Design of a Block Chain and Machine-Learning Based Blood Donation Supply Chain Management

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Abstract

The existing blood management system is built on centralized database management system. Even though it serves better for the community than the manual system existed in the past, still lot of challenges persist such as lack of traceability of blood component from its collection till consumption, proper blood quality check, storage of blood in particular temperature and possibility of transfusion related diseases such as AIDS, Hepatitis- B, Hepatitis-C, Malaria. Some places face scarcity in blood on the other hand, in some places there is wastage of blood due to its short life time. Hence Blockchain Technology (BCT) can be used in blood donation supply chain management as it is suitable because of its traceability, immutability nature of the data stored in the chain. Nowadays BCT is adopted by various real-time cryptocurrency and non-cryptocurrency applications.

This paper aims to propose the architecture for block-chain and machine-learning (ML) based blood donation supply chain management system which comprises of two modules. First module is based on BCT for the effective management of blood among the donors, blood bank/centres, hospitals, patients. Second module is based on machine-learning for detection of blood transfusion transmissible infections/diseases (TTI). In this paper we plan to implement the initial stage of the proposed architecture ie checking if the donor is eligible for donation (based on various criteria such as age, last donated date, medical history etc), collection of blood from donor and storing of the same in blockchain after ensuring if he is eligible to donate.

The proposed model can be implemented with Hyperledger Fabric tool, an open-source, permissioned BC platform with general purpose distributed ledger which offers versatility and modularity. With the proposed model, the blood can be easily traceable by the users of the system. The collected blood is tested twice for TTI. One with blood testing centre and another check with proposed ML based detection. Hence, the blood recipient can confidently obtain and get utilised by the blood as there exists transparency in supply of blood from its origin till consumption. Also, Donor can get updates once their donated blood is been consumed. This engages them to donate blood again in the future.

1. Introduction

Blood is essential in human life. Blood has different components such as plasma, platelets, red and white blood cells. Developed and developing countries encourage blood transfusion for supportive clinical care in surgeries, anaemia etc. Timely donation of blood and its transfusion can save millions of life. Since 1992, National AIDS Control Organization (NACO) has been responsible for ensuring the provision of sufficient, quality, affordable and safe blood and blood products to the needy in India. NACO supports the network of blood banks and blood transfusion services across the country. The supply of the blood components from donor to consumer comes under blood supply chain management (BSCM). The participants of blood supply chain management are donors, blood banks, blood testing centres, vehicles that transport blood, hospitals and patients.

Blood collection, processing, inventory management, and distribution are all part of the blood supply chain management. The need for blood is driven by human sickness, which is uncontrollable. Donors who are willing to donate blood are used to replenish the blood supply. Blood demand and supply fluctuations are unavoidable. Blood has an expiration date, which is usually only a few days after it is obtained. Furthermore, blood requirements are unpredictable and uncontrollable. The blood supply chain is more complex and dynamic as a result of the aforementioned qualities than the old one. As a result, it is critical to research a well-managed system in order to maximise the benefits of blood, which is the primary performance indicator of the blood supply chain. Nowadays blood bank is digitized and running in almost all the places.

Even though, blood bank system is digitized, there exist different challenges such as lack of traceability of blood products from collection phase till recipient's consumption such as transmission of collected blood, proper storage of the blood in desired temperature and checking the quality of blood. According to World Health Organization (WHO), a blood cold chain is a system to manage blood and blood products with correct range of temperature. Deviations from precise temperature may lead to life threatening reactions, such as septic-shock or may lead to death. Hence a traceable and transparent blood supply chain management with real-time information exchange among the various participants should be designed to track the blood and blood components. Block-chain technology (BCT) is well suited for this scenario. BCT is becoming familiar for its decentralized [1], transparent, immutable and unforge-able nature of data stored in block-chain.

Another major challenge with transfusion of blood include possible transmission of infectious blood with HIV, HBV, and HCV etc. Between 2010 and 2017, 14,474 cases of HIV transmission through transfusion of infected blood were documented. Improving the disease diagnosing process and predicting for any diseases in the collected blood is the current challenge and research can be carried on recent technological tools and algorithms such as machine learning and artificial intelligence to come up with the solution for this problem. In India, the blood transfusion service management is highly decentralised and lacks many critical resources such as manpower, sufficient infrastructure, and a solid financial foundation [2].

New pathogens are emerging, may pose new risks to the safety and availability of blood supplies, highlighting the importance of an effective global and national monitoring and vigilance system for blood and transfusion safety. Hence, in this paper we propose a new block-chain and machine-learning based blood supply chain management model to track the various processes / stages involved in blood supply chain and to predict the TTI diseases in the collected blood.

The rest of the chapter is organized as follows: section 2 discusses about the literature of already researched and developed model/systems. In section 3, we have discussed the literature of blockchain and supply chain management and also on role of blockchain in supplychain management. In section 4, we have given an overview of existing blood cold chain manement system, the flaws and drawbacks in the existing system. In section 5, we have given in-detail understanding of our proposed architecture with various modules and the stake-holders involved in the system. In section 6, we have provided our initial implementation we have done ie donor registration and blood collection processes with the algorithm used for the same.

2. Literature survey

Blockchain is a game-changing technology for securely storing data in a fault-tolerant, transparent manner. In addition to crypto-currency applications, researchers now are expanding blockchain applications to non-financial fields. Some of the fields that have adopted BCT are healthcare [3], Pharmaceutical Industry [4], supply chain [5], Tourism and Hospitality Management [3], Education [6], Agriculture [7].

In 2018, Fan et al. [8] implemented a system called 'SmarySupply', a blockchain based supply chain management using Ethereum platform with Solidity programming. In that, they have highlighted several challenges with respect to system design and performance. In addition, they have put SmartSupply to several tests and discussed about the trade-off between query latency and accuracy.

In 2020, Abbas et al. [7] suggested and implemented a revolutionary medicine supply chain management and recommendation system based on blockchain and machine learning in their article. It consists of two modules, one for drug supply chain and next for medicine recommendation based on machine learning models. First module is designed with Hyperledger Fabric tool called Hyperledger Composer in which they have logged in, monitored and tracked the medicine from its production till consumption. In the second module they have used N-gram, LightGBM models for recommending top-rated medicines best suites a particular health problem. They have also performed several tests to check the performance and usability of their system.

In 2020, Kabra et al. [8] have proposed an automated cheque clearance system called 'Mudrachain' where the process is handled by blockchain network. It includes a multi-level authentication mechanism among participating financial group of actors to make the blockchain-based infrastructure secure and tamper-proof. They have also designed a QR code generating algorithm to be signed on the cheque. The main aim of this work is to provide a seamless connection between payer and payee without any intermediary parties.

In 2019, Bodkhe et al. [9] have proposed a framework for tourism and hospitality management called 'BloHosT'. In the proposed system, tourists can engage with a variety of stakeholders using a single wallet identity that is linked to a crypto currency server to make payments. Each transaction in the blockchain is validated by miners based on PoC ie Proof of Collaboration. They have also proposed TeDL - Tourism Enabled Deep-Learning as a design framework that evaluates prior tourist itineraries to provide rating scores for a specific toured destination to future visitors in the chain.

In 2018, Turkarnovic et al. [6] have proposed a system for higher education institutions called 'EduCTX' which is designed on top of blockchain network. They presented the prototype implementation of the system using open-source Ark blockchain platform. It is a credit platform which includes students' complete course history with earned credits that can be stored and shared with different employers, universities. As the credits of the student is evaluated by the institution and stored in blockchain, the employers need not do double verification.

In 2020, Song et al. [7] have proposed a blockchain based agri-food supply chain system. The actors of the system are agri-food producers, food processing enterprises, food distributors, and retailers. They have also discussed how food information is being floated between parties and how it is been managed and stored.

In 2020, Gatteschi et al. [33] have come up with a chapter on blockchain usecases which includes overview on how blockchain and smart contracts are implemented in existing usecases, such as insurance, finance, industrial applications, government etc. They have also explored which use cases would gain the most from blockchain and smart contracts, and which might be implemented successfully using existing technologies.

[10] Kim et al. have proposed and implemented blood cold chain management using BCT. They implemented the prototype with Hyperledger Composer. With their model, they have provided clear traceability of blood between different parties. They have also implemented logic for discarding blood in case if the stored blood temperature is not in normal range.

Lakshminarayanan et al. [34] proposed and implemented for blood donation system using Hyperledger Composer, where they considered ten hospitals and two blood banks within five kilometres for their analysis. Best blood is matched for a request based on blood group, locality and blood expiry date. Blood donor is notified once it is been consumed and if blood is unfit for donation, the same is too communicated to the donor and is discarded.

In a chapter by Mehmet et al. [35] they proposed the KanCoin Ethereum blockchain-based architecture to manage and alter processes for efficient distribution planning in the blood supply system from donors to distribution centres and patients at medical centres in a more effective way than traditional procedures.

3. Literature of Blockchain

The development of crypto-currency based applications has made blockchain technology more popular in recent years. Blockchain Technology is a distributed ledger technology, with immutable and hashed data blocks which is connected in a chain [1] in chronological order. Decentralization, Transparency, Durability and Auditablity are the primary characteristics of Block chain [11]. Block-chain system is categorized into three types namely public, private and consortium blockchain. The consensus process in public blockchain is permission-less whereas private and consortium blockchain [12] are permissioned. Private ledgers can be used for sensitive data, while public ledger can be used for applications that require highest trust level [13].

Blockchain(BC) is a chain of valid blocks that are linked together; First block in the chain is called genesis block. Each block contains two components namely header and body. The Header comprises of previous and current hash value of the block as shown in the Figure 1 which makes blockchain traceable and resistant to change [14]. In addition, header contains the timestamp, nonce value etc. Body of the block contains one or more transactions.

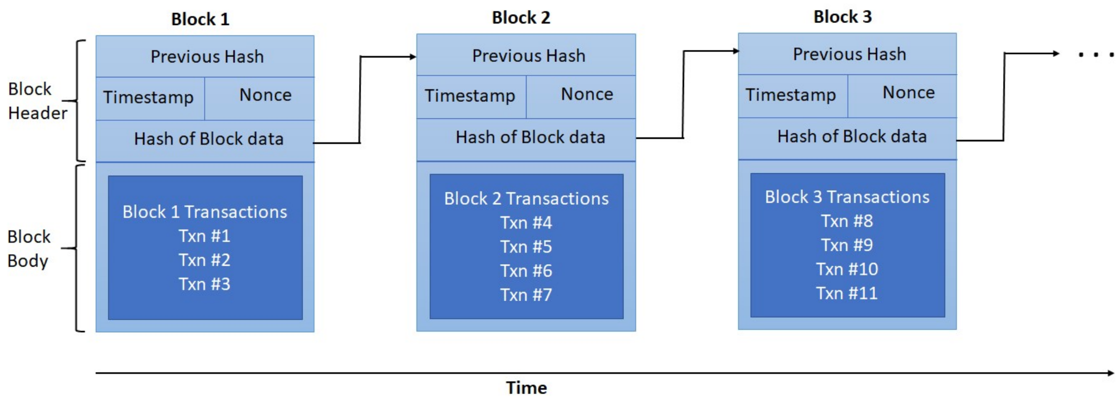

Figure 1: Chain of Blocks in Blockchain

Blockchain is a decentralized peer-to-peer (P2P) network [15]. Hence there is no central node. Each node in the network agrees to a consensus and based on the validation, blocks are added to blockchain. Hashing algorithm is used in BC ensures data integrity i.e. to verify if the data is illegally tampered with. Message of any length is converted into a fixed length value called message digest with hash function and is stored in blocks. Once the message is been converted into a message digest, if anybody tries to tamper the data the hash value will change. Therefore, with hashing algorithm the data integrity can be preserved. The SHA256 is the widely used hashing algorithm with 256-bit message digest. The selection of algorithms is based on the type of the BC network (private, public or consortium) also based on the consensus of the peers in the network.

3.1 Blockchain Platforms

Decentralized governance and data infrastructure underpin blockchain-based platforms, allowing marketplace actors to interact directly with one another without the need for a third party [16]. As a result, blockchain-based platforms provide an extreme case of "openness," with decentralised governance and a distributed data infrastructure capable of removing middlemen from transactions. The benefits of blockchain-based systems outweigh the benefits of centralised platforms. In this section we will discuss the various blockchain-based platforms available in the market.

3.1.1 Ethereum

Ethereum is a decentralized blockchain technology that creates a peer-to-peer network for securely executing and verifying smart contract code [17]. Participants can transact with one another without relying on a trusted central authority. Participants have full ownership and visibility of transaction data since transaction records are immutable, verifiable, and securely distributed across the network. User-created Ethereum accounts are used to send and receive transactions. As a cost of processing transactions on the network, a sender must sign transactions and spend Ether, Ethereum's native coin [18]**.** Ethereum is used mainly for public blockchain network.

(i) Plasma chains:

A plasma chain is a separate blockchain that is linked to Ethereum's main chain [19] and incorporates fraud proofs (such as optimistic rollups) to settle disputes. Because they are effectively smaller replicas of the Ethereum Mainnet, these chains are also referred to as "child" chains.

3.1.2 Hyperledger Fabric

Hyperledger is an open-source, permissioned BC platform with general purpose distributed ledger which offers versatility and modularity.

Hyperledger Fabric Ledger consists of two types of parts namely world state and block-chain (transaction log). World state database stores the current value of the set of ledger state [3]. Hence world state can be used to instantly check the current value without checking the sequence of transaction log. The value in world state are made as key-value pair. The default state database is LevelDB. CouchDB is an alternative state database which we can choose for our application which has more advantages over LevelDB hence we are using CouchDB in our application.

3.1.3 R3 Corda

Corda is a permissioned blockchain technology that is largely utilised by companies in the financial sector [20]. Unlike public blockchains, which allow anybody to join, permissioned blockchains only allow access to those who have been approved by the network. Corda is written in the Kotlin programming language, and it supports both Kotlin and Java development.

3.1.4 Vechain

VeChainThor [21] is a public blockchain that aims to make blockchain technology more accessible to businesses of all sizes. Its goal is to lay the groundwork for a long-term and scalable corporate blockchain ecosystem.

From a technical standpoint, the VeChainThor blockchain is based on existing blockchain advancements as well as innovative technology developed for mass deployment. The Proof-of-Authority ("PoA") consensus method, meta transaction features, transaction fee delegation protocols, on-chain governance mechanism, built-in smart contracts, and developer tools are among these technologies.

Below Table 1 illustrates the comparison of most used block-chain platforms by various companies for building block-chain based applications.

Characteristic	**Hyperledger Fabric**	**Ethereum**	**R3 Corda**	**Ripple**
Governance	Linux Foundation	Ethereum Developers	R3 Consortium	Ripple Labs
Ledger Type	Permissioned	Permissionless	Permissioned	Permissioned
Access Type	Private	Public or Private	Private	Private
Smart Contract	Chaincode with Go, Java	Smart contract code with Solidity programming	Smart contract code with Kotline, Java	Oracle based Smart Contract code.

Used in	Cross-industry	Cross-industry	Financial Services	Financial Services

Table 1: Comparison of most used block-chain platforms

3.2 Application of Blockchain in Supply-chain Management

With more use cases and challenges, blockchain technology is influencing variety of applications in every field. One such field where blockchain technology can be used to synchronize different processes is the supply chain. The control of the movement of products or services is known as supply chain management (SCM). Because of increased consumer demand, short product life cycles, modern supply chains are more complex than conventional ones [22]. Ever though digitization of supply chain solves several issues, still there exists lack in management among different supply chain partners / members. BCT provides common platform to supply chain partners with greater accuracy, speed and reliability. Block chain stores transactional data in sequential order which cannot be erased by anybody and is shared between the members. This can solve trust related problems among the members. Block chain technology can help with demand forecasting, inventory management, and back-up in the event of a demand interruption etc.

According to [13], the five main reasons why BCT can be applied in supply chain are (i) Improved quality (ii) Reduced cost (iii) Shortened delivery time (iv) reduced risk (v) Increased trust. The above supply chain benefits can be achieved through tamper-proof transaction records, information synchronization and sharing and execution of smart contract for consensus among partners.

4. Overview of Blood transfusion services in healthcare

A critical aspect of the health-care system is the blood transfusion service. Donor control, blood storage, grouping and cross matching, checking for transmissible diseases, rationale usage of blood and delivery are part of blood transfusion management system (BTMS).

BTMS can be designed under supply chain management. In existing blood transfusion supply chain management system as shown in Figure 2, first and foremost step is to collect blood from donors [23]. There are different types of donors such as voluntary non-numerated, family/replacement or paid donors. Collection of blood from donors happens through blood banks and blood donation camps. Blood collection can be whole blood collection or through apheresis procedures where blood components such as red blood cells, plasma or platelets are collected from the donor [24]. The collected blood is then sent to blood banks and is tested in blood testing centers/labs which are standalone or attached to blood bank.

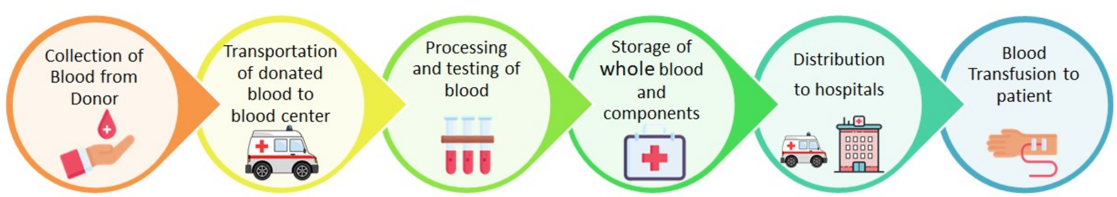

Figure 2: Existing Blood Transfusion System

In laboratory screening of blood, blood sample is tested for following factors [2].

i) Determination of ABO group.

ii) Determination of Rh(D) type
iii) Checking donor's previous record of ABO and Rh(D) to verify both new and old record are similar.
iv) Testing of infectious diseases such as HBV, HCV, HIV, Syphilis or Malaria.

Once testing is done, blood is processed and preserved in blood bank. Storage of whole blood and blood components is done in appropriate controlled conditions. Then the blood products are transported to hospitals at required temperature and again one more testing is done called 'cross-matching' and finally blood transfusion to patient is done.

The National Blood Transfusion Council (NBTC) is the federal organisation in India that regulates and manages the Blood Transfusion Service. NBTC was founded in 1996. The NBTC is responsible for assessing the status of blood transfusion services and conducting annual quality tests in blood banks, along with the State Blood Transfusion Councils (SBTCs). The National Blood Transfusion Council (NBTC) and the National AIDS Control Organization (NACO) are the technical bodies in charge of developing guidelines to ensure safe blood transfusion, providing infrastructure to blood centres, developing human resources, and formulating and implementing India's blood policy. By following the policies, a number of governmental and non-governmental blood donation organisations have been established in the country. However there are various places where issue still persists with Blood supply chain. In the following section we will discuss about the various issues associated with Blood Supply Chain.

4.1 Risks involved in managing blood transfusion services(BTS):

Most of the established organizations maintain online portal to connect to donors and advertise the various camps that happens in and around the various places in the country. However, they cannot track and manage the entire system of blood chain completely. Also there are sequences of problems in blood transfusion services that are unnoticed yet may lead to fatal consequences. In this section we will discuss various problems with existing blood transfusion services.

4.1.1 Legal and Ethical issues in BTS:

Legal considerations are critical in establishing a framework for the Indian blood transfusion service (BTS), while ethical concerns help to ensure quality. Despite the fact that all blood banks are licenced, the Drugs and Cosmetic Act (D and C Act) has not been updated, putting quality at risk [16]. The Drugs and Cosmetics Act (D and C Act) of 1940 and the Drugs and Cosmetics Rules of 1945 treat blood as a "drug." The drugs controller became the regulatory authority after blood was classified as a drug. Licensing is just the beginning of the road to excellence. With approximately 2500 blood banks, the Indian BTS is highly fragmented, posing distinct issues.

4.1.2 Issues in Regulation of blood banks

A number of adjustments, establishment of standards, guidelines, and policy changes have resulted from the periodic evaluations of laws, rules, policies, guidelines, and standards relating to BTS in India [25]. Despite the fact that these initiatives have increased the supply and accessibility of safe blood, there are still concerns and challenges that impede service efficiency and effectiveness. In India, the BTS has multiple levels of power, with Central Drugs Standard Control Organisation (CDSCO) and the State Drug Controller/FDA serving as regulators, and National AIDS Control Organization (NACO), National Blood Transfusion Council (NBTC), State AIDS Prevention and Control Societies (SACS), and State Blood Transfusion Council (SBTC) serving as advisors and programme implementers. Blood banks suffer from a lack of coordination, insufficient monitoring, and regulation as a result of this. Furthermore, the current regulatory functions are neither consistent nor homogeneous across the country.

4.1.3 Transfusion Transmissible Infections

When a germ, parasite, virus, or other possible pathogen is delivered in donated blood to the transfusion recipient, it is known as a transfusion-transmitted infection. The main challenge in blood transfusion service is the risk [26] associated with blood transfusion such as

i) Donation of infectious blood.
ii) Recipients being victim of the infectious blood.

Therefore, any blood transfusion involves high-risk of transmissible diseases or transfusion-transmitted infection (TTI) [27].

According to a report on assessment of blood banks [28] in Tamil Nadu, India provided by NACO, National Blood Transfusion Council (NBTC) and Ministry of Health and Family Welfare, Government of India, some of the transfusion transmitted infections (TTI) include HIV seroreactivity (0.05%), Hepatitis-B (0.68%), Hepatitis-C (0.11%), Syphilis (0.07%) and Malaria (0.01%).

4.1.4 Bacterial Contamination of Blood Components

The presence of bacteria in blood or blood components that are collected and/or processed for transfusion is known as bacterial contamination of donated blood. The organisms most commonly recovered from donated blood are Gram-positive skin commensals like Staphylococcus epidermidis and Bacillus cereus. Such contamination occurs in blood platelets by means of blood collection needles. Other causes of bacterial contamination [29] of blood components include:

i) Donor with an asymptomatic bacteremia.
ii) Contamination during the whole blood collection procedure.
iii) Contamination of the collection pack.
iv) Contamination during the blood processing procedure.

4.1.5 Donor selection and retention

Because of the dynamic nature of the socioeconomic environment and the human elements involved, donor recruitment and retention is difficult in the blood service [30]. While the degree of adequacy in blood supply is commonly used to measure the efficiency of recruiting and retention, some qualitative but crucial issues like donor satisfaction and loyalty are sometimes disregarded. Hence blood transfusion service providers should find an efficient way to select and retain the donors for future donations.

4.1.6 Gap in demand and supply of blood

The need for blood is driven by human sickness, which is uncontrollable. Donors who are willing to donate blood are used to replenish the blood supply. Blood demand and supply fluctuations are unavoidable. Some areas experience blood scarcity, while others experience blood wastage due to its limited shelf life. Hence the existing system faces issues with managing the demand and supply of blood.

Hence to eliminate the risks listed above and for the safe and efficient use of blood and blood products, a well-organized Blood Transfusion Service (BTS) with quality management system in place is essential. This is an integral aspect of every health-care system. For the elimination of transfusion-transmitted infections (TTI) and the provision of a healthy and sufficient blood supply to the people, an integrated blood safety strategy is required.

In our study we introduce a new block-chain and machine learning based blood supply chain management for the dynamic supply of blood and management of different aspects of the blood transfusion services.

5. Architecture of Block-chain and Machine-learning based Blood Donation Supply Chain Management(BDSCM)

In this section we discuss about the overview of our proposed system, the advancements of the proposed system over existing system, overview of the tool we have chosen for system implementation and in depth understanding of the architecture of our proposed system with the initial implementation that we have done.

5.1 Overview of proposed system

Our proposed system consists of various participating stakeholders such as donor, blood collection centre, transporting vehicle, blood testing centre, blood banks, hospital and patient. As the participants are specified, permissioned / private block chain approach is appropriate.

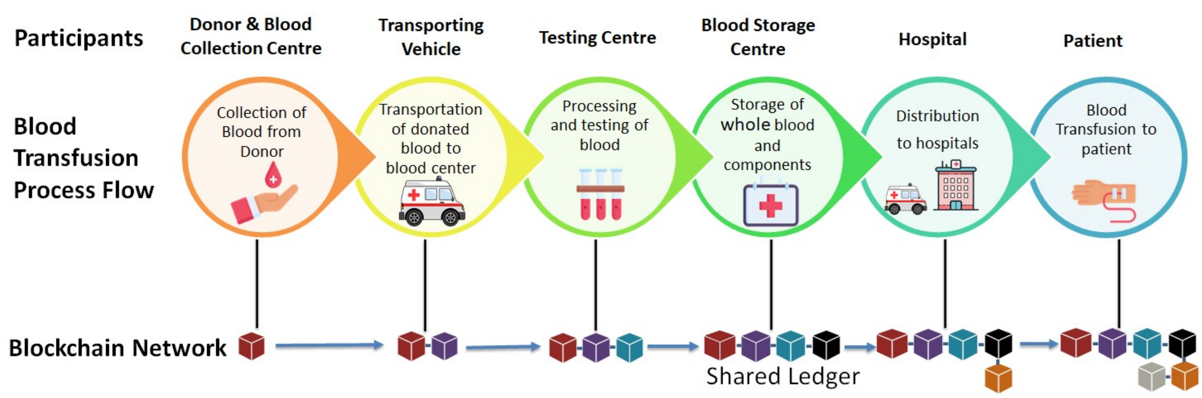

Figure 3: Overview of flow of process in our proposed System

The overview of flow of process of our proposed system is shown in Figure 3. Our proposed system has many improvements over the existing system shown in previous section (Figure 2). The advancements over the existing system are:

1. All the participants of the blood transfusion chain can directly communicate with the distributed ledger based on the access rights allocated to them.

2. All the process flow in blood transfusion is transparent to everyone.
3. The donor gets clear information on how and when his blood is been utilised which can encourage and boost him to donate blood in near future. This in turn will help the blood bank to retain the donor for future
4. Patient is confident to get the blood without fear as he can be able to see the blood life from origin till consumption. It leads to increased patient trust formation.
5. No participants are allowed to make any changes in the chain of data. This ensures the truthfulness of the various processes involved in blood donation.

5.2 Overview of chosen Blockchain-based Platform

We chose Hyperledger Fabric platform for our implementation because of the below reasons.

- BDSCM consists of various participants from different/independent organisations(such as blood bank, hospital)
- It is better to have private system as only authorised organisations alone can participate in any transaction.

Based on above conditions, Hyperledger Fabric tool is been chosen as it is a permissioned BC platform which supports cross-industry.

5.3 In-depth understanding of the proposed architecture:

In this section we discuss about each component we have defined in the proposed architecture (Figure 4).

5.3.1 Participants / Stakeholders:

The various stakeholders of the system are explained below.

5.3.1.1 Donor: The person who is willing to donate blood can register into the system and they will be provided with a generated donor-id. Using donor-id, the donor can be identified and all his basic and blood donation details are stored with donor-id as reference. Donor can themselves register into the system or the system admin will collect the details from donor and can feed the same into the system.

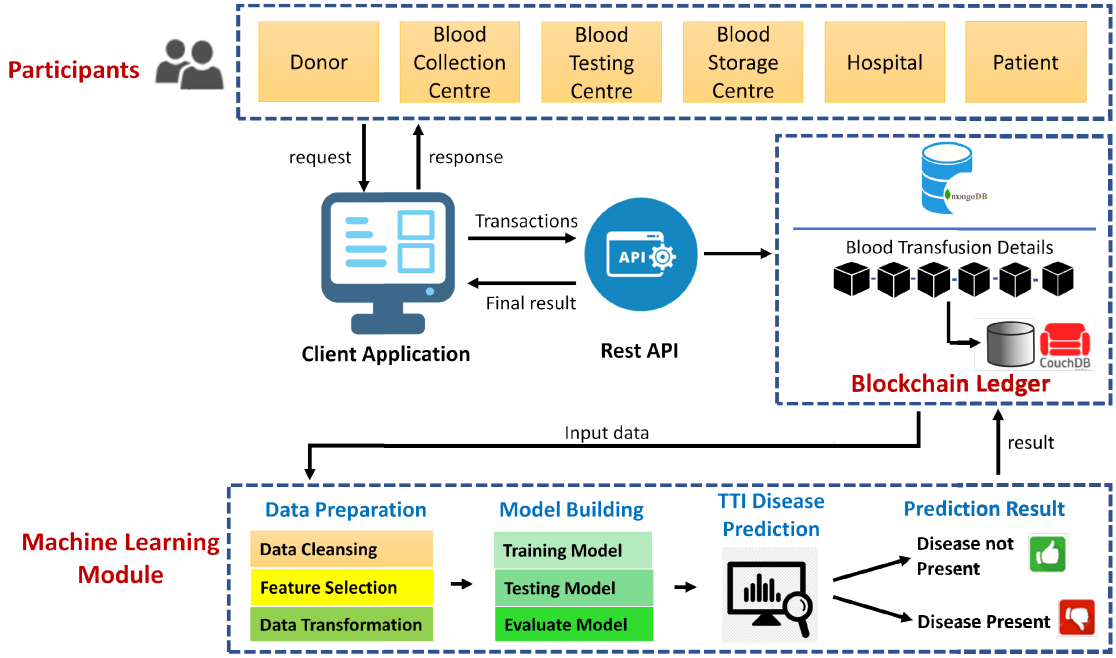

Figure 4: Detailed Architecture of Block-chain and Machine-learning enabled Blood Donation Supply Chain Management System

5.3.1.2 Blood collection centre: This is the part of blood bank which functions as a separated unit with various staff of the centre under the supervision of the medical officer. Here, donor pre-donation counselling, blood collection and post-counselling are done. Blood collection centre is responsible for checking the donor's eligibility for donation, conducting the basic tests to donor such as haemoglobin level, blood pressure, body temperature, pulse rate etc. Also first time donors are asked to fill a questionnaire to assess donor's medical history. After all this processes, the following information should be recorded such as,

i) Blood donor ID
ii) Blood bag ID
iii) Blood group
iv) Date of collection
v) Date of Expiry
vi) Assurance of no risk factor with donor's medical history

The above details are recorded in blood bag as well as block-chain block with timestamp as shown in Figure 4.

5.3.1.3 Blood Processing & Storage Centre:

The primary functionality of this centre is to check the blood for Blood group, Rh(d) type and to check if it contains any infection for transfusion transmissible (TTI) diseases. After the processes, the following information should be recorded in the block-chain block such as,

i) Blood bag ID
ii) Blood group
iii) Rh(d) type
iv) Negative for TTI diseases (Yes / No)

Here, if the test is negative for TTI diseases, then it is eligible for blood transfusion. But if it is positive for any of the TTI diseases, then it should be tested again and donor should be intimated of the same. Also the collected blood is discarded and same has to be recorded in block-chain as well.

Below diagram explains how and what data are stored in block chain by each stakeholder of the system.

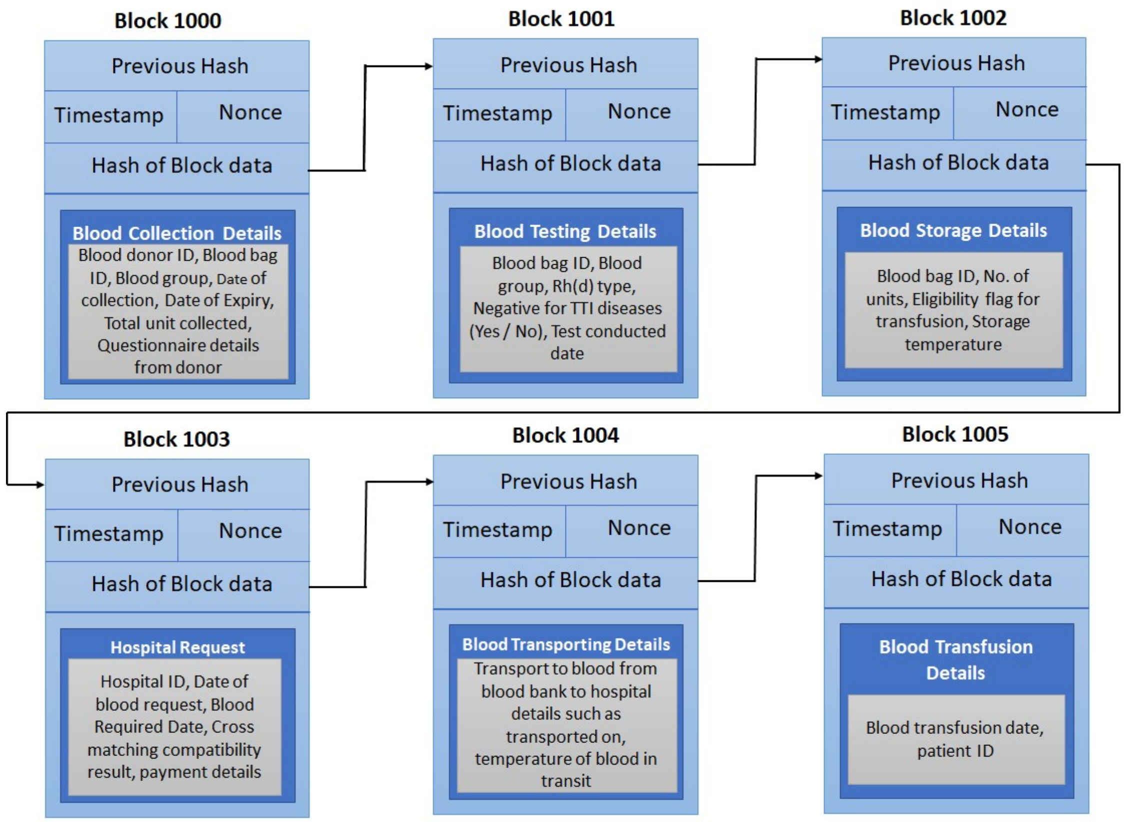

Figure 5: Blood Donation Supply chain Management Details stored in a Block-chain

5.3.1.4 Hospital:

Hospital makes the request for blood to the blood bank using the web portal. Once the blood is arrived, they will do cross-matching of the blood. If it is suitable with the patient, then blood is transfused. Once blood transfusion is done, the same is been recorded in block-chain and the life-cycle of donated blood is ended at this point.

5.3.1.5 Patient:

In addition, to all the actors, we have added patients in the system. As some of the patients' are curious about knowing the history donated blood, they can verify the chain of history of the blood in the system by providing blood bag ID in web portal. This gives the confident of getting the blood.

5.3.2 Client Application & Rest API

Client application is nothing but the web application through which the participants can interact with the system. Front-end application can be created with HTML, CSS, ReactJS etc. Backend code can be designed Go Lang, Java, Node JS. In our implementation we have taken Node JS (Javascript) for backend and chain code.

Rest API is an application programming interface that uses HTTP requests to communicate with databases / blockchain ledger. It can be used to invoke a transaction or query or to view the state of the set of transactions. In our implementation Rest API can be used to check the blood status, donor's donation history etc.

5.3.3 Blockchain Ledger & CouchDB

In our implementation if we provide Blood bag ID, transaction log will tell the history of traversal of blood between different centres with timestamp. World state will tell at present time, where the blood bag is available. ie UNDER_TESTING, STORED, IN_TRANSIT, CONSUMED.

5.3.4 MongoDB

MongoDB is basically a NoSQL database [31], which comes under document database model. It is a non-relational database that supports complex data types [32]. In our system we use MongoDB to store possible changing values such as donor's information (donor's mobile number, email which may change time to time), hospital contact number etc. Not all the details can be store in blockchain. It is mainly used to store immutable (non-changeable) details such as blood collected date, tested date, storage date, blood bag details, blood consumed date etc in Block-chain and CouchDB.

5.3.5 Machine Learning (ML) Based TTI Detection Module

ML is a branch of computer science which takes past data, learns from it, constructs a model out of it, and act to the future data in its own without explicit coding [33]. It also aids in predicting the future values as well decision making in many fields. ML is of three types (i) Supervised learning, (ii) Unsupervised learning, (iii) Reinforcement learning.

In our proposed system, after collection of blood from donor, it cannot be directly consumed. There are some blood tests to be conducted to check for transfusion transmissible infections such as Hepatitis B, Hepatitis C, HIV, Syphilis, and Malaria. We plan to involve ML techniques in clinical data results obtained from blood tests to do medical decision making if the blood is infected with TTI diseases or not. In our current proposed system, we have provided only the ideology but we plan to do detailed research in our next research article.

In real-time blood donation system the transport vehicles are used to transport the blood from blood bank to hospital. If the distance between the source and destination is long, with proper IOT devices we can track the temperature of the blood. IOT device can also be implemented in blood storage centre to monitor the blood storage temperature. However, tracking temperature with IOT device is out of scope of our system.

6. Implementation of the proposed system

In this research work, we have developed business logic for donor registration, blood collection details using Node JS with normal backend code and chaincode. The implementation tools used for our research are mentioned in Table 2.

System Component	Description / Specification
Operating System	Ubuntu 20.04
CPU	Intel(R) Core(TM) i3-2370M CPU @ 2.40GHz
Primary Memory (RAM)	8 GB
Hyperledger Fabric	Hyperledger Fabric v2.2
IDE (Platform)	Visual Studio
Database	MongoDB
Backend Code Development	Node JS v10.24.1
Docker Engine	Docker version 20.10.7
Docker Composer	version 1.29.2

Table 2: System Specification

Only valid donors are allowed to be registered into system. Donor selection process is a crucial one as the number of eligibility conditions is relatively high. Below diagram (Figure 6) illustrates the various steps involved in donor selection process.

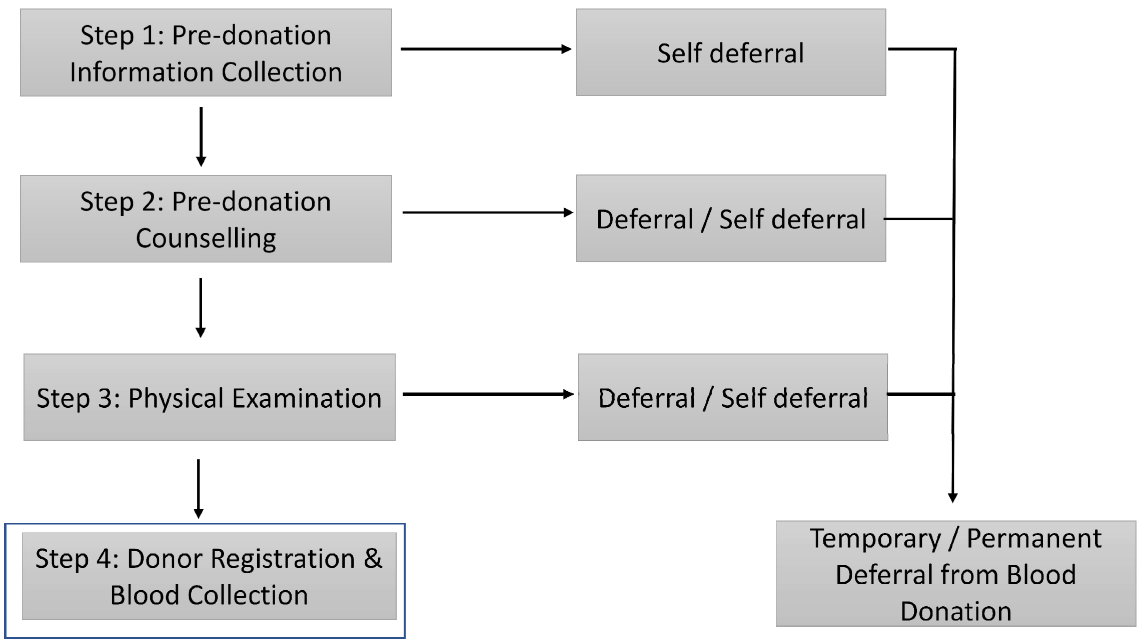

Figure 6: Steps involved in Donor Selection Process

First, second and third steps involve in manual and physical process by medical officers and blood collection centre. Once it passes through all the three steps, the donor is considered eligible for donation. However the tests for TTI diseases will be conducted later with which alone the donor's blood will be considered for transfusion. In first three steps if there exist any discrepancies with the expected values, then the donation will be deferred temporarily or permanently. At step 4, donor registration will be done online with the details collected from donor as well as medical officer. The collected details are stored in MongoDB and Blockchain. Before storing the details in blockchain, the donor eligibility conditions are checked through chain code and then are stored in blockchain. Below is the algorithm (Algorithm 1) for checking the donor's eligibility for blood donation.

Algorithm 1: Checking Donor's basic eligibility for Blood donation

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Input: Donor's details: Age of the donor (D_{age}), Donor's present weight in Kg (D_{weight}), Donor's willingness to donate Flag (D_{WF}), No known diseases or problems flag (D_{fit}), Body temperature (D_{temp}), Haemoglobin level (D_{haemo}), Donor's gender (D_{gender}), Donor's last donation date (D_{LDD})

Output: Accept / Defer / Reject for Donation

if $D_{age} >= 18$ and $D_{age} <= 65$ **then**
    if $D_{weight} >= 45$ **then**
        if D_{WF} = True & if D_{fit} = True **then**
            Do Donor registration & Add donor's details to blockchain network
        else
            Deferral from blood donation
    else
        Deferral from blood donation
else
    Not eligible for blood donation
if Donor registration done **then**
    if body temperature $D_{temp} <= 98.6^{o}$ F and $D_{haemo} >= 12.5$ g/dL **then**
        if D_{gender}=Male &D_{LDD} > 90 days **then**
            Accept for donation
        if D_{gender}=Female &D_{LDD} > 120days **then**
            Accept for donation
    else
        Reject for donation
else
    Redirect the user to do Donor Registration
end

After checking the donor's eligibility for donation, blood collection happens in blood bank or blood collection centre. Blood is collected in a bag, which is then stored in blood bank. Below algorithm (Algorithm 2) is for checking the collected blood if it is eligible for transfusion. The same is implemented with chaincode using Node.js

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Algorithm 2: Checking if collected blood can be taken for next level of Testing before transfusion & can be stored in blockchain.

Input: Donor's physical details while blood collection & blood collection details: Blood expiry date of collected blood (B_{ED}), Pre-donation medical examination and counselling done Flag (D_{Flag})

Output: Store the details in blockchain / discard the blood

1: **if** B_{ED}> current_date & D_{Flag} = True **then**

2: Collected blood can be considered for transfusion and can be stored in blockchain

3: **else**

4: Reject for transfusion & discard the blood

5: **end**

The chaincode methods developed for storing and retrievel of donor's details and blood collection details as listed in Table 3.

Chaincode Method	Type	Job
createDonorRegDetails	Transaction (through invoke method)	This method checks for the basic eligibility of donor and allow/deny the donor to register and details are stored in blockchain
createDonationDetails	Transaction (through invoke method)	This method checks for the basic conditions before blood collection from donor and the collection and collection centre details are stored in blockchain.
getDonorRegDetails	Transaction (through query method)	This method takes the corresponding donor's information from ledger based on donorid and displays the same
getDonationDetails	Transaction (through query method)	This method takes the blood bag and donor's details if provided with blood bag id.

Table 3: Implemented Chaincode methods with details

Below figures (Figure 9, 10), are the screenshots taken from our implementation environment shows the donor details and blood collection details stored in the blockchain ledger.

The request to the blockchain network is made through Advanced REST Client (ARC) tool. Below (Figure 7 & 8) are the sample request sent through ARC. In the JSON format the donor details and blood collection details are sent. But in real time, client applications can be created with React JS, HTML and CSS to create interactive webpages for getting the data from the users of the system.

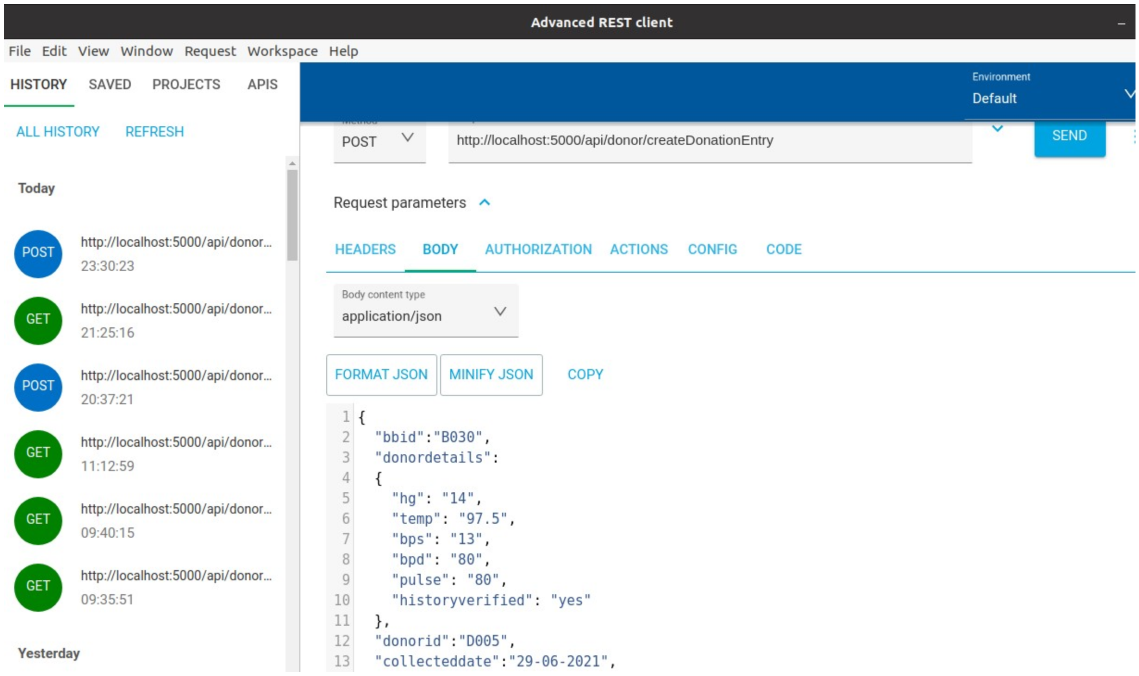

Figure 7: JSON object of Blood collection details sent through Advanced Rest Client

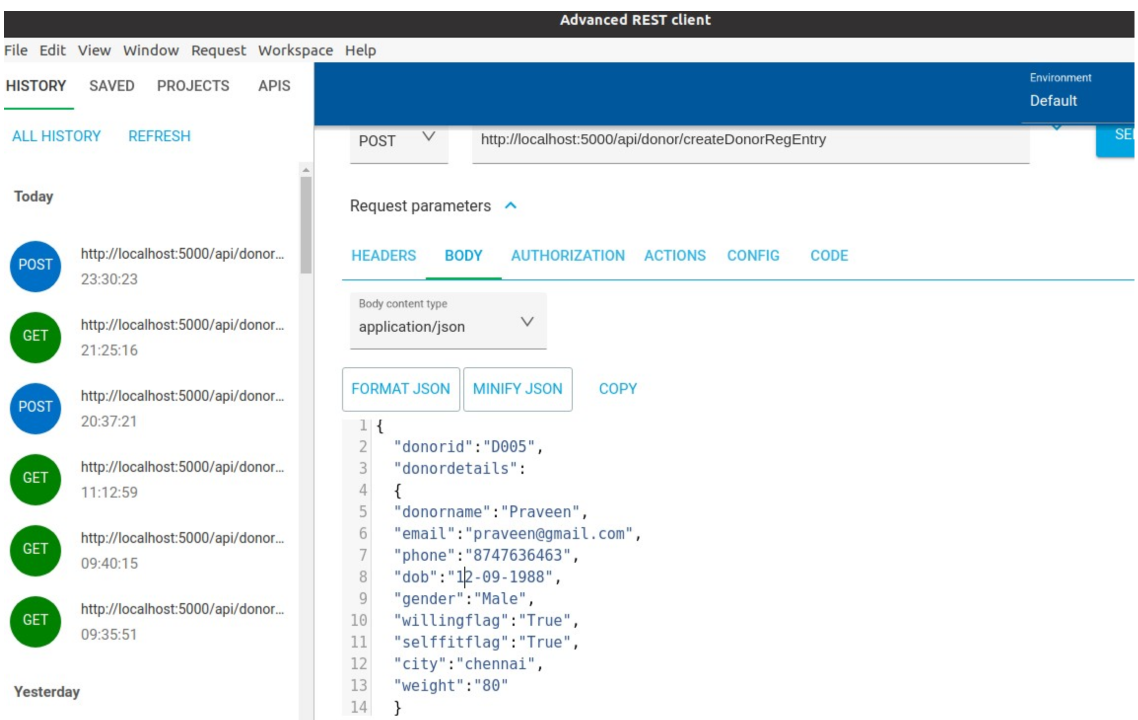

Figure 8: JSON object of Donor's registration details in Advanced Rest Client

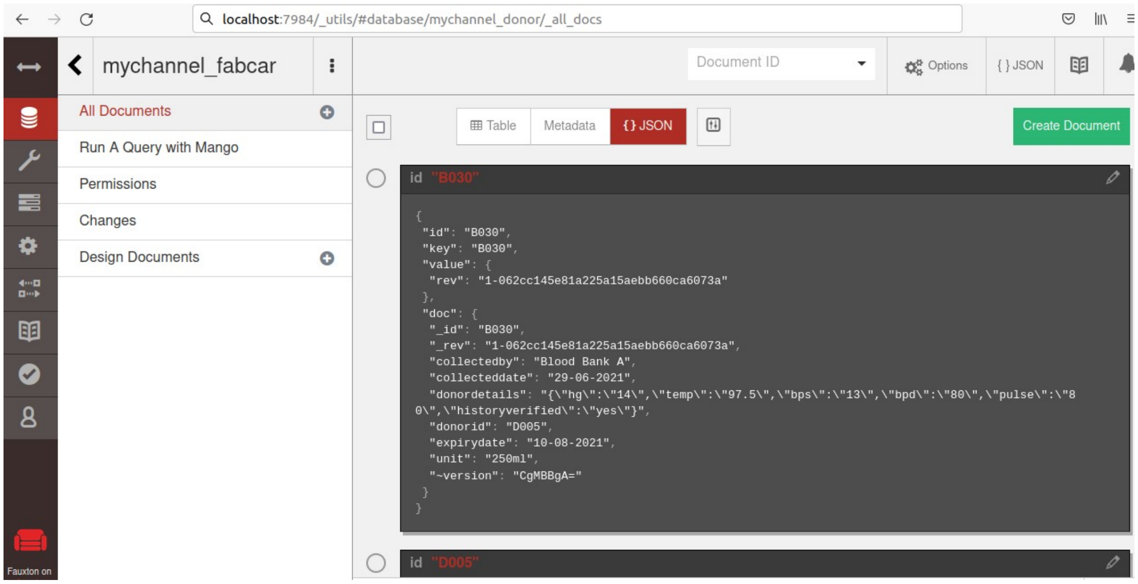

Figure 9: Blood bag details after blood collection stored in blockchain ledger

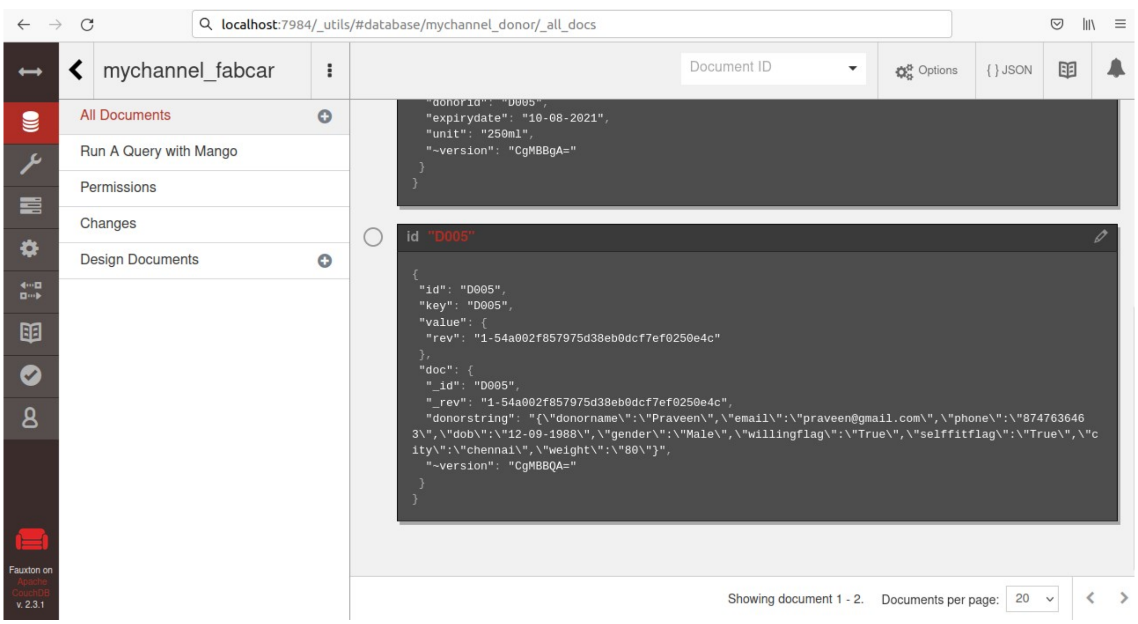

Figure 10: Donor registration details stored in blockchain ledger

Figure 9 & Figure 10, clearly shows how the details are stored in blockchain ledger. Once the details stored in ledger it can never be changed or tampered. With the help of blockchain network we have implemented the initial part of our implementation of blood donation management system.

7. Conclusion & Future Work

The role of blockchain and machine learning plays a major role in all the fields. With the help of these latest technologies, process can be thoroughly verified in supply chain management and other fields as well. In this chapter we have proposed a unique architecture for blood donation supply chain management and have implemented the part of the proposed architecture ie donor's registration and blood collection stages of the blood transfusion system. Donor's basic details are verified with chaincode before donation. Also the collected blood is stored with various validated details in blockchain which ensures the valid data entry in the system. Hence our solution provides immutability, transparency, security and privacy of data for various stakeholders in addition to reliability of the data stored in system. In our system we have used permissioned blockchain network and hence only the valid users can enter into the system. Once the blood collection details are stored in the blockchain, donor is intimated of the same which ensures that the collected blood is under process. This can enable traceability and transparency for the stakeholders involved in the system. In our future work, we plan to implement blood testing process, storage process, transfusion to patient etc. In addition, we plan to implement the machine learning module for detecting TTI disease. Also we plan to optimize the performance of the system by means of block size, endorsement policy and also increasing the security by means of cryptographic algorithm.

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