Czech University of Life Sciences Prague
Faculty of Economics and Management
Department of Information Technologies

Master's Thesis

Blockchain in the Pharmaceutical Industry

Amanuel Aberra Chala

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Blockchain in the Pharmaceutical Industry

Objectives of thesis

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60-80 pages

Keywords

Blockchain, ledger, supply chain, traceability, Ethereum, design, schema.

Recommended information sources

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The Diploma Thesis Supervisor

Ing. Miloš Ulman, Ph.D.

Supervising department

Department of Information Technologies

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doc. Ing. Jiří Vaněk, Ph.D.

Head of department

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Ing. Martin Pelikán, Ph.D.

Dean

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Declaration

I declare that I have worked on my master's thesis titled "Blockchain in the Pharmaceutical Industry" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the master's thesis, I declare that the thesis does not break any copyrights.

In Prague on 31.03.2022 ______________________________

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Blockchain in the Pharmaceutical Industry

Abstract

The importance of pharmaceutical companies is undeniable in the world we live in. Pharmaceutical companies do extensive work in clinical research, drug development and in increasing market access. Pharmaceutical companies spend billions of dollars each year on a quest to solve humanity's biggest health issues. The advancement in the technology that pharmaceutical companies have collectively brought to our world has increased the longevity of humans and animals alike, and at the same time has improved quality of life and alleviated suffering.

As with every other industry, pharmaceutical companies and their supply chains have a complex and high stakes relationship. The pharmaceutical supply chain often involves multiple stakeholders that contribute from the raw material sourcing to the packaging and shipping of the end product to the patient in need. Supply chain suffers from an archaic way of records keeping where data is oftentimes centralized and there is no easy way of verifying the veracity of records in a reasonable amount of time. Cold chains, which are effectively supply chains that need to adhere to a regulated temperature, suffer from this issue in particular because there needs to be a way to keep temperature records throughout the lifecycle of a certain product or material.

This thesis aims to show a way to solve one of the most persistent issues in healthcare in general which is the blood cold chain. The current ways of making sure that the blood needed by a patient is actually safe to use are outdated because there is a risk of falsification associated to them. The thesis presents a better way to handle the blood cold chain by using blockchain technology to design an application that would solve most of the issues associated with the current way of working.

Keywords: Blockchain, ledger, supply chain, traceability, Ethereum, design, schema, healthcare

Blockchain v farmaceutických společností

Abstrakt

Význam farmaceutických společností je ve světě, ve kterém žijeme, nepopiratelný. Farmaceutické společnosti odvádějí rozsáhlou práci v oblasti klinického výzkumu, vývoje léků a při zvyšování přístupu na trh. Farmaceutické společnosti utrácejí každý rok miliardy dolarů na hledání řešení největších zdravotních problémů lidstva. Pokrok v technologii, kterou farmaceutické společnosti společně přinesly do našeho světa, zvýšil dlouhověkost lidí i zvířat a zároveň zlepšil kvalitu života a zmírnil utrpení.

Stejně jako v každém jiném odvětví mají farmaceutické společnosti a jejich dodavatelské řetězce komplexní a vysoce sázkové vztahy. Farmaceutický dodavatelský řetězec často zahrnuje více zúčastněných stran, které přispívají od získávání surovin až po balení a přepravu konečného produktu pacientovi v nouzi. Dodavatelský řetězec trpí archaickým způsobem vedení záznamů, kdy jsou data často centralizována a neexistuje snadný způsob, jak ověřit pravdivost záznamů v rozumném čase. Chladírenské řetězce, což jsou ve skutečnosti dodavatelské řetězce, které musí dodržovat regulovanou teplotu, trpí tímto problémem zejména proto, že musí existovat způsob, jak uchovávat teplotní záznamy po celou dobu životního cyklu určitého produktu nebo materiálu.

Tato práce si klade za cíl ukázat způsob, jak vyřešit jeden z nejtrvalejších problémů ve zdravotnictví obecně, kterým je zmrazovací řetězec krve. Současné způsoby, jak zajistit, aby krev potřebná pro pacienty byla skutečně bezpečná, jsou zastaralé, protože je s nimi spojeno riziko padělání. Práce představuje lepší způsob, jak se vypořádat se studeným řetězcem pomocí technologie blockchain k návrhu aplikace, která by vyřešila většinu problémů spojených se současným způsobem práce.

Klíčová slova: Blockchain, účetní kniha, dodavatelský řetězec, sledovatelnost, Ethereum, design, schéma, zdravotnictví

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TRV – Temperature Regulation Verifier

SCM – Supply Chain Management

Introduction

The healthcare industry is critical to humanity's wellbeing and longevity of life. To ensure that we survive and thrive in this world, constant innovations in the healthcare space are needed. New viruses such as Ebola and COVID-19 have shown the cracks in our healthcare system, and it would be naïve to assume that these would be the only healthcare disasters we will face in our lifetimes.

Pharmaceutical companies are on the forefront of the effort to ensure that we stay ahead of the curve in the quest for better and longer lives. They spend billions of dollars per year for clinical research as well as trials in trying out new combinations for new drugs and treatments. As with any other critical industry it faces many challenges in their effort to become more efficient and leaner.

One of these challenges is in the space of supply chain management. Some of the practices in supply chain are not up to date with what the modern pharmaceutical world requires. In this thesis, the blood cold chain is selected as a showcase to exemplify the benefits that the healthcare industry as a whole can get from using innovative technology to drive for more value.

The technology raised in this thesis is Blockchain. Blockchain is a distributed ledger technology where several actors on its network have the right to view and approve changes made on the network in real time. This technology makes forging and falsifying data extremely difficult, if not impossible. The technology is discussed in more detail throughout the thesis and an application based on it is designed.

Objectives and Methodology

1.1 Objectives

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3. Literature Review

3.1. Blockchain

Even though the principles underpinning Distributed Ledger Technology have been around for a long time, Blockchain is a relatively new notion in computing. Large chunks of stone known as "Rai" stones were the money of choice thousands of years ago on the Micronesian island of Yap. The Yapese people used these stones as everyday payment as early as 1000 BC, when they weighed up to 3600 kg and stood 12 feet tall. While rai were not exactly cash, their worth is arbitrary and dependent on both real and perceived features, as is the case with other traditional and modern things. (Fitzpatrick, 2019)The difficulty with utilizing such massive things as cash was, of course, their immovability. To circumvent this problem the Yapese people had to employ the use of ledgers.

According to (Blockchain and Democracy, 2019) the cost of each stone was determined by the amount of work required to chisel and move it. Even if a stone's ownership is shifted, the stones will stay in the same location. There would be no disagreements about who owned what because the agreement as to who owned what was valid via the memory of the local communities.

3.1.1. History of blockchain

The potential use of blockchain in computing was proposed by a white paper put forward by a person only known as Satoshi Nakamoto in 2008 whose real identity is not known to this day as the person (or group) has never stepped up publicly and taken credit for his/her work. (Berentsen, et al., 2018)

The most critical issue with the Blockchain is trust. Instead of depending on trusted third-party entities to enable transactions, Blockchain network participants rely on the Blockchain network itself. (A Taxonomy of Blockchain-Based Systems for Architecture Design , 2017)The interactions between the network's nodes guarantee that trust is established.

According to (Angelis, et al., 2019) the various types of blockchain technology and applications are divided into four stages.

Blockchain 1.0 is primarily concerned with transactions, namely the usage of cryptocurrencies in cash-related applications such as currency transfer, remittance, and digital payment systems. Bitcoin, a decentralized digital money, is the most well-known example. Bitcoin is a decentralized system that leverages peer-to-peer transactions with no central authority to enforce regulations.

Blockchain 2.0 is a development of the original Blockchain. Privacy, smart contracts, and the introduction of non-native asset blockchain tokens and capabilities are all covered. Ethereum is a well-known example of a platform that supports smart contracts, but there are several other options, including the IBM-Maersk blockchain for global shipping and the trade finance blockchain consortium we.trade.

Blockchain 3.0 broadens the scope of the blockchain to include decentralized applications (dApp). A decentralized application (dApp) is made up of back-end code that operates on a peer-to-peer network that connects consumers and suppliers directly. This open-source software platform uses cryptographic tokens to construct decentralized blockchains. For example, a well-established distributed ledger might serve as a platform for application developers to conduct their business. Flexible, transparent, distributed, robust, and with a clear rewarded structure, the dApps are developed. The ability to create decentralized storage and decentralized compute allows dApps to scale more easily.

Similarly, the most recent and still-developing blockchain iteration—Blockchain 4.0—offers tremendous value potential. This entails combining artificial intelligence (AI) with blockchain technologies, which are on opposite ends of the technological spectrum. To represent uncertainty, AI uses probabilistic theory. It's always changing, and the algorithms are designed to predict — or make assumptions about — reality.

For the uninitiated, several concepts in blockchain might be puzzling, thus there is a need to define them. The term "ledger" refers to a book in which transactions are recorded. As a result, a "distributed ledger" is essentially a collection or network of ledgers that are geographically dispersed that keep and append the same entries.

3.1.2. Security in blockchain

The blockchain's security is ensured by a specialized information technology. Each time a new transaction is added to a blockchain, a digital imprint known as a hash is added to the chain. After adding a new block to an existing blockchain, a new hash is generated using the prior chain, previous hashes, and the new block, making modifying old transactions very difficult, as the old hashes can be reconstructed with a probability extremely near to zero from purposefully modified data. The computation of the hash values necessitates the participation of some labor or other resources from the participants, who must be paid for their efforts. Without motivation, it's possible that no one will look after the blockchain's upkeep. The method of compensation makes a substantial difference in various applications. (Blockchain and Democracy, 2019)

In a money driven blockchain network, compensation may be based on a number of factors. The blockchain consensus might use a number of protocols to establish how compensations are generated for the various entities participating in hash mining.

A few instances of these protocols may be seen below:

Proof of Stake (PoS) is a methodology for achieving distributed consensus on a blockchain network. The validator of transactions in PoS-based blockchains is chosen based on wealth or another interest in the blockchain ("the stake"). Whereas in Proof of Work (PoW) to validate transactions and produce new blocks, the algorithm of proof-of-work-based blockchains performs computationally intensive mathematical operations (i.e. mining). The miner's success is determined on their computing resources and chance.

Proof of Elapsed Time (PoET) is a popular technique for blockchain networks in which players fight for mining rights. The node in the network is obliged to wait for a randomly set time period, and the first node to fulfill the allotted waiting time gets the new block, based on random drawings, where every node has an equal chance of receiving mining rights (Frankenfield, 2022)

Proof of Capacity (PoC) is a technique that allows the mining devices in the network to decide mining rights based on their available hard drive capacity. The greater the amount of accessible disk space, the more likely a node will be granted mining rights (Scott, 2018)

Proof of Burn (PoB): This method operates on the idea of letting nodes who participate in the verification of transactions to "burn" or "destroy" virtual currency tokens, granting them the right to write blocks in proportion to the amount of money burned. Burning a coin includes sending it to a publicly accessible address where it cannot be recovered (2018)

Proof of Activity (PoA) is a mix of Proof of Work (PoW) and Proof of Stake (PoS). The mining process in PoA begins as a conventional PoW method, with several miners competing for higher processing power to discover a new block. The system switches to POS when a new block is discovered (mined), with the newly discovered block comprising merely a header and the miner's reward address. (Blockchain and Democracy, 2019)

Blockchains are distributed (i.e., without a single repository) and typically decentralized digital ledgers that are tamper obvious and resistant to tampering (i.e., a bank, company, or government). At their most basic level, they allow a group of users to record transactions in a shared ledger within that group, with the result that no transaction can be modified once it has been published, as long as the blockchain network is operational. (Yaga, et al., 2018)

3.1.3. Blockchain and Trustless Systems

In a trustless system, there is always the possibility that one of the other players would behave maliciously, and the system is built to function well in such an environment.

A trustless system functions without the necessity for the system's components to be trusted. A computerized transaction system as an IT application – such as money transfer – is traditionally based on the fact that the transaction source, the communication infrastructure and all of its elements and networks, as well as the people who work on the system and all of the organizations involved, are all trustworthy. In this sense, reliability indicates that the risk of purposeful or random errors is acceptable to the consumers. Either the potential consequence of an incident is insignificant, or the likelihood of it occurring is low, or a third party, such as an insurance company, reimburses the damage.

In the case of cryptocurrencies, a blockchain system is a distributed trust system rather than a trustless one. Participants must trust a number of parties: transaction validators, the quality of the cryptographic techniques used, platform developers who maintain and enhance the code, and platform users. However, because confidence is spread, no single party can be trusted (Blockchain and Democracy, 2019)

3.1.4. Categorizations of blockchain

We may categorize blockchains based on their permission system, for example. We may divide blockchain networks into permissioned and permissionless blockchain networks based on who has the power to publish new blocks. Permissioned blockchain networks are used in "closed circle" groupings where the participants on the network must be controlled. Permissionless blockchain networks are those in which no restrictions on who can participate apply.

3.1.4.1. Permissionless blockchain networks

Permissionless blockchain networks are distributed ledger systems that allow anybody to publish blocks without the requirement for permission from anyone. Permissionless blockchain systems are frequently open-source software that anybody may download for free. Because everyone has the ability to publish blocks, anyone can read the blockchain and conduct transactions on it (through including those transactions within published blocks). Within a permissionless blockchain network, every blockchain network user can read and write to the ledger. Because permissionless blockchain networks are available to everyone, malevolent individuals may try to manipulate the system by publishing blocks in an unauthorized manner. (Yaga, et al., 2018)

3.1.4.2. Permissioned blockchain networks

Permissioned blockchain networks are those in which users who publish blocks must be approved by a third party. It is feasible to control read access and who may issue transactions since the blockchain is maintained by only authorized users. Permissioned blockchain networks can either enable anybody to read the blockchain or only allow authorized persons to read it. They may also let anybody submit transactions for inclusion on the blockchain, or they may limit access to just approved individuals. Open source or closed source software can be used to create and manage permissioned blockchain networks (Yaga, et al., 2018)

3.1.5. Components on a blockchain network

- Hash functions, transactions, asymmetric-key cryptography, addresses, ledgers, and blocks are the major components of a blockchain component. Each network component is explained in further depth below.
- Functions that have a hash value
  Hashing is a way of calculating a somewhat unique output (called a message digest, or simply digest) given an input of practically any size using a cryptographic hash function (e.g., a file, text, or image). Individuals can separately take input data, hash that data, and obtain the identical output, showing that the data hasn't changed. Even the tiniest modification in the input (such as a single bit) results in an entirely different output digest.

- Transactions

  A transaction represents an interaction between parties. With cryptocurrencies, for example, a transaction represents a transfer of the cryptocurrency between blockchain network users. For business-to-business scenarios, a transaction could be a way of recording activities occurring on digital or physical assets. Figure 1 shows a notional example of a cryptocurrency transaction. Each block in a blockchain can contain zero or more transactions. For some blockchain implementations, a constant supply of new blocks (even with zero transactions) is critical to maintain the security of the blockchain network; by having a constant supply of new blocks being published, it prevents malicious users from ever “catching up” and manufacturing a longer, altered blockchain.

- Asymmetric-Key Cryptography

  Asymmetric-key cryptography makes use of a public key and a private key that are mathematically linked to each other. The process' security is not jeopardized by making the public key public, but the data's cryptographic protection requires keeping the private key concealed. Despite the fact that the two keys are linked, the private key cannot be properly determined just by knowing the public key. Data can be encrypted using a private key, which can then be decoded using the public key. Another method is to encrypt with a public key and then decode with a private key.

- Addresses

  Some blockchain networks utilize an address, which is a short alphanumeric string of characters produced from the blockchain network user's public key using a cryptographic hash function, as well as some other data (e.g., version number, checksums). Addresses are often used as the "to" and "from" endpoints in a transaction in most blockchain systems. Addresses are not private and are shorter than public keys. Creating a public key, applying a cryptographic hash function to it, then translating the hash to text is one way to produce an address.

- Ledgers

  A ledger is a collection of transactions. Throughout history, pen and paper ledgers have been used to keep track of the exchange of goods and services. In modern times, ledgers have been stored digitally, often in large databases owned and operated by a centralized trusted third party (i.e., the owner of the ledger) on behalf of a community of users. These ledgers with centralized ownership can be implemented in a centralized or distributed fashion (i.e., just one server or a coordinating cluster of servers).

- Blocks

  Blockchain network users submit candidate transactions to the blockchain network via software (desktop applications, smartphone applications, digital wallets, web services, etc.). The software sends these transactions to a node or nodes within the blockchain network. The chosen nodes may be non-publishing full nodes as well as publishing nodes. The submitted transactions are then propagated to the other nodes in the network, but this by itself does not place the transaction in the blockchain. For many blockchain implementations, once a pending transaction has been distributed to nodes, it must then wait in a queue until it is added to the blockchain by a publishing node.

After putting all of these pieces together on a blockchain network, the next step is to link the blocks together. Blocks are chained together if they contain the hash information from the previous block's header. If a block is added to the chain that does not include this information, it will change the network's whole makeup.

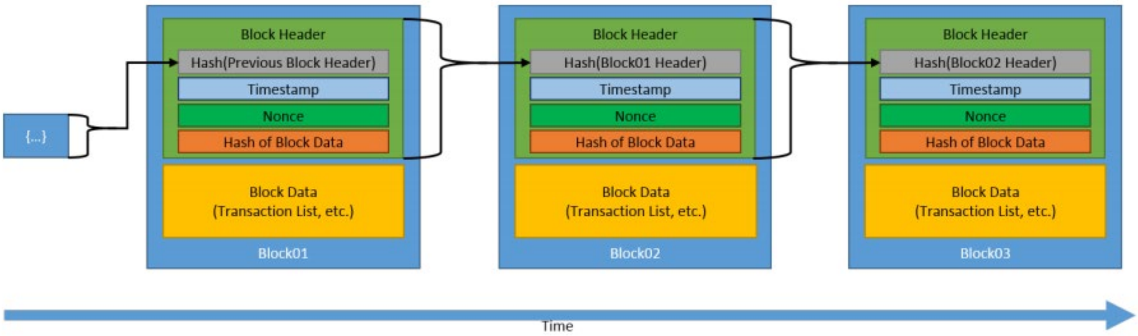

Figure 1 Generic Chain of Blocks ((Yaga, et al., 2018)

3.1.6. Applications of blockchain technology in real world situations

According to (Blockchain in Logistics and Supply Chain: A Lean Approach for Designing Real-World Use Cases, 2018) for financial applications, blockchain has emerged as a major platform. Nonetheless, in recent years, academics and practitioners' emphasis has shifted to the application of Blockchain technology to other fields. With the establishment of numerous start-ups and the entrance of the Blockchain into the agenda of governments and enterprises, Supply Chain and Logistic support are the issues paying increasing emphasis towards Blockchain in this respect.

However recently blockchain applications in agribusiness and fresh produce have attracted a lot of attention. The rationale behind this is the necessity of integrity and immutability of data in such applications, as well as the engagement of multiple actors and the expenses associated with the need to provide proof for various rules and unique incidents, such as food poisoning.

3.2. Pharmaceutical Industry

Pharmaceuticals are a group of emergent organic compounds that have contributed to enhance our quality of life. The pharmaceutical industry is responsible for the development, production, and marketing of branded and generic pharmaceuticals. (Pharmaceuticals Market, Consumption Trends and Disease Incidence Are Not Driving the Pharmaceutical Research on Water and Wastewater, 2021)

Pharmaceutical industry is one of the most research-intensive sectors in the world, producing a steady stream of innovative medications that save lives and improve quality of life. (J. Culyer , et al., 2000) The sector has already made major contributions to patient well-being. Europeans today might expect to live up to 30 years longer than their forefathers did a century ago. (Associations, 2020)

A pharmaceutical manufacturer is a company that carries out operations such as production, packaging, testing, repackaging, labelling and/or relabeling of pharmaceuticals (WHO, 2010)

Top 20 pharmaceutical companies worldwide based on prescription drug market share in 2019 and 2026* (Light blue = 2019   Blue black = 2026) (Statista, 2021)

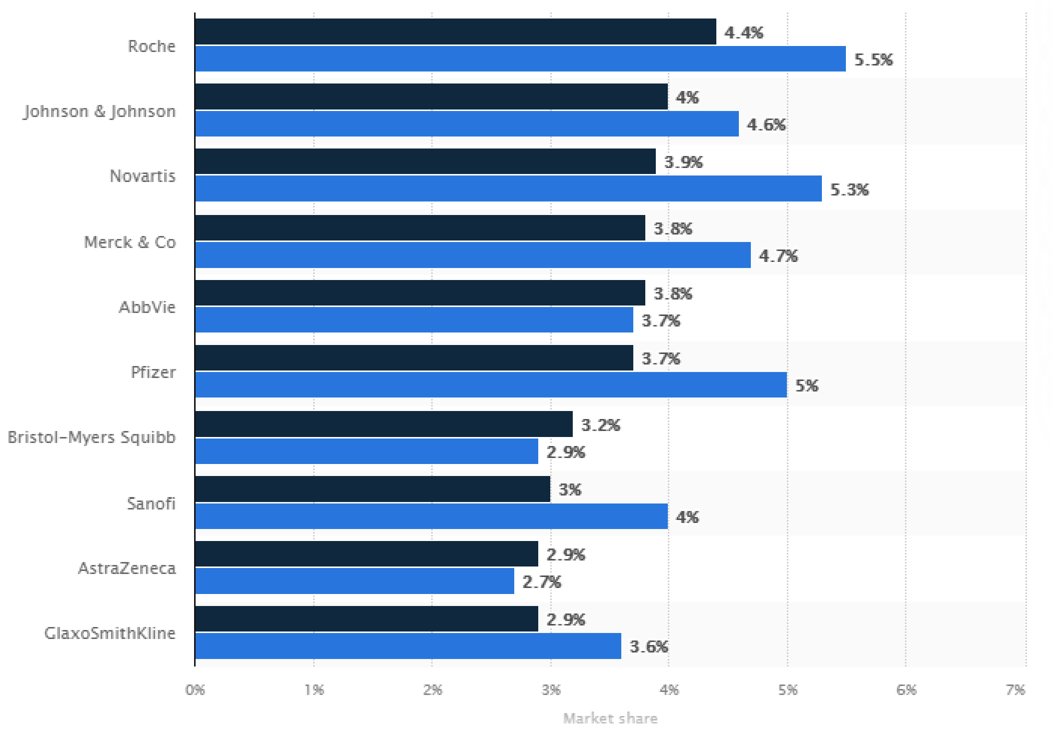

Figure 1 Drug market share of the top 20 Pharmaceutical companies

As far as most people are concerned, the Pharmaceutical Industry consists of a small number of very large multinational corporations with household names such as AstraZeneca, GlaxoSmithKline (GSK), Eli Lilly, Merck, Novartis, Roche and Pfizer. (The Pharmaceutical Industry and the Future of Drug Development, 2016)

The supply chain is a linked set of operations that deals with the planning, coordination, and management of materials, components, and completed items from supplier to client. Traditionally, material flow has been examined exclusively from an operational standpoint. (Integrating the Supply Chain, 1989)

Because pharmaceutical operations are particularly sensitive to quality and time bound, logistics is recognized as a critical component of the sector. Pharmaceuticals require temperature-controlled storage and transportation, as well as stringent regulatory oversight.

The industry has given logistics increasing importance throughout time by focusing on supply chain and logistic level operations such as getting the product to the end-customer at the right time, in the correct place, in a secure condition, and at a competitive operating cost.
The interdependency between relevant process and product attributes is required due to the complexity of the pharmaceutical supply chain. Based on product stability, product history, packaging information, and the transport mechanism employed, pharmaceutical items are sent in such a way that they should not be negatively impacted by environmental conditions. (Bigoniya, 2012)

Based on the questionnaire responses form the survey conducted among employees of a selected Pharmaceutical company, the main issues related to the pharmaceutical supply chain are below**. (See Appendix 2)**

1. Issues related to Counterfeiting
2. Unfavorable reaction of the drug to the patients
3. Issues rose due to entities of supply chain operations
4. Manufacturing issues like mixing incorrect input raw materials, or cross contamination due to manufacturing more than one drug in the same facility, or improper labeling of the final product
5. Retailer's issues including improper temperature controls and handling
6. Transportation issues caused by mishandling, improper temperature controls, and the use of improper shipping mode
7. Storing and warehousing issues such as using improper temperature controls, improper handling in the warehouse and mixing products with raw materials.

3.2.1. The Pharmaceutical Industry and Blockchain

Blockchain technology has a lot of applications within the pharmaceutical industry and its supply chain system. The technology is used in pharmaceutical supply chains to improve several common shortcomings within the industry. According to (Blockchain Technology in Pharmaceutical Industry to Prevent Counterfeit Drugs, 2018) the purposes stated below are the main ones:

- Increased trust and transparency – the ability for manufacturers and customers alike to be able to track the changes that are happening throughout the lifecycle of the product. The manufacturing body will be able to see when and how their products were received by their customers. The customers in turn would be able to see that the products that they are receiving were made by trustworthy manufacturers and that there were no dishonest methods involved in developing the product.

- Improved traceability – when a product has been manufactured then it is registered on the blockchain, and this would give the parties involved the ability to trace the product's lifecycle from beginning to end. Manufacturers of pharmaceuticals will be able to monitor the route of their goods at any moment, from conception to completion.

- More visibility and privacy - Visibility and privacy are frequently directly opposed, and obtaining one often necessitates sacrificing the other. Blockchain is the ideal solution for the exchange that can ensure the originality of information that is made available to the public while maintaining an entity's private data hidden but without violating privacy.

- Better security - Blockchain is widely regarded as being one of the world's most reliable ledger systems. Blockchain is an immutable database, which means that information recorded on it cannot be removed or updated once it has been saved. A permissioned blockchain will be utilized in the proposed model, which is more reliable than a public blockchain since only authorized players will be allowed access to upload data towards the blockchain.

- Database for better insights - The impact of medications on the patient will be documented, and physicians will be able to use this information to recommend the appropriate dose to a patient in the long term. This sort of record keeping was not secure using traditional databases, putting individuals' confidentiality at danger. However, utilizing blockchain, a patient's data may be preserved without having to provide their personal information.

3.2.2. Successful implementations of blockchain the pharmaceutical industry

Blockchain technology has been used in several industries where modernization was critical to ensuring success. The industries in which blockchain has been used include the financial, technology, manufacturing, shipping, automotive and energy sectors. We can take a closer look at the successful use cases of blockchain in the pharmaceutical industry to gain a better understanding of what the technology is capable of.

One potent example can be the study discussed on (Kim, et al., 2018) where the authors argued that the technology could help modernize the blood cold chain system. The current system (centralized blood cold chain) makes it hard to accurately estimate the amount of blood stored at each distribution center. It also creates longer reaction times to emergencies as the whereabouts and quantities of each blood type. Thus, the study proposes a blockchain based blood cold chain storage system where the technology generates a record for each unit. The tamper-proof nature of blockchain makes it impossible to counterfeit any records and therefore the information on the system will be verified by all actors within the network. The old model had the “blood bank”, hospitals, ambulances, blood service headquarters and the inspection centers working on a non-organized manner. One actor could make changes to the collective status and the other actors might not be aware of the changes made. This would lead to incorrect estimations of the quantity and type of blood stored in the blood bank – which could potentially lead to life threatening mistakes. The model proposed in the study however has all the actors contributing to a “shared ledger” where each change is recorded and verified by every actor on the network.

3.3. Supply Chain

Supply chains are essentially networks between a company and its suppliers covering how a specific product is being manufactured and how it gets to its end users. There are four types of supply chain entities and their combinations create a supply chain. These are products, facilities, vehicles and routes. (2018)

Entity	Role	Characteristics
Products	Things in demand	Cost, selling price, time spent, etc..
Facilities	Places of production	Storage space, operating cost, location, etc..
Vehicles	Methods of moving goods	Cost, carry volume, speed, fuel and maintenance costs, etc...
Routes	Path of how the goods are moving	Distance, fuel cost, delivery time, timing related to perishing goods, etc...

Table 1 Elements in a supply chain network

3.3.1. Supply Chain Management Principles

In supply chain management several principles are used to ensure optimum profitability and to cut the time spent end to end. Supply chain management takes a significant part of the day to day work overseen by any manager in a firm where goods have to move from place to place and therefore great importance is placed upon it. The traditional approach of seeing a company and its components as distinct entities has slowly been replaced by the modern approach of seeing them as one big entity where change in one affects the whole.

The most important principles can be summarized into seven points (Monja, 2013):

a. Segment customers based on the service needs of distinct groups and adapt the supply chain to serve these segments profitably. The traditional approach in segmentation was to group customers based on their industry or product and then to create a one size fits all approach in order to satisfy their needs. However, segmenting the customers by their needs instead of their profiles helps companies better align their strategies with the customer and improves the customer relationship. This would in turn increase the profitability of that relationship for both parties involved.

b. Customizing the logistics network to the service requirements and profitability of customer segments.

c. Listening to market signals and align demand planning accordingly across the supply chain, ensuring consistent forecasts and optimal resource allocation.

d. Differentiate product closer to the customer and speed conversion across the supply chain.

e. Manage sources of supply strategically to reduce the total cost of owning materials and services.

f. Develop a supply chain-wide technology strategy that supports multiple levels of decision making and gives a clear view of the flow of products, services, and information.

g. Adopt channel-spanning performance measures to gauge collective success in reaching the end-user effectively and efficiently.

3.3.2. Supply Chain Analytics

Supply chain analytics is an area focusing on making better insights from data generated by supply chains. A well-developed supply chain analytical model gives a company valuable insights about the end to end lifecycle of their goods and how they get from manufacturing to their end customers. Since the 1990s, Enterprise Resource Planning (ERP) systems have been helping companies make more efficient decisions by integrating supply chain analytics capabilities.

The Supply Chain Operations Reference (SCOR) model as developed to provide a good framework for classifying the analytics applications in supply chain management. (Souza, 2014)

SCOR Domain	**Source**	**Make**	**Deliver**	**Return**
Activities	Order and receive materials and products	Schedule and manufacture, repair, remanufacture, or recycle materials and products	Receive, schedule, pick, pack, and ship orders	Request, approve, and determine disposal of products and assets
Strategic (time frame: years)	• Strategic sourcing • Supply chain mapping	• Location of plants • Product line mix at plants	• Location of distribution centers • Fleet planning	• Location of return centers
Tactical (time frame: months)	• Tactical sourcing • Supply chain contracts	• Product line rationalization • Sales and operations planning	• Transportation and distribution planning • Inventory policies at locations	• Reverse distribution plan
Operational (time frame: days)	• Materials requirement planning and inventory replenishment orders	• Workforce scheduling • Manufacturing, order tracking, and scheduling	• Vehicle routing (for deliveries)	• Vehicle routing (for returns collection)
Plan	Demand forecasting (long term, midterm, and short term)			

Table 2 SCOR model (Souza, 2014)

Analytics techniques can be grouped in three ways and these are descriptive, predictive and prescriptive analytics. Descriptive analytics draws insight from large volumes of data and provides easily digestible information for the business needs. In a supply chain, real time information about the whereabouts of goods and resources will provide managers the necessary information on how to plan for refills, new orders, possible emergencies, and the like. Global positioning system (GPS) and radio frequency identification (RFID) data are the most commonly used data sources in supply chain descriptive analytics.

Predictive analytics in this field draws insight into possible forecasts by analyzing past data and tries to optimize the response that the manager can make so that it will maximize profitability.

Prescriptive analytics on the other hand provides recommendations by looking at both the descriptive and predictive models and also mathematical optimization models. (Souza, 2014) It tries to answer the question of what the business should be doing and as such most of the software and discussion around supply chain analytics focuses on this type of analytics.

Strategic (time frame: years)	• Strategic sourcing • Supply chain mapping	• Location of plants • Product line mix at plants	• Location of distribution centers • Fleet planning	• Location of return centers
Tactical (time frame: months)	• Tactical sourcing • Supply chain contracts	• Product line rationalization • Sales and operations planning	• Transportation and distribution planning • Inventory policies at locations	• Reverse distribution plan
Operational (time frame: days)	• Materials requirement planning and inventory replenishment orders	• Workforce scheduling • Manufacturing, order tracking, and scheduling	• Vehicle routing (for deliveries)	• Vehicle routing (for returns collection)

Table 3 Analytical techniques used in SCM ((Souza, 2014)

3.3.3. Blockchain in Supply Chains

Blockchain technology is still in its early phases of development. There are several potential applications to it of which several are in the supply chain field. Blockchain technology has the ability to modernize the way in which goods are traced, authenticated and identified.

There are several interpretations as to how blockchain technology can be used in the supply chain space. Some supply chain networks can be permissioned meaning that they would be private requiring permission to join and typically have a limited number of players within. Others however can be permissionless thus are relatively open to the public space.

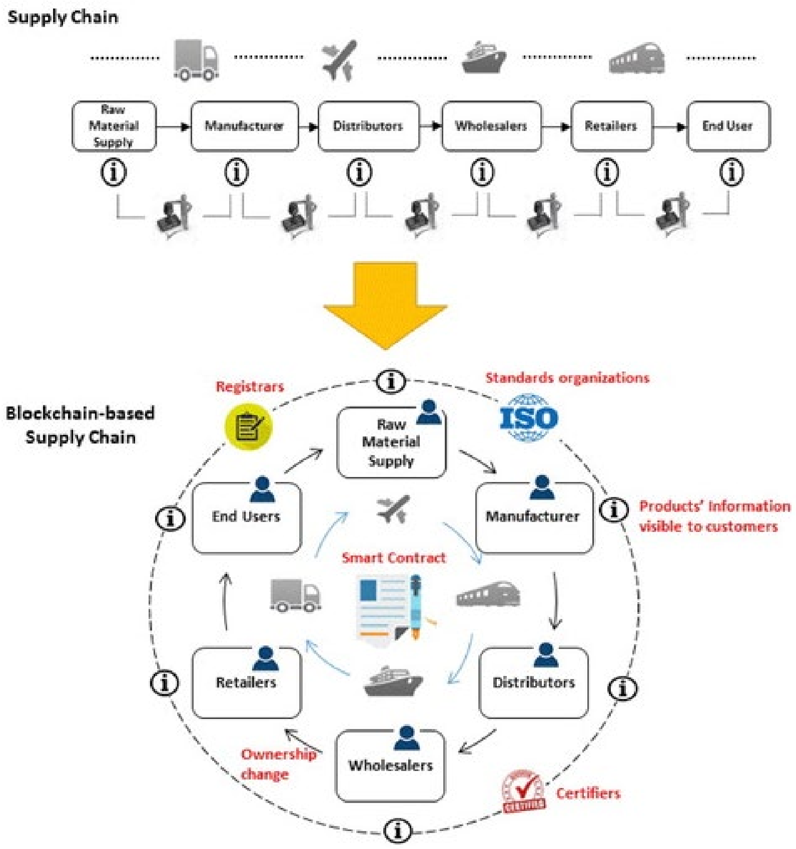

Figure 2 Supply chain & Blockchain technology (Blockchain technology and its relationships to sustainable supply chain management, 2019)

There are four main entities that exist in a blockchain backed supply chain system. These are “Registrars”, “Standards Organizations”, “Certifiers” and “Actors”. Registrars, who provide unique identities to actors in the network. Standards organizations, who define standards schemes, such as Fairtrade for sustainable supply chains or blockchain policies and technological requirements. Certifiers, who provide certifications to actors for supply chain network participation. Actors, including manufacturers, retailers, and customers, that must be certified by a registered auditor or certifier to maintain the system trust (Blockchain technology and its relationships to sustainable supply chain management, 2019)

3.3.4. Information systems for SCM

There are information systems carefully designed to optimize the different stages of a product's lifecycle and its overall value to the company. The SCM system helps the company to notably better meet demand for its products while also lowering logistics and purchasing expenses. SCM encompasses the complete process of buying raw resources, manufacturing, and distributing finished goods. According to (Information systems for supply chain management: uncertainties, risks and cyber security, 2018), supply chain management focuses on six major areas: production, suppliers, location, warehouse inventory, transportation, and information.

The tremendous potential of the internet has defined current trends in the development of SCM technology. Producers, vendors, contractors, transportation, and trade firms are all connected in a very close manner and are already functioning as virtual networks. Companies blend into the broader business world, and the lines between them blur. However, because joint operations are transparent, performers may swiftly react to consumer needs and provide new goods to the market utilizing improved forecast and planning methods.

The internet is the most straightforward, cost-effective, and effective way to administer and govern partner networks. Companies often begin by combining the most basic operations utilizing emails and process automation tools, then progress to virtual docking of the most critical business processes, and finally merging into a single virtual corporation with synced network. This is effectively leading the way for the transition to global e-commerce, in which all commercial transactions and payments are conducted exclusively over the Internet. As a consequence, not only does output rise, but all operations also speed up, resulting in fundamentally different outcomes.

3.3.5. Benefits that blockchain technology can bring to SCM

There are many areas in the current supply chain management landscape that blockchain can bring value to. We can look at the main functions in SCM to get an understanding of these values.

a. Supply Chain Provenance

Provenance in the supply chain context refers to the origin of goods. It's very important in order to ensure fair trade practices were maintained as well to ascertain no violence or illegal activities were involved in the making of the final product. Blockchain technology can help alleviate concerns about provenance because it can be used to catalogue the products life cycle. SC provenance is delivered by providing certifiability, traceability, verifiability and tractability of product information, origin and authenticity assurance and integrity along the entire SC spanning across borders. (Dutta , et al., 2020)

b. Supply Chain Resiliency

Resiliency in supply chains can be affected by a host of problems such as natural disasters, civil unrests, pandemics, and inflation - just to name a few. Blockchain can help solve these problems because it can be used to document the risks associated with each "node" (participant) in the supply chain.

c. Supply Chain Security

Implementing blockchain technology in a supply chain can help solve security issues. Blockchain can enable the formation of risk control analytics framework to study the connection among business, information and engineering and to gather an analytics perspective on digitalization in supply chain. (Ivanov, et al., 2019)

There are several ways in which blockchain can help with security. One of these is in the area of IoT security. Due to the fact that blockchain is decentralized, it makes it harder for malicious actors to hack one IoT device and be able to hack the others.

Blockchain can also be used to further enhance the use of RFID (radio-frequency identification) tags. RFID tags can be used to track and trace goods. Blockchain can improve the transparency, data protection, reliability and cost management for RFIDs using an ultra-light weight mutual authentication RFID protocol. (Dutta , et al., 2020)

d. Supply Chain Transparency

Blockchain technology can also be used to instill transparency and trust in the business in question. One of the ways it can do that is by showing the price increments a product has from its production to its retail stage. Oftentimes, the price setting of a product is done in a non-transparent manner, and this can lead to the customer feeling like they have been cheated out of their money. The technology can show customers the exact price the raw materials cost as well as how much the different steps in the supply chain contributed to the final price that they see in the retail stage. A pilot implementation has been done through smart contracts on Ethereum network where price transparency is guaranteed. (A Study on the Transparent Price Tracing System in Supply Chain Management Based on Blockchain, 2018)

4. Practical Part

4.1. Selection of blockchain use case for thesis

The supply chain that is involved in certain food and beverage industries has to be at a controlled temperature. This type of a supply chain is called a cold chain, because it is mainly concerned with ensuring that the temperature is at the advised degree for the product concerned. Perishable food and beverages that are danger of going bad include fish, red meat, milk, cheese, fresh juices and certain vegetables. These goods need a certain level of humidity, sunlight and temperature exposure in order to maintain their freshness and safety to consume. The food and beverage industry has seen some innovative tools that help mitigate the risk faced by the products stated above.

Another cold chain item that has not yet seen many innovations in minimizing the risk for is blood. Blood donations are an important part of the healthcare lifecycle. Blood donations happen when volunteers have blood drawn from them and stored in a blood bag which would later on be used to transfuse blood to a patient that needs the blood donation. Donors undertake a short survey where they are asked for their medical history to ensure that their blood donation would be safe to use. They would also take a basic physical examination to ensure their health.

Blood is always in demand as the need for blood transfusions has never seen a decline. There are always medical emergencies where the patients require blood transfusions and the need for donated blood will always be there as there is no chemically synthesized substitute for blood at this point of human history. The most in demand blood category, which are red blood cells and whole blood, need to be kept between two to six degrees Celsius and have a shelf life of 35 days from donation.

The application selected for this thesis is a cold chain verification tool which for the purposes of this thesis will be called “Temperature Regulation Verifier” or “TRV” for short. From an application design standpoint, there is a need to determine the functional and non-functional requirements. Both of these will be discussed in the coming sub-chapters and use case as well as entity relationship diagrams will be created using Universal Modelling Language (UML).

The application that will be designed is going to be used for cold chain storage and it will have a client version as well as an end user application that would connect the user to a portal. It will help record and verify that the product has been stored in the specific temperatures needed for its safety and effectiveness.

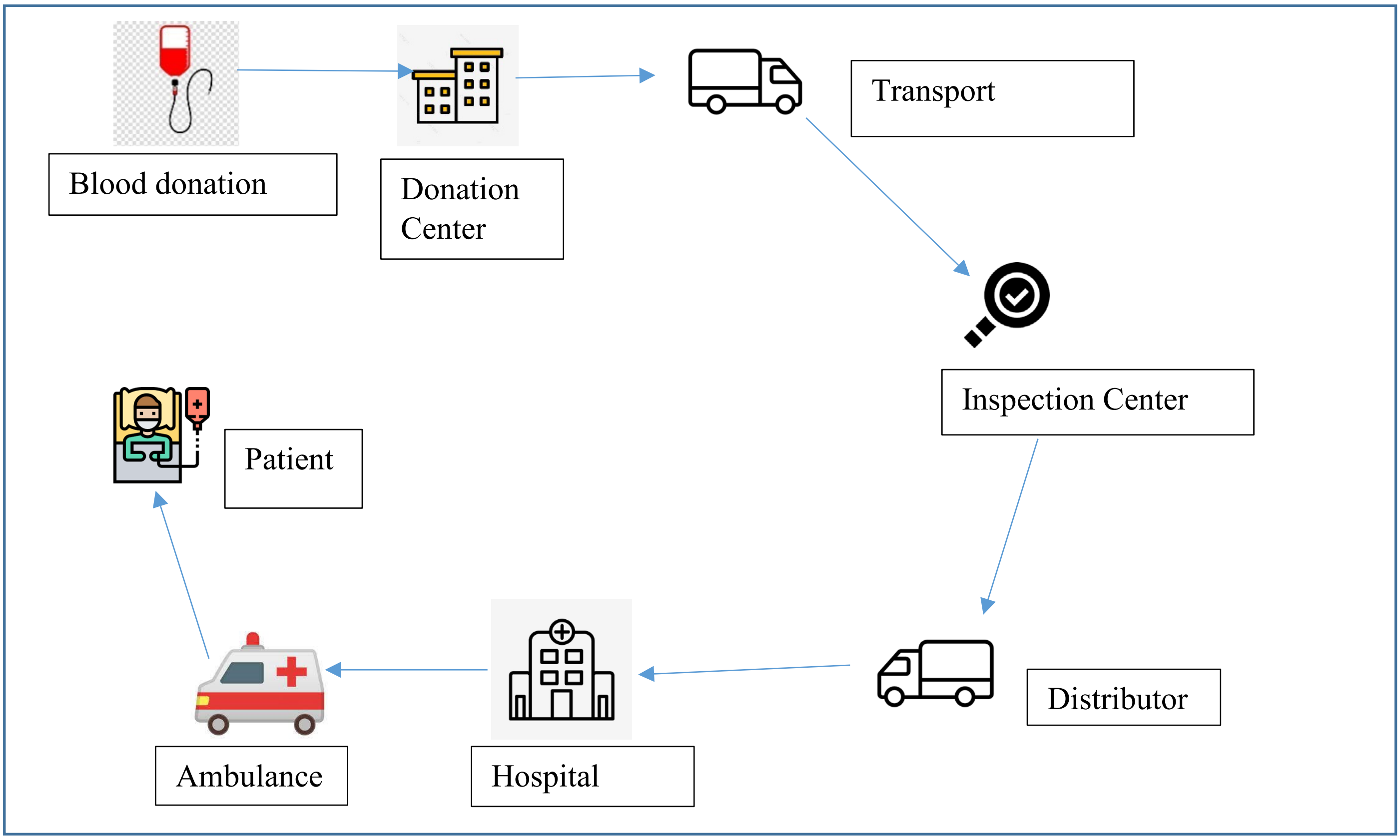

Figure 2 Current Blood Supply Cold Chain

4.1.1. Functional requirements for the application

We can break down the functional requirements into three parts as we are going to design an application that will have two versions (client and end user applications).

Client Version

The client version of the application will be used to create logs of the journey the material that needs to be kept in a cold chain storage actually undertakes. Operators would be the registered clients using the client version of the app. A QR code would be used to log the details that pertain to the transaction of the goods in question. The whole system would be decentralized thus making it impossible for malicious actors to interfere and tamper with data.

End user portal version

The end user portal would have searchable database at the user's disposal. It should allow the customers to search for the shipment's geographical history. It also will provide information about the shipment's storage temperature and whether or not it has been stored at the optimal temperature required. It would also provide a dashboard of all the important numbers that would pertain to such an operation.

Front and back-end integration

The integration of the end user portal to client portal would be critical in upholding the critical infrastructure in place.

4.2. Architecture of the application

The application architecture aims to show the interrelations between the different instep levels of the application hierarchy. We can see the components in the diagram in more detail below.

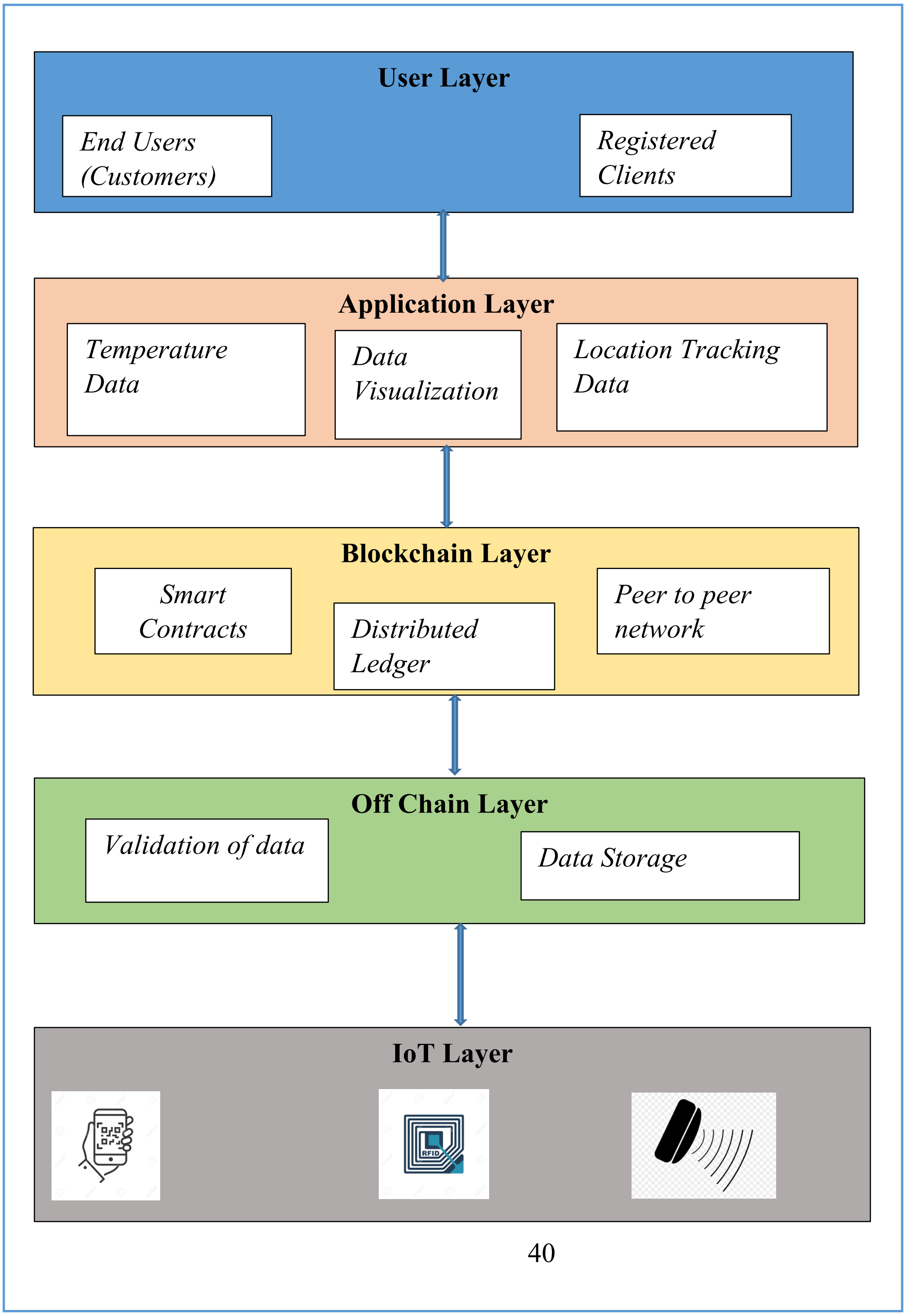

Figure 3 Architecture of the application

4.2.1. User Layer

In the user layer, the registered clients are able to upload the information in relation to the package temperature condition throughout the supply chain journey. They would also be able to record the geolocation data of the package from start to finish – so in the meantime any questions about the veracity of the package would be answered. The end users or customers would be able to enter their search parameters in the end user portal and ascertain any information in regard to temperature, origins or quality of the package being delivered.

4.2.2. Application layer

Data visualization is one of the features offered by the application. Dashboards that show the progression of temperature, countries involved in supply chain and other business critical KPIs (Key Performance Indicators) can be integrated. Embedded Power BI visualization will be used to make this component a reality.

4.2.3. Blockchain Layer

The blockchain layer in the architecture can be considered as the 'engine room' in this setup. It will contain the smart contract which will be the mode of consensus in the network. The smart contract will be critical in achieving real time exchange between the various stakeholders about the condition of the goods being transported. The nodes on the network would represent the actors on the cold chain. These nodes would use a function on the smart contract to verify the transaction at each step of the cold chain. The smart contract will also be used to notify when approvals are needed from the current node in the network by the previous node and vice versa.

4.2.4. Off Chain Layer

The need for the off-chain layer arises from the challenge of storing large amounts of data on the blockchain network. The application is used sparingly as the need for checking the conditions of transport in the cold chain come by occasionally. This means that storing the data off-chain would suit the needs of the application as it would conserve storage space.

The application will also need to only have the currently requested nodes verifying the smart contract. The off-chain layer for the application essentially composes of the data validator and storage components.

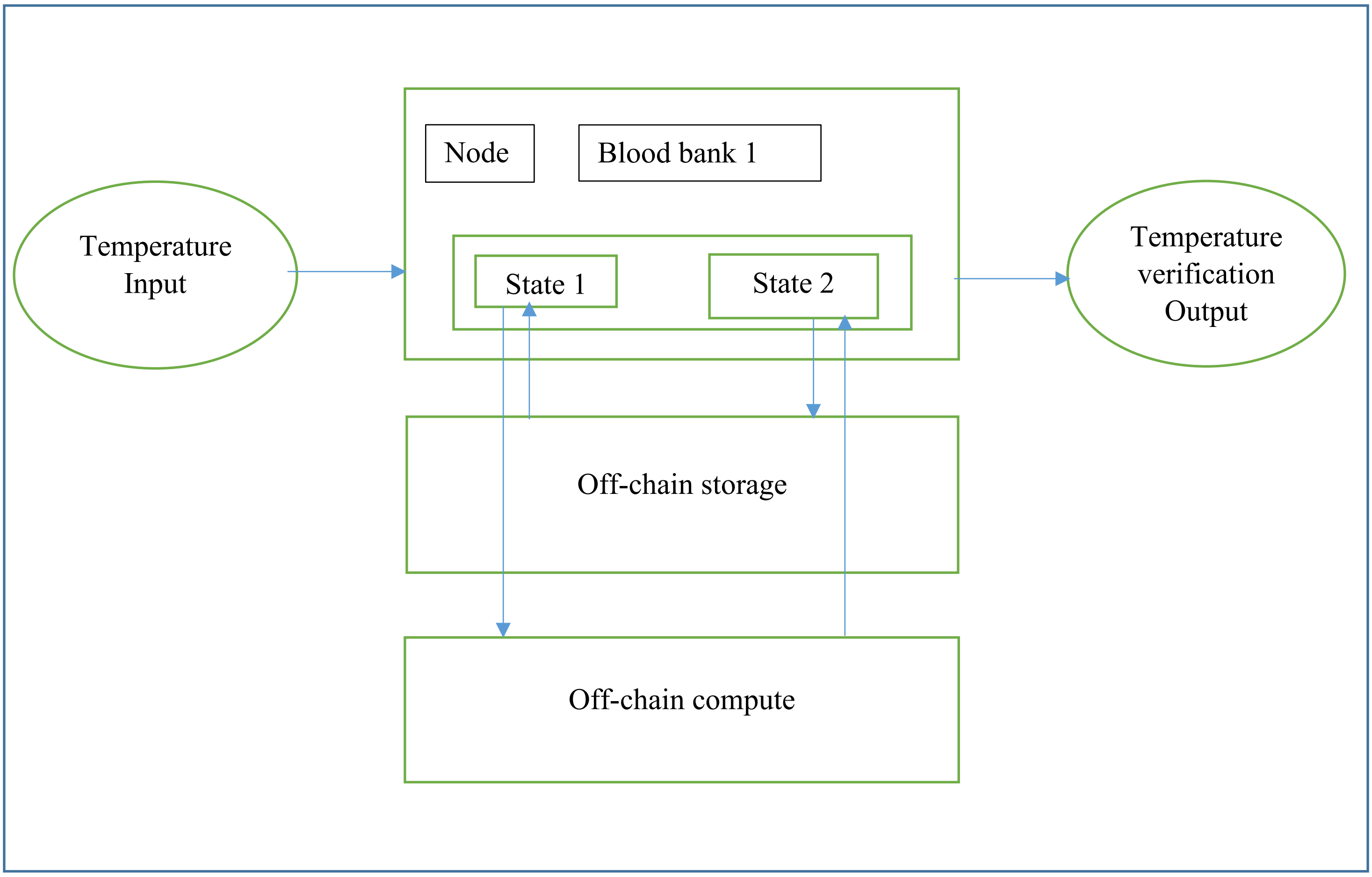

Figure 4 Illustration of how the application's off chain storage and computation function

4.2.5. IoT Layer

The IoT layer in the proposed architecture would mainly consist of the RFID (Radio-frequency identification) tag readers. The RFID tag readers enable the collection of real time data that will be subject to verification. They do this by triggering an electromagnetic pulse from a tag attached to the item of which we want to learn the temperature information.

The types of information that would be encoded on the tag will be:

- The donation center where the blood was taken
- The blood type of the owner
- The amount of blood
- Time and date of the packaging
- Storage temperature recorded onto the specific bag

The information that is listed above, would be stored in the RFID tag as well as the blockchain network. This redundancy of data will serve as a proof of veracity when the records on both are checked against each other.

4.3. Use case diagrams for the application

The figure below describes the real-life sequence of a blood donation lifecycle. There are five main actors involved in the lifecycle and these are the blood donator, donation centre, quality inspector, hospital and the blood donation receiver (patient).

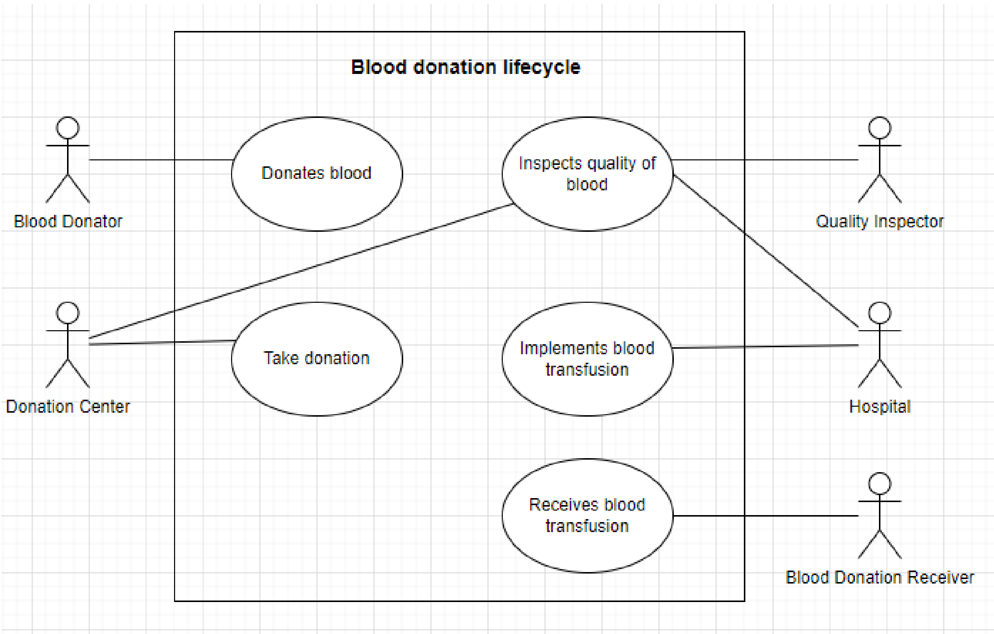

Figure 5 Use Case Diagram for the Blood Donation Lifecycle

The use case diagram shows the interaction between the different actors in the blood donation lifecycle. It aims to visualize the different roles that the blockchain nodes will replicate once the network for the application has been laid out.

The blood donator’s role would be to simply go to the donation center and give the blood donation. They would be responsible for making sure that they fulfill all the necessary health and legal requirements needed to donate blood. In the happy path, after the blockchain network and application has been set up the donator shall be able to get some insight into how and when their donation has been used. The insight however will not reveal any identifiable information.

The donation center will take on the responsibility of taking the blood donations as well as inspecting the quality of the samples. The tasks in the blockchain scenario would also include putting a data matrix tags to the blood bag. These tags would be encoded with the information on the blood donators vital details as well as the data on the collection center, collection time, temperature at donation and the like.

The quality inspector is a specialized function that has the sole purpose of testing the quality of the blood coming from the donation centers. They use industry standard equipment to test quality and create records on each donation bag. After blockchain implementation, they would update these records on the blockchain network and be able to verify the appends done by the donation center.

The hospital is responsible for taking in quality blood and administering to the appropriate patient. In the currently existing model, the hospital would be checking the blood quality from a centralized database. This model is prone to man in the middle attacks as well as data falsifications for several reasons. On the blockchain model, however, this change as the hospital node is able to check for veracity affirmations from the other nodes on the network.

The blood donation receiver has the least changed course of action as their role is solely to receive the blood donation. They would, however, have the guarantee that they are receiving quality blood that is suitable for their conditions.

4.4. Transparency of the application

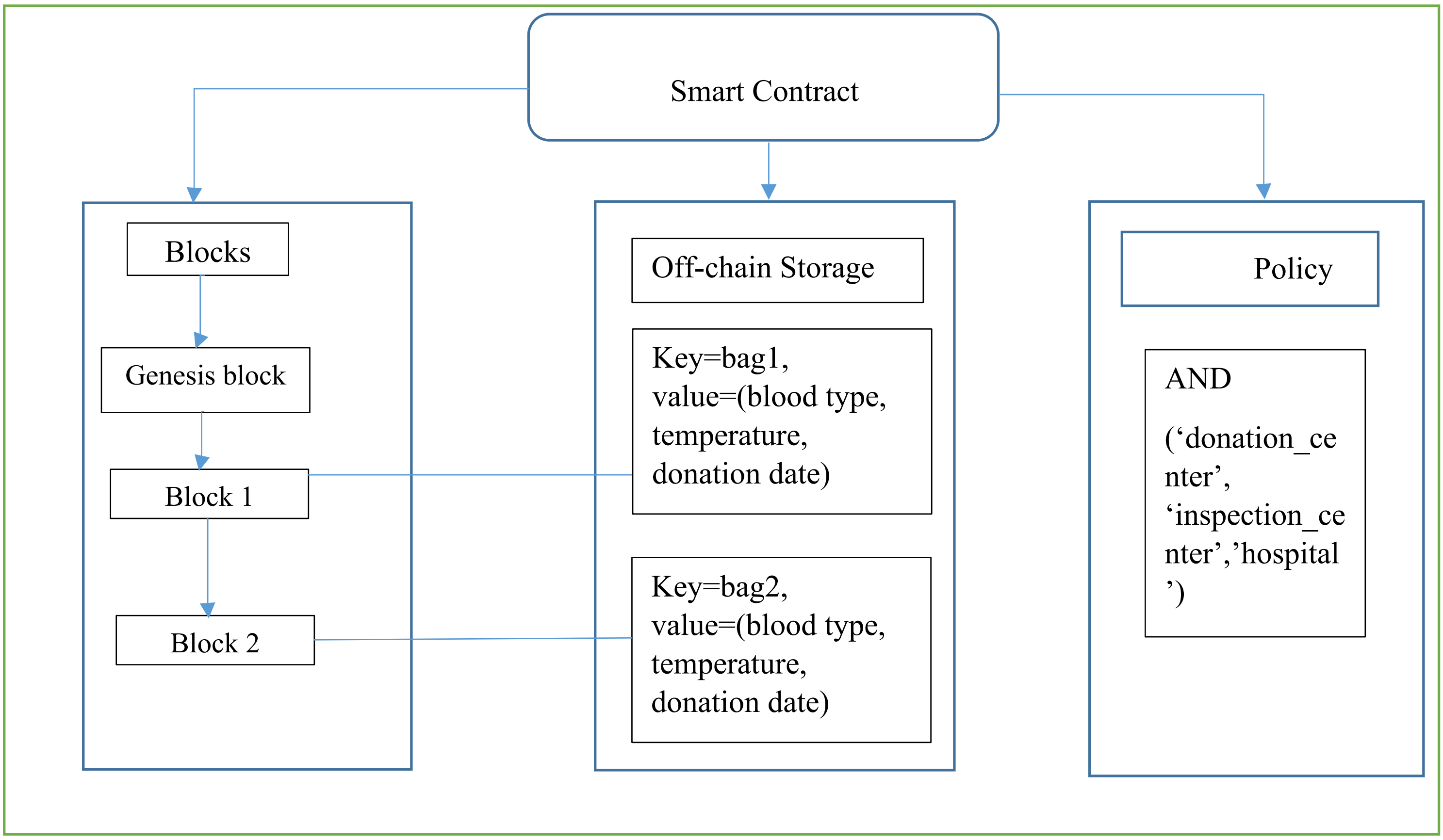

Figure 6 Node architecture of the application

The node architecture shown above goes to visualize the interconnections between the different node components underpinning the smart contract on the application. Each block is complete with the different details that are relevant to it such as blood type, temperature and donation date.

The policy component ensures that an "AND" principle is implemented making sure that any append has been agreed upon by the "pusher" and the "verifier". Only after the append has been agreed on by both parties would it be added on to the chain. The off-chain storage was chosen as its benefits regarding the latency of the application outweigh the benefits of using the on chain storage option.

4.5. Entity Relationship Diagrams for the application

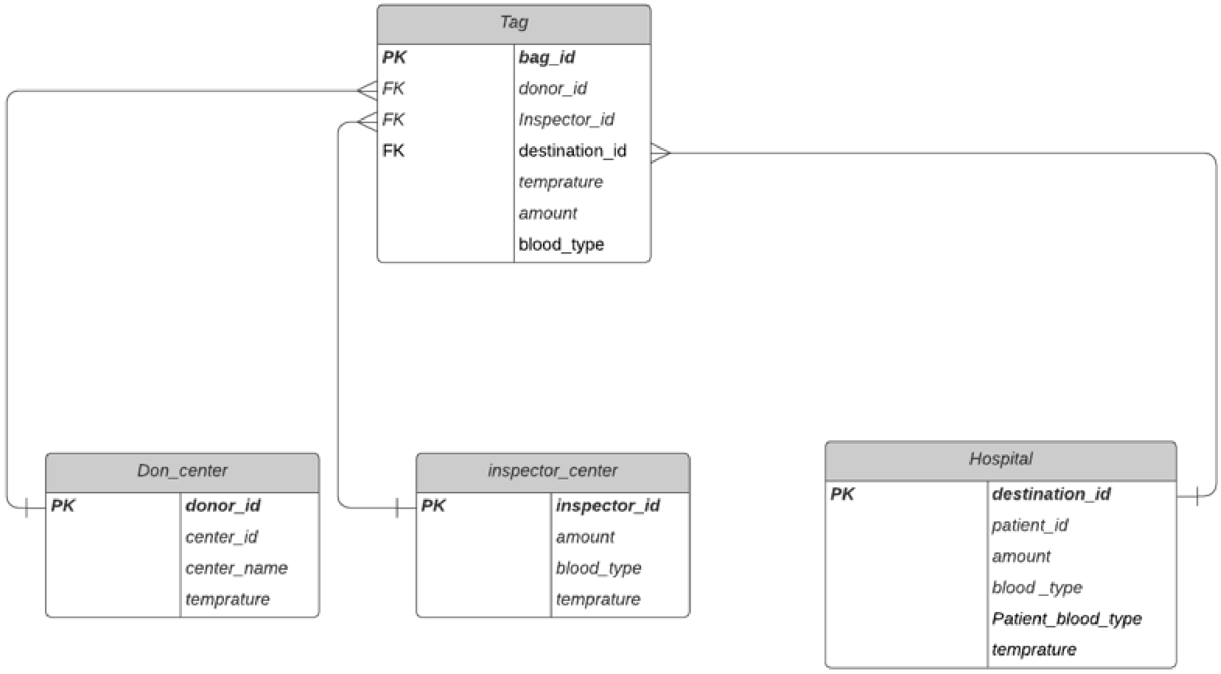

Figure 7 ERD for the application

This Entity Relationship Diagram (ERD) aims to show the relationships between the four entities represented namely the tag, donation center, inspection center and hospital. The vertically drawn diagrams stand for each individual entity and the list contained in each represents the attributes for that entity.

The "don_center" table contains information on the donation center itself by storing the center's ID and name. It also contains information on the blood temperature recorded at the center. The "donor_id" acts as a primary key and as a foreign key in the "tag" table.

"Inspector_center" contains information about the inspection center which is represented through the "inspector_id" attribute which will also serve as the primary key and foreign key on the "tag" entity. This entity also contains information about the amount of blood, blood type and the temperature recorded at the inspection center.

The "hospital" entity has attributes on the destination of the blood that pertains to the hospital where the blood ended up and is waiting to be distributed. It also includes the patient information, patient blood type as well as the temperature it was stored at in the hospital. The "destination_id" will serve as the primary key for the entity as well as being the origin key in the "tag" entity.

The "tag" entity will serve as the "master" entity where all the foreign keys correspond to the other entities. It has the all-important "bag_id" that acts as the primary key for the entity. This would contain the unique digits of the individual bag that would make it distinguishable from other blood bags.

4.6. Wireframes for the application

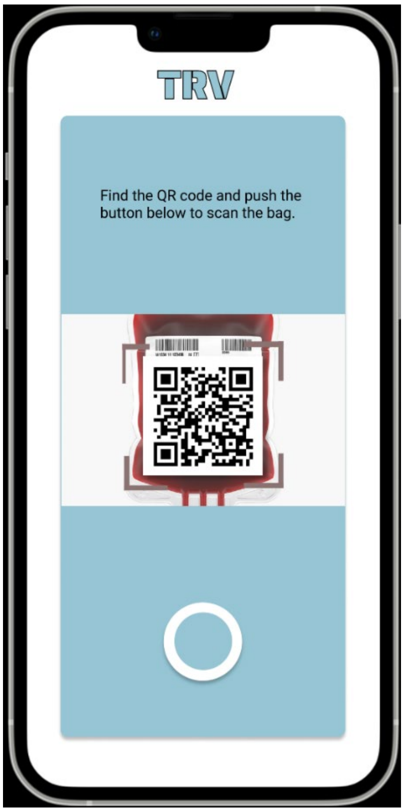

Figure 8 Screen for scanning tags

The wireframe shown above shows the screen for scanning a blood bag. The user would need to simply open the TRV application on their device and point their camera at the data matrix on the blood bag.

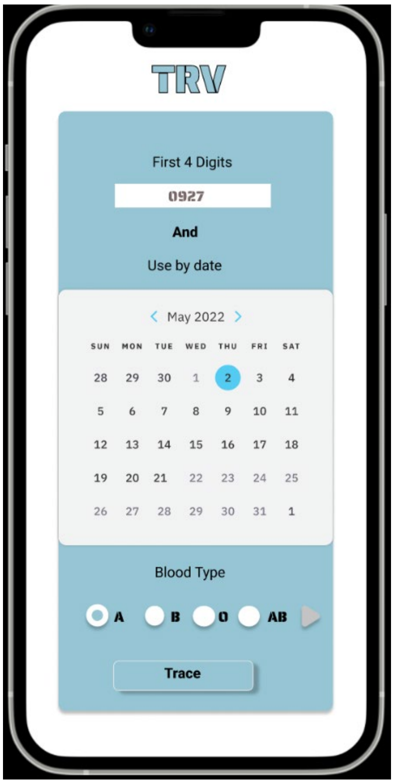

Figure 9 Screen for entering tag information

The figure above shows the screen presented when the user is filling in the details of a blood bag. They have the opportunity to fill in the date when the blood donation after which the blood would not be suitable for use. They also fill in other important details such as the blood type.

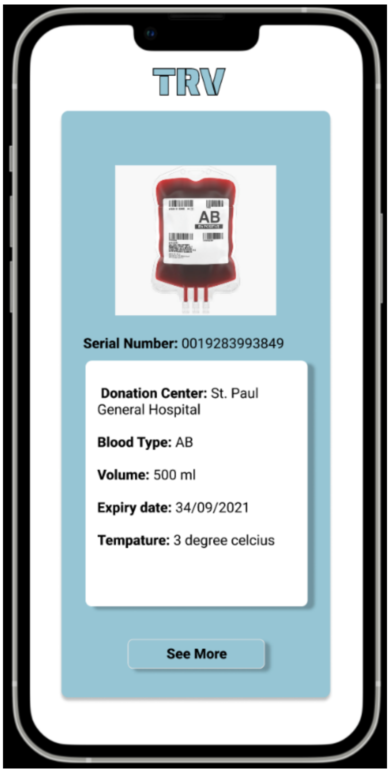

Figure 10 Screen for displaying tag information

On this screen, the end user has the opportunity to look at important details from the blood bag's tag. They can see the serial number as well as the donation center where the blood was packaged into the bag. They can also access information on the blood type, blood volume, expiry date and the temperature at which it was stored or transported.

4.7. Blockchain framework chosen for application

While evaluating the blockchain framework that would be used as the basis for this blockchain application, a few choices were evaluated. These were the Hyperledger Fabric, Ethereum and MultiChain platforms. Based on several factors such as ease of setting up, available technical support, platform security and manageability; Ethereum was chosen as the preferred platform to build the application on.

The blockchain network will be a permissioned network as the information contained on the blocks will be sensitive and therefore a certain authentication process is needed before admitting actors onto the network. As they have a more selective way of allowing node participants, there will be a lower number of participants and therefore faster transaction. The drawbacks in using permissioned blockchain networks lie in the fact that there is considerable admin work needed to allow participants onto the network. However, for the purpose of the application proposed on this thesis a permissioned network was found to be more beneficial as security and veracity had more weight in the selection process.

5. Results and Discussion

5.1. SWOT Analysis

After the application design was done, an exercise to measure the feasibility of the proposed blockchain solution was carried out. This table contains the SWOT analysis done. The entries in the table are discussed in detail below.

Strengths	Weaknesses
• Increased transparency • Less risk of data being tampered with • Data security	• Slower transaction speed • Maturity and awareness of underlying blockchain technology • High consumption of computing power
Opportunities	**Threats**
• Integrations with vaccine cold chain application • Data visualization features to create a one stop shop for insights into quality of blood coming from certain suppliers	• Cost of developing the application • Institutional willingness to adopt technology

Table 4 SWOT Analysis of proposed blockchain application

a) **Strengths:** One of the main strengths of the proposed design are the security features installed on a blockchain network. The ledger's location is unknown during the transactions are being done, therefore eliminating the risk of man in the middle attacks. There would be no single point of failure as the distributed nature of the network prevents that. This would also mean that there is a lower probability of experiencing downtimes.

The increased transparency aspect of this blockchain application is also another big feature that works in its favour. Data is available for everyone on the network so it creates a sense of trust between the participants.

b) **Weaknesses:** The considerable computing power required to process blockchain transactions is a major drawback of using the technology. There is a network of computers and their collective computing powers that needs to work intensively in the background to make those transactions happen.
Another issue that can be classified as a weakness is the fact that blockchain technology is still in its infancy as an emerging technology. This means that there are still legal and ethical issues that need to be figured out on the go as the technological development is also taking place.

c) **Opportunities:** The possibility of integrating this application with some of the other similar needs in the area that need a technology for managing cold chain operations would make the pharmaceutical industry a more robust and efficient industry. Vaccines also need to be transported at a regulated temperature and this application can be used to regulate that environment in the future. Similar studies that target the vaccine industry can be done and can provide the justification as to why such an application would be a good addition. The recent COVID-19 pandemic has also shown that transporting huge numbers of vaccine doses in sub-zero temperatures across different geographies is a necessity that is not as far-fetched as we would have liked to believe.

Data visualization is also another area that can be utilized to make the application more complete. It would offer the users a chance to gather some collective insights into which blood donation centres are having the most problem with collecting and storing blood at the right temperature. It provides a one stop shop for all the metrics that would be needed to facilitate the daily running of the cold chain.

d) **Threats:** the cost of developing the application might be a big barrier for the adoption of this technology. As there are several actors within the network, making the communications between their nodes automatic requires more effort and therefore costs more. As mentioned earlier, the technology is still relatively new and new technologies might emerge- making some of the costly pieces more efficient and reducing the expenditure needed.

   Institutional willingness to adopt the technology also might hinder efforts made to transition to this technology. Unclear communication as to why this approach would make more sense in the long term might be a factor in non-adoption of the application. Stakeholders that are not tech-savvy might not see the difference between using this application and a more traditional centralized database using application; therefore, they might be unwilling to undertake the necessary financial and time investments to make it a reality.

5.2. Risk Analysis

To make this chapter more complete, a risk analysis was also carried out. The risk analysis was done by comparing the blockchain application and the traditional centralized database approach. As with the previous sub chapter, a more detailed analysis can be found under the table.

	Centralized Database	TRV
Blood Quality	Risk of falsification leading to possibility of contaminated blood entering circulation	Falsification is prevented because different nodes can check for blood quality and append data
Availability of Blood	Diminished incentives for donating blood because of middlemen	Increased incentives for donators because they can directly take control of their data and see where their donations go.
Regulatory Sanctions	Noncompliance with the strict rules around blood donation can bring irreversible reputational damage to the donation centre and the whole cold chain	Increased transparency and trust can lead to an increase in blood donations and therefore alleviation of the supply shortage surrounding blood.

Table 5 TRV versus Centralized Database Application- Risk Analysis

a) **Blood Quality:** When it comes to the quality of blood collected at the donation centres the risk of falsification is higher in centralized models, as there is a single point of failure within the system. Falsification made in the central database can derail the veracity of the record and bring into question the reputation of the whole system. Blockchain and its decentralized model can help answer the quality question, as it is near impossible to forge a certificate of quality as each appendix to the blockchain ledger is visible for everyone to see.

b) **Availability of Blood:** The centralized model offers little to no incentives for a potential blood donor. There is no possibility for the donor to know whether his contribution has actually made it to a person in need and helped save a life. The blockchain application can change this by giving information in a non-identifiable format that is in line with PII (Patient Identifier Information) protocols. This way all the unique identifiers that can be used to identify a person will be encrypted making it impossible for any malicious actors to gain any sensitive information.

c) **Regulatory Sanctions:** Non-compliance with the existing strict rules around blood donation might bring the actors involved serious legal consequences. The possibility that even one record of data tampering and falsification can bring severe health consequences to a patient in need is not something that can be taken lightly. The underlying technology in TRV is able to alleviate these problems by creating transparency between the nodes on the network and therefore creating checks and balances in the system.

5.3. Recommendation

There is a growing interest in the value that blockchain technology can bring to the world of supply chain and healthcare. The technology is still in its infancy and is considered by some to be at the same stages as the internet was in the early 2000s. There is hope among the tech enthusiastic community that the technology can grow to replace the centralized database technology and that it would outgrow the reputation it gained from the cryptocurrency movement.

This thesis aims to show that there is more to blockchain than just the cryptocurrency utilisation its associated with. In the thesis, blockchain is used to design an application that tries to solve the common issues related to blood cold chains. The TRV application aims to show the capabilities of blockchain as a platform that allows data verification in real time and where data falsification is near to impossible.

As a recommendation for future work based on this thesis, the author proposes incorporating other products onto the application’s framework. End users for vaccines and other pharmaceutical products benefit from ensuring that they are kept at a regulated temperature. There is a potential room for growth by integrating these products into the application.

There is also potential in using some business intelligence tools to build dashboards on top of the data gained from the application's use and to create a one stop shop for assessing the trends and potential areas of improvement. Users can have the option to create visualizations using tools such as Tableau or Power BI and identify the donation centres and transportation facilities with the highest number of unregulated blood and identify the weakest links in the cold chain. This will help with targeted decision making at a higher level that can impact the way that the cold chain is set up and that partners are chosen.

6. Conclusion

As the world grappled with the onset of the coronavirus pandemic, the need for a resilient cold chain application has come to the fore. Vaccines as well as blood donations require a certain range of temperatures for storing and transporting. If these temperature conditions are not met, the quality of the goods is compromised. As the very purpose of vaccines and blood donations is to save peoples lives, the impact in their quality would inevitably jeopardize lives.

Existing methods of handling cold chain industries are not able to cope with the demand and regulations needed by such a sensitive line of products. As the traditional methods would involve the use of centralized databases, this would introduce a single point of failure.

This thesis aims to uncover ways on how to use emerging technologies to aid with this problem. To that end, blockchain technology was evaluated as an alternative for the centralized database. There are many fundamental differences between the two technologies, the main one being that blockchain doesn’t have a single point of failure that can jeopardize the integrity of its network.

The TRV application aims to solve this issue by creating a blockchain network that allows several permissioned actors on an Ethereum network to append and verify changes made to the blood bag’s record. The application’s proposed architecture was discussed in detail in this thesis. Also, possible areas of future development in business intelligence and other products were raised in the Recommendations part of the thesis.

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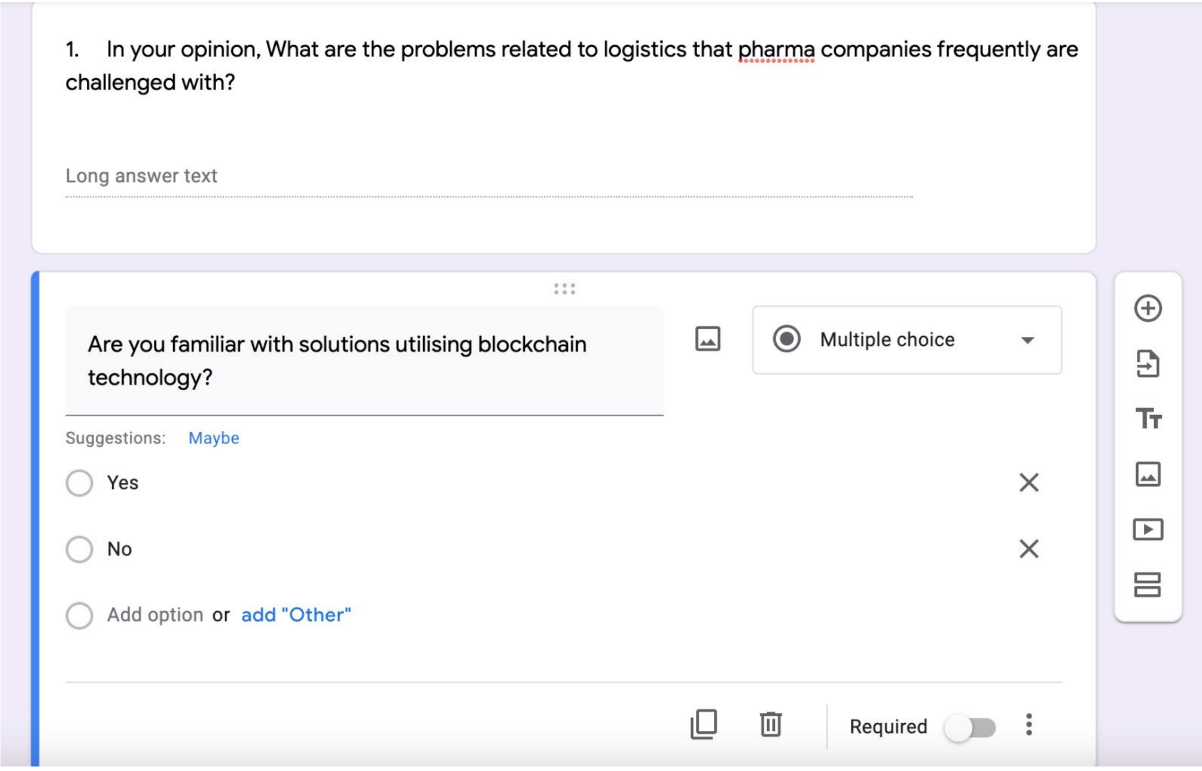
8. Appendix

Appendix 1

Google Forms Survey



Appendix 2

No	1. In your opinion, What are the problems related to logistics that pharma companies frequently are challenged with?	Are you familiar with solutions utilising blockchain technology?
1	Missing temperature and environment controls during storing and delivery of products	No
2	Counterfeiting of drugs	Yes
3	Fraudulent activities related to drug transport	No
4	Patient adverse events	Yes
5	Product mixing	Yes
6	Product Mix up and labelling mistakes	Yes

7	Supplier delay	No
8	Retailers being negligent on the proper storage spec of the drugs	No
9	shipping issues related to transport spec controls	Yes
10	unregulated warehouses with regards to temperature humidity	Yes
11	Unregulated transportation environment	No
12	Improper drug storage and warehousing issues	Yes
13	Fake drugs being suppied to end customers	No
14	Products being delivered to wrong distributer/Pharmacies	Yes