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Development of smart logistic framework for blood donor information system based on Internet of Things

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ABSTRACT
In 2021, the amount of blood production by the Indonesian Red Cross was higher than the existing needs. This can result in wasted blood bags. The availability of abundant blood bag supplies is not balanced with access to information on the availability of these blood bags. This study aims to build a smart logistics system that can provide information on the availability of blood bags in real-time. This study utilized a quantitative and explorative approach and employed the waterfall Software Development Life Cycle (SDLC) method using PHP and the CodeIgniter 3 framework, which was integrated with IoT devices such as sensors and GPS for real-time monitoring. In addition, this system will provide a tool to predict the number of donors needed, as well as estimate the number of donor quotas required during upcoming blood donation activities. This study has succeeded in developing a blood donor information system that adopts the smart logistics concept to control blood bag stock. The resulting system is capable of reducing the risk of shortages and obsolescence while enhancing synergy among stakeholders. The design of a system that facilitates openness of information on the level of blood needs and simplification of the donor system is expected to increase community responsibility in creating sustainable blood supply availability.

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1. INTRODUCTION

Blood is one of the most important entities in the medical world. There are various types of diseases that require blood transfusions for the treatment of patients with medical conditions, such as anemia, cancer, blood disorders, and those undergoing surgery [1]. The amount of blood supply and demand for blood is stochastic so the process of managing blood donations received from blood donation activities needs to be managed properly and systematically [2]. The complexity of managing the blood supply is also influenced by the characteristics of the age of the blood [3]. Blood has a shelf life of about 45 days. Beyond that, it expires and can no longer be used [4]. On the other hand, every year the world's population will continue to grow, including diseases and health problems, with the increase in population, the need for blood will also increase [5]. This research was conducted at the one of indonesia's red crosses in yogyakarta blood transfusion unit, where one of indonesia's red crosses in yogyakarta served as a blood bank in the blood bag supply chain. So far, indonesia's red crosses has had an information system that records the number of donors, but its system can only be accessed by one of indonesia's red crosses in yogyakarta admins and has not provided information on the availability of blood stocks that are updated in real time to be accessed by people who need it. The system's limitations have caused supply-demand imbalances. As an illustration throughout 2024 the amount of blood produced at one of indonesia's red crosses in yogyakarta was much higher than the existing demand, as shown in Figure 1.

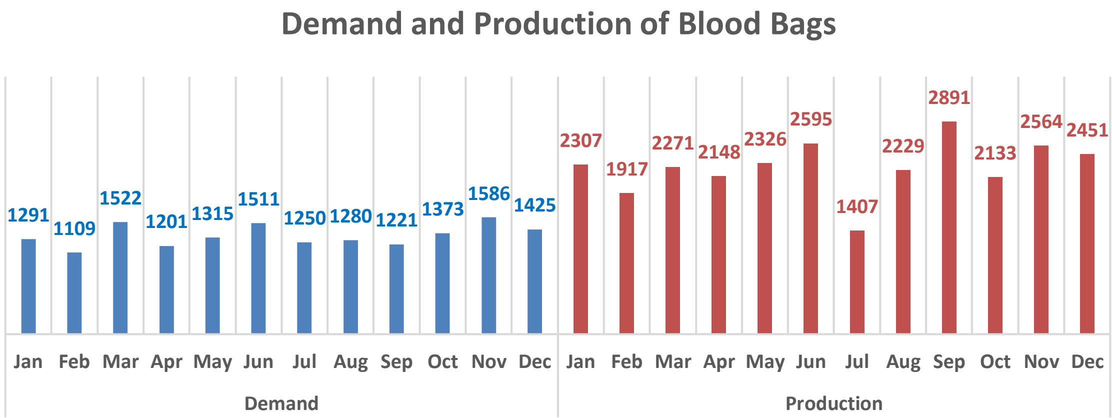


Figure 1. Comparison of demand and production of blood bags, (59,05% demand to production)

Blood supply chain management is considered very important because it is related to a person's life. Unavailability of the required blood can lead to death and complications for the patient. However, if there is high blood wastage, it will result in high costs as well [6]. Blood waste raises costs and reduces life-saving resources, making efficient management vital [7]. Effective decisions in the blood supply chain must be made strategically to minimize blood deficiency and wastage. [8]. Many factors contribute to blood wasting, including: damaged or broken blood bags, infected blood bags, damaged seals, lack of proper storage, delays in conducting tests due to personnel shortages or resource constraints, problems with blood component manufacturing and testing, and expired blood bag units, insufficient transportation, and returned after use [9]. These inefficiencies highlight the need for a more effective and technologically driven approach to blood management. Although not all of these things can be avoided completely, at least the use of IoT can minimize the amount of blood that is lost or cannot be used so that it will reduce waste [10]. IoT enables real-time tracking, inventory monitoring, and forecasting to improve storage, distribution, and reduce waste, ensuring that more patients receive the critical care they need [11].

Real-time updates are made possible through IoT technology. IoT is an internet-based information and communication technology. IoT can expand the physical world (real) in the form of data into a virtual world, allowing for seamless data collection, analysis, and automation in various industries. As well as developing information transfer and interactive processing between objects, IoT enables a more efficient and responsive system that reduces human intervention and errors [12]. IoT has also been expanded in its use to support smart logistics, which integrates IoT-enabled tracking, monitoring, and automation to optimize the movement of goods and resources [13]. The key to the development of smart logistics is to effectively utilize the latest technology such as IoT in the logistics world, enhancing operational efficiency, reducing costs, and improving overall service quality [14]. This IoT concept will be used to create a system for indonesia's red crosses to provide comprehensive information to the public about the existing blood stock, ensuring transparency and enabling better planning for blood donation campaigns [15]. Besides that, the use of IoT can help the logistics process for blood bags which will later be referred to as smart logistics, where real-time tracking and temperature monitoring ensure that blood bags are stored and transported under optimal conditions [16]. The use of IoT and smart logistics helps indonesia's red crosses in developing a strategy that is able to balance between the amount of blood produced and the amount of existing demand or vice versa, minimizing shortages or excess supply while maintaining the quality and availability of blood for patients in need [17].

This study aims to help indonesia's red crosses and stakeholders improve blood bag management using a smart logistics system in enhancing the efficiency and effectiveness of blood bag management through the development of an integrated smart logistics system based on the Internet of Things (IoT). While previous studies have examined the use of IoT in healthcare logistics, most systems are limited to internal use, lacking transparency, real-time accessibility, and predictive capabilities. They generally do not incorporate comprehensive features such as public access to current blood stock levels, forecasting future demand, or tracking blood bag expiration. To address this research gap, the proposed system introduces a novel framework that integrates real-time data sharing, automated forecasting, location-based donor services, and shelf-life monitoring into a unified platform. This innovation not only supports operational decision-making but also strengthens stakeholder collaboration and public involvement in blood donation. By offering a more responsive, transparent, and data-driven approach, the system contributes significantly to reducing waste, ensuring the timely availability of blood, and setting a new standard for IoT-based logistics solutions in the management of perishable medical resources.

2. LITERATURE REVIEW

2.1. Internet of Things (IoT)

IoT utilizes telecommunications infrastructure and internet-connected devices to exchange information with each stakeholder [18]. Utilization of this internet-connected infrastructure can create opportunities to integrate the physical world and internet-based systems so as to increase efficiency, accuracy, and economic benefits [19]. The main concept of IoT is to connect anything physically (for example: sensors, devices, machines, people, animals, goods etc.) and then monitoring and controlling functions are carried out via the internet [20]. Figure 2 illustrates a simplified definition of IoT.

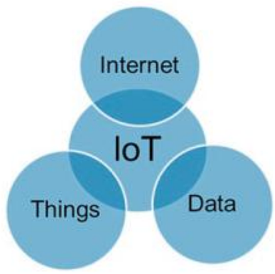


Figure 2. IoT definition in its simplest form

2.2. Smart Logistics

Smart Logistics has attracted a lot of attention from several research fields, one of which is Business Process Management. Not only that, research is also carried out in various fields of work as well in order to increase the ability to monitor the implementation of the ongoing logistics process and to be able to predict the possibilities in its development [21]. This continuous research effort helps organizations to optimize their logistics operations, streamline supply chains, and minimize inefficiencies, which ultimately enhances overall performance and competitiveness [22]. Technological developments, and the emergence of industry 4.0 poses several new challenges in the logistics process. Businesses must adapt to complex systems, real-time data, and faster delivery demands. The industrial revolution 4.0 can accelerate the integration of technology into all logistics processes [23]. This integration makes it possible to automate warehouse management, optimize transportation routes, and utilize predictive analytics for more accurate demand forecasting. The integration between technological developments and logistics processes has led to the emergence of a new concept called smart logistics [24]. Smart logistics leverages digital transformation to create a more interconnected and adaptive supply chain system that can respond to market changes with agility [12].

Smart logistics refers to using technology to develop and expand smart products and services. This approach leverages advanced technologies such as the IoT, Artificial Intelligence (AI), and Big Data analytics to streamline operations and enhance decision-making processes [25]. Smart logistics is an integration of technology, administration, and human activities to enable predicting a problem and minimizing its impact on a particular area [26]. By analyzing real-time data, logistics systems can anticipate disruptions, optimize routes, and allocate resources dynamically to maintain efficiency and responsiveness [27]. Smart logistics also coordinates resources for the achievement of accepted goals effectively and removes barriers to communication between supply chains. This coordination enhances collaboration across stakeholders, reduces delays, and fosters a more resilient and adaptive supply chain ecosystem capable of meeting evolving market demands [28].

Smart Logistics connects the physical world and the virtual world assisted by the IoT. The physical world is represented by a logistics ecosystem that requires products to arrive at the end user at the right condition, at the right time, and at the right place [29]. This ecosystem involves a complex network of interconnected activities, ranging from inventory management, warehouse operations, order fulfillment, and real-time tracking of shipments. Each component must work in harmony to maintain the efficiency and accuracy of logistics services [30]. To support these logistical needs, it is necessary to have supporting elements such as machines, vehicles, and humans who are always moving every day to send goods and track the position of millions of vehicles around the world [31]. For example, autonomous vehicles and drones are increasingly being used to streamline deliveries, reducing human error and cutting delivery times [32]. In addition, warehouse automation systems help accelerate the sorting and packaging of goods, ensuring that supply chains remain agile and responsive to fluctuating market demands. These physical elements are crucial in bridging the gap between manufacturers, distribution centers, and consumers, enabling logistics companies to meet customer expectations in an era of fast and precise deliveries [33].

On the other hand, the virtual world is represented by the advancement of the world's computing and communication technology programs. The advancement of these two technologies brings new approaches and solutions to the world of logistics [34]. Sophisticated software platforms equipped with artificial intelligence and machine learning algorithms can now analyze vast amounts of logistics data to optimize delivery routes, predict potential disruptions, and suggest alternative strategies in real time. This reduces operational costs and increases overall service reliability [35]. This technology has contributed greatly to the emergence of a new paradigm called the Internet of Things. IoT plays a role in data acquisition mechanisms (e.g., sensors and GPS), communication technologies (e.g., 4G/internet), and data processing solutions. For instance, smart sensors installed in shipping containers can monitor temperature, humidity, and vibration levels, ensuring that sensitive products like pharmaceuticals and fresh food are transported under optimal conditions. Meanwhile, cloud-based systems allow logistics managers to access real-time data from anywhere, facilitating faster and more informed decision-making. The combination of this IoT-assisted logistics ecosystem connects the physical world where the logistics process runs and the virtual world (IoT) where various decisions are made, creating a highly integrated and adaptive logistics network capable of evolving alongside technological innovations [36]. This research's perspective is elucidated in Table 1, which presents prior studies completed by various researchers.

Table 1. Research positioning

No	Title	Blood Management	IoT	Smart Logistic
1	Real-Time-Based Blood Wastage Management Using IoT and Blockchain Technology [37]	✓	✓	
2	Automating inventorying of blood stations: A system based on ultrahigh-frequency radio-frequency identification (UHF RFID) technology [38]	✓	✓	
3	Perioperative Blood Management Programme in Jehovah's Witnesses Undergoing Total Hip Arthroplasty [39]	✓		
4	Firoj Shaikh & Asst. Prof. V. S. Karwande	✓	✓	
5	Smart Logistics Based On The Internet Of Things Technology: An Overview [14]		✓	✓
6	A new risk predictive scoring system of vasovagal reactions in patients with preoperative autologous blood donation [40]	✓	✓	
7	Method for Systematic Assessment of Mobile Network Coverage for Logistic Applications on the German Highway [41]	✓	✓	

No	Title	Blood Management	IoT	Smart Logistic
8	Threat Modeling for Communication Security of IoT-Enabled Digital Logistics [42]		✓	✓
9	Blood Bank Monitoring and Blood Identification System Using IoT Device [43]	✓	✓	
10	A multiple criteria decision-making model for minimizing platelet shortage and outdating in blood supply chains under demand uncertainty [44]	✓		

Based on observations of ten previous studies, most studies focus on one aspect of the blood management system, such as stock monitoring or reducing blood waste, and several other studies highlight aspects of smart logistics or IoT technology separately. However, none of the studies comprehensively integrates all components of blood stock management, real-time IoT-based monitoring, and smart logistics approaches into one integrated system that can be accessed by the public and managers simultaneously. The position of this study can be used as a multidimensional innovation that fills the gap between a closed internal monitoring system and the real need for a responsive, predictive, and open information system. The novelty of this study lies in the development of an IoT-based information system that not only records and unifies blood stocks in real time, but also includes features for predicting donor needs, tracking blood age, and community involvement through a digital transparency system through a holistic approach that has not been found in previous studies.

3. MATERIAL AND METHODS

This study adopts a quantitative and explorative approach to design an Internet of Things (IoT) and smart logistics-based information system aimed at enhancing the efficiency of blood collection and demand management at one of indonesia's red crosses in yogyakarta. The quantitative approach is justified by its ability to analyze historical data to identify patterns in blood demand and donor response, providing an empirical foundation for forecasting needs. Meanwhile, the explorative approach is essential for uncovering the potential of emerging digital technologies to solve complex logistical challenges in blood donation services. This dual-method approach enables the development of a system that not only relies on data-driven insights but is also adaptive to contextual and technological innovations. Technically, the system is built using PHP and the CodeIgniter 3 framework, structured with the SDLC waterfall model, and integrated with IoT devices such as sensors and GPS for real-time monitoring of blood bag stock levels and expiration dates. It also includes features like donor scheduling, automated notifications, and a web-based interface to ensure accessibility and transparency for both indonesia's red crosses administrators and the public. This methodological and technical integration ensures that the system is not only functional but also strategically aligned with the needs of modern healthcare logistics.

This 2024 study focused on the blood donor unit at one of indonesia's red crosses in yogyakarta as a case study. Primary data was collected through structured interviews with the head of the donor unit and logistics analysts, who have strategic roles in the operational management and distribution of blood supplies, thereby strengthening the accuracy of the system model and the relevance of its implementation. Meanwhile, secondary data was obtained from internal reports, historical donor records, and literature related to health logistics information systems and statistical and machine learning-based prediction methods. The entire research process was carried out in six sequential stages: (1) planning and analysis of system requirements; (2) system analysis and identification of user roles; (3) system design based on the SDLC waterfall model; (4) preparation of business processes and website-based user interfaces; (5) development and implementation of the system using PHP and the CodeIgniter 3 framework integrated with IoT and smart logistics; and (6) system testing, analysis, and evaluation to assess performance and prediction accuracy [45]. The overall research flow is depicted in Figure 2.

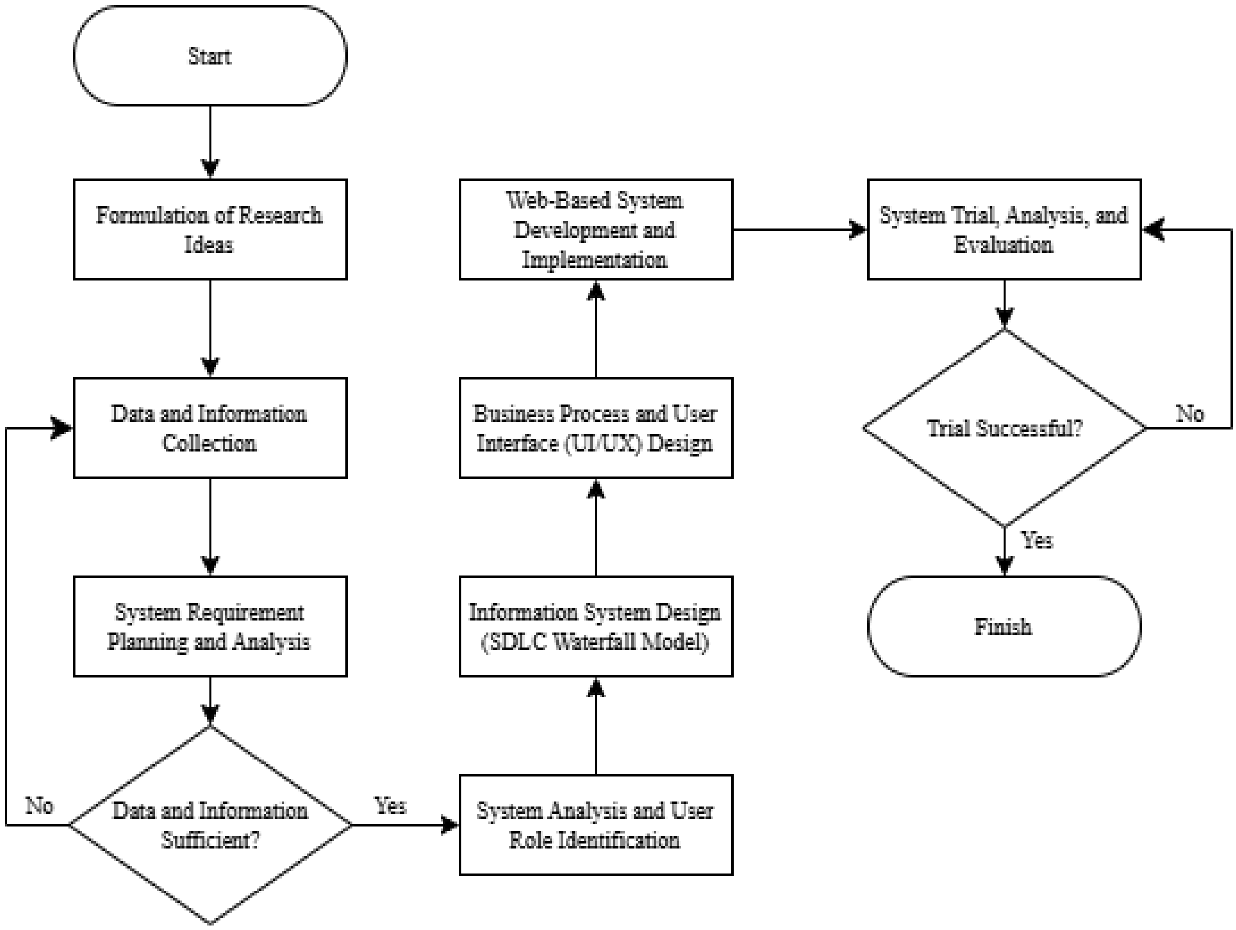


Figure 2. Research flow

In order to clarify the research flow above, the following is an explanation of a number of main points in the research flow:

1. Planning and analysis of system requirements
   This stage identifies indonesia's red crosses key problems, such as difficulty predicting donor needs by one of indonesia's red crosses in yogyakarta, namely the difficulty in predicting blood donor demand and the absence of an effective decision support system. Data collection was carried out through observation and interviews to determine the functional needs of the system. As a result, a plan for an information system based on donor data was prepared that would help manage blood stock demand and availability.
2. System analysis and identification of user roles
   This stage analyzes how the system works in meeting organizational needs by involving three main actors: donors, donor applicants, and admins. Donors register and donate blood, applicants need blood, while admins manage data, forecast demand, and disseminate information. The system is designed to predict blood needs and send automatic notifications to donors who are ready to donate again.
3. Information system design (SDLC Waterfall Model)
   The system is developed using the Software Development Life Cycle (SDLC) waterfall model approach, which includes five main stages: needs analysis, system design and UI/UX, implementation, integration and testing, and evaluation. Each stage is carried out sequentially to ensure that the system is built according to needs and functions optimally. The Waterfall SDLC model is a linear and sequential software development approach, where each stage must be completed before the next stage begins as described in Figure 3. The Waterfall model begins with requirement definition and proceeds in requirement definition, where user needs are collected and thoroughly analyzed. This stage is continued with System and software design, which aims to design the system and software architecture based on the needs that have been determined. This process is then repeated for each new module or component that is developed, as seen in the cascade diagram. Each step in this model is interdependent and executed sequentially without overlapping, making it suitable for projects with clear and stable needs from the start [46].

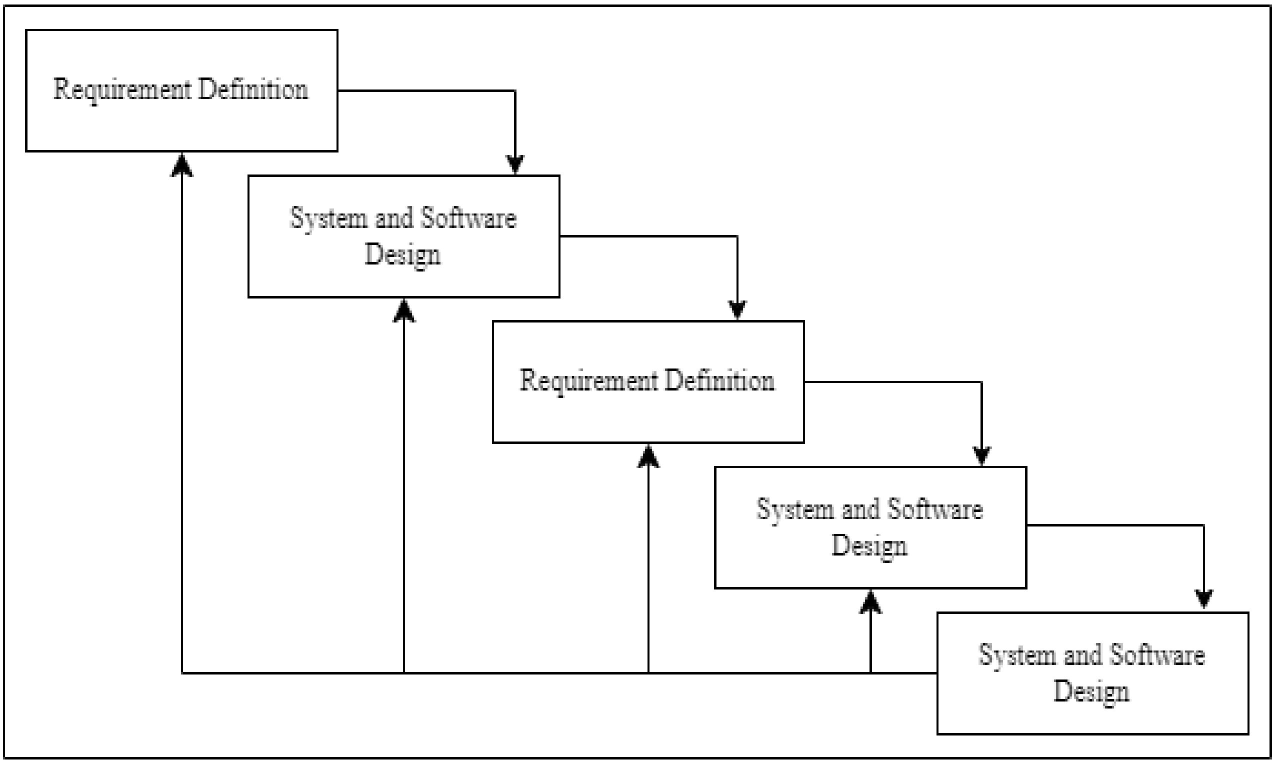


Figure 3. Stages in the Waterfall model

4. Business process and user interface (UI/UX) design
   This system is equipped with a use case diagram to visually describe the relationship between actors and system functions. In addition, the system interface is designed based on a website to be easily accessible and user-friendly. The UI/UX design is made to ensure that users can access features such as data input, view blood stock, and get donor information quickly and easily.
5. Web-based system development and implementation
   The system was built using PHP and CodeIgniter 3, following the planned design and adopted the concept of the Internet of Things (IoT) and smart logistics. The goal is for the system to be integrated with various devices and provide real-time information to donors and indonesia's red crosses.
6. System trial, analysis, and evaluation
   This stage is carried out to test whether the developed system runs according to plan. The trial includes aspects of performance, suitability of UI/UX design, and accuracy of system logic. After testing, an analysis of the implementation results and a discussion of the effectiveness of the system are carried out. This stage ends with drawing conclusions and providing suggestions for further development.

4. RESULT

This study uses the Software Development Life Cycle (SDLC) method in designing an information system that will be built using the waterfall model. The waterfall model is one of the SDLC methods that emphasizes sequential and systematic phases [47]. Each step needs to be completed individually before moving on to the next step. These steps include analysis requirements, flow design & UI design website, design, and implementation, design integration and testing, and analysis of results [48]. This structured approach ensures that each phase is thoroughly analyzed and validated before progressing, minimizing the risk of errors and rework in later stages. Additionally, the waterfall model is particularly beneficial for projects with well-defined requirements, as it provides clear documentation and systematic progression, making it easier to manage and maintain. By following these steps, the system development process becomes more structured and efficient, ensuring that the final product aligns with stakeholder expectations. The use of the SDLC concept is also used to compile the information requirements required by stakeholders. Data on stakeholders and their needs can be shown in Table 2.

Table 2. Information requirements required for SDLC

No	Stakeholder	Data Requirements	Action on the Website
1	Donor	a) Donor Schedule b) Location of blood donation activities c) Required blood type d) Time of blood donation activities e) Usefulness of blood donation activities	Check and input data
2	Administrator	a) Stock real-time availability of blood bags b) Donor Data c) Blood Age d) Number of Requests e) Forecasting the number of future Demand f) Target Donors g) Information Blasting h) Data management	Login, check data, data manegement & input data
3	Hospital	a) Stock real-time availability of blood bags b) Blood Type c) Age of blood bags	Check cata
4	Patient's Family	a) Stock real-time availability of blood bags b) Blood Type c) Blood bag location	Check data

Developing information systems using the PHP programming language with the CodeIgniter 3 web-based framework is commonly used in building efficient, dynamic, and easy-to-develop applications. PHP, as a server-side programming language, allows fast interaction with databases. At the same time, CodeIgniter 3 offers an MVC (Model-View-Controller) structure that separates business logic from the display, making it easier to manage and maintain code.

4.1. Existing System

One of indonesia's red crosses in yogyakarta blood collection and distribution process follows a structured procedure to ensure safety, efficiency, and the availability of high-quality blood supplies. Blood procurement relies on voluntary donors who either visit one of indonesia's red crosses in yogyakarta directly or participate in organized blood donation events held at various locations. Upon arrival, donors must complete a registration form, providing personal details and medical history to assess their eligibility. Medical personnel then conduct initial health screenings, checking vital parameters such as blood pressure, hemoglobin levels, and blood type to ensure the donor is fit for donation. If all health criteria are met, the donor proceeds to the blood collection room (aftap room), where trained staff perform the blood extraction process under strict hygiene and medical standards. Once the blood is drawn, it undergoes further testing to screen for infectious diseases and ensure it meets safety standards before being processed into various blood components based on medical needs. Meanwhile, the donor's information is recorded in the Blood Donor Management Information System (SIMDONDAR), an internal system used for documentation and monitoring blood service activities. This comprehensive approach ensures that only healthy donors contribute, maintaining the integrity of the blood supply while also facilitating efficient distribution to hospitals and patients in need.

In the aftap room, the donor's blood is drawn and undergoes a thorough screening process before it can be used for transfusions. The first step is to check whether the blood contains diseases or substances that make it unsuitable for donation. If the blood does not meet the required standards, it will be immediately discarded to ensure safety. However, if the blood passes the screening, it is then processed into various blood components according to medical needs. Meanwhile, the donor's information is recorded in the SIMDONDAR, a specialized internal system used for documentation, data recording, and managing information related to blood donation services at one of indonesia's red crosses in yogyakarta. This system is strictly for internal use and helps streamline the operations of blood donation activities. The entire process of blood donation at one of indonesia's red crosses in yogyakarta is illustrated in Figure 4, detailing each stage from donor registration to blood processing.

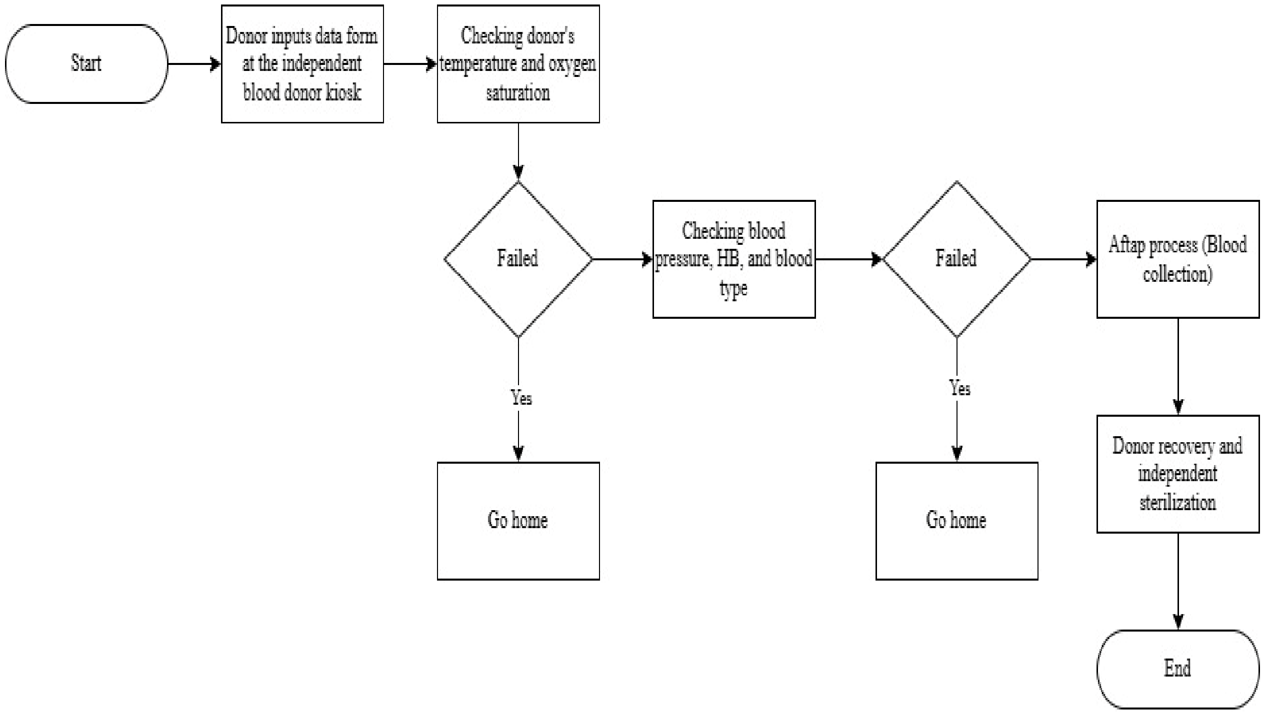


Figure 4. Process business existing

SIMDONDAR lacks a real-time stock display, making blood bag availability hard to monitor categorized by blood type and type of blood bag, making it difficult to monitor availability efficiently. Additionally, the system does not yet include a forecasting feature to predict future blood demand, which could help in strategizing the balance between blood bag production and actual needs. Without this capability, indonesia's red crosses faces challenges in anticipating shortages or surpluses. Another limitation is the lack of an expiration tracking feature for blood bags, which is crucial for determining whether stored blood is still viable for use. The absence of this information in SIMDONDAR forces indonesia's red crosses staff to rely on alternative methods, which can be less efficient and more prone to errors.

4.2. Proposed System

The proposed system design is expected to serve as an additional reference while addressing the weaknesses of the existing system at one of indonesia's red crosses in yogyakarta, particularly in aspects that have not been extensively studied by researchers. One of the key improvements is the provision of real-time information on blood bag availability, allowing the public to access up-to-date data anytime and anywhere, ensuring a more transparent and efficient distribution process. Additionally, the system will incorporate forecasting capabilities to predict blood demand for upcoming periods, enabling better planning and resource allocation to prevent shortages or oversupply. Another crucial enhancement is the integration of information regarding the service life of blood bags, ensuring that blood stock is utilized efficiently before expiration, thereby minimizing waste. By implementing these three essential features, the system will contribute to a more balanced and effective blood donation management process, ensuring that supply meets demand in a timely and accurate manner. Broadly speaking, the concept of the business processes an information system that runs on the website that will be created is shown in Figure 5.

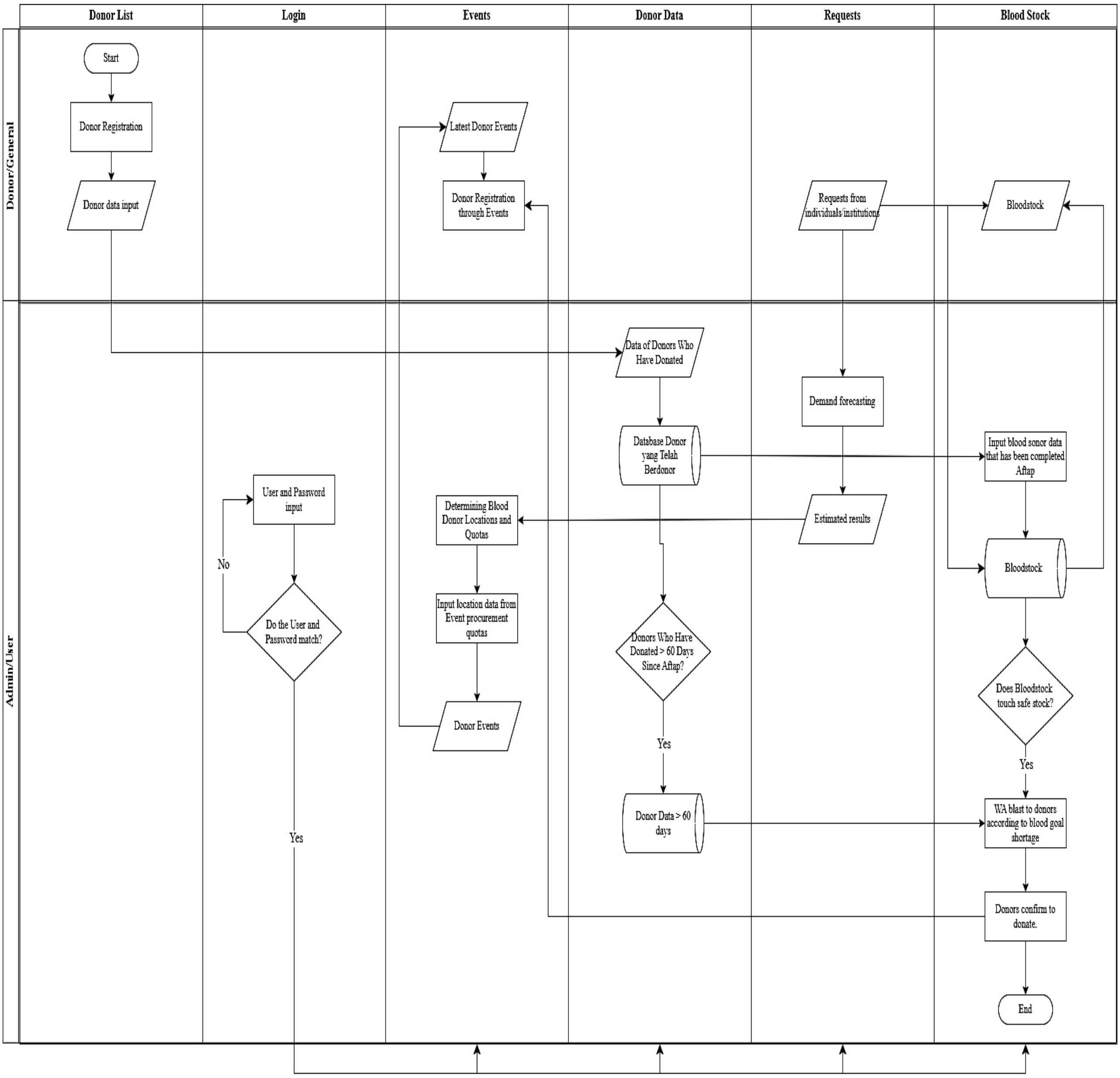


Figure 5. Proposed of blood bank system information

The information system created will provide the information needed by stakeholders, such as:

1. Registration of blood donors through the website
2. time always updates
3. The location of the blood donor event and the number of quotas for each location
4. Age of the blood bag so that you can find out which bag will expire
5. Forecasting The request is used as a indonesia's red crosses reference in determining stock in the future period.

Donors can register on-site or via the website, streamlining the donation process, ensuring a more efficient and organized donation process. Once the required data is inputted, it is securely stored in the donor database, which serves as a valuable resource for monitoring donor activity and maintaining adequate blood supply levels. This database is also used to send automated notifications via WhatsApp when blood stocks are running low, specifically targeting donors who have not donated for more than 60 days. The WhatsApp message contains essential details about upcoming blood donation events, including the date, location, available quota, and a direct link to the one of indonesia's red crosses in yogyakarta website for easy registration. Donors who receive this notification are presumed to be physically ready to donate and can confirm their participation by clicking the link and completing the registration form. Once registered, they can proceed to the designated location at the scheduled time to complete the donation process. Furthermore, data from individual patients or hospitals requesting blood donations is systematically recorded and analyzed to forecast future blood donor needs, ensuring a sustainable and responsive blood supply management system.

The results of this forecast can be utilized to determine the optimal location and number of quotas for each blood donation activity, ensuring an efficient distribution of resources. To enhance accessibility and engagement, information about these activities will be actively disseminated via WhatsApp, allowing potential donors to conveniently choose their preferred donation location based on availability and proximity. Additionally, before a patient or hospital submits a request for blood, they can access real-time updates on blood bag availability through a dedicated website, which is continuously updated to reflect the latest stock conditions. This transparency not only streamlines the blood supply chain but also helps prevent shortages and ensures that blood is readily available when needed. An organized system architecture is key to optimizing data flow and functionality, mapping the flow of information in a clear and systematic manner, as illustrated in Figure 6.

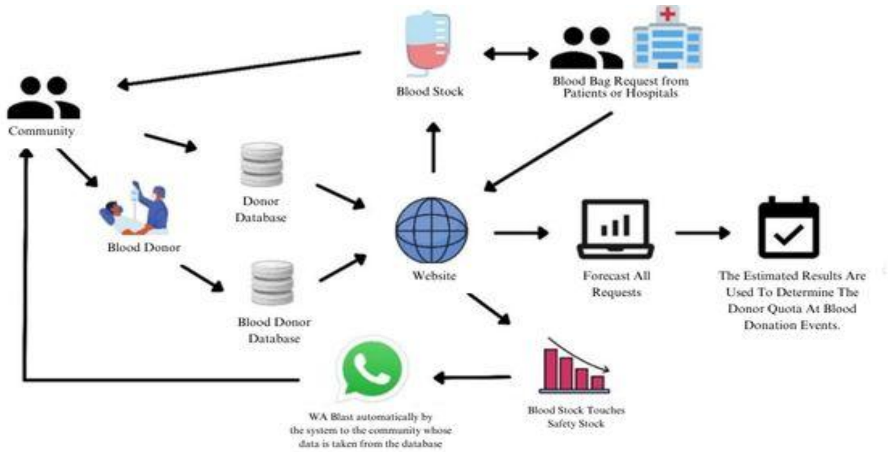


Figure 6. System architecture

4.3. Implication System

SIMDONDAR helps indonesia's red crosses manage blood service operations and workflows in accordance with the SOP for blood services. This system ensures that every stage of the blood donation process, from donor registration to final distribution, is meticulously tracked and managed to maintain service quality and patient safety. SIMDONDAR also covers all blood service activities starting from recruitment, donation, examination, processing and distribution of blood. Each of these stages is integrated into a centralized database, enabling indonesia's red crosses to streamline operations, reduce errors, and improve service response times. The SIMDONDAR system also has data on the number of blood stocks owned by indonesia's red crosses. However, the blood stock information is only used by PMI internally. This limitation means that external parties, such as hospitals or clinics, must manually contact indonesia's red crosses to inquire about blood availability, potentially causing delays in critical situations. This new framework system was built to provide new air for stakeholders who need blood. By expanding access to real-time data, this system bridges the gap between indonesia's red crosses and external stakeholders, creating a more collaborative and responsive blood supply chain. This new system will be able to provide information on the amount of blood stock that is updated in real time and access information on blood donor service activities for donors who want to donate blood.

In this research, the system design created can provide additional benefits for indonesia's red crosses and the general public. For the public, the real-time stock information feature increases transparency and allows potential donors to see where their contributions are most needed, encouraging more frequent donations. For indonesia's red crosses, in particular, the design of this system will provide benefits in forecasting demand for the next several periods, so that indonesia's red crosses can make a more efficient and targeted strategy in making the agenda for blood donation activities to meet the demand. There is an indicator for expired blood bags so that you can find out the amount of blood stock that can still be used. This feature minimizes waste by allowing indonesia's red crosses to prioritize the use of older blood bags, ensuring that resources are utilized optimally and fewer donations go unused. In addition, the Whatsapp blast function is also able to make it easier for indonesia's red crosses to provide notifications to people to donate their blood back which currently almost everyone uses the Whatsapp application for daily activities. This communication approach helps maintain stock and builds a stronger donor community who feel more connected and valued through consistent engagement.

5. DISCUSSION

Based on the results of the information system development that have been explained in the previous section, the validity of the system can be seen from the suitability between stakeholder needs and the features implemented in the platform. The system that was built is able to provide real-time blood stock availability data updates, blood bag age monitoring, and predictions of future demand. Initial validation was carried out through limited trials and showed that the system can run according to plan and fulfill its basic functions. However, for stronger validity, quantitative testing of system performance such as access speed, data synchronization accuracy, and predictive ability based on historical blood demand data is needed.

Although the new system brings a number of significant improvements compared to SIMDONDAR, this study also has limitations. First, the system relies on an internet connection to update and access data in real time. This is an obstacle in areas that do not yet have adequate network infrastructure. Second, the forecasting algorithm used in the system is still conventional based on historical data and frequency requests, so it cannot capture complex patterns such as demand due to disasters or health crises.Third, the system has not adopted blockchain technology to guarantee the integrity, authenticity, and tracking of data in the inter-institutional blood distribution network. Future blockchain integration has the potential to strengthen transparency and trust between stakeholders, especially in situations of coordination between hospitals and monitoring of the medical supply chain.

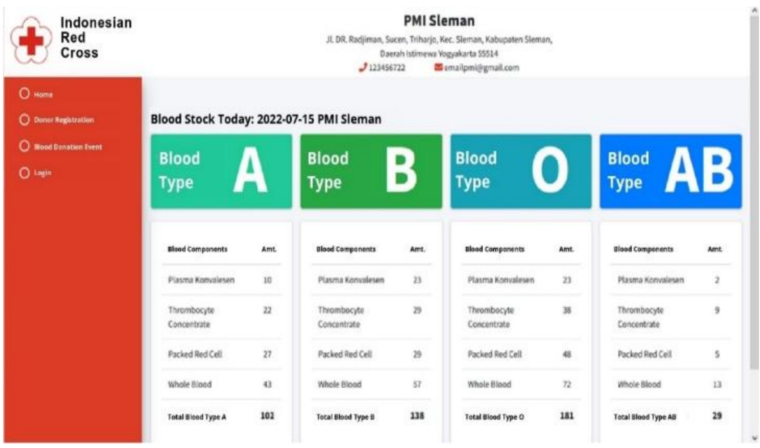
In future development, the system can be enhanced by integrating artificial intelligence (AI) and IoT technologies to improve forecasting accuracy and operational efficiency. AI, through machine learning and NLP-based chatbots, can predict blood demand patterns and facilitate adaptive user interaction, while offline mobile apps ensure access in low-connectivity areas. Simultaneously, IoT devices like RFID and automated storage enable real-time tracking and minimize human error through automated stock updates and low-stock alerts. This synergy reduces waste, supports faster decision-making, and strengthens the reliability of the blood supply chain. Improvement of the system that has been successfully built compared to the existing conditions is summarized in Table 3.

Table 3. Improvement system

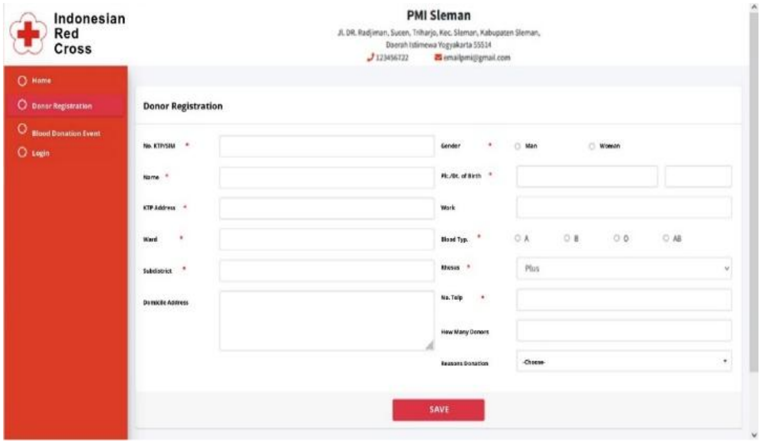
No	Aspect	Existing System Description	Proposed System Description	Feature Mapping *(Before → After)*
1	Access to Blood Stock Information	Only accessible internally by indonesia's red crosses staff	Public access via real-time web interface	*Internal-only stock data → Public-facing live dashboard*
2	Administrative Functionality	Passive documentation of donor and blood stock	Interactive system with forecasting, quota setting, and donor targeting	*Manual admin logs → Smart dashboard with analytics and scenario planning*
3	Blood Bag Expiry Monitoring	Difficult to monitor; expiry date tracking not available	Real-time expiry alerts and prioritization for use	*Manual inspection → Automated expiry alert system*
4	Donor Communication	No automated contact mechanism	WhatsApp blast based on donor inactivity (>60 days) with direct registration link	*No outreach → Automated, targeted donor engagement via messaging*

No	Aspect	Existing System Description	Proposed System Description	Feature Mapping (Before → After)
5	Demand Forecasting	Not available	Forecasting module based on request data from hospitals and historical trends	*No prediction → Predictive model for future blood demand*
6	Public Engagement Interface	No online registration; limited public interaction	Web-based donor registration, location-based quota view, and schedule participation	*Offline manual forms → Online self-registration with quota visibility*
7	Communication with Hospitals/Patients	Must contact indonesia's red crosses manually to inquire about blood availability	Online portal allows hospitals and patient families to view real-time blood stock by type and location	*Phone/email inquiries → Instant stock check via website*
8	Operational Efficiency	Dependent on internal staff to manually update and communicate	Integrated data flows between stock status, requests, donor records, and automated communication	*Disjointed processes → End-to-end real-time information synchronization*
9	Data Utilization for Planning	Used only for archival and basic reporting	Active use of data for dynamic forecasting, spatial planning, and scheduling of donation drives	*Passive logs → Data-driven operational planning tool*

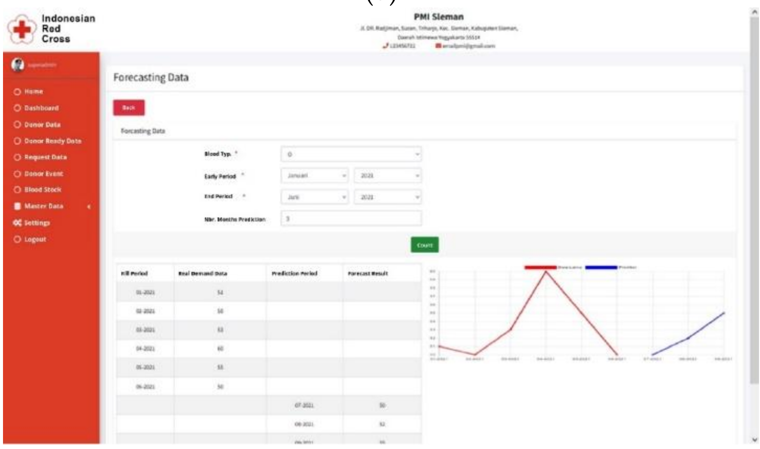
Figure 7 displays of the results of the website that has been successfully develop in this paper. In the existing system, blood bag availability data is only accessible internally, limiting transparency and slowing down the distribution process if the information is not immediately available to those in need. However, in the proposed system, stock availability data is accessible to anyone, which can improve coordination between various parties such as hospitals, blood banks, and potential donors. In addition, the administration system that previously only functioned as a recording system is now enhanced with forecasting and decision-making capabilities, allowing for more accurate analysis of blood demand trends and assisting in more optimal supply planning. One of the main problems in the old system was the difficulty in knowing and monitoring the date of blood bag leakage, which could lead to wastage or stock shortages that were not detected early. The proposed system offers a solution with easier monitoring features for blood bags approaching the leakage period, allowing for faster action to prevent wastage and ensure more efficient blood use.



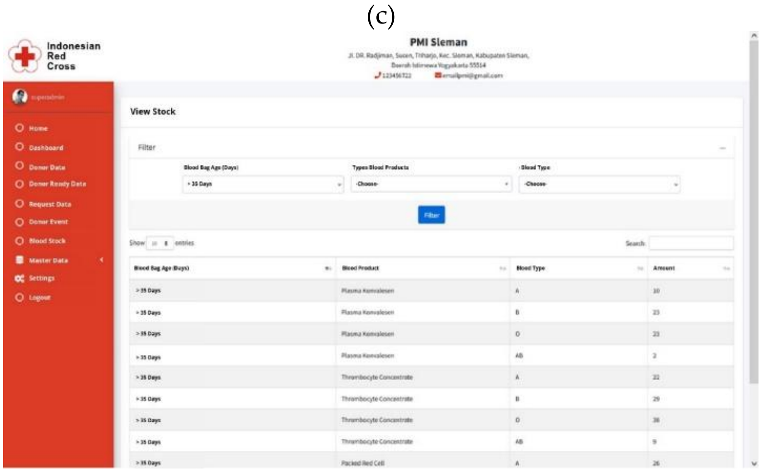
(a)



(b)



(c)



(d)

Figure 7. Information system: (a) information on availability of blood bags; (b) display of blood donor registration; (c) display of demand forecasting for the next period; (d) display of blood bag age information

6. CONCLUSION

This study highlights critical challenges in blood supply chain management at one of indonesia's red crosses in yogyakarta, including the mismatch between production and demand, and the limitations of the existing information system, which lead to inefficiencies and blood waste. Through the integration of IoT and smart logistics, the proposed system enables real-time blood stock monitoring, demand forecasting, and expiration tracking, which together help reduce waste and improve stock utilization. The system also enhances accessibility for hospitals, patients, and donors, supporting faster decision-making and improving overall service responsiveness. By leveraging automated features and transparent data access, it addresses coordination gaps and supports strategic planning for blood donation activities. Furthermore, it introduces a predictive approach to balance supply and demand more effectively and builds a foundation for data-driven healthcare logistics.

These findings support managerial improvements, particularly in terms of enhancing planning accuracy, optimizing communication with donors, and reducing inefficiencies in blood distribution logistics. With the real-time blood stock monitoring feature, indonesia's red crosses can plan blood donation activities more effectively based on predicted data requests [49]. In addition, this system allows hospitals and patients to directly access information about blood availability, thereby accelerating crucial medical decision-making (required resources). Reducing blood waste due to what happens can also be achieved with the blood age monitoring feature, thereby increasing the efficiency of resource use [50]. indonesia's red crosses management can use this system to optimize storage and distribution strategies, as well as improve coordination with donors through the WhatsApp blast-based notification feature, which ensures that blood availability is maintained without significant surplus or deficit. This notification feature has proven effective in increasing donor participation by providing timely reminders based on blood stock needs that are currently experiencing shortages [51].

From an operational perspective, the implementation of this system significantly enhances work efficiency at indonesia's red crosses by automating previously manual processes, thereby reducing administrative burdens, minimizing data errors, and streamlining blood stock management. With the integration of a demand prediction feature, indonesia's red crosses can proactively anticipate blood needs during emergencies or disasters, improving its responsiveness to urgent medical conditions. Moreover, the system optimizes logistics by aligning blood distribution with consumption patterns and demand hotspots, ultimately boosting the overall efficiency of the supply chain. The integration of IoT not only improves transparency and stakeholder collaboration but also positions the system as a strategic tool for indonesia's red crosses decision-making. This study contributes to the literature on blood supply chain management by incorporating IoT and smart logistics concepts into a digital-based system, enhancing coordination across the healthcare ecosystem [52]. Theoretically, it underscores how IoT can optimize perishable supply chains, particularly in healthcare, by minimizing waste and improving adaptability to demand fluctuations through real-time tracking, automated inventory monitoring, and predictive analytics. Thus, from an organizational management viewpoint, this system facilitates more data-informed strategies and resource optimization.

This study adds a theoretical contribution by integrating demand forecasting into an IoT-based blood supply chain. Most previous studies have focused only on developing blood stock monitoring systems or optimizing distribution, without considering the demand prediction aspect, which is a key factor in the blood supply chain [53]. With a system that integrates historical data and predictive algorithms, this study expands the concept of technology-based supply chain management by adding a more accurate demand planning element [54]. In addition, this system can also be used as a tool in strategic decision-making, allowing medical institutions to be more proactive in managing blood supplies based on predicted demand trends. The model developed in this study can be a reference for future studies that want to explore the implementation of similar technologies in other medical sectors, such as the distribution of medicines and medical devices, which also face challenges in efficient stock management and distribution. Thus, this study not only contributes to the context of blood supply chain management but also paves the way for IoT-based innovations in various health sectors that require high efficiency and a distribution system that is responsive to changes in demand.

The system hasn't been tested across indonesia's red crosses units and still depends on manual data entry at certain stages, which may limit scalability. Although the integration of predictive algorithms marks a significant theoretical advancement in the field of IoT-based supply chain management, the system’s operational feasibility and robustness across varied institutional contexts remain to be empirically validated. Differences in infrastructure readiness, human resource capacity, and digital literacy across indonesia's red crosses regional units could influence the consistency and accuracy of data input and system usage. Therefore, future research is recommended to conduct broader system implementation across different regional indonesia's red crosses units and to explore full automation in data collection to reduce dependence on manual input. Automating the data acquisition process through IoT sensors, RFID tags, or connected diagnostic tools would not only enhance data reliability but also increase system responsiveness in real time. This could help validate the model’s generalizability and improve its operational reliability at scale, enabling its application in other domains within the healthcare sector. By addressing these limitations, subsequent research can further strengthen the theoretical contribution of this study while offering practical insights for scalable and adaptive digital health infrastructure development.

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