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Blockchain apply to the supply chain of essential medicines for the treatment of Covid-19 in Colombia

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A B S T R A C T

Introduction: The outbreak of SARS-CoV-2, called COVID-19, in Colombia as well as in a great part of the world, has been declared as a public health emergency of international concern, affecting different aspects of the daily life, being one of the most important the access and distribution of necessary medicine, not only for the known deceases but also for the mitigation of COVID 19.

Objective: the distribution of medicines should maintain stability in the supply chain of essential medicines, thus ensuring high quality medicines that could help in the treatment to fight the virus.

Methodology: through this work a detailed analysis of the variable and critical points in the supply chain of essential medicines to mitigate COVID-19 is developed.

Results: A new architecture based on the Blockchain Hyperledger is presented. It will help to solve those critical points found, through the secure trace of the medicine supply chain. In Colombia, by using this architecture all actors take responsibilities in the distribution chain, ensuring a high level of transparency in the distribution process.

Discussion: by verifying the proper functioning of the model, the main difficulty when using Hyperledger is the lack of suppliers with experience; besides, there are not enough standardization or regulations of Blockchain.

Conclusion: It is proved that Blockchain is an optimal technology to ensure essential medicine supply chain for the COVID 19 treatment in Colombia.

1. Introduction

According to the World Health Organization-WHO, this new COVID-19 virus has been classified as an international public health emergency, since cases have been identified on all continents; In Colombia, the first case of an infected person was confirmed on May 6, 2020, this virus is transmitted when the person infected coughs, expelling the virus particles, causing people who have contact with the virus to become infected [1], to mitigate this virus the Colombian government has chosen to carry out a quarantine, which has led to difficulties in different aspects of daily life, including the access and distribution of medicines, this distribution should not be affected, this medical supply chain should be maintained and the government must comply with it [2,3].

As of April 18, 2021, there are 141,011,168 confirmed cases worldwide, in Colombia, there are around 2,652,947 confirmed cases of COVID-19 and 68,328 deaths, and this continues to increase day after day [4], although there is no medicine that helps to end COVID-19 there are indeed several medicines that are necessary for the treatment of patients with COVID-19; what these medicines do is relieve the symptoms of infected people, these medicines are, Remdesivir, Chloroquine/Hydroxychlor, Ritonavir and, Lopinavir; these have already been used before to fight against different viruses, and it has been demonstrated that although they do not end with COVID-19 they do provide a treatment to combat it [5].

A serious concern that can be identified is that Latin America has major public health failures, which put us in a very vulnerable situation against this virus, if you take Colombia as an example, which invests in public health with a 4.1% of GDP, compared to Spain or France which invest more than 8%, the great inequality can be recognized in these times of crisis [6]; as a consequence, a great dilemma can be evidenced in terms of the supply chain of medicines, which is overshadowed by the pacification of medicines, their deviation, and pharmaceutical theft.

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This generates quite a few inconveniences when wanting to obtain quality medicines, only in La Guajira, compared to January 2019 and 2020, there is evidence of three times higher number of illegal medicines than this year, counting as of 2019 with 12,942 units of illegal medicines worth 7 million pesos [7].

Colombia is among the 10 countries in the world that produce the most counterfeit medicines, according to the international institute against counterfeit medicines. In Colombia, by the year 2017, 3.8 million counterfeit medicines had been seized, for a value of 7 billion pesos, by the year 2019 a seizure of 4.6 million counterfeit medicines is expected, according to Punto Azul, an association aimed at the search for illegal medicines in Colombia, the supply medical chain which includes from raw material suppliers, pharmaceutical laboratories, distributors and institutional channels, pharmacies and, operators to consumers or patients, is in great deficit in several of its parts, where a great focus of this predicament is centered on pharmacies and operators, who can open drugstores in garages or even simply open the truck and sell medicines on the street, where pharmacies buy smuggled medicine from abroad [5].

It is of crucial importance to have control over this supply chain, and more so with the arrival of a new virus, due to the fact that these counterfeit medicines threaten Colombians' health it is significant to have high-quality medicines [9]. In 2018 through Invima there were more than 100,000 cases of adverse medical effects, Colombia is the fifth country where most of these cases are reported being the United States the first, in the world 44,000 and 98,000 people die annually due to health care errors and 7000 due to medication errors [10].

One of the main problems that affect the healthcare system in Colombia is the difference between the contributory and subsidized regime. As a consequence, the integration of the supply chain of essential medicine in both sectors becomes complex [11], one important aspect in the supply chain is the traceability of the medicine. It is necessary to ensure the track and trace from the initial phase which goes from all the manufacture process to the medication administration to the patient. Some institutions use bar codes and the electronic data interchange -EDI with the purpose to expedite the flow of hospital logistics. Article 23 of the national pharmaceutical policy establishes all the activities that should be taking into account in the management of the supply chain in the healthcare sector [12,13]. In Colombia, there are two ways to purchase medicine, first one by direct purchase from the laboratories and the second one through the distributor. Most of the purchase comes from imports which become more difficult to control and there is no knowledge of the way they enter the country.

On the other hand, the economic factors play an important role because each one of the actors in the chain seeks the higher possible profit without caring for the impact on the other actors. Because of this lack of information from the point of view of the traceability, it becomes necessary to search for new alternatives from the new technologies point of view to improve the quality and efficiency of the process [14]. One alternative could be the use of Blockchain technology, being a decentralized network, all the actors in the chain could have the absolute knowledge of the process and besides, it would guarantee a high level of transparency. As explained [15], one of the challenges in the supply chain is the adequate integration of the chain, in which the actors have different interests.

A solution will be proposed and developed to monitor the supply chain of medicines necessary for COVID-19 through an application based on Blockchain, initially the variables and critical points that this supply chain has, will be determined, after that it will be possible to analyze different Blockchain protocols to identify which of them is the one that best suits the variables and requirements, once the Blockchain protocol has been selected, we can proceed to make an architecture which allows complying with this supervision, finally, this developed architecture will be tested and the necessary adjustments will be made if required.

In Colombia, it is very important that the health systems prioritize the essential medicine that should be available and accessible for patients in the intensive care units during health emergencies. List of essential medicine for patients in the intensive care units with suspected or diagnosed COVID 19 infection [16].

The main motivation to carry out this study was the lack of essential medicine for the treatment of COVID 19 in Colombia; for several reports of counterfeit medicine, which is critical for the pandemic management. Some reports: EFE Agency January 24, 2020 informed that two children died after ingesting the wrong medicine delivered by a pharmacy in Bogota [17]; November 30, 2021 the AS newspaper reported the counterfeit of the Vaccination Certificate in Colombia [18]; RCN Radio reported on August 4, 2022 an alert on counterfeit medicines being commercialized in the country [19]; On April 21, 2022 The Pan American Health Organization alerted on the sale of fake COVID-19 vaccines [20]. Due to this situation new secure tracing and monitoring models for the essential medicine supply chain are required [9,21].

The authors propose this model which applies to the general access for other medicines because during the COVID 19 pandemic, several low, middle and high income countries have experienced shortage of the essential medicine reserves, necessary for the treatment of COVID 19 patients in the intensive care units -ICU. Countries health emergencies preparedness plan require the inclusion of a list of essential medicines and other necessary medical devices in the ICU to face health emergencies [22].

2. Blockchain in the supply chain

In this section, the parts of the medical supply chain will be evidenced, and also how this virus can be mitigated through this chain, such as the use of vaccines, medicines, and others, we will point out the risks or critical points to be found in this process, to identify how to solve them in an efficient and low-cost way. To reveal the main failures in the supply chain of medicines necessary to mitigate COVID-19, it will initially be necessary to take into account the intervening variables, such as its production chain and the different logistics services found throughout the manufacturing and distribution process, from raw material to the final customer, as all these variables are necessary for the correct deployment and operation of the supply chain of essential medicines for the mitigation of COVID-19. Initial, intermediate and, final processes are found to generate the flow of these medicines [11].

As an initial part of the supply chain are the laboratory suppliers Fig. 1, which are in charge of providing the raw material for the production of medicines, in Colombia the production of this raw material is very low, therefore, it is necessary to import this raw material from other countries which have a large production capacity, such as the European Union or the United States [23]. Once the pharmaceutical laboratories obtain the raw material, they proceed to transform it into medicines, in this way giving a value to this raw material, providing quality products that will be consumed by customers [24], to give the added value to this raw material, six steps must be taken into account, the main one is to carry out research and development of raw materials, once it have clarity on this raw material the asset is purified, to proceed to a pre-clinical study of the purified raw material, having the certainty of the data obtained, the preparation of the medicine starts, when the medicine is ready, it is bottled and packaged, having as a final step the quality control, to have clear certainty that the delivered product achieve a high quality and safety factor [25].

Another important variable to be treated will be the distribution, once the medicines are prepared for their packaging, logistics operators are needed for transporting, storing, and distributing these medicines taking into account all the necessary protocols so that these medicines comply with the quality indexes, these are extremely important for the vaccine, since this vaccine must be below 80° Celsius during transport, or it will be rendered ineffective as it will lose key characteristics to fight the virus [26]; this variable is one of the most essential and with the greatest conflict given that most pharmaceutical companies are not
responsible for the distribution of their products, this leads to outsourcing this process in the chain so that the medicines reach clients safely [27]. The final variable in this supply chain is the most important due to the fact that they are the customers, they can be the health promoting entities - EPS or general social security systems, considering that these are the main sources of the distribution to patients although, it is also possible to find distribution centers, where medicines are stored and then distributed to drugstores and wholesalers [28].

In this supply chain, there are three flags or critical points, which are among the manufacturer or laboratory and the logistics operator, which is called commitment, mainly there are variables such as Time, Type and, Quantity, another identified critical point which is between the logistics operators and the trade carrier, which will be called deterioration, at this point, there are variables such as Temperature, Quantity and, Location, finally, there will be another flag between the trade carrier and the EPS or IPS, which will be called quality variables such as Temperature, Type and Location as seen in Fig. 2.

3. Blockchain in the distribution of medicines

Following, we will show the reason for the need for a Blockchain network, as well as the analysis of different types of architectures with their respective protocols, analyzing which of them best suits the needs. Taking into account the data obtained previously, a detailed analysis is carried out on the need to use Blockchain technology, for a better understanding of the choice see Fig. 3. At first, it is evaluated whether during the supply chain process a common database is needed since all actors will require information on the status of the vaccine in real-time, it will be necessary for this database to be common to all actors, on the other hand, there are several actors in the supply chain and these actors do not trust each other because they do not have a clear knowledge of the treatment of the vaccine during transport or production and processes. The record must also be immutable since the vaccines sent must be the ones received, with the same conditions, regarding the transaction rules, these will be the same and the governance rules are decentralized as no one has total control and everything is visible, it is known that these transactions must be private since they are assets of great value and only those involved in the transaction can see the status of said transaction.

As described above, to carry out a Blockchain application to a supply chain, there are several possibilities. Initially, there are three types of Blockchain architectures: public, private, and federal or consortium [29], a public architecture is characterized by the fact that anyone can participate in the network and the transaction information is visible to all actors, there are protocols such as Bitcoin, Litecoin and, Ethereum. On the other hand, in a private architecture, nobody can access the Blockchain, only the administrator determines who can enter this transaction, there are protocols such as Hyperledger, NEO, Quorum, then federal or consortium Blockchain that provides a combination of these two, so it can be private or public and this architecture is the most suitable for business Blockchain [30].

There is a great variety of protocols in the process such as Ethereum, Hyperledger, Neo, Multichain, Quorum, among others, the protocol that will be used to develop the Blockchain network is selected in relation to the defined evaluation criteria. Table 1 shows the different characteristics that said protocols have. Though all these characteristics are very useful, for the development of the following work, it will be necessary to take into account those characteristics that allow and facilitate making a good choice in the traceability of the supply chain. As shown, characteristics such as cryptocurrency or Coin Market Cap, although important, will not have a great impact on the following work, but smart contracts, programming languages and others will have a great influence on the choice of which Blockchain technology or protocol to be used.

The supply chain includes suppliers, wholesaler, manufacturers, distributors, traders and customers, all of them represent the direct actors. Financial entities and contractors represent indirect actors. It is evident that actors do not know each other. This type of systems could use a scheme of information storage in a data base.

With this scheme, the confidentiality and integrity would be guaranteed and also the level of performance is optimal compared with the Blockchain technology. But at the same time this scheme does not guarantee reliability and origin of the data as opposed to the Blockchain technology, which also guarantee the confidentiality and integrity of the data. On the other hand, the process of validity and verification of the transactions depends on the consensus among the participants on the
network, thus guaranteeing reliability and transparency among them. In Ref. [31] a critical analysis between the Blockchain technology versus the use of Data Base is carried out. In a data base scheme, the status is administrated by a central system. The access to the data is restricted by the access control mechanism established by the system. On the other hand [32], considers that with one user it would be enough to use a scheme of data base, which is not the same in the supply chain because there are different actors.

Therefore, using a scheme based on data base management would not guarantee a high level of security and immutability. All this because the administrator has the control, he can grant access to any type of actor without the other actors knowledge. In this case, the process of validation and verification depends on the organization where the data base is located [33] explain a series of results based on the comparative analysis between the Blockchain technology and the centralized or decentralized data base architecture through several variables, the authors conclusion is that the Blockchain technology would offer better guarantee from the reliability, integrity and immutability point of view.

| Focus on industry | Ethereum Developers | Hyperledger | Neo Developers | Multichain Developers | Quorum Developers & JP Morgan Chase |
|-------------------|---------------------|-------------|----------------|-----------------------|----------------------------------|
| Developers        | Innovation between industries | Innovation between industries | Innovation between industries | Innovation between industries | Innovation between industries |
| Account book      | unpermissioned      | permissioned | unpermissioned | permissioned | permissioned |
| Cryptocurrency    | Ether (ETH)         | No          | No             | No                    | No |
| % Suppliers with experience | 93% | 93% | unknown | 10% | 27% |
| Coin market Cap   | $91.5 B 18%         | Pow and PoS | does not apply | does not apply | does not apply |
| Consensus algorithm| PoS, PoET, PoW and IBFT | does not apply | PBFT (Byzantine fault tolerance) | PBFT (Byzantine fault tolerance) | Raft, Istanbul BFT (Byzantine fault tolerance) |
| Smart Contract    | Yes                 | Yes         | Yes            | Yes                   | Yes |
| functionality     |                     |             |                |                       |       |
| Programming language | Solidity           | Golang, Java, Go, Python, Solidity | C#, Python, JavaScript, Golang, Java | C++, with interface in JSON-RPC | Solidity |

Table 1
Blockchain protocol analysis.

Fig. 3. Need for a Blockchain network.
aspects required in the supply chain to minimize the risks of the process flow. Other variables to be considered form the transactional point of view are: insertion, read, update and delete of records. In Table 2 we present an analysis taking into account as variables data base operations at a transactional level.

Any operation on a data base could be audited by the main administrator or the actors authorized by said main administrator. Unlike the Blockchain technology which allows all data to be shared thanks to a consensus mechanism. In this case, a main administrator is not required. In the previous table it is clearly observed that the Blockchain technology does not permit the manipulation of the records by keeping their immutability.

Chitti, Murkin and Chitchyan [34] carried out an experiment based on other documents and showed the results of their experience by recovering data from Blockchain and data base. They used as variables: quantity of transactions processed by second, cost, integrity, transparency. This type of experiments constituted the base to define other variables, taking into consideration that any alteration of any data in the supply chain has a negative impact on the flow of the process causing a reputational damage for any of the actors in the chain.

Based on the previous study, an analysis is presented in Table 3, through variables that have been taken into account from the security of the information and access to the operations point of view.

We can observe in the previous table that the Blockchain technology offers greater benefits when compared to the use of a data base for the supply chain.

After this, we gave weight to certain selection criteria of these Blockchain protocols as shown in Table 4, where the percentage of providers with experience has the greatest weight, this, because during the development we can find a large number of resources that help in the process, as well as communities and help centers in the industry. It is also key to take the programming languages so that we can choose which one will be more feasible and efficient to carry out the development and other present criteria.

According to these criteria, Hyperledger is the protocol with the highest percentage; therefore, this is the one we are working with. To enter a Hyperledger development environment, it is necessary to understand the reason for its creation and its different libraries, tools, domains, and projects. Initially, Hyperledger was created to advance in the development of blockchain in the industry; it is open-source, in other words, anyone can become a developer and contribute to the projects, it facilitates the integration of complex business logic (thus maintaining the information storage). The actors of the network authorize the record of the transactions. Hyperledger Besu, which through the Ethereum virtual machine -EVM, allows the implementation and execution of smart contracts through transactions within an Ethereum blockchain, it also allows the implementation of several consensus algorithms, such as Proof Authority, IBTF and, Proof of Work, is a peer-to-peer network; provides a user-oriented API, allows monitoring node and network performance, as well as the ability to keep transactions private between the parties involved.

Hyperledger Burrow, which was developed according to the specifications of the Ethereum virtual machine, they can be configured to manage processes, exchange value or perform calculations, all this without intermediaries, it has a light and fast smart contract design with an algorithm of Byzantine fault-tolerant consensus with transaction purpose, optimized for sharing processes between organizations, provides an API Gateway that provides interfaces for the integration of systems and user interfaces, the smart contract application engine facilitates the integration of complex business logic (thus maintaining the network stack between the nodes and the order transactions) and has an application binary interface –ABI that is to say that the transactions must be formulated in binary format, which is processed by the Blockchain node.

Hyperledger Fabric, which is an enterprise-grade, authoritative distributed ledger platform that offers versatility for quite a few use cases in the industry such as consensus, privacy, and membership services. One of the best features of Fabric is the enablement of a network of networks which means the members of a network work together, but because companies need some of their data to remain private they maintain separate relationships within their networks in that way, personal data is not available to the entire network, that is, if a member is not one of the agreed parties, the transaction should not appear in his ledger.

In summary, Hyperledger Fabric is an authorized, secure, and high-performance Blockchain Network that has a powerful container technology to host any conventional language for the development of smart contracts such as Go, Javascript, or Java, SDRs are made in Node.js, Java, Go, REST and Python.

Hyperledger Indy which provides strong privacy guarantees as private data is not written on the ledger, but is exchanged through encrypted peer-to-peer connections, it also ensures that both people and institutions always know who they are dealing with, so fewer resources will be spent storing this data and trying to protect it.

Hyperledger Iroha is a project that allows simple and easy management of digital assets, generating greater trust and reliability in

| Table 2 | Variables operations on a database at transactional level. |
|---|---|---|
| Transactions | Data base | Blockchain |
| Record | permitted | permitted |
| Verification | permitted | permitted |
| Update | permitted | Not permitted |
| Delete | permitted | Not permitted |

| Table 3 | Variables based on information security and access to operations. |
|---|---|---|
| Criteria | Data base | Blockchain |
| Transactions information storage | Implementation of other components. | Permitted. It is one of the technology characteristics. |
| Shared Access of the information | Controlled by the Administrator | Controlled by all the actors of the network. |
| Guaranteeing confidence implies knowledge of the actors | Required | Not required |
| Transactions record verification | Each actor, according to the privileges granted by the Administrator | The actors of the network authorize the record of the transactions |
| Confidentiality | Guaranteed by the Administrator | Guaranteed by the technology |
| Integrity | Guaranteed by the Administrator | Guaranteed by the technology |
businesses, thanks to its robust permission system that guarantees that all interactions within the system are safe and controlled.

Iroha’s integrated smart contracts are called “commands” allowing developers to incorporate Blockchain into their business processes, giving users less complexity and less risk by allowing them to perform common functions using these commands unlike other platforms; these commands help developers by relieving them of the need to write complex smart contracts and thus complete a transaction in

| Weight Criteria selection | Ethereum | Hyperledger | Neo | Multichain | Quorum |
|---------------------------|----------|-------------|-----|------------|--------|
| Account book - 10%       | unpermissioned | permissioned | unpermissioned | permissioned | permissioned |
| % Suppliers with experience – 40% | 93% | 93% | unknown | 10% | 27% |
| Consensus algorithm – 15% | Pow and PoS | PoS, PoET, PoW and IBFT | PBFT (Byzantine fault tolerance) | PBFT (Byzantine fault tolerance) | Raft, Istanbul BFT (Byzantine fault tolerance) |
| Smart Contract functionality – 15% | Yes | Yes | Yes | Yes | Yes |
| Programming language | Solidity | Golang, Java, Go, Python, Solidity | C#, Python, JavaScript, Golang, Java | C++, with interface in JSON-RPC | Solidity |

Fig. 4. Hyperledger greenhouse.

Fig. 5. Proposed structure.
approximately 5 min, Iroha’s consensus algorithms allow full Byzantine fault tolerance without mining, making it ideal for companies that require verifiable data consistency at low cost.

Briefly, Iroha allows easy implementation and maintenance, a variety of developer libraries, role-based access control, a set of out-of-the-box commands and queries, multi-signature transactions, has fault-tolerant Byzantine consensus algorithm, emphasizes mobile app development for Android and iOS, which sets it apart from other Hyperledger frameworks.

Hyperledger Sawtooth based on the development of decentralized ledgers and secure and scalable smart contracts, it uses a single node type, which simplifies the implementation, the participants, add policies and accept configuration changes, as a result, algorithm of consensus can be changed in real-time on a running network, it can start with an algorithm like Raft, then upgrade to PBFT or switch to Elapsed Time Proof –PoS as the network grows, a wide variety of languages are also available in programming, contracts can be written in almost any programming language.

According to the characteristics obtained, it was decided to take the Hyperledger Fabric project to develop the Blockchain application, because it can work on different programming languages and its libraries and experienced providers are greater.

In this section, the architecture that will be used to develop the Blockchain network will be described; its transactional flow, development environment, topology to be implemented, and construction of components in the network.

Initially, the challenge is to record the required information in a distributed ledger of the transactions carried out, in a proposed structure as evidenced in Fig. 5, this network is made up of four organizations that will use a smart contract and a database manager such as CouchDB, although there are 5 organizations present in the entire system, the organization of raw material suppliers is not present in this network since there is evidence that it is not a critical point that should be addressed; All this is consolidated in a domain or consortium called vaccine.com, on the other hand, we have Orderers which is an ordering service, not specific for a channel, but behaves as a technological service within the network to be able to transact and order the requests, requests or transactions that are carried out between the organizations.

There are four organizations, Manufacturer (Org1), Operator (Org2), logistics operator (Org3), and Pharmacy (Org4), each of them has a node that is capable of saving data and storing a smart contract, which is responsible to support transactions and write to the distributed ledger, each node has the responsibility of maintaining a replica of a Blockchain, and processing transactions, these nodes have a smart contract, chain blocks, database, and policies. The database helps store the status of the distributed ledger, so it is possible to determine the information at any date and time, each entry made to the ledger contains the data of the vaccine batch, it also has variables such as Id, Name of the vaccine, temperature, and quantity.

These organizations are located in a secure and private channel, where only the four organizations will be able to see the information that is in this channel. Fig. 5 shows how the environment of the five organizations would be observed, the peers or nodes, the ordering service, its channel, through which they will communicate and transact. These organizations are: Node 1: producers of raw materials, node 2: manufacturers or laboratories, node 3: logistics operator, node 4: logistics operator, and node 5: EPS/IPS or pharmacy.

To demonstrate how each transaction occurs, a transactional flow is evidenced in Fig. 6 where initially, a client application usually sends a simulated transaction via broadcast (step 1) and executed by each of the peers or nodes, then each peer returns it signed and endorsed to the client application (step 2), then the client application sends it to the ordering service so that the transaction is added in a block (step 3) and thus it is already sent via broadcast to all nodes (step 4).

The environment in which the medical supply chain management project was carried out was based on a Docker environment as shown in Table 5, the development was implemented in an Ubuntu Linux 20.04 LTS environment with an AMD processor Ryzen 5 3400G and a 4996 MB base memory. On the other hand, a Docker engine version 20.10.3 was implemented, with a Hyperledger Fabric version 2 project, which is

Fig. 6. Transactional flow drug supply chain.
The topology of the four organizations can be seen in more detail in Fig. 7, it should be noted that in the entire network there are three types of nodes or peers, first, we find the committing peer, highlighted in dark blue, which have the function to maintain the state of the ledger, confirm transactions and can contain the smart contract, then endorsing peers, with dark blue color, this is another type of node, whose tasks is to receive transaction proposals to be backed up and respond if it confirms or does not confirm the endorsement, in this node it is essential to have the smart contract and verify that its content or information is from a smart contract, and finally, the ordering node, with a pink color, which is responsible for approving the inclusion of new blocks of transactions in the ledger and communicates with the peers to see if it supports this information or not, this node does not have the smart contract and does not have a distributed ledger.

It is evident that there is only one node per organization, because of practical decentralization effects, regardless of the number of nodes in the organizations, the level of participation or decentralization is not affected, considering that what really matters is the number of participants in the network; there is also only one certification authority –CA, which is located in the first organization with yellow color, it should be clarified that each organization can obtain its own CA, this CA component is of vital importance in the network due to the fact that it is in charge of controlling and granting the enrollment of applications and organizations within the network, in this case only organization 1 has the control of granting and denying access to the network. Another aspect to take into account is a ledger, it is observed that in each organization there is a ledger or distributed book which in this case is CouchDB, each of them also has a smart contract or chain code of red color, which is written in Golan, this smart contract has two characteristics or functions, one is Set, which allows adding information to the ledger, and Query, which allows queries about the ledger that you have. Component P is also present, which refers to the endorsement policies, or policies for the approval of transactions, which indicate that only Org1, Org2, and Org4 will be able to approve transactions, in other words, these three organizations can propose transactions and the third organization only plays a role of reading, since the logistics operator will only be in charge of seeing the information of the product that is transporting.

Each component mentioned is dockerized, all this was developed on a single host, but thanks to Docker everything is divided into different containers. The first step to create the network is to create the cryptographic material, certificates, private keys, and users that will be on the network, as evidenced in Fig. 8, the organizations created.

After this, it is possible to verify the certificates of the organizations created, in Fig. 9, the name of the organization is shown as well as the address where this certificate was created, because the main servers are in California, these organizations are certified there. We can also see the 10 year validity period, the issuer of the certificate and the keys, fingerprints, and extensions.

After that, the Genesis block is created, through a file called configtx.yaml as well as the other blocks of the organizations, then the GOSSIP protocol is used, which allows maintaining the network because if a network that has an organization goes down, for any reason, the network can continue to operate, as long as a consensus can be made, when this organization is back online the book will be out of date, then through the GOSSIP protocol, it connects to the closest node so that said node can pass it the data and thus retrieve the information from the network, it is also very important to create a CLI file, using the fabric tools. This fabric tool allows the creation of four containers with alpine, where each container that has been created gets an operating system and a set of internal ports, once you have these four containers, you can enter the portainer in the localhost, to show the containers created that are shown in Fig. 10.

In order to verify that the containers were created, we enter the portainer and review the containers that are available so far, Fig. 11, you

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**Fig. 7. Architecture to be developed.**

**Table 5**

| Component                  | Description                                      |
|----------------------------|--------------------------------------------------|
| Operating Systems          | Ubuntu Linux 20.04 LTS                           |
| CPU                        | AMD Ryzen 5 3400G                                 |
| Hyperledger                | V 2                                              |
| Docker Engine              | V20.10.3                                         |
| Docker compose             | V1.24.0                                          |
| CLI Tool                   | Hyperledger tools                                |
| Programming Language       | Go (V go1.13.15)                                  |
| IDE (Platform)             | Visual Studio                                    |
| Memory                     | 4996 MB                                          |

open-source, provided by Linux Foundation, Go version go1.13.15 for the smart contract.
Fig. 8. Organizations created.

Fig. 9. Organization certificate 1.

Fig. 10. Containers created.
can see CLI, which is the main tool, which allows executing the necessary commands, also the four nodes or peer of the four organizations, also the CouchDB of each organization, the certification authority and the ordering service, after this it will execute a program written in go called peer, with the specific configurations for each of the nodes, as it is written in go when started it provides a go service, which provides a gRPC server to carry out transactions, this gRPC design is agnostic, this means that it runs different languages, for the containers to communicate it is necessary to build a Docker network, which uses a driver software to create a network, which we will call vaccinenetwork_basic generally with the addresses of the images, each container will have an IP, these containers use the same port since they are different operating systems.

In this way the entire Hyperledger network would already be developed, finally, a smart contract will be executed in Golan, which will allow two functions to be carried out, Set, which allows adding information to the ledger, and Query, which allows queries about the ledger, to verify that each organization has an active smart contract to carry out transactions, see Fig. 12, in which you can see the vaccine tracking containers, of the organizations Org1, Org2 and Org4, Org3 is not included because it has a read-only role in the network so it will not be able to propose transactions on the network, in this way we can show an entire Blockchain network working with a smart contract.

**Fig. 11.** Containers in portainer.

**Fig. 12.** Vaccine tracking containers.
4. Results

Once the network is created, the configurations made can be verified, in Fig. 13, it can be seen that there are four organizations in the network. Org1, Org2, and Org4 have the permission to perform transactions, so they can perform Set and thus upload information to the network, on the other hand, Org3 will not be able to perform these writing actions, it will only be able to perform Query, to observe data.

Once several Sets have been made, any container or organization is accessed, in this case, organization 1 is entered, localhost: 5985, Fig. 14, there the different transactions proposed on the network can be seen, each one must have a different ID because if they contain the same ID, no other data will be added to the network, but the data that is already identified with this ID will be overwritten, when entering any of these ID, the information of each transaction is evidenced, Fig. 15, in Id1 it is observed that the variety of the vaccine has the name “xtrasmol”, transported at a temperature of –70 °C, and a quantity of 28 doses.

On the other hand, we can evidence, using the Query command, that the data of the ID are being taken correctly, employing the command “peer chaincode query –C $CHANNEL_NAME -n $CHAINCODE_NAME -c ‘{"Args": ["Query", "$dis:3"]}’”, where it is evident that the data obtained are correct in comparison with Fig. 16.

 Colombian Government through the Statutory Law 1751 of 2015 establishes the definition of a pharmaceutical policy to protect the fundamental right to health. The scheme for the acquisition, storage, production, purchase and distribution of supplies and medicines, as well as the mechanisms of regulation are established in this law. However, each one of the actors in the supply chain has his own interests and in most of the cases said policy is not fully complied. As for the distribution process, there are two channels in Colombia: Institutional channel, the health promoting entities EPS are in charge of the supplies acquisition through pharmaceuticals, and Commercial channel, corresponding to the commercialization in drugstores and chain stores. There is no a standard protocol to carry out the distribution and commercialization of medicines. These scenarios facilitate the diversity of the transactions which could be avoided by making the process more transparent with the use of the Blockchain technology.

Fig. 13. Organizations policies.

Fig. 14. CouchDB in organization 1.

Fig. 15. Information block 1 Id_1.
5. Discussion

Following, we will analyze and describe the challenges that may be encountered when making or implementing the use of these Blockchain applications in drug tracking.

In the beginning, several research questions were asked, thus identifying the challenges and problems that would be addressed, so that once these questions were solved, we could propose and carry out an architecture of a Blockchain network, all this with the help of related standards, Blockchain architectures, and Blockchain information based on the health system.

One of the main problems that can be found at the time of the implementation of a Blockchain network, is on the users of the network, because at the time of decentralizing all the information of each party, this confidential and private information will become visible to all parts of the network, which would lead to some organizations or parts of the network not wanting to belong to it considering that they would lose a competitive advantage over other organizations, after this, another key factor to consider is the cost of implementing a Blockchain network, the costs are somewhat high, starting with the design, due to the fact that there is still not enough information about existing solutions, which are still under development, the lack of regulation and standardization about Blockchain, so it would be quite expensive to design it taking into account factors such as scalability, security, and interoperability [29]. There is another challenge considering that the organizations must have an integration of all the software and hardware necessary for the correct operation of the network so that all organizations have the same characteristics and can carry out their transactions without any inconvenience, implementation costs have a huge advantage when it comes to energy consumption given that currently, centralized networks have high energy and maintenance costs, so they are not very efficient, on the other hand with a Blockchain network, it is possible to reduce these costs significantly.

As mentioned above, the main difficulty in carrying out Hyperledger networks or developments is the lack of experienced providers, in addition to the fact that there are not many standardizations or regulations regarding Blockchain and implementation costs, on the other hand, there are advantages such as the low cost of energy, efficiency, and security, this security is because a conventional network is subject to suffer several cybersecurity attacks, scams and others, with Blockchain these insecurities are diminished since being decentralized all organizations have a clearer control over what information is entering the Blockchain network.

6. Conclusions

Blockchain technology demonstrates its great characteristics and virtues to change the drug supply chain, providing a more solid, secure, decentralized, transparent, and highly trusted chain, preventing fake drugs from entering the chain. This monograph describes the design, application, and results obtained in the proposal to monitor the supply chain of drugs necessary for COVID-19 based on Hyperledger Fabric.

This proposal is a proof of concept carried out to an application that maintains a registry of batches of vaccines necessary for COVID-19, allowing different organizations to manage access to information, to achieve transparency, security, and privacy in the proposed network, using a smart contract developed in Golan, with a blockchain-permitted network, our results indicate that the use of Blockchain technology increases the performance of the process, minimizes the counterfeiting of medicines and considerably increases the business of medicines. Some ideas are based on security stickers could be added using chain codes in all products. The potential future direction could be to increase the network in size and then test the performance and feasibility of the network deployment in a real existing environment as proposed by Ref. [55].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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