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# A Blockchain-Based Blood Donation System: Enhancing Transparency, Accountability, and Sustainability in Healthcare

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**Abstract:** The increasing global population has led to a corresponding rise in the demand for blood in healthcare settings, necessitating the development of efficient and transparent blood management systems. The process of blood donation and transfusion is critical to public health and patient well-being, requiring robust systems to ensure safety, reliability, and traceability. This study proposes a blockchain-based blood donation system designed to enhance transparency, accountability, and privacy in both the donation and transfusion processes. Blockchain technology, with its inherent capabilities for secure and decentralized record-keeping, offers a solution to the challenges of maintaining confidentiality, particularly in relation to the sensitive personal information of both donors and recipients. The adoption of blockchain also facilitates a more sustainable approach to blood donation management, promoting the optimization of resources and reduction of waste, which contributes to environmental sustainability in the healthcare sector. The integration of blockchain within blood donation processes is expected to not only improve operational transparency but also support the broader goals of sustainability by reducing carbon footprints associated with resource management and logistics. This study outlines the design of such a system, highlighting its potential benefits in terms of improving system reliability, protecting sensitive data, and enhancing the sustainability of healthcare operations.

**Keywords:** Blockchain technology; Blood donation system; Transparency; Accountability; Sustainability; Healthcare; Privacy and confidentiality

## 1. Introduction

Blood is the fluid responsible for transporting oxygen, nutrients, and antibodies to tissues while removing carbon dioxide and waste products from the body. Blood plays a vital role in sustaining life, and its deficiency can lead to significant health issues. Globally, there are challenges related to the supply of blood. Some of these challenges include the insufficient number of blood donors in many countries and inadequate oversight during the storage, testing, and transportation of blood. Blood, which is critical for treating many diseases, often fails to meet demand, particularly in developing countries, resulting in an imbalance between supply and demand. Similarly, Turkey also faces difficulties in ensuring an adequate blood supply. During crises, such as pandemics and earthquakes, the available blood stocks in the country are often insufficient. Raising awareness to encourage regular blood donations and increasing the number of donors are important steps toward overcoming these challenges, but they are not enough. The lack of transparency and reliability in current blood donation systems underpins the issues related to traceability and monitoring of blood.

Blood donation holds immense importance not only for human health but also for environmental sustainability. A more environmentally friendly and efficient blood donation system is expected to contribute to reducing carbon footprints, improving resource management, and minimizing waste. According to data from the Turkish Red Crescent, 1,373,168 units of blood were donated in the first half of 2024. While this figure is expected to meet a significant portion of Turkey's blood needs, issues related to the management of donated blood continue to perpetuate the problem. The deterioration and disposal of blood due to delays in delivery, improper storage conditions, or negligence represent a major issue in blood management. Such inefficiencies harm the sustainability of the healthcare sector and lead to blood wastage exceeding acceptable levels.

The use of blockchain technology in blood donation systems is aimed at enhancing traceability and contributing to environmental sustainability. Blockchain is a decentralized database system managed by multiple participants. It functions as a digital ledger where transactions are sequentially recorded, distinguishing it from traditional databases. Blockchain utilizes distributed ledger technology, allowing for faster transactions without requiring centralized approval. The fundamental features of blockchain technology, such as distributed ledger technology, immutability, and smart contracts, enable enhanced transparency and traceability of data. In this context, all transactions are systematically recorded on the blockchain, making them accessible to all participants within the system. The entire process following a blood donation can be tracked, as each transaction is executed sequentially and accompanied by a timestamp. These core features of blockchain technology play a critical role in ensuring transparency and traceability within the blood donation system.

By utilizing a distributed ledger, transactions are recorded in a decentralized manner, eliminating the need for central authorization. And blockchain's immutability feature significantly reduces the risk of data manipulation or tampering. The integration of smart contracts further optimizes the process by automating transactions, thereby guaranteeing error-free execution. Furthermore, the addition of timestamps to each transaction enables real-time monitoring of all stages in the process, facilitating the review of past transactions in a structured and chronological manner. Consequently, the combination of blockchain's distributed ledger, immutability, and smart contract functionalities ensures a transparent, reliable, and traceable blood donation system.

This study proposes the design of a more reliable and transparent system for blood donation by taking advantage of these features of the blockchain, aiming to minimize problems in the management of donated blood and improve sustainability in the health sector.

## 2. Related Work

In the field of blockchain, Haber & Stornetta (1991) first proposed a cryptographic method for securely storing data in 1991. In the 1990s and early 2000s, research in blockchain technology stalled or failed to achieve success. However, Nakamoto (2008) introduced the Bitcoin system, which significantly enhanced the interest in blockchain technology. Initially, blockchain was used in the cryptocurrency domain. After Bitcoin, many other cryptocurrency platforms emerged. As blockchain proved successful in the cryptocurrency field, its potential for application in other areas was explored. Ethereum is the most widely used platform for blockchain-based smart contracts (Buterin, 2013). The next step in the development of blockchain was the introduction of decentralized applications (DApps), which offer significant advantages in terms of time and transparency. These benefits have led to blockchain research in various fields, including healthcare systems, aviation, and supply chains.

Blockchain has numerous applications across different domains. For instance, blockchain-based electronic voting systems using smart contracts ensure voter privacy while also reducing election costs (Hjálmarsson et al., 2018). In pharmacies, blockchain is used for tracking medications, which contributes to protecting patient rights and improving the pharmaceutical industry (Pashkov & Soloviov, 2019). In the healthcare sector, blockchain technology plays a key role in ensuring transparency and security in organ donation processes (Dajim et al., 2019). Beyond healthcare, blockchain is also being researched in areas, such as supply chains (Dujak & Sajter, 2019), Internet of Things (IoT) network management (Yavari et al., 2020), food safety (Xu et al., 2022), reward programs (Srivastava et al., 2019) and money transfers (Sood & Simon, 2019).

A significant challenge in healthcare is the increasing volume of personal health data and ensuring its security. The use of blockchain technology can help manage and secure data, leading to significant improvements in the healthcare sector. There is significant research on the use of blockchain in blood donation, which is an important aspect of healthcare.

In 2021, a blood donation system based on the InterPlanetary File System (IPFS) protocol was created, where each participant on the blockchain network was assigned both a private and a public key. A digital signature was used with the private key to execute transactions, while the public key was used to verify the transaction. After the key operations, a consensus algorithm ensured the security of the network by having other nodes and validators verify the transactions. One of the key issues in blockchain-based projects is user data privacy. In a study by Sadri et al. (2021), the necessary authorizations were implemented based on the Ethereum network, where specific nodes had specific rights to access particular data.

In 2024, a blockchain-based system was proposed in a report to eliminate inefficiencies in the blood supply chain. This system incorporates reward-based incentives, hospital operations, and transaction traceability. Designed as a web application with a front end built with React and a back end using Ethereum, the system aims to improve blood management and meet healthcare sector demands in Saudi Arabia (Aljuhani et al., 2024). Malhotra et al. (2024) conducted research on the benefits of blockchain technology in the blood donation process, focusing on scalability, privacy, interoperability, and transparency. While their work provides valuable insights, the study does not elaborate on the specific technologies used or the details of the method. Mulkallapalli et al. (2024) implemented QR code authentication to ensure that the blood reaches the patient. In this system, donor records, blood information, and user identities are securely stored, providing full transparency in contrast to traditional systems.

A key focus of this study is blockchain technology, but sustainability is also an important aspect. In addition to studies on blood donation, there are significant research efforts on the impact of blood donation on sustainability. The concept of sustainability stems from the Brundtland Report of 1987, which emphasizes the limited nature of natural resources and the need for their balanced use for future generations. Efforts to ensure sustainability are being made in nearly every field, including healthcare. Ouhbi et al. (2015) assessed the greening potential of blood donation practices based on individual, environmental, and technical sustainability criteria. This study identified the key factors affecting sustainability in blood donation applications.

Alghamdi (2023) discussed the importance of selecting the right blood distribution method for a sustainable blood donation process. By examining various distribution methods globally, it was concluded that using drones for blood transportation would be more cost-effective compared to traditional systems and would lead to less blood wastage. Reducing costs and minimizing blood waste are two crucial factors for environmental sustainability. James et al. (2024) examined factors affecting sustainability in blood production in Uganda. Blood processing and blood storage management were identified as two key factors influencing sustainability, while the blood collection factor was found to have little impact on sustainability.

Several studies have also focused on the contribution of blockchain technology to sustainability. Mulligan et al. (2024) explored the effects of blockchain on sustainability across three key areas: energy systems, supply chains, and smart cities. The study presents a wide literature review of blockchain projects in various countries and their impact on sustainability. Dal Mas et al. (2023) investigated sustainability in the food sector, highlighting the significant advantage of blockchain technology in digitizing food supply chains. It was also found that blockchain's transparency, security, and traceability features are encouraging for sustainable business models. Alzoubi & Mishra (2023) compared cryptocurrency platforms to identify environmentally friendly options. The study discusses the effects of energy consumption and carbon dioxide emissions on 23 blockchain platforms.

While many studies have been conducted on sustainability and blockchain technology, there is limited research on the impact of blockchain-based blood donation systems on sustainability. This study aims to fill this gap in the literature. The existing literature emphasizes the use of blockchain technology in blood donation systems to enhance transparency and security within the healthcare sector. In addition to these benefits, blockchain technology offers other advantages. This study aims to not only ensure transparency and security in the healthcare sector but also to increase the efficient use of resources. Unlike other studies, this research discusses how the implementation of blockchain technology in the blood donation process can reduce the carbon footprint and contribute to a more sustainable process. Another aspect addressed in this study is the increased demand for blood during crises and how a blockchain-based system can provide a solution during such periods. Therefore, this study approaches blockchain technology, which is recognized for its transparency and security, from the perspective of sustainability—an important issue for future generations. One of the primary objectives of this study is to fill the gap in the literature regarding the impact of a blockchain-based blood donation system on sustainability.

## 3. Blockchain Technology

Blockchain is defined as an advanced database that enables the transparent and secure storage of information in digital environments. Utilizing distributed ledger technology facilitates the execution of transactions in a decentralized and faster manner, independent of a central authority. Blockchain technology gained global attention following the publication of the study by Nakamoto (2008). Although the concept of blockchain was not explicitly mentioned in that study, it introduced Bitcoin, a secure digital currency operating without central oversight. The Bitcoin system records data using robust encryption techniques and achieves immutability by distributing this data to all users.

Blockchain is composed of blocks, and each block contains the encrypted code of the preceding block. Figure 1 illustrates the relationship between the blocks within the blockchain.

In this database, which is formed by data blocks, each block is linked to the next by including the hash value of the preceding block. In blockchain technology, central authority is eliminated, and transactions are decentralized. In this system, data added to the network is recorded not by a single central entity but by all participants in the network, enabling all users to monitor the process. If any modification is attempted in the data chain, all participants in the system are notified. In a distributed network structure, transactions are executed without requiring the approval of one or more central authorities.

Transactions performed on a blockchain cannot be altered or deleted; instead, they are distributed among the participants in the system. If an error occurs during a transaction, it is corrected through a new transaction, and all activities, including erroneous ones, remain visible in the system. This inherent structure of blockchain fosters trust among its users.

Blockchain first emerged in the field of cryptocurrencies and, even today, remains the most widely used in this domain. This period is referred to as the Blockchain 1.0 era. The Blockchain 2.0 era marks the introduction of smart contracts, a technology that enables the creation of agreements in a secure environment without central oversight. Smart contracts created using blockchain technology provide a secure and transparent alternative to traditional contracts. The Blockchain 3.0 era refers to the period when DApps became feasible through blockchain technology. These applications offer a platform to enhance reliability and expedite processes across various industries. Blockchain aims to eliminate centralized control.

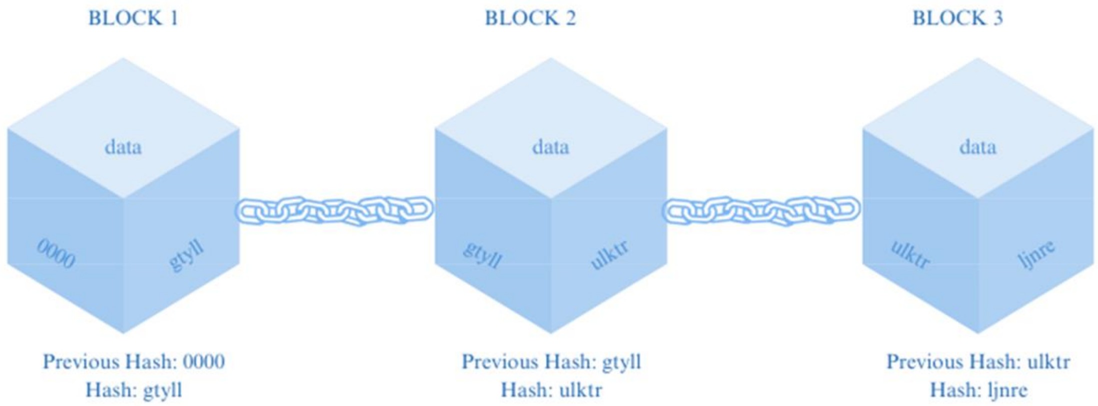


**Figure 1.** Relationship and hash structure of blocks in the blockchain

The Blockchain 4.0 era focuses on ensuring security by incorporating the automation, planning, and integration of information systems. This phase addresses the practical and sectoral demands for blockchain technology, providing solutions for its broader application. It is anticipated that this era will lead to significant industrial advancements. The most beneficial applications of this technology can be observed in financial services, supply chain management, IoT-based data collection, healthcare management, and asset management. This period brings blockchain technology closer to real-world applicability.

Blockchain technology is generally divided into two categories: permissioned blockchain and permissionless blockchain. In a permissioned blockchain, the network administrator controls who can participate in the blockchain network and what data they can view. In contrast, a permissionless blockchain allows transactions to be conducted publicly and openly.

### 3.1 Cryptography

Blockchain technology has gained attention for its ability to ensure both transparency and the security of data. One of the fundamental components of this secure and decentralized technology is encryption techniques. Understanding the cryptographic methods used in blockchain networks has become essential.

Cryptography is a technical process aimed at protecting data. It ensures the security of transactions occurring between two nodes in a blockchain. One of the strongest features of blockchain technology is its use of cryptographic techniques. By converting data into random-appearing, reversible data based on specific rules, it aims to protect the confidentiality of sensitive information even in the event of unauthorized access. Only individuals with the appropriate key can restore the data to a meaningful form. The replication of data across extensive networks in blockchain demonstrates the importance of encryption in maintaining data security and integrity.

Cryptography relies on the following two fundamental technologies:

a) Symmetric encryption

In symmetric encryption, a single key is used for both encryption and decryption processes. While this method requires less computational power and enables faster transfers, the shared use of a single key by both sender and receiver compromises security.

b) Asymmetric encryption

Asymmetric encryption uses two distinct keys for the encryption and decryption processes: a public key and a private key. The public key is responsible for encryption, while the private key handles decryption.

An important cryptographic term in blockchain is the hash function. It ensures the immutability and security of blockchain data by protecting it. Signing blocks with their hash values is crucial for upholding the principle of immutability in blockchain. Instead of using encryption keys, hash functions generate a fixed-length value using a hash algorithm. Regardless of the input data length, the hash value is of a predetermined length, and it is nearly impossible to reconstruct the original data from the hash value.

The linking of blocks using their hash values preserves data integrity. Any change to a block alters its hash value, disrupting the subsequent blocks in the chain. As a result, no modifications can be made to the created blocks. The most commonly used hash algorithm is SHA-256. The Secure Hash Algorithm (SHA) is designed to perform cryptographic hash functions, and SHA-256 was introduced in 2001 as part of the SHA family to address security vulnerabilities. This algorithm, used to generate hash values, forms the foundation of blockchain technology. SHA-256's high-security performance makes it suitable for applications where data privacy is critical.

### 3.2 Consensus Algorithms

Consensus algorithms are software protocols that determine key characteristics of blockchain. Various consensus algorithms are used in blockchain, each with its own advantages and disadvantages. Consensus algorithms should be evaluated based on their security and efficiency. These algorithms are what ensure the security of decentralized blockchain networks. As they operate in a fully automated manner, consensus algorithms must be designed logically and flawlessly to maintain the integrity of the blockchain.

Some consensus algorithms prioritize security, while others focus on efficiency and speed. The choice of algorithm depends on the application area and the relative importance of speed versus data security. Examples of consensus algorithms include Proof of Work (PoW), Proof of Stake (PoS), Delegated PoS (DPoS), Byzantine Fault Tolerance (BFT), Proof of Authority (PoA), and Proof of History (PoH).

### 3.3 Sustainability

Sustainability is the principle of using natural, economic, and social resources in a balanced manner to ensure that future generations can also meet their needs with these resources. The issue of sustainability has been a subject of debate across various fields for many years, and in the last century, it has been addressed by researchers and environmental protection advocates as a critical problem for future generations.

Historically, the first practical application of sustainability was seen in the replanting of trees to prevent deforestation caused by tree cutting. However, scientifically, sustainability discussions traced back to the study by Malthus (2007) in the late 18th century, in which scarcity and poverty were connected to the limited nature of natural resources and population growth. This study laid the foundation for sustainability debates. While this topic has been periodically discussed across different fields, the negative environmental impacts of industrialization gained attention after World War II.

In the 20th century, many conferences began to address environmental issues on an international scale. The 1972 report “Limits to Growth” warned about the depletion of limited natural resources due to population growth and economic expansion (Meadows et al., 1972). The modern definition of sustainability appears in the "Our Common Future" report, prepared by WCED (1987). According to the report, “Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987).

In the 21st century, numerous studies and conferences have been held on sustainability. The United Nations has set development goals and initiated sustainability-focused projects. In 2015, the United Nations declared a sustainable development plan consisting of 17 goals, which are considered a significant step towards achieving sustainability (Cf, 2015).

Today, individuals and organizations in every field view sustainability as an essential issue and continue their work with this problem in mind. Renewable energy sources and environmentally friendly technologies are key focal points in sustainability efforts. As in every sector, sustainability in healthcare is equally vital. In this field, the goal is to reduce environmental and economic costs. Managing medical waste, using renewable energy sources in healthcare, reducing carbon emissions, and utilizing eco-friendly materials are considered critical steps in contributing to sustainability.

To achieve sustainability goals in the healthcare sector, the use of innovative technologies is crucial. This study proposes the use of blockchain technology in the critical area of blood supply in healthcare. Blockchain technology represents a significant step in advancing sustainability within the sector.

## 4. Methodology

The blockchain-based blood donation system manages the entire process from collecting blood from donors to its transfusion to patients. The detailed flow of this process is illustrated in Figure 2.

The donated blood is transported to blood banks for storage. When needed, blood is delivered from the blood bank to hospitals upon their request. The proposed system aims to perform these steps in a more innovative, transparent, and reliable manner.

The system consists of two distinct parts: blood donation and transfusion. The blood donation section manages the processes of collecting blood from donors and storing it under optimal conditions at blood storage facilities. The second part, blood supply, involves selecting the most suitable blood for the patient and requesting it from the blood bank. Once the request is approved by the blood bank, the delivery process can commence.

This blockchain-based system operates on two primary smart contracts: one for blood donation and another for blood transfusion. The smart contract for blood donation records data related to blood collection, separation, testing, labeling, and storage. Meanwhile, the smart contract for blood transfusion stores data regarding blood requests, dispatches, and transportation details. The distributed ledger and smart contracts are illustrated in Figure 3.

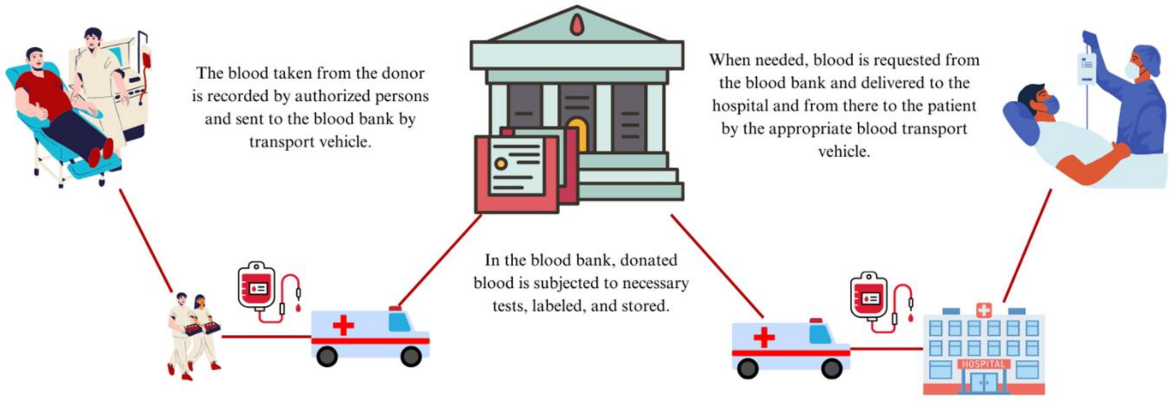


**Figure 2.** Blood transfusion process

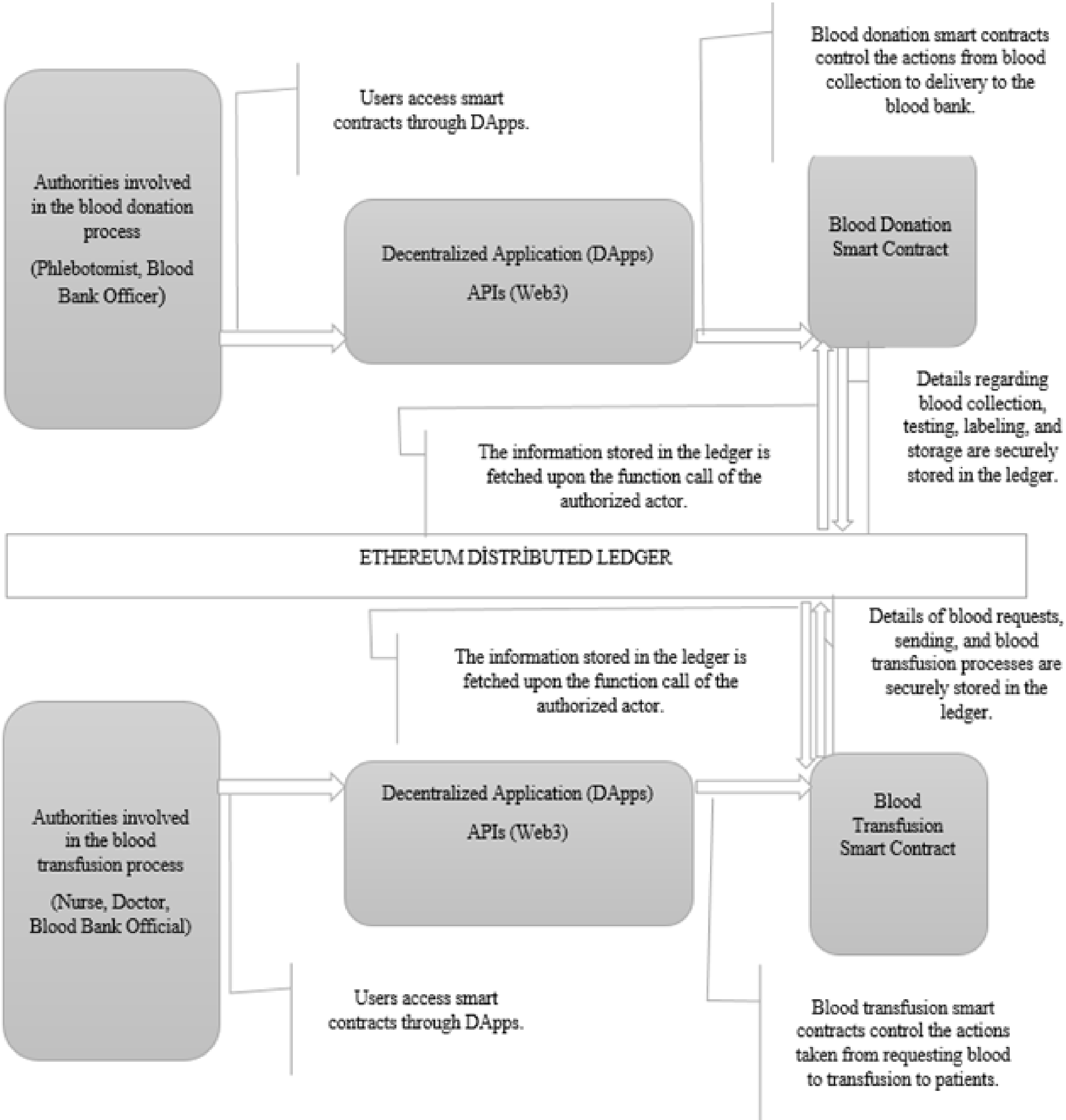


**Figure 3.** Smart contracts and transactions in the blockchain-based electronic blood donation system

The proposed system utilizes the Ethereum network. Ethereum is an open-source, public blockchain network with smart contract functionality. It serves as a decentralized ledger used to validate and record transactions. The Ethereum network is primarily known for its ability to enhance privacy. Since the proposed blood management system involves certain sensitive information, access to this data must be restricted to specific individuals and institutions. The Ethereum network's ability to provide the necessary privacy and authorization makes it the key factor in its selection for this study. Other reasons for choosing the Ethereum network include the following:

a) The Ethereum network offers a highly suitable infrastructure for smart contracts. Thanks to smart contracts, which are essential for this study, transactions can be executed automatically.

b) Ethereum is open-source and continually open to development. It has a broad ecosystem and can be easily applied to different projects across various sectors.

c) It features a robust security mechanism. The large number of nodes reduces the risk of network attacks.

d) The Ethereum network offers advantages in terms of integration. Once the proposed system is implemented, it must integrate with other applications in the healthcare sector. At this point, Ethereum can provide a significant advantage.

e) With Ethereum's PoS mechanism, transactions can occur more quickly, while transaction costs can be lower.

Since the Ethereum network is designed to enhance privacy, it is the most reliable network for this study. In this system, authorization is used to ensure that only individuals with the proper credentials can access the blockchain. Since the blood management system contains sensitive patient and donor information, only authorized persons and institutions should be able to access this data.

This system uses the smart contract of the Ethereum network. Smart contracts are digital agreements stored on the blockchain that are automatically executed when predefined conditions are met. The blockchain-based blood donation system is built upon smart contracts. By ensuring that transactions are executed automatically, smart contracts can prevent manipulation of the blood donation process according to predefined rules.

The interface through which users interact with the blockchain is provided via DApps. DApps are open-source software applications. A combination of a smart contract and a front-end user interface built on a decentralized network results in DApps. DApps use smart contracts to authorize transactions and link them to the blockchain. They transfer incoming data to the blockchain and trigger the execution of smart contracts. The communication between the DApps and the blockchain is facilitated by the Web3 Application Programming Interface (API), allowing users to perform transactions on the blockchain. All operations, such as invoking smart contracts, sending, signing, or querying transactions, are carried out through this API.

The technological infrastructure of this system is based on smart contracts. These smart contracts were created using Solidity, a high-level programming language. The code was written and compiled in Visual Studio Code, an environment compatible with Solidity’s compilation. The Truffle framework was used to test the system. Truffle was also utilized for the development, testing, deployment, and management of smart contracts. Finally, MetaMask, a browser extension, was used to interact with Ethereum via the web browser. MetaMask is a browser extension used to connect to blockchain networks and perform Ethereum transactions.

The creation of smart contracts is the most crucial stage of the blockchain-based blood donation system. Each transaction in the blood donation process is meticulously planned to create corresponding smart contracts. Testing and security analysis of the created smart contracts are vital to ensure the reliability of the system. Smart contract testing was performed using the Ganache test network. Ganache is a virtual Ethereum network that works in integration with the Truffle framework. It plays a critical role in testing smart contracts and ensuring that the system operates flawlessly. Testing transactions on this virtual network before they are executed on the actual network facilitates a faster development process. Since transactions were conducted on a virtual network during testing, no transaction costs were incurred. Due to these advantages, tests were initially conducted on the Ganache test network.

The Oyente test tool is an important analysis tool that works directly with the Ethereum Virtual Machine (EVM) bytecode to detect security vulnerabilities in smart contracts. Oyente was also used to conduct security analysis for this study. With this tool, security vulnerabilities in the system can be detected in advance, ensuring the safe operation of the smart contracts. Penetration testing was conducted to simulate cyber-attacks on the system. These tests help identify potential security vulnerabilities, allowing for preventive measures to be planned. Through comprehensive testing, the blockchain-based blood donation system can be ensured to function securely and without errors.

The system built using the Ethereum network includes two smart contracts. The smart contract for blood donation stores data related to blood collection, separation, testing, labeling, and storage, while the contract for blood transfusion stores data related to blood requests, delivery, and the transportation of blood. In this part of the proposed system, various employees are assigned different levels of access. The phlebotomist should record the date, donor identification, the blood's condition, and the identity of the healthcare worker collecting the blood. Once this information is recorded, the person responsible for transporting the blood from the donation point to the blood bank can be identified. After these details are captured, the tracking of the blood can be possible. The next step involves the delivery of the blood to the blood bank. The blood bank employee is responsible for registering the delivery, the blood's final condition, the identity of the healthcare worker receiving the blood, the transporter's details, and the date of receipt in the system. Access through authorization is restricted so that only personnel from the relevant unit can perform these actions, which is crucial for system security.

In the second phase, when blood is required, the process of preparing the blood and transporting it to the hospital can be defined. The system logs the blood's condition when it leaves the blood bank, the destination hospital details, the transporter's information, and the date. The blood is handed over to the transporter, and the entire transport process is transparently monitored in the system. When the blood arrives at the hospital, the hospital staff can receive the blood and register the information about the compatible patient and the blood's condition in the system. After the blood is transfused to the patient, the hospital staff can also update the patient's condition in the system.

These operations are carried out through algorithms written into the smart contracts. The algorithms are as follows:

- *donatedBlood()*: This operation handles the process of collecting blood from the donor and registering the donor's information into the system.
- *transferredToBloodBank()*: This operation ensures the tracking of blood as it is transported to the blood bank via a carrier vehicle.
- *storedBlood()*: This algorithm is responsible for the storage of blood in the blood bank and allows for monitoring its status once it has been stored.
- *requestedBlood()*: This operation manages the request for blood made by a hospital, including defining the quantity and type of blood required.
- *approvedBlood()*: This operation handles the process where the blood bank approves the requested blood and sends it to the hospital through a carrier vehicle.
- *transferredToHospital()*: This algorithm tracks the journey of the blood from the blood bank to the hospital, ensuring that the transfer process is monitored until it reaches its destination.
- *transfusedBlood()*: This operation manages the final step, where the blood, once it reaches the hospital, is administered to the patient.

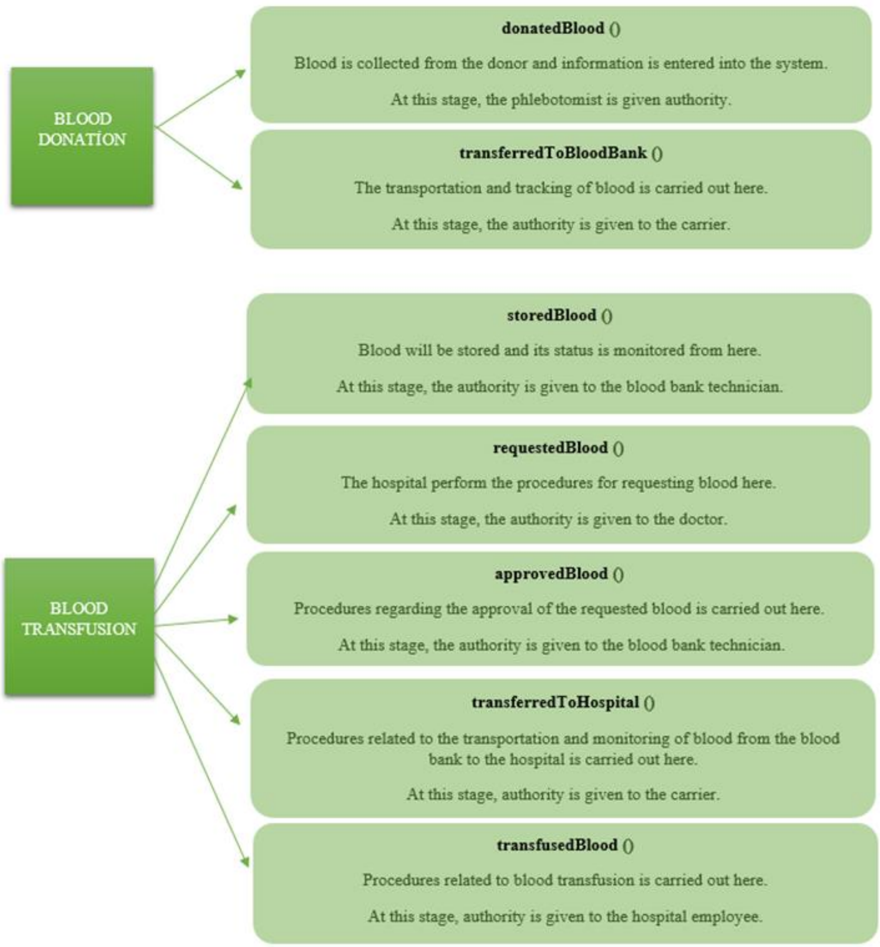


**Figure 4.** Defining smart contract algorithms and authorization processes

As shown in Figure 4, there are two smart contracts, within which the authorization algorithms are implemented. This section outlines the general principles of the system's operation, the technologies used, and the structure of the smart contracts.

## 5. Discussion

The operational framework of the proposed blockchain-based blood donation system has been explained above. The blockchain-based blood donation system offers an advantageous approach in terms of transparency, security, and traceability. A comparison between the blockchain-based blood donation system and an existing system is presented in Table 1.

**Table 1.** Comparison of the proposed system and an existing system

| | Existing System | Blockchain-based Blood Donation System |
|---|---|---|
| **Transparency** | Information about the blood donation process is often not given to the user or is not informed simultaneously. This causes the system to be non-transparent. | The steps of the blood donation process are defined in the system simultaneously and users in the system are able to access this information transparently. |
| **Donation History** | Donors can view their previous donations through this system. However, information about whether the donated blood has been used or not is not transparently provided to the user. | Donors are able to see their past donations in this system. There is also information about whether the blood they donated has been used or not. |
| **Tracking Donated Blood** | Donated blood can be tracked with a barcode system. This tracking includes more general information rather than all the stages the blood goes through. | The stages that the donated blood goes through are defined through the system and enable the user to follow up. |
| **Urgent Need for Blood** | In case of urgent blood need, donors are informed and directed to the nearest donation point. | In case of urgent blood need, storage centers can be quickly checked and an urgent blood need warning is placed in the system. |
| **Past Health Information** | The donor's past health information is recorded by filling out a form. This situation causes the use of paper to continue. | The donor's past health information is digitally recorded in the system, thus reducing the carbon footprint. |
| **Informing the User** | Information about who receives blood donations is often not shared. In addition, the donation reminder system may not work regularly. | Full information is provided on whether the donated blood has been used or not. Information about the donated patient may be shared upon the patient's request. |
| **Personal Data Security** | There are concerns about data security because the organization doesn't provide sufficient information about how personal data is protected. | Personal data is protected by using the data privacy infrastructure of blockchain technology. |
| **Integration with Other Health Institutions** | There is no integration with alternative blood donation channels or private hospitals. | This system aims to increase communication with different health institutions and to establish national cooperation in blood donation. |

Another important topic of this study is to ensure sustainability in the healthcare sector through the proposed system. This system has significant environmental, economic, and social sustainability impacts:

a) Full digitalization: This technology enables complete digitalization, minimizing paper usage. As a result, the carbon footprint can be reduced, and the number of trees in forests can be preserved or even increased.

b) Efficient blood distribution: Blood can be delivered to necessary healthcare facilities more effectively and quickly, reducing energy consumption.

c) Minimized waste: By better managing the blood donation process, the amount of wasted blood can be significantly reduced.

d) Enhanced transparency: The transparent tracking of the blood donation process can prevent fraud in the sector, fostering trust between donors and the system. This trust can increase the number of donors and allow donated blood to be used more efficiently.

e) Crisis management: During emergencies, blood needs can be quickly identified, and required blood units can be effectively distributed.

Blockchain-based blood donation systems contribute significantly to sustainability by optimizing resource utilization, preventing waste, and improving logistics processes.

The blockchain-based blood donation system offers significant advantages beyond sustainability as well:

a) Data security: Blockchain technology plays a crucial role in protecting sensitive health data, such as patient information, by ensuring that records are immutable and securely stored.

b) Real-time monitoring: Due to its transparent structure, users can track the stages blood undergoes from donor to recipient in real time.

c) Efficient matching: The system facilitates the rapid matching of donated blood with the most suitable patient, accelerating the process.

d) Fraud prevention: Recording and verifying all transactions related to blood donation can prevent fraudulent donations and incorrect data entries.

e) İnternational collaboration: Blockchain simplifies data sharing among healthcare systems across different countries, enabling international cooperation.

Despite its numerous advantages, blockchain-based blood donation systems also have some challenges. These challenges can be addressed with solutions as follows:

a) High energy consumption: Blockchain technology, particularly the PoW algorithm, can lead to high energy consumption, potentially conflicting with environmental sustainability. To address this, a more eco-friendly consensus algorithm, such as PoS, can be adopted for this system.

b) Integration costs: Integrating this technology into the existing systems of healthcare institutions may initially be costly.

c) Adaptation of personnel and donors: Healthcare personnel and donors must adapt to this new system. Educational and awareness programs can resolve this issue.

d) Legal adaptation: Countries need to adapt legally to this technology. Regulatory frameworks can facilitate technological advancements in the healthcare sector.

Blockchain-based blood donation systems have both advantages and disadvantages. However, as a new technology, blockchain holds a significant place in sustainability, especially with its increasing applications in the healthcare sector and beyond. With continued research and development, it is poised to contribute substantially to various industries.

## 6. Conclusion

The blockchain-based blood donation system holds a critical position due to its transparency, reliability, and traceability. By leveraging blockchain technology, the proposed system enhances auditability and ensures that authorized personnel operate with greater discipline. Additionally, the privacy features inherent in blockchain technology guarantee the protection of users' data during the blood donation process.

By fully digitalizing the blood donation process, this system minimizes paper consumption, thereby reducing the carbon footprint. Implementing blockchain technology in blood donation facilitates balanced resource utilization, minimizes waste, and improves logistical processes. These advancements make the system invaluable in enhancing environmental sustainability within the healthcare sector.

Despite the numerous advantages offered by this technology, several practical challenges persist. For instance, the high energy consumption associated with certain consensus algorithms, such as PoW, could negatively impact environmental sustainability. However, adopting more environmentally friendly algorithms and tailoring them to this system's requirements can mitigate such issues.

Future technological advancements are expected to enable the broader application of this system, further enhancing its potential to revolutionize the healthcare sector and contribute to sustainable development.

## Data Availability

The data used to support the research findings are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare no conflict of interest.

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