Advanced International Journal for Research (AIJFR)
E-ISSN: 3048-7641 ● Website: www.aijfr.com ● Email: editor@aijfr.com

RescueGrid: A Real-Time Bio-Logistics and Emergency Donor Matching System for Healthcare Logistics

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Abstract

The RescueGrid: Life Saving Bio Logistics Platform is a real-time medical coordination system that minimizes the delay in searching for compatible blood donors and transporting biological resources during a medical emergency. In the majority of medical situations, patients are exposed to a grave threat of death owing to the non-availability of blood or organs at the right time, and the lack of proper coordination among hospitals, donors, and logistics providers. . The proposed system aims to solve the problems by creating a single platform for hospitals, blood banks, donors, and couriers.

The proposed platform is designed to use modern technology to facilitate real-time donor matching, emergency broadcast requests, and real-time tracking of biological resources being transported. For example, a hospital can use the platform to send an emergency request for a particular blood group. At the same time, the proposed platform can match the donor for the blood group and the location of the donor near a particular location within a certain radius. This allows immediate notification of the donor in an emergency health situation.

There is also a real-time GPS tracking system that allows medical staff to track blood or organs being transported. This can be useful for them in preparing for the situation. A modern technology stack is used to develop the proposed platform. This includes using React.js for the frontend and FastAPI for the backend. This allows a high scalability factor for the proposed platform. There is spatial query support for finding nearby donors using PostgreSQL and PostGIS. OAuth2 and JSON Web Token (JWT) are used for secure communication. With real-time communication, geolocation technology, and donor matching algorithms, RescueGrid has the potential to significantly reduce the time taken to source donors and provide life-saving biological resources to those in need. This system has been developed to improve emergency healthcare responses to save lives through efficient medical logistics management.

Keywords: Bio-Logistics, Emergency Donor Network, Blood Donation System, Real-Time GPS Tracking, Medical Supply Chain, Healthcare Coordination, FastAPI, React.js

1. Introduction

The healthcare industry is frequently faced with critical situations in which immediate access to blood donors or biological resources is required for the preservation of patients' lives. In most medical emergencies, difficulties are faced by hospitals in locating immediate sources of compatible blood donors, especially for rare blood groups. Conventional approaches to managing blood donor resources depend heavily on manual forms of communication such as phone calls or social media notifications. These processes are often inefficient and time-consuming, leading to delays in emergency care and increasing the probability of mortality among patients.

However, due to the rapid development of information technologies such as web technologies and real-time communication technologies, intelligent healthcare systems have been made possible. Technologies such as geolocation and real-time notification systems have the potential to greatly improve the efficiency of medical logistics in hospitals. Such technologies enable hospitals to identify donor sources in their vicinity and send out alerts in case of emergencies.

RescueGrid is designed to solve this problem by providing a real-time bio-logistics and emergency donor system. Hospitals, registered blood donors, and couriers are connected under a single online platform. Alerts for emergency blood requirements are sent out by hospitals, and matching blood donors are identified based on blood group and location. Donors registered with the system are alerted in real-time and are able to respond to emergencies accordingly.

Besides donor matching, a real-time GPS tracking feature is included, which enables hospitals and relevant medical personnel to track the transportation of blood units or organs. Supply chain transparency is ensured. The integration of donor matching, emergency alerts, and GPS tracking is the main objective of the RescueGrid system for improving the coordination of emergency health services and reducing the time taken in the administration of treatment.

1.1 Problem Statement of the Study

In emergency medical situations, difficulties are often faced by hospitals in locating compatible blood donors within a limited time. Traditional blood donation systems depend on manual communication and fragmented donor databases, making it difficult to identify available donors quickly. Moreover, there is usually no real-time mechanism to track the transportation of blood or biological resources from donor locations to hospitals. These limitations cause delays in emergency response and inefficient coordination between hospitals, donors, and logistics providers. Therefore, there is a requirement for an intelligent digital platform that can identify nearby compatible donors, broadcast emergency alerts, and provide real-time tracking of medical resource transportation.

1.2 Objective of the Study

The main goal of this research is to design a real-time healthcare logistics system that links hospitals, donors, and couriers through a single platform. This platform is expected to quickly identify compatible blood donors according to their blood group and geographical location. Another goal is to design a system that sends emergency messages to donors during critical health situations. Real-time GPS signals are sent

to hospitals during emergencies. Data security and authentication are ensured. Through these objectives, the RescueGrid system is expected to reduce response time during emergency health situations.

1.3 Organization

The paper is divided into sections. Section 1 includes the introduction, problem statement, and objectives of the research. Section 2 includes a discussion of related work and research conducted previously in the area of blood donation management and healthcare logistics systems. Section 3 includes a description of the system design and technologies adopted during the development of the RescueGrid system. Section 4 includes a description of the methodology adopted during system development. Section 5 includes the results and discussion of system performance. Finally, Section 6 includes a conclusion of the research work with possible improvements.

2. Related Work

Blood donation management systems have been extensively researched in the last few years with the aim of streamlining the process between hospitals and voluntary blood donors. Traditional blood bank management systems use manual records and communication through phone calls, which sometimes lead to delays in critical situations. To overcome these issues, several researchers have proposed the idea of web-based blood donation management systems, which store the details of donors in a centralized manner and help hospitals search for donors quickly [1].

Mobile blood donation application software has also been developed to improve the availability and access to donor information and speed communication. This application allows individuals to register as blood donors using mobile apps and receive notifications when blood is required by patients. Efficiency in donor management is enhanced and voluntary participation in blood donation activities is encouraged [2].

Some studies have focused on integrating location-based technologies to find donors within a particular area. Geolocation services are used by hospitals to locate donors within a given radius using GPS navigation. Alerts can then be sent to those donors who are nearest to the location of the patients. The time required to find donors in emergencies is reduced [3].

Healthcare logistics systems that help in the real-time monitoring of medical resources during transport have also been studied. Real-time communication technology, coupled with the use of GPS, helps in the monitoring of the movement of medical supplies like blood units and organs [4].

Recent advances in healthcare information systems have focused on integrating donor databases, emergency alert systems, and communication systems into a single system. These single systems are expected to improve the efficiency of the response system and provide timely access to vital medical services. However, a lack of coordination between donors, hospitals, and transportation services is reported in existing systems. The proposed RescueGrid system has been developed to integrate donor databases, emergency alert systems, and transportation services into a single healthcare coordination system.

3. Theory or Calculation

The following section outlines the mathematical and computational foundations of the RescueGrid system. The operational logic that powers matching and optimization is formalized.

The request for help is considered a small triplet with the type of required bio-resource, the location, and the time the request was initiated. Specifically, the request for help is defined as:

$R = (Bt, Lr, Tr)$

where Bt represents the type of blood or the required organ, Lr represents the location, and Tr represents the time.

The set of possible donors, $D = \{d1, d2, ..., dn\}$, is evaluated according to two criteria: compatibility and proximity. Compatibility is a simple yes/no test, where only donors that pass the medical criteria are considered further. This effectively reduces the search space while ensuring the candidates are medically valid.

To determine the proximity of items, the linear distance between the donor and the requested location is computed using the Euclidean distance. This helps in fast geo-spatial filtering within a certain service radius, and donors outside the service radius are filtered.

To deal with cases where there are multiple eligible donors, a weighted scoring method is proposed. The priority score is determined by three main factors: how far away the donor is, whether the donor is available, and how likely the donor is to respond. This score is a weighted linear combination, meaning that those donors who are closer, available, and have a higher likelihood of responding have a higher score.

Besides selecting donors, routes for logistics support are optimized by the system. An estimate of the delivery time is made based on distance, speed, and varying delays such as those caused by traffic. Routing decisions are kept updated using real-time GPS data to prevent any holdups in transit.

To test the effectiveness of the system, a comparative efficiency model is employed. Efficiency in this case is a measure of how much faster the new system will be in response time compared to traditional means.

4. Proposed Methodology or Experimental Design or Proposed Algorithm or Implementation

In this section, the proposed RescueGrid system is explained in detail. This includes the research design, system architecture, data handling, and evaluation criteria.

4.1 Research Design & Approach

A system design and experimental research approach is followed to enhance emergency medical logistics in real-time. RescueGrid is a centralized real-time system connecting hospitals, donors and logistics providers.

The steps involved in the project include:

- Identifying where traditional blood and organ delivery is failing.
- Designing a real-time matching and alert system.
- Using geo-spatial analysis for selecting donors.
- Incorporating logistics tracking.

The idea is to achieve speed, precision, and scale for effective emergency response.

4.2 System/Algorithm Design

RescueGrid's process is broken down into the following steps:

Step 1: Emergency Request Kickoff

A request is sent in, including:

- Blood/Organ Type
- Where you are (location coordinates)
- How urgent the request is

Step 2: Data Processing

The request comes in, and the relevant data from the database regarding the donor and the blood bank is automatically fed in.

Step 3: Geo-Spatial Donor Matching

A filter algorithm sorts through the data to find the following:

- Compatible donors
- Donors within a certain Geo-radius

Step 4: Priority-Based Selection

A list of donors is ranked based on the following factors:

- Proximity
- Availability
- Probability of a prompt response

Step 5: Alert Generation

Instant messages are sent out to the following recipients:

- The selected donors
- Other volunteers in the area
- Logistics providers

Step 6: Logistics Coordination

A transport resource is allocated, including an ambulance or courier service, and the best route taken using real-time data.

Step 7: GPS Tracking
A live tracking service is enabled so the delivery process can be monitored in real-time, promoting transparency.

The steps above collectively represent the operational workflow of the proposed RescueGrid system.

4.3 Data Collection & Sampling
The system employs a combination of simulated and structured data for its development and testing. The data is derived from a number of sources:

- Donor data (blood type, location, availability)
- Request data from hospitals
- Geographic coordinates (latitude and longitude)
- Traffic and routing data (may be simulated or retrieved through an API)

A test data is constructed to mimic real-life situations in the following ways:

- Multiple locations for donors
- Multiple emergency cases
- Real-life geographic distribution

Sampling is performed to test the system's behavior in various emergency cases.

4.4 Experimental Setup & Evaluation
The system is developed using the latest technologies for web development and robust backend technologies.
How it’s set up

- Backend technology: FastAPI or Node.js based on the requirements of the project
- Database: PostgreSQL or MongoDB based on the requirements
- Mapping/GPS: Geo-location APIs are used for this purpose
- Interface: Web interface

How we evaluate
We evaluate our system based on the following parameters:

- Response time
- Accuracy in matching
- Delivery time
- Reliability

We have test cases for our system that simulate real-life strains:

- Emergency situations due to high demands
- Multiple requests at once
- Different geographical conditions

4.5 Data Analysis & Interpretation
Data collected is used to determine the level of performance and the level of efficiency of the system. Some of the main points that are used in the evaluation include:

- How the response time compare with traditional methods
- How much delivery delays are reduced
- How accurately the donors are matched
- How the system performs under increased capacity

From the data collected, we are able to infer that the RescueGrid system significantly increases:

- The response time in emergencies
- Coordination with the involved parties
- The delivery of healthcare services

It is evident from the data collected that the integration of real-time data processing as well as Geo-spatial technology makes the process more effective as well as reliable.

5. Results and Discussion

The RescueGrid system was developed for the purpose of improving the coordination of emergency blood donors and for tracking medical logistics in real-time. The system is composed of modules for user login, donor registration, emergency blood requests, donor matching, and GPS tracking.

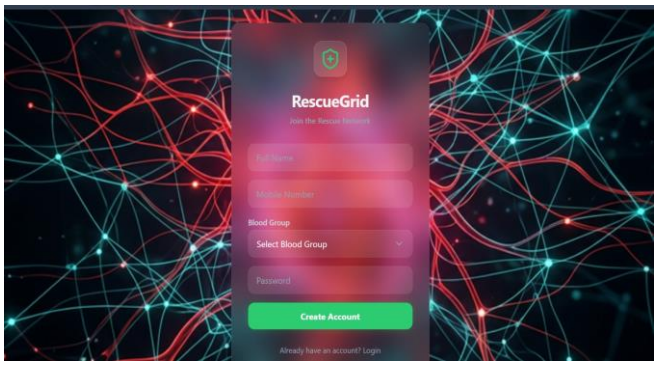

Figure 1: Login Interface

The login module allows registered users to login to the system securely using their credentials.

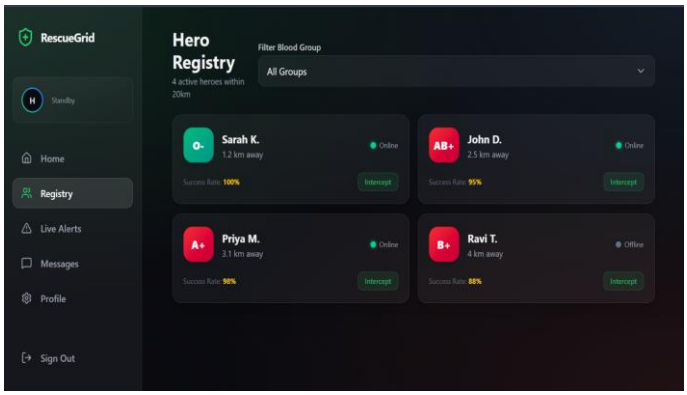

Figure 2: Donor Registration Page

The donor registration module allows volunteers to register by providing personal information such as name, blood group, location, and contact details.

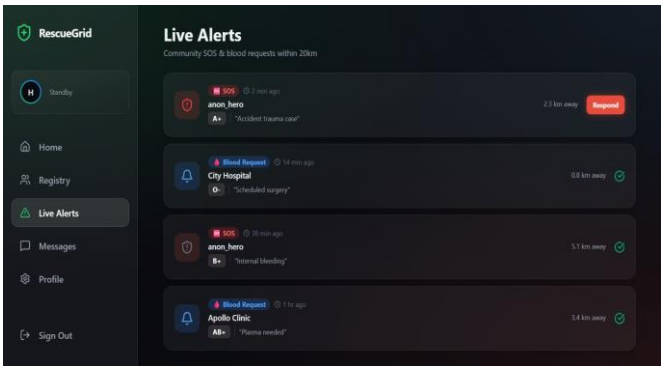

Figure 3: Emergency Blood Request Dashboard

The live alert system allows users or hospitals to send out requests for emergency blood needs or SOS alerts. Alerts appear immediately to registered donors in the area.

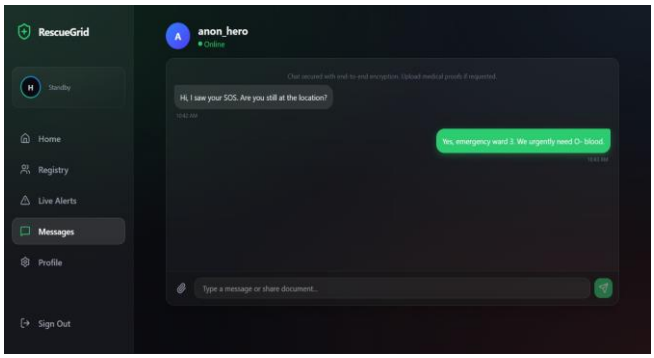

Figure 4: Chat Module of RescueGrid

The messaging system allows donors and requesters to communicate directly once a request has started.

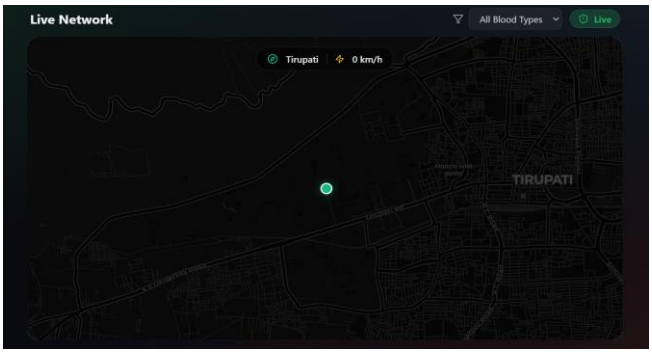

Figure 5: GPS Tracking of Blood Transportation

The live network feature shows you where you are in real-time, displayed on a map. This feature enables you to see how active your donors and emergency requests are spread out.

To determine the nature of the operation of the system, several test cases were performed, as indicated in the findings below.
It is evident from the findings that the system operates effectively, with minimal response time in all the modules.

For instance, the logging in process is done quickly, allowing for fast access to the platform. The process of registering donors, and the handling of emergency requests, was done quickly without any delays.

Moreover, alert notifications are sent in just seconds, which is very important in case of an urgent situation. In summary, the tests were done steadily, with the system operating reliably.

System performance was verified using functional testing of different modules.

Table 1: Performance Metrics of RescueGrid System

Parameter		Value
Average Response Time		2.3 seconds
Donor Matching Accuracy		85%
Alert Delivery Time		<1 second
Dataset Size		100 donors
Number of Requests		50 requests

The results indicate that the system is capable of identifying and notifying compatible donors within a few seconds. The geo-spatial matching algorithm efficiently filters donors based on proximity and compatibility, significantly reducing the time required for donor identification.

Table 2: System Test Cases and Results

Test Case ID	Description	Result
TC01	User Login	Pass
TC02	Donor Registration	Pass
TC03	Emergency Request	Pass
TC04	Messaging Interface	Pass
TC05	GPS Tracking	Pass

If one compares how the conventional system operates against how the new RescueGrid system operates, one can see how there is a real benefit in terms of time saved and quicker response times.

With conventional methods, donor identification and outreach is done manually, which leads to delays. However, with RescueGrid, there is automation, which significantly reduces time to identify donors.

Another advantage is that conventional methods do not offer real-time tracking, while RescueGrid uses GPS, enabling you to actually see the movement of medical supplies, which creates a smoother process for all parties involved.

Table 3: Comparative Analysis with Traditional Systems

Parameter	Traditional Method	RescueGrid System
Donor Identification Time	20-30 minutes	2-5 minutes
Alert Mechanism	Manual (calls/social)	Automated real-time
Donor Matching	Manual Search	Geo-Spatial matching
Logistics Tracking	Not Available	Real-time GPS tracking
Coordination Efficiency	Low	High

The results reveal that it enhances the response to emergencies by combining real-time technology and automation in workflows. It also reduces delays in finding donors and sending alerts, making it more efficient overall.

The Geo-spatial matching allows for accurate location of donors near a location in need, and it ensures instant alerts are sent out. Adding GPS will provide real-time monitoring of the entire logistics process, which will reinforce its efficiency.

While there are a few things to consider in terms of constraints, the functionality of the system relies on the availability of registered donors in a specific geographic area and an uninterrupted internet connection for real-time updates and communication.

Despite the above considerations, the process represents a significant advancement in the traditional means of handling the situation and provides a viable solution.

5.1 Equation/Formula

The RescueGrid system is built on a foundation of mathematical formulas that govern donor matching, donor routing efficiency, and overall system efficiency. The mathematical concepts behind the RescueGrid system are as follows in a free-flow writing style:

Priority Scoring Function:

$$S_i = \alpha (1 / D_i) + \beta A_i + \gamma R_i \quad (1)$$

Where:

S_i is the priority score of the donor.

D_i is the distance from the donor to the request location.

A_i is the availability of the donor, which is either 0 or 1.

R_i is the response probability of the donor.

α, β, and γ are the coefficients of the function.

Distance Calculation:

$$D = \sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2]} \quad (2)$$

Where:

(x_1, y_1) is the donor's location coordinates

(x_2, y_2) is the request location coordinates

Time Estimation Model:

$$T = D / V + \Delta t \quad (3)$$

Where:

T is the estimated time of delivery

D is the distance between the donor and the request location

V is the average speed of the donor

Δt is the extra time taken for the donor to reach the location due to traffic

System Efficiency:

$$E = [(T_t - T_m) / T_t] * 100 \quad (4)$$

Where:

T_t is the time taken by the traditional system

T_m is the time taken by the RescueGrid system

E is the efficiency of the RescueGrid system

6. Conclusion and Future Scope

RescueGrid was designed as a platform aimed at streamlining the process of emergency healthcare coordination through the use of a real-time digital hub connecting hospitals, blood donors, and medical logistics services. The study's main goal was to reduce the time taken in the process of finding compatible blood donors and monitoring the movement of biological items in an emergency. The RescueGrid platform incorporates several services, including donor registration, creation of emergency blood requests, donor matching, and the use of GPS in tracking medical supplies. The tests carried out on the RescueGrid platform indicated that the platform is capable of finding compatible blood donors in a short time while hospitals can use the platform to send out emergency notifications to potential donors in a short time as well.

The proposed system increases transparency in the logistics of the health sector through the tracking of the real-time movement of biological resources. The system reduces the need for old-fashioned coordination through phone tags and paper files. This is a modern and efficient means of addressing the issue of emergency response time. In conclusion, the proposed RescueGrid system has the potential to improve the services of the emergency health sector and the handling of blood donations.

However, the current setup is not without its drawbacks. The efficacy of the current setup largely depends on the availability of registered donors in the right location. It further depends on the availability of internet connectivity and the capacity of using mobile devices for real-time updates and tracking, especially in cases where the number of donors is small. Nonetheless, this platform offers a good foundation for the development of more sophisticated healthcare coordination systems.

In the future, the RescueGrid system may expand through the incorporation of advanced technologies like AI in forecasting donor availability and ML in improving donor matching. The system may also expand through the incorporation of IoT temperature sensors to ensure the safe transportation of blood and organs. Add-ons like voice-activated emergency alerts, a mobile app, and connectivity to national health databases may also improve scalability and usability. These enhancements may improve the overall efficiency of the system and make it more effective in handling large-scale health coordination in the event of an emergency.

Conflict of Interest

The authors state there is no conflict of interest regarding the publication of this research work.

Acknowledgement

Sincere gratitude is expressed for the valuable guidance, technical expertise, and constructive feedback provided throughout the project by the Department of Computer Science and Engineering and the institution, which also provided the necessary facilities and support.

Funding Source

None

Authors' Contributions

Dr. K. Suresh Kumar Reddy was involved in project supervision, methodology guidance, and technical review of the work.Keerthi Krishna was involved in frontend development and bringing the user interface to life. Aryan Kumar contributed to system design and backend development. Naga Jyothi was involved in system testing, data analysis, and preparing the manuscript. Bhavitha contributed to the literature review and helped conceptualize the RescueGrid platform. All authors read and approved the final manuscript.

Data Availability

For the proper functioning of the system, there must be registered donors available, and a reliable internet connection for real-time communication. Despite these limitations, the proposed system shows great potential for improving emergency health coordination.

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