

Blockchain Traceability in Healthcare: Blood Donation Supply Chain

Samin Sadri, Aamir Shahzad, Kaiwen Zhang

Department of Software and IT Engineering

École de Technologie Supérieure

Montréal, Canada

samin.sadri.1@ens.etsmtl.ca, aamir.shahzad@etsmtl.ca, kaiwen.zhang@etsmtl.ca

Abstract—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

I. 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 crowded in healthcare centers [1], [2].

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 [3], [4]. In total, 136,908 donors made 216,639 donations. A blood donor can give blood 1.6 times per year, on average [2]. 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 [3]. 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 [4].

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 [5]. 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 [6]. 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 [7]. It is, therefore, 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 [1], [7]. 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 [5], [6], [7].

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 [1], [5], [6], [7]. 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.

II. RELATED WORKS

In [8], 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 counterfeit 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 make separate the entire network from another private network [8].

Modum.io AG used IoT sensors and Blockchain technology for tracking information during the transport of medical products [9]. 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 [9], [10].

MedRec applied Blockchain to Electronic Medical Records (EMR) framework and concentrate on resolving four significant concerns related to better management of EMR like incomplete medical data, slow access to them, system compatibility, patient agency, improve data quality for further research purposes [11]. 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 [11].

In [12], the authors propose MedicalChain, which has a permission-based Hyperledger Fabric architecture, making a client-focused electronic health record that keeps just a single version of the user record by using Blockchain technology. Medical chain provides conditional access to healthcare agents to connect, and any interaction with medical records that will be saved as a transaction on Medicalchains distributed ledger

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 limited 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 [12].

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 [13]. 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 pharmaceutical 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 [13].

Medicohealth is a Blockchain-based solution that permits completely anonymous, secure, and effective communication with physicians and tries to improve the imperfect healthcare system [14]. For limited time patients, data stored anonymously 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 functional layer(s) that are used in processing [14].

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 [15].

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 [16]. Blockchain helps that without the need for third-party evaluation, keep and store all of this information. Provenance has four important 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 [10], [16].

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 [17], [18].

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 [19].

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 [20]. 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 accurate, 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 [20].

III. 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 [10], [21]. Blockchain, based on its data accessibility, can be classified into four categories [22]: 1) Public Blockchain: anyone can read and acknowledge the transactions in opened networks, and of course, the information can be accessible in a public domain. 2) Private Blockchain: reading and submitting transactions just can be done by only one organization or multiple organization together in a group. 3) Consortium Blockchain: read and submitting transactions would be possible for a group of organizations that form the consortium. 4) 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 cryptography, which creates an immutable, not-hackable distributed database of digital assets [23]. 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 [23]: 1) 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. 2) 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. 3) 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.

IV. SYSTEM MODELING

Blockchain comes with various solutions to transform the traditional supply chain industry into a decentralized, anonymous, persistent, automated, and secure supply chain [10], [21]. 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 [2], [3], [4].

Fig.2 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 6°C, 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()`, `separateBlood()`, `packBloodUnit()`, `bloodDonation()`, `shipBloodsUnit()`, and `updateBloodsUnitShippmentEnv()`, executed as parts of BDSC, and Fig. 3 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 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.

1) *Function approveDonation()*

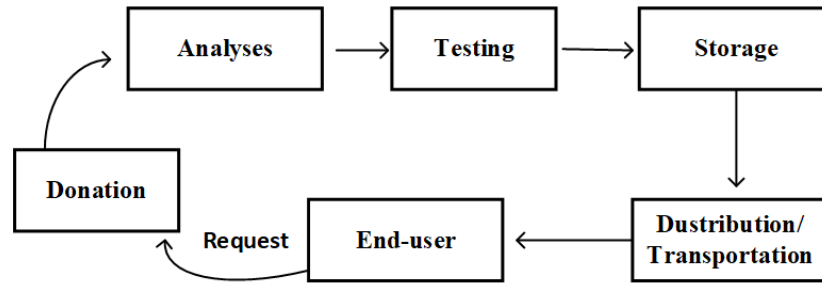


Fig. 1. Blood Donation Supply Chain

TABLE I
TRANSACTIONS OUTCOMES

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	✓	✓	✓	✓

```

/// 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 separateBlood()

```

/// 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);
}

```

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

```

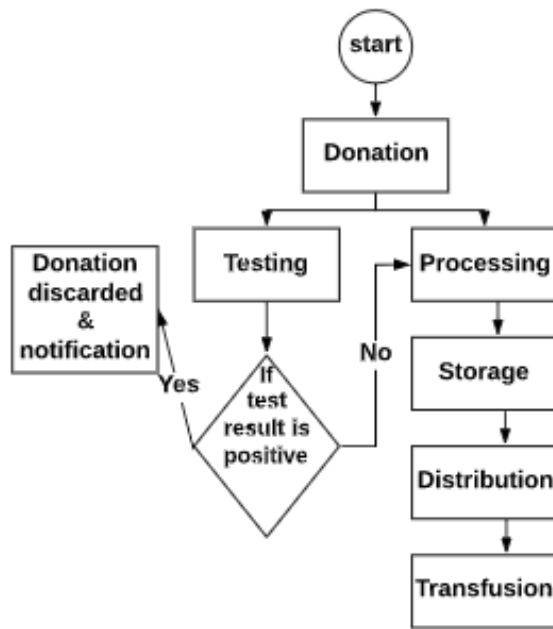


Fig. 2. Blood Donation Data Flow in Supply Chain

```

    )
    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 envuirmnt
    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);
    }
  
```

V. RESULTS AND DISCUSSION

Fig. 4 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 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 Table 1, we performed the random selection of transactions and then calculated the probability

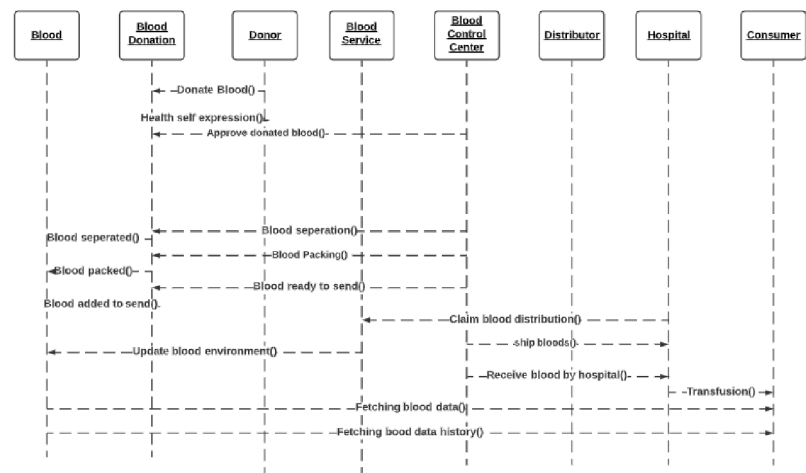


Fig. 3. Operational Sequence in BDSC



Fig. 4. BDSC Dashbroad

(%) in Fig. 5. 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 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.

VI. 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.

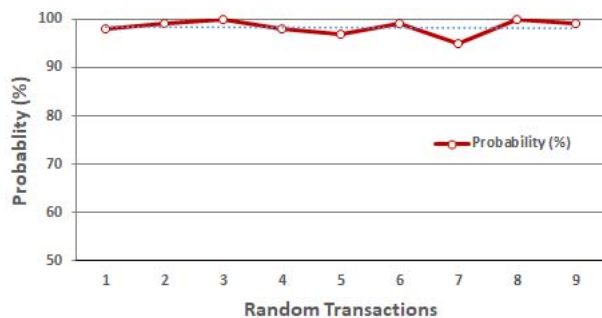


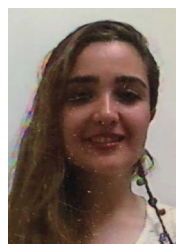
Fig. 5. Estimated Probability.

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SAMIN SADRI is currently pursuing a master's degree with FUSEE lab at ÉTS, Montréal, Canada. Her research interests include Blockchain Technology, Smart Contracts, and Supply Chain Management.



AAMIR SHAHZAD received his Ph.D. degree from the University of Kuala Lumpur, Malaysia. Currently, he is working as a Research Associate in the Department of Software and IT Engineering, ÉTS, Montréal, Canada. His research interests include the Internet of Things (IoT), Blockchain Technology, Industrial Internet of Things (IIoT), Industry 4.0, Supply Chain Management, Machine Learning, and Network Security.



KAIWEN ZHANG received the B.Sc. and M.Sc. degrees from McGill University, Montréal, and the Ph.D. degree from the University of Toronto. He was an Alexander von Humboldt Postdoctoral Fellow in computer science with TU Munich. He is currently a Professor with the Department of Software and IT Engineering, ÉTS. His research interests include blockchain technologies, publish/subscribe systems, massive multiplayer online games, performance modeling, and software-defined networking.