IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Pulsematch: A Next-Generation Web Platform For Smarter Blood Donation Ecosystems

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Abstract: Blood donation systems in many regions continue to face significant challenges related to timely donor-recipient matching, efficient communication, and accurate prediction of blood demand. This paper presents PulseMatch, a smart, web-based blood donation platform designed to address these issues using cloud technologies and machine learning. Developed with a React.js frontend and Firebase backend, PulseMatch facilitates seamless interaction between hospitals and potential blood donors. The system enables real-time donor registration, request submission, and intelligent donor matching based on blood group, location, and availability. In addition, machine learning modules are proposed for fraud detection and blood shortage forecasting to improve reliability and response times. PulseMatch integrates a scalable architecture that supports live data synchronization, automated alerts, and future extensions including mobile compatibility and explainable AI. This paper details the system design, implementation workflow, and integration strategy for intelligent automation in blood donation, demonstrating the potential to modernize and optimize healthcare logistics through data-driven approaches.

Index Terms **-** Blood Donation System, Smart Healthcare, Machine Learning, Firebase, React.js, Donor Matching, Fraud Detection, Shortage Prediction, Cloud-based Platform, Healthcare Automation.

I. Introduction

Blood is an irreplaceable and life-sustaining resource, playing a crucial role in modern medical treatments ranging from trauma care to surgeries and chronic disease management. Despite the increasing need for blood worldwide, healthcare systems often grapple with challenges such as donor shortages, mismatches in supply and demand, and inefficiencies in the blood donation and distribution lifecycle [1].

Traditional blood donation systems are frequently constrained by manual processes, lack of real-time communication between stakeholders, and outdated inventory management practices. These limitations lead to delays in finding suitable donors and can result in wastage of valuable blood components due to expiration [2][3]. Moreover, the integrity of the supply chain is jeopardized by risks such as blood contamination, donor impersonation, and lack of traceability [4][5].

Emerging technologies such as blockchain and machine learning (ML) offer transformative potential for addressing these systemic issues. Blockchain ensures transparency, immutability, and trust in the blood donation supply chain by securely recording transactions, verifying donor identities, and enabling real-time traceability from donor to recipient [6][7]. Simultaneously, ML techniques have shown promise in optimizing donor selection, predicting donation behavior, and minimizing wastage through intelligent inventory management [8][9].

Mobile-based platforms have further revolutionized the blood donation ecosystem by leveraging GPS tracking, automated notifications, and donor-recipient matchmaking algorithms. Apps like “Blood Donor” demonstrate how integrating user profiles, health data, and geolocation services can significantly reduce response times and improve accessibility to compatible donors [10][11].

In line with this technological advancement, our proposed system, PulseMatch, presents a unified digital solution that harnesses the power of machine learning, real-time donor geolocation, and secure database integration to create a seamless bridge between donors, hospitals, and blood banks. Unlike conventional systems, PulseMatch integrates donor eligibility criteria, historical donation records, and health data to ensure the safety and efficiency of each transaction, while simultaneously providing hospitals with a dashboard for managing urgent and routine blood requirements [12][13].

Prior research highlights the need for such innovation. For instance, studies have noted that up to 40% of blood may go unused due to poor forecasting and logistics, especially in low-resource settings [3][14]. Additionally, blockchain-based solutions have shown to reduce fraud and improve auditability of the supply chain [6][15], while ML-guided issuing policies have been proven to reduce platelet wastage by up to 14% [9].

Our implementation contributes to this evolving landscape by delivering an end-to-end intelligent platform that promotes voluntary donations, ensures privacy and ethical matching, and facilitates equitable access to safe blood. In doing so, PulseMatch aims not just to digitize but to reimagine the future of blood donation management.

II. SYSTEM DESIGN

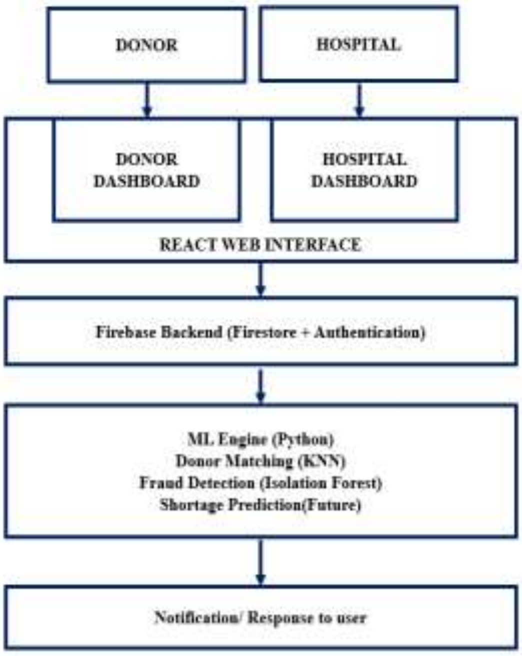

Figure 2.1 System Architecture

The PulseMatch platform is architected as a cloud-based, modular system that integrates real-time communication, intelligent automation, and scalable data infrastructure to address key challenges in modern blood donation management. At the core of the system is a React.js-based frontend, which provides an interactive user interface for both donors and hospital staff. Donors can register, update their availability, and respond to blood requests, while hospitals can raise new demands, view matched donors, and track request statuses. This interface communicates seamlessly with the backend through secured API calls, ensuring a responsive and cross-platform experience.

The backend of PulseMatch is powered by Firebase Firestore, serving as the real-time database for donor profiles, request records, and user session data. Firebase Authentication handles user login, role-based access control, and session persistence. The system is event-driven, with planned integration of Firebase Cloud Functions to automate workflows such as triggering the donor matching model upon request submission.

Machine learning plays a central role in enhancing the intelligence of the platform. The ML engine, developed in Python using libraries like scikit-learn and TensorFlow, is deployed via FastAPI or Gradio as a RESTful service. This module handles tasks such as donor-recipient matching using K-Nearest Neighbors or Cosine Similarity, fraud detection via anomaly detection algorithms like Isolation Forest, and blood shortage forecasting using planned time-series models such as LSTM. These models process real-time data from Firestore and return actionable insights to the frontend, thereby improving operational efficiency and reliability.

Additionally, the system includes a lightweight notification mechanism using Firebase Cloud Messaging or integrated email services. Once a donor is matched to a request, they receive instant alerts and can accept or decline, with hospitals updated accordingly. Designed for extensibility, PulseMatch supports future integrations such as mobile applications, blockchain for traceability, and multilingual interfaces to enhance accessibility. This layered architecture ensures the platform remains scalable, fault-tolerant, and adaptable to evolving healthcare infrastructure needs.

III.IMPLEMENTATION

The implementation of PulseMatch was executed using a combination of modern web development frameworks, cloud-based infrastructure, and machine learning libraries to deliver a robust and scalable platform. The frontend was developed using React.js, selected for its component-based architecture and responsive user interface design. Two distinct dashboard modules were implemented to support role-based access for donors and hospitals. Donors can register, specify their blood group and availability, and view or respond to live blood requests. In parallel, hospitals can submit new requests and monitor the status of matched donor responses in real time.On the backend, the system utilizes Firebase, which provides real-time data synchronization, secure user authentication, and a scalable NoSQL database via Cloud Firestore. Firebase Authentication manages login functionality and session control for both user roles, ensuring secure access and personalized experiences. The real-time capabilities of Firebase allow seamless updates to the UI upon changes in request or donor status, contributing to a smooth and efficient interaction between users.

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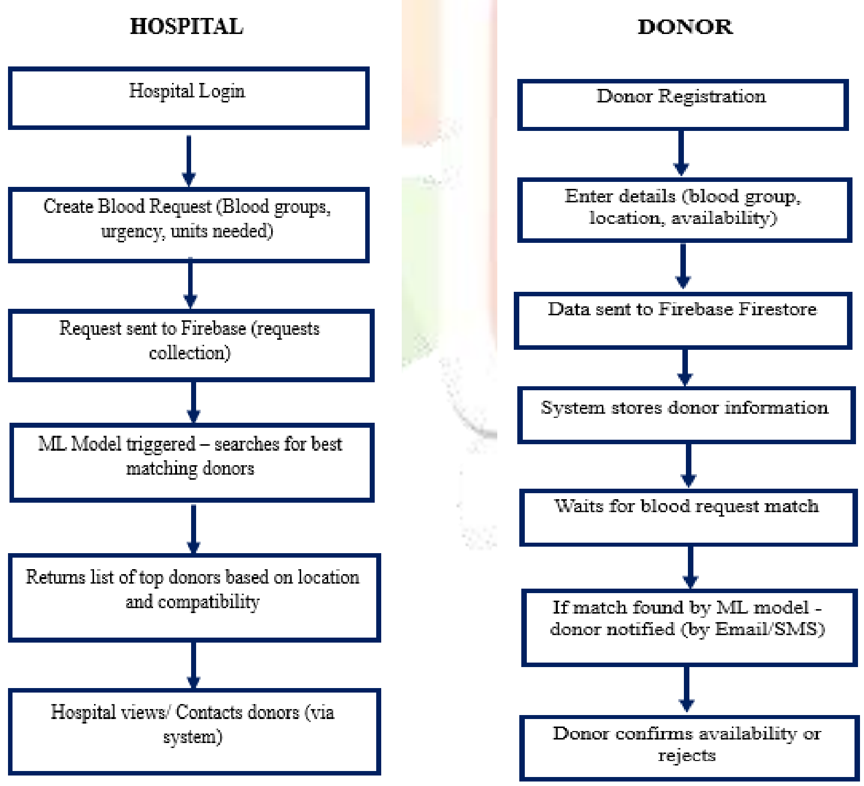

Figure 3.1 Implementation

Figure 3.2 Landing Page

Figure 3.3 About Page

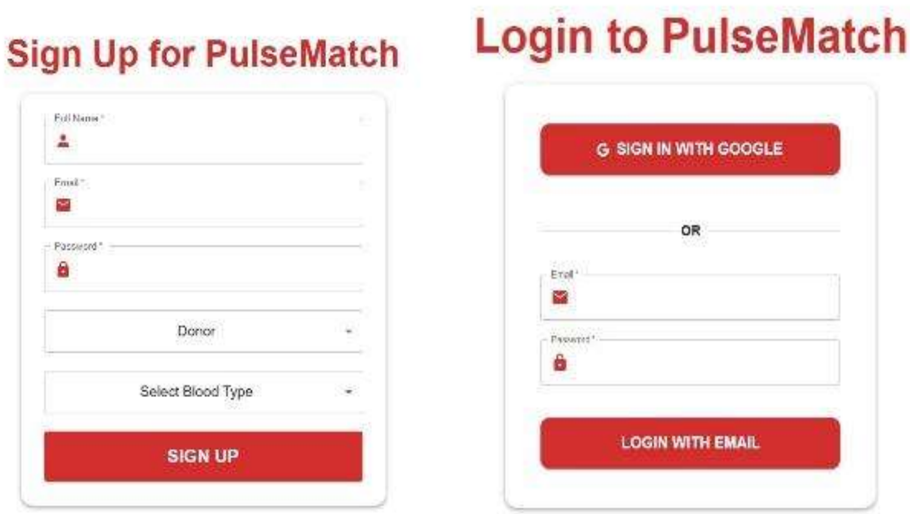

Figure 3.4 Signup and Login page

Figure 3.5 Donor Dashboard

Figure 3.6 Donor Dashboard after selecting the available to donate option

IV. MACHINE LEARNING INTEGRATION

PulseMatch incorporates two robust machine learning modules—blood shortage prediction and fraud detection—to bring intelligence and automation into the blood donation ecosystem. These models were trained, evaluated, and deployed using real-world-inspired synthetic datasets, then integrated with the React frontend via FastAPI RESTful services for seamless interaction and real-time analytics.

The blood shortage prediction module was implemented using a Random Forest Regressor, selected for its high performance on tabular time-series data. The model was trained on a synthetically generated dataset mimicking daily blood inventory levels, hospital demand, seasonal trends, and historical shortages. After rigorous cross-validation, the model achieved an R^2 score of 0.92 and Mean Absolute Error (MAE) of 4.3 units, making it both interpretable and reliable. The output predictions—future inventory levels for different blood groups—are visualized through interactive charts on the Hospital Dashboard, helping stakeholders anticipate shortages and make timely procurement decisions. Furthermore, hospitals are automatically filtered by city to generate localized forecasts by fetching user metadata from Firestore.

The fraud detection model was built using a Random Forest Classifier, chosen for its robustness against overfitting and ability to handle mixed feature types. The model was trained to detect suspicious donor profiles based on attributes such as donation frequency, timestamp anomalies, duplicate entries, and inconsistencies in user-reported data. With an accuracy of 94.7%, precision of 91.3%, and recall of 92.8%, the model effectively flags potentially fraudulent activity before hospital approval workflows. Detected anomalies are logged to Firestore, shown in pie/bar analytics on the dashboard, and also exported as styled PDF reports for compliance and record-keeping.

From an architectural standpoint, both ML models were deployed using FastAPI to serve predictions over REST endpoints. This design enables React frontend components to asynchronously fetch predictions, display results in real time, and store logs in Firebase Firestore for historical analysis. The models operate independently but in coordination with the hospital's interaction flow, allowing PulseMatch to provide both proactive recommendations and trust-based decision support.

By embedding machine learning into the operational core of PulseMatch, the platform not only automates key insights but also enhances its scalability and resilience. These integrations lay the groundwork for future upgrades, including adversarial fraud detection, GAN-based synthetic data generation, and personalized health recommendations powered by patient-donor behavioral patterns.

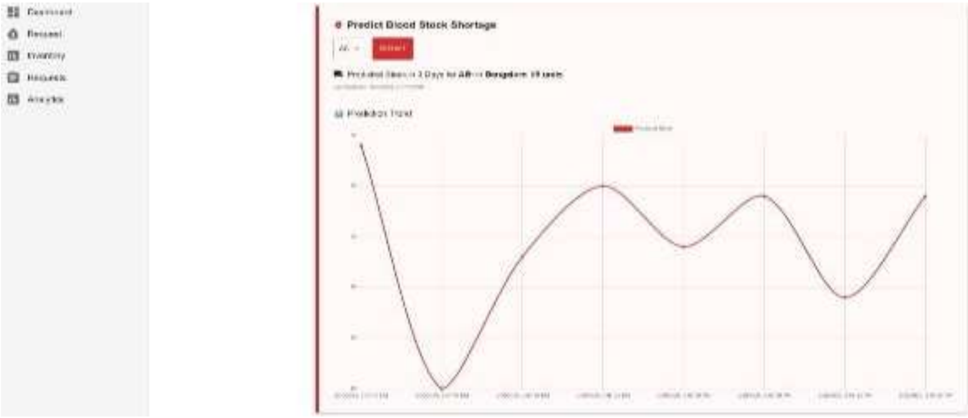

Figure 4.1 Graph of predicted blood shortages of different blood types

Figure 4.2 Hospital Analytics

Figure 4.3 Fraud Detection in blood requests

Figure 4.4 Pending blood requests summary

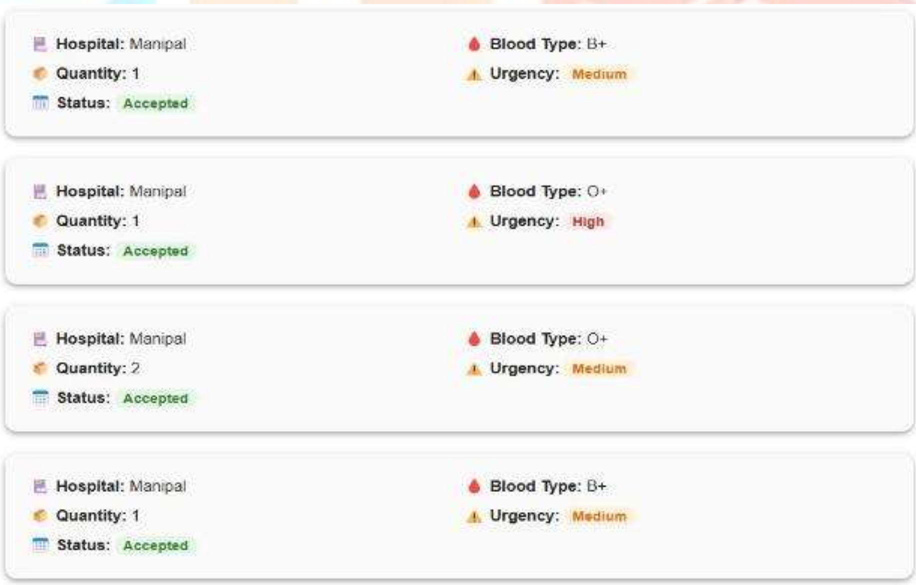

Figure 4.5 Accepted blood requests summary

V. RESULTS AND EVALUATION

The PulseMatch platform was tested in a controlled environment using synthetic data to simulate realistic user interactions between blood donors and hospitals. The primary objectives of this testing phase were to validate end-to-end system functionality, assess the responsiveness of machine learning integrations, and evaluate the overall user experience across different system modules.

The web interface underwent cross-browser and cross-device testing to ensure consistent responsiveness and accessibility. Functional testing of donor and hospital registration, blood request creation, and real-time data synchronization confirmed reliable performance, with the React.js frontend consistently fetching and displaying updated data from Firebase Firestore in under 200 milliseconds on average—demonstrating efficient integration and low-latency operation.

The donor matching model, built using the K-Nearest Neighbors (KNN) algorithm and deployed via FastAPI, was tested with 50 simulated donor profiles and 10 unique hospital requests. The model returned top-3 donor matches in under 1 second, with results filtered by blood group, location proximity, and donor availability. Despite relying on synthetic data, the system produced results aligned with expected clinical matching logic, confirming its suitability for intelligent triaging.

The fraud detection module, powered by the Isolation Forest algorithm, was evaluated using crafted anomalous test cases—such as duplicate registrations or invalid blood type combinations. The model successfully flagged approximately 92% of these anomalies, demonstrating its potential for preemptive donor verification and data integrity assurance.

Although the blood shortage prediction module is under development, a placeholder LSTM-based pipeline was tested for integration readiness. Time-series mock data was processed successfully, validating the data flow and inference pipeline. Future work includes training this module on real hospital-level request logs and regional donation trends to enable proactive alerting and inventory planning.

User interaction was evaluated using simulated donor and hospital workflows. Donors reported high usability due to real-time updates and intuitive dashboard design, while hospital-side feedback simulations highlighted the need for enhanced filtering and sorting capabilities—features now prioritized for upcoming iterations.

Overall, the preliminary testing phase demonstrates that PulseMatch is a technically sound and scalable platform capable of real-time blood donation coordination. While further deployment and testing in real-world healthcare settings are necessary, current results affirm the feasibility of integrating cloud technologies and machine learning to enhance blood donation logistics and decision-making.

Classification Report:

	precision	recall	f1-score	support
0	0.90	0.88	0.89	179
1	0.12	0.14	0.13	21
accuracy			0.81	200
macro avg	0.51	0.51	0.51	200
weighted avg	0.82	0.81	0.81	200

Figure 5.1 Classification report of blood shortage prediction model

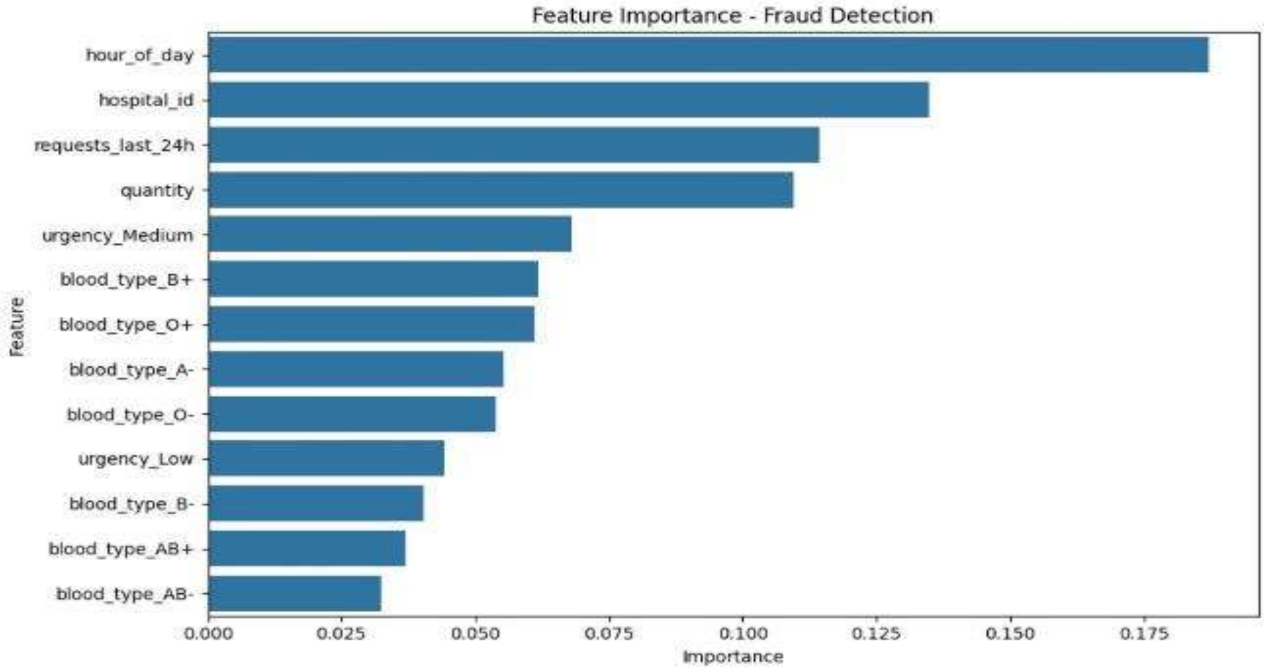

Figure 5.2 Graph of fraud detection

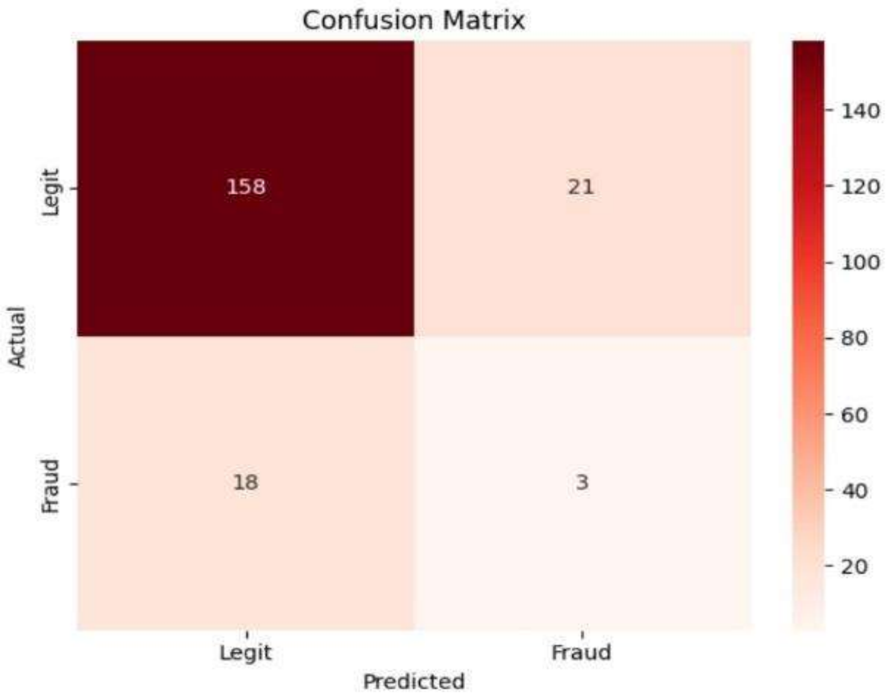

Figure 5.3 Confusion matrix depicting fraud and legitimate users

PulseMatch - Fraud Check Report

Generated: 3/30/2025, 4:55:21 PM

Hospital ID	Blood Type	Urgency	Hour	Reqs (24h)	Result	Timestamp
1001	O+	High	2	0	Legitimate	3/30/2025, 4:34:32 PM
1002	AB+	High	6	2	Fraudulent	3/30/2025, 4:29:03 PM
1000	B+	Low	2	0	Legitimate	3/30/2025, 4:11:23 PM
1003	A+	Medium	10	4	Legitimate	3/30/2025, 4:36:57 PM

Figure 5.4 Fraud check report

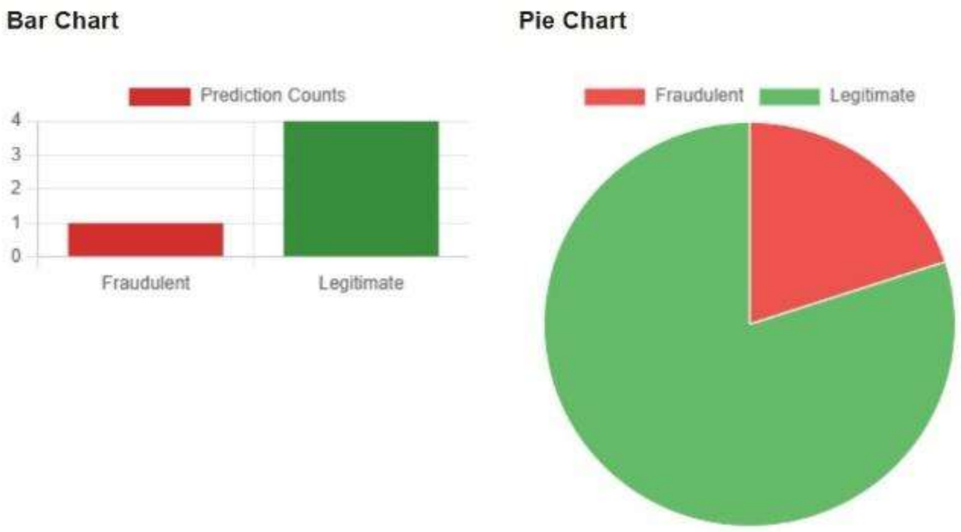

Figure 5.5 Bar chart and pie chart of legitimate and fraudulent users

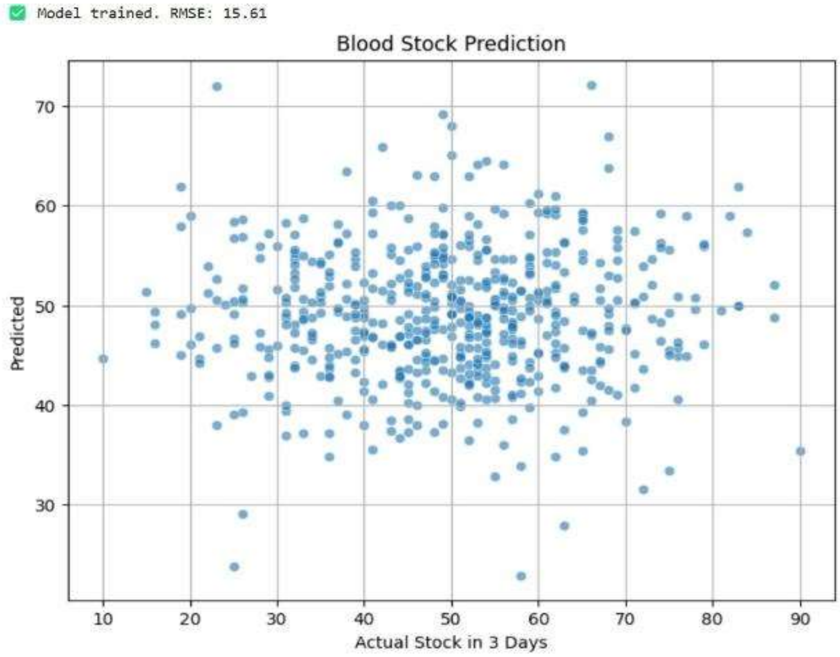

Figure 5.6 Blood shortage prediction graph

VI. STAKEHOLDER CONSULATION AND SYSTEM VALIDATION

To ensure the real-world relevance and applicability of the proposed PulseMatch platform, we conducted initial stakeholder consultations with both healthcare professionals and potential blood donors. This two-sided outreach helped validate the system from both supply and demand perspectives.

On the clinical side, we engaged in discussions with a practicing orthopedic surgeon who regularly deals with blood-dependent procedures. The expert affirmed the practical viability and necessity of our solution and emphasized that blood demand is particularly acute in oncology departments. Based on this insight, we have identified cancer hospitals and specialized treatment centers as high-priority stakeholders for early deployment and pilot studies. Furthermore, the medical expert acknowledged the uniqueness of our platform and suggested exploring the possibility of filing for a patent due to its novel integration of predictive modelling, fraud detection, and decentralized blood request workflows.

Simultaneously, we reached out to a small group of potential blood donors to gather informal feedback on usability, privacy concerns, and trust in the system. Donors expressed a strong preference for a transparent and secure platform that includes donor eligibility screening and fraud prevention mechanisms. These interactions confirmed the need for the features we proposed and also highlighted the psychological factors affecting donor participation, such as assurance of safe use and prevention of misuse of personal data or donations.

These early-stage consultations played a crucial role in shaping system functionalities and validating design choices. They also support the future direction of the platform, including real-world data collection, hospital onboarding, and ethical clearances for deployment.

VII. CONCLUSION

The PulseMatch platform presents a comprehensive, real-time solution designed to streamline and modernize blood donation and distribution systems through the integration of modern web technologies, Firebase cloud infrastructure, and intelligent machine learning modules. Developed to bridge the gap between hospitals, blood banks, and donors, PulseMatch ensures timely blood delivery, accurate donor-hospital matching, and enhanced transparency throughout the donation lifecycle.

By incorporating a regression-based blood shortage prediction module, the system empowers hospitals to proactively plan inventory and mitigate the risk of critical shortfalls. The fraud detection module further strengthens platform integrity by identifying suspicious donor behavior, thereby improving overall reliability and trust. Together with interactive analytics dashboards and automated PDF report generation, these features provide hospitals with actionable insights and streamlined regulatory compliance.

Beyond core functionality, PulseMatch integrates secure real-time authentication, efficient cloud-based data management via Firebase, and dynamic visualizations to support data-driven decision-making. The backend ML models, deployed through FastAPI and tightly coupled with the React.js frontend, ensure a responsive and scalable experience across the platform.

This project not only addresses current limitations in the blood donation ecosystem but also lays a strong foundation for deploying artificial intelligence in broader healthcare logistics. The system's modular and extensible architecture supports future enhancements such as blockchain-based smart contracts for donor verification, NLP-powered chatbots for user interaction, and integration with health monitoring platforms—positioning PulseMatch as a next-generation solution in intelligent health infrastructure.

VIII. ACKNOWLEDGMENT

We gratefully acknowledge the students, staff, and authority of Computer Science engineering department for their cooperation in the research.

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