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ORIGINAL CONTRIBUTION

Design And Development of a Nationwide Centralized Blood Bank System for Efficient Blood Donation and Distribution

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Abstract— A centralized digital system, the Nationwide Centralized Blood Bank System (NCBBS), is proposed to address operational inefficiencies in blood donation and distribution in Sri Lanka, driven by decentralization and semi-manual processes. Although a well-founded National Blood Transfusion Service (NBTS) and a well-established voluntary donor culture are in place, a lack of real-time nationwide visibility into blood stocks leads to shortages, wastage, and delays in emergency situations. This report describes the design and development of a centralized, web-based application that integrates donor registration, health screening, laboratory testing, blood unit management, request processing, and emergency prioritization into a single, secure system. The system uses an Agile System Development Life Cycle (SDLC) and a layered multi-tier architecture comprising presentation, business logic, data management, and security layers. A role-based access control model with eight user roles implements accountability for operations and data in accordance with the Personal Data Protection Act in Sri Lanka. Modular system design helps in scalability, maintainability, and integration of predictive analytics and decision support in the future. Nationwide blood bank management through consolidation of stakeholders, such as blood collectors, blood storage facilities, requester organizations, and administrators into a single coordinated ecosystem, NCBBS promotes transparency, enhances inter-institutional coordination, and creates a safe platform on which nationwide blood bank management can be realized in accordance with international best practices of digital health.
Index Terms— Blood bank management, Centralized system, Agile SDLC, Role-based access control, Healthcare information systems, PDPA compliance

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I. INTRODUCTION

Blood is a non-substitutable resource in healthcare systems. Early availability of safe blood transfusion may spell out life or death, especially in emergency situations like trauma, obstetric emergencies, cancer treatment, and chronic conditions like thalassemia. According to the World Health Organization (WHO), effective blood transfusion services are key to a strong health care system and call for the creation of unpaid, voluntary donor programs, centralized and supported by robust information management systems. The challenges in the collection, processing, storage, and distribution of blood remain significant in low- and middle-income countries despite these recommendations. Inefficient coordination, disjointed systems, and the continued use of manual or semi-manual procedures often lead to insufficient supplies, waste, unfair distribution, and avoidable deaths [?].

The government of Sri Lanka enjoys a strong culture of voluntary blood donation, supplementing the national healthcare system. However, limited coordination, ongoing reliance on semi-manual work, and underutilization of digital technologies remain barriers to effective blood management. Requestors and regional centers often rely on telephone communication, physical records, and personal networks to organize blood stocks and mobilize donors during shortages. While sufficient for routine needs, these methods become inefficient and time-consuming in emergencies. The absence of a unified digital platform restricts real-time access to nationwide blood stocks, equitable distribution, and regular donor follow-up.

As demand for healthcare services and emergency cases increases, Sri Lanka needs a national, centralized, and secure blood bank system to enhance transparency, accountability, and efficiency in donation and distribution. This would streamline current processes and deliver lifesaving blood products more rapidly to those in need.

The use of decentralized structures creates significant inefficiencies. For example, in certain Requestors, requests for certain blood categories may be acutely unmet, whereas neighboring Requestors waste unused blood units because demand forecasting and redistribution systems fail to function properly [?]. The lack of real-time national access to blood stocks poses problems not only for healthcare providers but also for patients, as disparities in blood resource access may lead to uneven clinical outcomes. Additionally, due to the lack of systematic donor deferral monitoring, valuable epidemiological data on the prevalence of anemia, hypertension, and transfusion-transmissible infections cannot be used, thereby reducing the potential for preventive interventions in public health. These gaps are an opportunity that can be met through the rapid global development of digital health technologies. The use of web-based platforms, centralized databases, and integrated information systems can go a long way in enhancing the blood bank operations through real-time donor registration, centralized Blood Collector management, automated donor requests by Requestors,

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and coordinated emergency response mechanisms [?]. Besides making operations more efficient, those systems also increase trust among the population by ensuring that data protection mechanisms, such as the Personal Data Protection Act of Sri Lanka (which classifies health data as highly sensitive and requires strict controls), are adhered to.

The digitization of blood banks has shown promising results in several case studies across different countries. The test deployments in Nigeria were reported to have enhanced Blood Collector management and inter-Requestor communication, resulting in reduced shortages and wastage [?, ?]. Equally, Indian system implementations revealed that integrated web-based systems were useful for streamlining donor registration, Requestor requests, and Blood Collector planning by reducing reliance on manual procedures [?, ?]. Despite these achievements, most current solutions have been localized, and a clear gap in research and implementation persists at the national level.

A. Problem statement

One of the major issues in the management of blood in Sri Lanka is the continued reliance on decentralized operations and the limited use of integrated digital systems. Despite the formation of the National Blood Transfusion Service (NBTS) to bring blood transfusion services across the country under a single umbrella, several inefficiencies persist to date in blood collection, testing, storage, and delivery. Such issues are mostly due to the fact that none of the healthcare institutions has a unified information management system that facilitates real-time coordination. The lack of a real-time, nationwide blood inventory catalogue is a major problem. This is because Requestors are operating in a vacuum, without access to the latest blood from other Requestors. Consequently, healthcare providers often face severe shortages in emergency situations, while other Requestors discard expired blood products due to insufficient redistribution systems. This unequal distribution results in the additional unjustified wastage of life-saving resources and the incompetence of current allocation policies.

Without a centralized online platform, Requestors tend to use ad hoc, manual processes to manage blood shortages, such as telephonic communication, personal networks, and social media platforms. While these approaches offer short-term relief, they are often unreliable, poorly coordinated, and inadequate for emergencies requiring time-critical responses. The lack of an organized system for managing donor relationships prevents healthcare providers from mobilizing eligible donors during periods of high demand. Inadequate data management further exacerbates these challenges. Outcomes of donor screening—such as deferrals and rejections—are not systematically or consistently recorded, limiting meaningful analytics and hindering population health monitoring. Without reliable data, preventive healthcare planning and evidence-based decision-making are impaired, making it impossible to identify trends related to anemia, hypertension, or transfusion-transmissible risks. Additionally, disjointed data storage and inconsistent documentation result in inaccuracies, redundancy, and inadvertent information loss.

Overall, the lack of a centralized, secure, and intelligent blood bank information system has resulted in inefficiency, poor stakeholder coordination, insufficient monitoring, and delays in transfusion services. These deficiencies weaken operational effectiveness and affect patient outcomes, resulting in preventable morbidity and mortality. National-scale solutions that organize all aspects of blood collection, storage, distribution, and control into a single, coordinated system are required.

1) Objectives

The objective of this project is to develop a centralized digital platform for nationwide blood bank management in Sri Lanka. Secondly, it is to integrate real-time donor registration, health screening, and blood stock monitoring. Finally, to enhance nationwide coordination and transparency in blood donation and distribution through a centralized digital system.

2) Project scope

The project scope will focus on designing and developing a web-based information system for nationwide blood bank coordination. It integrates donor management, Requestors requests, real-time blood stock monitoring, and prioritization of emergency dispatch. The scope excludes medical testing but emphasizes data handling, digital coordination, and information security.

II. LITERATURE REVIEW

A. Introduction to literature review

Blood donation and transfusion have been the subject of extensive research over the past decades, but the challenges of recurring shortages, wastage, delayed availability, and poor coordination among stakeholders still jeopardize patient outcomes, particularly in developing countries. The analysis of more recent literature suggests a steady shift toward the use of digital technologies, supply chain optimization models, artificial intelligence, and data protection mechanisms to make blood bank systems more efficient, transparent, and reliable. [?] noted that implementing blood bank enterprise systems in Europe is successful not only in terms of technology but also in terms of contextual controls, stakeholder alignment, and the multi-level challenges that must be considered when extending local to national platforms. In addition to this, other work like [?] investigated the idea of mobile apps to communicate with patients and, as noted, provided evidence of their ability to shorten the response time yet revealed their inability to scale, maintain data integrity, and integrate with hospital infrastructures. Equally, studies conducted in Sudan [?, ?, ?] and Bangladesh [?] found that, although mobile solutions can modernize the system of donor engagement, such systemic issues as manual record keeping, low level of motivation, and outdated databases of donors significantly limit their effectiveness in the long term.

As with mobile solutions, there have been numerous developments in web-based and hybrid platforms by scholars. Django and PHP were used by [?], [?, ?] to develop systems that streamline donor registration, hospital request processing, and inventory management. The above efforts highlighted that centralized systems are clearly superior to disjointed manual systems, but also observed difficulties such as the inability to examine prototypes, the absence of sampling in the system design, and the inability to interoperate systems across hospitals. [?] in Iraq have shown that web and IoT technologies can be used together to monitor inventory. Sensor-based monitoring of blood bags had the potential to reduce data losses and enhance responsibility, but connectivity and infrastructure constraints in conflict areas prevented the adoption of IoT. In a similar manner, [?] proposed an IoT-based e-blood bank in India that combines real-time monitoring, React, Node.js, and MongoDB, demonstrating that it is feasible nationwide, provided that connectivity issues in rural areas and logistics challenges can be overcome.

Another important aspect of literature concerns the implementation of predictive analytics and machine learning in blood banks. In predicting the demand, classifying donors, and scheduling donations, [?, ?], and Walid Elmir et al. (2023) have suggested forecasting models based on ARIMA, ANN, and support vector regression. These research works have consistently found that demand forecasting and donor classification can reduce shortages and waste by more than 20% and increase efficiency and donor satisfaction. Nevertheless, they also noted that deploying such models requires strong datasets, regular retraining, and sophisticated infrastructure, which most developing countries do not yet have. Similar works by [?] proposed mathematical and supply chain optimization models that considered perishability, equity, and waiting times at the donor side, demonstrating the value of optimization in national-scale networks. These models have utilized the most advanced methods, including NSGA-II heuristics, genetic algorithms, and particle swarm optimization, to achieve competing goals such as minimizing costs and waste and maximizing freshness. However, since they are mostly hypothetical, real-world pilot testing is also a clear gap in the research.

Security and data protection have become the focus issues of various research as well. Agarwal designed a MySQL- and PHP-based encrypted blood bank system to address donor hesitation stemming from privacy concerns. The same focus on the safe implementation of MIS was evident in Pakistan among [?], who attributed ineffective management to disjointed, unsystematic systems. Their comparative analysis has highlighted the pressing need for harmonized MIS at the national and international levels. Moreover, recent systematic reviews [?, ?] examined 54 studies and found that although AI, blockchain, IoT, and cloud computing hold a lot of potential for smart blood bank systems, the issues related to privacy, usability by elderly donors, and scalability under limited resource settings were not addressed.

Behavioral and motivational factors in blood donation were also considered, though [?] reviewed smart methods, including gamification, social media, and SMS campaigns, to sustain donor motivation and retention. Although these approaches demonstrate potential to increase voluntary contributions, especially during crises, their long-term effects are not well documented. Similarly, Researcher proposed intra-hospital logistics using a real-time blood product tracker in operating rooms to reduce communication delays, lost products, and so on, but, once again, demonstrate that most solutions remain situation-specific and inappropriate for nationwide implementation. At the higher policy and comparative level, [?] conducted a survey on fifteen developed countries and discovered that there is little association between healthcare systems and the introduction of safety innovations, thus highlighting the role of cultural, financial, and operational factors in the formation of system adoption in comparison with the role of policy frameworks.

Across the 30 studies examined, several convergent points emerge. First, local and small-scale systems, such as mobile and web applications and IoT-enabled prototypes, have evidence of concept but fail to scale to national infrastructure due to interoperability, funding, and policy issues. Second, predictive analytics and AI-based forecasting models have great potential to be efficient but require robust data ecosystems and governance. Third, although security and privacy frameworks have been discussed, their large-scale practical implementation in a blood bank system remains limited, and donor trust remains a significant hindrance. Lastly, motivation methods, gamification, SMS notifications, and more should be more thoroughly validated to achieve donor retention and sustainable engagement. Collectively, these results reaffirm an obvious research need: though much effort has been put into fragmented solutions, there remains a lack of an integrated Nationwide Centralized Blood Bank System to provide a single platform that integrates donors, hospitals, inventory, and administrators in a secure, predictive, and user-friendly manner. The emerging point of such a system, based on best practices in supply chain optimisation, data protection, predictive analytics, and donor engagement, is the future of ensuring efficiency in blood donation and distribution at the national level.

B. Review of existing systems

The evolution of blood bank management systems has already achieved significant milestones over the last 20 years, advancing from simple manual records and local databases to advanced web platforms, mobile apps, and predictive analytics tools. On closer examination of the existing systems, it can be observed that although many prototypes and regional applications have been developed, they lack integration, are implemented locally, and have only a small-scale effect. [?] reviewed the implementation experience of enterprise blood bank systems in Europe and found that, although this practice has strong government support, most projects incurred cost overruns and coordination issues due to poor integration of contextual controls. It underscores the fact that such a centralized design is inherently difficult, i.e., it must strike a balance among various hospital needs, donor management protocols, and data-sharing regulations. Researcher aimed to minimize donor-patient communication disconnects by using BLOODR, a mobile app that leveraged clinic-mediated notifications so that only suitable donors could see the alerts. Although useful for real-time matching at the local level, these systems were not interoperable with larger health systems and could not scale beyond community-based operations.

The systems that are in place rely on mobile and web-based platforms. [?] introduced a Django-based system, Blood Warrior, that included donor and patient registration, hospital requests, and support for chatbots to assist users. Although the study has promising features, it identified that rigorous testing was not conducted and that there were gaps in prototype testing and scalability. [?] investigated the use of an Android application with a hospital portal based on the web in Sudan to minimize donor waiting time and improve communication. The dual platform was novel for combining donor notifications and hospital appointments, but adoption was low due to infrastructure constraints and insufficient digital skills among end users. On the same note, [?] developed a cross-platform mobile app that provides donor location services via GPS and an emergency panic button, aiming for the Bangladeshi setting with low donor recruitment. The system was technically sound; however, outdated donor databases and limited integration with hospital records were weaknesses of isolated mobile solutions in maintaining donation chains.

The lack of web-based model capabilities has been alleviated over the last few years by the increased presence of hybrid and Internet of Things-enabled systems. [?] mentioned a hybrid of QR-coded blood bags and a centralized database for real-time inventory monitoring as the pilot of the web-and-IoT system for a blood bank in Tikrit, Iraq. This innovation improved traceability and accountability; however, it was unreliable due to low internet connectivity and power supply in the war-affected areas. In India, in an E-blood bank system, [?] developed an IoT-based system using React, Node.js, Express, and MongoDB, enabling real-time donor-recipient matching, hospital inventory tracking, and geolocation of nearby blood camps. The authors found significant challenges to rural internet coverage and a lack of national integration policies to facilitate integration despite its scalability and national implementation opportunities. These results indicate that, although technically possible, infrastructural and governance challenges hinder the large-scale adoption of IoT-based solutions.

Another important aspect of the existing literature is the application of artificial intelligence and predictive analytics to blood bank systems. [?] proposed predictive blood donor management, a system that uses machine learning algorithms to predict donor demand and forecast donor availability, thereby reducing shortages and improving the efficiency of the planning process. In the same way, [?] developed a smart platform that includes demand forecasting based on ARIMA and ANN models, donor classification using machine learning, and appointment optimization. The Algerian case study showed reduced waste and better stock control, though the system was limited to a province. Reearcher used queuing theory to reduce donor waiting time and, combined with location-allocation optimization, to improve the performance of the blood supply chain. [?] further elaborate on this research question by developing a comprehensive supply chain model that leverages genetic algorithms and particle swarm optimization to balance shortages, reduce expiry-related waste, and prioritize patient equity. Although these models have significant potential, most are theoretical or pilot-tested and not nationally implemented. Their dependence on high-quality longitudinal data also raises questions about developing areas with poor data infrastructure.

Another theme is data security and Management Information Systems (MIS). Agarwal have proposed a blood bank management platform that leverages database encryption to alleviate donor hesitancy driven by privacy concerns. Using application-level encryption and hashing, the system provided a higher level of confidentiality but was not tested for national interoperability. [?], conducted a comparative study of MIS in Pakistan and found significant gaps in functionality, funding, and adherence to international safety standards. In their findings, they indicated that there was no coordinated MIS that could connect regional and hospital databases to a unified national system. The absence of such systems led to inconsistent and unreliable reporting, affecting decision-making processes. Such obstacles support the significance of data security and centralized management in any national system.

Another significant aspect of the existing systems is motivational and behavioral strategies. [?] reviewed smart strategies such as gamification, SMS-based donor alerts, social media campaigns, and even a mobile application designed to keep donors engaged. Although these systems have been implemented in other countries such as Russia, Malaysia, and Bangladesh, there is scant long-term empirical evidence regarding their ineffectiveness. The process of donor retention remains weak, as most systems have shown spikes in voluntary donations during the crisis but cannot sustain those inflows once the situation returns to normal. [?] focused on intra-hospital systems and developed a real-time blood-tracking system for operating rooms to minimize communication delays among employees. Although this was an innovation that met another, but essential, aspect of the blood chain, such as logistics at hospitals, its size was local and was not linked to a national donor or inventory database.

An extended perspective on current blood bank systems reveals significant disparities worldwide. [?] compared the designs of the health and blood supply systems in 15 developed countries and found that the correlation between governance models and the introduction of safety innovations was weak. It means that even countries with adequate resources struggle to implement modern technologies uniformly, often because of cultural and institutional differences rather than technical difficulties. The case of the Pakistani experience examined by [?] also demonstrates how inefficiency and data loss are aggravated by poor governance and fragmented infrastructure. In comparison, the National Blood Authority of Australia has already deployed several ICT solutions, including BloodNet and BloodSTAR, which enable real-time inventory management, donor registration, and order processing. All these instances highlight that, even with mature systems, effectiveness relies on strong governance, financial investment, and national strategies.

In all the systems that were analyzed, some patterns can be observed. To begin with, most available platforms are local or regional, and they are not particularly interoperable or scalable. Mobile and web applications tend to register donors and send emergency alerts, but they are not connected to a hospital inventory system or a national health database. The IoT-enabled systems provide traceability and real-time monitoring, but are crippled by inadequate infrastructure. Demand forecasting and supply chain resilience, predictive analytics, and optimization models have immense potential but are still in the academic or pilot-testing stage. Data security systems enhance user trust but are not standardized across regions, and motivational strategies need to be empirically validated to maintain their impact. Therefore, the gap in uniting such disparate solutions into a nationwide centralized blood bank system is always evident in the literature. This system would require integrating donor engagement, hospital requests, predictive analytics, IoT-based monitoring, and encrypted MIS platforms into a single framework, with support from government policy and proper infrastructure. The lack of these combined systems underscores the urgent need for further research and implementation projects that go beyond piecemeal prototypes to develop comprehensive, national-scale solutions to make blood donation and distribution more efficient.

C. Theoretical framework

The theory behind a Nationwide Centralized Blood Bank System is informed by various overlapping fields such as the information systems theory, supply chain management, predictive analytics, data security frameworks, and behavioral motivation models, all of which, when combined, give the foundation behind creating a system that is efficient, equitable, and sustainable in blood donation and distribution. The initial point of departure is the theory of information systems, which stresses that technological solutions can be effective only when they are in tandem with the social, organizational, and regulatory environments in which they are used. [?] emphasized that contextual controls, stakeholder buy-in, and adaptive governance would impede enterprise blood banking initiatives in Europe, underscoring that system design cannot be approached as a technical project; it must take socio-technical perspectives into account. It can be linked to the concepts of Socio-Technical Systems Theory, which holds that technological tools such as databases, mobile applications, and Internet of Things sensors must be balanced with organizational activities, user interactions, and policies to have a long-term effect. It is based on this that the project takes the approach of the System Development Life Cycle (SDLC) as a methodological approach to structuring development in form of iterative phases requirements gathering, design, implementation, testing, deployment, and evaluation such that all actors such as donors, hospitals, inventories and administrators are integrated into a structured, role based access control model.

The other important aspect of the theoretical framework is the theory of supply chain management, particularly in the blood supply chain, where donor supply is uncertain, the product is perishable, and demand is emergent and life-saving. Such study as [?] incorporated mathematical optimization into their models of donor waiting times, perishability, and patient equity, according to classic supply chain models, and showed that the mathematical optimization tools, such as mixed-integer programming, NSGA-II heuristics, and genetic algorithms, could reduce wastage and improve freshness and patient equity dramatically. Such works align with the Theory of Constraints, which holds that the system's bottleneck determines its performance.

The reasons behind such bottlenecks in blood supply chains may include low donor attendance, slow processing speeds, or inefficient delivery, and the system must focus on alleviating these bottlenecks through proactive planning, dynamic distribution, and real-time monitoring. Furthermore, the application of Queuing Theory employed by Rahimzadeh et al. provides mathematical grounds for minimizing donor waiting time and optimizing blood collection flow, thereby justifying the system's credibility in its functioning.

The other pillar of the framework is premised on the theories of predictive analytics and artificial intelligence, in particular the use of time-series forecasting and machine learning to forecast demand, donor behaviour, and inventory variations. As demonstrated by [?] and [?], blood demand patterns can be modeled with high accuracy using algorithms such as ARIMA, ANN, and SVM, thereby facilitating proactive planning and reducing waste. Theoretically, this is a data-driven decision-making model that highlights the predictive models used to convert past data into actionable insights that inform policy and operational decisions. A further way to propose integrating forecasting into national blood systems is to consider it through Decision Support System (DSS) theory, which provides a conceptual framework for developing systems that integrate data, models, and user interfaces to support real-time decision-making by managers and administrators. This, in practice, implies that the system is not only to store the records about the donor and inventory but also to analyze them continuously to predict the needs in the future, which highly probable donors can be found, and which regions may run out of blood, thus converting reactive blood supply management to a proactive, smart service.

Since health information is a sensitive topic, the theories of information security and privacy are another critical element of the framework. [?] reported that database encryption can enhance donor reluctance, and [?] demonstrated that flawed MIS structures undermine the trust and reliability of blood services. These align with the Confidentiality, Integrity, and Availability (CIA) Triad of information security, which states that secure systems should protect against unauthorized access, maintain the integrity of their information, and make it available to authorized users when required. Additionally, the need to adhere to legal policies, such as data protection laws, supports the Regulatory Compliance Theory, which holds that national and international privacy laws drive the design of the system, thereby increasing donors' trust and adoption. The use of encryption, role-based access control, audit logging, and compliance monitoring in a nationwide system cannot be considered a technical necessity, but rather a theoretical one grounded in well-established principles of information assurance.

Since the system is built on the pillars of technical efficiency and data security, its sustainability is influenced by behavioral and motivational factors, as blood donation is a voluntary act shaped by social, psychological, and cultural factors. [?] emphasized the power of innovative solutions, including gamification, SMS notifications, and social media use, which align with the Theory of Planned Behavior (TPB), which predicts human behavior as a function of attitudes, perceptions of norms, and perceived control over behavior. TPB holds that donors' willingness is not necessarily influenced by their selflessness, but also by the level of their faith in the safety, accessibility, and recognition of the process. The gamification practice aligns with Self-Determination Theory (SDT), which holds that intrinsic motivation can be promoted through rewards, recognition, and achievement. Likewise, the merger of geo-enabled notifications and personalized outreach to donors is reminiscent of the concepts of Behavioral Economics, in which nudges such as reminders, convenience, and recognition can substantially boost donor turnout rates. All these theories of motivation guide the development of engagement modules in the proposed system, where the most vulnerable component of technology systems is the human factor that should be covered holistically.

Finally, all these theoretical elements need to be coordinated within a broad conceptual framework that integrates them into a comprehensive nationwide deployment plan. It is offered through the Integrated Systems Theory, which proposes the coordination of technological, organizational, and human subsystems within one framework. Here, in the Nationwide Centralized Blood Bank System, it involves optimizing supply chains and predictive analytics, integrating data security protocols into the MIS, and overlaying motivational strategies onto the donor-facing modules. The product is to be a system that is not merely technological and operationally sound, but also socially acceptable, legally compliant, and responsive to future innovations. In such a way, the theoretical framework is based on a multidimensional foundation: the socio-technical systems theory is used to ensure compliance with the context; the supply chain and queuing theories are used to optimize the logistics; the decision support and data-driven models are used to inform the predictive intelligence, the security frameworks and behavioral theories are used to maintain the engagement of the donors. All these theories create a comprehensive conceptual frame for designing and implementing a nationwide centralized system that ensures the long-standing inefficiencies in blood transfusion and distribution, and preconditions the realization of healthcare innovation that can be scaled, equitable, and sustainable.

TABLE I
RESEARCH FINDING COMPARISON AND RESEARCH GAPS

Paper Author	Title	Key Features	Challenges	Methodology	Research Gap
[?]	Blood bank system using database security	Encryption, secure authentication; donor/event modules	Privacy concerns; limited standards	PHP/MySQL; app-level crypto & hashing	Standardized security & compliance at scale
[?]	Improving and supporting blood donation practices in Khartoum, Sudan blood banks through Android mobile app and web application	Android donor app + web portal; reminders, booking	Manual records; low digital literacy	Dual-platform design; literature-informed	Large-scale trials; integration with transfusion services
[?]	Geo-location in blood bank systems	GPS routing; nearest donor/hospital	Infrastructure, mapping accuracy	Google Maps APIs; implementation study	Nationwide geo-services under variable coverage
[?]	A comparison of health care and blood supply system structures	Cross-country system comparison; safety tech adoption	Structural diversity ≠ uniform innovation	Survey/Comparative policy analysis	Why adoption lags despite resources—causal factors
[?]	Mobile blood donor engagement system	Recruitment via mobile; engagement tools	Digital literacy; workflow fit	Mobile app development; pilot	Integration with hospital requests & stock
[?]	Smart platform for data blood bank management: Forecasting demand in blood supply chain using machine learning	3-module AI platform: forecast, classification, scheduling	Staff capacity; short shelf-life	Time-series (ARIMA/ANN/SVR); Algeria data	Integrated AI platform at national scale
[?]	An extended research on the blood donor community as a mobile application	Cross-platform app; GPS/GSM donor search; panic button	Outdated donor lists; weak hospital links	Survey (n=230); app design	Up-to-date registries; seamless hospital integration

CONT...

Paper Author	Title	Key Features	Challenges	Methodology	Research Gap
[?]	Are my blood products coming? Implementation of a novel blood product tracker in the operating room	Real-time product tracking in OR; comms visibility	Intra-hospital delays; misplaced products	Implementation study; workflow redesign	Link OR logistics to national inventory platforms
[?]	Cloud-based hospital	blood systems	Centralized cloud DB; cross-site access	Rural connectivity; downtime risk	Cloud design & prototypes & Resilience and offline-first capabilities
[?]	Mathematical modeling for optimizing the blood supply chain network	Location–allocation + queuing; donor wait minimization	Donor uncertainty; perishability	Nonlinear multi-objective; NSGA-II	Incorporate real demand shocks & routing constraints
[?]	AI models for donor prediction	Return-donor prediction; shortage mitigation	Data sharing/privacy constraints	ML modeling; retrospective data	Deployment & governance for predictive services
[?]	Online blood donation reservation and management system (Saudi Arabia)	Donor/recipient portal; hospital mediation	Human error; distribution complexity	Web system; hospital pilots	End-to-end traceability & stock integration
[?]	A systematic review on smart blood bank system: Taxonomy, motivations, challenges, study directions and recommendations	Taxonomy of AI/IoT/Blockchain/Cloud solutions	Security, privacy, usability, connectivity	Systematic review (2017–2021)	Real-time IoT + privacy-preserving national architectures
[?]	The use of web technology and IoT to contribute to the management of blood banks in developing countries	QR-coded bags; sensor-based stock tracking	Power/Internet instability; wartime constraints	Case study; interviews; pilot (n=22 staff)	Scalability and resilience in low-resource settings
[?]	IoT-based e-blood bank system for real-time hospital monitoring and inventory management	Real-time inventory; geo-search donors; IoT devices	Rural connectivity; national policy gaps	Full-stack (React/Node/MongoDB + IoT); prototype	National IoT deployment & interoperability
[?]	Predictive analytics for blood supply chain management and data security in healthcare system	ML forecasting; donor prediction; security emphasis	Balancing privacy with analytics; operationalization	Proposed web BB-DMS; encryption + ML models	Real-world deployment and evaluation at scale
[?]	An integrated supply chain model for predicting demand and supply and optimizing blood distribution	Forecasting + GA/PSO routing; equity focus	Demand uncertainty; fairness in allocation	ARIMA/ML + metaheuristics; Tehran case data	Robust, real-time decisioning under crises
[?]	Automated blood management system: Streamlining search, inventory, and patient care information	Centralized online BBMS; Agile ASD; Django/MySQL	Manual legacy processes; access constraints	Design & implementation; comparative review	National-level rollouts and interoperability
[?]	Personal Data Protection Act of Sri Lanka	Legal framework for data protection	Compliance complexity	Policy/Regulatory framework	Not system-specific; requires applied solutions
[?]	Automated blood bank management system	Automated donor registration; real-time stock updates	Limited to small regional scale	Prototype system design and testing	Does not address nationwide integration
[?]	Blood bank management system	Cloud-based BBMS; reduces paperwork; traceability	Academic prototype; limited validation	OOP design; ER/UML; proposed cloud impl.	Real-world pilots and integration with hospital EMR
[?]	Proposed a web-based intelligent system to manage the blood bank in Zakho District	ML (ANN/DT/LSTM) for RBC forecasting; notifications	Manual records; sparse data	PHP/MySQL; ML pipeline; case study	National predictive platforms with clean data
[?]	BBIS: Blood bank information system based on cloud computing (Indonesia)	National donor linking; web/mobile; cloud	Donor availability; emergency readiness	Cloud architecture; feature-rich portal	Nationwide availability + privacy compliance
[?]	Donor deferral analytics	Deferral insights; epidemiology focus	Inconsistent data capture	Analytical/observational	Feed deferral analytics into national planning
[?]	The evolving nature of information systems controls in healthcare organisations: The case of a blood banking enterprise system from Western Europe	Enterprise-scale IS controls across lifecycle; multi-stakeholder governance	Cost/time overruns; weak contextual control	Longitudinal case study of three implementations	Need dynamic, context-aware control portfolios for national rollouts
[?]	Smart approaches for encouraging the blood donation	Gamification, social media, SMS, apps	Sustained retention; effect measurement	Literature review; global exemplars	Long-term, controlled impact studies
[?]	Research paper on blood bank donation and management using Django	PWA (Blood Warrior); donor–hospital workflow; chatbot	Limited evaluation; unclear sampling	testing & Web app (Django/MySQL); experimental demo	Rigorous user studies; ML/GPS integration and scaling

CONT...

Paper Author	Title	Key Features	Challenges	Methodology	Research Gap
[?]	BLOODR: Blood donor and requester mobile application	Clinic-mediated donor alerts; compatibility filtering	Limited interoperability with hospital systems	Ruby on Rails, PostgreSQL; UML prototype	Real-time national integration and secure clinic interfaces
[?]	Deterministic model for blood bank inventory control with increasing demand and logistic considerations using multi-objective optimization	Multi-objective model; perishability; logistics	inflation	Practical data/parameterization & MATLAB optimization; differential modeling	Validation on multi-hospital datasets
[?]	Analysis of management information system in blood transfusion services, Pakistan	MIS gap analysis vs. standards; module comparison	Fragmented systems; poor data quality	Mixed-methods; 6-facility case analysis	Synchronized national MIS & vigilance systems

This study addresses the identified gap by proposing a unified nationwide centralized platform, the Blood Bank System for Efficient Blood Donation and Distribution. Table 1 presents research findings and comparisons and identifies research gaps for each study. There is a total of 30 comparisons being made to identify the main gap between 2015 and 2024.

METHODOLOGY

D. Research and development approach

The creation of the Nationwide Centralized Blood Bank System (NCBBS) is based on a System Development Life Cycle (SDLC) methodology, with an agile-oriented implementation approach, to ensure an orchestrated, iterative, and documented process for system design, development, deployment, and maintenance. It was chosen as a suitable methodology because it enables the development of a secure, efficient, and responsive online platform for blood transfusion services without violating the Sri Lankan Personal Data Protection Act (PDPA). System design, testing, deployment, and maintenance phases are used systematically throughout the project lifecycle, e.g., in the SDLC phases: planning, requirements analysis, system design, development, testing, deployment, and maintenance. The combination of Agile principles enables incremental change through continuous testing and continuous improvement of system features; thus, the given approach is appropriate for a complex healthcare system with ever-changing work processes and user access profiles. Using the same methodology, each important system user, such as donor management, health screening, lab testing, Blood Collector, Requestors' blood requests, and emergency prioritization, is installed and tested individually. The modular structure can also be designed to be expandable in the future, e.g., for predictive analytics and decision support, without compromising data security, privacy, or auditability.

E. Agile system development life cycle

The Agile Software Development Life Cycle (SDLC) is employed to create the Nationwide Centralized Blood Bank System (NCBBS) to introduce flexibility, incremental development, and continuous improvement. Agile was chosen because the dynamic healthcare system needs to be flexible to accommodate changes in requirements, processes, and compliance requirements over time. In contrast to the classical linear development model, Agile emphasizes iterative development, with continuous stakeholder feedback and routine testing. Such an approach enables gradual improvement in system capabilities, timely response to emerging operational requirements, and early bug avoidance. Agile is especially appropriate for blood transfusion services in Sri Lanka, where efficiency, security, reliability, and regulatory compliance are paramount. Agile SDLC also enables the project to be responsive and supports the quality of the system, data security, and scalability in the long run. Figure 1 shows the typical SDLC process.

Fig. 1 *Agile System Development Life Cycle (SDLC)*

1) Planning

The Agile development process begins with the planning phase, during which the development team, along with other key stakeholders such as the Ministry of Health, NBTS officials, Requestors, and potential donors, will discuss the project's high-level goals. These objectives include donor registration, handling blood requests in Requestors, providing real-time visibility to Blood Collectors, and prioritizing emergencies. At this stage, user stories and a product backlog are created to define functional and non-functional requirements, while project roadmaps and sprint plans are developed to provide realistic delivery schedules and ensure compliance with national healthcare policies and regulatory requirements, particularly the Personal Data Protection Act [?].

2) Design

At the design stage, the system architecture, role-based access model, and user dashboards are stated to meet the requirements of all stakeholders. The core processes, such as donor management, Requestor's blood request, Blood Collector control, and emergency handling, are broken down into modular components to enable incremental development in line with Agile principles. Stakeholders are given prototypes and wireframes at an early stage to ensure the system is usable, functional, and aligned with the workflow before it is fully implemented.

3) Development

System implementation is carried out in the Agile development process through iterative sprints that may last 2 or 4 weeks. A sprint delivers a functional system component, such as donor registration, blood item management, or request management. Development and testing activities are carried out simultaneously through continuous integration, validation, and feature development, rather than in a programming, integration, planning, and testing process. The iterative pattern minimizes risks of development, and the project has elements of the system available in time. For example, a first sprint can focus solely on donor registration and authentication, and once these are validated through a test cycle, the following sprints can expand to include advanced features such as prioritizing emergency requests and reporting dashboards.

4) Testing

Testing is an essential part of the Agile development cycle and is performed continuously throughout the project, not just at the end. Testing activities will be conducted in each sprint and will include unit testing, integration testing, and user validation to verify that the implemented features satisfy the requirements. User Acceptance Testing (UAT) ensures that system workflows align with real-world processes, with key stakeholders, such as Requestor staff and system administrators, involved in the technical aspects. Moreover, it provides continuous testing for security and regulatory compliance by verifying encryption mechanisms, role-based access controls, and audit logging to protect sensitive health data. This can be achieved through extensive testing that reduces defects, improves system usability, and builds user confidence that the system is safe and secure.

5) Deployment

In the agile method, the system is deployed in steps. When core system features are in stable development, the application is rolled out in a pilot environment with a select number of Requestors or blood bank settings, which are evaluated in real-world conditions. Feedback from these deployment cycles informs subsequent iterations and enhances the system's functionality and usability. A staged deployment plan reduces operational impact and allows healthcare staff to take time to become familiar with the system. Also, continuous delivery practices help provide timely updates and patch releases with minimal downtime, enhancing the overall system's reliability and maintainability.

6) Iteration and continuous improvement

Agile development is not terminated with deployment because it continues to make enhancements throughout the system's lifecycle. User feedback from policymakers and system administrators is often added to the product backlog and addressed in subsequent sprints. This cyclical quality helps the system adapt to new demands and future opportunities, and to incorporate predictive analytics, AI-assisted donor matching, and mobile-based donor engagement to ensure long-term internal relevance and sustainability. Planning, designing, coding, testing, and implementing the Nationwide Centralized Blood Bank System through recursive steps helps the system adapt to real-world healthcare needs, become secure, and remain responsive. Along with continuous improvement driven by user feedback and system performance, Agile SDLC provides a systematic approach to ensuring reliability and scalability, ultimately enhancing blood transfusion services in Sri Lanka and improving patient outcomes.

III. REQUIREMENTS ENGINEERING

A. Stakeholder identification

The success of the Nationwide Centralized Blood Bank System (NCBBS) will be determined by the identification and participation of the major stakeholders in blood transfusion services in Sri Lanka. The main institutional stakeholders are the Ministry of Health and the National Blood Transfusion Service (NBTS), which have the mandate to develop the policy, comply with the regulations, and coordinate the country. Healthcare facilities, especially Requestors and blood request centers, are vital stakeholders because their businesses depend on the timely availability of blood products and the real-time status of their inventories. The blood requester administrators and staff also have the role of entering, prioritizing, and tracking blood requests, particularly during emergencies. There is also the role of blood collectors and blood storage facilities. Blood collector administrators and staff handle donor registration, health screening, laboratory testing, and blood unit creation, whereas blood storage administrators and staff handle Blood Collector, stock checking, and blood dispatch. One stakeholder group is voluntary blood donors, who are directly involved in the sustainability and safety of blood in the blood supply. Platform governance, security, and system reliability are achieved by system administrators and administrative staff, and indirectly by patients and the general population through greater availability of blood, reduced waste, and greater responsiveness to emergencies. The findings of these stakeholders will ensure the system's requirements are complete, practical, and aligned with the objectives of national healthcare.

B. Requirement gathering techniques

To ensure that the Nationwide Centralized Blood Bank System (NCBBS) responds to the country's healthcare priorities and operational requirements, several methods of requirements gathering were used. The interviews and consultations with stakeholders were conducted with national blood transfusion employers, Requestor administrators, and Blood Collector managers to identify operational issues, such as delays in the allocation process, manual coordination, and inconsistencies in Blood Collector management. Donor/Requestors/Ministry workshops provided the Requestors' staff and the ministry with the opportunity to discuss the issue jointly and helped foster a user-centered design approach by involving everyone in the decision-making process. On-site verification of the current workflow in Requestors and blood banks identified inefficiencies in manual Blood Collector accounting, shortcomings in emergency response, and deficiencies in donor deferral tracking. Also, appropriate documents, such as national health reports, WHO guidelines, and data protection laws, including the Personal Data Protection Act, were consulted to ensure compliance with all regulations. The survey was also used to collect expectations regarding the convenience of donation, transparency, and data security for voluntary donors. All these methods provided holistic, practical, and policy-aligned system requirements suitable for nationwide adoption.

C. Functional requirements

Functional requirements outline the capabilities and functions that the Nationwide Centralized Blood Bank System (NCBBS) must accommodate to provide efficient, transparent, and timely blood transfusion services. These requirements outline system functions to facilitate role-based administration of blood donors, blood collection and testing, Blood Collector tracking, requestors' blood requests, approval procedures, and emergency prioritization within the healthcare system of Sri Lanka. Table 2 shows the requirement type for functional requirements and the description.

TABLE II
FUNCTIONAL REQUIREMENTS

Requirement Type	Description
Donor Management	It enables blood collectors to register donors, update donor profiles, conduct health screening, record laboratory test results, and track donor eligibility and deferrals.
User	Role Management & Provides secure role-based access control for Admin, Admin Staff, Blood Collector Admin/Staff, Blood Storage Admin/Staff, and Blood Requester Admin/Staff.
Organization Registration	Approval & Allow blood collectors, blood storage facilities, and blood requester organizations to register and undergo approval or rejection by system administrators.
Blood Collector Management	Tracks blood units by blood type, component, status, expiry date, and storage location, including inter-facility stock movements.
Blood Request Management	Enables blood requester organizations to submit, prioritize, track, cancel, and manage blood requests through structured approval workflows.
Emergency Prioritization	Routing & Supports urgent and emergency requests using geo-enabled routing to identify the nearest suitable blood storage facility.
Notification Management	Sends automated notifications for registrations, approvals, requests, dispatches, and system events via email or system alerts.

D. Non-functional requirements

The quality attributes established through non-functional requirements ensure the secure, reliable, and efficient operation of the Nationwide Centralized Blood Bank System (NCBBS) at the national level. Such requirements revolve around such important areas as data security, data privacy, system performance, scalability, availability, and usability. Since health and donor data are sensitive, the Personal Data Protection Act [?] of Sri Lanka is strictly enforced through encryption, access controls, and audit logging. The system must also be highly available and responsive to support simultaneous users in all Requestors, blood collectors, and storage facilities around the country. Besides, the platform must be scalable and serviceable to accommodate eventual growth, higher transaction volumes, and the incorporation of subsequent analytics or decision-support capabilities. Table 3 shows the requirement type and description for non-functional requirements.

TABLE III
NON-FUNCTIONAL REQUIREMENTS

Requirement Type	Description
Security	Implements AES encryption, role-based access control, and audit logs.
Performance	Supports real-time data processing with minimal latency under peak loads.
Compliance	Adheres to Sri Lanka's Personal Data Protection Act [?].
Usability	Provides an intuitive, user-friendly interface for all stakeholder groups.
Scalability	Accommodates growing numbers of Requestors, donors, and inventories nationwide.
Maintainability	Designed for easy updates, patches, and integration with new technologies.

IV. SYSTEM ARCHITECTURE AND DESIGN

The Nationwide Centralized Blood Bank System (NCBBS) high-level architecture is based on a multi-tier, layered design in which layers are independent and coexist to establish a secure, safe national platform. This construction methodology accepts scalability, maintainability, and a clear separation of concerns between system components. The Presentation Layer will provide web portals (by role) to the major stakeholders, including administrators, blood collectors, blood storage staff, and blood requestors (Requestors). The user interfaces of both portals are tailored, and access to system functions is controlled so that users have access only to features relevant to their responsibilities. The Business Logic Layer is the component of the system that handles the system's primary functional aspects, including workflows, donor registration, health screening, laboratory tests, blood collection, blood storage procedures, request processing, approvals, and status management. This layer implements business policies and operational rules to ensure consistency and correctness in the execution of blood donation and distribution processes. The Data Management Layer oversees centralized data storage, secure data access, backup and recovery, and data integrity. It provides consistent management of donor records, blood unit data, requests, and transaction logs to facilitate real-time system operations. The Security Layer implements the standards of the Personal Data Protection Act [?] of Sri Lanka by using authentication software, role-based access control, encryption of confidential data, and audit logging. These layers, when combined, create a robust, secure, and scalable architecture that can support national blood bank operations. Figure 2 shows a High-Level System Architecture Diagram.

A. Layered architecture

1) Presentation layer

The Presentation Layer is the main user interface of the Nationwide Centralized Blood Bank System (NCBBS) and the first point of contact for all system stakeholders. It can be accessed with standard web browsers and offers role-based portal interfaces tailored to each user group's operational needs. The system has four portals: the Admin Portal, Blood Collector Portal, Blood Storage Portal, and Blood Requester Portal. Each portal will be responsive, so it can be accessed on desktop, tablet, and mobile devices. The Blood Collector Portal is an application that allows administrators and employees of the blood collector organization to record donors, conduct health screenings and laboratory tests, register donations, and formulate blood units. It also enables collectors to handle donor deferrals, view assigned blood storage facilities, and track collection activities using dashboards. The Blood Requester Portal will be targeted at Requestor administrators and staff to allow them to set regular and urgent blood orders, set priorities, request required blood components and quantities, and monitor request status in real time. The portal will aid Requestors to plan their transfusion requirements and act promptly in emergency cases. The Blood Storage Portal allows blood storage administrators and storage staff to process received blood units, update the storage Blood Collector, track expiry dates, accept or reject

Requestors' requests, and ship the blood units. Real-time Blood Collector visibility helps maximize stock use and minimize blood waste. The Admin Portal offers system-wide management features that enable administrators to control users, blood collectors, blood storage facilities, blood requesters, and contact records. It also provides access to audit logs and an analytical dashboard to facilitate operational monitoring, compliance, and policy-level decision-making. On the whole, the Presentation Layer provides rigorous role-based access control and implements usability features such as structured input and validation systems to minimize human error, ensuring a safe, reliable, and user-friendly system experience.

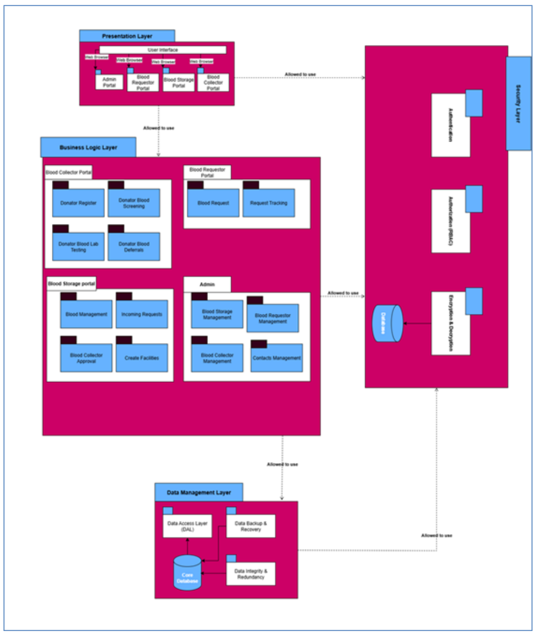

Fig. 2 *High-level system architecture diagram*

2) Business logic layer

The Business Logic Layer consists of the core functional component of the Nationwide Centralized Blood Bank System (NCBBS), which interacts with user requests, system logic, and the implementation of business policies. This layer converts the Presentation Layer's requests into system operations, ensuring a coordinated, controlled collection of blood, blood storage, and request execution across the entire system. It has been organized into four main functional modules: Blood Collector, Blood Requester, Blood Storage, and Admin. The Blood Collector Module handles all operational activities related to donors, including donor registration, health screening, laboratory testing, donor deferrals, donation records, and the creation of blood units. Automating these workflows helps the system reduce manual processing, improve data accuracy, and ensure donor eligibility requirements are met. The Blood Requester Module streamlines Requestors' work for blood requests. It allows one to generate, rank, place, and cancel blood requests. The requests are checked with the available Blood Collector and processed in accordance with established priority rules, supporting both everyday and urgent transfusion requirements. The Blood Storage Module ensures real-time records of blood collectors, handles incoming blood units collected by collectors, records expiry dates, handles Requestors' orders, issues allocations, refuses allocations, and dispatches blood units. This module is used to maximize the use of stocks, minimize wastage, and enhance redistribution in storage plants. The Admin Module provides system-wide administrative features, including user administration, blood collector administration, blood storage site administration, blood requester administration, and contact administration. It also enhances audit log monitoring and reporting capabilities, ensuring accountability, operational controls, and regulatory compliance. Generally, the Business Logic Layer replaces scattered, manual coordination with computerized, rule-based workflows that adhere to uniform policies for donor management, Blood Collector management, and request handling. This provides a fair, timely, and correct distribution of blood and makes the systems reliable and transparent in their operations.

3) Data management layer

The Data Management Layer of the Nationwide Centralized Blood Bank System (NCBBS) is responsible for securely storing, effectively retrieving, and ensuring the long-term reliability of system data. It is built as a scalable, multi-tier data management system that facilitates the operation of nationwide blood banks in Sri Lanka. The system consolidates formatted data on donors, blood collectors, blood storage centers, blood requesters, blood units, requests, and transactions in a relational SQL database. The design enables real-time access to data to support timely blood collection, storage, and fulfillment of requests. A Data Access Layer (DAL) serves as the interface between the Business Logic Layer and the database, providing secure, role-based controls over data access and authorization for various user groups. Automated periodic database backups will ensure the system is resilient against data loss from system failures or hardware malfunctions. Moreover, the mechanisms of data integrity and redundancy -e.g., enforcement of referential integrity and controlled data replication- are applied to avoid inconsistency and replication of data at distributed blood storage centers. In general, this layer will ensure the soundness, accessibility, and expansiveness of data and provide a foundation for the future integration of analytical and epidemiological tools to support national public health planning and decision-making.

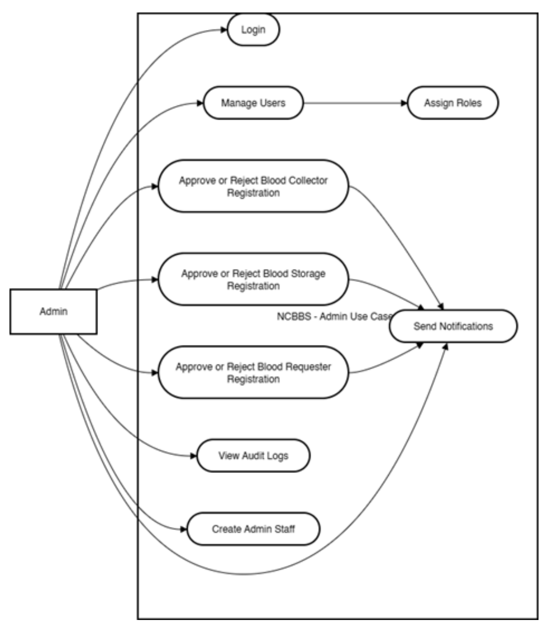

Fig. 3 *Admin use case diagram*

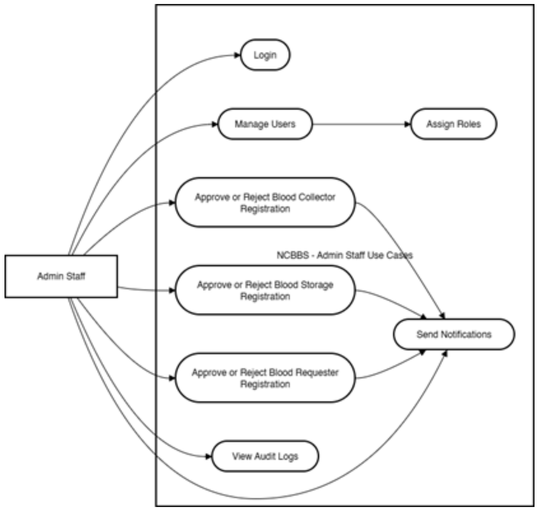

Fig. 4 *Admin Staff Use Case Diagram*

4) Admin staff use case

The Admin Staff Use Case figure 4 depicts how the System Administrator assigns responsibility for executing administrative duties to the admin staff, which affects the day-to-day operations of the NCBBS (Nationwide Centralized Blood Bank System). Through their login, the admin staff has limited but specifically defined access to administrative functions needed to maintain ongoing operations; however, they still report directly to the System Administrator for all actions taken. To manage system access of authorized organizations and personnel, the administrators (through the admin role) must create users and assign them a role(s). The admins have a controlling role in approving or rejecting blood collecting organization registration requests, blood storage facility registration requests, and blood requester organization registration requests based on the registration information submitted by applicants.

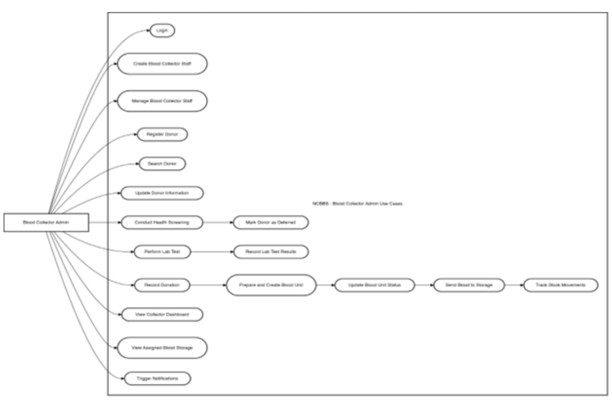

Fig. 5 *Blood collector admin use case diagram*

5) Blood collector admin use case

Figure 5 of the Blood Collector Admin Use Case outlines the duties assigned to the blood collector administrator at the NCBBS. When logged in to the system, they have full access to all aspects of blood collection operations, including oversight of the staff involved. They also create and manage staff accounts so that only authorised employees perform the blood collection function.

The Administrator of Blood Collectors manages tasks within the donor collection process, including registering donors, searching for and/or updating donor information, and conducting health screenings. Based on the results of the health screening, an individual may be deferred from donating blood due to safety or compliance issues. Laboratory activities include lab testing, recording lab test results, and clearing a donor for donating blood. A Laboratory Supervisor will then apply the laboratory results to determine whether that individual is eligible to donate blood. After approving a donation, the blood collector administrator logs the donation in their database, sets up and creates blood units, updates their status, and manages the distribution of the blood to the appropriate storage sites. The movements of the stock are tracked, allowing for transparency and traceability of the blood supply chain. The blood collector administrator can also monitor dashboards and check the status of their assigned blood storage locations. By performing these tasks, the blood collector administrator supports the safe, compliant, and efficient operation of the national blood collection system.

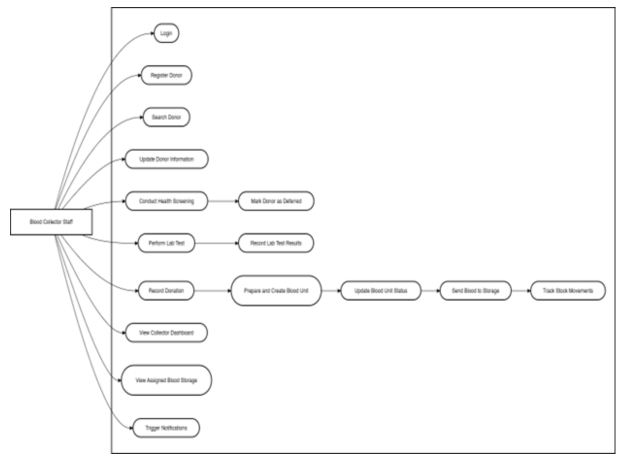

Fig. 6 *Blood collector staff use case diagram*

6) Blood collector staff use case

Figure 6 of the Blood Collector Staff Use Case illustrates the roles and functions performed by staff of the Blood Collection Department when interacting with the National Centralized Blood Bank System (NCBBS). After logging in, Blood Collection staff perform routine blood collection activities under the guidance of the Blood Collection Administrator. Blood collector employees are responsible for entering donor information into the computer system, maintaining up-to-date records of all donors, performing all required health screenings on potential blood donors, and amending donor records based on the results of those screenings. The blood collector employees are also responsible for performing laboratory tests and accurately recording their results as part of blood donor eligibility verification. Once a donation has been approved, staff members will document pertinent details about the donor's donation, generate and prepare the donated blood units, update the status of each unit, and coordinate with the assigned blood storage facility for the transfer of each unit. Blood collection stock movements will be tracked to ensure full transparency and traceability of all blood products throughout the blood supply chain. Staff members also have access to the collector dashboard, where they can view information regarding the facilities to which they are assigned and receive notifications from the system regarding activities related to collection/distribution. The blood collector staff's responsibilities are to support safe, efficient, and compliant blood collection operations nationwide.

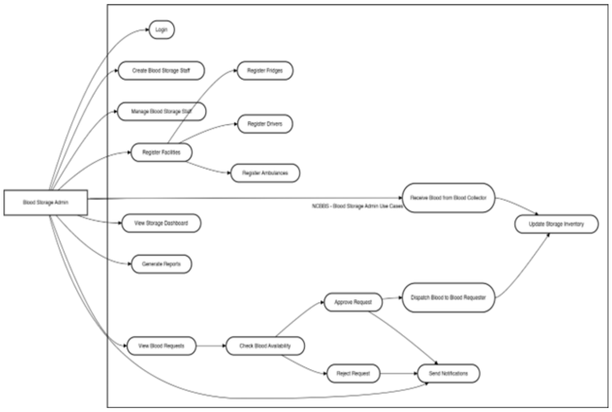

Fig. 7 *Blood storage admin use case diagram*

7) Blood storage admin

A blood storage administrator's responsibilities within the NCBBS (Nationwide Centralized Blood Bank System) are represented in this Blood Storage Admin Use Case in Figure 7. Once the blood storage administrator logs in to the system, they will be responsible for overseeing operations, facilities, and personnel who handle and distribute blood clusters. The blood storage administrator will establish blood storage staff accounts and supervise them for custody confirmation. Blood storage administrators are also tasked with creating and maintaining records and databases of blood storage facilities (refrigerators, ambulances, and drivers) used to maintain secure blood storage conditions and to facilitate the safe and timely transportation of blood. The blood storage administrator will also manage the blood storage dashboard, enabling them to track current Blood Collector status, storage capacity, and operational activity.

The blood management administrator is responsible for processing blood requests submitted by blood requesters; this includes reviewing incoming requests, checking the system to determine whether blood is readily available for dispatch, and approving or rejecting requests based on stock availability and patient eligibility. Once a blood request is approved, blood will be dispatched from the administrator's facility to your requesting organization, and the appropriate storage record will be updated. The blood management administrator is also responsible for tracking the return of blood from blood collectors to the blood storage facility by receiving units from them and updating the Blood Collector records for both incoming and outgoing units. The Blood Storage Administrator is responsible for managing operational reports and, through these responsibilities, creates an environment of efficient Management of Blood Products; Compliance with Federal Regulations on their storage; full traceability of Blood Products from the collection site to the patient at the time of transfusion; and the ability to effectively manage distributed Blood Products throughout the National Blood Supply Chain.

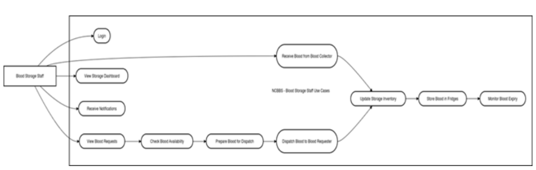

Fig. 8 *Blood storage staff use case diagram*

8) Blood storage staff use case

In the Blood Storage Staff Use Case in figure 8, illustrate how Blood Storage Staff perform their day-to-day functions in the Nationwide Centralized Blood Bank System (NCBBS) by logging into the system and completing daily storage and shipping tasks as directed by the Blood Storage Administrator. In general, Blood Storage employees obtain blood from Blood Collection Locations and submit it to the Blood Donor Timestamp System as an item in the Blood Collector list. Blood Storage is responsible for storing blood in designated Blood Storage refrigerators, monitoring each item's use-by date, and maintaining appropriate conditions to ensure the blood's quality and safety. Using the Blood Storage Dashboard application, Blood Storage employees can track current blood collection and receive system notifications about blood expected to arrive or dispatch requirements based on expiration status. Blood storage personnel help fulfill hospitals' blood requests by processing incoming requests, verifying blood availability, preparing blood units for transport, and delivering blood to requesting organizations. All logistics associated with blood dispatch are reflected in Blood Collector logs, including Blood Collector updates, to preserve accurate blood stock status and traceability. Blood storage personnel also play a key role in providing hospitals with blood when needed, minimizing blood loss due to waste, and providing for secure and efficient distribution of blood throughout the country.

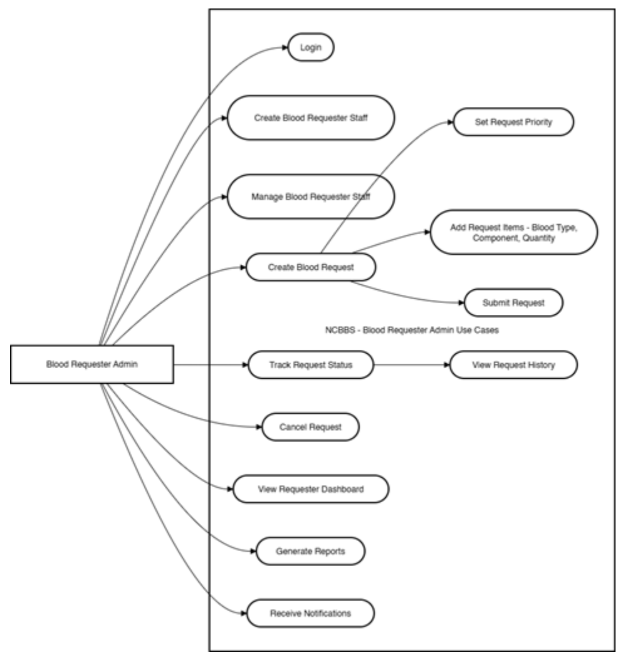

Fig. 9 *Blood requester admin use case diagram*

9) Blood requester admin use case

In the Blood Requester Admin Use Case, as shown in Figure 9, the duties an administrator is responsible for in the National Centralized Blood Bank System (NCBBS) are shown graphically. Once an administrator logs in, they are responsible for the operation of all blood requests for Requestors and for managing the personnel who coordinate blood transfusions. An administrator with blood request permissions will create and supervise the accounts of personnel responsible for blood requests, enabling authorized staff to submit them. Another responsibility of the administrator is creating blood requests, during which the administrator will enter information for each request, including the type of blood needed, the component type(s) needed, the requested quantity, and the request's urgency level (priority). The submitted requests will be processed and fulfilled through the automated system. Requestors can monitor the status of their requests in the request dashboard in real time and view historical information for each request. Requestors may also cancel or withdraw their requests at any time through the requester dashboard. The requestors' dashboard provides the administrator with visibility into all active and completed elements of any combination of requests, enabling him/her to effectively coordinate and plan blood requests. Requestors can generate and receive notification reports for request updates, notice of completed blood orders, changes to fulfilled blood orders, etc., via the administrator's dashboard. The administrator is responsible for managing blood orders in a timely, accurate, and priority-based manner to ensure patients receive their blood when needed.

10) Blood requester staff use case

Figure 10 in the Blood Requester Staff Use Case shows the key functions of the blood requester staff within the Nationwide Centralized Blood Bank System (NCBBS). After logging in to the NCBBS, the blood requester staff assist with daily blood-requesting activities in conjunction with their supervisor (the Blood Requester Administrator). Blood Requestor Staff are tasked with making blood donation requests from Donors, specifying blood types, components, & qty's needed, as well as setting request priority levels (e.g., Clinical Priority). Once the blood requests are made, they will be able to see real-time status updates, review request history, and cancel donations at the time of the request if necessary. Therefore, staff will be better able to coordinate transfusion needs & respond timely to patient needs.

On the blood requester dashboard, blood requester personnel can view both active and closed requests and receive email alerts whenever their requests are approved, shipped, or rejected. Performing this activity allows blood requester personnel to facilitate proper request management, promote faster emergency response times, and help maximize the effective use of available blood products in the National Blood Supply Chain.

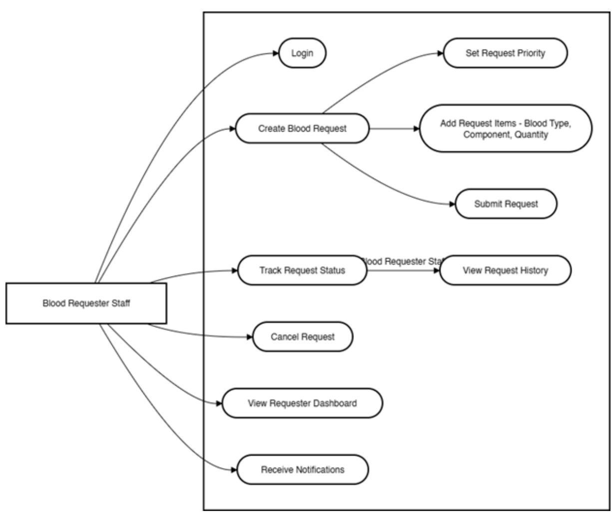

Fig. 10 *Blood requestor staff use case diagram*

V. SECURITY AND COMPLIANCE FRAMEWORK

The Security Layer oversees safeguarding confidential health information in the Nationwide Centralized Blood Bank System (NCBBS) by providing data confidentiality, integrity, and availability throughout the system lifecycle. Under the Personal Data Protection Act [?] of Sri Lanka, information relating to blood donors and patients is categorized as highly sensitive and requires the application of formidable, all-inclusive security measures across all system components. Access control is implemented using Role-Based Access Control (RBAC) to enforce authentication and authorization, ensuring that each user has only the functions and data access specific to their assigned roles. In addition, a multi-factor authentication system and a session management system provide further protection, helping reduce the risk of unauthorized access and the abuse of inactive sessions. To protect sensitive information, data is encrypted at rest and in transit. The system deploys the Advanced Encryption Standard (AES) to ensure the security of data storage, and applies the Secure Sockets Layer (SSL)/TLS protocols to ensure the safety of data transfer across networks. These actions will ensure that personal and operational information is not collected and revealed without approval. In addition, intrusion prevention and incident management mechanisms are combined to detect and trace unusual behavior or unauthorized access attempts within the system. The existence of predetermined procedures for responding to a security incident reduces response time and thereby increases the likelihood of a timely response. Overall, the Security Layer will ensure regulatory compliance, build greater trust among citizens, and provide a secure foundation for efficient and stable blood bank operations nationwide.

VI. DISCUSSION

A. Centralized architecture vs. fragmented systems: Why centralized architecture is preferable to fragmented systems

Centralized architecture for nationwide healthcare information systems tends to offer significant operational, administrative, and strategic benefits compared to fragmented, decentralized systems. Within the framework of managing a blood bank, fragmented systems are usually homogeneous in that each Requestor, blood collector, and storage facility has its own database, manual records, and communication channels that are not coordinated. The result of such structural separation includes data inconsistencies, slow information sharing, duplication, and partial real-time access to blood inventories across regions. These waste issues eventually result in shortages in certain regions and waste in others, thereby impacting patient outcomes and contributing to preventable deaths. By centralizing the architecture, these structural constraints are removed, as all stakeholders are incorporated into a single digital ecosystem. With centralized data management, donor records, blood unit stock, and request status can be updated in real time. Such visibility is an added advantage, as it helps equalize blood supply: an excess stock in one area can be distributed to another that is short. Centralized platforms replace informal networks and telephone calls in inter-hospital communication within fragmented systems, where request routing and approval processes rely on predefined priority rules and availability checks.

Fragmentation is always cited in literature as one of the greatest impediments to efficiency. [?] highlighted that fragmented MIS structures in Pakistan led to unreliable reporting and poor decision-making. On the same note, [?] noted that mobile-based donor applications that were not integrated with hospital systems lacked up-to-date registries and a well-coordinated system. Although numerous regional web-based solutions are increasing local workflow automation (Shravani and Raghavendra, 2022; [?], their lack of scalability at the national level highlights the drawbacks of local approaches. Conversely, central systems allow standardization of operations, data formats, and compliance systems. Through centralized audit logging and role-based access control, regulatory compliance, including trading under the Personal Data Protection Act [?], can be regularly monitored across all organization participants. Moreover, centralized forms of governance minimize ambiguity in policy enforcement and accountability. The practice of more mature systems, such as the Blood Net in Australia, demonstrates that national integration enhances transparency and robust inventory management. Thus, centralized architecture is not a simple choice of technique but an organizational requirement for the country's healthcare work. It unites the activities of isolated institutions into an organized national structure, eliminates operational redundancies, increases data accuracy, and enhances responsiveness to crises. Centralized architecture offers greater efficiency, transparency, scalability, and policy alignment than disconnected systems operating in silos.

B. How agile methodology supports healthcare systems

The healthcare setting is dynamic by nature, marked by evolving clinical guidelines, regulatory changes, emergency situations, and changing user needs. Most traditional linear approaches to development do not respond to these constant changes, resulting in a rigid system that is either obsolete or no longer within operational parameters. On the contrary, the Agile System Development Life Cycle (SDLC) can assist healthcare systems by enabling flexibility, incremental development, and continuous stakeholder engagement. Agile methodology focuses on development cycles conducted in iterations called sprints, in which functional modules are created, tested, and improved in small incremental stages. The strategy is especially applicable to healthcare systems like the Nationwide Centralized Blood Bank System (NCBBS), where various stakeholders like administrators, blood collectors, storage facilities, and Requestors engage in complicated workflows. By creating donor management, inventory tracking, and request processing modules in a series of steps, system functionality can be tested early and enhanced gradually based on actual user feedback. The literature emphasizes that many blood bank system prototypes have not been thoroughly evaluated or scalable due to insufficient testing (Shravani and Raghavendra, 2022; [?]. Agile addresses this weakness by integrating testing into the development cycle rather than delaying validation until the project is complete. The ongoing integration and user acceptance testing also minimize defects and improve the usability and alignment with the operational workflows. [?] have also noted that extensive healthcare enterprise systems require adaptive governance and contextual portfolios that are closely aligned with the iterative principles of Agile.

In addition, the healthcare laws and information protection provisions often change. Agile enables developers to address regulatory changes immediately, such as those related to PDPA compliance, encryption, and audit reporting. Rather than overhauling the entire system, modular updates can be integrated into later sprints without the architecture experiencing any hitches. Agile is also better at creating trust and adoption. Healthcare staff play a very active role in shaping their system through regular demonstrations, prototype trials, and joint planning. Such a participatory development method reduces change resistance and fosters greater user acceptance, which is vital in healthcare environments where operational continuity and safety are the primary considerations. So, Agile methodology assists healthcare systems by enabling responsiveness, minimizing implementation risks, enhancing quality assurance, and encouraging collaboration among stakeholders. Agile approaches to complex healthcare projects at a national scale ensure that the system is adaptive, secure, and aligned with operational and regulatory needs.

C. Why layered architecture improves scalability

A basic feature of healthcare systems across countries is scalability, because the number of users, transaction volume, and data complexity grow steadily. Layered architecture enhances scalability by dividing system components into independent functional layers: Presentation, Business Logic, Data Management, and Security. This segregation of concerns increases extensibility, maintainability, and modularity. The architecture in a layered architecture has the responsibility of each layer. The Presentation Layer handles user interfaces and interactions; the Business Logic Layer handles workflows and policy enforcement; the Data Management Layer handles storage and retrieval; and the Security Layer handles compliance and the protection of sensitive information. Since these layers work autonomously and in harmony, alterations made in one layer do not always affect the others. Fragile or monolithic systems often combine user interface logic, data processing, and storage code into a single structure. This kind of tight coupling is restrictive to scalability, since an increase in system capacity would require reorganizing the entire application. Layered systems, in contrast, can be scaled horizontally. However, for example, database servers can be scaled independently to support more donor records or transaction logs without changing user interface modules. Equally, more application servers may be implemented to support increased processing requests during emergencies in a country. The literature indicates that numerous regional systems lacked scalability planning. According to [?], rural connectivity and policy gaps were identified as challenges for scaling IoT-based solutions nationally. According to Ben Elmir et al. (2023), predictive analytics systems need robust data ecosystems and infrastructure to be scaled effectively.

These results show that scalability is not possible without a structured architectural design to support future expansion. Predictive analytics, machine learning modules, and decision-support dashboards are other advanced functionalities that are also easily integrated through the layered architecture. By introducing a forecasting algorithm into the Business Logic Layer but not the Presentation Layer, incremental innovation would be possible. This plug-and-play flexibility aligns with the long-term sustainability goals of national healthcare systems. Also, a layered design increases system security and compliance. The security measures can be implemented at a specific layer, with encryption, authentication, and audit logging remaining uniform across all modules. This concentration of enforcement minimizes vulnerabilities and eases compliance controls. So, layered architecture enhances scalability by enabling modular growth, reducing system interdependence, supporting infrastructure growth, and facilitating integration with emerging technologies. Layered design offers a stable yet flexible structure backbone for nationwide healthcare systems, where long-term sustainability and adaptability are critical.

D. Comparison with gaps Found in literature

In the literature reviewed, a similar divide can be observed between localized prototype systems and fully integrated national platforms. A large number of studies demonstrate the technological feasibility of solutions through mobile applications, web-based portals, IoT integration, and predictive models. Nonetheless, most implementations are small-scale, partial, or confined to pilot settings. To begin with, there is the issue of replicated interoperability. Some of them are independent and not integrated into national health databases or hospital inventory systems [?]. This disintegration limits real-time coordination and hinders fair resource reallocation. Second, there are still scalability and governance issues. Despite the potential of cloud-based and IoT-enabled platforms, infrastructural barriers and the absence of well-coordinated national policies are obstacles to widespread implementation [?, ?, ?]. Technology is not a solution to nationwide consistency without a centrally governed government. Third, predictive analytics models are still mostly theoretical or locally tested. Although optimization and machine learning methods demonstrate their effectiveness in reducing waste and shortages (Niakan et al., 2024; [?, ?], they are not yet implemented in national systems. This gap indicates the lack of a centralized, data-rich infrastructure needed to support AI. Fourth, large-scale systems are not always standardized to security frameworks. Encryption mechanisms were demonstrated by Agarwal et al. (2020), but their practical implementation at the interoperability level has not been achieved in the country.

The Nationwide Centralized Blood Bank System is a proposed centralized, Agile-developed, and layered system that directly addresses these literature gaps. The system addresses fragmentation, improves interoperability, facilitates regulatory compliance, and provides a foundation for predictive analytics integration by unifying stakeholders through a centralized architecture, adopting an Agile development approach, and enabling scalable layers. To sum up, although past studies have provided an essential technological building block, there is still a clear need for a nationwide framework that integrates architectural centralization, Agile adaptability, and scalability within a secure governance framework. The identified research gap aligns with the proposed system, which offers a methodological approach to the efficient, equitable, and sustainable management of blood donation and distribution at the national level.

VII. CONCLUSION

The proposed system is of immense importance to Sri Lanka's healthcare system. Better healthcare delivery within the system will also ensure that, when patients require a transfusion, the process can be initiated promptly, as clinicians and administrators can track blood stocks in real time, preventing unnecessary deaths in emergencies. Wastage minimization, where centralized monitoring will ensure that expired blood is not wasted by returning it to centers that need it, helping reduce nationwide shortages and maximizing a country's resources. Recording donor deferrals and rejections in their entirety generates epidemiological data on the prevalence of health issues, including anemia, hypertension, and infectious diseases. This will support the Ministry of Health's preventive health planning. Enhanced trust and compliance with the [?] will increase public confidence in digital health systems, attract more donors, and enable long-term implementation in line with global best practices. Centralized checking will help prevent the wastage of expired blood by redistributing it to centers that need it, helping cut down on shortages, and maximizing the country's resources.

The Nationwide Centralized Blood Bank System will not only be a social innovation that directly benefits citizens, but will also be a non-profit-making center. One such social business positive contribution is Non-Profit Orientation, in which the system is set to be financed and supported by the Sri Lankan Ministry of Health and NBTS to ensure its sustainability through public health budgets and not commercial models. The investments will be reinvested in upgrades, training, and the expansion of the system, in line with the principles of social business. Second, the system reduces inequities between urban and rural Requestors by centralizing coordination and ensuring equity and access. The same timely resources reach out to patients in underserved areas as they do to those in urban centers. Thirdly, sustainability and SDGs in which the system will directly progress: SDG 3 (Good Health and Well-being) through minimizing preventable mortality, SDG 9 (Industry, Innovation, and Infrastructure) through the implementation of a national health information infrastructure, and SDG 16 (Peace, Justice and Strong Institutions) through enhancing transparency, accountability, and efficiency in the public health systems. And the last indirect socio-economic value. The system saves the healthcare industry money by reducing emergency expenses and blood waste, and makes the system more efficient. It also provides decision-makers with real-time information to improve allocation decisions, thereby indirectly supporting the economy. A suggested digital, centralized, and secure platform will address these issues by providing real-time visibility, enabling donor management, improving data security, and enhancing emergency response. Social innovation and sustainability are significant contributions to the project. Besides its direct impact on healthcare, the project also aligns with national priorities and the broader development of the world. In conclusion, it is a technological, humanitarian, and social business technology, designed to save lives, optimize the utilization of healthcare resources, and place Sri Lanka at the forefront of the world as an example of blood transfusion with digital services.