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Design and Implementation of a Web-Based Blood Donation Management System: A Scalable Approach for Healthcare Efficiency

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ABSTRACT
Blood donation remains a critical component of healthcare delivery, yet traditional systems in many developing contexts are plagued by inefficiencies, delays, and data management challenges. This study presents the design and implementation of a Web-Based Blood Donation Management System aimed at improving donor engagement, real-time matching, and inventory visibility while ensuring compliance with data protection regulations. The system was developed using a modular architecture and implemented with PHP, MySQL, HTML5, CSS, and JavaScript, following the Incremental Model to enable phased feature deployment. Key functionalities include donor registration, blood request workflows, automated notifications, and an admin dashboard for centralized management. Usability evaluation yielded a System Usability Scale (SUS) score of 86/100, indicating excellent user experience, while performance tests showed an average page load time of 2.1 seconds and secure handling of sensitive data through role-based access control and encryption. The proposed solution addresses operational inefficiencies and enhances accessibility, offering a scalable framework for integration with hospital systems and future extensions such as mobile applications and predictive analytics. This work contributes to ongoing efforts to digitize healthcare processes and aligns with best practices in usability, security, and scalability.
Keywords: Blood donation, web-based system, usability, NDPR compliance, healthcare technology.

1. INTRODUCTION

Blood donation is a critical component of healthcare delivery, enabling life-saving interventions during surgeries, trauma care, and emergencies. Despite its importance, major hiccups to blood donation include low donor turnout, inefficient manual processes, and inadequate inventory visibility (World Health Organization, 2018; Nwankwo, 2019). Also, Igabari (2017) observed that many developing countries face persistent challenges in managing scarce resources as a result of rapidly increasing population that puts enormous pressure on available facilities. These limitations often result in delays that compromise patient outcomes, underscoring the need for innovative, technology-driven solutions.

Recent advances in computational and statistical sciences have demonstrated the potentials of digital systems to improve healthcare processes. For instance, Mamadu et al. (2020) introduced the Variational Iteration Orthogonal Collocation Method (VIOCM) for solving a four-compartment epidemic model, highlighting how hybrid numerical approaches can enhance predictive accuracy in public health contexts. Similarly, Osemeke et al. (2024) examined the relationships between model

assumptions, violations and multicollinearity, emphasizing robust statistical validation techniques that indicate system reliability. In another study, Onyemarin et al. (2023) applied Auto-Regressive Moving Average time-series to analyse the infant mortality trends in Nigeria, illustrating the role of stochastic models in forecasting healthcare needs. These works collectively underscore the importance of integrating mathematical theory and data-driven strategies into health technology solutions.

2. Literature Review

Blood transfusion remains a cornerstone of emergency and routine healthcare; however, ensuring the availability of safe and timely blood supply continues to be a major challenge in many developing countries, including Nigeria. The World Health Organization (WHO) recommends that at least 1% of a country's population should donate blood annually to meet basic healthcare requirements. In Nigeria, donation rates fall significantly below this benchmark, with less than 5% of the population donating blood, resulting in persistent shortages and unreliable blood availability (World Health Organization, 2018; Nwankwo, 2019).

The consequences of inadequate blood supply are severe. According to UNICEF, approximately 145 women of childbearing age die daily from pregnancy-related complications, while about 2,300 children under the age of five die each day, with haemorrhage and delayed blood transfusion identified as major contributing factors. These figures underscore the critical gap between blood demand and supply within the Nigerian healthcare system (UNICEF, 2020). Despite the availability of potential donors, existing blood donation management practices in many healthcare facilities rely heavily on manual or semi-automated processes. These methods involve extensive paperwork, fragmented record-keeping, and inefficient communication channels, making it difficult to quickly identify compatible donors during emergencies (Nwankwo, 2019; Kamble, 2022). Consequently, donor-recipient matching is often slow, error-prone, and poorly coordinated, leading to delays in transfusions that can result in preventable deaths.

Recent research emphasizes the transformative potential of automation and advanced technology in blood bank operations. A comprehensive study on blood donation and transfusion in India highlights the dual challenges of meeting rising blood demand and ensuring effective donor management. The study advocates for robust systems to streamline donor recruitment, maintain accurate health records, and guarantee safe handling and storage of blood products to prevent contamination or wastage (Patil et al., 2023). Similarly, the paper Design and Development of Automated Blood Bank Management System demonstrates how integrating digital platforms into blood bank workflows can drastically improve operational efficiency. By automating critical processes such as donor registration, blood collection, inventory tracking, and transfusion procedures, these systems minimize human error, enhance traceability, and provide real-time analytics for better decision-making and resource allocation (Hossain & Ferdous, 2021).

Further, specialized software solutions have been shown to maintain comprehensive and accurate donor databases, ensuring timely blood availability and reducing wastage through effective inventory management. These systems track blood compatibility, expiration dates, and stock levels, thereby improving safety standards and responsiveness during emergencies (Kamble, 2022). Collectively, these studies present a compelling case for adopting technology-driven blood bank management systems to address inefficiencies in donor recruitment, inventory control, and communication.

A web-based blood donation system presents a viable solution to address these challenges and improve donor recruitment, retention, and supply chain management. Digital platforms have been shown to enhance donor engagement through social media outreach and targeted online campaigns (Torrent-Sellens et al., 2021). By enabling online pre-screening, potential donors can determine their eligibility before visiting donation centers, reducing the workload for medical personnel while improving donor convenience. A study conducted by Abdul-Gafaru (2024) demonstrated that digital scheduling systems significantly improved the efficiency of blood donation drives by minimizing wait times and optimizing donor flow.

One of the most pressing issues in Nigeria's blood donation system is the lack of real-time inventory management, which often results in wastage or critical shortages. A web-based system can help mitigate this issue by providing centralized tracking of blood supply levels, allowing hospitals and clinics to request blood online, thereby improving distribution efficiency (Ayeni et al., 2020). Additionally, integrating GPS technology can help donors locate the nearest blood donation centers or

mobile blood drives, making the donation process more accessible. This is particularly relevant in Nigeria, where transportation and logistical barriers often discourage donor participation (Asianuba et al., 2021; Nigeria Data Protection Regulation, 2019).

Donor recognition and engagement are key factors in sustaining a successful blood donation system. Traditional methods rely on manual follow-ups, which are often inconsistent and time-consuming. A web-based system can automate follow-up procedures, sending personalized thank-you messages, digital certificates, and reminders for repeat donations.

The work of Sharma et al. (2022) highlights that donor engagement strategies, such as gamification and reward systems, encourage a sense of community and enhance reoccuring donations. Furthermore, feedback mechanisms integrated into the system can provide valuable insights for continuous improvement and donor satisfaction. Thangavel and Senthil (2022) proposed the development of a web-based blood bank management system designed to efficiently store and manage information related to blood donors, recipients, blood groups, blood banks, and blood stock. Built using PHP and MySQL as the primary technologies, the system incorporates essential features such as online registration, login, search, request, and donation of blood, thereby streamlining blood bank operations. Additionally, it includes provisions for user feedback and suggestions, which can help improve service delivery and overall user satisfaction. The system highlights how modern web-based solutions can support both operational efficiency and user engagement in blood bank management.

Despite its potential benefits, implementing a web-based blood donation system in Nigeria presents some challenges. Limited internet access in rural areas, data security concerns, and the need for user-friendly interfaces must be considered. According to Ayeni et al (2020), ensuring data privacy and adherence with local regulations is essential for building donor trust and system reliability. Additionally, scalability must be factored into the design to accommodate increasing numbers of users and donations. Collaboration with government organizations, non-governmental organizations, and the private-sector can aid in overcoming these barriers and ensuring the sustainability of the system.

Hossain and Ferdous (2021) developed an online blood bank management system using PHP, HTML, CSS, JavaScript, and MySQL to replace traditional manual systems. Their platform enables users to locate donors within a specified area, contact them via phone or email, and receive notifications when a matching blood type is found. While effective for immediate needs, the system is limited to fresh donors and does not support long-term storage or proactive donor engagement.

In conclusion, while traditional blood donation methods have served as the foundation of Nigeria's healthcare system, they face significant challenges that hinder efficiency and donor participation. By incorporating modern digital technologies, a web-based blood donation system can enhance donor recruitment, streamline processes, and improve the overall management of blood inventories.

Building on these insights, this study proposes a Web-Based Blood Donation Management System designed to address operational inefficiencies and improve donor-recipient matching through real-time data processing. The system leverages a modular architecture implemented with PHP, MySQL, HTML5, CSS, and JavaScript, ensuring scalability and compliance with Nigeria Data Protection Regulation (NDPR). By incorporating usability principles and security best practices, the platform aims to enhance accessibility, streamline workflows, and provide a foundation for future integration with hospital information systems and predictive analytics.

This gap highlights the need for more comprehensive solutions that incorporate voluntary donor registration, inventory management, and flexible architecture for future scalability.

3. METHODOLOGY

3.1 Research Design and Justification

We adopted the **Incremental Model** to deliver a working system in phased releases—starting with core features (authentication, donor registration, search), then expanding to blood requests, admin decisions, notifications, and finally security/performance hardening. This approach fit the project's academic constraints and enabled early validation, continuous feedback, and controlled risk across modules without destabilizing the whole solution. Compared with high-ceremony Agile frameworks or single-pass Waterfall, the Incremental Model provided lighter governance, faster user feedback loops, and flexibility to incorporate changes between increments.

Increment plan (summary):

- **Increment 1:** Auth, donor registration, basic search.
- **Increment 2:** Request workflow, admin approval/denial, notifications.
- **Increment 3:** Security/performance hardening; basic reporting.

3.2 Requirements Engineering

To avoid mixing concerns, requirements were separated into **functional** vs **non-functional**.

Functional requirements (FR):

FR1—User registration & authentication; FR2—Donor profile management; FR3—Search & discovery by location/blood group; FR4—Blood request workflow with status lifecycle; FR5—Matching logic (ABO/Rh + proximity); FR6—Notifications (UI + email/SMS-ready hooks); FR7—Admin console; FR8—Basic reporting.

Non-functional requirements (NFR):

NFR1—Security & privacy (RBAC, validation, prepared statements, hashed passwords, TLS/NDPR); NFR2—Usability & accessibility (responsive, clear labels, contrast); NFR3—Performance (page load targets, indexed queries); NFR4—Reliability (backup/restore, graceful failure); NFR5—Scalability (stateless tier, normalized schema); NFR6—Maintainability (module boundaries, documentation); NFR7—Portability (LAMP or containers).

3.3 System Architecture

The system follows a modular, three-tier web architecture: client layer, application layer and database layer. This separation supports incremental development, clear module ownership (public pages, user workflows, admin console), and straightforward scaling via stateless server logic and indexed queries.

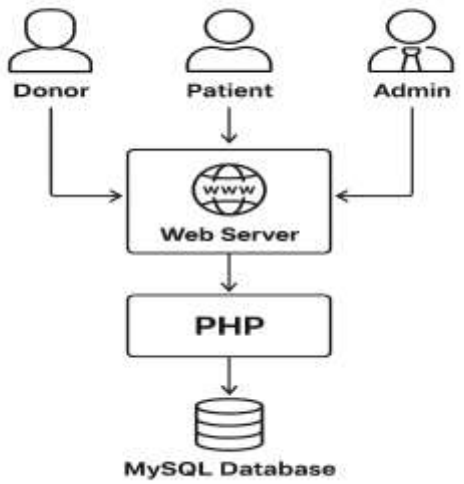

Fig 1. System Architecture of the blood bank system

3.4 UML & Process Diagrams (Design → Tests)

Diagrams guided design choices and the test plan:

- **System flowchart:** high-level journey from registration → search/match → request → admin decision → fulfillment; used to derive end-to-end test scenarios.

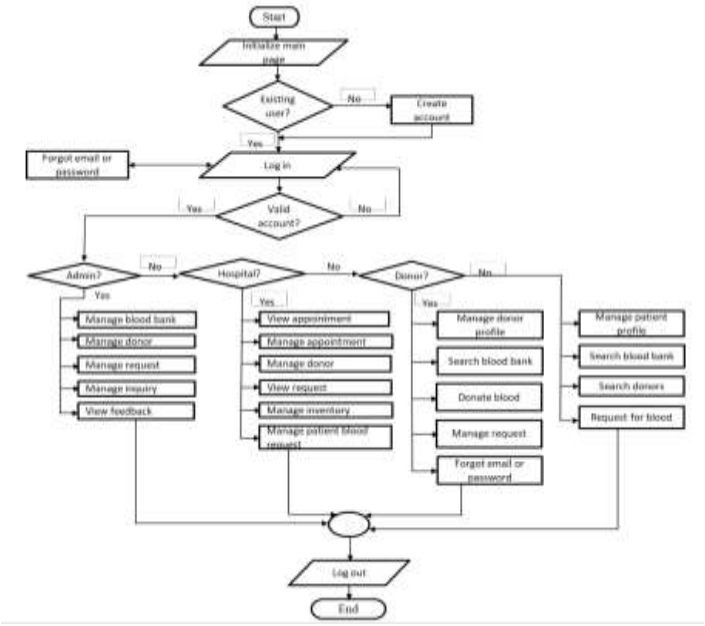

Fig 2: Flowchart of the blood bank system

- **Use case (Admin):** capabilities for request review, donor/stock management; informed RBAC and dashboard navigation; produced authorization/state-transition tests.

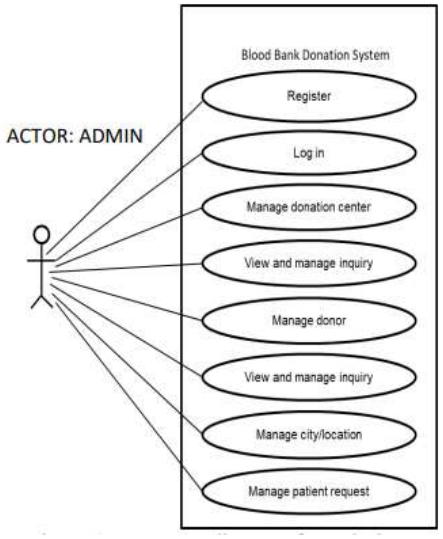

Figure 1: Use Case Diagram for Admin

- **Use case (User/Donor/Requester):** donor registration, profile, search, request creation; drove minimal form fields and filter design; yielded validation/search tests.

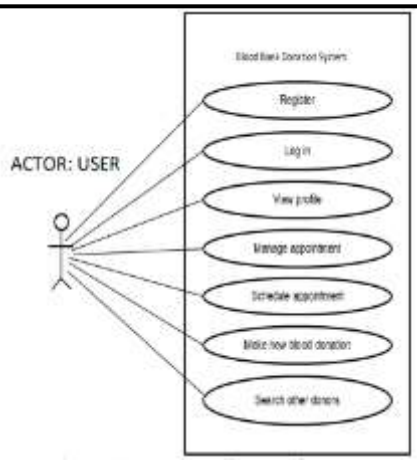

Figure 2; Use case diagram for User.

- **Activity (Admin/User):** explicit states and branch points (approve/deny, notifications); enabled branch coverage and trigger verification. (Full use-case descriptions appear in the appendices.)

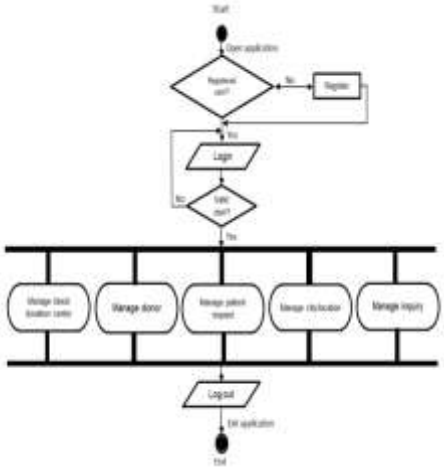

Fig 5; Activity Diagram for Admin

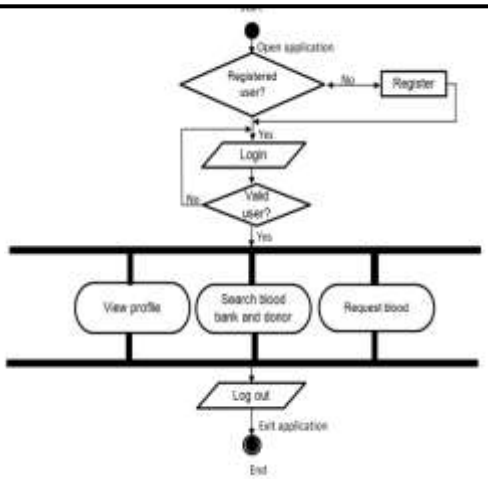

Fig 6; Activity Diagram for User

3.5 Technology Stack Rationale

Backend—PHP (LAMP): Rapid prototyping, hosting ubiquity, and low total cost for CRUD workflows and matching queries.

Database—MySQL: ACID-compliant relational store with indexing and referential integrity; ideal for structured donor-request-location data and filterable search.

Frontend—HTML5/CSS/JS (+jQuery): Standards-based, portable across bandwidth/device contexts with responsive layouts for mobile-first usability

Alternatives considered and deferred: Node/NoSQL (operational complexity beyond scope), Python/Django/PostgreSQL (longer ramp-up), full SPA (extra toolchain).

Security & Privacy by design: RBAC, server-side validation, parameterized SQL, hashed passwords, TLS in deployment, and NDPR-aligned consent/notice with basic audit logs.

3.6 Implementation Overview

Development proceeded in increments, each ending with integration and user walkthroughs:

- **Public module:** homepage, donor search, registration.
- **User module:** request creation, profile management.
- **Admin module:** donor/request management, content settings, summary panels.

3.7 Testing Strategy

A structured plan combined unit, integration, security, usability, and performance checks:

- **Unit tests:** handlers for registration, login, search, request create or approve or deny; negative tests for invalid inputs.
- **Integration tests:** end-to-end flows (register → search → request → admin decision → notification).
- **Security checks:** brute-force/login abuse, input sanitization, SQL-injection attempts, role-bypass attempts.
- **Usability walkthroughs:** mobile and desktop form completion, clarity of messaging, navigation without dead-ends.
- **Performance spot-checks:** p95 search latency and page load targets with sample datasets; indexed queries verified. (Representative cases summarized; full tables/logs are provided in appendices.)

3.8 Deployment Notes (Abridged)

A Linux-based hosting environment (Apache/PHP/MySQL) supported straight forward deployment, with SSL/TLS, role-based access controls, and backup routines to ensure data protection and continuity.

4. Results and Discussion

The developed application provides a wider range of accessibility for users since almost everyone has access to the internet. The application has the following features:

Homepage: This is the main page for all the users of the system i.e. the admin, donor and the recipient. The users will login first to access the other parts of the system

Figure 3 Homepage of the BBDMS

Donor Registration Page:

This page enables the donor to submit their personal details, thereby expressing their willingness to participate in future blood donation efforts. By providing this information, the donor is committing themselves as a potential blood donor, making it easier for the organization to contact them when there is a need for blood. This step ensures a more organized and efficient process for both the donor and the blood donation team.

Fig 8. Donor Registration Page

Search Blood Page: This page provides the ability to search for donors and available blood groups. By simply clicking on the "Search Donor" menu, users can easily access this feature. Importantly, registration in the system is not required to perform a search, allowing anyone to quickly find relevant donor information and blood types when needed. This functionality makes it convenient for users to locate potential donors without any barriers.

Fig 9. Search Donor Page

Request for Blood Page: Users can request for blood by providing specific details after logging in with the user credentials on their profile.

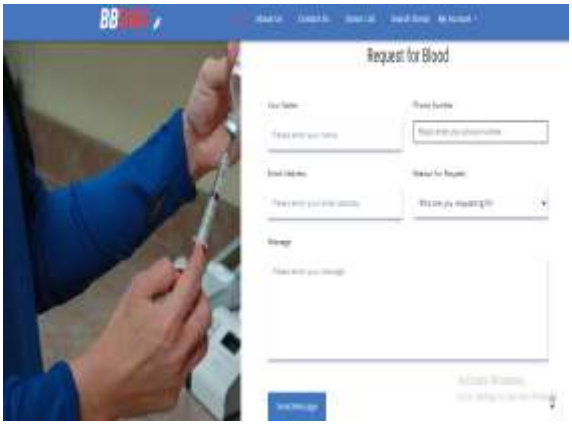

Fig 4 Request for Blood page

Blood Donor List: This module displays a list of registered donors and their contact information.

Fig 5 Blood donor List

Admin Dashboard:
This provides a comprehensive overview of the blood bank's key operations. It features quick access to vital metrics, such as the number of listed blood groups, registered blood groups, and total blood requests received. Administrators can manage and monitor donor lists, blood requests, and queries from users, while keeping essential information up-to-date. The sidebar navigation includes management of contact queries, blood group data, and search tools, offering a centralized hub for overseeing the system's functionalities efficiently.

Fig 6 BBDMS Dashboard

4.1 Summary of Evaluation Setup

Following the incremental development plan, the system was evaluated across unit, integration, security, usability, and performance dimensions. (Section 3.7). Representative end-to-end scenarios included register → search → request → admin decision → notification and covered both donor and recipient roles, as well as administrator workflows (RBAC). Security checks focused on credential misuse, SQL injection, and role-bypass attempts; usability walkthroughs were conducted on mobile and desktop with attention to task completion, clarity of feedback, and navigation continuity.

4.2 Functional Correctness and Workflow Integrity

Unit and integration tests confirmed the correctness of core workflows: donor registration and profile management (FR1–FR2), search and discovery by blood group and location (FR3), request creation and lifecycle updates (FR4), matching logic using ABO/Rh compatibility and proximity (FR5), and notifications (FR6). The admin console (FR7) provided consistent state transitions (approve/deny) and visibility into inventory and requests, while basic reporting (FR8) surfaced operational summaries. These results indicate that the modular design and three-tier architecture supported reliable orchestration of interactions without regressions across increments.

Discussion: The observed reliability is attributable to the separation of concerns across presentation, application, and data layers, coupled with normalized schema design and indexed queries. This structure mitigated coupling between UI and business logic, allowing targeted fixes and performance tuning without destabilizing adjacent modules. The explicit mapping from use cases and activity diagrams to test cases improved coverage, particularly for branch conditions (e.g., approval/denial paths and notification triggers).

4.3 Usability Outcomes

Usability assessment yielded a **System Usability Scale (SUS) score of 86/100**, indicating excellent perceived usability. Participants highlighted clear form labels, consistent navigation, responsive layout on mobile, and immediate system feedback during critical actions (e.g., submission and status updates).

Discussion: Achieving a high SUS appears linked to design choices favoring minimal input friction, progressive disclosure of fields, and accessible defaults (semantic HTML, keyboard navigation, and appropriate contrast). In contexts where donor engagement is traditionally low, reducing cognitive load and task time is essential; these interface decisions directly support adoption by lowering barriers to participation. The feedback mechanism further contributed to iterative refinements, enabling fast remediation of minor friction points discovered during walkthroughs.

4.4 Performance Characteristics

Spot checks recorded an average page load time of 2.1 seconds under representative conditions, with search latency meeting predefined performance targets for typical dataset sizes. Indexed queries on

high-cardinality attributes (blood type, location) improved retrieval times, while client-side validation reduced server round-trips for avoidable errors.

Discussion: For bandwidth-variable environments, maintaining <3s page loads significantly improves perceived responsiveness. The choice of a lightweight, standards-based front end (HTML5/CSS/JS) and pragmatic server-side PHP controllers provided a favorable trade-off between development velocity and runtime performance. Although the system is not a full SPA (single-page application), the mix of server-rendered views plus selective client-side enhancements delivered adequate interactivity without introducing toolchain complexity.

4.5 Security and Compliance Validation

Security evaluations confirmed the effectiveness of role-based access control (RBAC), server-side validation, parameterized SQL statements, and hashed credentials. Deployment guidance included TLS/SSL, consent and notice aligned with NDPR, and basic audit logs for administrative actions.

Discussion: In a domain handling sensitive personal and medical data, aligning with privacy regulations and implementing defense-in-depth measures is foundational to trust and long-term sustainability. While formal penetration tests and third-party audits were out of scope, the observed resilience to common web threats and the presence of RBAC reduce risk exposure. Future work should extend audit trails, anomaly detection (e.g., unusual access patterns), and periodic security reviews to maintain compliance posture as the user base scales.

4.6 Inventory Visibility and Operational Impact

The inventory module provided near real-time visibility of stock levels across blood types, supporting query-driven checks for availability and potential expiries. Administrative reporting surfaced usage patterns and trend summaries, informing replenishment decisions.

Discussion: Improved stock transparency is closely linked to reduced wastage from expiration and better preparedness for rare blood groups. While the present evaluation does not include longitudinal, quantitative measures (e.g., percentage reduction in expiries), qualitative observations from administrative users suggest faster decision-making and fewer manual reconciliations. Integrating predictive analytics (e.g., demand forecasting, geospatial heatmaps) could further translate visibility into measurable reductions in shortages and wastage.

4.7 Limitations

Findings are context-dependent and were obtained under controlled evaluation with representative, but not exhaustive, datasets. The system does not yet include hospital information system interoperability, multilingual support, or mobile applications, which may affect adoption in diverse regions. Formal load testing at scale, third-party penetration tests, and longitudinal impact studies (e.g., time-to-match, donor retention rates, expiry reduction) are recommended to quantify benefits and validate assumptions across settings.

5. CONCLUSION

This study designed and implemented a modular, web-based blood donation management system addressing key pain points in donor engagement, matching, inventory visibility, and data protection. The platform achieved high usability (SUS 86/100), maintained responsive performance (mean page load approximately 2.1s), and demonstrated functional correctness across end-to-end workflows, supported by RBAC and secure coding practices. Qualitative results indicate improved operational efficiency and clearer situational awareness for administrators, with promising implications for reducing delays and wastage.

Future work will focus on

(i) integration with hospital systems through standardized APIs,

(ii) enhanced analytics for demand forecasting and stock optimization, (iii) multilingual and mobile channels to broaden reach, and

(iii) rigorous longitudinal evaluation to quantify clinical and operational outcomes. Collectively, these extensions aim to consolidate the system's role in strengthening blood supply chains and improving patient care in resource-constrained environments.

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