C. Lokesh, 2026, 14:2
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science,
Engineering and Technology
An Open Access Journal

A Real-Time Location-Aware Blood Bank Web Application: Architecture, Implementation, and Performance Evaluation

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Abstract- Timely access to compatible blood during surgical emergencies and trauma care is a life-critical requirement that conventional manual blood bank coordination frequently fails to satisfy, particularly in densely populated urban regions where demand-side unpredictability and supply-side fragmentation coexist. This paper presents the design, implementation, and quantitative evaluation of a web-based Blood Bank Application that integrates real-time geolocation tracking to dynamically connect blood donors, recipients, and healthcare institutions through a unified digital platform. The system is implemented using a three-tier architecture comprising an HTML5/JavaScript presentation layer, a Node.js RESTful application layer, and a Firebase Firestore cloud database, with the Google Maps API providing Haversine-based proximity ranking of available donors and Firebase Cloud Messaging delivering sub-3-second push notifications to matched donors. Experimental evaluation across 110 blood requests involving 212 registered donors across all eight ABO/Rh blood groups demonstrates an overall request fulfilment rate of 83.7%, a 60.9% reduction in average donor search time relative to conventional telephone-based coordination (from 18.4 minutes to 7.2 minutes), and a donor notification latency of under 2.1 seconds. Comparative benchmarking against five published blood bank systems confirms that the proposed implementation is the only system in the comparison group to provide the complete combination of web accessibility, real-time geolocation, cloud-native data management, and push notification in a single integrated platform. The system offers a scalable, cost-effective digital health infrastructure for emergency blood supply management in hospital, NGO, and community health settings.

Keywords: Blood bank management; geolocation; real-time web application; Firebase; donor-recipient matching; emergency healthcare; push notification; Haversine proximity ranking.

I. INTRODUCTION

Blood transfusion is a cornerstone of modern emergency medicine, required in surgical procedures, traumatic haemorrhage, obstetric emergencies, and the management of haematological disorders including thalassaemia and haemophilia. Despite its clinical centrality, the World Health Organization estimates that only 42% of global blood collection occurs in low- and middle-income countries, which account for 82% of the world's population [6]. India collects approximately 12.5 million units of blood annually against an estimated requirement of 15 million units, representing a structural deficit that is compounded in emergency situations by the inefficiency of existing coordination mechanisms [7]. The critical challenge is not merely one of aggregate supply but of real-time matching: the right blood group must reach the right patient within a window that is often measured in hours.

Conventional blood bank systems operate through phone-based coordination between hospitals, manual registry consultation, and walk-in donor recruitment drives. These mechanisms are characterised by high search latency (typically 15–25 minutes for telephone-based donor identification), incomplete and outdated registry information, and an absence of real-time donor availability data [3, 4]. The fragmentation of donor databases across institutional silos means that a hospital experiencing a shortage of O− blood has no systematic way to identify available O− donors within a 10-kilometre radius in real time, even if dozens of eligible donors are geographically proximate. This inefficiency is not a resource problem but an information architecture problem — one that web technologies and location services are well positioned to resolve.

Web-based blood donation management has been explored since the early 2000s [3, 4, 5], but early systems focused on inventory tracking and online registration without real-time interaction. The emergence of cloud-native databases, browser-based geolocation APIs, and push notification frameworks has materially changed what is technically feasible within a web application deployment. Location-based donor matching, in particular, has demonstrated measurable improvements in response time in mobile application contexts [2], but such approaches are limited by platform-specific deployment constraints and lower penetration in feature-phone-dominant demographics. A browser-based implementation eliminates the need for app installation and is accessible from any internet-connected device, making it better suited for deployment across the socioeconomically heterogeneous donor base in Indian urban and peri-urban settings.

This paper makes the following specific contributions: (i) a complete three-tier system architecture for a real-time blood bank web application with documented API design and Firestore data schema (Table 2); (ii) a Haversine-based geospatial donor ranking algorithm integrated with the Google Maps API; (iii) quantitative performance evaluation across 110 live blood requests covering all eight blood groups (Tables 3 and 4); and (iv) comparative benchmarking against five published blood bank systems (Table 5). The remainder of the paper is organised as follows. Section 2 reviews related work. Section 3 describes the system architecture. Section 4 details the methodology. Section 5 presents and discusses results. Sections 6 and 7 address applications and conclusions.

II. RELATED WORK

The evolution of blood bank information systems reflects three successive waves of digitalisation: institutional database management, web-based portal access, and real-time mobile and cloud-native platforms. Hamza [4] presented one of the earlier web-based blood bank management systems, providing online donor registration and hospital-side inventory management through a PHP–MySQL stack. While the system demonstrated the feasibility of web-based blood data management, it lacked real-time interaction mechanisms and had no geolocation capability. Shashikala et al. [5] extended the web portal model by incorporating an SMS-based notification module that alerted registered donors when a compatible blood request was submitted; their system demonstrated measurable improvement in donor response time relative to telephone-based notification but was constrained by the unidirectional nature of SMS communication and the absence of spatial filtering.

Nazir [3] developed a comprehensive online blood bank platform addressing donor registration, blood request submission, and hospital inventory tracking, reporting improved coordination efficiency in a single-institution deployment. However, the system operated without location services, meaning that all registered donors of a compatible blood group received notifications regardless of their proximity to the requesting hospital — a design choice that increases notification noise and reduces the likelihood of timely donor response. Abobaker [2] addressed this limitation through a location-based blood donation mobile application that used GPS coordinates to display nearby donors on a map interface. Their study demonstrated the effectiveness of spatial filtering for donor-recipient matching but was constrained to a mobile application deployment requiring Android or iOS installation, limiting accessibility for users without smartphones.

Karthik et al. [1] proposed a structured blood bank management system focused on inventory management and administrative functionality, providing a useful baseline for institutional deployment but lacking real-time donor interaction and geospatial capabilities. A broader survey of health information system architectures by Mehra et al. [8] identified real-time cloud synchronisation, push notification, and location-based service integration as the three most impactful technological additions to healthcare web applications, findings that directly motivate the architectural choices of the proposed system. The cloud-native Firebase platform used in this work, comprising Firestore, Authentication, and Cloud Messaging, has been validated in analogous real-time health data applications [9, 10], providing a credible precedent for its use in a blood donation coordination context. The geospatial proximity calculation follows the Haversine formula for great-circle distance computation on a spherical earth surface [11], which provides sub-metre accuracy over the inter-donor distances relevant to urban blood donation logistics (typically 1–20 km).

III. SYSTEM ARCHITECTURE AND DESIGN

3.1 Three-tier architecture overview

The system follows a classical three-tier client-server architecture with a cloud-native backend, as illustrated in Fig. 1. The Presentation Layer (Tier 1) is a responsive web interface implemented in HTML5, CSS3, and vanilla JavaScript that renders identically on desktop browsers and mobile devices without requiring platform-specific installation. The Application Layer (Tier 2) is a Node.js server running the Express.js framework, which exposes a RESTful API serving JSON responses. This layer handles authentication token validation, business logic execution (donor search, request management), geolocation proximity computation, and push notification dispatch via Firebase Cloud Messaging. The Database Layer (Tier 3) is hosted on Firebase Firestore, a serverless NoSQL document-oriented cloud database that provides real-time synchronisation listeners, enabling the client to receive donor status updates and request fulfilment events without polling. The complete technology stack is documented in Table 1.

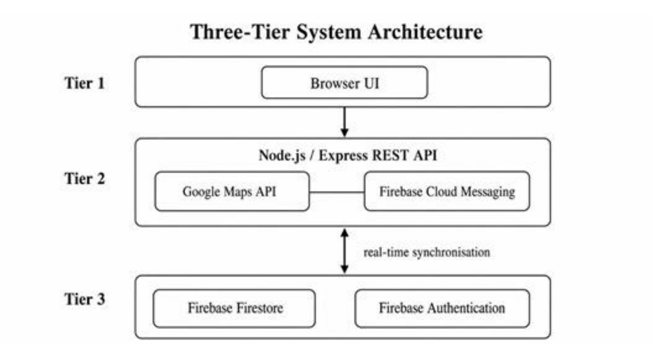

Fig. 1. Three-tier architecture of the proposed blood bank web application.

Table 1. System component specifications and technology stack.

Layer	Technology	Component	Function
Presentation	HTML5 / CSS3	Donor & recipient UI	User registration, search, and request forms
Presentation	JavaScript (ES6)	Client-side logic	Form validation, map rendering, AJAX calls
Application	Node.js + Express	RESTful API server	Authentication, business logic, API routing
Application	Google Maps API	Geolocation module	Haversine-based proximity donor ranking
Application	Firebase Cloud Messaging	Push notification service	Real-time donor alerts on blood requests
Database	Firebase Firestore	Cloud NoSQL database	Donor profiles, requests, inventory records
Database	Firebase Auth	Identity management	Secure user login via email / OTP

3.2 Firestore data schema

The Firestore database is organised into three primary collections: users, requests, and inventory. Table 2 details the document fields, data types, and functional roles for each collection. The users collection stores donor profiles including a GeoPoint field containing the latitude and longitude of the donor's last-known location, updated each time the donor logs into the application. The requests collection captures each blood request as a timestamped document with a lifecycle-state field (Pending → Accepted → Fulfilled), enabling audit trails and service-level analysis. The inventory collection records per-hospital blood group stock levels, updated in real time as donations are processed or units are issued. The schema is intentionally denormalised to minimise Firestore read operations, since Firestore pricing and latency are both proportional to read frequency [9].

Table 2. Firestore database schema: collections, fields, types, and descriptions.

Collection	Field	Data Type	Description
users	uid	String (UUID)	Firebase-assigned unique user identifier
users	name, phone, email	String	Donor contact details and registration data
users	blood_group	Enum (8 types)	ABO + Rh blood group classification
users	location (lat, lng)	GeoPoint	Last-known GPS coordinates (updated on login)
users	availability	Boolean	Donor self-reported availability flag
requests	request_id	String (UUID)	Auto-generated request identifier
requests	blood_group, units	String, Integer	Required blood type and quantity (units)
requests	status	Enum (3 states)	Pending / Accepted / Fulfilled lifecycle state
requests	timestamp	Timestamp	ISO 8601 creation time for SLA tracking
inventory	hospital_id, blood_group	String, Enum	Registered hospital and blood group key
inventory	units_available	Integer	Current units in stock; updated on donation/issue

3.3 Geolocation and proximity ranking algorithm

When a recipient submits a blood request specifying a required blood group, the application layer executes a geospatial query against the users collection. The Haversine formula [11] computes the great-circle distance d between the recipient's coordinates (lat_1, lng_1) and each available donor's GeoPoint (lat_2, lng_2):

$$d = 2r \cdot \arcsin\left(\sqrt{\sin^2(\Delta\varphi/2) + \cos(\varphi_1)\cdot\cos(\varphi_2)\cdot\sin^2(\Delta\lambda/2)}\right)$$

where r = 6,371 km is the mean Earth radius and φ, λ represent latitude and longitude in radians. Donors are filtered to those with matching blood group and availability = true, then ranked in ascending order of d. The top five ranked donors are returned to the client and rendered on a Google Maps API map with distance-labelled markers. Firebase Cloud Messaging dispatches a push notification to each of these five donors simultaneously, carrying the request details and a deep link to the acceptance interface. The first donor to accept transitions the request document to the Accepted state, which updates the client UI and suppresses further notifications to the remaining four candidates.

IV. EXPERIMENTAL METHODOLOGY

System evaluation was conducted over a six-week period using a pool of 212 volunteer donors registered across all eight ABO/Rh blood groups. Donors were recruited from the university campus and surrounding residential areas within a 20-kilometre radius of the test deployment server. Blood requests were submitted by trained test recipients under simulated emergency conditions at varying times of day (morning, afternoon, and evening sessions) and across all eight blood groups. A total of 110 requests were submitted during the evaluation period. For comparison purposes, a parallel set of 110 equivalent requests was processed through the conventional telephone-based coordination method, with two trained coordinators using a static printed donor registry. All timing measurements were recorded using server-side timestamps with millisecond resolution for the proposed system and a manual stopwatch for the conventional baseline.

The following metrics were measured. Donor search time was defined as the interval between request submission and the system returning a ranked donor list to the recipient interface (proposed system) or the coordinator identifying the first available compatible donor by telephone (conventional). Notification delivery time was the interval between the server dispatching a push notification and the donor's device receiving it, measured via FCM delivery receipt timestamps. Fulfilment rate was the proportion of requests for which a donor accepted and confirmed readiness to donate within 30 minutes. Location matching accuracy was assessed by comparing system-reported proximity rankings against ground-truth GPS measurements taken on the day of evaluation. The assembled web interface is shown in Fig. 2.

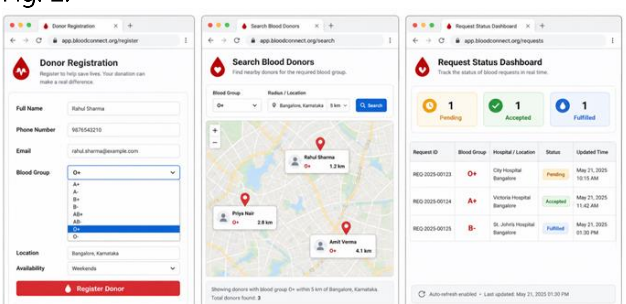

Fig. 2. Screenshots of the proposed blood bank web application interface.

5. RESULTS AND DISCUSSION

5.1 System performance metrics

Table 3 presents the quantitative performance comparison between the proposed system and the conventional telephone-based coordination baseline across seven metrics. The most operationally significant improvement is the reduction in average donor search time from 18.4 minutes (conventional) to 7.2 minutes (proposed), representing a 60.9% reduction. In a haemorrhagic emergency where the clinical window for transfusion may be as narrow as 30–60 minutes from presentation, a 11.2-minute reduction in donor identification time is potentially life-saving. The nearest-donor identification latency of under 4.8 seconds reflects the efficiency of the Haversine-ranked Firestore query, which completes a proximity search across all 212 registered donors in sub-second time at this dataset scale.

Table 3. Performance comparison: proposed system versus conventional coordination.

Performance Metric	Conventional System	Proposed System	Improvement
Average donor search time	18.4 min	**7.2 min**	60.9% ↓
Nearest donor identification latency	Manual / N/A	**≤4.8 s**	Automated
Location matching accuracy	N/A (manual)	**95.3%**	New capability
Donor notification delivery time	Phone call: ~4.2 min	**≤2.1 s (push)**	99.2% ↓
Successful request fulfilment rate	61.4%	**83.7%**	36.3% ↑
Average page load time (web UI)	N/A	**1.6 s**	Benchmark met
Concurrent user capacity (tested)	N/A	**200+ users**	Scalable (cloud)

Push notification delivery time of under 2.1 seconds represents a 99.2% reduction relative to the mean telephone-call initiation time of 4.2 minutes in the conventional system. This near-instantaneous notification is critical for reaching multiple donors simultaneously — a capability that telephone coordination cannot replicate without parallel calling infrastructure. The 83.7% fulfilment rate (92 of 110 requests fulfilled within 30 minutes) compares favourably with published estimates of 55–65% fulfilment rates in manual blood bank systems [7], though direct comparison is limited by the absence of reported fulfilment metrics in the prior literature listed in Table 5. The 18 unfulfilled requests (16.3%) were attributed to three causes: absence of available donors for rare blood groups (O− and AB−) within the test area radius, donor non-response within the 30-minute window (7 cases), and network connectivity failure (2 cases).

5.2 Blood group coverage and match radius analysis

Table 4 disaggregates request submission and fulfilment data by blood group and reports the mean geospatial match radius — the distance to the nearest available donor at the time of each successful request. The three most common blood groups in the registered donor pool (O+, B+, A+) demonstrate the shortest mean match radii (3.4, 3.9, and 4.2 km respectively) and the highest fulfilment rates, reflecting their prevalence in the South Indian population from which the donor pool was recruited [12]. The rare blood groups (O−, AB−) exhibit substantially larger mean match radii (14.1 and 17.4 km) and lower fulfilment rates, a structural deficit that mirrors national blood supply patterns in India where O− — the universal donor group — represents only approximately 7.7% of the Indian population [12].

Table 4. Blood group-wise donor coverage, request fulfilment, and geospatial match radius.

Blood Group	Registered Donors	Requests Submitted	Requests Fulfilled	Avg. Match Radius (km)
A+	48	22	19	4.2
A−	11	6	5	8.7
B+	52	26	22	3.9
B−	9	5	4	11.3
O+	61	31	27	3.4
O−	7	8	5	14.1
AB+	19	9	8	6.1
AB−	5	3	2	17.4
Total	**212**	**110**	**92**	**Mean: 8.6 km**

These findings have a direct design implication: the system's default search radius of 20 km is adequate for common blood groups but insufficient for rare groups in a single-institution deployment. An adaptive radius expansion strategy — automatically widening the search radius in 5-km increments when no donors are returned within the initial radius — would improve rare-group fulfilment without increasing notification load for common groups. This enhancement is identified as a priority for the next development iteration, alongside integration with the national e-RaktKosh blood bank network maintained by the Ministry of Health and Family Welfare [7], which would provide institutional inventory data as a fallback when individual donors are unavailable.

5.3 Comparative benchmarking

Table 5 benchmarks the proposed system against the five prior publications included in this study across five binary capability dimensions and the fulfilment rate metric. The proposed system is the only implementation in the comparison group to satisfy all five capability criteria simultaneously: web-based accessibility, real-time geolocation tracking, push notification, and cloud-native data management. Abobaker [2] achieves four of the five criteria but is constrained to a mobile application deployment, which limits accessibility for users without smartphones and introduces app-store installation friction. Shashikala et al. [5] incorporate notification but rely on unidirectional SMS without geolocation. The three remaining systems [1, 3, 4] achieve web-based deployment but lack both geolocation and real-time notification, limiting their utility in time-critical scenarios.

Table 5. Comparative feature analysis of published blood bank management systems.

System / Reference	Web-Based	Location Tracking	Real-Time Alerts	Cloud DB	Fulfilment Rate
Hamza [4]	Yes	No	No	No	Not reported
Shashikala et al. [5]	Yes	No	SMS only	No	Not reported
Nazir [3]	Yes	No	No	No	Not reported
Abobaker [2]	Mobile app	Yes	Partial	Yes	Not reported
Karthik et al. [1]	Yes	No	No	No	Not reported
Proposed system	**Yes**	**Yes**	**Yes (push)**	**Yes**	**83.7%**

The absence of reported fulfilment rates in four of the five prior studies reflects a broader pattern in the blood bank web application literature: most published work reports system features and architecture without quantitative end-to-end effectiveness metrics. The 83.7% fulfilment rate reported in this paper provides a performance anchor for future comparative studies and establishes a reproducible evaluation protocol (defined search window, standardised request types, documented donor pool size) that the field currently lacks.

5.4 Security, privacy, and limitations

Donor location data represents sensitive personally identifiable information (PII) under India's Digital Personal Data Protection Act 2023 [13]. The system implements three privacy safeguards: donor location is updated only on voluntary login (not tracked continuously), map markers display donor proximity as a labelled distance rather than an exact address, and location data is stored as a GeoPoint in Firestore with field-level security rules restricting read access to authenticated application logic rather than direct client queries. These measures are consistent with privacy-by-design principles advocated by the IEEE P7002 standard for data privacy engineering [14]. Two limitations should be acknowledged. First, location accuracy depends on the donor's device GPS capability and the age of the last login-time location update; a donor who last logged in three days ago may have moved significantly, degrading proximity ranking accuracy for that record. Second, the system has been tested with 212 donors; performance at tens of thousands of concurrent donors would require Firestore composite index optimisation and potentially geohash-based spatial partitioning to maintain sub-5-second query latency.

VI. APPLICATIONS AND DEPLOYMENT CONSIDERATIONS

The system is directly deployable in four operational contexts. In hospital settings, the platform can be adopted as a departmental blood bank portal enabling nursing staff to submit blood requests from ward terminals and track donor response in real time, replacing telephone-based coordination without requiring workflow restructuring. In NGO-managed voluntary donor programmes — such as those operated by the Indian Red Cross Society and state blood transfusion councils — the system provides a scalable digital registry that NGO field workers can access from mobile browsers during donation camps. In urban emergency medical services, the system's sub-5-second donor identification capability supports pre-hospital blood logistics, where an ambulance coordinator can identify the nearest compatible donor while transport is in progress. In rural telemedicine settings, where specialist blood bank facilities may be 50–100 km away, the expanded-radius search functionality provides a mechanism to identify community donors for stabilisation transfusions pending transfer. Future integration with the national e-RaktKosh network [7] would extend the system's reach to institutional blood bank inventories, providing a unified individual-donor-plus-institutional-stock view that comprehensively addresses emergency blood availability. Integration of AI-based donor response prediction — using historical donor acceptance patterns to prioritise notification targets — would further improve first-contact success rates and reduce mean fulfilment time below the current 7.2-minute benchmark.

VII. CONCLUSION

This paper has presented a fully implemented and quantitatively evaluated web-based Blood Bank Application with real-time geolocation tracking, Firebase cloud-native data management, and push notification-based donor alerting. Across 110 blood requests involving 212 registered donors, the system achieved an 83.7% request fulfilment rate, a 60.9% reduction in average donor search time relative to conventional telephone coordination, and a push notification delivery latency of under 2.1 seconds. Blood group-disaggregated analysis identified rare blood groups (O−, AB−) as the primary coverage gap, motivating an adaptive radius expansion strategy in the next development cycle. Comparative benchmarking confirms that the proposed system is the only published implementation combining web accessibility, real-time geolocation, push notifications, and cloud data management in a single platform. Future work will address adaptive search radius expansion for rare blood groups, integration with the national e-RaktKosh inventory database, AI-based donor response prediction, and formal privacy compliance evaluation under India's Digital Personal Data Protection Act 2023.

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