A Concept for Modernizing the Organ Donation and Transplantation System with Blockchain, Smart Contracts, and the Internet of Things

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Abstract

The healthcare industry encompasses various sectors, including organ donation and transplantation as one of its components. Organ donation is considered one of the most commendable acts of humanity, aimed at safeguarding the life of the patient. The key requirements for organ donation and transplantation encompass the optimal functioning of the organ, compatibility between the donor and recipient, and the donor's well-being post-organ removal. The primary issue at hand is that the demand for organs far exceeds the available supply. Another issue to consider is that the data relevant to organ donation, organ allocation, and organ transplantation is stored in centralized storage which suffers from many challenges; including; lack of data transparency, interference of third-party, trustless environment, issue of single-point failure, unethical organ donation process, illegal organ trade, and hospitals take advantage of centralized data storage. The paper introduces a concept of a decentralized system that replaces the traditional centralized database with distributed, transparent, immutable, and cryptographically secure blockchain database, the traditional apps with more robust smart contracts DApps, and embeds IoT sensors to track, monitor, and preserve organs during transportation to avoid their contamination on the way.

Keywords and Phrases: Organ donation, organ transplantation, blockchain, smart contracts, Internet of Things.

1. Introduction

The healthcare sector is among the most notable, extensive, and rapidly expanding industries worldwide. The healthcare sector strives to promote health, provide healing, deliver care, and enhance the well-being of the individuals it serves. The healthcare sector comprises diverse domains, and organ donation and transplantation stand as one of its integral components. Organ transplantation involves the surgical extraction of an organ from an individual known as the organ donor and its subsequent transplantation into another individual referred to as the organ recipient. The organ can be a kidney, liver, lung, eye, heart, and so forth. When the organ of the recipient fails or sustains damage due to disease or injury, the need for transplantation arises. Organ donation is widely regarded as one of the most admirable acts of compassion, dedicated to preserving the life of the recipient. The essential prerequisites for organ donation and transplantation involve the proper functionality of the organ, compatibility between the donor and recipient, and the donor's postoperative well-being. In 1954, the first triumphant organ donation and transplantation took place. The kidney was willingly donated and effectively transplanted between twin brothers. Since that time, there has been a consistent increase in the number of donations and transplants. The main concern lies in the fact that the demand for organs significantly surpasses the existing supply. According to recent reports and statistics, around 17 individuals succumb each day while waiting for an organ transplant, and a new patient is added to the waiting list approximately every ten minutes. Another aspect to take into account is that the data about organ donation, organ allocation, and organ transplantation is stored in a centralized repository, which poses several challenges. The paper introduces the concept of a decentralized system that substitutes the conventional centralized database with a distributed, transparent, immutable, and cryptographically secure blockchain database. Moreover, it suggests replacing traditional applications with more resilient smart contract DApps and incorporating IoT sensors to track, monitor, and safeguard organs during transportation, thereby preventing potential contamination along the way (Levan ML, Klitenic S, Massie A, et al (2022); Putzer G, Gasteiger L, Mathis S, et al (2022)).

2. Literature Review

This section explores various authors' models and proposals regarding the utilization of blockchain technology, decentralized applications (DApps), smart contracts, and the Internet of Things (IoT) in the realm of organ donation and transplantation.

2.1 Blockchain use-case in Organ Donation System

Hawashin et al (2022) presented an Ethereum-based private blockchain solution for organ donation and transplantation. Their proposal prioritizes transparency and reliability to improve the experience and trust of patients. The authors developed six smart contract algorithms, offering in-depth descriptions of their implementation, testing, and results. Francesco Maria Carrano et al.

(2022) explored blockchain's potential application in healthcare, focusing on its role in health economics. They proposed a fee-for-value model as an alternative to the fee-for-service model, highlighting how blockchain could revolutionize the economic aspects of healthcare delivery. Anmol Soni and Ganesh Kumar (2021) proposed a web application using blockchain technology, employing a four-layer architecture: browser (Layer 1), internet (Layer 2), smart contracts (Layer 3), and blockchain (Layer 4). They aim to enhance organ allocation for eligible patients by leveraging blockchain's transparency and efficiency. Clemence Niyigena et. al. (2020), proposed a blockchain-based decentralized system for kidney allocation. They designed specialized algorithms and evaluated the drawbacks of centralized solutions like UNOS and Eurotransplant. Their objective was to introduce an efficient and transparent alternative for kidney allocation. Anuradati Kulshrestha et. al (2020), proposed a safe platform to analyze and assist the procedure of organ donation by deploying it on a blockchain-based decentralized framework via a web portal that interconnects organ donors with organ recipients. Various smart contracts were written using Ganache and deployed using Metamask. P.L. Wijayathilaka et. al. (2020), proposed a secure and intelligent blood and organ donation management system; namely; LifeShare which provides a safe and smart organ and blood donation web-based system where the patients as well as healthcare providers, can access blood and organ-related data. LifeShare uses blockchain-based technology and Ethereum-based smart contracts to perform tasks. Benita Jose Chalissery and V. Asha (2018), talked about a blockchain-based system that maintains a transparent patient waiting list, does automatic donor-patient matching, validates and verifies each transaction carried out in the system; and easily traces any alterations made to the waiting list of patients.

2.2 *Decentralized Application for Organ Donation System*

Lama Abdulwahab Dajim et. al. (2019), proposed a decentralized web-based application; named Kidner; for a kidney donation system where patients could register their information; such as; medical identification number, blood group, type of organ needed, and other credentials using blockchain technology. Pratyush Ranjan et. al. (2019), proposed an Ethereum-based decentralized and distributed secure transparent web-based model for tissue as well as organ donation and its transplantation into the patient’s body using blockchain technology.

2.3 *Smart Contracts for Organ Donation System*

Amal Abid et. al. (2021), did a case study on the usage of drones for the delivery of organs using blockchain-based smart contracts by considering the temporal constraints in smart contracts. The authors used ‘Caterpillar’; a blockchain-based engine for executing processes that execute on the Ethereum blockchain.

2.4 *Internet of Things use-case in Organ Donation System*

Gowru Devraj et. al (2022), proposed shipping containers embedded with location tracking as well as an environment monitoring system using IoT sensors; such as temperature sensor, humidity sensor, LDR, and gas sensor; to continuously examine the weather state surrounding the container and transfers the entire information to the cloud server-based web application. The proposed model uses IoT, cloud computing, and MQTT protocol for monitoring shipping containers. Benita Jose Chalissery et. al. (2020), proposed an IoT-based intelligent organ procurement and delivery system which assists in bringing significant enhancement in the timely delivery of organs to prevent their contamination and hence their wastage.

3. Research Gap

Table 1 shows a comparative study of the existing models based on a few criteria or parameters. The survey shows that there is a need for a model which uses blockchain technology as the database to store data and transactions of the system of organ donation and transplantation, smart contracts to code the entire logic of the system, decentralized application for the interaction of the stakeholders with the system, and Internet of Things sensors for keeping track of organ after its removals and preventing any contamination during preservation and transportation.

Table 1: Comparative summary of the existing models

S.No.	Authors	(a)	(b)	(c)	(d)	(e)
1.	Amal Abid et. al. (2021)	✓	✓		✓	
2.	Anmol Soni and Ganesh Kumar (2021)	✓		✓		
3.	Anuradati Kulshrestha et. al. (2020)	✓	✓	✓		
4.	Benita Jose Chalissery & V. Asha (2018)	✓	✓			
5.	Benita Jose Chalissery & V. Asha (2020)				✓	
6.	Clemence Niyigena et. al. (2020)	✓	✓			

7.	Diana Hawashin et. al. (2022)	✓	✓			
8.	Francesco Maria Carrano et. al. (2022)	✓				
9.	Gowru Devraj et. al. (2022)					✓
10.	Lama Abdulwahab Dajim et. al. (2019)	✓		✓		
11.	P.L. Wijayathilaka et. al. (2020)	✓	✓	✓		
12.	Pratyush Ranjan et. al. (2019)	✓	✓	✓		
13.	**The Concept Introduced**	✓	✓	✓	✓	✓

Legends: (a) for 'Does the model uses blockchain for data storage?', (b) for 'Has the model developed smart contracts to handle the logic of the system?', (c) for 'Has the model designed decentralized applications for better user interactions?', (d) for 'Does the model uses IoT sensors to keep track of organ while its transportation?', (e) for 'Does the model uses IoT sensors to monitor the environmental parameters, like temperature, pressure, and humidity, to keep track of organ and prevent it from contamination?'.

4. Problem Formulation

Many IT tools, applications, software, and databases are being designed and implemented to gather and store the data regarding organ donation and transplantation life cycle and cater to the rising needs for organ transplantation and cover the increasing gap between the requirement for and availability of transplantable organs. But mostly, this entire data regarding organ donation and transplantation life cycle resides in centralized databases managed by different organizations individually. The data relating to donor's registration, donor's medical reports, organ to be donated, matching tests reports, waiting lists, organ transportation, organ preservation, recipient's registration, organ transplantation, and other relevant data generated is stored in centralized storage. Centralized data storage suffers from many challenges. Table 2 reflects the challenges and issues that are faced when the data related to organ donation, organ transportation, and organ transplantation resides in centralized storage (Nieto-Galván, R., Durantez-Fernández, C., Madrigal, M. Á., et. al. (2022); Ibrahim, B., Dawson, R., Chandler, J. A., et. al. (2021)).

Table 2: Challenges in the centralized system of organ donation and transplantation

S. No	Issue	Description
1	Lack of data transparency	Donors and recipients lack direct access to comprehensive organ donation and transplantation information, including organ waiting lists, available organ data, organ condition data, and other relevant information.
2	Interference of third-party	Donor and recipient registration, blood data matching, organ retrieval, transportation, transplantation, and related data are managed by a third party. Data security depends solely on the third party's ability to protect against hacking and unauthorized access by fraudulent individuals.
3	Trustless environment	A centralized storage system creates an environment where trust is compromised, potentially eroding an individual's confidence in the accuracy and reliability of the organ's "wait list."
4	Lack of security standards	These centralized systems lack real-time updates and often have inadequate security measures since they rely on traditional databases to store sensitive data of patients and donors.
5	Issue of single-point failure	If a centralized server experiences a failure, the entire database would be at risk of being permanently lost.
6	Unethical organ donation process	The absence of data transparency exacerbates the issue of unfair allocation of organs, favoring certain individuals or biased groups in the process.
7	Illegal organ trade	The lack of transparency also facilitates illicit organ trade, making it challenging to detect and monitor medical professionals involved in unethical practices such as organ trafficking.
8	Hospitals exploit centralized data storage for their benefit	As a result of these limitations, hospitals exploit the desperation of patients in need of organs by creating opportunities to transfer organs to those who are willing to pay exorbitant prices, prioritizing financial gain over ethical considerations.

9	Slow-moving process	The existing centralized transplantation system is excessively sluggish, which is unacceptable, particularly in critical and life-threatening situations.
10	Expensive software	Software and applications developed using centralized storage solutions incur significant costs, as owners have to invest thousands of dollars to acquire them.

Table 2 shows that the centralized storage of data lacks accountability, immutability, auditing, transparency, traceability, trust, accessibility, interoperability, and most important security of the data related to donors and patients. A recent survey reveals that each day, 17 individuals pass away waiting for an organ transplant, and every 9 minutes a new individual is included on the waiting list for organ transplantation. Figure 1 shows a pie chart depicting the percentage of organs needed; according to a survey conducted by the Health Resources and Service Administration (HRSA) on January 2023 *('other' consists of homograft transplants such as the face, hands, and abdominal wall*). Figure 2 presents a bar graph highlighting the number of organ-wise transplantations performed; as per a survey conducted by HRSA on January 2023. Figure 3 highlights the number of patients on the waiting list by their age; as per a survey conducted by the HRSA on January 2023. Figure 4 depicts a bar graph comparing the number of patients on the waiting list and the number of transplants performed region wise; according to a survey conducted by HRSA on February 2022 *('other' consists of American Indian/Alaska Native, Pacific Islander, Multiracial*).

Figure 1: Organs needed for transplantation; according to a survey conducted on January 2023

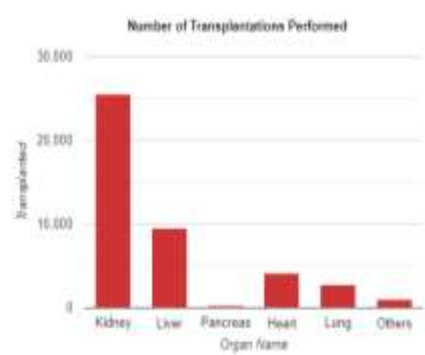

Figure 2: Number of transplantation performed (organ-wise)

Figure 3: Number of patients on the waiting list (age-wise)

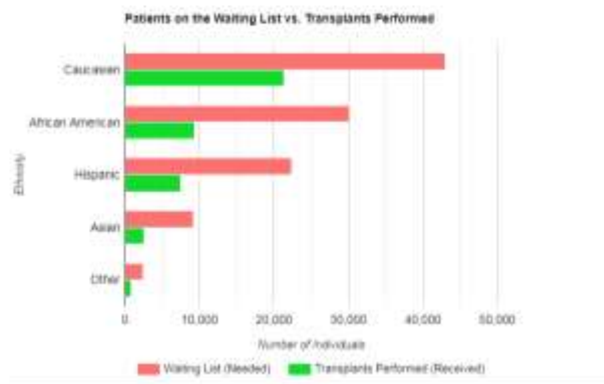

Figure 4: Region-wise comparison of the number of patients on the waiting list and number of transplants performed

Figure 4 show that there is a significant disparity in the supply and demand of transplantable organs, and hence the fairness, accuracy, privacy, and transparency of the organ donation systems are paramount. So there is a need to design a system that not only stores the relevant data safely and securely; but also maintains a single version of truth by preventing manipulation of sensitive data; such as the organ waiting list. There is a need for a system that provides complete transparency, of all the actions and transactions being performed, to all the stakeholders involved in the organ donation, transportation, and transplantation process (Shi, B. Y., Liu, Z. J., & Yu, T. (2020); Ali, A., Ahmed, T., Ayub, A., et. al. (2020)). The concept introduced would make the organ donation process efficient, distributed, traceable, and immutable. This could be achieved by replacing the traditional centralized database with distributed, transparent, immutable, and cryptographically secure blockchain database, the traditional apps with more robust smart contracts DApps, and embedding IoT sensors to track, monitor, and preserve organs during transportation to avoid their contamination on the way.

5. Research Objectives

- To present the challenges in the current centralized system of organ donation and transplantation.
- To highlight the significance of blockchain technology, smart contracts, decentralized applications, and the Internet of Things in the organ donation and transplantation system.

- To present the diagrammatic representation of the concept which has been introduced for organ donation and transplantation system using blockchain technology, smart contracts, decentralized application, and Internet of Things sensors.

6. Research Methodology

The concept introduced for organ donation and transplantation system uses blockchain as the database to store the relevant data and transactions, smart contracts as the programming environment for coding the entire logic of the system, decentralized applications for better user interaction, and Internet of Things sensors to prevent contamination of organ while its transportation.

6.1 The Blockchain Distributed Ledger technology

Blockchain has appeared as amongst the most propitious technologies of Industry 4.0. Blockchain is a decentralized chain of a list of records and transactions called blocks, linked with each other. Blockchain provides storage and sharing of data in a distributed, transparent, and immutable way. Table 3 shows the effectiveness and assistance of blockchain technology in organ donation, transportation, and transplantation process (Berdik, D., Otoum, S., Schmidt, N., et. al. (2021); Namasudra, S., Deka, G. C., Johri, P., et. al. (2021)).

6.2 Smart Contracts

Smart contracts are tamper-proof decentralized digital programs that are implemented and executed on blockchain architecture and are coded using high-level programming languages and get executed automatically when a certain set of conditions are met. They are implemented on blockchain platforms such as Ethereum, Rootstock, Chainspace, Zether, Hyperledger Fabric, NXT, and Sidechains and are deployed on Ethereum Virtual Machine (EVM). Smart contracts work using simple ‘if..else..’ statements and are written using high-level languages, such as Solidity or Serpent, with the help of deployment platforms and tools like Remix, Truffle, Metamask, and Mist Browser. Once written and implemented on the blockchain, smart contracts execute automatically when some pre-defined conditions are met, without any interference from third-party, hence preventing unauthorized or unlawful manipulations in the logic and code of the contract. Table 4 provides the benefits of using smart contracts in organ donation, transportation, and transplantation system (Sawant, V., Gaikwad, S., Dhangar, C., et. al. (2022); Dhand, G., Pahwa, N., Bhadri, R., et. al. (2022)).

6.3 Decentralized Applications (DApps)

DApps stands for Decentralized Application. DApp is a front-end web application that interconnects with users on one end and smart contracts on the other end. DApps are implemented on the Ethereum blockchain network of computers. Tools like Metamask and Truffle framework can be adopted to design a DApp. The logic behind DApp is coded using smart contracts modules. The concept introduced would have different modules in DApps as mentioned in Table 5, to achieve a decentralized, secure, and transparent system for organ donation, transportation, and transplantation. Table 6 reveals various benefits of using DApp over traditional apps for organ donation, transportation, and transplantation system (Fatoum, H., Hanna, S., Halamka, J. D., et. al. (2021); Soltanisehat, L., Alizadeh, R., Hao, H., et. al. (2020)).

6.4 Internet of Things (IoT) Sensors

The Internet of Things (IoT) is an Internet-based network where almost all physical entities and objects can connect to deliver services to individuals. Every organ has a fixed surviving time and has fixed temperature, pressure, humidity, altitude, and vibration requirements. If the temperature; for example; of the removed organ goes higher than the required threshold, then it may lead to hypoxic injury of that particular organ. In case the temperature falls, the risk of cold injury of that particular organ would be there. The introduced concept would embed IoT-enabled sensors in the organ vehicle. These sensors would then keep track of the environment surrounding the organ. The IoT-enabled sensors would collect in real time the data related to the temperature and pressure of organ containers and would send this data to the smart contracts deployed on the Ethereum blockchain. The smart contract would then verify whether the organ is being transported in a safe environment or not. The major advantage of this entire process would be that the patient or the patient's family and even the patient's doctors; whoever has access to related DApp; can see the real-time condition and state of their organ and can ensure that the organ would reach the destination safely and in a healthy environment. The entire process would provide complete transparency to the patient or his family who are going to pay lots of money for that organ (Bansal, M., Chopra, T., & Biswas, S. (2021); Peloso, A., Moeckli, B., Delaune, V., et. al. (2022)).

Table 3: Significance of blockchain technology in the organ donation and transplantation process

S. No	Advantage
1	Decentralization of data
2	Data security and privacy
3	Consensus mechanisms
4	Immutability
5	Elimination of third-party control and intermediaries
6	Integrity
7	Traceability
8	Trustful environment
9	Simplification of process
10	Elimination of single-party control
11	Transparency
12	Aid in the post-donor study
13	Enforcement of regulatory standards
14	Cost-effectiveness

Table 4: Significance of smart contracts in the organ donation and transplantation process

S. No	Advantage
1	Autonomy
2	Trust
3	Provides Backup
4	Immutability
5	Accuracy
6	Cost-effectiveness
7	Fast processing
8	Anonymity
9	Prevent wastage of organs

Table 5: List of modules of DApps of the concept introduced

Sr. No.	Module
1	Donor's Registration Model
2	Patient's Registration Model
3	Organ's Registration Model
4	Adding patient on Waitlist
5	Donor-patient matching model
6	Approval by patient's doctor model
7	Organ removal model
8	Organ transportation model
9	Organ receiving model
10	Organ transplantation model

Table 6: Significance of using DApp for organ donation and transplantation system

S. No.	Advantage
1	Transparency connecting donor and patient/patient's family
2	Security and immutability
3	Decentralization of data
4	Elimination of the issue of a single point of failure
5	Trustfulness
6	Data integrity

7. The Concept Introduced for Organ Donation and Transplantation System using Blockchain, Smart Contracts, and the Internet of Things

Figure 5(a-k) shows the diagrammatic representation of the concept introduced for organ donation, transportation, preservation, and transplantation.

Figure 5(a): Donor's Registration Model

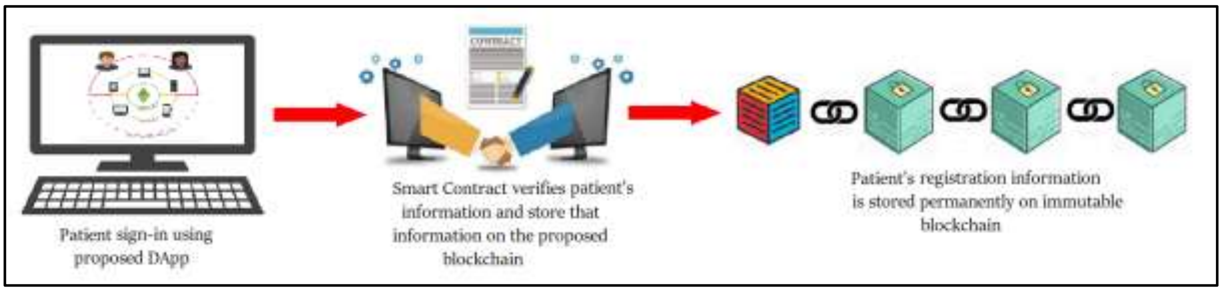

Figure 5(b): Patient's Registration Model

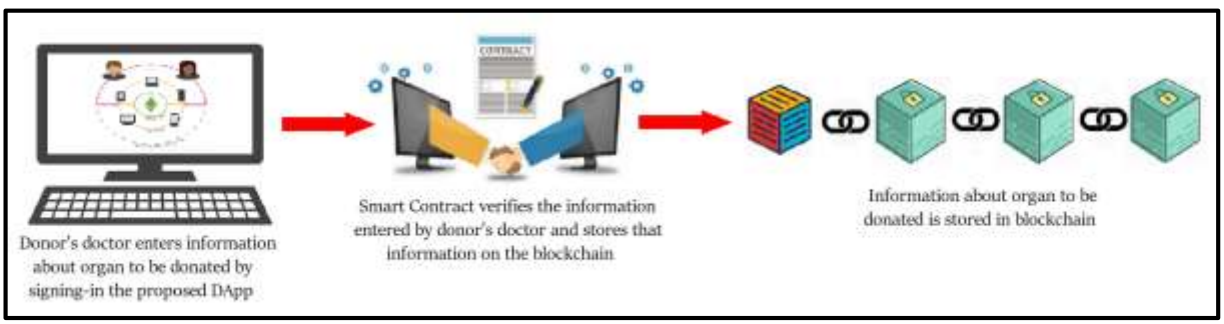

Figure 5(c): Model for storing donor's organ to be donated

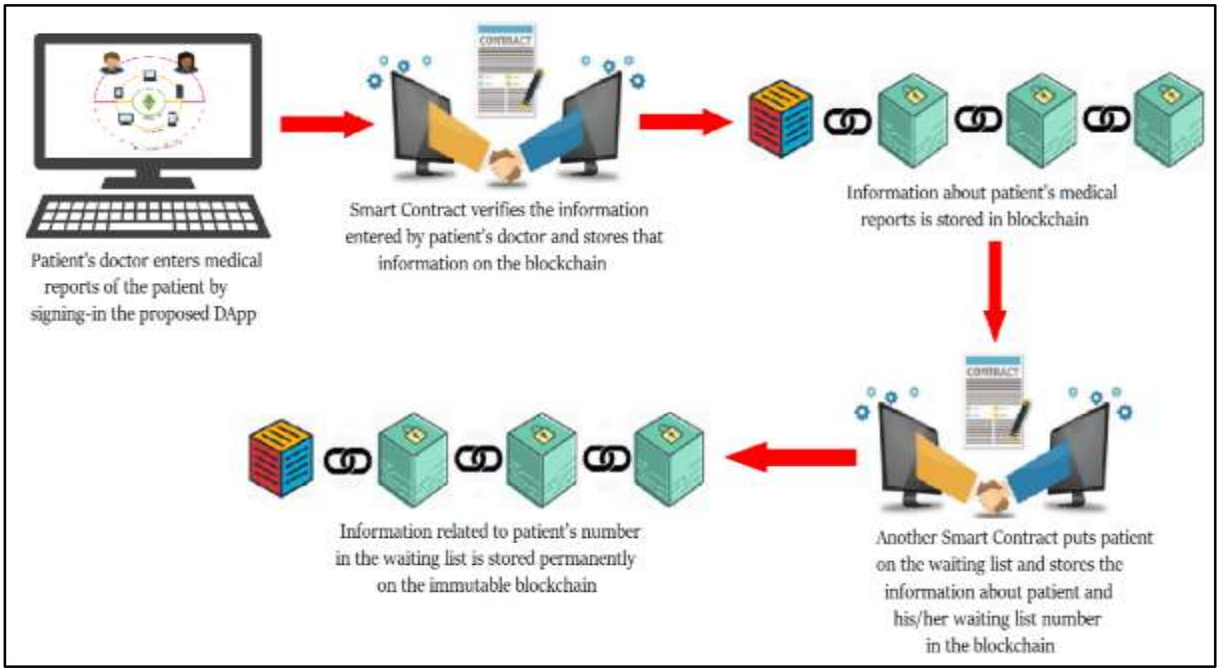

Figure 5(d): Model for storing patient medical reports on blockchain and adding patients to the organ waiting list

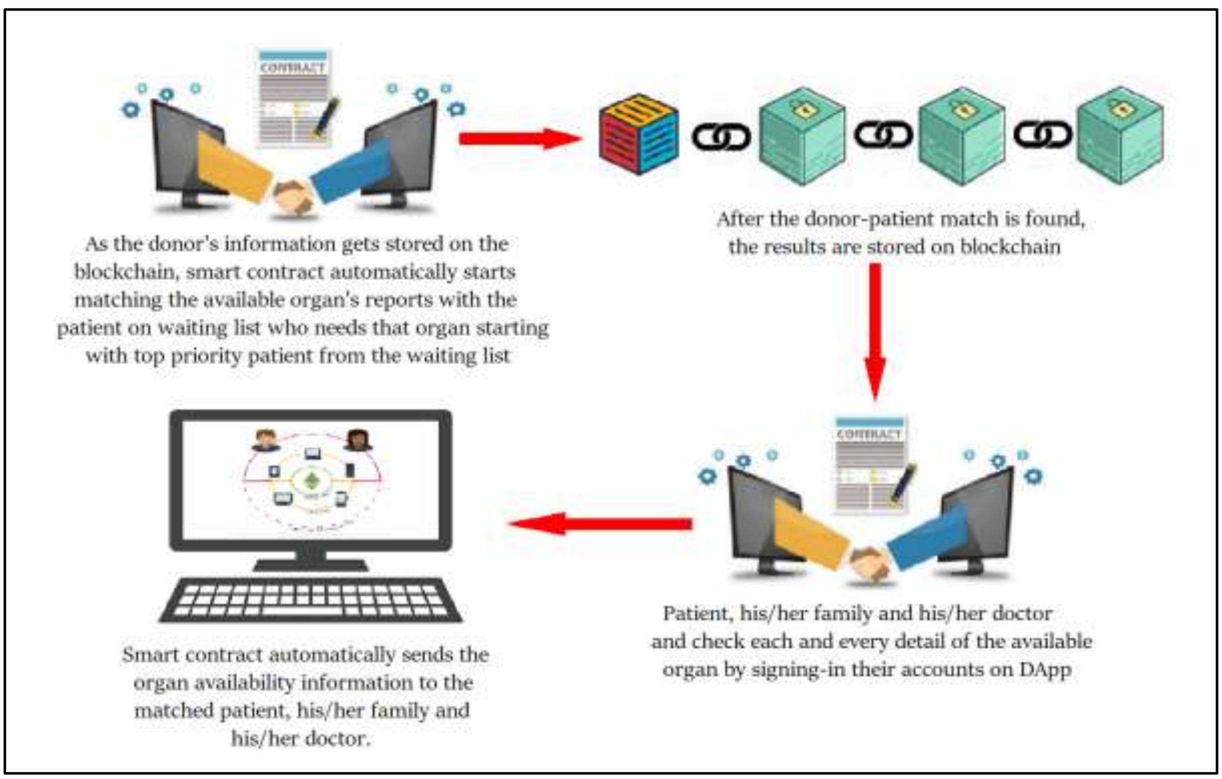

Figure 5(e): Donor-patient matching model

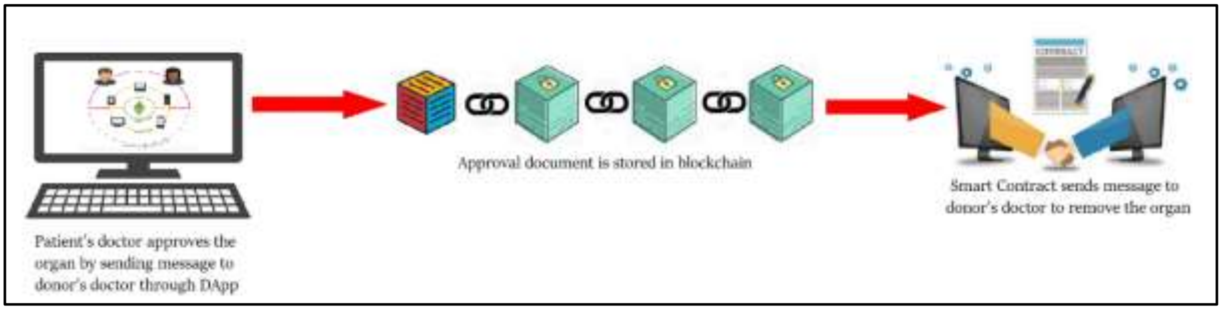

Figure 5(f): Approval by patient's doctor model

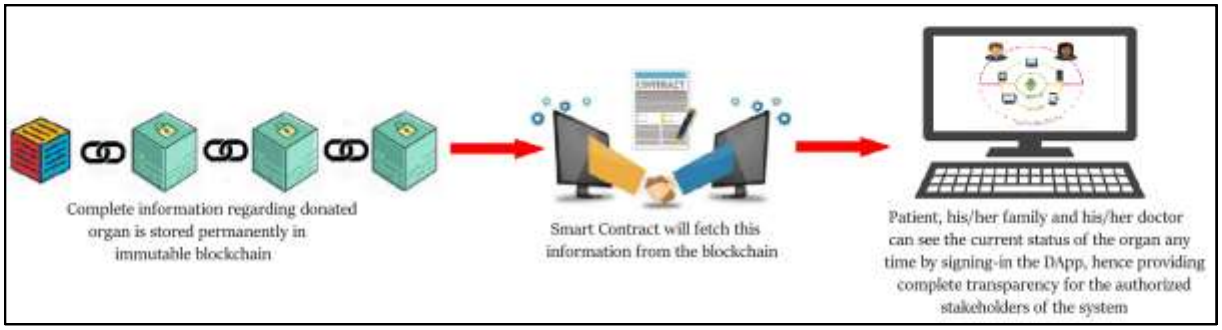

Figure 5(g): Model to provide organ information transparency to the patient, his/her family, and his/her doctor

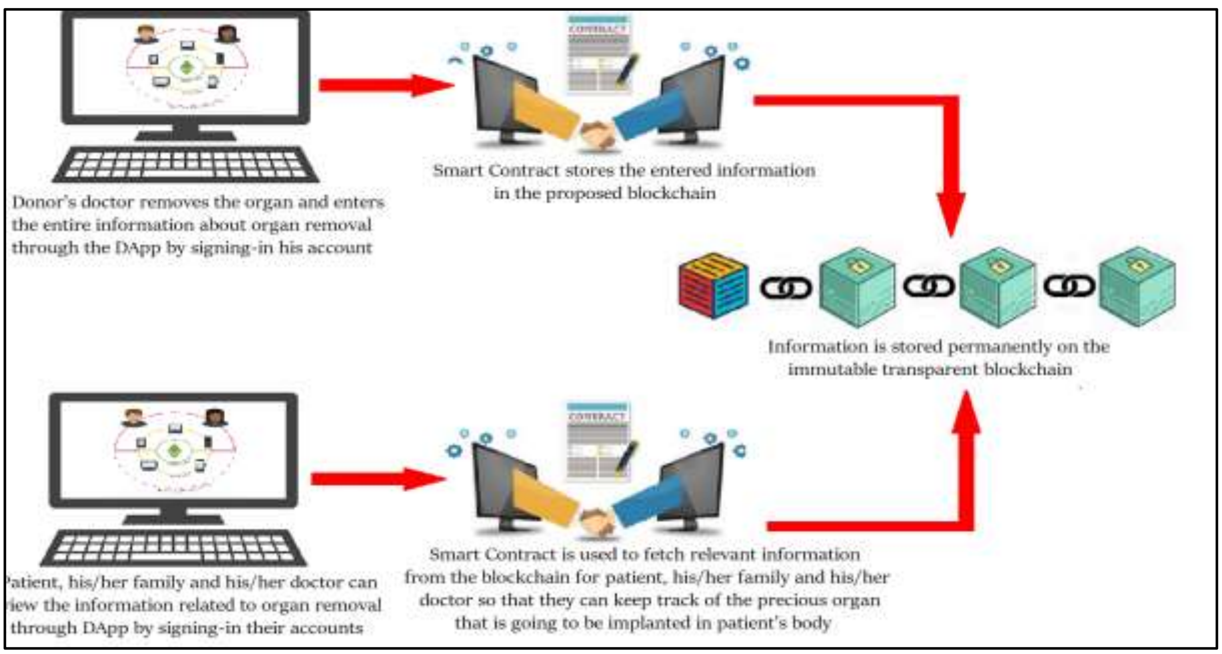

Figure 5(h): Organ removal model

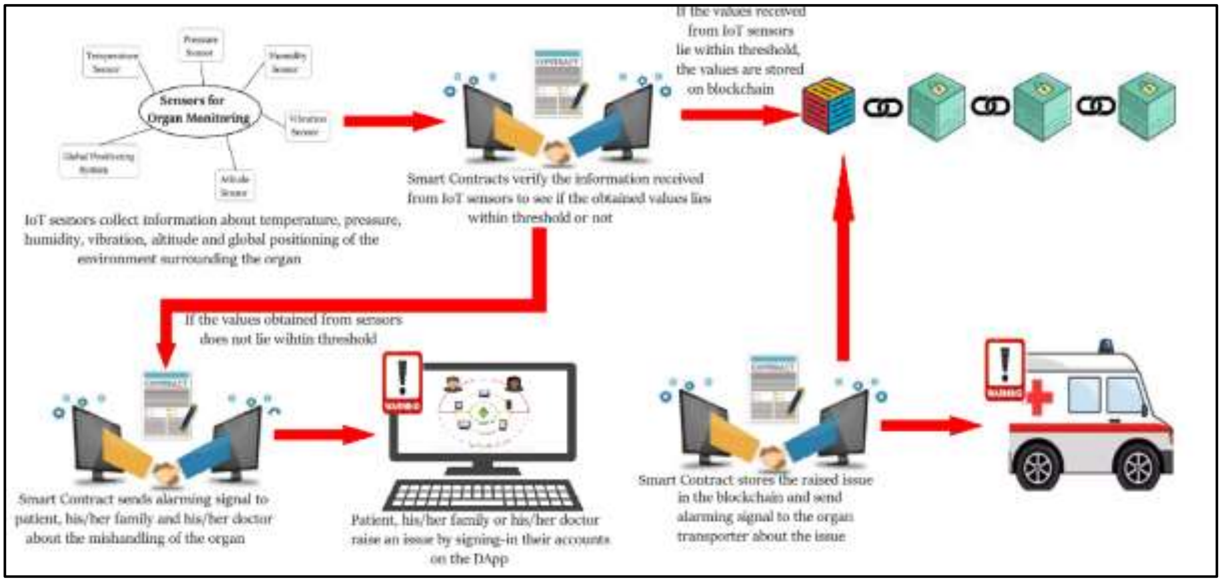

Figure 5(i): Organ transportation model

This process would be repeated after fixed time intervals and if the smart contract finds that the organ is being contaminated, the organ would be returned to the donor's hospital and an issue regarding this mishandling of the precious and needy organ would be raised. All the data would be stored on blockchain side by side and the patient, his/her family, or his/her doctor can see the information through DApp. This will ensure that the patient is not implanted with contaminated organs and this will ensure that the transporter can find the root cause of the mishandling and would be careful next time.

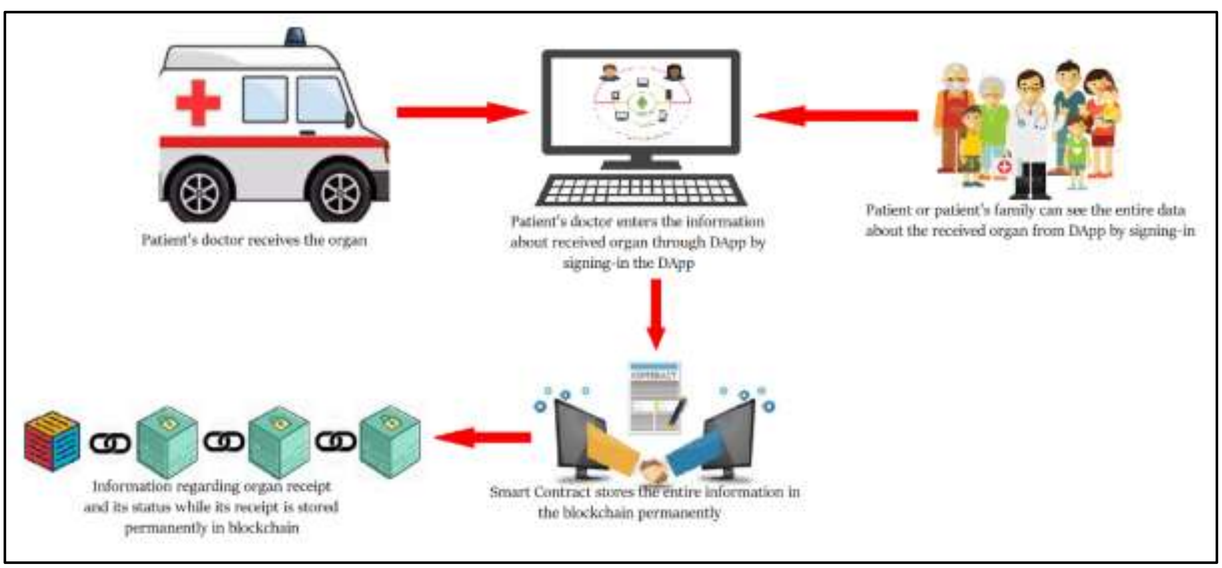

Figure 5(j): Organ receiving model

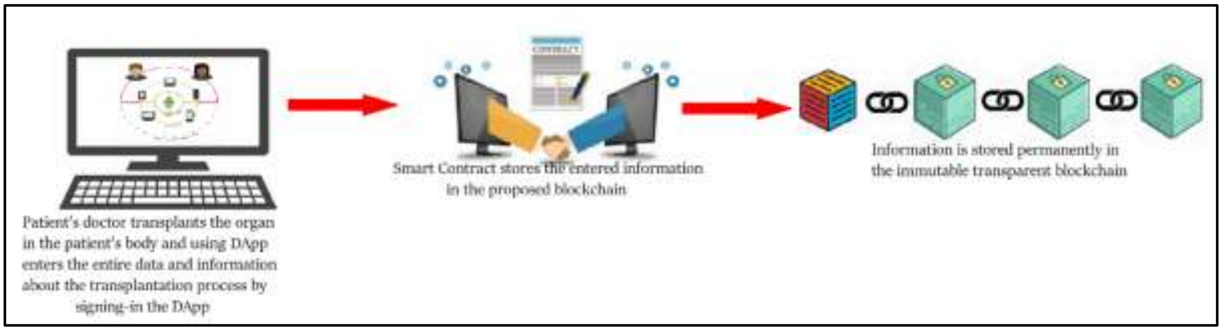

Figure 5(k): Organ transplantation model

8. Expected Outcomes and Results

- Equitable distribution of organs, deterring organ trafficking and unethical organ trade
- Transparency of organ donation and allocation process.
- Immutability of the patient's organ waiting list.
- Security of patient's and donor's data.
- Mitigates the risk of single-point-of-failure.
- Trustful environment to the donor and receiver of the organ.
- Complete traceability of the organ after it is removed and allocated to a best-matched patient.
- Complete autonomy of organ donation, organ matching, organ allocation, and organ transplantation process.
- Avoids involvement and expenditure on third-party services.
- Proper preservation of organs after their removal and during their transportation.
- Real-time monitoring of organs after their removal and during their transportation.
- Facilitates efficient matching of organ donors and recipients, minimizing organ wastage.

9. Conclusion

The current system of organ donation, transportation, and transplantation uses a centralized database to store the relevant data and transactions. Centralized storage suffers from various issues and challenges. The paper suggests an alternative decentralized system that replaces the conventional centralized database with a distributed, transparent, immutable, and cryptographically secure blockchain database. Additionally, it replaces traditional applications with more resilient smart contract DApps and incorporates IoT sensors to track, monitor, and preserve organs during transportation, thereby preventing contamination in transit. The diagrammatic representation of the concept introduced for organ donation, transportation, preservation, and transplantation is also presented. This concept ensures transparency, immutability, data security, data backup, a trustful environment, robustness, traceability, autonomy, cost-effectiveness, organ preservation, real-time monitoring of organs, and minimizing organ wastage.

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