Enhancing Healthcare using Blockchain Technology: Blood Donation Supply Chain

by

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FOREWORD

I would like to thank all the people who contributed to the success of my master’s degree and who helped me in writing this thesis.

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Finally, I dedicate this thesis to my mother and father, who were by my side since the beginnings of this journey, and my sister for her advice, moral support and constant encouragement.

Améliorer les soins de santé grâce à la technologie de la chaîne de blocs : Chaîne d'approvisionnement des dons de sang

Samin SADRI

RÉSUMÉ

La banque du sang est une affaire compliquée : c'est une industrie de plusieurs milliards de dollars où la majorité du produit est donné puis vendu par des organisations à but non lucratif. Selon les responsables gouvernementaux, la dégradation des normes de sécurité, la mauvaise formation des employés, la détérioration des équipements et le désir de faire des profits ont mis le secteur en péril. Les banques de sang se livrent une concurrence féroce pour obtenir les contrats d'approvisionnement des hôpitaux nationaux. Le sang peut également être raffiné en une variété de produits plus coûteux, comme le pétrole, les valeurs du marché fluctuant largement en fonction de l'offre et de la demande mondiales. L'objectif principal du choix de la technologie Blockchain est d'améliorer la traçabilité dans les processus de la chaîne d'approvisionnement ainsi que la traçabilité et le suivi des médicaments pendant la fabrication et l'expédition. Ils permettent également de tracer et de suivre les médicaments pendant la fabrication et l'expédition. Dans cette étude, nous avons déployé une solution basée sur la blockchain pour la chaîne d'approvisionnement des dons de sang. Les systèmes actuels étant vulnérables à la contamination et à la falsification, il est clair que la blockchain peut réduire le risque de don de sang contaminé. En outre, elle peut aider à vérifier la source du sang et à s'assurer qu'il provient d'une source fiable. La solution proposée permettra de réduire le risque éthique en créant un registre décentralisé des donneurs. En utilisant ce système, les donneurs peuvent contrôler leurs données et le processus de don. Dans notre système, nous avons utilisé Blockchain, qui nous a permis d'introduire la transparence et la traçabilité ainsi qu'une couche supplémentaire de sécurité dans la chaîne d'approvisionnement du don de sang. En appliquant la fonctionnalité de contrat intelligent dans Ethereum Blockchain, nous avons pu concevoir une gestion d'accès décentralisée avancée pour les entités dans notre système proposé. Pour évaluer notre solution proposée, nous avons évalué notre système de différents points de vue et en optimisant notre conception, nous avons observé que la consommation de gaz a été considérablement réduite par rapport aux contrats intelligents similaires de la chaîne d'approvisionnement. Notre système aidera à créer un don de sang innovant qui permettrait d'augmenter le nombre de donneurs à l'avenir.

Mots-clés: Chaîne d'approvisionnement, Don du sang, Chaîne de blocs

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ABSTRACT

Blood banking is a complicated business: it's a multibillion-dollar industry where the majority of the product is donated and then sold by nonprofit organizations. Slipping safety standards, poor employee training, deteriorating equipment and a desire for profits, according to government officials, have put the industry in jeopardy. Blood banks compete fiercely for contracts to supply domestic hospitals. Blood can also be refined into a variety of higher-priced products, similar to oil, with market values fluctuating widely based on global supply and demand.(new your times) The main goal of choosing Blockchain technology is to improve the traceability in supply chain processes as well as tracing and tracking drugs during manufacturing and shipment. They also trace and track drugs during manufacturing and shipment. In this study, we deployed a blockchain-based solution for the blood donation supply chain. Because current systems are vulnerable to contamination and falsification, it is clear that the blockchain can reduce the risk of contaminated blood donation. Moreover it can help to verify the source of blood and make sure it comes from a trusted source. The proposed solution will decrease ethical risk by creating a decentralized donor registry. By using this system, donors can control their data and donation process. In our system, we used Blockchain, which enabled us to introduce transparency and traceability along with additional layer of security in the Blood donation supply chain. By applying the smart contract feature in Ethereum Blockchain we were able to design an advanced decentralized access management for the entities in our proposed system. For evaluating our proposed solution, we assessed our system from different perspectives and by optimizing our design, we observed that gas consumption was decreased significantly in comparison to the similar supply chain smart contracts. Our system will help to create an innovative blood donation that would help to increase the number of donors in the future.

Keywords: Supply Chain, Blood Donation, Blockchain

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LIST OF ABBREVIATIONS

ETS	École de Technologie Supérieure
DLT	Distributed Ledger Technology
DAG	Directed Acryclic Graph
TPS	Transactions Per Second
DOS	Denial Of Service
POW	Proof Of Work
KYC	Know Your Customer
KYB	Know Your Business
FDA	U.S. Food and Drug Administration
EVM	Ethereum Virtual Machine
KVS	Key-Value Store
IoT	Internet of Things
GDP	Good Distribution Practices
SCM	Supply Chain Management
BDSC	Blood Donation Supply Chain
ABI	Application Binary Interface
EU	European Union
JSON	Java SCript Object Notation
HTTP	Hyper Text Transfer Protocol

REST	Representational State Transfer
API	Application Programming Interface
WHO	World Health Organisation
GHN	Gem Health Network
EHS	Electronic Health Record
BFT	Byzantine Fault Tolerant
TCP	Tendermint Consensus Protocol
PDS	Patient Data Structure
LDS	Login Data Structure
OBDI	Open Blood Donation Index
ORDI	Open Research Data Index
SIS	Sysmbiq Infusion System
IoHT	Internet of Healthy Things
AHT	Anonymized Health Tokens
USNS	United States National Strategy
GSCS	Global Supply Chain Security
DSCSA	Drug Supply Chain Security Act
HF	Hyperledger Fabric

INTRODUCTION

Blood has a crucial role in human life and delivers essential substances like nutrients and oxygen to the cells (Sadri, Shahzad & Zhang, 2021). Blood transfusion is a way of adding blood to the human body after an illness or injury. For medical treatment, availability of blood is very important because no other substance exists to replace blood. On the other hand, there is always the risk of receiving tainted blood, which has previously resulted in the spread of HIV and other diseases between people, or someone else attempting to donate blood under a false identity. The need for blood and blood products is growing every year, so an increase in blood donation is urgently needed (Kumar & Dhanya, 2020).

According to the "American Red Cross," blood is a valuable resource, and it is critical to ensure that it is not wasted (Cross, 2017). In Quebec, anyone in good health and has age 18 or more than that and also meet Hema-Quebec eligibility criteria can donate blood every 56 days, that means 6 times per year (Lavoie & Lapierre, 2020). In Canada, sixty percent are eligible to donate blood and based on the study that done before, just four percent of eligible Canadians donate blood each year because Donors have a hazy understanding of the blood donation process; most of them only know about the donation part and have no idea what will happen to their blood or how many products of blood will be extracted from it. Whereas, if there is a system in place that allows them to see the entire process and track their donated blood all the way to the end, they will be far more motivated to do so. On the other side, the number of elderly people (aged 65+) will be increased to 9.8 million by 2036 and that includes twenty-five percent of the total population and this group of people need medical resources which involve procedures that are based on blood products (Drackley, Newbold, Paez & Heddle, 2012). A shortage of 25–40 % in the blood supply around the year 2035, has been predicted in Canada (Drackley *et al.*, 2012) thereby, always there is a need for blood and this process never stop (Gargava & He, 2018).

0.1 Challenges and Overview of Methodology Used

0.1.1 1st Challenge: Blood Contamination

Unfortunately, around 600 people have been infected with HIV, AIDS, and Syphilis as a result of contaminated blood transfusions in the last two decades. Furthermore, in developing countries like South Africa and India, transfusion polluted blood is common (Gargava & He, 2018). There are several risks associated with carrying an effective blood donation supply chain. For example, in the late 80s, HIV infections had reached epidemic proportions due to the polluted blood carried in the supply chain (Farrugia, 2016). There are also some ethical risks involved among others, the donors that belong to lower social status, such as underprivileged and drug addicts, will be more motivated to donate blood frequently by remunerating donors, although the health consequences of those frequent donors are not very clear (Peltoniemi & Ihalainen, 2019). These are efforts incurring important risks in terms of infection and the quality of blood and its actual type. As a result, it is clear that the occurrence of any or all of these risks would have a significant reputational impact on the entire supply chain ecosystem (Kumar & Dhanya, 2020) , (Agency, 2020) .

0.1.2 2nd Challenge: Identity Impersonation in Blood Donation

Regulators are paying attention to the serious issues and setting rules that should be followed in the blood supply chain.FDA, Department of Health and Human Services define various standards for laboratories, general requirements, labelling, transfusion and circulation of information specifically for blood and its components (Farrugia, 2016) , (Peltoniemi & Ihalainen, 2019). It's very likely that the blood will become contaminated (e.g., polluted blood) during the supply chain, or that it will be replaced or labelled with a different type, either intentionally or unintentionally. (Agency, 2020) . The other problem in the blood supply chain process is that the identity of the donor cannot be verified, and there is a possibility of identity impersonation. Another challenge of every supply chain process is protecting the privacy of information. In the blood donation process, keeping the donor information secure is really important. A breach of confidentiality could have a negative impact on the blood donation supply chain. The use of unique numbers for donors and donations, as well as codes for infection markers, should ensure the confidentiality of donor records. The issue of confidentiality is sometimes referred to as "privacy rules" or "privacy laws." (WHO, 2014)

0.1.3 Research Objective

Our objective is to provide traceability, transparency and security to the blood supply chain, in order to address issues with blood contamination and identity impersonation. To accomplish this, we propose in this thesis a novel supply chain solution for blood donation by means of having a distributed, public (permissionless) Blockchain. The main goal of the proposed solution is having the supply chain process with more traceability, transparency and security. Even though this proposed solution is based on a public Blockchain, access control vulnerabilities have been reduced by using a smart role-based access management scheme for different participants in the supply chain. Moreover, privacy-preserving concerns have been alleviated by encrypting the donor's personal information before submitting it to the Blockchain. Blockchain presents high-level supply chain resiliency and security, decreases bottlenecks in third-party certification and reduces the need for paper-based documentation (Kauschke,P.and Tipping, 2016).

0.1.4 Proposed Approach

To address the two aforementioned challenges, we require the supply chain process that involves several steps in which information needs to be shared between relevant parties. And it is clear that using a centralized management system for such a complicated supply chain would not be a rational decision, since it has some challenges such as making the central authority a single point of failure, and also all the entities performance would only depend and rely on the supply chain management system's operation. These parties in the Blood supply chain include donors, blood service, blood control center, distributor, hospital, and patients. The supply chain process has remarkable challenges related to scalability and immutability, such as handling the processes and considering the delays related to large number of users in the system. Having a blockchain in the blood donation system has numerous advantages:

- anyone can join (openness)
- blood donors can be rewarded (tokens)
- the blood availability is transparent to all (transparency)
- less transportation time and efficient blood bag monitoring (traceability)
- the network has no owner (distributed)
- guaranteed privacy (anonymization)
- the blood donors and receivers can see all their previous records (immutability)

Blockchain technology brings more transparency to our solution through the necessary encryption and control mechanisms, blockchain store information in a way that cannot be altered without recording the changes made. In our solution we creates efficiencies in processing transactions by optimizing our functions in our system. Besides all the blockchain advantages for our solution, there are some disadvantages. The first one is high energy consumption. Every node creation and simultaneously communicate with other nodes at the same time. Transparency is created in this way. For validating transactions, network miners using a considerable amount of computer power per second are trying to solve a lot of solutions. Activities like ensuring zero downtime, preparing data stored on the blockchain constantly unchangeable and censorship-resistant, burning electricity and time. Another challenge for the blockchain is signature verification, big computing power is essential for calculating the process of signing each transaction with the cryptographic scheme.

0.1.5 Thesis Outline

Chapter 1 explains the Blockchain fundamentals that are crucial to understand the rest of this thesis as well as realize the potential of the Blockchain Technology. chapter 2 provides a summary of related works in areas such as Health, Pharmaceutical, Food with a focus on Blockchain. Chapter 3 introduce our work process of Our paper published in the 23rd International Conference on Advanced Communication Technology (ICACT)(PyeongChang,

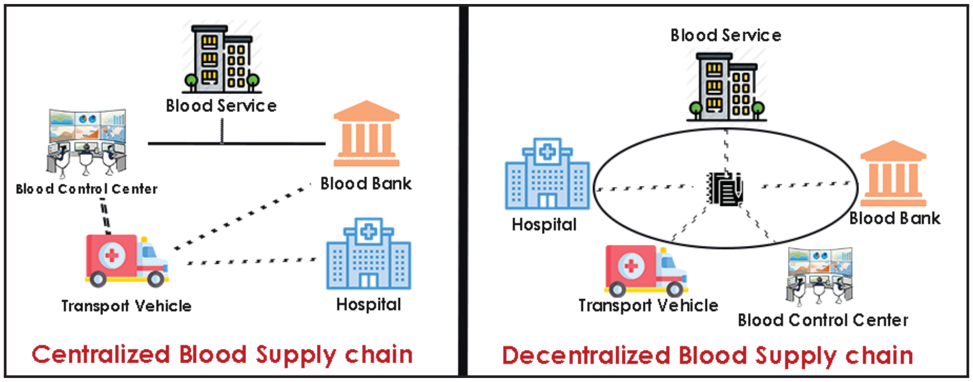


Figure 0.1 Decentralized vs Centralized Blood donation supply chain. Taken from Kim *et al.*, (2020)

Korea (South), Feb. 07-10, 2021). Chapter 4 delineates the design and implementation of our proposed solution which comprises the system architecture and design sections and also presents a detailed description of the development environment, and next the evaluation results and conclusions made from the research are shared. Furthermore, recommendations of the proposed solution are discussed in this chapter.

CHAPTER 1

BLOCKCHAIN BACKGROUND

In this chapter, foundational principles of the Blockchain are discussed and the tools and technologies in these criteria such as Ethereum smart contract, permissioned and permissionless blockchains are being reviewed.

1.1 Supply Chain (SC) and Supply Chain Management (SCM)

SC is described as the complete procedure of manufacturing and promoting commercial goods, this includes all phases from the providing of substances and the producer of the items to their delivery and selling (Sarkis, 2019) . Properly controlling SCs is vital for every enterprise that hopes To challenge For a company to fulfill customer orders, a practical, optimized SC is already so essential. Yet, it can also result in much lower costs if handled correctly and in shorter development cycles. SCM includes product development, sourcing, manufacturing, distribution, logistics, and more about SC operations (Linton, Boyson & Aje, 2014) . Without it, businesses are at risk of reducing their customers and losing a competitive edge in their respective industries. SCM is about building the most effective process possible and about reducing risks and ensuring that everything runs smoothly. That's because the SC is made up of so many components, from producing location to storage, stock management, and command accomplishment (GRIMSHAW, 2020a). every stage of this system bears many risks and probabilities to obstruct a customer's whole order.

In typical supply chain management, by using RFID technology, it can trace the product, but as soon as the product goes out of the chain, tracing and transferring ancient data related to the product to their clients will be hard.

In 2018, the incident of contaminated Romaine lettuces with fatal bacteria made a crisis. About five people have died, and more than 200 people in the US were infected (Fox, 2018). At that time, they could not find the source of the problem. Therefore, all remained lettuces were thrown

away. After this incident, Walmart decided to use blockchain to trace all the products from the soil to the dinner table (Smith 2018).
They can trace the origin within seconds, and the client can trust their food safety by using blockchain technology.

1.2 Blood Donation Supply Chain

The blood Donation Supply Chain includes different steps; at the First Step, after completing Health history and mini-physical tests, one pint of blood and several small test tubes of blood for testing will be collected and an identical barcode assigned to the donated pint of blood, test tubes and donor information. At the second step, the donated blood at the laboratory is processed and separate Into different components: Red cells, Platelets and Plasma and every component will be packed as a "unit," based on the standards that doctors will use when transfusing the patient. At the third step, parallel with step two, test tubes are also tested for checking the donated blood is healthy or infected; if the result is positive, donated blood will be discarded, and the donor will be notified. At the fourth step, every component of blood must be stored based on the standards; red cells stored in the refrigerator for up to 42 days; Platelets can be stored at room temperature for five days, and Plasma must be stored in freezers for up to one year. At the fifth step, blood is available to be shipped to the clinics or hospitals 24 hours a day and seven days a week, and finally, blood will be transfused to the patients that need it.

1.3 What is Blockchain Technology

Blockchain is a distributed ledger technology (DLT) that can be programmed to record and track any value like financial transactions, medical records. Information in the blockchain will be saved in the blocks and blocks connected to each other and created a chain of blocks. As soon as the record is added to the chain, it is tough to change the content of the record. Each block contains data, hash and the hash of the previous block. Hash is unique and identifies blocks and all of the contents, and hash is very useful when we want to detect changes in the block if the hash changes is no longer the same block. Blockchain uses a peer-to-peer network, and everyone allows to join, and when someone joins the network, he gets the full copy of the blockchain. When someone is creating a new block, that block is sent to everyone on the network and each node to make sure that it has not been tampered with; after that, each node asks this block to their own blockchain.

1.4 Ethereum and Smart Contracts

In this thesis, we designed and developed our solution on a blockchain platform called Ethereum. In 2014, Vitalik Buterin presented "A Next-Generation Smart Contract and Decentralized Application Platform," called Ethereum. Ether is the cryptocurrency of Ethereum, and Ethereum Virtual Machine is Turing-complete, which means it is a fully programmable blockchain.

The smart contract is a small program in Ethereum that connects transactions to the statement; smart contracts based on what language developers choose can be written in several languages. However, solidity is near to JavaScript and C programming language. It is the most popular smart contract programming language. A new generation for blockchain has started with the creation of Ethereum.

(Çağlıyangil, Erdem & Ozdagoglu, 2020)Companies realized that they could migrate some of their business processes to the blockchain with this new programmable blockchain, and this action will be helping to make the processes more transparent to the public and more traceable, and also helping to decrease the total cost and improve the security. The essential part is that they understand this migration and could solve most chronic problems.

These problems include issues of communication, human mistakes, manufacturing costs and fraud, all without trusting a central authority or third party.

In Ethereum network, gas is essential for the smart contracts to operate successfully. The component that calculates the quantity of computational operation that necessary for executing some operations on the Ethereum network applied to the Gas. Every transaction in the Ethereum needs computational resources, that means each transaction also needs fees.

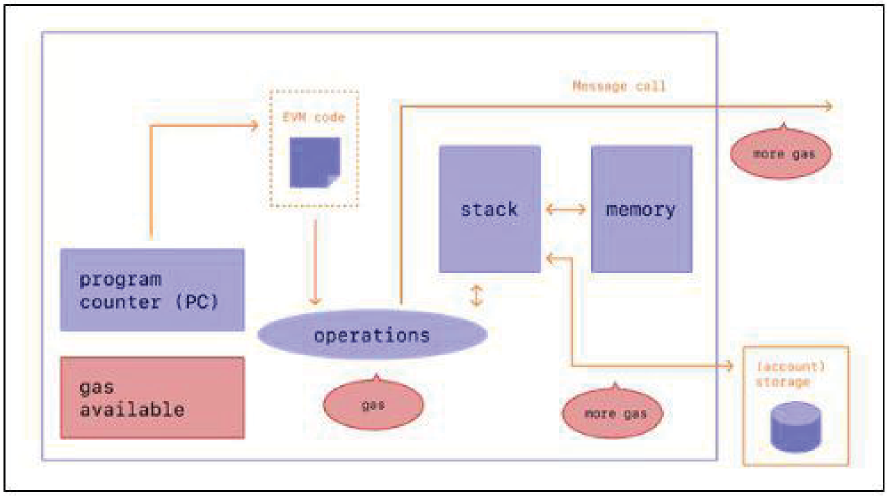


Figure 1.1 Gas Cost Diagram adapted from T., (2018)

Gas prices are defined in gwei which is the smallest unit of calculating gas consumption fee in Ethereum though gas fees are paid in Ethereums currency called Ether, which is equal to 1 ,000, 000 ,000 gwei. Ethereum network will be kept secure by the gas fees because spamming the network will be prevented by that. The maximum amount of gas that will be used in a transaction is called Gas Limit and it depends on transaction how much gas will be used, the complicated transactions that include smart contracts use more gas and the simple ones require a simple payment. The gas limit that is required for a standard ETH transfer is 21,000 units of gas. Ethereum Smart contract is intrinsic part of our project since it brings special functionalities to our system that enables automation of tasks and submission of data over a distributed data registry. Moreover, it enables having traceability and access management along with the processes occurring inside the supply chain.

CHAPTER 2

LITERATURE REVIEW

We will go over all of the blockchain-based supply chains in detail in this chapter, and we will look at the state-of-the-art works to see where the boundaries and flaws of integrating blockchain into supply chain systems are. In addition, we attempt to identify the roadblocks to achieving an ideal supply chain system, which would undoubtedly provide the necessary motivation for our work.

2.1 Blockchain Technology in Pharmaceutical Industry

Modum.io (Bocek, Rodrigues, Strasser & Stiller, 2017) AG is a startup that integrates Internet of Things (IoT) sensors and blockchain technology into the pharmaceutical industry to keep product temperature data immutable and accessible to the public, which can help to reduce operational costs in the pharmaceutical supply chain.

The IoT sensors measure the temperature of pharmaceutical products during shipment based on the Good Distribution Practices (GDP) regulation and managing the supply chain process of the medical product from the distribution step until they arrive at the client is very important.

Based on the updated regulation of the European Union (EU) “Good Distribution Practice of medicinal products for human use (GDP 2013/C 343/01) (Agency, 2020), Any change in a medicinal product, such as the temperature of the parcel, must be reported to both the distributor and the recipient of the product. The temperature of the medicinal products must also be monitored at all times.

By merging IoT sensors with blockchain technology, Modum.io will analyze all essential data during the supply chain process of medicinal products (Norton, 2016). The merging of this two technologies will assure the data reliability and makes it infeasible to modify the data.

A smart contract is executed as soon as delivery begins to ensure that all temperature rules are followed. The information stored in the blockchain is unchangeable and can be verified by other peers. For the time being, only the distributor and receiver have access to the data and reports, but the customer will be able to check the temperature in the near future.

The architecture of Modum.io includes backend, front end and IoT sensors and it contains the following components:

Ethereum(Team, 2016): Blockchain Network used to validate temperature data saved in the front end. Ethereum Virtual Machine (EVM) possible validation data by smart contract: Smart Contract is in charge of ensuring that the temperature data is associated with the shipments and that each new shipment is launched.

Database: For maintaining raw temperature data and user license, the system uses a relational database.

Server: Attempts to make communication between front end users and blockchain more accessible, as well as the design and alteration of smart contracts and the storage of data in the database. Consumers use mobile devices for recording new shipments and sending the temperature data to the server. Sensors are devices that can be matched with Bluetooth technology and programmed to send data to the mobile devices. The temperature adaptation will be ensured on the back end by a smart contract written with solidity. It is crucial to have a smart contact insuring that the GDP rules are adjusted and established on the server. The mapping between the shipment and the related smart contracts will be done by relational databases with low levels of complexity and fees.

At modum.io AG, the server hosts Ethereum nodes that participate in the Ethereum network and can monitor smart contract changes as well as create and call smart contracts. The Ethereum node uses JavaScript Object Notation (JSON) to communicate with the Hyper Transfer Protocol (HTTP) server JSON. Because the raw temperature data is too large to be stored in smart contracts, it is instead stored in PostgreSQL; smart contracts validate the temperature range and save the verification result in the smart contract.

Clients communicate with servers on the front end using the Representational State Transfer (REST), Application Programming Interface (API), and they try to encode and decode requests and responses using JSON. About 7576 temperature data points were measured for about 55 shipments in Modum.io AG's first pilot project, and in the second phase of the project, they plan to increase the number of shipments to about 500 with more distributors and wholesalers.

In addition, there is some difficulties due to the warehouses' poor internet connections. As a result, it is preferable to include offline capabilities in the application. During the first phase of the project, the get Ethereum client version is not resilient, and the server storage needed to be increased to withstand DoS attacks on Ethereum. The blockchain must be resynchronized to see how the fork turns out. That will take a couple of days and the GUI has to be simple.

Many financial institutions decided to use blockchain to reduce costs and bureaucracy; Moreover, non-financial institutions and startups prefer to use this technology as well. Using blockchain technology in pharmaceuticals allows (Plotnikov & Kuznetsova, 2018) to track all stages of drug production and ensures their quality. Blockchain technology In the pharmaceutical helps to track all stages of drug production furthermore the quality of pharmaceutical products is guaranteed.

Digital technology advancements not only make the economic interaction safer, faster, and less expensive, but also they aid in the resolution of many societal and economic problems, ultimately improving the economic and social aspects. In the case of the pharmaceutical industry, the author of this article examined these positive effects. According to World Health Organization (WHO) statistics, the illegal global drug market worths around 30 billion, which means one out of every ten medicines in developing countries is fake. People who use counterfeit medicine not only lose money, but also risk their lives and health. Every year, around 100,000 children die from pneumonia as a result of the use of non-original antibiotics. The author of the article expresses concern about the problem of drug quality and legitimacy in Russia. Every pharma firm has network, database, reporting, and accounting system. In addition, the information is unrelated to the previous. As a result, being a part of the drug supply chain implies that there is not an easy way for these companies and government agencies to exchange information. Furthermore, the completeness and reliability of transferred information cannot be guaranteed, posing a risk to medicine consumers by increasing the likelihood of the fake drug production and unregistered medicine importation into the country.

Walmart is one of the first companies to use blockchain technology to track food products from the producer to the end user, demonstrating the need for a system that uses digital technologies to monitor all steps of developing and supplying pharmaceutical products. It is difficult to create a blockchain-based pharmaceutical system at first, and it also requires the solution of a complex of organizational, technological, legal, social, and economic tasks; accordingly, the pilot projects are recommended.

Since April 2018, Russia have a blockchain-based system for tracking the distribution of medicines. During the project's implementation, the hospital created a single register of electronic prescriptions that is integrated with the hospital information system. This system is open, and patients with access have the ability to manage their personal medical information. The use of blockchain in this case aids in the protection of personal data from unauthorized access and ensures its reliability. Blockchain technology can be used at any point in the pharmaceutical supply chain. One method could be to label drugs with a special chip and use blockchain technology and these chips to distinguish natural medicine from counterfeit medicine. Big pharmaceutical companies like Pfizer, Amgen, and Sanofi have used blockchain to document drug testing, which has sped up the process of developing new drugs and bringing them to market. Russia, China, and other countries fighting drug counterfeiting may be involved in international cooperation in the future. This project is a good example of how blockchain can be used to facilitate supply chain tracking processes, and by analyzing its benefits and drawbacks, we can improve the design of our system.

2.2 Blockchain Technology and Medical Records

The work presented in (McGhin, Choo, Liu & He, 2019) attempts to comprehend the current state of research in relation to the healthcare blockchain application. As this type of data becomes easier to collect through smart devices, privacy of patient medical information and sharing them is a concern. In this regard, the healthcare industry has some needs such as authentication, compatibility, data sharing, exchange of medical records, and evaluation for mobile health. The goal of this paper is to examine the current state of research on the feasibility of blockchain applications in healthcare. The sharing and privacy of patient medical information is a concern, as this information is becoming easier to gather through smart devices, and the healthcare industry has specific requirements in this regard, such as authentication, compatibility, data sharing, exchange of medical records and evaluation for mobile health.

System Security: The need for access controls and authentication is felt to maintain the integrity, confidentiality, and availability of medical information. Medical data is divided into two categories. One is medical data, which is gathered from body sensors and other applications, and the other is medical records, which includes patient files. To maintain the integrity, confidentiality, and availability of medical information , access controls and authentication are required.

Compatibility: This feature is required in a medical information system to share and transfer data between different sources. One of the most crucial problems that medical institutions encounter, is centralized data storage, which slows down access to medical data and reduces system interoperability.

Data Sharing: Medical information access and sharing are security issues; sometimes, storing medical information in multiple locations and updating scattered medical information are difficult because patients do not have a unified view of the disorganized data.

Mobility: Mobility is comprised of three major components: mobile health, wireless, and IoT. Patients are becoming more mobile in the healthcare industry, and medical information must also meet the same level of portability. Furthermore, real-time sharing and access to medical information from any device and from any location are required. Blockchain technology has some useful features that can be applied in the healthcare industry. The first one is decentralized storage, which is one of the key features that improves the security and authentication of data stored in the system. In this feature saving, data is transferred from a centralized type and a single major server to multiple servers via blockchain's ledger. This feature makes the absolute access to the data easier and faster which is a considerable improvement in the system's interoperability. Blockchain systems must have immutability, integrity, and data security. Instead of storing the data on a single computer, the data is stored on multiple computers. The security is improved because the malicious actor is unable to make any changes without changing the information on all systems. The second authentication is accomplished by requiring a distinct private key linked to a public key to begin the construction, modification, or visibility of data stored in a blockchain. Because blockchain has limitless potential in healthcare technology, there are specific software solutions and variety of existing experiments in this area that are discussed in this paper. Healthcare data sharing via the Gem Health Network (GHN) is one of them. Now a days, we are confronted with a vast number of medical information whose security and privilege policies are critical. The centralized database storing method has some problems with security and interoperability when sharing medical records, particularly in medical tourism when someone needs medical care in another country. In this situation, accessing such information and the patient's medical profile is extremely difficult. GHN attempts to solve this problem by utilizing Ethereum blockchain technology. An authorized person now has real-time access to medical information by creating a shared network infrastructure and removing the centralized database limitation. Certainly, there is a challenge in terms of how information can be recovered if the patient loses the public key.

OmniPHR: It is a blockchain-based system that provides a unified view of a patient's medical records and Electronic Health Records (EHR) differences. Medical information in an EHR is updated by a medical professional, but in a PHR, this process is handled by the patient. OmniPHR is a blockchain-based operational model that focuses on the distribution and compatibility of PHR data with a unified view of health records splitting across several health organizations. The problem with this approach is that the medical information must follow the specific data structure supported by this model.

MeDshare: This study focuses on the shared medical data between medical professionals who work in an untrustworthy environment. MeDshare provides data provenance, auditing, and management of the shared medical data between large companies in a cloud-based environment. Clinical trials and precision medicine blockchain is a platform used in MeDshare that adds data integrity to clinical trial data, and the use of blockchain in this approach helps to increase transparency and accuracy of the data analytics. Today's healthcare industry encounters variety of issues that can be addressed by utilizing new technology. Blockchain technology in healthcare, in particular, aims to aid in the improvement of security, integrity, availability, and authentication through block-related infrastructure.

Another study presented in (Gupta, 2019) discusses various blockchain solutions that can be used to implement EMR in a different ways. Medi-Chain uses BigChainDB to leverage the Byzantine Fault Tolerant (BFT) system with state replication across multiple nodes as a blockchain-based technology.
Desktop and blockchain applications are included in Medi-Chain. The Medi-Chain application is built-in, and it tries to cover the back-end operation by providing users with a level of abstraction. The access control list, which includes the login details of doctors and administrators, aids blockchain in access control. patients privacy is guarantied by encrypting patient information in this method. Storing medical data for multiple patients is a monumental task. Hence, built-in functional database management and BigchainDB as the blockchain architecture are necessary. When using the BSON data type, the read and write processes in BigchainDB are faster because multiple data entries are stored in a single entity or object. BigchainDB has a fast transaction rate of 320 transactions per second, which means 1 million transactions can be completed in just 26 minutes. The BSON data structure used by the Medi-Chain blockchain is similar to JSON, but it includes support for storing timestamps, dates, and binary objects, as well as a faster encoder to support fast transactions. Furthermore, BigchainDB is a type of blockchain solution that is 33.3% fault-tolerant. This fault-tolerant percentage is due to using the Tendermint Consensus Protocol (TCP), and its transaction fee is lower than the Hyperledger blockchain service.
MediChain is attempting to solve two issues with the blockchain-based decentralized application: transaction costs and adoption facilitation by providing a user-friendly interface for the general public. The Patient Data Structure (PDS), which includes basic patient information such as name, gender, age, and health history, is one of the four parts of the MediChain architecture. When a doctor prescribes medication for a patient, three things are verified by blockchain: patient data associated with the prescription, the key used by a doctor to sign transactions, and the prescription data structure. The third part of the MediChain architecture is Login Data Structure (LDS). In this architecture, aside from saving patients information, the login details

are also saved. When a query for the number is made, it can display all patient data, previous prescriptions, and login verification details. MediChain is a blockchain-based medical record system that contains millions of patient records and can be used in a variety of healthcare applications and frameworks. Doctors can see potential blood donors and their blood types using the Open Blood Donation Index (OBDI). Medi-partnership Chain's with e-Insurance companies simplifies the billing and claims process, and the data in the Med-Chain blockchain can be used as an Open Research Data Index (ORDI) while maintaining patient privacy. Finally, MediChain presents IPFS based prescription data, which is an open, decentralized storage platform.

(Cyran, 2018) talks about health data sharing blockchain-based solutions and challenges, such as protecting sensitive medical data as well as installing and deploying blockchain software on various hospital systems.

Data Sharing and Security Solutions: The blockchain network actors can see decrypted transactions, which adds transparency to the system. Interactions between users and smart contracts are encrypted, but the blockchain network actors can see decrypted transactions.

The data on blockchain can be accessed by all users given the blockchain's transparency feature. When having sensitive data on blockchain that is not supposed to be seen, it's better to use an extra software to accelerate additional layers of encryption. This software controls the confidentiality of content fixed inside transaction data. In order to share the medical data between hospitals, users and groups need to have secret sharing solution compatible with hospital privacy and security. In this blockchain solution, the data owners who have access and sharing rights are defined. Every piece of data contains a descriptor, which is visible to everyone on the blockchain network.

The solution presented in this paper ensures that critical information is never exposed on the blockchain by utilizing private and document keys, which are critical for maintaining user-controlled data privacy and security. Moreover, this solution has an additional security level that maintains the critical property of cancellation, where the data owner can revoke access to the shared data. Even a private key receiver with the raw blockchain transaction is insufficient to gain data access. A specific virtual machine image supports this solution in this system, which is called containerization. Through a different infrastructure environment, the containerized platform implemented across several hospital systems, this concept ensures software mobility, clarifies implementation, and reduces preservation overhead. Easy deployment within the hospital structure necessitates solution measurability and services within the blockchain architecture that perform critical data distribution functions such as encryption, decryption, transaction signature assistance, and the storage of cryptographic artifacts linked to security best practices. The ability of this solution to activate semantic compatibility within and between hospital systems is critical to its operation.

The technologies used in this solution are the Ethereum platform for smart contract usability with Docker containers and distributed architecture using microservices. This technology uses different cryptographic algorithms to make this system more secure. Hashing and digital signature algorithms are necessary components for blockchain implementations to maintain data immutability and the authenticity of submitted transactions.

Blockchain technology is not designed for large transaction data payloads. Hence, a different software solution is used in this study for data sharing called Interplanetary File System (IFPS). This software works alongside blockchain nodes to maintain large files. All data is completely encrypted because this file storage is not centralized. The presented solution uses permissioned blockchain with encryption components, attempting to improve the compatibility of health data, security, and portability.

Finally, as part of a larger solution, this system relies on software elements embedded within EHR systems which are part of the blockchain network to propose health data.

2.2.1 Medical Devices and Medical Supplies

In recent years, millions of patients with pacemakers have been referred to hospitals for framework updates due to security failing to detect their devices as vulnerable to hacking. Another issue that Symbiq Infusion System (SIS) encounters is that someone could access the hospital network and change the patient's dosages. Blockchain has a vital role in lowering costs and enhancing patient immunity as well as fighting medical device falsification.

Table 2.1 Health and Blockchain related projects

Project List		
Company	**Features**	**Website**
Block Verifies	Present anti-falsify solutions for luxury goods and medications	http://www.blockverify.io
IBM Blockchain	working on food products supply chain management with different partners	https://www.ibm.com/blockchain/ Supply Chain
FarmaTrust	It's the UK-based organization design blockchain solution for pharmaceutical supply chain, Initial Coin Offering (ICO) principally for the European market	https://www.farmatrust.com
iSolve	It platform to break down data by creating a compatible platform to present systems and processes and can integrate new technology like Big Data and Machine Learning	http://isolve.io
Modum	Provide a blockchain-based solution for supply chain automation and intelligence with collaboration IoT sensor technology and artificial intelligence	http://modum.io
OriginTrail	Identified by Walmart Food Safety	https://origintrail.io
VeChain	Integrate blockchain and IoT in food and drug supply chain	https://www.vechain.com

The Internet of Healthy Things (IoHT) is a subclass of the IoT that focuses on health and well-being. Wearable sensors and autonomous instruments with usage involving activity, sleep, cardiac task, and some specific illness are among the "things." Bowhead Health, a linked tool that provides nutraceuticals, is one of the first blockchain solutions with IoHT. Patient health data and routines are presented as input in the form of Anonymized Health Tokens (AHTs). In public health, supply chain frustration includes disaster and crisis reduction and management, as well as a preventative presence for healthcare workers during public health crises and the acquisition of critical medicines and vaccines. In public health, blockchain is also referred to as cryptocurrencies, which can be thought of as a form of currency that can be used to better catalyze foreign aid and charity while reducing fraud and dishonesty in the field.

The following are some of the advantages of using blockchain technology to improve supply chain management:

- Decreasing inaccuracy and corruption
- reducing bureaucracy and paperwork delays
- improving stock management
- increasing consumer and partner trust

More research, sponsorship, design and implementation of new solutions are required to extend these benefits.

2.3 Blockchain and Health Supply Chain

Given the importance of patient safety and health, supply chain management in healthcare is more complicated and risky. Countless efforts are made to protect supply chain processes in general, such as merchandise and goods, as outlined in the United States National Strategy (USNS) regarding Global Supply Chain Security (GSCS).

This strategy for securing the supply chain is important in any industry. But in the healthcare supply chain, there are several failures in healthcare delivery that directly affect patient safety. Failures include failing to secure the distribution of life-saving facilities, various events linked to supply chain fractures, and an increase in the number of sick and dying people. The grey market for medical products such as pharmaceuticals, medical devices, and biologics is estimated to be worth around 200 billion per year.

patient's safety requires effective supply chain management The collapse of the health supply chain is a sign of forgery medicine trading, medication shortages, and inventory outs. In this industry, solutions must be balanced and maximize the supply chain management, as well as ensuring an efficient supply chain with lower risks. Improving the strength, reliability, data provenance, and utility of all health supply chains is critical. Most of these issues necessitate cutting-edge supply chain management techniques that blockchain technology makes possible. This paper discusses how to improve supply chain management in a variety of industries, including pharmaceuticals, medical devices, Internet of Things, and public health. They can understand in the pharmaceutical supply chain using blockchain by using the Drug Supply Chain Security Act (DSCSA) approach is helpful or not.

Table 2.2 Blockchain Applicability, Taken from (Clauson *et al.*, 2018)

Requirement List		
Key Requirement	**Blockchain Applicability**	**Compatible**
Product identification	Every product needs a unique ID because it is essential for validating the product	YES
Product tracing	Blockchain lets the supply chain parties to tracing information and also validating important information will be done	YES
Product verification	Create a system to validate product ID and other related information	YES
Detection and response	Permits private and public actors to discover and report drugs supposed as fake, unauthorized and harmful	YES
Alerting	Build a shared structure to report the FDA and other collaborators if an illegal drug is discovered	YES
Data required	Build a shared archive of product and transaction data containing the validation of knowledge	YES

The current blood management system has some drawbacks in the presented work in (Kim *et al.*, 2020) such as the inability to display information in real-time and a lack of detailed blood information. This study aims to create an innovative blood cold chain system that helps reducing blood transfer time on special occasions. It also ensures the visibility information of the entire system. WHO defines the cold blood chain as a system that stores and transports blood at an exact temperature and conditions from donors to the final receiver.

In general, there are two crucial issues with the existing blood management system. One is about the clarity of the information flow from collection to usage or disposal. Blood is used not only for transfusion but also for medical research. Thus, some information such as quantity and disposal reasons need to be shared. Transferring blood is also the second critical issue which needs to improve. By creating a single record for each point in the blood donation supply chain system, blockchain technology improves traceability and brings more clarity to the system. Additionally, blockchain technology can recognize management problems of the entire blood cold chain actors due to the inability to forge or change with information. It also helps to have a stable blood donation supply chain.

(Kim *et al.*, 2020) introduces a Hyperledger Fabric (HF) architecture system suitable for B2B transactions. HF limits the entry of unauthorized participants by membership service. Walmart uses HF in the drug supply chain to prevent the production of counterfeit medicines with the help of IBM. This study utilizes a private blockchain system that only blood cold chain participants such as the general headquarters of the blood service, blood banks, examination centers, transportation mechanisms, and hospitals can have access to. This work presents two different scenarios: first, blood that is ready for transfusion and is consumed in hospitals. the second is the blood that cannot be supplied by a blood bank and delivered to the hospital in a timely manner.

All transactions are recorded and shared in a distributed ledger format within the blood cold chain network. In this design, a Key-Value Store (KVS) secures the most recent state by storing the transaction processing results. KVS is HF-based and manages the status of blood changes. This paper presents a system for supplying blood directly between hospitals during the golden hour when the blood bank does not deliver blood to the hospitals.

All participants must accept transactions, and the state of the verification nodes must remain synchronized to maintain the same ledger. Specific verification nodes use a distributed consensus algorithm in the HF. There are two benefits to this system: 1) a new system that reduces the costs. 2)The blood information is recorded at every supply point through the distributed ledger structure and transaction flow; this achievement resolves the limitation of information in the centralized blood cold chin system and helps information visibility.

The other paper (Pradhan, Singh & Kumar, 2021) considers the blood as one of the most sensitive medical records, which is problematic to distribute securely. It is considerably immutable to access, track, manage and share the blood-related data in a blockchain-based blood bank system. Therefore, this system serves as a secure communication hub between donors, doctors, testing laboratories, and patients. Having a blockchain in the blood-donation system has numerous advantages: 1) anyone can join (openness), 2) the blood donors can be rewarded (tokens), 3) the blood availability is transparent to all (transparency), 4) less transportation time and efficient blood bag monitoring (traceability), 5) the network has no owner (distributed) 6) guaranteed privacy (anonymization), 7) the blood donors and receivers can see all their previous records (immutability). In this approach, the donor, patient, and hospital information is saved in the block. This system allows for quick tracking of the bloodstock transfer to the nearest blood bank with a shortage of blood. Patient medical records are encrypted and saved in a private blockchain in this solution, and indexes are secured using a consortium blockchain. Each of the three entities, sender, receiver, and transport, has its own Ethereum address implemented as a smart contract in the Solidity Language.

The standard unit collects raw blood, which is labeled with an RFID tag. The temperature is monitored while the blood is being processed. Every blood bag contains a donor number, collection date, blood group type, and expiration date which are recorded in the blockchain. There are five steps in the blood processing process. First, the raw blood is tested for infectious diseases. Then, different blood types such as plasma, serum, and red blood cells are extracted in the laboratory; finally, before the transfusion, the compatibility of donors and patients needs to be assessed. This solution mitigates operational costs, human errors, and blood waste while increasing transparency and efficiency in the blood donation system.

2.4 Conclusion

This chapter has looked at several articles and works that have addressed issues relevant to our research. We investigated various blockchain-based solutions for the health supply chain, pharmaceutical industry, EMS. Based on the reviews in the literature, all of the discussed solutions can help to reduce the risks, maintain patient privacy, and make medical data records immutable. Furthermore, blockchain helps to maintain the originality of medical and pharmaceutical products during the supply chain process, which is exactly what we wanted to achieve with this study. We planed to make this process traceable, transparent, and secure by designing a blockchain-based solution for the blood donation supply chain.

CHAPTER 3

BLOCKCHAIN TRACEABILITY IN HEALTHCARE: BLOOD DONATION SUPPLY CHAIN

To support effective supply chain management (SCM) is a challenging issue for healthcare sectors. In healthcare, the requirements of blood to be fulfilled on demands are always directly or indirectly connected to its supply chain. For that, an effective blood supply chain system is required in which blood relevant information will be traceable at each stage of the blood supply (e.g., from donor to blood recipient), with trust and safety in testing, storage, and distribution phases and to keep the privacy of each donor. This study uses a Blockchain Ethereum platform as a solution to leverage traceability in the blood donation supply chain (BDSC). Blockchain is a highly efficient, decentralized, and peer-to-peer distributed technology deploys to provide end-to-end traceability, safety, immutability, and security in the BDSC ecosystem. As a part of this study, a role-based smart contract solution is used to define the access per each role, which therefore assists to ensure traceability and security of information in the BDSC ecosystem.
Index Terms: Supply chain management, Blockchain, Blood donation supply chain, smart contracts

3.1 Introduction

Blood plays an essential role in human life as it flows via the body and carries all the necessary substances. Blood transfusion always essential for various surgeries, organ transplants, parturition, critical treatments for cancers and anemia, and during other various emergencies. Therefore, the availability of blood is always integral to have for various medical treatments; there is no alternative of Blood to be replaced, thereby demands of blood or/and blood donation is also required and increasing to manage various medical treatment crowed in healthcare centers (Kumar & Dhanya, 2020) , (Lavoie & Lapierre, 2020).

Increased demand for blood products is having an impact on the number of donors and donations that are needed. In 2018–2019, 156,728 donors made 252,064 visits to blood drives or donor centers (Joseph, 2018) ,(Gargava & He, 2018) . In total, 136,908 donors made 216,639 donations.

A blood donor can give blood 1.6 times per year,on average (Lavoie & Lapierre, 2020) . Blood is considered a costly product, therefore it should avoid wasting, stated by the "American Red Cross", when almost 38% population of the United States is authorized to give blood, just around 10% of them are allowed to donate blood. So, the requests to donate blood in U.S. healthcare centers, however, is continuously increasing.It is somehow important that approximately every day, almost 40,000 pints of blood are required, thereby requests for blood never stops (Joseph, 2018). Unfortunately, in the last two decades, in the US about 600 cases because of transferring polluted blood at the blood donation centers got HIV, AIDS, and Syphilis. Besides, this problem is enormously widespread in developing areas, e.g. South Africa and India, where there are a subsidiary liability and traceability of blood (Gargava & He, 2018).
There are several risks associated to carry an effective blood donation supply chain. For example, in the late 80s, the infection-HIV was an epidemic because of the polluted blood carried in the supply chain (Farrugia, 2016). There are also some ethical risks, among others, the people that belong to lower social status, such as poor and drug addicts, will be enriched by remunerating donors to donate blood frequently, although the health consequences of that frequent donors are not very clear (Peltoniemi & Ihalainen, 2019).
Another concern is the counterfeiting and forgery of medicinal products. In this context, a falsified product will be replaced with the original product,whereas false medicinal products are illegal copies of original products(Agency, 2020). It is, there- fore, possible the blood during the supply chain was effective (e.g., polluted blood)or might intentionally or unintentionally replace or label with another type.These are efforts expose important risks in terms of infection and the quality of blood and its actual type. Thus, it is clear that all or one of these risks happening would have a serious reputational effect, and there probably have no trust in the whole supply chain ecosystem (Kumar & Dhanya, 2020), (Agency, 2020). Regulators are paying attention to the serious issues and set rules that should be followed in the blood supply chain. "U.S. Food and Drug Administration (FDA),Department of Health and Human Services" define various standards for laboratories,general requirements, labeling, transfusion, and circulation of information specifically for Blood and its components (Farrugia, 2016),(Peltoniemi & Ihalainen, 2019), (Agency, 2020).

Blockchain-based blood donation supply chain can help to reduce the various risks of contamination as this emerging technology came with solutions to verify the source of the blood by tracing information and trusted at every stage of the supply chain (Kumar & Dhanya, 2020),(Farrugia, 2016),(Peltoniemi & Ihalainen, 2019),(Agency, 2020). Thus, in this paper, we used Blockchain and smart contract solutions to enable a blood donation supply chain(BDSC) to trace the information in each stage of blood supply ecosystem- blood supply information is tracked and validated at each pace until the final stage of the supply chain; therefore, the patient receives the blood without having any risks that could associate with any traditional. supply chain.The conducted results in this study also examined the truth, safety, and provenance in the supply chain, and examined the privacy of each participant as part of the supply chain ecosystem. The rest of the paper is organized as follow: Section II details in-depth the literature on the existing important studies that have been done as parts of the supply chain, especially in cases of the blood supply chain; Section III details the Blockchain and its technological importance; Section IV details the system modeling for the proposed blood donation supply chain and the sample programming codes that used and executed to show and validate the results; Section V details the measured results and their relative discussions; Section VI concludes the overall paper works and details some important directions for future contributions.

3.2 Related Works

In (Jamil, Hang, Kim & Kim, 2019), the authors introduced a novel medical Blockchain model for the drug supply chain by using Hyperledger Fabric, a permissioned Blockchain platform.Blockchain solution was used to manage secure supply chain records by considering the most crucial problems in pharmacology, i.e., the fake drugs, as it is hard to discover counterfeits drugs because they're passing through variant complicated distributed networks- therefore, by featuring through Blockchain immutability and time stamping the fake drug and traffickers can easily be recognized.The overall was accomplished using permissioned Blockchain because, in the healthcare area, the permission less nature of Blockchain can lead to integrity and privacy problems for managing data related to the medical report, patient information, and drug management. So, the development of drug delivery Blockchain system in which all of the information related to electronic prescription, medicines, health specialist and patient's data is kept secure and shared in an effective way shared across various departments and hospitals. This platform improves the functionality of the control of equipment and clients inside of the firm by using a web-based user interface; the use of smart contracts present stability of drug data and other health-related information;by determining access control policy, the system authorizes the requests for the successful transactions. The Blockchain transaction has comprehensive "CRUD (create, read, update, and delete)" procedures that modify continuous information between nodes for increasing the security level in this platform. They also used the subnetwork solution to makes separate the entire network from another private network (Jamil *et al.*, 2019).

Modum.io AG used IoT sensors and Blockchain technology for tracking information during the transport of medical prod- ucts (Bocek *et al.*, 2017). Using these two technologies helps to make sure about the integrity of data, thus it will be hard to change the records. The use of smart contracts guarantees temperature during transportation. The architecture of modum.io AG includes the Ethereum Blockchain platform to check temperature data, per every new shipment for making sure that temperature standards will be followed the smart contract contents, users' certificates and to record unprocessed temperature data onto a database for further analysis. The server is set up to create and edit smart contracts, record data onto the database, allow end-users by their Mobile devices to execute and record new shipments, and followed up with the temperature information being stored onto the server. IoT sensors are used that have compatibility with Bluetooth and are designed to transmit data to mobile devices (Bocek *et al.*, 2017), (Shahzad & Zhang, 2020).

MedRec applied Blockchain to Electronic Medical Records (EMR) framework and concentrate on resolving four signif- icant concerns related to better management of EMR like incomplete medical data, slow access to them, system compat- ibility, patient agency, improve data quality for further research purposes (Ekblaw, Azaria, Halamka & Lippman, 2016). MedRec congregates directs to discrete medical information, and by using Blockchain encoding them, and they can design a convenient breadcrumb trail for medical history by classifying references. This system presents the pointers having on-chain permissioning and data credibility logic by doing record accuracy, authorize individuals, data exchange, and ability to evaluate and also MedRec construct sturdy modular API to incorporate with present provider database for compatibility. MedRec not only helps to improve medical data management but also is an innovative EMR solution with Blockchain technology and introduced a completely utilizable prototype.

MedRec creates the idea to use Blockchain for theoretical key management in a healthcare setting and initiate actual workload in distributed data recovery, smart contract, allowing solutions, data sharing, and supply and order by mining processing of Blockchain. For MedRec, the block content is the possession of the data and permissions to viewership represented by private members in a peer-to-peer network. The relationships between patient and provider that linked the healthcare data with view permission and data recovery instruction for execution on an external database will be logged, and also by including the record hashed via cryptography onto the Blockchain, data integrity will be ensured. Furthermore, MedRec manages validation by public- key cryptography.

Smart contracts in this system help to create an intuitive illustration of existing medical records that are keeping inside of individual nodes on the network. MedRec, by executing three types of contracts, tried to direct a large amount of data on the Blockchain first contract is Registrar Contract (RC), the Ethereum address identity is mapped with participant identification strings. Patient-Provider Relationship Contract (PPR) is a second smart contract in which one node keeps and manages the medical record for another node. The third contract is Summary Contract (SC), the system's entities can able to search their healthcare data record. Thus, keeping substantial and tentative health records of patients in the healthcare system (Dr. Albeyatti, 2018) is comprehensible, safe, and auditable. The first Blockchain is utilizing Hyperledger Fabric, using for controlling access to the health records and creating them, and the second Blockchain that impacts all the applications and services is made by an ERC20 token.

Doctor prescription, test results,and pharmacy dispenses will be recorded as a transaction onto the Blockchain and the patient for a short time give access to the insurer to verify the payments.The patient also gives limit access by smart contract to the doctor for reviewing medical cases and providing a recommendation. Patients, by giving limited access to the research institute for using health records for the medical trial version, receive a token as a reward.

Patients keeping electronic health records like wearable fitness data, payment, and transfer value on the Blockchain by using Med Token presented by MedicalChain (Dr. Albeyatti, 2018).

FarmaTrust Blockchain-based solution offers practical data verification and administration layer, which provides transparency, efficiency, and immutability for the information that will transfer from the starting point in the supply chain to the end customer(Group, 2018a). FarmaTrust securely analyzing and tracking the information of legitimate items across its widely distributed network of pharmaceutical products through Zoi (Blockchain- based) supply chain system. Tracking of released pharmaceuti- cal products through an unbroken chain of custody across the supply chain, possibly using FarmaTrust's Zoi platform that supplies a secure, compatible, and immutable source of data. Zoi system assists in suppressing falsified products and fake drugs to be entered into the market. Furthermore, FarmaTrust presents value-added solutions like foresighted deliveries and effective ways to access the market (Group, 2018a).

Medicohealth is a Blockchain-based solution that permits completely anonymous, secure, and effective communication with physicians and tries to improve the imperfect healthcare system (Group, 2018b). For limited time patients, data stored anony- mously will be accessible by elected physicians, and patients have full control over deciding which physicians can have access to their medical data and in what depth. The payment executes on the Blockchain is completely tokenized and also anonymous.Token execute the healthcare system and offset the platform, service providers,protocols, and Blockchain func- tional layer(s) that are used in processing (Group, 2018b).

MeFy is a merged health platform that presents a platform for everyone to play their part for the improvement of society and human being's health and try to join worldwide doctors with worldwide patients due to eConsult function. MeFy by making a private cloud and unifying that with a private Blockchain permits participants to share their data through the platform and by using Blockchain not only establishes health records and shares them but also allows auto health record-making throughout IoT-enabled MeMe Edge device. Doctors, by using MeMe eConsult,write a prescription that will not store as an image or file, but every detail in the prescription like diagnosis, prescription of medication, or a lifestyle correction could help to user health. This will be pursued with diet and lifestyle management throughout the MeMe Care app and Retail pharmacies also by using MeMe smart AI Supply chain, manage their stock and supply chain (Syafa'a, 2018) .

Provenance is a public, permissioned Blockchain that uses the consensus module from Hyperledger and is a framework that uses Blockchain to confirm the source of the products and also verify the accuracy of the product (Group, 2019b).Blockchain helps that without the need for third-party evaluation, keep and store all of this information. Provenance has four impor- tant participants:administrator, members, omnibus banks, and stakeholders(nodes). The administrator is responsible for specifying the cost of transactions on the protocol and review smart contracts connected to each node's permission for executing and keeping transactions, furthermore giving permissions to a member and acclaim of stakeholders. Members can be institutions or individuals, and also,they could be a node and pay a transaction fee to use provenance either they can be units that conduct on Provenance involving Hash investors. Every transaction that includes fiat originates will be done through an omnibus bank.Members can send/receive fiat throughout another bank to the omnibus bank, or they can have a direct account on the omnibus bank. The validation transaction is not the responsibility of the node. Encrypted data is transferred to the node, executed by smart contracts, and added to the Blockchain, and for this process, nodes generated the hash (Shahzad & Zhang, 2020), (Group, 2019b).

Kidner, a Blockchain platform,developed to use for the kidney donation system, which is secured with cryptographic tools and this system tries to make it easier to find a match for kidney paired-donation and also the chance to find immediately a perfect match while being completely protected is escalated. In the case of the match is found, Kidner is announced, and doctors and healthcare get every information that necessary for arranging the operation. Kidner securely and quickly suggests the opportunity to extend paired exchange for all inconsistent donor-recipient (Dajim, Al-Farras, Al-Shahrani, Al-Zuraib & Mathew, 2019), (Group, 2017a). Blockchain is a platform that brings together the real and potential blood donors on the same blood donation platform. This Blodon Bloodchain solution is intelligence and resilience that use Blockchain technology and big data for predicting the demand for blood, help to make a balance between the supply and demand and decrease the storage costs and reduce the shelf life of stored blood to 21 days. This solution focus on collaboration with public healthcare and blood collecting organization (Group, 2019a). A decentralized medication management system (DMMS) is a kind of decentralized network, considering as a part of the Hyperledger Fabric framework, uses to manage medication histories. Within the architecture of DMMS,one prescriber is dedicated to performing prescription for a patient and also can-do query about the history of each prescription and, in comparison, with a centralized DMMS system is more accu- rate, secure, and have privacy. The prescription is encrypted by the patient's public key; therefore, the patient uses its private key to decrypt the desired prescription. A patient can view records with different viewpoints, and at the same time, doctors, after recognition of the patient,can also view the patient's record (Li, Nelson, Malin & Chen, 2019).

3.3 Background Study: Blockchain Technology

A Blockchain is a peer-to-peer distributed system that =enables information sharing between nodes. Information that shares per block (unit) will require to be authorized by the consensus algorithms and the dedicated nodes or users that run authorization are the miners. Block after its confirmation will be added to the Blockchain and also shared among all entities being parts of the system.Chaining the blocks in the Blockchain makes them harder to be changed because there should be a change to the entire Blockchain (Shahzad & Zhang, 2020), (Tapscott & Kirklan, 2016). Blockchain, based on its data accessibility, can be classified into four categories (Group, 2017b):

- Public Blockchain: anyone can read and acknowledge the transactions in opened networks, and of course, the information can be accessible in a public domain.
- Private Blockchain: reading and submitting trans- actions just can be done by only one organization or multiple organization together in a group.
- Consortium Blockchain: read and submitting transactions would be possible for a group of organizations that form the consortium.
- Hybrid Blockchain: this is a system to integrate any or all of the three Blockchain systems,such as Public, Private, or Consortium, to perform transactions.

Blockchain uses state-of-the-art technology, called cryptog- raphy, which creates an immutable, not-hackable distributed database of digital assets (Shrivas & Yeboah, 2018). Thus, users are free to perform their transactions (e.g., data exchange) through asymmetric cryptography: the public key is applicable for everyone to let the system send encrypted data to the receiver, and the receiver can access the data by the paired private key.In recent years, there has been substantial progress made in Blockchain technology;so that, Blockchain revolution can be classified into three main categories (Shrivas & Yeboah, 2018):

- Blockchain 1.0 is the type of system that uses currency and include financial transaction based on Blockchain and cryptocurrency as a decentralized digital currency that helps the transactions to be quicker while being registered publicly on the Blockchain as they are validated.
- Blockchain 2.0 introduces a smart contract which is a computer program that tries to accelerate, check, or control the contract performance. Ethereum is a Blockchain platform that makes possible the distributed applications in the Blockchain network; smart contracts can help in trading money, property, and anything that has value.
- Blockchain 3.0 involves DAPP (decentralized application) using decentralized depository and decentralized contacts. This includes Blockchain applications alongside finance and currency, especially in the areas of health, science, and government.

3.4 System Modeling

Blockchain comes with various solutions to transforms the traditional supply chain industry into a decentralized, anonymous, persistent, automated, and secure supply chain (Shahzad & Zhang, 2020), (Tapscott & Kirklan, 2016). Thus, this paper employs Blockchain decentralization and distributive ledger solutions to fulfill the equipment of blood donation supply chain (BDSC). As human blood is valuable, and it can't be produced in factory-like other various electronic devices. For example, in the U.S. every two seconds, someone needs blood. There are other trust and safety issue in the blood donation supply chain; for example, in the 1990s, a report stated that Red Cross closed its blood donation center in Washington DC after they have informed that 235 people that received blood from donors' HIV test were tested positive; there were also similar situations happened in 2008, in some developing countries like Sri Lanka, India, etc (Lavoie & Lapierre, 2020), (Joseph, 2018), (Gargava & He, 2018). Fig.3.1 illustrates the flow of information to fulfill the operations connected to Blood at the blood control center.

In the first phase, donations are collected from donors. Before doing so, each donor's medical history and also his/her current physical health conditions are collected and completed. After donor health examination, blood is collected in a Blood Bag having a storage capacity of 450 ml, the bar code is then printed and labeled onto the blood bag with donor information. In the second phase, analysis is done. For that, the Bar code is scanned to get overall information added from the first phase and the blood bag is set into centrifuges where transferable components such as "red cells, platelets, and plasma" are then separated.

In the third phase, laboratory testing is done on blood, where the detailed tests are conducted to examine the blood type and mainly to examine some possibility of infectious diseases in the blood. Thus, the final test results on blood are delivered in a day; however, in cases of positive results if examined during the laboratory test- the collected donation will be surely denied. In the fourth phase, storage is done for those blood bags which were examined negative during the laboratory tests. If the transfusion process is done, it will be labeled onto blood bags after the results are received and examined. Thus, after the transfusion, platelets can be stored in agitators' units may up to five days at room temperature, Red cells can be kept shore in refrigerators up to for 42 days period at 6ºC, and Plasma in frozen can be stored for a duration of a year. In the fifth phase, distribution or transportation has been done between blood control center and hospital in a day or in a week.

Given samples codes (e.g., Sample Code 1-6) demonstrate various main functions,such as approveDonation(), separte- Blood(),packBloodUnit(),bloodDonation(),shipBloodsUnit(), and updateBloodsUnitShippmentEnv(), executed as parts of BDSC, and Fig.3.6 illustrates the detailed sequence of operations that have been done, for example, from donor or donation to hospital or end-user, to fulfill the requirements of the proposal study. In detail, if the donor, he or she, decided to donate blood. Thus, after completing the health examination process, a donation process is being started; the blood and the required tests so far done and collected are

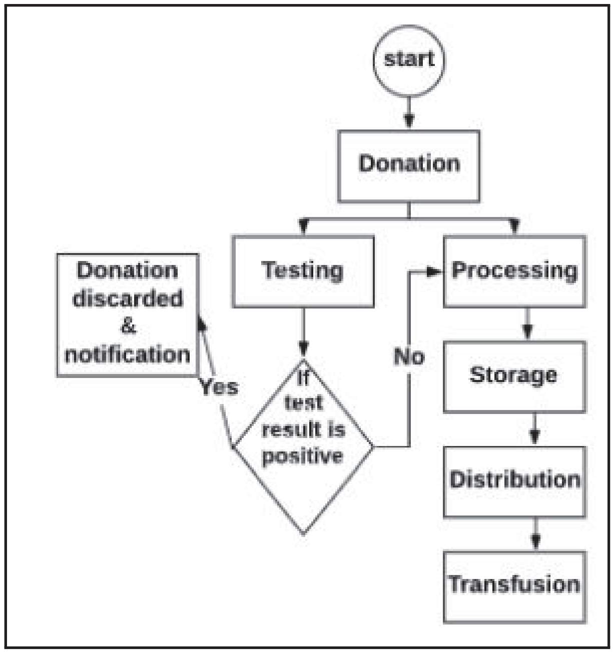


Figure 3.1 Blood Donation Data Flow

finally approved by the blood control center and then stored. In case, the hospital sends the request for the blood or blood products, blood control center will prepare the blood products for transportation, as per the contents written into the smart contract.

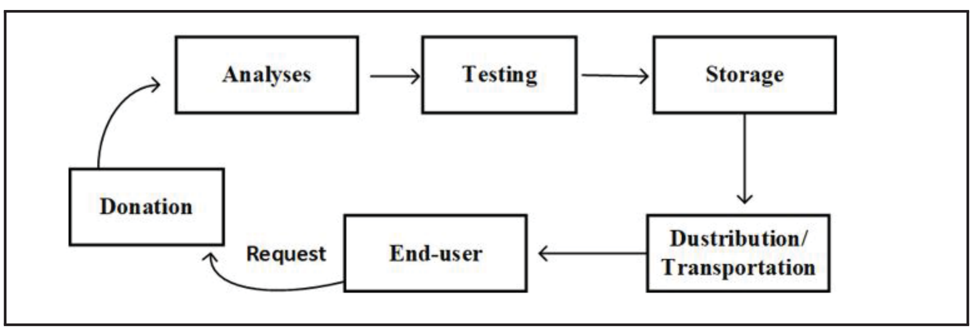


Figure 3.2 Blood Supply Chain Supply Chain

1) *Function approveDonation ()*

```
/// Function to approve donation
by a bloodControlCenter only
function approveDonation(uint _DIN)
public isTested(_DIN) {
bDItems[_DIN].state=
BloodDonationState.Approved;
emit Approved(_DIN);
}
```

2) Function seperateBlood()

```
/// Function helps bloodControlcenter
to separate a new Blood Unit
function separateBloodsUnit
(uint _DIN, uint quantity) public {
uint _slu = ++slu;
BloodItem memory newBloodItem;
newBloodItem.DIN = _DIN;
newBloodItem.slu = _slu;
newBloodItem.state = BloodState.Separated;
newBloodItem.currentOwnerId = msg.sender;
newBloodItem.centerId = msg.sender;
newBloodItem.envUpdateCounter = 0;
for (uint i = 0; i < quantity; i++) {
uint _pku = ++pku;
newBloodItem.pku = _pku;
dItems[_pku] = newBloodItem;
stockLouds[_slu]. push(_pku);
        }


emit Separated(_slu);
    }
```

3) Function packBloodUnit()

```
/// Function helps bloodControlcenter
to Pack a isSeparated Blood Unit
function packBloodsUnit(uint _slu)
public
isSeparated(_slu)
onlyCenterOf(_slu)
    {
uint quantity = stockLouds[_slu].length;
for (uint i = 0; i < quantity; i++) {
uint _pku = stockLouds[_slu][i];
dItems[_pku].state = BloodState.Packed;
dItems[_pku].packingTimeStamp = now;
        }
emit Packed(_slu);
    }
```

Figure 3.3   Main Functions Sample Code group 1

4) Function bloodDonation()

```
/// Function helps Donor to establish
a new Blood Donation
function bloodDonation(
string memory _donorName,
string memory _groupName,
string memory _description,
string memory _notes


    )
public
    {
DIN ++;
BloodDonationItem memory newDDItem;
newDDItem.DIN = DIN;
newDDItem.currentOwner = msg.sender;
newDDItem.donorId = msg.sender;
newDDItem.donorName = _donorName;
newDDItem.state =
BloodDonationState.Owned;
newDDItem.metaData =
 BloodDonationMeta
(_groupName, _description, _notes);
bDItems[DIN] = newDDItem;
 emit Owned (DIN);
    }
```

5) Function shipBloodsUnit()

```
/// Function helps bloodControlcenter
to ship a Blood Loud
function shipBloodsUnit(uint _slu)
public
onlyCenterOf(_slu)
{
uint quantity = stockLouds[_slu].length;
for (uint i = 0; i < quantity; i++) {
uint _pku = stockLouds[_slu][i];
dItems[_pku].state = BloodState.Shipped;
        }

emit Shipped(_slu);
}
```

6) Function updateBloodsUnitShippmentEnv()

```
/// Function helps bloodcenter and
distributor to update Blood Loud envuirment
function updateBloodsUnitShippmentEnv (
uint _slu,
uint _humidity,
uint _temprture
    )
public
isShipped(_slu)
onlyCenterOrDistributorOf(_slu)
    {
uint quantity = stockLouds[_slu].length;
EnvUpdateOpj memory _envUpdate =
EnvUpdateOpj(
now,
_humidity,
_temprture,
msg.sender
        );
for (uint i = 0; i < quantity; i++){
uint _pku = stockLouds[_slu][i];
dItems[_pku].envHistory[dItems[_pku].
envUpdateCounter] = _envUpdate;
dItems[_pku].envUpdateCounter ++;
        }
emit EnvUpdated(_slu);
    }
```

Figure 3.4 Main Functions Sample Code group 2

3.5 Results and Discussion

Fig.3.7 illustrates the BDSC system's dashboard (design), and the solidity smart contracts are written, in the remix. All the system's participants are connected to the BDSC system

Transactions	Date, Time	Approved	Participants	Traceability	Truth	Safety	Privacy
Donation	2020-10-21,15:12:30	Successful	Donor # D001(Hashed)	✓	✓	✓	✓
Donation	2020-10-21,15:32:15	Successful	Donor # D002(Hashed)	✓	✓	✓	✓
Donation	2020-10-22,14:03:10	Successful	Donor # D003(Hashed)	✓	✓	✓	✓
Donation	2020-10-22,14:33:15	Successful	Donor # D004(Hashed)	✓	✓	✓	✓
Donation	2020-10-22,15:05:30	Successful	Donor # D005(Hashed)	✓	✓	✓	✓
Donation	2020-10-22,15:20:55	Successful	Donor # D006(Hashed)	✓	✓	✓	✓
Donation	2020-10-22,16:10:18	Successful	Donor # D007(Hashed)	✓	✓	✓	✓
Donation	2020-10-22,16:15:45	Successful	Donor # D008(Hashed)	✓	✓	✓	✓
Analyses	2020-10-22,18:11:41	Successful	BloodControlCenter C05	✓	✓	✓	✓
Testing	2020-10-22,19:05:20	Successful	BloodControlCenter C05	✓	✓	✓	✓
Storage	2020-10-22,20:10:10	Successful	BloodControlCenter C05	✓	✓	✓	✓
Distribution	2020-10-23,04:00:00	Successful	Transportation C05-T01	✓	✓	✓	✓
End-user	2020-10-23,08:00:00	Successful	Hospital-Patient H01-P07	✓	✓	✓	✓

Figure 3.5 Transaction Outcomes

through the private blockchain Ethereum network, and are allowed to execute their operations and can trace the information at each stage of blood supply ecosystem, as per roles defined via system or contents written in smart contracts. Dashboard shows the number of donors, blood centers, distributors, hospitals as end-users, etc. that have been participated to perform several operations in the BDSC system. The smart contracts (role-based) are written to define the role per participant, and on each execution, they assist to track and trace the information flow at each stage of the blood donation supply chain. Therefore, in Table 1, the conducted results for each transaction that are performed in the BDSC system satisfy the traceability of information, ensure that every transaction was done with great trust, examine that blood was circulated with safety, e.g., from its origin to end-user, and each participant successfully performed their belonging operations as per the roles defined by the system or in smart contracts and mainly each participant privacy was not revealed, in each level of the blood donation ecosystem. Thus, based on the results given in Figure 3.5, we performed the random selection of transactions and then calculated the probability (%) in Fig.3.8 Overall, this study performed well to combat the issues (and risks) associating with the existing supply of blood, using Blockchain. It helps to follow up the blood from the time it's donated until it is transfused and distributed. Each time, a transaction is performed, for example, when the blood is donated or when the blood donation center obtains the blood, a new block was created, stored on the distributive Blockchain ledger, and chained. In case, the blood that sent to the laboratory for testing was examined infected- therefore the transaction discarded automatically because of the contents written in

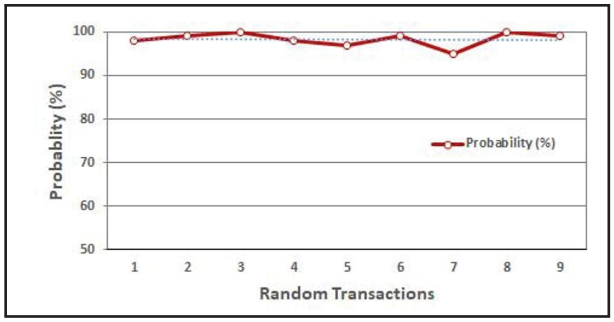


Figure 3.6 Estimated Probability

smart contracts. However, in case of negative results then overall donation operations will be done, and therefore the end-user will be received the blood.

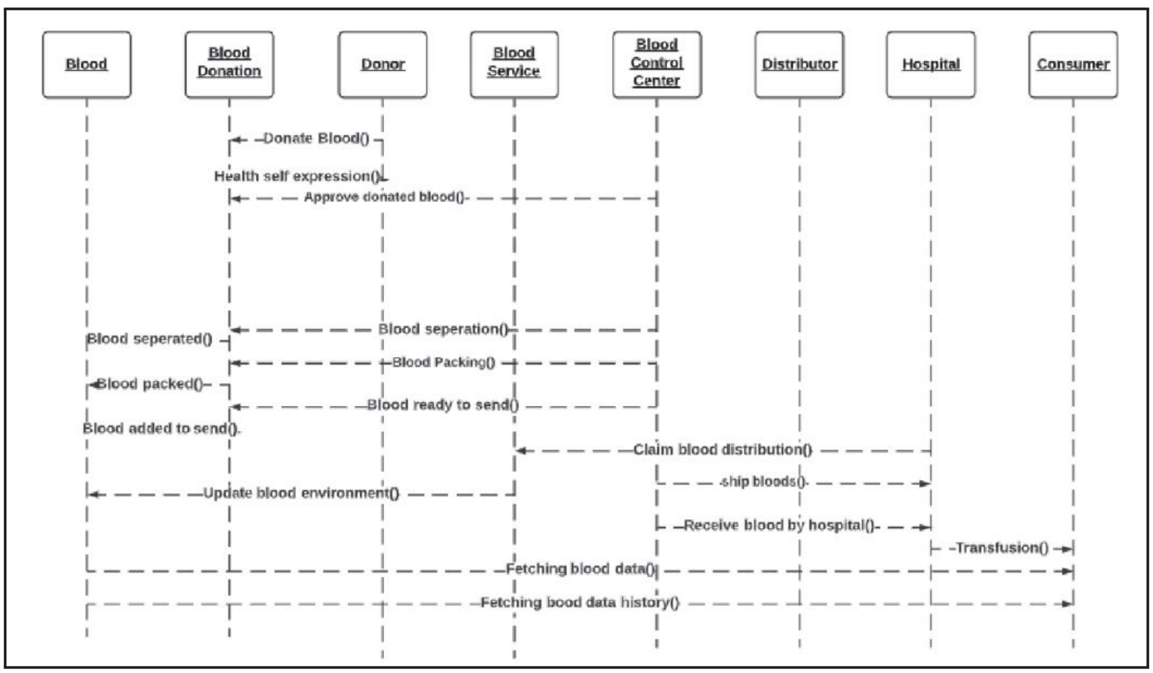


Figure 3.7 Operationl Sequence in BDSC

Figure 3.8   BDSC Dashboard

3.6 Conclusion and Future Work

This paper targeted a major supply chain problem to enable an end-to-end blood donation supply chain. Blood is an integral unit to save human life, therefore healthcare centers have always the requirements of blood on time. However, some several issues and risks always connected to the supply chain of blood, for example, from the donation phase to end- user(e.g., patient) perspectives. This study highlighted and considered all the majors' challenges and risks of the blood supply chain, and used the Blockchain Ethereum platform and smart contract solutions to trace and track the information of blood at each phase of the supply chain. Smart contracts are written and executed to control the overall tasks,as per given contents, in the blood donation supply chain ecosystem. The conducted results validate the performance of the proposed study such that every transaction, as part of the supply chain, has been done in order, having great trust, safety, and kept secure the privacy of each participant in the blood donation supply chain. In future work, we intend to deploy Blockchain and smart contract solutions to trace the provenance of COVID-19, as this one of the major issues nowadays, and target to use artificial intelligence (AI) based solutions to maximize the probability of success in tracing the origin of COVID-19, and as well other epidemic diseases.

CHAPTER 4

RESULTS AND DISCUSSION

The idea of the Blood donation supply chain project ignited by our visit to Hema Quebec Blood Donation Center as a part of a research going on at the time on Blockchain based supply chains. As a member of Blockchain Lab at ETS, we felt this obligation to mitigate the concerns and issues related to Blood Donation. Hence, we started to investigate the existing implementations of Blood donation and detect their vulnerabilities and after careful analyzation of the existing implementations and designs, then we tried to design a blood donation supply chain system in accordance with the actual use case scenario.

4.1 System Design

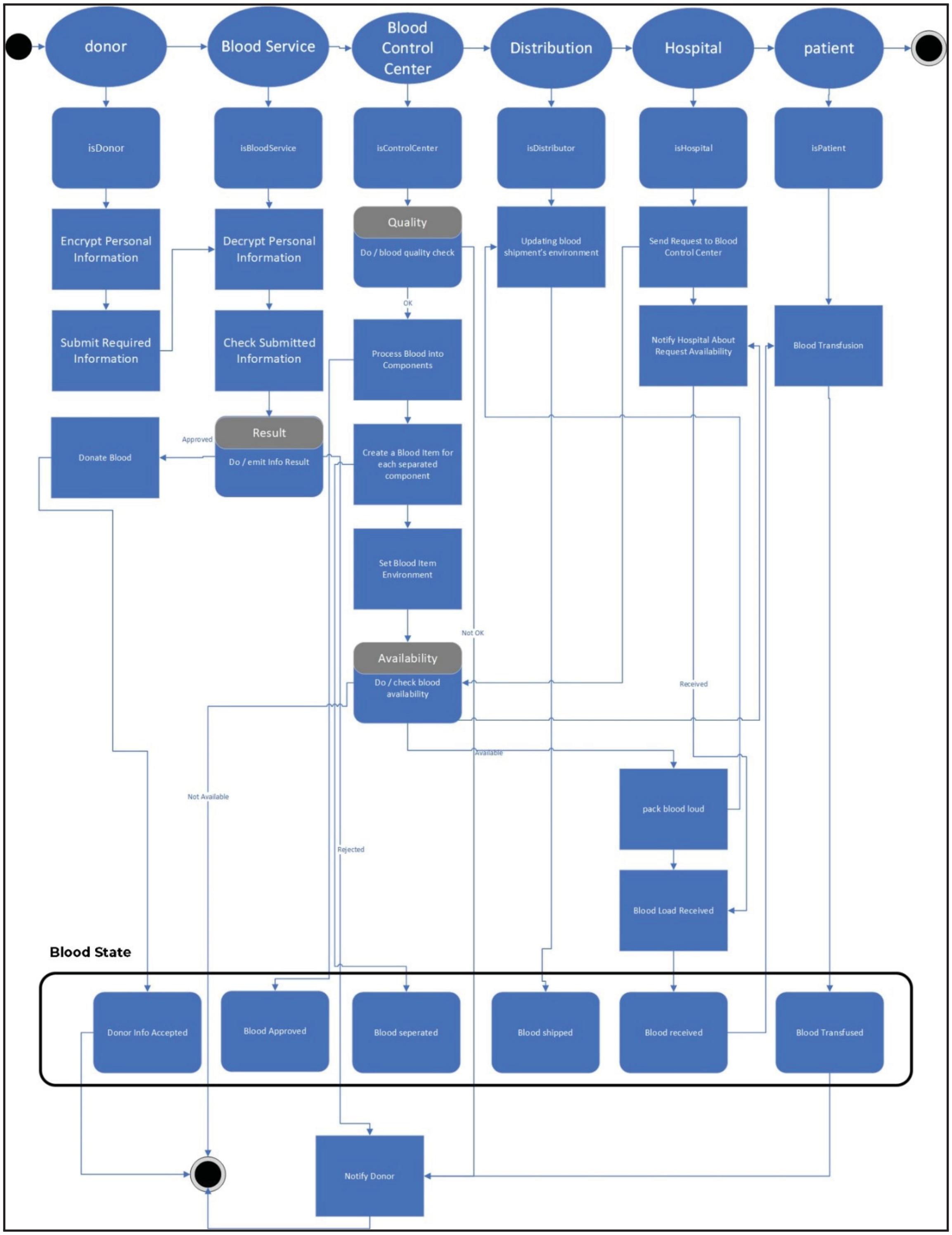


Figure 4.1 Blood Supply Chain Sequence Diagram

The donor will register on the system and submit the required information to check for donation eligibility, and as soon as the information is reviewed by blood service, the donor will be notified, and the state will be changed to donor info accepted. It is worth mentioning that all the submitted information by the donor will be encrypted because of privacy-preserving concerns, and to check this information, Blood Service decrypts the donor's data to review. After the information is approved, the donation process will start. Next, the donated blood will be sent to Blood Control Center, and in that place, the quality of blood will be checked. If the quality reached the standard, the blood's state would be changed to Blood Approved, and the blood separation process into various blood components will be ignited. As a result, blood's state will be changed to Blood Separated. In the following, for every component, a blood item will be created. The hospital sends the request for a specific blood item to the blood control center. The blood availability would be checked at the blood control center. If the blood item with the requested amount was available, the blood item will be packed, and after updating the packed blood item's environment, it will be shipped by the selected distributor to the hospital. Blood item's states will be converted to Blood Shipped. In case of unavailability of the requested blood item, the process would be terminated, and the hospital will be notified. Once the blood item is received by the hospital, its state will be altered to Blood Received. Finally, the received blood item is going to be transfused to the designated patient, and subsequently, the blood item's state will be modified to Blood Transfused.

4.2 System Architecture

After designing our system, we tried to integrate the Blockchain technology with the Blood donation supply chain to improve the efficiency, transparency and traceability of the blood supply chain. The proposed system's architecture consists of two main sections, Interface and Application Core, The User Interface layer's main task is to handle user interaction and display data on the web page. To have a more efficient app for our project, we used one of the widely used React design patterns called Container-view, which comprises two types of components, View (Presentational) and Container Components. UI Views consist of several

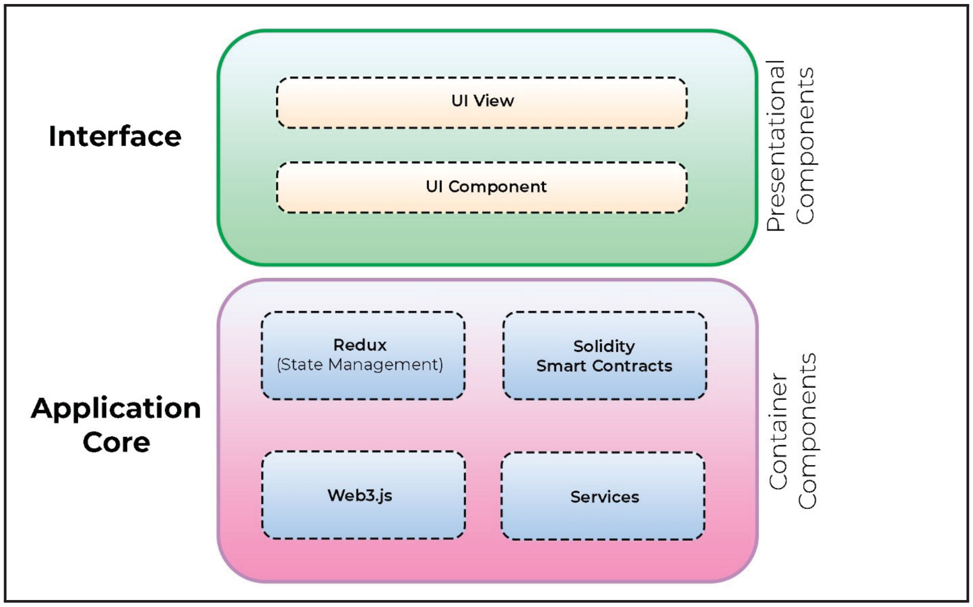


Figure 4.2 Application Architecture Overview

React UI components and is responsible for the presentation part of our application. Hence all the presentation logic of our dApp will reside in this section. The Container component is concerned with managing the states of our application and tasks such as fetching the data and redux integration. In our Application core, we have Redux for managing the states in our application. It does so by holding the entire state of our application in a central store, and each component can access its stored state with no need of sharing states with other components. Redux consists of three building parts that we are going to depict their roles, actions, Store and reducers briefly. Actions are the events that are used to sending data from the application to the Redux store. Reducers are functions that change the state of the application and return the new states, which are stored as objects. And Lastly, we have the Store, as mentioned earlier, which holds the state of the application and components access it to retrieve the state. On the other hand, to handle the communications with the Ethereum blockchain, we used Web3.js. Web3.js is a collection of libraries that provides the ability to interact with a local or remote Ethereum node using JSON RPC. These libraries are available in JavaScript, which makes them directly usable within the React project. The smart contract files have been included within the project to facilitate the maintenance of the dApp. To use the smart contracts and call their functions, we compiled them using Truffle, which is one the most dominant development environments for Ethereum, and we used the ABI (Application Binary Interface) to interact with the Ethereum ecosystem by using the contracts' addresses. Based on DCS Conjecture for DLTs that states it is impractical for a distributed data store like blockchain to provide at the same time more than two out of three promises: Consistency, Scalability and Decentralization. We decided based on our needs for our solution, to put Decentralization and Consistency as priorities, and because these two items are more important for us, in this case, Ethereum is a good choice for our system.

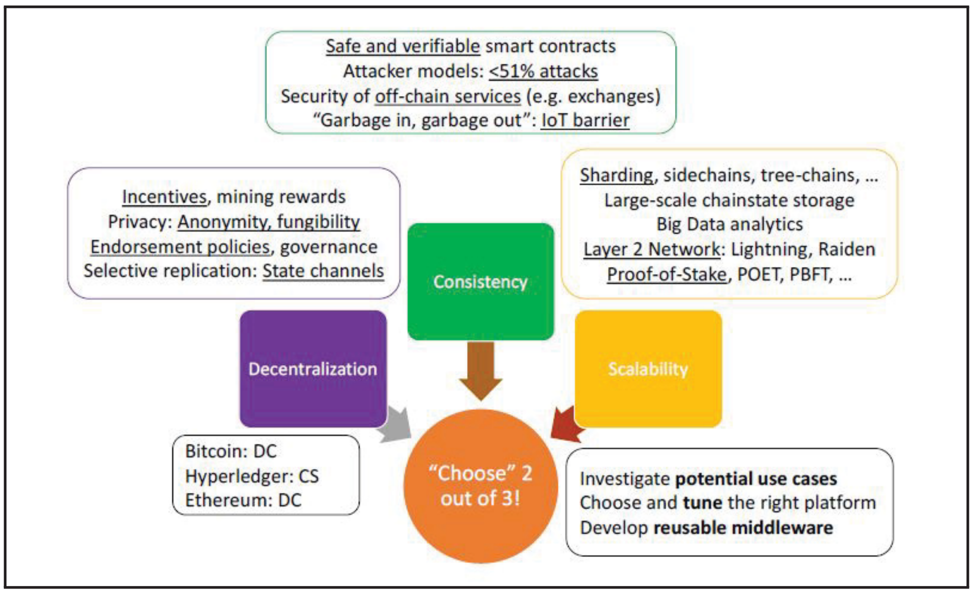


Figure 4.3 DCS Conjecture. Taken from Zhang *et al.*, (2018)

The proposed system is divided into two main sections, namely the WebApp and the Ethereum Blockchain. For facilitating the use of this dApp, we decided to use React frameworks; it is one of the best development frameworks for the web environment. In order to connect the application to the Ethereum blockchain, we considered using Web3.js to connect to the Ethereum node, and we used Metamask, which is a cryptocurrency wallet, to manage accounts and sign transactions to communicate with Ethereum Blockchain. For blockchain connection, Infura is used to connect to the Ethereum node using API without the need to run a full node locally.

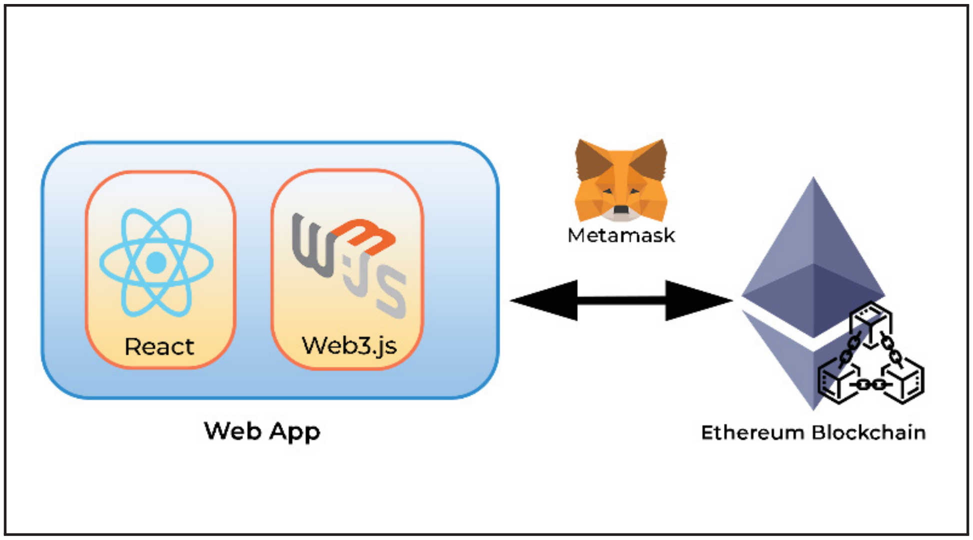


Figure 4.4 System Architecture Overview

4.3 Application Demonstration

UI Implementation

We chose a side navigation-based design to facilitate ease of use and improve the user experience. As shown in the Figure 4.5, each tab of the sidebar indicates one of the entities involved in the blood donation supply chain process. Also, as depicted in Figure 4.6, a section called dashboard has been designed to show a list of reports based on the overall performance of the whole supply chain process. These reports include the total number of donations, blood centers, distributors, hospitals registered in the system so far. In addition to this, we delineated the daily donations, shipments, and completed donations in a statistical view to make the analysis easier.

We also added two tables to show the traceability of our supply chain. The first table consists of three sections, namely Donor, Blood Center and Distributor. In Donor, the details of the donors are displayed. It is worth mentioning that this information is shown to demonstrate the system's capabilities in the Demo version and only to the system administrator, and it would be well hidden from other participants to preserve the privacy of the donors. Next, we have the Blood Center tab, which shows the quality result of the donated blood has reached the standards and whether it was approved or not, and we have a list of the successful fragmentation of the blood

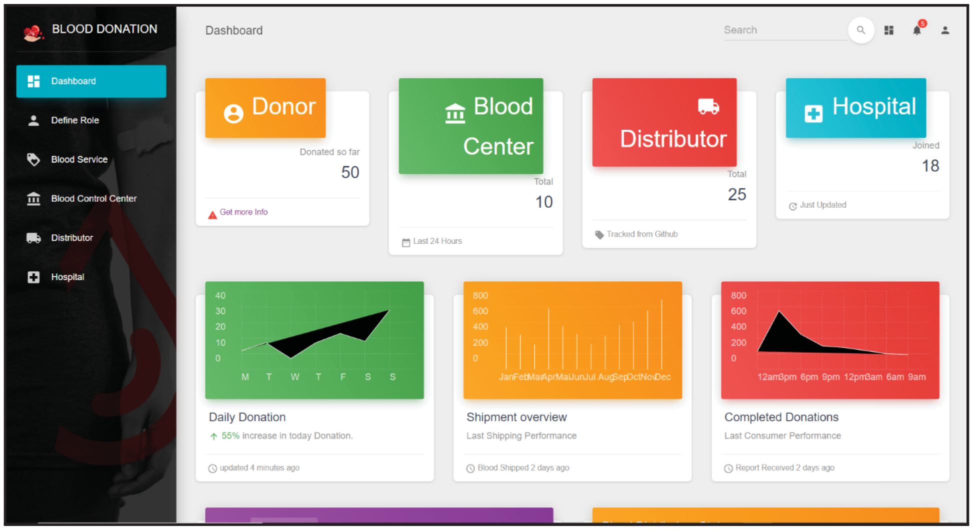


Figure 4.5 Blood Supply Chain dApp Dashboard Overview

into different components. In the distributor section, the shipment environment and the status of the blood item is shown. Additionally, we have blood distributors' status shown in the dashboard

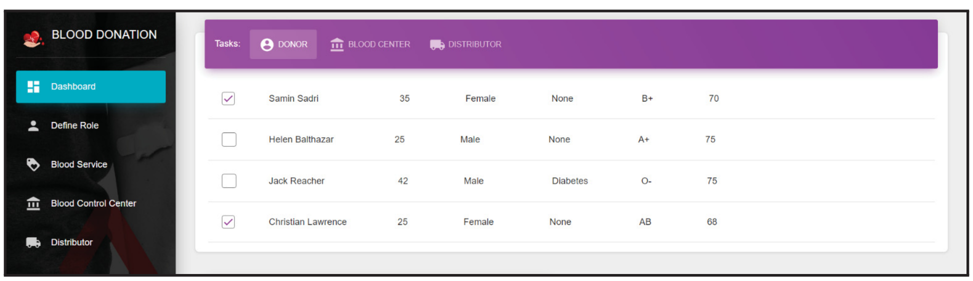
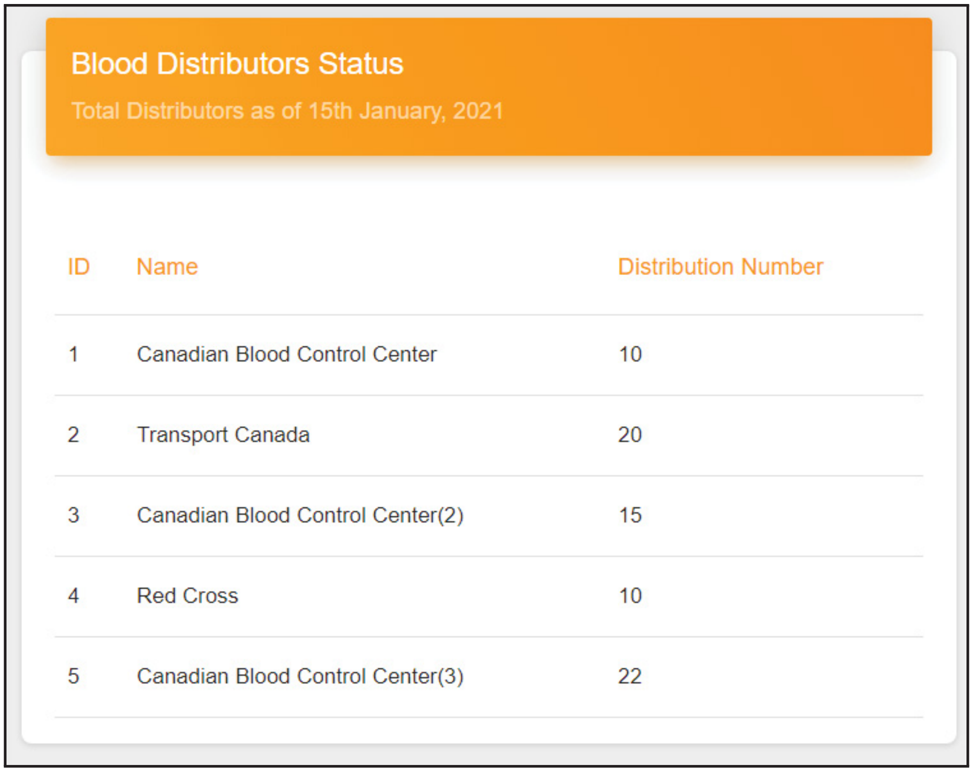


Figure 4.6 Blood Supply Chain dApp Donor Overview

tab. This Table is also added to present the total distributors involved in the distribution process and the number of distributions made by them so far. The next tab is called Define Role as shown in Figure4.8 , in which we have designed a section for entities involved in the supply chain process to add their role to the system, and by adding their role, an Ethereum account would be created and assigned to their role to check their privilege in each step and signing and sending the transactions under these accounts.

Donor's information will also be added in this section. When the donor role is selected, the additional required information will become visible to be filled and submitted by the donor.



Blood Distributors Status

Total Distributors as of 15th January, 2021

ID	Name	Distribution Number
1	Canadian Blood Control Center	10
2	Transport Canada	20
3	Canadian Blood Control Center(2)	15
4	Red Cross	10
5	Canadian Blood Control Center(3)	22

Figure 4.7 Blood Supply Chain dApp UI Overview

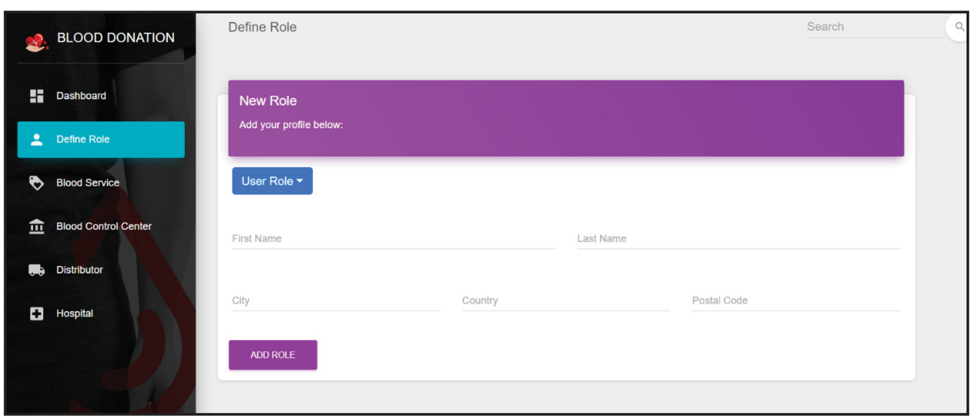


Figure 4.8 Blood Supply Chain dApp UI Overview for Define Role

This additional information will be the donor's age, sex, patient history record, blood type, and weight, as delineated in Figure 4.9. This personally identifiable information will become encrypted and then registered on the blockchain. Later, the Blood Service will decrypt and check this information using the associated keys to assert the eligibility of the donor. In each section, we added a notification to deliver if the process was successful or not.

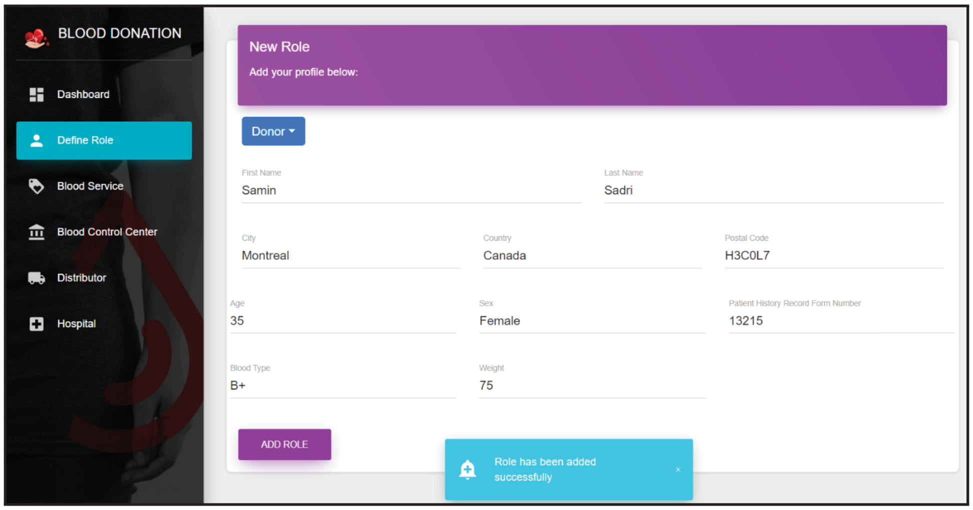


Figure 4.9 Blood Supply Chain dApp UI Overview for Donor Role

The Blood Service tab was designed to show the responsibilities of the Blood Service Role. Based on Figure 4.10, This section has a list showing the volunteered donors' names and their information obtained from the Blockchain and decrypted using the associated keys. In this table, Blood Service can select the donors and determine if they are accepted to donate or not. As soon as the Blood Service submits the decisions made for each case through a transaction in the blockchain, each donor will be notified of the blood service decision and will behave on the result accordingly.

Next, as seen in Figure 4.11, we have the Blood Control Center that has an Important Role in the Blood Donation supply chain. We tried to show the maximum capability of the Blood Control Center in this section by designing three different tables. The first table was created to show the quality result of the donated blood and whether its quality was approved or refused for the next step, which would be processing the blood into different components. The second table shown in the Blood Control Center depicts the processed blood into different components and their Donation Identification Number (DIN), blood type, and their associated Stock Loading Unit (SLU).

The last table in the Blood Control Center section is designed for the Blood Control Center role

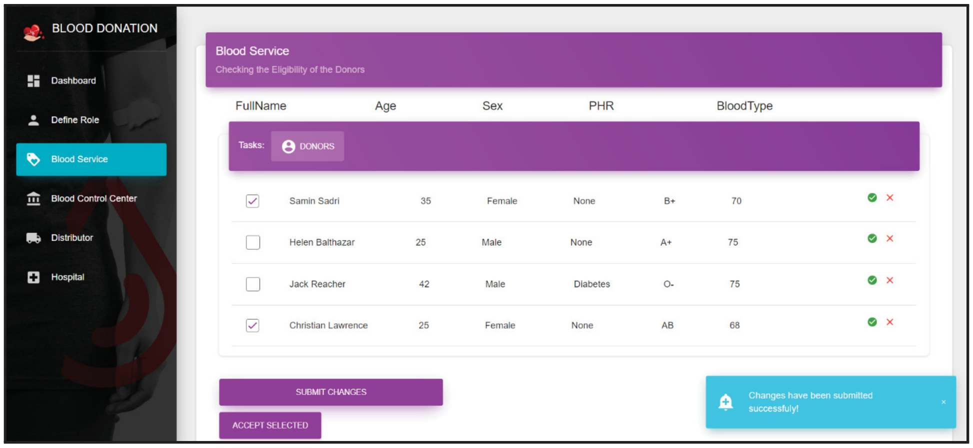


Figure 4.10 Blood Supply Chain dApp UI Overview for Blood Control Center

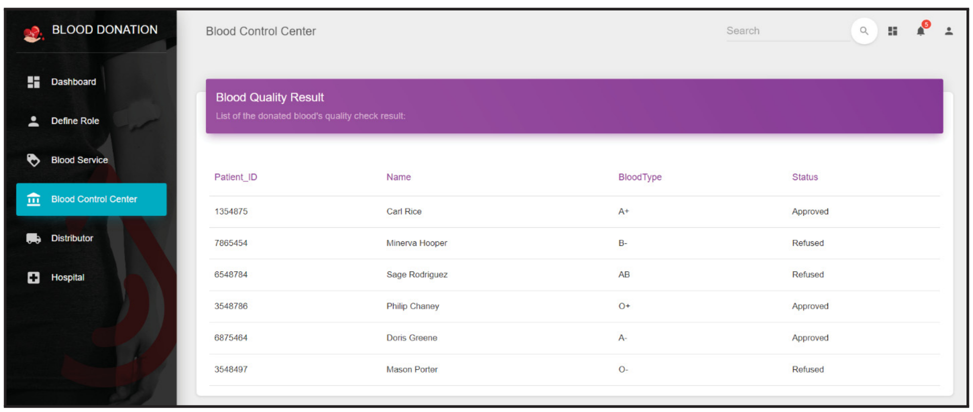


Figure 4.11 Blood Supply Chain dApp UI Overview for Blood Control Center's component processing

to accept or reject the requests sent over from the hospital for the components in need. The Blood Control Center will notify the hospital if it has the requested quantity or no. If the requested blood component is available, it will be accepted and sent to the next step in the supply chain, which would be packing the blood items and selecting the distributor to ship the blood item. Hospital is the last section in our Dapp as can be seen in Figure 4.12, which comprises of two tables. The first table is called the Transfusion List, which displays the status of the patients in the transfusion queue. Each row consists of several sections, namely patient ID, name, blood type, and the transfusion status for each patient.

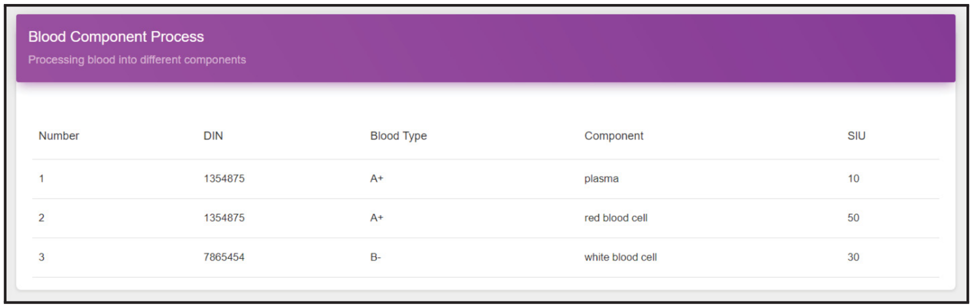


Figure 4.12 Blood Supply Chain dApp UI Overview for Blood Control Center's request management

The final table gives the option to the Hospital's role to notify if the blood is received or not

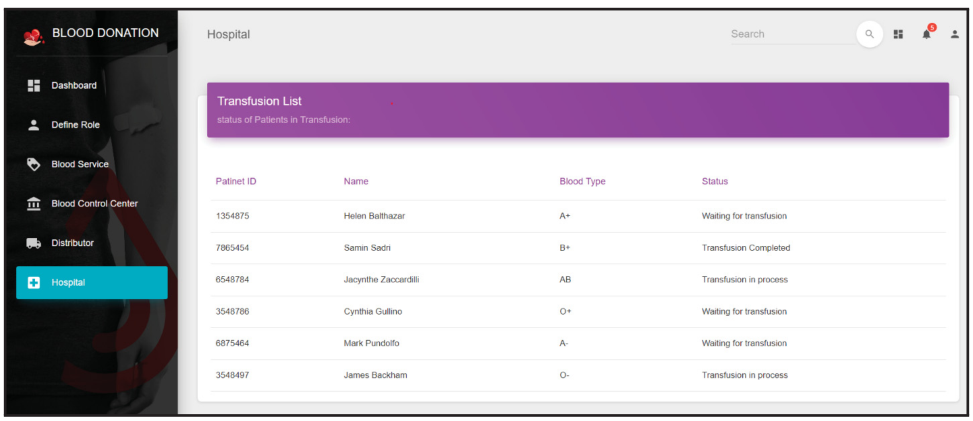


Figure 4.13 Blood Supply Chain dApp UI Overview for Hospital

and check and update the transfusion status of the blood item.

Transparency

Transparency is one of the crucial aspects of the design of this system. The goal of this project is to strengthen the transparency presented by blockchain technology. Our solution is transparent in the following ways. Inside the network, all contracts are apparent to everyone, and anyone who wants to takes part in the provided infrastructure can have an awareness of what a particular system does and how it declares to do what it does. As soon as a system has been executed to the network, the fundamental code cannot be changed. This brings trust into the system. Second, every transaction implemented on the Ethereum network is visible to everyone by the Event keyword we utilize in Solidity.

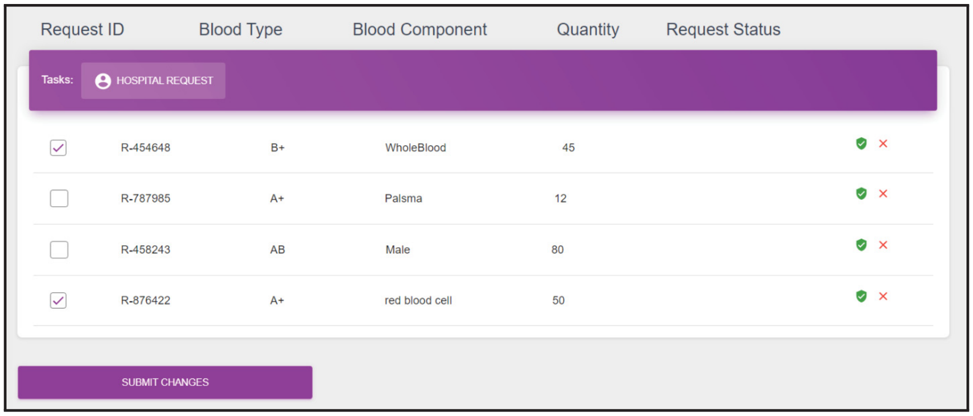


Figure 4.14 Blood Supply Chain dApp UI Overview for Blood Control Center's transfusion status

4.4 Performance Evaluation

We tried to evaluate our implementation in this section and draw a comparison between our implementation and other similar supply chain contracts in terms of performance and gas consumption. To evaluate our proposed solution, we decided to focus on the smart contracts and the gas consumption of the functions included in these contracts. We reviewed these functions' performance and tried to optimize them, compared them to similar implementations of other supply chain functions, and concluded based on the results. We carried out an in-depth analysis of the results of the following functions as they have essential roles in the functionality of the supply chain. Finally, we attempted to improve our smart contracts gas consumption and performance and share the results to demonstrate the refinements.

seperateBloodsLoud is the first function of the BloodDonation contract that we have tested. This function, as described before, is going to generate blood items with the given quantity of the blood load received after donation. Evaluation of this function was done by passing various quantities to the function and checking the consumed gas in each transaction.

As we can see from the Figure 4.15, the amount of gas consumption will increase as blood load increases. For example, we see that for 50 millilitres, we have over 710000 gas consumed, which might be unjustifiable in terms of system expenses. Hence, we decided to reduce the consumed gas by revising and modifying this function. We did this by following these steps,

Table 4.1 Blood Donation Contract Functions

Function	Execution Time(second)	Transaction Fee(Ether)	Transaction Fee(USD) 1 Ether = 1,937.36 USD
seperateBloodsLoad	30	0.007350574	14.14
packBloodsLoad	16	0.00002476	0.048
shipBloodsLoad	12	0.000024739	0.048
updateBloodsLoadShippmentEnv	10	0.00002537	0.049
receiveBloodsLoad	9	0.000024783	0.048

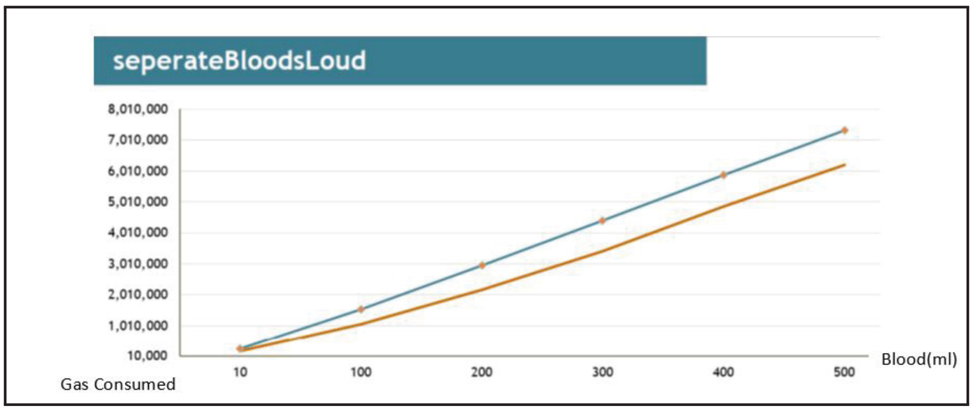


Figure 4.15 seperateBloodDonation function Evaluation Result

first by using 256-bit variables as EVM will fill up the missing digits in case of using variables such as the 8-bit one. We also focused on the loops as they were the main factor that increased the time complexity of this function. For this purpose, we tried to omit the reading and writing of the storage variables each time inside the loop which was introducing more consumed gas and transaction fee. As a result, we saw an acceptable reduction in gas consumption that its result can be seen in the figure. The second function is shipBloodsLoud which has the specific role of managing and processing blood load to be shipped from the blood control center. This function receives a stock loading unit and sets the status of each blood item in that SLU to be shipped as the shipment is processed. Similar to the previous seperateBloodsLoud, this function also includes a loop which is a main point for gas consumption increase in the function. After introducing the identical modifications to this function, there was a slight improvement in the gas consumption of this function as expected.

The following function as depicted in figure 4.17 is updateBloodsLoudShipmentEnv, in which

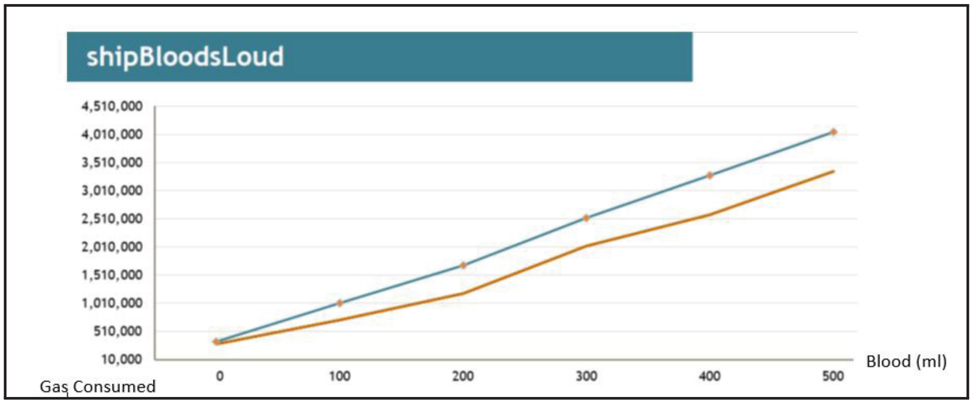


Figure 4.16 shipBloodLoud function Evaluation Result

the Stock Loading Unit (SLU), humidity and temperature of the blood items are received and updated for all the blood item packs. The environment of each product-keeping unit gets updated by being added as a new record to the environment update history, and for the last step, the EnvUpdated event gets emitted. All these operations take place inside a loop, and we tried to reduce the operations inside the loop to optimize the gas cost of this function. Using variable memory types instead of storage types inside the loop is another method in which gas consumption trade-offs can be managed when the suitable data types are selected. As a result, we witnessed an acceptable rate of gas consumption reduction.

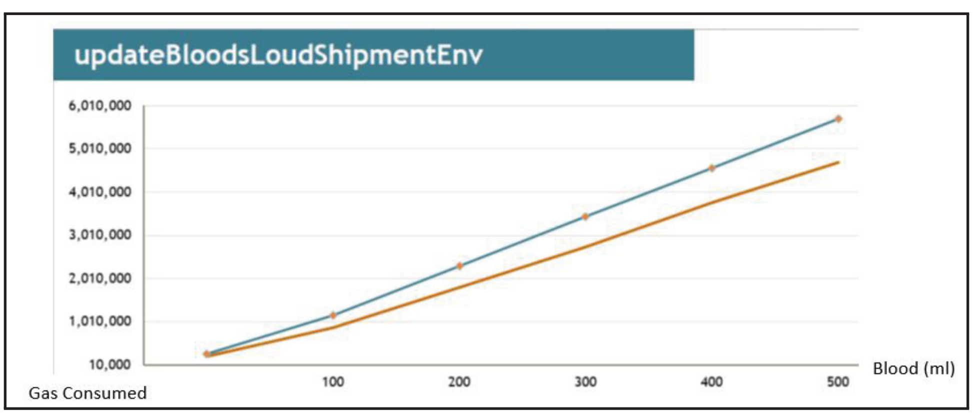


Figure 4.17 updateBloodLoudEnv Function Evaluation Result

By using blockchain technology in our solution we'll bring transparency to the blood donation system, the availability of the blood is transparent to all the participants. By encrypting donor's personal information, we bring more security and privacy-preserving to our solutions and efficient blood bag monitoring is possible by traceability that blockchain brings to our solution. The item that makes the difference between different blockchain solutions is gas consumption, we concentrate on optimizing our key functions and also tried to by using different ways like using 256-bit variable because in EVM Each storage slot has 256 bits. Hence, if we are storing just a uint8, the EVM will fill up all the missing digits with zeros, and this costs gas, We also focused on the loops as they were the main factor that increased the time complexity of this function and we tried to omit the reading and writing of the storage variables each time inside the loop which was introducing more consumed gas and transaction fee and finally, we tried to instead of using a storage variable, use the memory variable. In solidity, memory is a temporary place to store data and during the execution, solidity can use any amount of storage, and as soon as the execution stops the memory is completely wiped off for the next execution. On the other hand, the storage variable is constant and every execution of a smart contract has access to the data stored in the storage area before. Every transaction on EVM costs some gas for execution, gas consumption of memory variable in comparison with storage variable is not very notable and the lower gas consumption the better is your solidity code.

Ultimately, we learned that the integration of Blockchain within the supply chain can introduce more traceability, scalability and will move the security to an upper level. Hence, we encourage the further research and development in this area as it will bring more transparency and will definitely reduce the risk of blood contamination and infection. As a result of this, we will be observing a significant raise in the number of donations made each year since the donors will be encouraged due to the trust that made the whole system more appealing from their point of view.

CONCLUSION AND RECOMMENDATIONS

This thesis targeted the centralized supply chain problems to introduce an end-to-end blood donation supply chain and highlighted all the major challenges and risks of the blood supply chain.

We used the blockchain ethereum platform and smart contract as a solution to trace and track the information of blood at each phase of the supply chain. Smart contracts are written and executed to control the overall tasks, as per given content, in the blood donation supply chain ecosystem. The conducted results validate the performance of the proposed study such that every transaction, as part of the supply chain, has been done in order, having great trust, safety, and kept secure the privacy of each participant in the blood donation supply chain. I recommend in the future work we can concentrate more on investigating the reliability and stability of the proposed system by conducting tests (latency test, stress test, complex transaction test), scalability of the proposed solution, exploring vulnerabilities of the developed smart contracts and improve the security of the proposed solution and looking for alternative blockchains with lower latency and transaction fees.

APPENDIX I

SMART CONTRACT SOURCE CODE

```
pragma solidity ^0.5.0;

import "./Storage/Blood.sol";
import "./Storage/BloodDonation.sol";
import "../AccessControl/Rolable.sol";
import "../openzeppelin/contracts/lifecycle/Pausable.sol";
contract SupplyChain is Rolable, Pausable, BloodDonation, Blood {
    constructor() public {

    }




    function bloodDonation(

        string memory _donorName,
        string memory _groupName,
        string memory _description,
        string memory _notes
    )
        public
        //onlyDonor()
        whenNotPaused()
    {
        super.bloodDonation(
            _donorName,
```

```
            _groupName,
            _description,
            _notes
        );

    emit event(msg.sender,timestamp);
    }
    function addTestCaseByRegulaor(
        uint _udpc,
        string memory _description,
        bool _isPassed,
        string memory _notes
    )
        public
        onlyRegulator()
    {
        super.addTestCaseByRegulaor(
            _udpc,
            _description,
            _isPassed,
            _notes
        );
    }
    function approveDonation(uint _udpc)
        public
        onlyRegulator()
        whenNotPaused()
    {
        super.approveDonation(_udpc);
```

```
}
function purchaseBloodDonation(uint _udpc)
    public
    payable
    //onlyBloodCenter()
{
    super.purchaseBloodDonation(_udpc);
}
function buildPartnerContract(uint _udpc, string memory _name)
    public
    //onlyBloodCenter()
    whenNotPaused()
{
    super.buildPartnerContract(_udpc, _name);
}
/// Function helps blood center to blood center a new Blood Loud
function separateBloodLoud(uint _udpc, uint quantity)
    public
    //onlyBloodCenter()
    //onlyCenterPartnerOf(_udpc)
{
    super.separateBloodsLoud(_udpc, quantity);
}
function buyBloodsLoud(uint _slu, address _receiver)
    public
    payable
    //onlyDistributor()
    whenNotPaused()
{
```

```
        //require(isHospital(_receiver));
        /// collect info about the whole proccess
        BloodItem memory sampleUnit = dItems[stockLouds[_slu][0]];
        uint _udpc = sampleUnit.udpc;
        uint price = sampleUnit.price;
        uint quantity = stockLouds[_slu].length;
        uint totalPrice = price*quantity;
        ///colect shared worker addresses to payed them
        address payable sallerId = address(sampleUnit.currentOwnerId);
        require(msg.value >= totalPrice, "Not Enough!");
        uint amountToReturn = msg.value - totalPrice;
        if (amountToReturn != 0)
            address(msg.sender).transfer(amountToReturn);
        super.buyBloodsLoud(_slu, _receiver);
        if (sallerId == bDItems[_udpc].currentOwner){
            sallerId.transfer(totalPrice);
        }
        else {
         uint shareOfSallerPresntage = bDItems[_udpc].bloodcenters.
         sharesOf(sallerId);
         uint shareOfSaller = (shareOfSallerPresntage*totalPrice)/100;
         address payable orignalSallerId =
         bDItems[_udpc].bloodcenters.owner;
         sallerId.transfer(shareOfSaller);
         orignalSallerId.transfer(totalPrice - shareOfSaller);
        }
    }
    function purchaseBlood (uint _pku)
        public
```

```
        payable
        //onlyConsumer()
        whenNotPaused()
    {
        uint price = dItems[_pku].price;
        address payable sallerId = dItems[_pku].currentOwnerId;
        address payable hospitalId =
        address(uint160(dItems[_pku].hospitalId));
        uint hospitalrBounty = (price*5) /100;
        uint developerBounty = (price*1) /100;
        require(msg.value >= price, "Not Enough!");
        uint amountToReturn = msg.value - price;
        if (amountToReturn != 0)
            address(msg.sender).transfer(amountToReturn);
        super.purchaseBlood(_pku);
        sallerId.transfer(price - (hospitalrBounty + developerBounty));
        hospitalId.transfer(hospitalrBounty);
    }
}
```

```
 pragma solidity ^0.5.0;

/// @title Blood Contract
contract Blood {

    /// Variable for tracking Product Keeping Unit (PKU)
    uint pku;

    /// Variable for tracking Stock Louding Uint (SLU)
    uint slu;

    /// Public mapping from PKU to a Blood Item
    mapping (uint => BloodItem) dItems;

    /// Public mapping from SLU to a array of PKU
    mapping (uint => uint[]) stockLouds;

    // Enumaration for defining variety of Blood State
    enum BloodState {
        Separated,
        Packed,
        ForSale,
        Sold,
        Shipped,
        Received,
        Purchased
    }

    // Structure for Environment update unit
```

```
struct EnvUpdateOpj {
    uint timeStamp;
    uint humidity;
    uint temprture;
    address updaterAddress;
}

/// Structure for keeping Blood Donation fields structured
struct BloodItem {
    uint udpc;
    uint pku;
    uint slu;
    BloodState state;
    address payable currentOwnerId;
    address centerId;
    address deistributorId;
    address hospitalId;
    uint price;
    uint packingTimeStamp;
    mapping(uint => EnvUpdateOpj) envHistory;
    uint envUpdateCounter;
}

/// Event to emit them for users in functions,
accept ‘slu‘ as input as stock expected
event Separated(uint slu);
event Packed(uint slu);
event ForSale(uint slu);
event Sold(uint slu);
```

```
event Shipped(uint slu);
event EnvUpdated(uint slu);
event Received(uint slu);
/// Event to emit them for users in functions,
accept ‘pku‘ as input as one product unit expected
event Purchased(uint pku);

/// Modifier that checks if an

BloodDonationItem.state of a udpc is Owned
modifier isSeparated(uint _slu) {
    uint firstPKU = stockLouds[_slu][0];
    require(dItems[firstPKU].state == BloodState.Separated);
    _;
}

/// Modifier that checks if an BloodDonationItem.state
of a udpc is Owned
modifier isPacked(uint _slu) {
    uint firstPKU = stockLouds[_slu][0];
    require(dItems[firstPKU].state == BloodState.Packed);
    _;
}

/// Modifier that checks if an BloodDonationItem.state
of a udpc is Owned
modifier bloodLoudforSale(uint _slu) {
    uint firstPKU = stockLouds[_slu][0];
    require(dItems[firstPKU].state == BloodState.ForSale);
```

```
    _;
}

/// Modifier that checks if an BloodDonationItem.state
of a udpc is Owned
modifier isSold(uint _slu) {
    uint firstPKU = stockLouds[_slu][0];
    require(dItems[firstPKU].state == BloodState.Sold);
    _;
}

/// Modifier that checks if an BloodDonationItem.state
of a udpc is Owned
modifier isShipped(uint _slu) {
    uint firstPKU = stockLouds[_slu][0];
    require(dItems[firstPKU].state == BloodState.Shipped);
    _;
}

/// Modifier that checks if an BloodDonationItem.state

of a udpc is Owned
modifier isEnvTracked(uint _slu) {
    uint firstPKU = stockLouds[_slu][0];
    require(dItems[firstPKU].envUpdateCounter != 0);
    _;
}

modifier isReceived(uint _slu) {
```

```
        uint firstPKU = stockLouds[_slu][0];
        require(dItems[firstPKU].state == BloodState.Received);
        _;
    }

    /// Modifier that checks if an BloodDonationItem.state
    of a udpc is Owned
    modifier onlyCenterOf(uint _slu) {
        uint firstPKU = stockLouds[_slu][0];
        bool isCenter = dItems[firstPKU].centerId == msg.sender;
        require(isCenter);

    }
```

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