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Original Article

Implementation of Trust-based Blood Donation and Transfusion System using Blockchain Technology

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Abstract *- The current solutions for managing blood are based on a centralised database management system. Even though it serves better than the manual system that was in place previously, several problems still exist, including the inability to trace blood components from their collection until consumption, lack of blood quality control and the potential for transfusion-related diseases like HIV, Hepatitis B and C, Syphilis and Malaria. Blood is scarce in some areas, while blood is wasted in other areas due to its short shelf life. The traceability and immutability of the data kept in the chain make Blockchain Technology (BCT) appropriate for blood donation and transfusion management. Numerous real-time cryptocurrency and non-crypto currency applications now use BCT. Hyperledger Fabric, a permissioned BC platform, is employed in constructing a block-chain-based Blood Donation and Transfusion Management System (BDTMS) in this research. The system users may quickly trace the blood with the established model. In addition, smart contracts have been developed to verify the accuracy of the blood data, so only the legitimate data may be kept in the blockchain. The implemented system's performance has been tested using real-time blood data obtained from a blood bank.*

Keywords *- Blockchain Technology, Blood Donation, Hyperledger Fabric, Hyperledger Caliper, Performance metrics.*

1. Introduction

Life is impossible without blood. Our blood flows throughout our body, supplying the cells with nutrients and oxygen necessary for life. Under the 1940 Drugs and Cosmetics Act (D and C Act) and the 1945 Drugs and Cosmetics Rules, blood has been classified as a "drug"[1]. As blood cannot be manufactured or created, the only option for getting blood is through blood donors who donate blood through blood banks and camps. Despite the high demand for blood, cities generally lack effective supply channels [2].

Additionally, those who receive blood for medical purposes are completely ignorant of the origin and quality of the blood they receive. To address these concerns, it is necessary to design a blood system that is open and built on trust. Hence, to assure that patients receive safe blood, nowadays, blood banks are adopting blockchain technology (BCT).

Since Satoshi Nakamoto first introduced the concept of bitcoin and its uses to the digital world, related blockchain applications have exploded in popularity across various industries. Some of them are healthcare[3][4][5],pharmacy[6], payments[7], transportation[8], agriculture[9], tourism and hospital management[10], education[33],supply chain[12][13][14],big-data management[15]. In this paper, a trust-based blood donation and transfusion system has been implemented using blockchain technology.

2. Background

2.1. Blood transfusion service in India

The blood transfusion service is a crucial component of the healthcare system. Generally, blood is collected and stored in a blood bank before being used for transfusions. Blood is collected through camps or blood collection centers. The collected blood undergoes various blood tests to check if it has any transfusion transmissible infections (TTI) such as HIV, Hepatitis B, Hepatitis C, Syphilis and Malaria [16]. TTIs are significant issues related to blood transfusion. Hence, blood should be thoroughly checked before further processing. Once blood testing is done, the blood is separated into components [35][18] such as Red Blood Cells (RBC), Fresh Frozen Plasma (FFP), and platelets. And finally, the blood component is transfused to recipients after cross-matching with the patient's and donor's blood. Below, Fig. 1 explains the various stages of blood donation and transfusion system.

Fig. 1 Steps involved in Blood Donation and Transfusion System

The National Blood Transfusion Council (NBTC), founded in 1996 [19], is the federal organisation managing and directing the Blood Transfusion Service in India. The NBTC is entrusted with evaluating the state of the blood transfusion services and carrying out yearly quality checks in blood banks along with the State Blood Transfusion Councils (SBTCs). The technical bodies NBTC and National AIDS Control Organization (NACO) are entrusted with developing rules to guarantee safe blood transfusion, providing infrastructure to blood centers, developing human resources, and developing and implementing the blood policy in India.

2.2. Blockchain Technology

By eliminating the need for a third party to validate transactions, distributed ledger technology like blockchain gives transactions more security. Blockchain technology combines several technologies, including distributed networks, cryptography, etc. Blockchain keeps track of all transactions or digital occurrences in chronologically ordered blocks [20]. The hash function is used to securely link blocks together in chain format. Blockchain uses a peer-to-peer [21] network to store data and transactions in the ledger in a decentralised manner.

One of the most well-known blockchain technologies is Bitcoin [22], a digital ledger. Users may mine, store, and exchange bitcoins on the decentralised Bitcoin network utilising a laborious computer procedure. Blockchains may be used as a register and inventory for all assets and utilised for transactions. Because of this, Blockchain technology is also used in non-cryptocurrency applications.
Blockchain can be classified[20] as

2.2.1. Permissioned blockchain (private)

Permissioned blockchain (private) also called Private Blockchain [23][32], where private ledgers are being implemented by different institutions and the system is controlled by a central authority.

2.2.2. Permission-less Blockchain (public)

Public Blockchain, where anybody can engage in the verification process without permission.

2.2.3. Hybrid Blockchain (combination of private and public)

Consortium Blockchain, where the ledger is permissioned and permissionless. For instance, sensitive data is kept in a private ledger, but highly trusted material is kept in a public ledger. Without relying on centralised governance, any stakeholder may create access restrictions to information using the two forms of ledgers.

Blockchain is a decentralised [23] storage network built to address the issues in centralised storage systems, such as trust issues, highly dependent on the network, network traffic problems etc. The following details some of the benefits [24] of utilising blockchain-based storage solutions.

- Openness & Transparency
- Distributed
- Flexible
- Consensus-based
- Secure

Some platforms used for blockchain-based applications are Hyperledger Fabric [25], Etherium and R3 Corda.

3. Related Work

In their study published in 2020, Abbas et al. [26] proposed and executed a ground-breaking machine learning and blockchain-based drug supply chain management and recommendation system. It comprises two modules: a medication supply chain module and a machine learning-based pharmaceutical recommendation module. They logged in, monitored, and tracked the medication from its manufacturing till consumption in the first module, developed with the Hyperledger Fabric tool Hyperledger Composer. The second module employed N-gram, LightGBM models to suggest the appropriate medications for a specific health issue.

Blockchain Technology has been suggested and used by Kim et al.[27] to regulate the blood cold chain. Using Hyperledger Composer, they put the prototype into practice. They have demonstrated the traceability of blood between various parties with their concept. Additionally, they have reasoned for rejecting blood if the blood temperature in storage is outside the typical range.

For their investigation, Lakshminarayanan et al. [28] studied 10 hospitals and two blood banks within a five-kilometre radius when they planned and constructed a blood donation system utilising Hyperledger Composer. The best blood is matched for a request based on blood group, location, and blood expiration date. When blood is used, the donor is informed, and if the blood is inappropriate for donation, the donor is also informed, and the blood is discarded.

Mehmet and colleagues suggested the KanCoin [34] Ethereum blockchain-based architecture in a chapter to manage and modify processes for effective distribution planning in the blood supply system from donors to distribution centers and patients at medical centers more efficiently than conventional procedures.

Le, Hai Trieu, and colleagues proposed BloodChain [2] in 2022 as an upgraded blood information management system that will provide more precise information about blood, such as blood use and disposal. For B2B (Business to Business) transactions, a private blockchain called BloodChain is being created. Performance evaluation of the system is carried out for several scenarios once it is constructed using Hyperledger Fabric.

Table 1 illustrates the detailed analysis of the existing system of blood banks using blockchain technology.

4. Motivation of the work

According to Press Information Bureau (PIB) [30], the number of licensed blood banks in India as on 27.11.2019 is 3263. The National Blood Transfusion Council (NBTC) and the National AIDS Control Organization (NACO) are the technical organisations responsible for designing and carrying out India's blood policy.

The majority of well-established organisations have web portals to interact with donors and promote blood donation camps that take place around the nation. Even while it benefits the community more, there are still several problems, such as

- Inability to track blood components from their collection to consumption.
- Lack of adequate testing for blood quality Storage of blood at a certain temperature and monitoring of the same.

Table 1. Detailed analysis of existing systems

Title of the paper	**Tools used & methodology followed**	**Merits**	**Demerits**
Implementation of a Blood Cold Chain System Using Blockchain Technology (2020) [27]	Private BCT using Hyperledger Composer, In Proposed system 1. Direct transmission of blood among hospitals without the interference of blood bank in case of emergency 2. If blood is not maintained at the proper temperature, the same will be intimated and discarded	1. Secured information visibility. 2. Proper record of blood information such as blood is moved, consumed, discarded 3. Blood transfer between hospitals without the interference of blood banks.	1. Entire blood donation functionality is not implemented. 2. Evaluation (Performance metrics) of the proposed system is not done.
Implementation of Blockchain-Based Blood Donation Framework (2020) [28]	Private BCT using Hyperledger Composer 1. A scenario with 2 blood banks and 10 hospitals within a 5 km radius was considered 2. The blood of the required blood group, with the earliest expiry date, is allocated first. 3. The implemented system is tested with 100 Sample EHR data created using volunteer data.	1. Blood matching is done based on the closest stock expiry date. It will avoid the wastage of blood due to expiry. 2. The donor is notified when blood is used, which motivates him to donate in future 3. The donor is alerted when the blood is found to carry any reactive disease.	1. Implemented only for whole blood, not for derivatives of blood. 2. Performance metrics not included
The proposed system is a blockchain-based Blood donation and Transfusion Management System. (BC-BDTMS)	Private BCT using Hyperledger Fabric. 1. A scenario with 2 blood banks and 1 hospital is considered. 2. The implemented system is tested with 100 real-time data. 3. Hyperledger Explorer and Hyperledger Caliper tools are used for dashboard display and performance analysis.	1. Whole blood and components such as red blood cells, plasma, and platelet are included for implementation. 2. If blood has any transmissible transfusion diseases, the corresponding blood data cannot be stored in the blockchain, ensuring the secured blood transfusion. 3. Performance analysis of the proposed system is done	1. Encryption algorithms The data stored in the blockchain are not implemented, which will be rectified in the next phase.

- Transfusion-related disorders called transfusion-transmitted infections (TTI) may be contacted by recipients of donated blood.
- The National Blood Transfusion Council (NBTC), NACO, and the Ministry of Health and Family Welfare of the Government of India published a report in 2016 [16] titled "Assessment of Blood Banks in Tamil Nadu, India," which lists some of the transfusion-transmitted infections (TTI) as HIV (0.05 percent), Hepatitis-B (0.68 percent), Hepatitis-C (0.11 percent), Syphilis (0.07 percent), and Malaria (0.01 percent). 14,474 instances of HIV transmission by blood transfusion were reported [19] between 2010 and 2017.

Individuals guilty of giving or selling blood in return for money may face up to three months in jail and a fine under the National Blood Transfusion Services Act of 2007. But forceful blood extraction has occurred frequently throughout the years. Even though paid donations were outlawed in 1996 by a Supreme Court decision, stories of the practice persisting have emerged. Despite government attempts to protect patients, there have been multiple instances where patients were required to find substitute blood donors to refill supplies even during crises. These significant Blood Transfusion Service hazards demand attention. Hence blockchain technology can be combined with blood transfusion services to provide a reliable and trust-based blood system.

This article has implemented a uniform, secure, end-to-end, permissioned blockchain-based blood chain management system to address these challenges. This system would provide transparency in the donation and testing processes and the ability to monitor given blood, thus guaranteeing secured blood transmission.

5. Overview and Architecture of the proposed system (BDTMS)

This section explains the overview of the proposed system 'Blood Donation and Transfusion Management System (BDTMS)' and its advancement over the existing system. Fig. 2 explains the overview of the proposed system.

The participants of the proposed system are donors, blood banks, hospitals and patients [31]. As the participants are specific private blockchain model is adopted. The responsibility of the blood bank is to register new donors into the system based on the donor's eligibility criteria and record the blood donation details such as blood collected date, blood group, unit collected, expiry date etc.

The collected blood then undergoes various testing to detect if any transmissible transfusion diseases such as HIV, hepatitis-B, hepatitis-C, malaria and syphilis exist in the blood or not. If the TTI diseases are negative, the blood is separated into components and stored in the blood bank at a particular temperature after labelling the components with corresponding expiry dates.

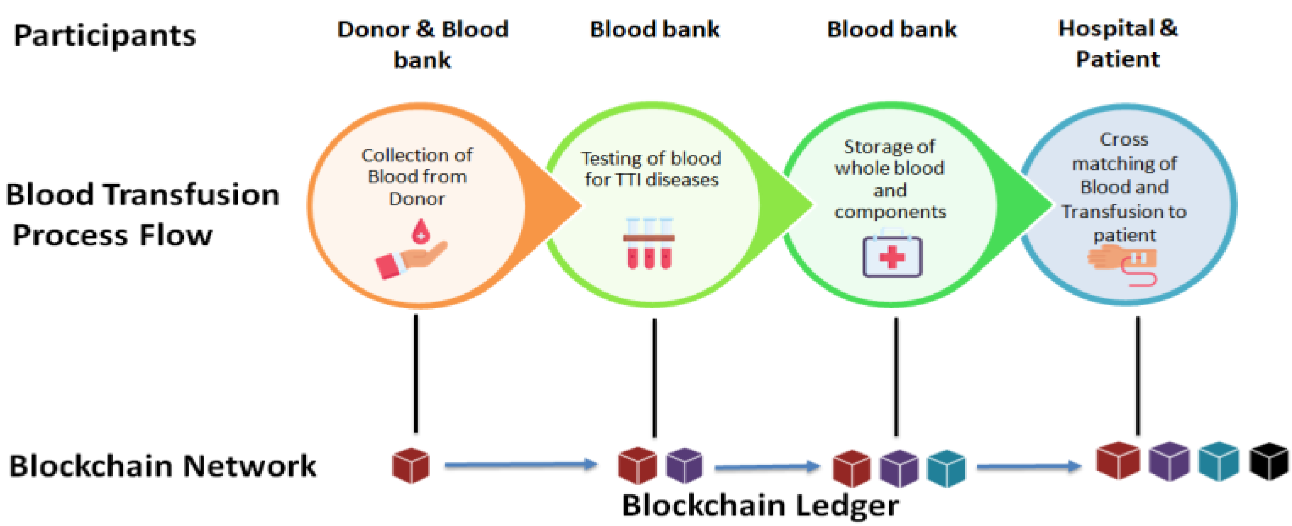

Fig 2. Overview of the proposed system

Finally, the blood transfusion details, such as patient's details, blood group, cross-matching of patient and donor's blood, hospital details etc., are stored while the blood transfusion is done. Hence, a new block is added to the blockchain ledger at each level of the blood transfusion process (refer to Fig. 3) after validating the process and the corresponding data.

Fig. 4 explains the architecture of the proposed system. The various participants interact with the blockchain ledger through client applications based on their accessibility level.

An application programming interface called the Rest API connects to databases and blockchain ledgers via HTTP queries. It can be used to start a transaction, run a query, or see the current state of a group of operations.

In addition to the blockchain ledger, the details are stored in MongoDB to do any data analytics for business purposes, if any, in the future.
The advancements of the proposed system over the existing system are as follows:

- Each BDTMS member has direct access to the distributed ledger based on their access privileges.
- The blood transfusion process is completely visible to all parties.
- The donor receives explicit explanations of how and when his blood is used, which may inspire and motivate him to provide blood again. Consequently, the blood bank will be able to keep the donor on board in the future.
- Donors can go to any blood bank of the BDTMS network as their details will be available in the shared distributed ledger and hence need not do registration again.
- The patient can trust the blood as its journey from origin to consumption is traceable.
- No participants are permitted to alter the data chain in any way. It guarantees the honesty and integrity of the blood donation and transfusion data.

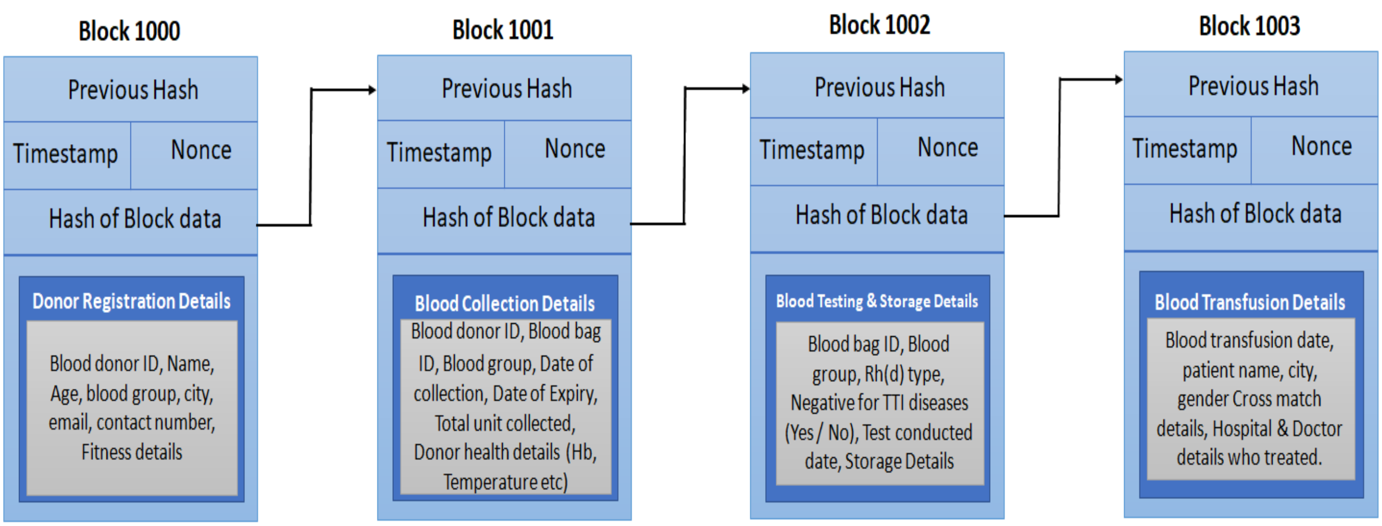

Fig. 3 Blood donation and transfusion details stored in Blockchain Ledger

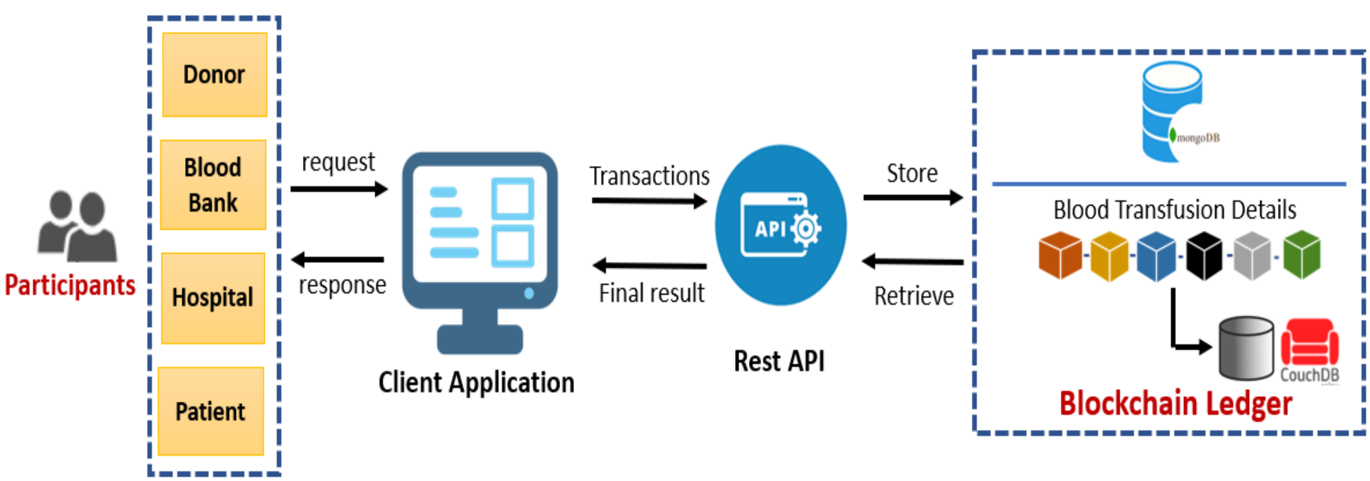

Fig. 4 Architecture of BDTMS

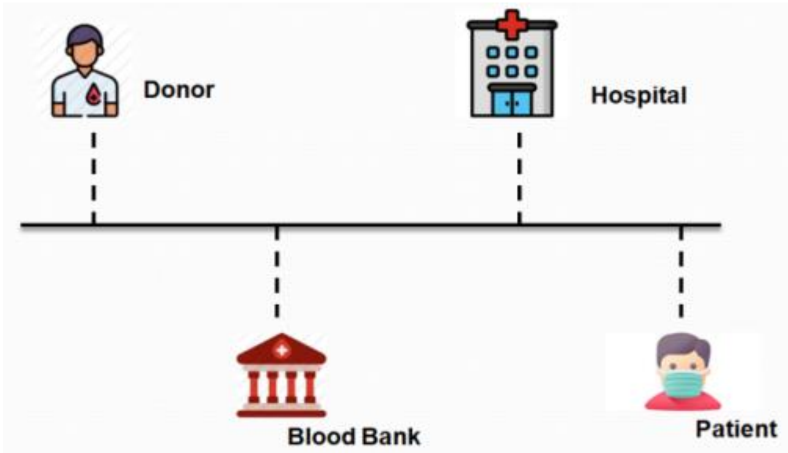

Fig. 5 BDTMS Blockchain Network

6. Implementation of BDTMS

The implementation of the proposed system is done with the Hyperledger Fabric platform. The below table (Table 2) specifies the system component with its specification.

Table 2. System Specification and Software used for implementation

System Component	Description / Specification
Operating System	Ubuntu 20.04
CPU	Intel(R) Core(TM) i3-2370M CPU @ 2.40GHz
Primary Memory (RAM)	16 GB
Hyperledger Fabric	Hyperledger Fabric v2.4
IDE (Platform)	Visual Studio
Backend Code Development	Node JS v10.24.1
Docker Engine	Docker version 20.10.7
Docker Composer	version 1.29.2

The system is designed with a permissioned blockchain model, allowing only the specific users and hence has better security and privacy. The complete Blood Donation and Transfusion Management System (BDTMS) with participants and blockchain network are illustrated in Fig 5. The users of the implemented system are the blood bank, hospital, donors and patients. Donor registers into the system through the blood bank and patients through the hospital.

Three peers have been configured to implement the BDTMS network (see Table 3 for more details).

Table 3. Peers of BDTMS Network

Organisation Name	Peer Name	MSP
Blood Bank A	/peer0.org1.example.com	Org1MSP
Blood Bank B	/peer0.org2.example.com	Org2MSP
Hospital A	/peer0.org3.example.com	Org3MSP

Peer nodes of the blood bank can register the new donors into the system by running the corresponding smart contracts. In a smart contract, the conditions of the agreement between two parties are directly encoded into lines of code [26] using a programming language, making it a self-executing contract. It is meant to carry out, manage, or record legally significant events and activities following a contract or other agreement's requirements. The smart contracts used in the system are listed in Table 4. The chain code / smart contracts are written in Node.js.

Each smart contract checks for the validity of the data and stores only the valid data in the blockchain, ensuring the data's truthfulness and integrity. Below, algorithms have been implemented in the chaincode for data validation and the creation of blocks in the blockchain.

Algorithm 1 Donor Registration

1. Input: Donor's name, age, weight, gender, and medical history.
2. Output: Donor registration to the system
3. **for** donor details, **do**
4. **if** age>18 **weight**>45 & **medical_history** verification done **then**
5. Register donor into the system and generate donor_id
6. **else**
7. Reject Donor
8. **end for**

Algorithm 2 Storing blood donation details in ledger

1. Input: donor_id, donor's weight, hb, bp, body temperature, blood group.
2. Output: store blood donation and donor details in a ledger
3. **for** donation details, **do**
4. **if** donor_id exists, **then**

5. **if** hb>12.5 & bp normal range & temp <99
6. Generate blood bag id & Store blood details in ledger
7. **else**
8. Reject Blood & Discard
9. **else**
10. Register donor into the system and generate donor_id
11. **end for**

Algorithm 3 Storing blood test details in ledger

1. Input: blood bag id, tti test result.
2. Output: store blood test details in the ledger
3. **for** blood test details, **do**
4. **if** tti test result is negative, **then**
5. Store blood test details in the ledger
6. **else**
7. Reject Blood & Discard
8. **end for**

Algorithm 4 Storing transfusion details in ledger

1. Input: donor blood group, patient blood group, cross-matching result.
2. Output: store blood transfusion details in the ledger
3. **for** blood transfusion details, **do**
4. **if** the donor & patient blood group is the same & cross-matching is done, **then**
5. Allow blood transfusion and store details in a ledger
6. **else**
7. Reject for blood transfusion
8. **end if**

Table 4. Smart contracts (chaincode) of BDTMS

Smart Contract	Type	Job
createDonorRegDetails (done by Blood Bank)	Transaction (through invoke method)	This method checks for the eligibility of donor, such as age, weight and allow/deny them to register, and details are stored in the blockchain (check Algorithm 1)
createDonationDetails (done by Blood Bank)	Transaction (through invoke method)	This method checks for the basic conditions before blood collection from the donor (such as body temperature, Hb level, weight, and BP) and the details are stored in the blockchain. (check Algorithm 2)
createBloodTestingDetails (done by Blood Bank)	Transaction (through invoke method)	This method checks for TTI disease, if any, in the tested blood. The details cannot be stored in the blockchain if it has any TTI infections (if there are any positive values). If negative for diseases, the details will be stored in blockchain (check Algorithm 3)
createBloodTransfusionDetails (done by the hospital)	Transaction (through invoke method)	This method checks if cross-matching is done for donor's and recipient's blood and if the blood group matches; if the condition is true, the details will be stored in the blockchain. (check Algorithm 4)

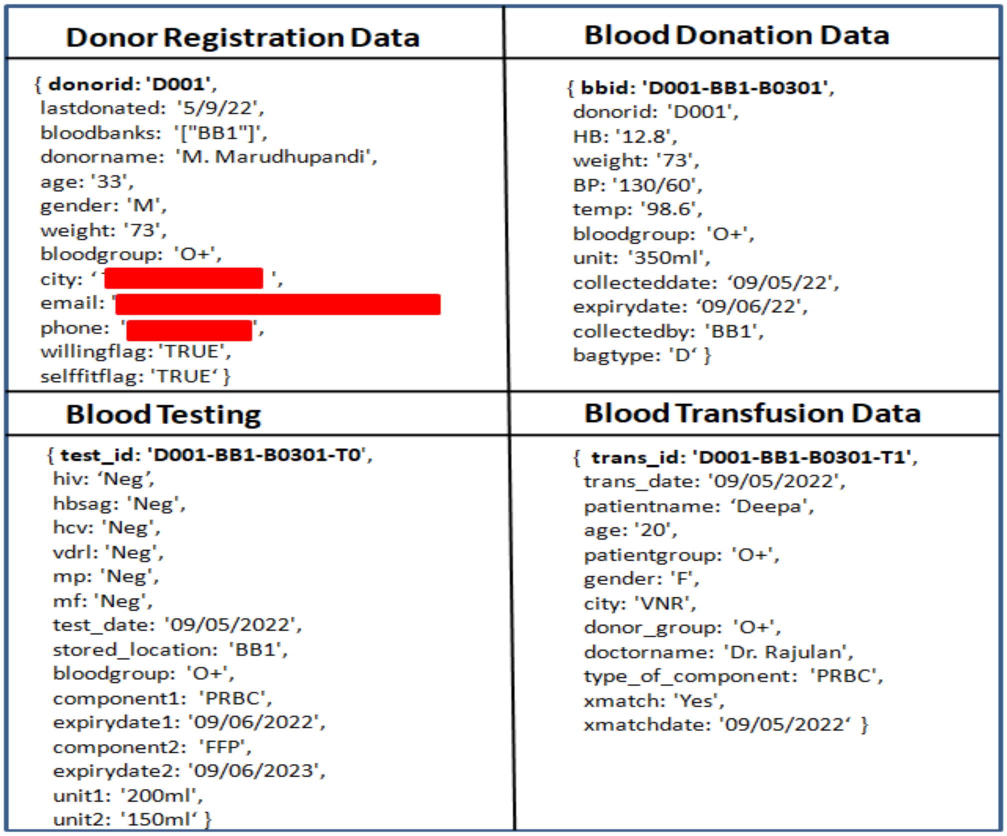

Fig. 6 Sample json object of blood bank data

After validation of chaincode, the data are stored in the blocks as json objects. Fig. 6 shows the sample json objects for donor's registration, blood donation details, blood testing details and blood transfusion details. As the Hyperledger Fabric platform is used, the transactions are stored as a Key-Value Store in the blockchain as a chain of blocks.

The queries sent to the blockchain ledger to retrieve the stored data from the blockchain are shown in Table 5. The queries are made using the 'Key' value to get the corresponding 'Value' pair.

Table 5. Sample query with 'key'

Sample Query	**Job**
/getDonorDetails	To get the donor registration details from the blockchain
/getDonationDetails	To get blood donation details
/getBloodTestingDetails	To get blood testing details
/getTransfusionDetails	To get blood transfusion details
/getEntireBloodDetails	To get the entire blood chain details such as donor registration, blood donation, blood testing, transfusion

7. Blood bank data set

The data is taken from an NGO blood bank in Virudhunagar District, Tamilnadu, to test the implementation. Below is the description of the data.

7.1. Blood Donor's Data

Donor's data is collected when they donate blood. Various details are collected, such as Donor name, age, gender, phone number, district, blood group etc. In addition, the donor's Hb level, blood pressure, and weight are checked, and the same is entered in a register while blood collection. Out of 100 data collected, it is clear that (regarding Fig 7. a) male donors are more than female donors. With Fig 7. b., the number of donors in the 20 to 30 is more than in other age groups. Fig. 7.c shows that the most common blood group is O+, and the rarest blood group is the A- group (in the given data set). Also, from Fig 7.d, it is incurred that 70% of the donors are from the same city as the blood bank. But in addition, 30% from other cities have shown interest in blood donation, which is more appreciable.

7.2. Blood Testing & Component Separation Data

The Blood is tested for various transfusion transmissible infections such as HIV, Hepatitis B, Hepatitis C, Malaria, Syphilis etc. If there are no infections in the tested blood, the same is separated into red blood cells, plasma, and platelets based on requirement and stored in the blood bank. The data maintained in this stage are blood test results and the expiry date of various components.

7.3. Blood Transfusion Data

This data contains the patient's details, the treated doctor's details, cross-matching details and date of blood transfusion etc.

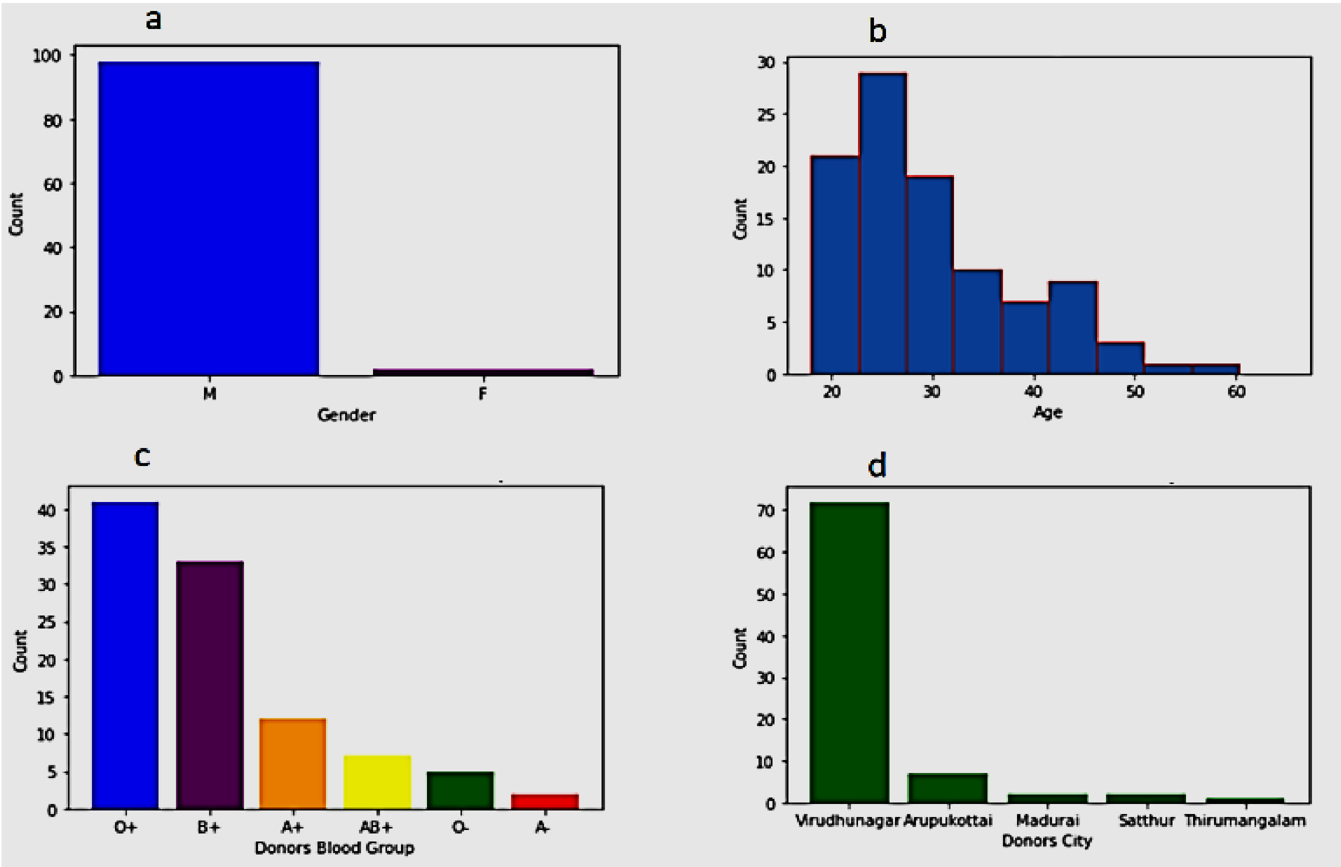

Fig.7. Interpretation of the various values of blood donor's data set.

(a) Donors count based on gender. (b) Donors' age chart. (c) Donors' count is based on blood group. (d) Donors' count based on city

7. Result and Discussion

Advanced Rest API' is used to send requests to the blockchain to create blocks (transactions) and query the ledger. Below (see Fig. 8) is the screenshot of the output for querying blockchain details.

If the user enters any invalid data, the chaincode will not allow them to be stored in the blockchain. In the below scenario (see Fig. 9), one of the TTI diseases (Hepatitis B) is positive while testing the blood, and the same is submitted to the system to be stored in the ledger. Still, as chaincode does not allow it, an error is thrown to the user. It ensures the truthfulness of the data that is stored in the blockchain.

'Hyperledger Explorer' is integrated to view the blockchain transactions in the dashboard. Below Fig. 10 is the snapshot from the explorer tool.

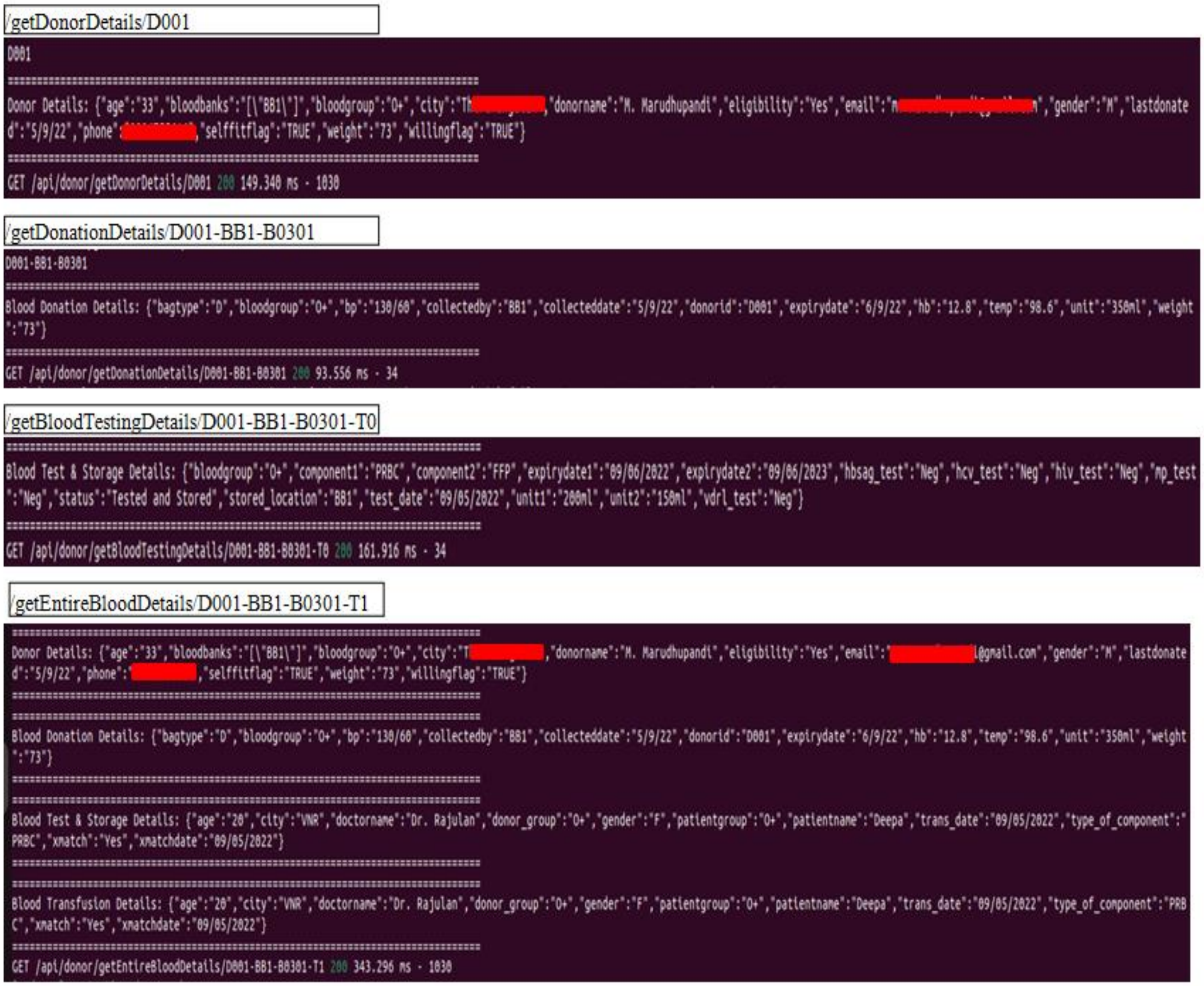

Fig. 8 Log output of the query to Blockchain

Fig. 9 Rejecting the transaction if invalid data is entered

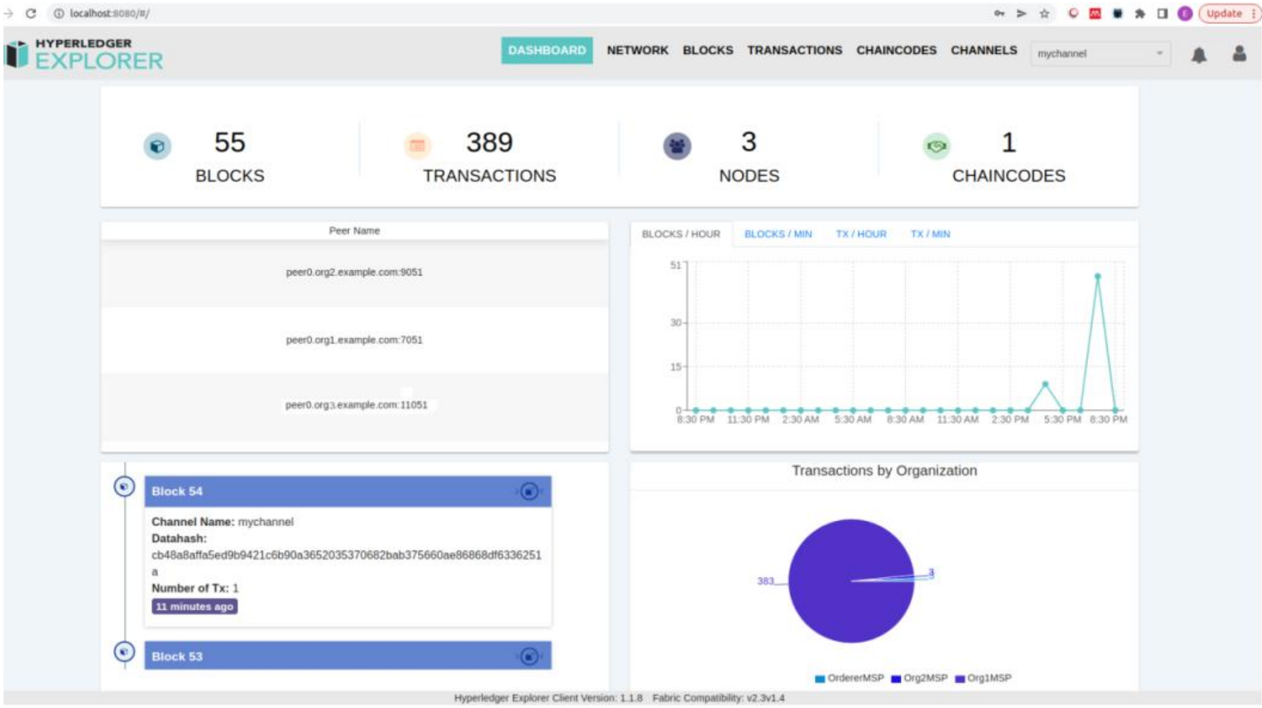

Fig. 10 Hyperledger Explorer Dashboard for BDTMS Blockchain Network

The performance of BDTMS is tested with real-time data using the Hyperledger Caliper platform. Below, Fig. 11 illustrates the transactions' minimum, maximum and average latency while creating blocks in the blockchain. Also, Fig. 12 illustrates the throughput of the transactions for the smart contracts written for the creation of blocks.

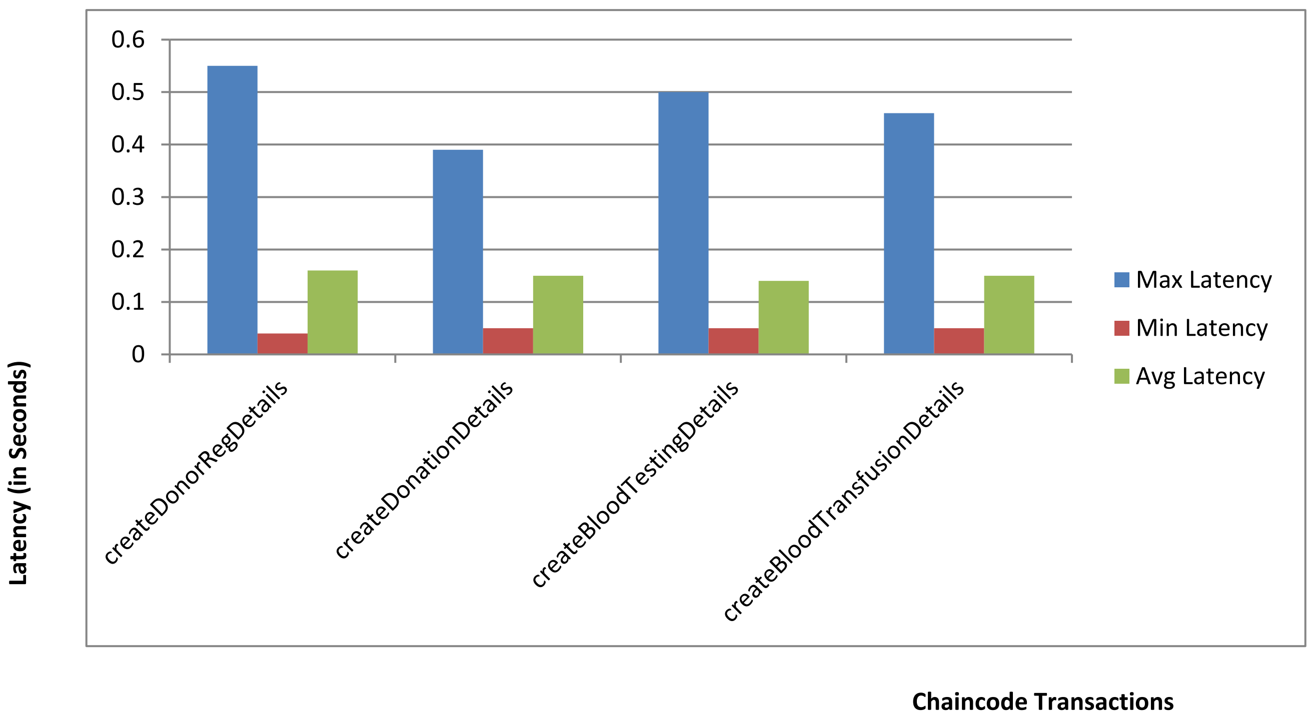

Fig. 11. Latency of the various transactions on 'creation' of blocks

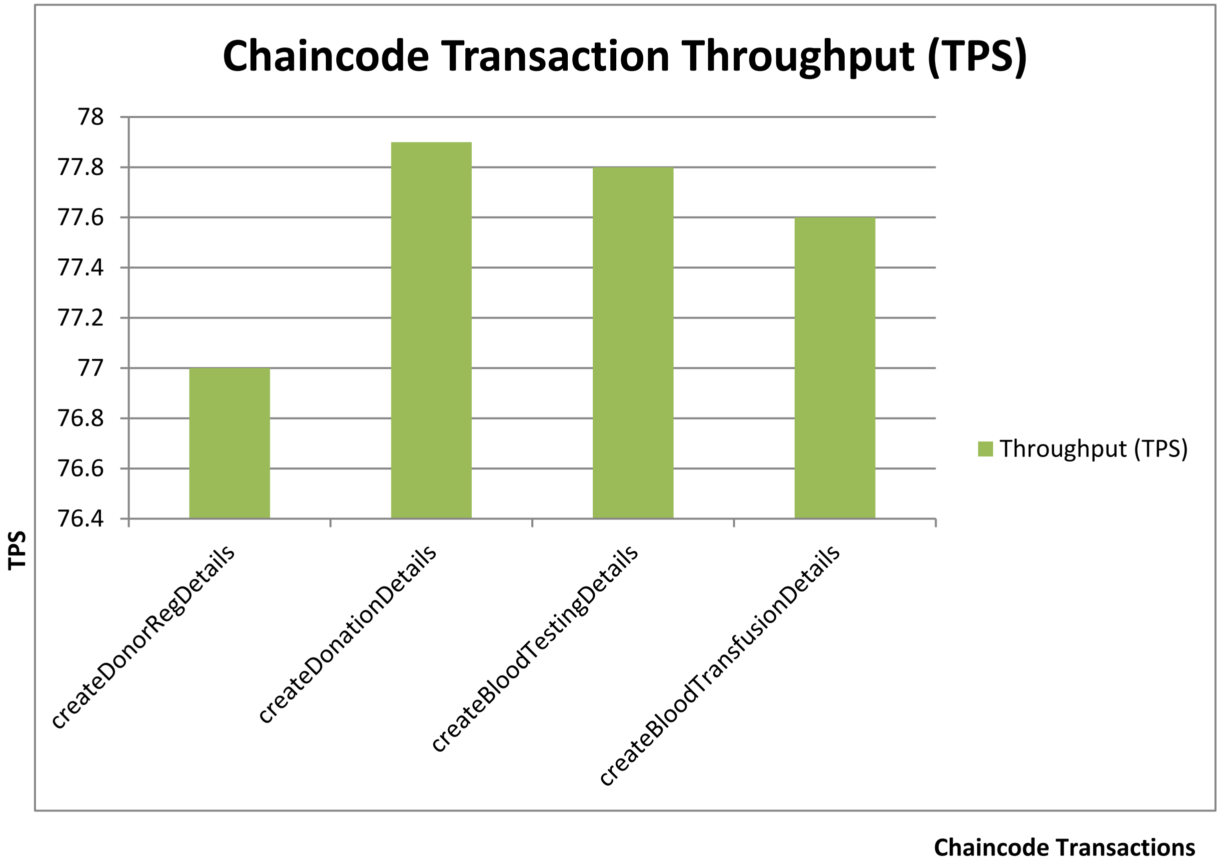

Fig. 12 Chain code Transactions Throughput (TPS)

In this research paper, an end-to-end blood donation and transfusion system have been developed using blockchain technology. This system developed with Hyperledger Fabric ensures that the patients get trustworthy blood as each step of the blood bank process is stored in blockchain. Also, BDTMS will not allow invalid data to be entered into the system as the integrity of the data stored in the blockchain is validated through several smart contract codes. Also, the system has been tested with real-time data. Whole blood and its components are incorporated in this research work, hence achieving an entire blood bank process. In addition, the performance metrics of BDTMS are evaluated in this paper.

8. Conclusion and Future work

To fulfil two objectives, (i) trust-based blood transfusion and (ii) implementation of an end-to-end blood process, a blood donation and transfusion system based on private blockchain technology have been proposed and developed using the Hyperledger Fabric platform. The BDTMS system ensures the safety of blood donation as several smart contracts have been implemented to achieve the same. The implementation is done for blood donation of whole blood and components, and the first-ever system developed as in previous existing works; only whole blood is taken for implementation.

With the Hyperledger Explorer tool, the peers, no. of blocks, and dashboard view transactions are visualised to understand the implemented system better. Also, with Hyperledger Caliper, the performance analysis of the BDTMS system is evaluated. In the future, it is planned to concentrate on the security of the data stored in blockchain, as every user in the network can see all the details stored in the blockchain.

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