

Toward a Design of Blood Donation Management by Blockchain Technologies

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Abstract. Nowadays, due to rapid changes in the population structure, which results in lower fertility rates and rapid aging, the demand for blood supply is increasing a lot. In most countries, blood quality and origin are managed by blood management information systems, such as national institutions. However, the existing system lacks limitations in that it lacked detailed blood information, which causes difficulties in managing blood quality, supply, and demand. Therefore, to solve this problem, this paper proposes an innovative system that supports managing the blood information, providing more detailed blood information such as blood consumption and disposal. A blockchain is currently a standard tool implemented in research, especially in supply chain management such as the medical field or financial system. Notably, private blockchain techniques with limited participants are relatively fast and reliable, making them suitable for B2B (Business-to-Business) transactions. Therefore, the proposed system is based on the architecture of Hyperledger Fabric. Moreover, the recorded information in blockchain technology will support dealing with the supply and demand of blood in the national institutions so that it is easier for national institutions to solve emergencies.

Keywords: Blood donation management · Blockchain · Hyperledger fabric · Blood quality · Information visibility

1 Introduction

Blockchain technology and distributed ledgers are gaining massive attention and are the main factor triggering multiple projects and research worldwide [12,13]. On top of that, healthcare is seen as a significant industry and a primary user

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of using the blockchain concept. This is not only because the most well-known application of this technology is the cryptocurrency Bitcoin, but sustainable process inefficiencies also drive it, and a massive cost base issue specifically in this industry [25]. On top of this industry, blood directly linked to human life is extremely vital because of the specificity of the storage, supply condition, origin, and blood quality. Globally, blood is banned from commercial distribution, and indeed, due to the complexity of blood management, building a blood supply chain system is extraordinarily vital and necessary. It is even more of a problem for the healthcare industry if the blood donator and blood receiver do not know anything about the quality and origin of blood they will give and take.

Consequently, the problem of clarifying all detailed information about blood donations in a supply chain system for every participant is already becoming a critical aspect of healthcare services. WHO (World Health Organization), which pays attention to this problem, already has a specific definition of a blood cold chain management system. It is referred to as a system that stores and transports blood at precise temperatures and conditions, from donors to the final transfusion site [10]. This system focuses on emphasizing the collection sites, storing sites, and distribution sites of the blood. However, none of the papers has investigated applying Blockchain technologies in finding blood origin and accessing the blood quality. In many countries, the blood donation system has been established due to its scarcity of blood resources for patients.

Nevertheless, few countries have a sound blood supply chain management system. In Korea, the Korean Red Cross Blood Service Headquarters, which contains fifteen blood banks, three blood inspections is established in 1958 [4]. This system is operated to collect, store, and distribute the blood only and has not well-evaluated blood quality and origin. Blockchain technologies are today's right solution for providing helpful information to blood ownership, hospital, and recipients. Blockchain performs the transparency and privacy of each involved party along the blood donation supply chain. Blockchain technologies promise to resolve the critical aspects in the healthcare industry, which have not been investigated before, representing "a shift from trusting people to trusting math," which plays an essential role in the evolution of the blood donation system.

In the current blood management system, there are two significant problems. Firstly, the flow of information from blood collection sites to consumption or disposal is not clear. Since blood donors are willing to give their blood for the lofty purposes of saving human life, they are perplexed about the information that their blood is ultimately used for medical purposes. In a centralized blood management system, it is tough to pinpoint the cause of blood disposal in many medical institutions. Therefore, how to improve the blood quality in some resources is becoming a challenging problem.

Moreover, some donors do not know about their health situation, which is represented in blood quality. If they have infectious diseases but do not know, it becomes a severe problem for both blood donors and receivers. Thus, having information transparency in the blood management system is becoming mandatory for the involved party to know their health better and receivers will feel guar-

anteed about the blood source. Secondly, since some hospital under centralized blood supply system has not controlled the supply and demand of blood types, the unbalanced between the supply and demand of blood types and the poor management of blood also causes unclear reasons for blood disposal. Moreover, the lack of necessary blood types in emergencies is hazardous to the patients' lives, so it is essential to have a platform that helps improve the blood management system and reduce the differences between supply and demand.

Therefore, this paper proposed blockchain-based blood donation management and provided a critical understanding for readers about how the process works. In the blood donation process with preliminary information about blood origin and quality, complex storage, and transportation conditions, the blockchain technologies can generate traceability by storing all information in the platform. Everyone has their private rights to access the system and sees the necessary information. Existing blood management system reports only information about the amount of blood collection but lacks information about the demand of patients; Blockchain will clarify the specific management problems that can deal with suddenly increased needs of particular blood types in a region or medical institutions in an area emergencies. By using a blockchain-based health care system, not only the involved party receives beneficiary for improving their health, but it also stabilizes blood supply and demand even in extraordinary situations.

2 Related Work

2.1 Blood Supply Chain Management System

Supply chain management integrates core business processes and information. The process goes through many steps, including customers and retailers, and wholesalers, manufacturers, and suppliers, which add value to customers and other stakeholders [18]. The system incorporates a highly complex process that requires synchronization of various activities resulting in randomness and supply chain risk [20,26]. Regarding the blood supply chain system, Nagurney et al. [24] proposed a model to minimize cost and risk by representing the decay characteristics of blood as an arc multiplier. Armaghan and Pazani [3] suggested a blood supply chain to handle urgent requests from blood units in the earthquake. It is a multi-level, multi-objective model to minimize the cost of blood supply chain networks and maximize the reliability of the selected routes for blood transportation. Eskandari-Khanghahi et al. [11] developed a supply model incorporating mixed-integer linear programming that simultaneously considers location, allocation, inventory, and delivery. Delen et al. [7] sought to support the decision-making process in the blood supply chain using both a geographic information system and data mining techniques. The blood supply chain can store and distribute blood. Still, it is also a vital issue to pay attention to regarding the medical field, especially to a patient's life. Thus, designing a system to improve information sharing in a blood supply chain is very mandatory and vital. Finding a better method by using blockchain technology to cope with urgent demand and tracking blood origin, and accessing blood quality is worth researching.

2.2 Application of Blockchain Technologies to Supply Chain Management

Blockchain is a state sharing and consensus-building technique that fulfills transaction record retention and synchronization of distributed network participant systems [6]. Without having a centralized server, transaction records are recorded, shared on the distributed ledger, and is organized into blocks when a new transaction is generated. According to blockchain structure, it is classified into three main types: public, private, and consortium with base technologies, including Bitcoin Core, Ethereum, Hyperledger Fabric, etc. Hyperledger Fabric is a Linux Foundation project that was launched with 17 member companies in December 2015. It is an open-source distributed ledger platform design for developing permission applications enterprise-grade. Fabric provides a platform to build fast, efficient, and secure enterprise blockchain applications. It is characterized as being suitable with B2B transactions, and its membership services have limitations to the entry of unauthorized participants [35]. Because of having a node for verifying the transactions during transaction processing, it is possible to remove uncertain transactions early and fast. Due to these benefits, we intend to design a Hyperledger Fabric architecture-based system for managing blood quality.

The benefits of using Blockchain are expected to improve the visibility of the product supply chain and streamline work among participants through real-time tracking capability and smart contract-based characteristics. Blockchain can be used in many industries to track the origin and quality of other products. One of the Blockchain-based supply chain projects is the case of China's Walmart and IBM affiliated in 2016, aiming at guaranteeing consumers' confidence in food safety [14]. Using this blockchain technology, consumers can track the food's origin, freshness, the authenticity of its certifications, such as whether the information of the source, production sites, and distribution process is transparent or not. Another project, the Counterfeit Medicines Projects, is one of the projects in the Hyperledger Research Network, which displays the timestamp for each drug to prevent the production of counterfeit medicines [23]. Blockchain technology can be applied in various fields. It can be used to track and classify forgery, quality degradation, and theft by following drug production time and location and clarifying their origin. It can also help to improve safety and reduce costs relating to medical sectors.

On the other hand, researches on blood supply chain management have been conducted by several approaches. Blockchain application in the healthcare supply chain is not as common as others; they are considered vital. Blockchain solutions are more suitable for healthcare supply chains; however, there are not yet that using blockchain solutions for healthcare. Although researches investigated applying Blockchain in this sector is increasing, it is mainly used for data sharing and recording data, while using it for supply chain management is rare [16]. Some companies, like Imperial Logistics and FarmaTrust, use Blockchain to manage pharmaceutical supply chains [1]. Other experimental projects such as OrganTree and Dhonor Blockchain also use this technology to connect organ

donors, recipients, and practitioners by using incentives such as paying for funeral cost [2]. Several articles have investigated blood donation tracking. BloodChain and SmartBag focus on preventing contamination in the supply chain and reducing the spread of HIV in developing countries [34]. Another project, which is called BLOODCHAIN, focusing on motivating blood donors by giving monetary returns. Wust and Gervais (2018) have proposed a flow chart to emphasize the importance of Blockchain application in blood tracking origin [32]. The model is presented and discussed in the paper to see whether Blockchain should solve the problem; however, the situation has not been solved well.

2.3 Limitation of Existing Research

This study overcomes the restriction of the prevailing research and methods regarding blood information systems and blood supply chain management. The proposed approach can secure the transparency of blood information management by using real-time information recording. When focusing on this point, the system has the advantages of clarifying blood types, such as blood types, origin, quality. In terms of blood supply and demand, this system can cope with emergencies when there is a sudden increase in blood demand in a specific region. Moreover, the Blockchain is actively investigated in the supply chain and healthcare sectors. This research contributes further to the scope of investigations in the healthcare system, especially in the blood supply chain, which blockchain technologies have not yet recovered.

3 Design of the Blood Donation Management Using Blockchain

In this paper, the design of a blood donation management using Hyperledger Fabric is proposed. This system can detect various problems related to blood donation supply chains such as blood origin or quality, especially for emergency blood requests. The most crucial issue to deal with in this system is the concern with the blood quality and tries to manage the supply and demand of the blood by transactions recorded in the blockchain technology. The procedure below shows the process of how our proposed system works.

As can be seen from Fig. 1, several steps in the system are performed. After donations from the volunteers, blood will be stored at the healthcare center; these blood samples are determined based on the ID of each volunteer. This blood data is only accessible by the facility's medical staff to prevent unauthorized exploitation of information from outside individuals. The blood samples will be shipped to other medical facilities or hospitals after the test is completed. After changing the storage location, data for each blood sample will be updated with the respective medical facility. The inquiry of staff at the new medical facility is also recorded in the system to help monitor and manage better; of course, the querying of information is only done by the staff of the new medical facility. Besides, blood using data such as emergency care, blood transfusion is

also recorded to determine which patients have used blood samples donated by volunteers. In many cases, when the donated blood samples have problems or are of poor quality, recording the data also helps in better traceability of the blood so that health facilities can know which volunteers are in poor health and how much blood did they donate at which health facilities.

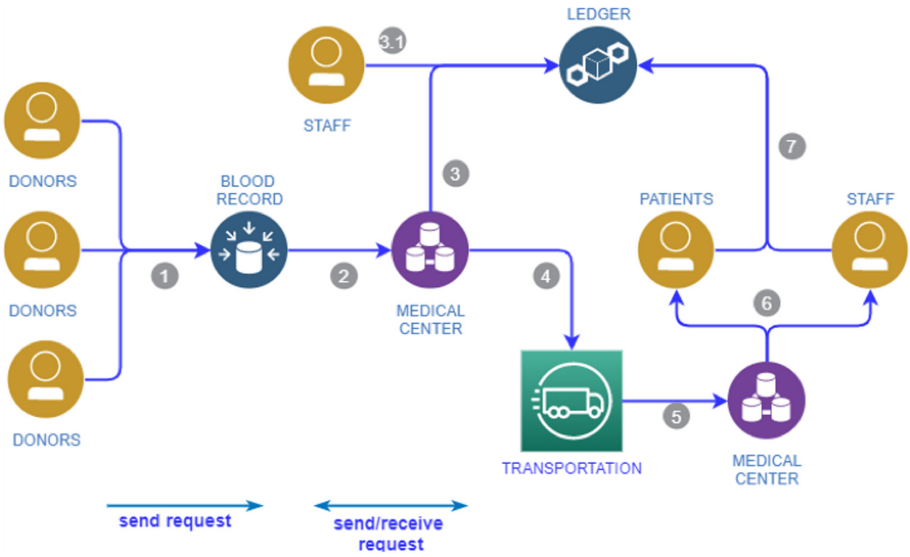

Fig. 1. Architecture of blood donation chain.

One of the important reasons to implement our proposed system in Blockchain is information visibility. Many medical institutions wherein blood transfusions are made generate data that records when the final blood is used or disposed of, which can improve blood inventorying as well as blood-demand predictability. The participant consensus algorithm of Hyperledger Fabric sequentially records transactions over time and manages information transparently so as to prevent forgery or alteration.

4 Implementation of the Blood Donation Management

In the proposed system, we have several algorithms to operate the system. The proposed method in this paper uses Hyperledger Fabric to conduct transactions. This tool, based on JavaScript, uses the blockchain network because it is suitable for a private business environment.

The participants in the blood management system are defined in the code below. There are five main participants in this system: Staff, Donors, Transporter, Medical center, and Patient. His/her corresponding ID identifies each

participant in the process. Besides, the information about the participants is also stored to support the data query and tracking purposes.

The donors who perform the blood donation are the first participants of the process. Information of this user group is collected after the blood donation procedure is completed, and it is stored together with the data of the blood sample collected from that donor. The code below describes donors' reports in detail with the information related to ID, name, age, gender, address, nationality, career, and health condition. This information is essential to evaluate blood quality.

Blood is and by a specific shelf life depending on its ingredients formulation. Therefore, the process to store blood and protect its quality is very critical in the whole process. This process is performed after completing the blood collection and donors' information storage. The blood sample data is identified by a separate ID, together with the donor's ID, so it is easier to manage the blood origin and quality. Also, it allows the user to view the number of blood assets based on donors' information. If the blood quality is recognized to have diseases that are not known when being donated, the medical institutions will inform the donors about their health quickly. Blood is and by a specific shelf life depending on its ingredient's formulation. Hence, it is necessary to continuously check the storage period and dispose of it after that period. It is the reason why we record the date and time information in the transaction. After one day in the system, the retention period of the entire blood asset is reduced by one day. The separate ID of blood types includes date and time, allowing users to see the retention period of blood donation. The blood moves according to the blood supply process for transfusion. The process to perform how to store data of blood samples is presented in the structure bellows.

```
{
  "donorID":"dn001",
  "name":"Jame Morrison",
  "age":"32",
  "gender":"female",
  "address":"Taipei",
  "nationality":"Italy",
  "career":"student",
  "healthcondition:"good"
}
```

The movement state is defined to indicate whether the blood is currently moving or within the organ. In addition, the blood ownership information is defined. Managing the blood process includes transportation, which is defined as one of the important steps in the whole process. Consequently, the information related to the shipping company is also needed to be stored in the system.

```
{
  "bloodsampleID":"bs001",
  "donorID":"dn001",
  "type":"AB",
  "date":"09/20/2020",
  "time":"11:45",
  "location":"Taipei",
  "medicalcenter":"Taipei"
}
```


As can be seen from the structure of the process to record blood sample information, the information of the delivery company is also recorded to serve the purpose of verification during the transport of blood samples. The information recorded in the system includes ID company (name of delivery company), ID delivery (name of delivery worker), name of delivery man, age, phone number, address of the delivery man. This info is structured in the process of recording transportation.


```
{
  "companyID":"company001",
  "deliveryID":"delivery001",
  "name":"deliverer001",
  "age":"30",
  "number":"12345678",
  "address":"Tainan"
}
```


The information of patient who receive donation blood is recorded in the system under the structure.


```
{
  "patientID":"volunteers001",
  "bloodsampleID":"bs001",
  "name":"John",
  "age":"20",
  "address":"Taipei",
  "medicalstatus":"status record 001"
}
```


Patient and medical personnel information is also created and stored to determine which patients have received which units of blood and determine whether healthcare staff has access to blood data. The information recorded in the system consists of six components, such as patients' ID, blood sample, name, age, address, medical status. The sample information can be seen clearly in the structure bellows.

```
{
  "staffID":"staff001",
  "name":"Jenny",
  "age":"25",
  "number":"+88 22334455",
  "gender":"female",
  "address":"Taipei",
  "workingStatus":"active"
}
```


5 Algorithms

In addition to the implementation of information is recorded in the system, several algorithms are also performed to illustrate how the system works. The system consists of two main algorithms, including Algorithms 1 (to describe the mechanism to store blood samples of donors) and Algorithms 2 (which summarizes delivering blood samples from the donation place to the medical center).

Algorithm 1 consists of five main steps. It describes the mechanism to store blood samples of donors. Blood samples, once collected, will be identified with the IDs of the respective donors. Each blood sample will have a separate ID to avoid duplication of data inside the ledger; after being donated, the blood will be stored at the medical facility. The blood samples will also be stored in the ledger.

Algorithm 1: storing blood samples of donors

1: Input: donors ID, name, age, date of birth, blood type, amount of blood unit
2: Output: data of donors and their blood is stored into ledger
3: **for** unit of blood **do**
4: storing data of donors and blood to ledger
5: **end for**

Algorithm 2 summarizes delivering blood samples from the donation place to the medical center via ten main steps. In the donation place, after storage, the blood samples will be transported to different medical facilities. Before shipping, the carrier information will be stored in the ledger to determine which company transports the blood and how many units of blood have been transported. The process's input is the data of the delivery unit, and the output of the algorithm is the data of delivery and the new medical center, which receives the blood from donors. Its corresponding ID further identifies each step.

Moreover, the authors provide the sources codes for the proof of concept, instruction of installation. Interesting readers might refer to our GitHub repository[1].

[1] https://github.com/Masquerade0127/bloody-blockchain.

Algorithm 2: transportation of blood samples from donation places to medical center

```
Input: data of delivery unit
Output: data of delivery is stored to ledger, new medical center also updated
for delivery unit do
    for blood samples do
        storing ID of blood unit with correspondence ID of delivery unit
    end for
    for blood samples do
        update location of new medical center of blood samples
    end for
end for
return Encrypted hash
```

6 Security and Privacy Discussion

The blockchain plays a vital role in the modern system; this model meets the transparency and availability requirements for the supply chain [5,19,30]. However, the blockchain-based system still has some problems that are listed in [17], especially in the security and privacy aspect. To improve the security and privacy issues in the blockchain-based blood donation system, we consider the authorization for the parties in the same transaction and the flexibility in the medical environment.

For the authorization aspect, we will exploit attribute-based access control (ABAC) [15,29] to manage the access control process. The main benefit of this model is only the authorized users can access the release data. Besides, the query rewriting can apply for the complex context where the release data can be shared to multiple users [28,33]. Finally, some approaches split the original policy into sub-policy [27,31] (i.e., public and private policy) to ensure the data is only accessed via permission even the parties in the same transaction.

For the flexibility aspect, we should embed the blood donation management system in the larger environment (e.g., medical, healthcare) were combining with the other supply chain [21,22] as well as connecting with the other smart things [8,9].

7 Conclusion

In this paper, we designed and implemented a blood donation management based on the private Blockchain technology to obtain several goals: blood secure information visibility and guarantee the blood quality for both receivers and donors. The real-time recording and sharing of information as blood is donated, classified, consumed in distributed ledgers enables efficient management of blood. The information among participants is transparent, which helps participants track the source of blood quality easily. In addition, this system, which prevents forgery and information tampering, will make the blood management operation

more transparent by solving problems that may occur in medical institutions and with medical staff, such as missing inputs of entry, exit, band errors. Besides, the system, which supports blood transactions between medical institutions, can manage blood quality. This function is beneficial for both receivers and donors because, for receivers, they feel safe when the blood quality is ensured, and for donors, they know their health situation.

At present, the use of blockchain technology in the medical field is actively discussed, but no previous relevant studies or application samples are dealing with blood origin or quality. To realize the blockchain network proposed by this paper, consideration should be given to the coordination of interests among participants in the blood chain system and the infrastructural, legal, institutional, and technical aspects.

Although this study proposes an innovative method for blood supply chain management and implementation of a prototype system, there is insufficient verification of the proposed approach. Hence, a thorough evaluation study will be performed to prove the effectiveness of the proposed scheme by integrating the proposed system with the existing blood information system. Furthermore, we will consider the proposed design's cost and network configuration and view the additional information, block size, and hacking-prevention potential required for actual hospital blood transactions.

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