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Simulation in Healthcare Supply Chains with Perished Products

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Abstract: Perishable healthcare products such as vaccines, blood products, biologics and temperature sensitive medicines incur high supply chain costs under limited shelf life due to uncertain demand with stringent storage requirements during transport. However, a type of approach is to analyze and enhance the operation via simulation-based methods without affecting the real-world systems. This paper presents an overview of studies that implemented simulation techniques in the healthcare supply chains for perishable products linking inventory optimization, cold-chain logistics, waste elimination and service-level improvement. The study uses discrete event simulation which models the movement, storage and consumption of perishable health care products through many supply chain stages which include suppliers, distribution centers, hospitals, and pharmacies. We look at key variables which include demand variability, lead times, spoilage rates, and storage capacity to see how the system performs in different operational settings. What we found is that which which optimized replenishment policies, dynamic routing, and real time monitoring greatly reduce product waste at the same time that we maintain product availability and patient safety. Results present that health care organizations which implement predictive analytics in to their simulation models see great benefit in terms of improved decision making which in turn they use to predict shortfalls, reduce waste at point of expiry, and better respond in emergency or pandemic situations. Also we see in our study that which digital technologies play a key role in this we look at IoT enabled cold chain monitoring and data driven inventory management.

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I. INTRODUCTION

Healthcare supply chains are at the core of what we do in terms of getting medical products and services to patients when they need them. As for which products that are very much in the fore front, we have perishing items like vaccines, blood components, insulin, bio drugs, and some diagnostic materials which have short shelf lives and very specific storage requirements. We see this area as a great challenge for health care organizations which in turn see delays, improper care in handling, or bad forecast as issues that lead to product spoilage and in turn higher operation.

In the past few years health care supply chains have seen a great increase in their complexity which is a result of greater demand uncertainty, globalization, pandemic situations, and the requirement for temperature controlled logistics. Also it has been found that which traditional supply chain management methods we have been using are very much out dated for the dynamic world of health care products which are perishable. Healthcare supply chains sit at the core of getting essential medical products to patients when they need them most. Among these products, perishable items — vaccines, blood components, insulin, biologics, and various diagnostic materials — present a particular challenge, since they carry short shelf lives and strict storage requirements. Even minor delays, mishandling, or forecasting errors in these supply chains can lead to spoilage, stockouts, or increased operational costs, all of which ultimately compromise patient care.

In recent years, healthcare supply chains have grown considerably more complex, driven by rising demand uncertainty, globalization, recurring pandemic pressures, and the need for reliable temperature-controlled logistics. Traditional supply chain management approaches, largely built around non-perishable goods, often fall short when applied to these dynamic, time-sensitive healthcare products. Simulation has therefore emerged as a valuable tool for analyzing, evaluating, and improving supply chain performance in this space. It allows decision-makers to test operational strategies and study the effects of uncertainty in a virtual environment, without disrupting real healthcare processes or risking patient safety.

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This study concerns the application of simulation techniques in the healthcare supply chain of perishable products. Its aim is to study the perishability related problems, analyze different supply chain strategies and explore the means to improve efficiency, minimize wastage and ensure that healthcare is not compromised. The study contributes towards developing sustainable and responsive healthcare supply chain systems that can meet the growing demands of modern healthcare services through simulation-based analysis.Progress in artificial intelligence, data analytics and automation is reshaping the management of perishable healthcare products.

II. RELATED WORK

Shah [1] performed a simulation study to evaluate the performance of inventory management strategies for the hospital supply chain of perishable medical products. We analyzed the impact of lead times, demand uncertainty and expiration periods on inventory performance using discrete-event simulation. Results indicated that optimized replenishment policies significantly reduced wastage and stock-out situations and improved patient service levels.

Van Donselaar et al. [2] used simulation and stochastic inventory models for blood supply chain management. Their work was on balancing shortages and expiration losses in blood banks. They accounted for demand variability and shelf-life constraints in the simulation framework and showed that dynamic inventory policies increase availability of blood and reduce spoilage .

Mustaffa and Potter [3] studied the simulation modeling of cold-chain logistics of vaccine distribution. Their work looked at transportation delays, refrigeration failures and storage constraints in healthcare distribution networks. Results demonstrated that simulation is useful to identify critical risk points and supports the development of resilient vaccine delivery systems

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Kelle et al. [4] designed a simulation model for pharmaceutical supply chains for hospitals with temperature sensitive medicines. The research evaluated inventory allocation approaches under uncertain demand conditions and emphasized the need for a coordinated planning for the supply chain to minimize the costs of medicine expiration and operation.

Lian and Deshmukh [5] presented a hybrid simulation method to study healthcare supply chains involving perishable products by integrating system dynamics and discrete-event simulation. Their model could describe the interactions between suppliers, distributors, hospitals and patients. The research showed that integrated simulation frameworks give a better understanding of the long-term behaviour of supply chains and policy effects.

Rais and Viana [6] extensively review the literature in healthcare logistics and supply chain optimization techniques. In their review, they found that simulation was one of the most common approaches used to study blood supply chains, organ transportation systems, and vaccine distribution networks. The authors found the simulation improves decision-making by allowing healthcare organizations to assess operational scenarios without disrupting actual services.

Torkul et al. [7] developed an agent-based simulation model to evaluate the distribution of emergency medical supplies in disaster situations. They took into account the limitations of perishable goods, transport disruptions and changes in demand. Simulation results indicated that collaborative distribution strategies improve responsiveness and reduce losses of critical medical supplies.

Ahmadi-Javid and Hoseinpour [8] studied inventory optimization of perishable pharmaceutical products by simulation and mathematical modeling techniques. Their study showed that the combination of simulation with forecasting techniques helps to improve the accuracy of inventory and reduce the unnecessary accumulation of stock in hospitals and pharmacies adaptability of heart disease prediction model.

Osorio et al. [9] worked with the blood platelet supply chains which have very short shelf lives. Regional blood center ordering and allocation strategies were evaluated using stochastic simulation. They found that simulation-based policies can substantially improve the utilization of platelets, while reducing wastage due to expiration.

Dehghani et al. [10] studied healthcare vaccine supply chains by system dynamics simulation. They studied the impact of storage capacity, transportation time, and demand spikes during epidemic outbreaks. The results highlighted the significance of flexible logistics planning and real-time monitoring systems in ensuring vaccine quality and availability.

Ivanov [11] examined the resilience of the healthcare supply chain via simulation in pandemic disruptions. The study examined the impact of supply disruptions, transportation constraints, and abrupt demand surges on the distribution of perishable medical products. The study said simulation models are vital for the design of resilient healthcare logistics systems to respond to emergency situations.

Zhang et al. [12] proposed an IoT-enabled simulation framework to monitor pharmaceutical cold-chain logistics. By using their model, which combined real-time sensor data with simulation techniques, they could monitor temperature-sensitive medicines in transit and storage. The approach gave better visibility, reduced spoilage risk and improved overall supply chain performance.

Aldrighetti et al. [13] proposed a simulation-based decision support system for hospital inventory management of perishable drugs. The study assessed a number of replenishment strategies and showed that simulation-assisted planning reduces inventory holding costs and ensures availability of medicines for the patients.

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Büyüktahtakın et al. [14] tackled vaccine distribution networks with epidemic simulation and supply chain optimization methods. Their work merged disease spreading models and healthcare logistics simulation to improve vaccine allocation during pandemics. The results showed that coordinated distribution strategies reduce shortages and improve public health outcomes.

Govindan and Fattahi [15] reviewed sustainable healthcare supply chain practices related to perishable products and stated that simulation is an important tool for reducing waste, energy consumption and operational inefficiencies. Their study stressed the importance of advanced technologies like IoT, RFID and predictive analytics in improving the sustainability and resilience of healthcare supplychains.

Sung Hoon Chung and Changhyun Kwon [16] proposed an integrated supply chain management framework for perishable products, specifically for pharmaceuticals. Their model included manufacturers, distribution centers, wholesalers and demand markets, as well as perishability and competitive market dynamics. The study demonstrated that collaborative decision-making throughout the supply chain can help reduce shortages and increase overall efficiency.

➢ *Proposed System*

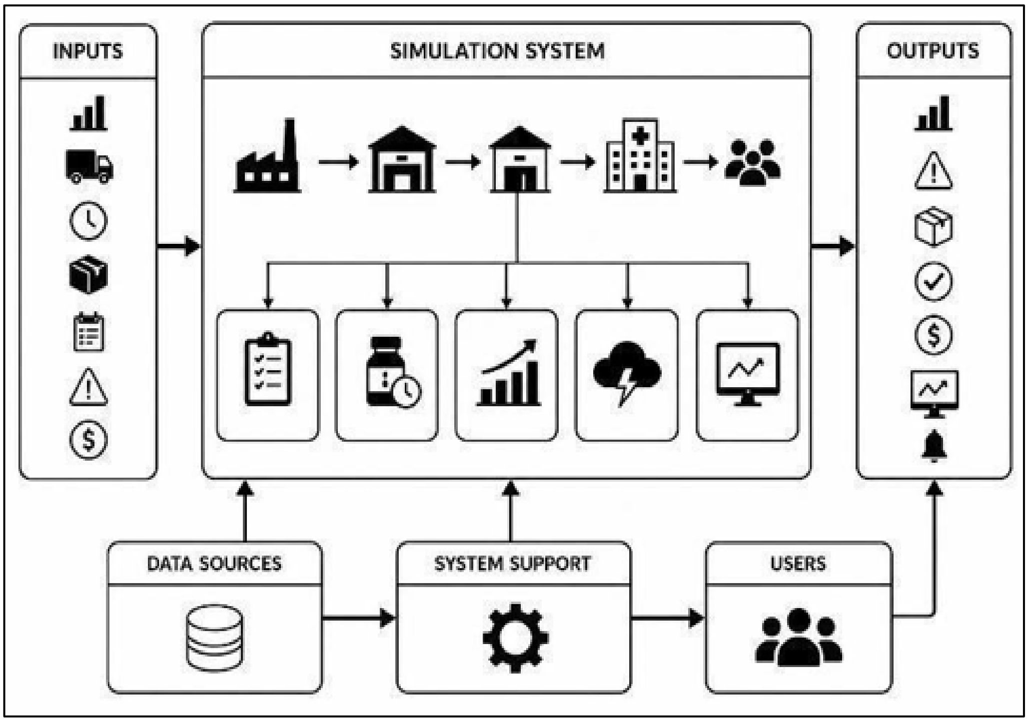

Fig 1 The Proposed System

Fig 1 Developed system for simulation of healthcare supply chains with perishable items The developed system is used to manage and optimize the flow of sensitive medical products such as vaccines, blood units, medicines, and other temperature-sensitive healthcare products.The system proposed in this study is designed to manage and optimize the flow of sensitive medical products — including vaccines, blood units, medicines, and other temperature-sensitive healthcare items — across the supply chain. Its central objectives are to reduce wastage, prevent stockouts, strengthen inventory management, and ensure that products reach hospitals and patients in a timely manner. By applying simulation techniques, the system is able to analyze and improve overall supply chain performance under realistic operating conditions.

The system begins by drawing on several categories of input data: demand information, supplier details, inventory records, lead time data, perishability data, disruption data, and cost parameters. Demand data reflects hospital and patient needs, while supplier data captures production capacity and delivery schedules. Inventory data is used to track current stock levels, and lead time information helps estimate delays that may arise during transportation or procurement. Because healthcare products are highly sensitive to time, perishability information — including expiry dates and shelf life — plays a particularly important role in the model. In addition, the system incorporates disruption data, such as transportation failures or sudden spikes in emergency demand, to more realistically simulate the uncertainties that healthcare supply chains routinely face.

The inventory management module monitors the stock levels and ensures proper storage of products. It monitors inventory in real time, tracks batches, calculates reorders and implements the FEFO (First Expiry First Out) policy, ensuring that products with the closest expiry dates are used first. This helps to avoid the loss of products and stock out.

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- *Flow Diagram*

The proposed system flow diagram which details how perishable healthcare products make their way through the health care supply chain and how we have structured the simulation to handle inventory, expiring products, demand, supply, and disruptions. We have designed this system to see that health care products which include vaccines, blood bags, insulin, medicines and other sensitive medical supplies are brought to patients in a safe and efficient manner before they go bad.

The flow diagram in Fig. 2 illustrates how perishable healthcare products move through the supply chain and how the proposed simulation has been structured to handle inventory, expiry, demand, supply, and disruptions in a coordinated way. The system is designed with one central purpose in mind: to ensure that vaccines, blood bags, insulin, medicines, and other sensitive medical supplies reach patients safely and efficiently before they expire.

The process begins with the collection of several types of input data — demand information, supplier information, inventory information, lead time information, expiry or shelf-life details, and disruption information. Demand data captures patient needs, hospital requirements, emergency demand, and seasonal variation, while supplier information reflects production capacity, supplier reliability, and delivery plans. Inventory information is used to track stock levels and storage conditions, and lead time data accounts for transport and procurement delays. Expiry and shelf-life information is especially critical here, given that the products under consideration are perishable and require close monitoring until they reach the end of their usable life. Disruption information, meanwhile, captures unpredictable events such as transport delays, supplier outages, or natural disasters that could otherwise catch the system off guard.

Once this data has been gathered, it is fed into the simulation system, which forms the core of the proposed model. The simulation represents the healthcare supply chain from end to end — beginning at the point of production with suppliers or manufacturers, moving through central warehouses for large-scale storage, then to regional warehouses positioned closer to healthcare facilities, and finally out to hospitals, clinics, and pharmacies.

The simulation system we have designed models the full health care supply chain. The supply chain which we model goes from the point of production at suppliers or manufacturers where health care products are produced. From there products are shipped to central warehouses for large scale storage. From central warehouse products are sent out to regional warehouses which are closer to health care facilities. Finally products are supplied from regional warehouses to hospitals, clinics and pharmacies.

In our simulation system we have various management modules which work together to improve supply chain performance.Within this simulation, several management modules work in tandem to strengthen supply chain performance. The inventory management module is responsible for real-time stock tracking, batch management, reorder point determination, and enforcement of the FEFO (First Expiry First Out) policy, which helps reduce waste by ensuring older stock is used before newer stock. The perishability management module handles shelf-life monitoring, expiry tracking, spoilage detection, waste management, and return handling — functions that are especially important given that expired healthcare products can pose a direct safety risk if not properly identified and removed. The demand management module takes care of demand forecasting, supply planning, and replenishment scheduling, and allows different scenarios to be tested to determine how best to get products to the right place at the right time. The risk and disruption management module models uncertain events such as supplier outages, transport delays, or emergencies, and helps develop strategies to mitigate their impact before they disrupt patient care.

The diagram also accounts for the data sources and system support elements that underpin the simulation. Data sources include information drawn from ERP systems, warehouse management systems, hospital information systems, supplier databases, and external market source.

A Decision Tree is a very basic and large used element of supervised machine learning which we apply to both classification and regression issues. We present data in a tiered structure which in fact mirrors human decision process. The tree starts at the top with a root node which includes the full data set which is then put into smaller sets via a series of decision nodes that are based on certain inputs which we test. Each branch is the result of a test and at each leaf node we have our end result or decision. For example in health care inventory management a Decision Tree may look at present stock levels, check product expiration dates, supplier lead times, and historic demand to determine if an item should be re ordered.

The algorithm which at each step chooses the most informative feature based on mathematically defined criteria like Information Gain, Gini Index, or Entropy builds the tree. These measures report how well a feature performs at splitting the data into separate classes. Features which create the purest subsets are selected first which in turn forms a tree that brings out the main patterns and relationships in the data. Decision Trees are able to work with both numerical and categorical data and do not require extensive data normalization or pre processing which makes them very practical for real world use. Also they are able to deal with missing values and will at the same time identify the key variables which play the greatest role in prediction.

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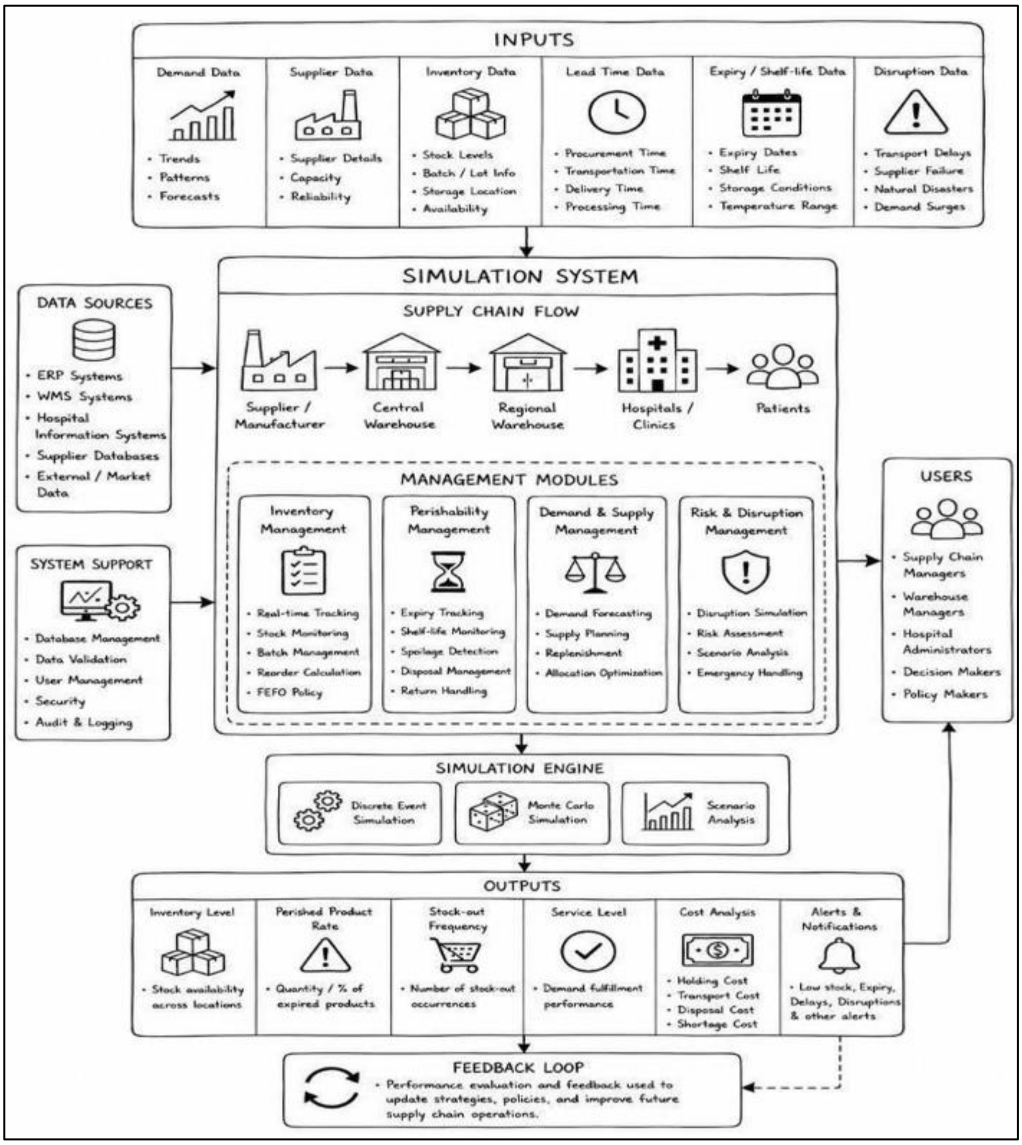

Fig 2 Represents Flow Diagram

➢ *Machine Learning Algorithms*

- *Decision Tree (DT):*

A Decision Tree which is a supervised machine learning algorithm that uses both classification and regression tasks. This type of algorithm breaks down the dataset into sub groups at each step via different feature values and defined criteria which in turn forms a tree like structure as shown in Fig 3 From the input data it creates a set of rules based on feature threshold which in turn produces predictions. Decision trees are also very much at home when it comes to model interpretability. They do a great job at modeling non linear relationships and also are able to use a mix of continuous and categorical features.

Decision which falls in the category of Machine Learning algorithms is the Decision Tree used in what pertains to classification and decision making tasks. We have a structure which is that of a tree which is built out of a series of questions and rules in the put forth system the Decision Tree plays a role in identifying when spoilage is going to happen, classifying the state of the inventory and in support of supply chain decisions. It is useful for determining whether products are safe, expired, or at risk of shortage. The algorithm is simple, easy to understand, and effective for operational management.

Decision Trees are very interpretable which is one of their greatest strengths. It is transparent and easy to understand, unlike many complex machine learning models, so users can see exactly how a prediction is derived. This is especially valuable in health care where accountability and explainability are important. Hospital administrators and pharmacists can look at the tree and see why the model suggests replenishing some medicines or prioritizing products nearing expiry.

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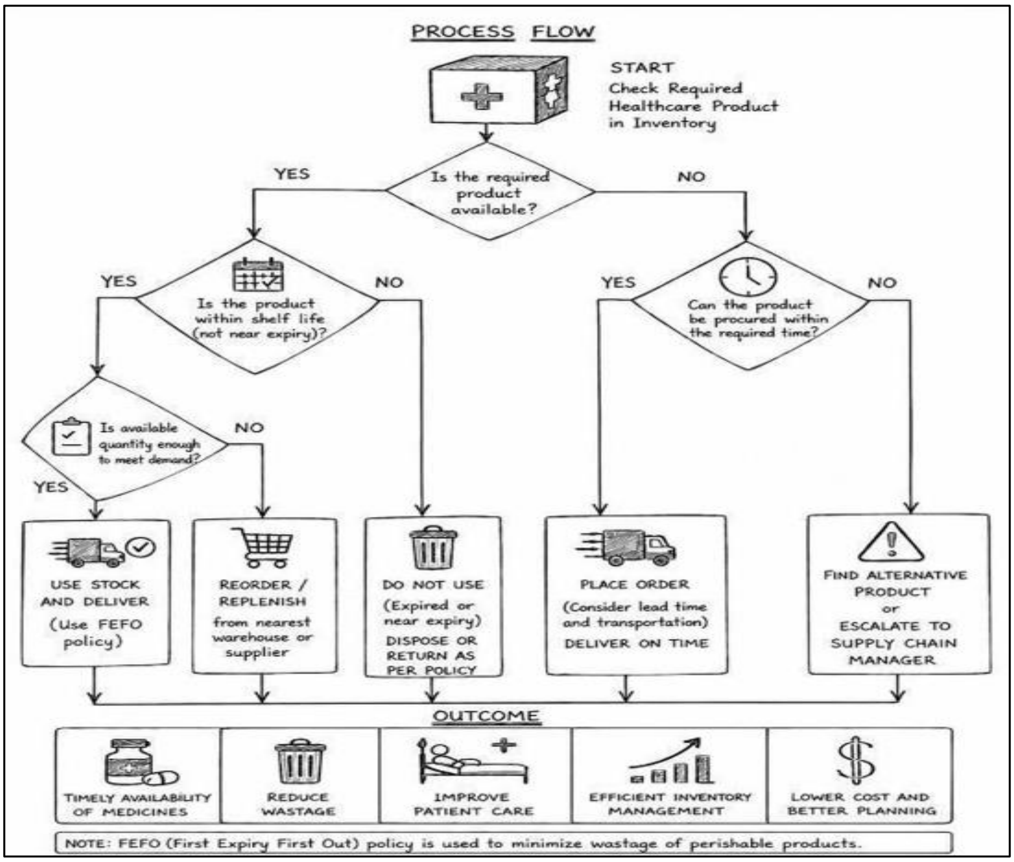

Fig 3 Process Flow

- *Random Forest (RD):*

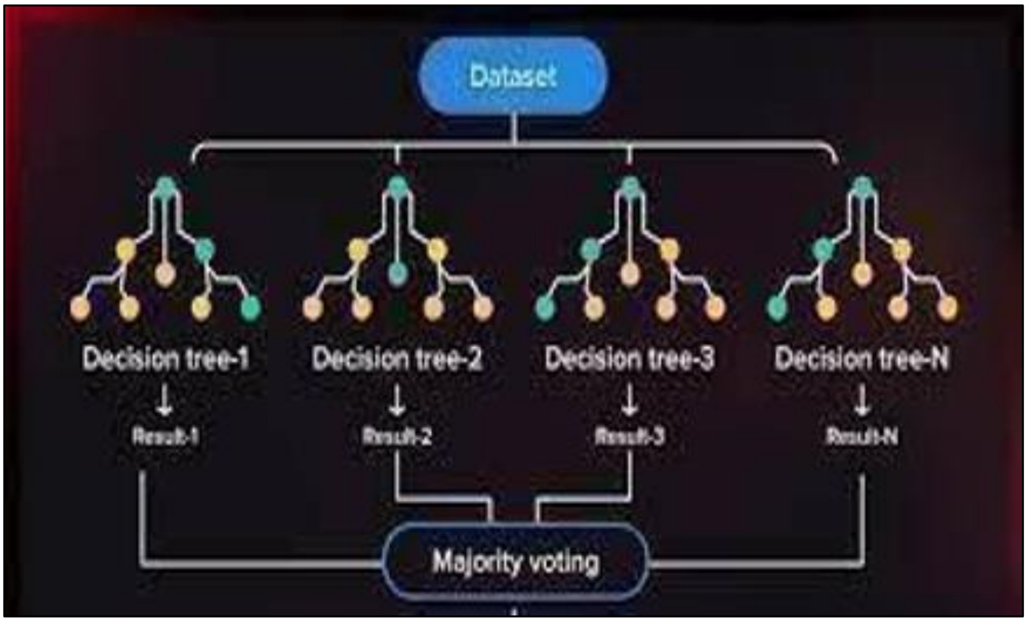

Fig 4 Example for Random Forest

Figure 4 shows that the Random Forest algorithm uses an ensemble strategy where multiple decision trees are built during training, and the results are combined to improve prediction accuracy. Combining the result of several randomly generated trees reduces the variances and overfitting. Random Forest is a very robust model, typically a good baseline for classification or regression tasks and especially good for tabular medical datasets.

Example:Imagine a Random Forest with 100 trees that predicts heart disease. 62 trees predict “HD” and 38 trees predict “No HD”.Final Prediction: HD with an approximate confidence of 0.62.

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- *Support Vector Machine (SVM):*

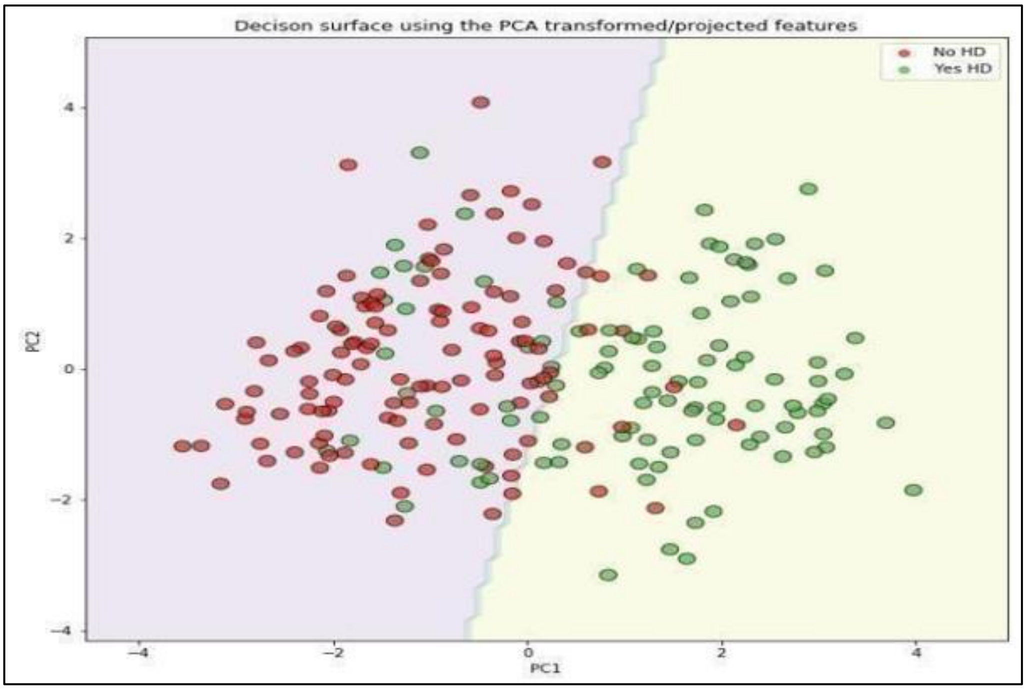

Fig 5 Scatter Plot Showing the Decision Surface of a SVM

Fig 5 shows the decision surface of an SVM as a scatter plot. SVM is a supervised learning techniques, that finds the hyperplane, that maximum the gap between different classes For data that is non-linear, kernel functions are used to map features to higher-dimensional spaces that allow the model to learn complex decision boundaries. SVM is suitable for high dimensional datasets and problems, it can capture complex decision boundaries. SVM works well for high dimension data sets and complex boundaries problems. It is robust against over-fitting with suitable tuning of parameter like regularization factor and kernel choice.

For example, if a new patient's blood pressure and cholesterol are above the line, the model might predict "high risk," while those below the line might be predicted as "low risk." D. K-Nearest Neighbors (KNN).

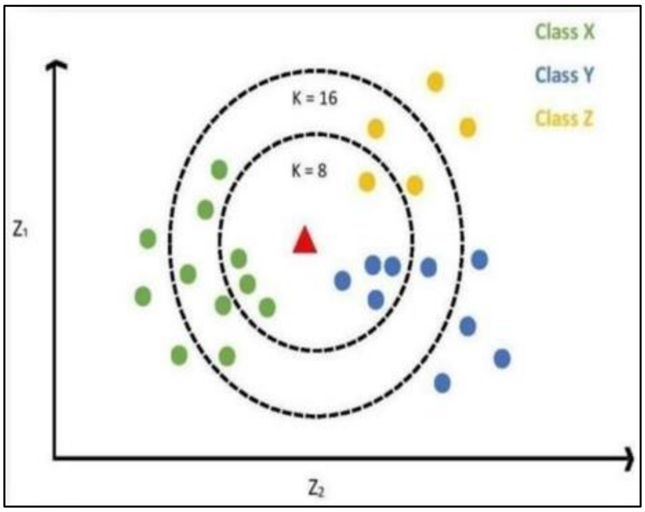

Fig 6 Analysis of KNN Classification

The KNN algorithm classifies a new data point by looking at the classes of its nearest neighbors in the feature space as shown in Fig 6 In essence, a point is predicted to belong to the class with the most common number of nearby data points. "You are just like your neighbors").

KNN is great fordatasets that possess non-linear decision boundaries and works well for small to medium datasets.

Example:

Let = 3

The three closest neighbors of a query patient are 2 positive and 1 negative.

- *Logistic Regression (Baseline Linear Classifier)*

The concept LR is a linear model of the association relationship between features and the probability of an outcome.It employs the logistic function to translate the linear combination of inputs into a probability.Best Use: Is suitable when features are roughly linearly separable and where the interpretable probability estimates are desired.

The model predicts the probability of heart disease from a patient's age and blood pressure.It takes the averages of these variables in a mathematical formula.For a 50-year-old with BP 140, the model produces a score that translates into a 668% chance.

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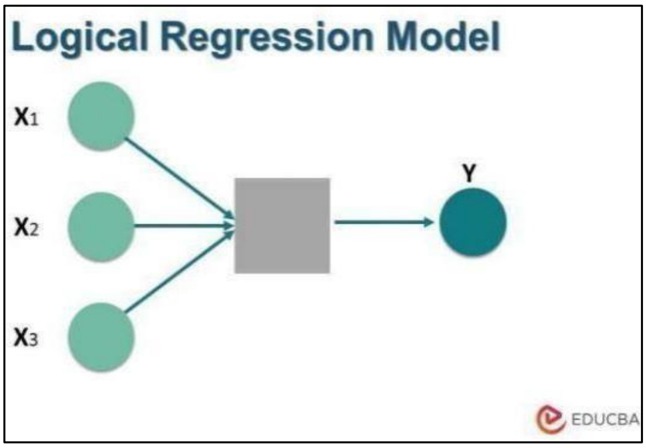

Fig 7 Logistic Regression Model

Linear Regression is a supervised learning algorithm that is commonly used for prediction and forecasting. The link between past demand data in healthcare and future needs is used to predict future product demand. In the proposed healthcare supply chain system, Linear Regression is implemented to forecast the medicine demand, vaccine requirements and future inventory levels. With accurate prediction, health organizations can maintain the right stock levels to avoid shortages or overstocking of perishable products.

III. METHODOLOGY

The methodology adopted for this study is centered on analyzing, managing, and optimizing the movement of sensitive healthcare products — including vaccines, blood units, medicines, insulin, and other temperature-sensitive items — through simulation and machine learning. The process begins with the collection of data from multiple sources, including hospitals, suppliers, warehouses, ERP systems, and healthcare databases. This data spans demand patterns, inventory levels, supplier information, transportation lead times, shelf-life details, expiry dates, and disruption-related records. Before being used in the simulation, the data is cleaned, validated, and stored in a central database to ensure consistency and reliability throughout the analysis.

Once collected, this data is used to model the healthcare supply chain network within the simulation system. The model simulates the movement of products from suppliers or manufacturers through central warehouses, regional warehouses, hospitals, and clinics, and ultimately to patients. Throughout this process, the system continuously tracks inventory levels, storage conditions, transportation times, and the expiration status of each product. Inventory management techniques such as FEFO (First Expiry First Out) are applied to ensure that products closer to their expiry date are used first, helping to reduce wastage across the supply chain.

Machine learning plays a supporting role in this methodology by enabling more intelligent forecasting and decision-making. Linear Regression and LSTM models are used to forecast demand, while Decision Tree and Random Forest algorithms support inventory management, disruption prediction, and spoilage detection. K-Means clustering is applied to group hospitals or products according to demand and risk patterns. Together, these techniques improve the accuracy of forecasts and help optimize how inventory is distributed across the supply chain.

Simulation forms the other key pillar of the methodology. Discrete Event Simulation, Monte Carlo Simulation, and Scenario Analysis are used to evaluate supply chain performance across a range of operating conditions, including emergency demand surges, supplier delays, transport disruptions, and stockouts. These simulated scenarios help assess how resilient the system is under stress, while the risk and disruption management module works alongside them to explore alternative strategies for mitigating the impact of such disruptions.

Following simulation and analysis, the system generates a set of performance outputs, including inventory levels, stock-out frequency, perished product rate, service level, transport performance, and total cost analysis. Alerts and notifications are triggered for low stock, expiring products, and supply disruptions, allowing the system to flag issues as they emerge rather than after the fact. These outputs are evaluated using performance metrics that help identify areas requiring improvement, and a feedback loop feeds this information back into the system to refine inventory policies, supply chain strategies, and forecasting models over time. This continuous cycle of evaluation and adjustment is what allows the system to remain adaptive and reliable, both under normal operating conditions and during emergencies.

Beyond forecasting and inventory control, the methodology also aims to improve overall resource efficiency. By combining simulation with machine learning, the system identifies optimal transport routes, appropriate stock levels for warehouses, and suitable refill schedules for hospitals and clinics. This, in turn, helps reduce storage costs, transportation expenses, and waste from expired products, while supporting broader efforts toward sustainable healthcare supply chain management.

Also we use a feedback element which is put back into the system to update inventory policies, supply chain strategies, and forecasting models as we go. This approach enables health care organizations to better control inventory, reduce waste, lower costs, improve service quality, and see to it that delivery of health care products to patients is timely.

Proposed approach also is to improve resource use and reduce operation costs. We put Simulation and Machine Learning together to identify for our system the best transport routes, optimal stock levels for warehouses, and the best refill times for hospitals and clinics. This in turn reduces storage costs, transportation prices, and waste from old products. Also we see this method as a way to support sustainable health care supply chain management by which we mean to say we are decreasing the disposal of unused medicine and we are seeing an improvement in overall resource efficiency.

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Another key element of our methodology is performance evaluation and feedback analysis. At each simulation turn the system puts forward predictions which it then compares to actual supply chain performance. We look at metrics like service level, demand fulfillment rate, stock out frequency, product waste percentage, and total ops cost to determine system performance. Based on this data the system improves its forecasting models, inventory policies and supply chain strategies which in turn improves performance. This continuous feedback and improvement cycle what makes the put forth system adaptive, intelligent and reliable for the management of perishable health care products in normal and emergency situations? These reports to track product flow, study health care demand trends, and base their procurement, distribution, and emergency preparedness on that info.Deployment is carefully controlled. A validated API applies preprocessing, calculates calibrated probabilities, and provides clear explanations.

IV. RESULTS AND DISSCUSSIONS

In Figure 8 the which we see is the home dashboard of what we have put forth as the AI Health care Supply Chain Management System for Perishable Products. We have designed the website to monitor, manage, and improve health care inventory which includes sensitive and perishable products like medicines, vaccines, blood units, and emergency medical supplies. The interface we present is very much modern and user friendly which in turn health care organizations may use to track inventory conditions, analyze supply chain performance, and get alerts for out of date or low stock. Also we have a dark theme dashboard with key analytics stands out which in turn gives users a professional health care management experience.

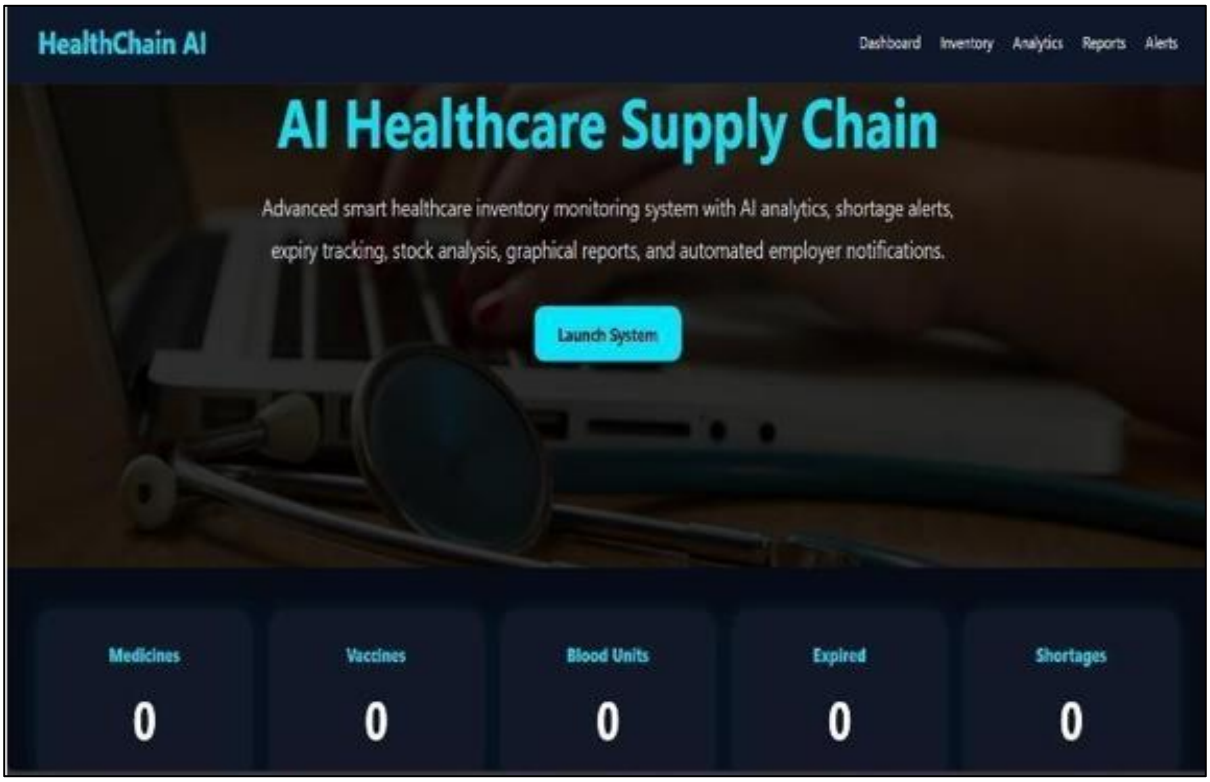

Fig 8 System Interface Representation

To evaluate the proposed approach, a prototype system — referred to here as HealthChain AI — was developed to demonstrate how simulation and machine learning concepts can be translated into a practical, usable interface for healthcare supply chain management. Figure 9 shows the home dashboard of this system. The interface was designed to monitor, manage, and improve the handling of sensitive and perishable healthcare products, including medicines, vaccines, blood units, and emergency medical supplies. A dark-themed layout was chosen to give the dashboard a clean, professional appearance, allowing healthcare organizations to track inventory conditions, review supply chain performance, and receive alerts for low or expired stock at a glance.

The interface is organized around a navigation bar containing five core modules — Dashboard, Inventory, Analytics, Reports, and Alerts — each supporting a different aspect of supply chain oversight. The Dashboard provides a high-level overview of current inventory status and supply chain activity. The Inventory module allows users to track stock levels, storage conditions, and product quantities. The Analytics module presents supply chain data in a forecasted, visual format, while the Reports module generates detailed reports on inventory movement, expiring products, service performance, and operational costs. The Alerts module notifies users of low stock, expiring products, transport delays, and other emergency supply issues. Together, these modules give users a comprehensive view of the supply chain from a single interface.

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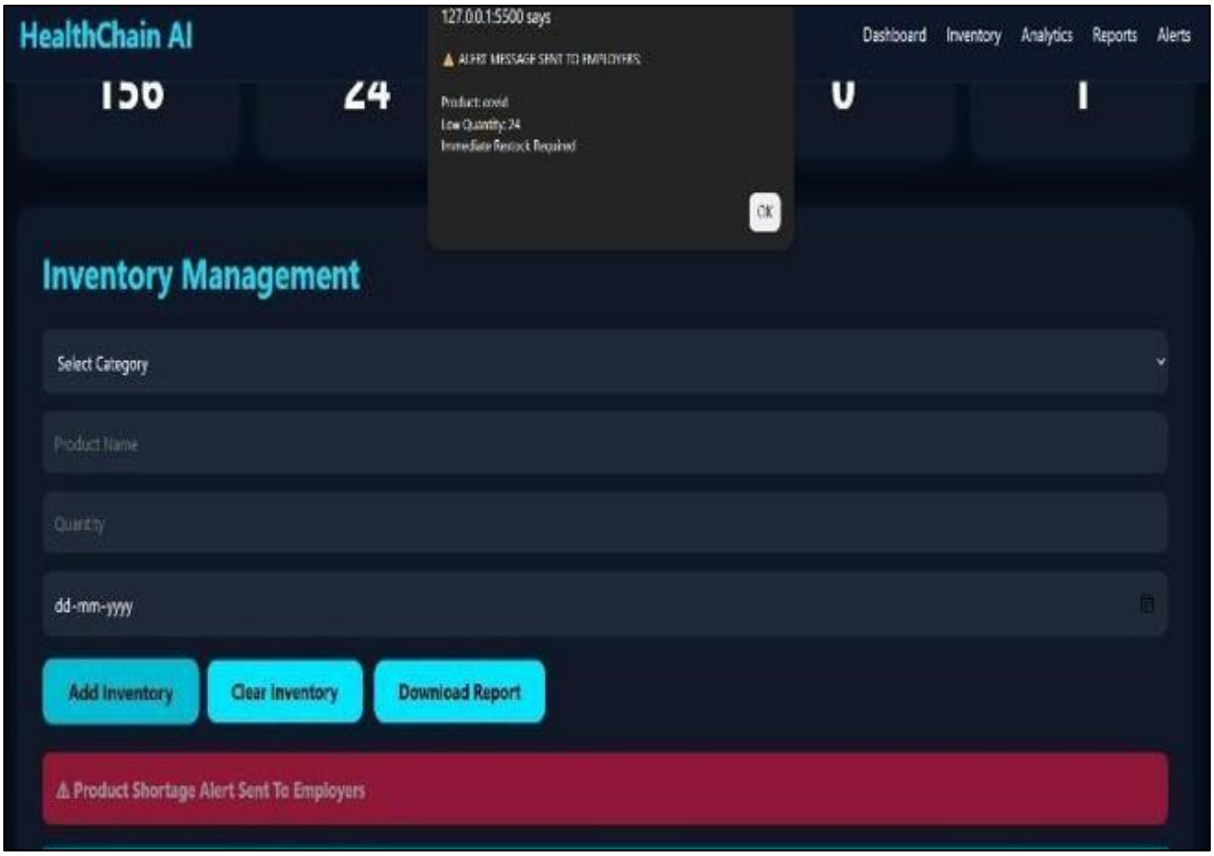

Fig 9 Input attributes

The present interface we have is of the Inventory Management Module in our put forth AI based Healthcare Supply Chain Management System. We have designed this module to improve health care inventory management by which we mean we are looking at stock levels, expiration dates, putting out alerts for short supplies and we also support decision making for hospitals, clinics and health care warehouses. Also the interface is very much into it we are talking mainly of very sensitive health care products like drugs, vaccines, blood units and emergency medical supplies which require proper storage and immediate distribution.

At the top of the interface we have the navigation bar which includes elements like the Dashboard, Inventory, Analytics, Reports, and Alerts. These modules in turn allow users to access various aspects of the health care supply chain. The Dashboard gives a broad picture of our present inventory status and supply chain performance. In the Inventory section you will find options to add, update and watch over health care products. The Analytics module we have AI based reports and forecasts. The Reports section is for generation of download able inventory and performance reports, the Alerts section is your go to for info on out of stock items, expired products, or emergency supply issues.

The main part of the interface is the "Inventory Management" panel. This panel is used to register and administer health care inventory details. The first one is the "Select Category" drop down, where users can select the type of healthcare product like medicines, vaccines, blood units or other medical supplies. This helps to categorize products into various categories for easy tracking & management.

The second field is the "Product Name" textbox where the user enters the name of the health care product. The information is required to identify and track specific inventory items in the healthcare supply chain system. The third field is "Quantity" input section where users can enter the available quantity of the selected product. This enables the system to monitor the availability of stock and detect situations of shortage.

The fourth field is the date section, where users enter the expiry date of the healthcare product. Since the proposed system deals with perishable healthcare items, expiry tracking is one of the most important functionalities.

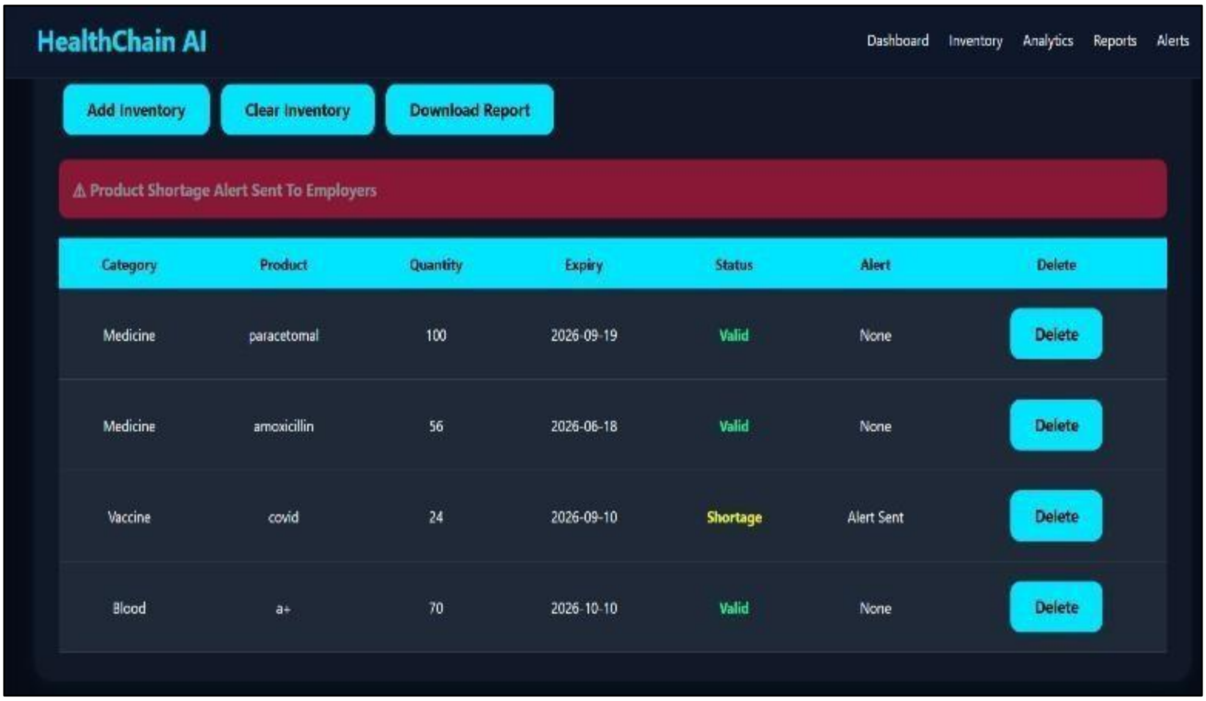

Fig 10 Result Representation

Fig 10 The HealthChain AI dashboard in the image is a healthcare supply chain management interface designed specifically to monitor and manage the perishable medical products such as medicines, vaccines and blood supplies.This functionality is reflected in Figure 10, which shows the resulting inventory table generated by the system. Each entry lists a product's category, quantity, expiration date, status, and alert condition. For example, Paracetamol appears with a stock level of 100 units and a "Valid" status, indicating it is adequately stocked and not close to expiry. Amoxicillin shows a similar status with 56 units in stock. By contrast, the COVID-19 vaccine entry shows only 24 units and is flagged as "Shortage," with the system automatically triggering an alert once stock falls below a defined threshold. The blood product entry (type A+) is listed as valid with 70 units available. This color-coded status system — green for healthy stock, yellow for shortages requiring attention — makes it easy for users to quickly identify which items need immediate action.The COVID-19 vaccine entry has 24 units and is labeled “Shortage,” with the alert column showing “Alert Sent,” showing the ability of the system to automatically trigger notifications when stock is below a certain threshold set. The Analytics dashboard, shown in Figure 11, presents this same data in aggregate form through a bar chart spanning five categories: Medicines, Vaccines, Blood Units, Expired, and Shortages. In this example, Medicines show a moderate stock level of around 44 units, while Vaccines sit lower at around 10 units — a level that, while low, remains within an acceptable range. Blood Units show the highest stock level at nearly 68 units, reflecting adequate preparedness for surgeries, trauma care, and emergency transfusions. The Expired category reports around 10 units, indicating a small number of products that have passed their usable date and should be removed from storage.

Taken together, these results suggest that a system combining real-time inventory tracking with automated alerts and visual analytics can meaningfully support healthcare supply chain decision-making. The low shortage count observed in this example points to a generally well-functioning supply chain, while the presence of expired products highlights an area where stricter adherence to FEFO-based rotation could further reduce waste. Similarly, the relatively high blood product inventory suggests a reasonable level of emergency preparedness, while stable vaccine and medicine counts support the continuity of routine immunization and treatment programs.

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Fig 11 Report Results Based on Input Parameters

The HealthChain AI which we present is their Analytics dashboard that has been put together to display in a visual way the health of our inventory levels and performance of the supply chain for perishable healthcare products like medications, vaccines, blood units, and other time sensitive medical supplies. We see a dark themed interface which includes the HealthChain AI logo in the top left hand corner and a top right hand corner navigation menu with options for the Dashboard, Inventory, Analytics, Reports, and Alerts. Also this layout is designed for health care managers, pharmacists, and supply chain administrators to easily switch between what modules they use for stock monitoring, trend analysis, report generation and emergency response to out of stock issues.

The bar chart contains five categories: Medicines, Vaccines, Blood Units, Expired and Shortages. In the Medicine bar which is in cyan we see it to be at about 44 units which is a moderate stock of basic drugs available for patient care. The Vaccines bar which is in green reports in at around 10 units which is a low but still acceptable level of vaccine dose inventory. Blood Products bar which is in yellow is the highest at nearly 68 units which indicates we have a large enough supply of blood for surgeries, trauma care and emergency transfusions. The Expired bar which is in red reports at about 10 units which indicates we have some products past their use by date which should be removed from storage to prevent use and to also reduce waste.

This analytics platform is very much so used in health care supply chain management which we see transform raw inventory data into action oriented information. We see admin personnel do visual comparison of what is in stock with what is expired and which areas are in shortage which in turn helps them to identify issues at hand and to put in place corrective measures. For instance the low level of shortages we see as a sign that the supply chain is doing well, also the presence of expired products which is a red flag for us to improve in the area of inventory rotation based on FEFO which is First Expire First Out. We also see high blood product inventory as a sign that we are prepared for emergencies and that we have a good handle on our vaccine and medicine counts which in turn supports continuous immunization programs and health care treatments. As a whole this dashboard supports better decision making, reduces waste of perishable products, improves stock visibility and we see it to be a asset for our patients.

The analytics suite which puts together in depth reports on inventory performance, expiry trends, short stock issues, procurement performance, how well suppliers do, transport results and also the total picture of the supply chain.

V. CONCLUSION

In conclusion, effective management of healthcare supply chains for perishable products is essential to ensure patient safety, reduce wastage, and maintain uninterrupted delivery of critical medical services.Effective management of healthcare supply chains for perishable products is not simply an operational concern — it is directly tied to patient safety and the continuity of care. Medicines, vaccines, blood units, diagnostic reagents, and other biological materials all carry limited shelf lives, which means that even minor lapses in monitoring stock levels, expiration dates, or storage conditions can result in shortages, wastage, or, in the worst cases, the use of compromised products. This study set out to examine how simulation and machine learning can be applied together to address these challenges in a more systematic and proactive way. The HealthChain AI prototype developed as part of this work demonstrates one way this can be achieved in practice. By bringing real-time inventory tracking, automated shortage detection, expiry monitoring, alert generation, and analytical reporting together into a single

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platform, the system gives healthcare managers a clearer, more immediate picture of their supply chain than manual tracking methods typically allow. The dashboards and visual analytics developed here make it possible to quickly identify low-stock items, expired products, and emerging inventory trends, which in turn supports faster, better-informed decision-making. In practical terms, this kind of visibility can help reduce the frequency of stockouts, minimize losses from expired stock, and improve an organization's overall responsiveness during periods of high demand or disruption. Emergencies. Most importantly, a well-functioning supply chain ensures that the right life-saving products are available in the right quantity, in usable condition and at the right time, ultimately improving the quality of care and health outcomes for patients.

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