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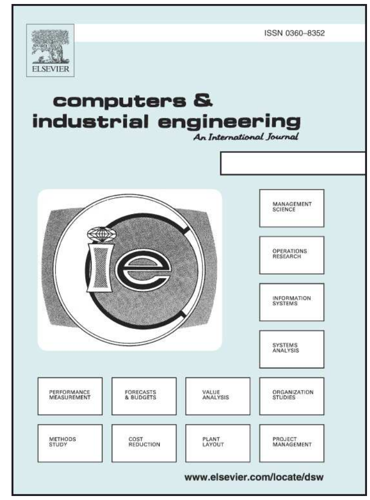

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Supply Chain Transparency through Blockchain-Based Traceability: An Overview with Demonstration

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Abstract

Traceability can be referred to as the ability to track and trace information. Application of traceability can create transparency in supply chains. Conventionally available, centralized traceability solutions are not preferable for supply chains as they are exposed to many problems such as data manipulations, single point of failure, etc. Blockchain, the recently emerged distributed ledger technology, is gaining popularity with its tremendous applications in various fields, particularly in supply chain management. Technically, blockchain is a decentralized and distributed database where information can be securely recorded. Blockchain-based traceability solutions can tackle the shortcomings of centralized traceability solutions. Firms have already started incorporating blockchain into their supply chain activities in order to improve the transparency through tracking and tracing the events. This paper ultimately aims to present an overview of the various blockchain-based traceability solutions reported in the literature. Primarily, this work provides an insight on the possibilities of blockchain traceability solutions in making a supply chain transparent. Apart from this, it analyses how blockchain traceability solutions affect the visibility of various supply chain distribution network designs, and gives an outline on how technologies such as the Internet of things (IoT), and smart contracts elevate the opportunities of blockchain. In order to demonstrate how blockchain traceability solutions improve supply chain transparency, a proof of concept (PoC) for a cold chain scenario is presented using Microsoft Azure Blockchain Workbench.

Keywords: Transparency; Traceability; Blockchain; Proof of Concept (PoC); Microsoft Azure

1. Introduction

Traceability and transparency are two terms, being wrongly used interchangeably, in the context of supply chain management. These terms are interconnected; but have entirely different meanings. Transparency is a term addressing the overall visibility of the supply chain. "Transparency of a supply chain is the extent to which all its stakeholders have a shared understanding of, and access to, the product related information that they request, without loss, noise, delay and distortion" (Hofstede, Beulens, & Spaans-Dijkstra, 2004, p. 290). Traceability represents the ability to access the granular level information about anything that remains as part of a supply chain. It can be about a particular inventory, process or one of the members of the supply chain such as retailer or wholesaler. Pant, Prakash, & Farooquie (2015) quoted the definition of traceability as the access of product related records in the upstream stages of the supply chain. In a more detailed form, traceability can be defined in terms of what, how, where, why and when aspects of the underlying product along a supply chain (Aung & Chang, 2014). Researchers have directly linked the term traceability with tracking and tracing (Jeppsson & Olsson, 2017; Pizzuti & Mirabelli, 2015; Sarpong, 2014). Tracking of a product starts from its origin and continues till its end point. Tracing is generally towards the origin from the endpoint. According to Hofstede (2007) transparency is of three types and the one, which can be achieved through tracking and tracing is history transparency. Operations transparency and strategy transparency are the other types. In short, traceability enables transparency through tracing and tracking.

Several researchers have incorporated traceability in various supply chain scenarios in order to erect transparency. For example, Scholten et al. (2014) introduced a novel system for a transparent meat supply chain. This system facilitates options for customers to trace the history of the meat available in the market. Suppliers and other participants of the supply chain can track the journey of meat throughout the supply chain, and government agencies can monitor the quality of meat. Kandel, Klumpp, & Keusgen (2011) presented a Global Positioning System (GPS) enabled traceability system called GPS.LAB to perform tracing and tracking in the context of production planning and supply chain event management to establish transparency in global supply chains. These kinds of traceability solutions, which rely on centralized systems, are not too good because of the chance of data manipulations. It is difficult to achieve traceability in a centralized environment. A centralized system lacks transparency and trust (el Maouchi, 2018). Tian (2016) addressed the centralized traceability system as a monopolistic, asymmetric and opaque information system. It can create issues such as corruption and falsification of information. Also, issues such as single point of failure can instantly interrupt the centralized systems from its functionalities.

Blockchain is an ingenious invention which can facilitate an immutable, distributed, transparent, secure and auditable ledger (Wamba, Kamdjoug, Epie Bawack, & Keogh, 2020). Blockchain is decentralized in nature and has incredible opportunities in supply chain management (Kouhizadeh, Zhu, & Sarkis, 2019). Events ongoing within a supply chain network can be appended to the chronologically arranged blocks of a blockchain in the form of transactions. In general, transactions executed by any one of the supply chain participants can be seen and verified by all the other participants and that ensures transparency in the whole network. According to Tapscott & Tapscott (2016), blockchain is capable of creating transparency and it can act as a single source of truth for the entire network of supply chain actors. All the blocks within a blockchain are cryptographically connected and this feature eliminates the possibility of data manipulations which are common in centralized systems. Blockchain can be mainly classified into three; public blockchain, private blockchain and consortium blockchain (Morkunas, Paschen, & Boon, 2019). Blockchain can mitigate many supply chain risks like information infrastructure breakdown, information delays, lack of information transparency, lack of compatibility in Information Technology (IT) platforms among supply chain partners and reduced Internet security (Tseng, Liao, Chong, & Liao, 2018). The integration of Internet of Things (IoT) and smart contract elevated the acceptance of blockchain-based traceability to a great extent (Reyna, Martín, Chen, Soler, & Díaz, 2018; Rouhani & Deters, 2019).

Even though many articles are being published in the area of blockchain-based traceability, a dedicated article consolidating the various use cases in supply chain management is not available. This paper primarily presents an overview on various use cases of blockchain-based traceability reported in the literature and outlines the potential of blockchain in bringing transparency for various supply chain scenarios. Here, in this paper, the term 'use cases' covers real world implementations, conceptual frameworks and working prototypes. An overview, in general, is a type of review that provides extensive and often comprehensive summation of a topic with differing degrees of systematicity (Grant & Booth, 2009). This paper summarizes the articles published on blockchain traceability, by pointing out the supply chain scenario considered, solutions implemented or proposed, and the benefits or limitations. In addition, this paper also discusses the distribution network associated with each supply chain scenario and thus, gives the readers an insight on how different distribution network designs get benefit from blockchain-based traceability solutions in terms of transparency. The way blockchain technology helps the supply chains in bringing the transparency through tracking and tracing is thoroughly investigated in this work. Finally, the content of this paper imparts an understanding on the relevance of IoT and smart contracts in blockchain traceability solutions. In short, this paper holds the essence of various blockchain oriented traceability solutions reported in the literature. Moreover, this work will surely be a good reference for those who work in the area of supply chain management and blockchain technology. Further, in order to demonstrate the idea of blockchain traceability, a proof of concept (PoC) for a cold chain scenario is developed and presented using Microsoft Azure Blockchain Workbench. This platform doesn't require much technical skills. In order to closely understand the applications of blockchain traceability solutions, readers can replicate the PoC presented in this work. The reminder of this paper is organized as follows: Section 2 elaborates various blockchain traceability solutions reported in the literature. Section 3 presents a PoC for a blockchain-based cold chain scenario particularly for tracing and tracking the journey of medicines that are sensitive to temperature and humidity. Section 4 discusses the characteristics of blockchain-based traceability solutions and the major inferences from the demonstration. Section 5 concludes the paper.

2. Blockchain Based Traceability Solutions: An Overview

Blockchain has already been incorporated in many supply chains in order to establish traceability and thereby to create transparency. This section describes various use cases of blockchain-based traceability solutions reported in the literature. Each use case is reviewed to understand the purpose of blockchain traceability in various contexts, limitations and advantages, and the methodology followed to develop the solution. Furthermore, the supply chain scenarios considered for blockchain traceability solutions are also scrutinized in terms of distribution network designs. According to Chopra, Meindel, and Kalra (2016), there are six major distribution network designs. Level of order visibility is one of the important factors in deciding the distribution network design. Visibility is the ability to access or share information across the supply chain. If the visibility is high, then the supply chain is said to be transparent.

The default level of order visibility in the six distribution network designs is given in Table 1. This section also looks for finding how blockchain-based traceability solutions improve the level of supply chain visibility under different distribution network designs. For the convenience of readers, the literature on blockchain-based traceability solutions are clustered thematically, based on the type of supply chain they are proposed for.

Table 1: Order visibility in different distribution network designs

Type of distribution network design	**Order visibility**
Manufacturer storage with direct shipping (drop shipping)	Very important from a customer service perspective and is more difficult to achieve
Manufacturer storage with direct shipping and in-transit merge	Similar to drop-shipping.
Distributor storage with carrier delivery	Easier than manufacturer storage.
Distributor storage with last-mile delivery	Less of an issue and easier to implement than manufacturer storage or distributor storage with package carrier delivery
Manufacturer/ distributor storage with customer pickup	Difficult, but essential.
Retail storage with customer pickup	Trivial for in-store orders. Difficult, but essential, for online and phone orders

2.1 Food/Agricultural supply chain

Blockchain traceability solutions are widely recognized in food and agricultural supply chains. Recently, Salah, Nizamuddin, Jayaraman, & Omar (2019) introduced a novel framework for the traceability of soybean. The framework was prototyped on Ethereum public blockchain. The framework aims to bring transparency in a supply chain consisting of a seed company, farmer, grain elevator, grain processor, distributor, retailer and customer. With the implementation of the proposed framework, tracking and tracing of soybean is possible and any sort of quality issues can be easily resolved by identifying the source of the product. Inter Planetary File System (IPFS) and standardized identifiers like Global Trade Identification Numbers (GTIN) are part of the framework. While retailers purchase products as batches, use of standard identifiers increases the effectiveness in tracking products and transaction related processes among the supply chain actors. Participants of the soybean supply chain have to interact with a smart contract deployed in the blockchain to add the information then and there.

In order to ensure food safety, Tian (2017) has introduced the concept of BigchainDB and presented a food supply chain traceability system based on Hazard Analysis and Critical Control Points (HACCP), blockchain and IoT. HACCP is a systematic method to avoid hazards related to food safety (U. S. Food and Drug Administration, 2018). Similar to this, by addressing the shortcomings of centralized traceability solutions, Rejeb (2018) explained how to combine blockchain with IoT and HACCP to have transparency in halal food supply chain. HACCP merged with Islamic dietary laws can be integrated with blockchain technology. This can reduce the risk in entering non-halal items into the market. The halal food supply chain considered in this work holds farmers or breeders, abattoirs, meat processors, wholesalers, distributors, retailers, and final consumers as supply chain actors. Blockchain-based traceability system for halal meat supply chain enables end customers to trace the whole history and provenance of halal meat products. Recently, Chandra, Liaqat, and Sharma (2019) also addressed this topic and conducted an experimental study using Hyperledger Fabric and Composer Playground.

Caro, Ali, Vecchio, & Giaffreda (2018) developed and implemented a blockchain-based traceability solution, named AgriBlockIoT particularly for managing agri-food supply chain. A use case called 'farm to fork' is selected to test the feasibility of AgriBlockIoT and deployed it using Ethereum and Hyperledger blockchain implementations. Architecture of AgriBlockIoT is made for a supply chain scenario consisting of six participants, and they are provider, producer, processor, distributor, retailer and consumer. These participants have to comply with the standards and other regulations instructed by the authorities.

Walmart recently collaborated with IBM for research on blockchain-based traceability solutions. Kamath (2018) claims that, in a pilot study of IBM, a blockchain-based traceability system developed on Hyperledger Fabric could trace the origin of mangoes just with 2.2 seconds which was possible earlier only within seven days.

Lin, Zhang, Shen, & Chai (2018) addressed the major causes of food safety hazards and presented a novel traceability solution that combines blockchain technology and Low Power Wide Area Network (LPWAN). Here, a traditional Enterprise Resource Planning (ERP) system and an IoT system act as the source for data. Data can be transmitted with LPWAN wireless systems directly to the blockchain network via IoT gateway. This work discloses the scope of blockchain technology in smart agriculture.

Palm oil industry has been criticized for rainforest loss, CO_2 emissions, and human rights violations and hence, the environmental and social sustainability is crucial in palm oil supply chains. As a remedy for this, Hirbli (2018) proposed a decentralized traceability solution by merging blockchain technology with an approach called Roundtable Sustainable Palm Oil (RSPO). RSPO basically provides assurance to the customers that the palm oil production is sustainable in terms of quality standards. For the production of certified sustainable palm oil, companies must follow the conditions of RSPO or similar approaches. Proposed traceability system is capable of monitoring the whole journey of mass quantity palm oil goods right from the plantation till it reaches the customer side. This work considers a traditional supply chain that includes farmers, manufacturers, oil mill operators, retailers and finally customers.

Tian (2016) proposed a blockchain-based traceability solution particularly to establish transparency in Chinese agro-food supply chains. Here, the term agro-food covers fresh fruits, vegetables, and meats like pork, mutton, chicken and beef. Proposed solution incorporates Radio-Frequency Identification (RFID) devices with blockchain technology. Conceptual framework of the proposed blockchain solution can facilitate real time tracking and tracing of agro-food items. Relevant data is to be acquired from different supply chain stages such as production, processing, warehousing, distribution and sales using RFID, GPS and other wireless network technologies. In addition to the regular supply chain actors, food safety authorities can also be a part of the blockchain network and this will ensure more safety and quality.

Branded items are always exposed to counterfeiting and this will pull down the sales as well as the brand value. Biswas, Muthukkumarasamy, & Tan (2017) presented a new framework for tracing the authenticity of wine. The framework was demonstrated using the open blockchain platform called 'Multichain'. The solution suggests a unique ID for each entity and a batch number for every batch from the manufacturer. Additionally, the final wine bottle will be having an ID labelled on it. Grape growers, wine producer, bulk distributor, transit cellar, filler, finished goods distributor, wholesaler and retailer are considered as the major entities of the supply chain.

Several attempts were done by different organizations like Provenance, and International Pole and Line Association (IPLA) to trace tuna fish (Visser & Hanich, 2018). Once a tuna fish is caught, tracking can be initiated. A reusable RFID tag is to be attached to each tuna fish. The RFID devices installed in the vessel and fish processing plant can collect and upload the details to the blockchain. Once the fish has been processed, the reusable RFID tag can be replaced with a Quick Response (QR) code tag. QR code can be attached to the product packing and the same can be used to trace the remaining journey till it reaches the consumer side. Idea of using reusable RFID tags in traceability solutions is a good strategy as it can improve the customer experience at lesser cost.

Blockchain traceability solutions suggested for food/agricultural supply chains are mainly for preventing food safety hazards. Once such a hazardous incident happens, its source can be easily traced out so that its spreading can be immediately suppressed. This makes the supply chains more resilient. Customers always prefer the quality of the food/agro products, and blockchain solutions in food/agricultural supply chains can always serve the customers in ensuring the same. Customers can trace the origin of the food products within seconds. Governing bodies like the food safety authority can take part in the frameworks of blockchain traceability solutions to continuously monitor the events in food/agricultural supply chains. With the support of smart contracts, they can regulate the entire supply chain by tracking the performance of members and imposing penalties on violating the requirements. In short, blockchain traceability solutions can make food/agricultural supply chains sustainable, resilient and efficient.

2.2 Pharmaceutical supply chain

Hasan, AlHadhrami, AlDhaheri, Salah, & Jayaraman (2019) demonstrated an Ethereum based traceability solution to track and trace the events in a pharmaceutical supply chain, which consists of a single sender, single receiver and an IoT based container as participants. The IoT based container can capture the information about parameters like temperature, pressure, vibrations, location, humidity, etc. and the data gathered will be processed with Raspberry Pi 3 hardware. Once a contract clause is violated, the processing unit will call a function within the smart contract and corresponding information will get broadcasted to the entire blockchain network. With this feature, it is possible to track the status of a pharmaceutical product in transit. In order to check the feasibility of the designed system, a vaccine supply chain was considered in the work.

Modum.io, a Swiss based start-up firm applied blockchain smart contract in the pharmaceutical supply chain to continuously monitor the temperature during transit by incorporating sensors and smart contract (Bocek, Rodrigues, Strasser, & Stiller, 2017). This system mainly measures temperature and records it into an Ethereum blockchain. A track and trace number is needed for each container. Sender can initiate the temperature measurement with an android smartphone. The receiver can get the whole history of the product journey just by scanning a QR code. Since the blockchain ledger is tamper proof, no one can change the data and thus the receiver can confidently ensure that the products are in good condition or not. An application prototype has developed as part of the work particularly by considering a distribution network with a supplier, wholesaler and warehouse. Archa, Alangot, and Achuthan (2018) proposed a traceability solution for the pharmaceutical supply chain to tackle fraud in the distribution stage. In the proposed architecture, an IoT framework known as Global Data Plane (GDP) was integrated with blockchain technology to perform tracking and tracing. During distribution, each of the products will have a unique hash representing a product state that can be tracked, but cannot be replicated. When one entity transfers a set of drugs to another, the transaction details are sent to the controller. The controller in turn stores the details onto a private blockchain.

Haq & Muselemu Esuka (2018) published literature on blockchain technology in the pharmaceutical industry to prevent counterfeit drugs. This work is all about the development of a mobile application which can track the journey of drug items from the manufacturing plant to the pharmacy. Every time the ownership of a product changes, a new transaction will be pushed to blockchain. In this way, by storing the history of a product in blockchain, one can easily trace its origin and other milestones. The proposed system can be used in pharmaceutical supply chains to track the drugs from its manufacturing phase till the final delivery. After the usage of a drug, its effect on patient will be recorded to a database for future statistics.

Interestingly, the blockchain traceability solutions proposed for pharmaceutical supply chains function almost in a similar way with slight differences in the methodology or technology incorporated. They all track the physical movements of medicines and monitor the quality and authenticity. Apart from these, blockchain traceability solutions have incredible applications in this area. For instance, the expiry date of each brand and batch of medicines can be automatically notified to the supply chain members. Blockchain traceability solutions have wide scope in pharmaceutical supply chains during pandemic situations. Consortium blockchain network consisting of hospitals, manufacturing companies and government bodies can be used for monitoring the demand and supply of essential medicines during emergencies.

2.3 Courier Express Parcel (CEP) supply chain

Blockchain has great opportunities in Courier Express Parcel (CEP) supply chains. Helo & Hao (2019) reported the possibilities of blockchain in operations & supply chain, and demonstrated a novel system for parcel tracking named Blockchain-based Logistics Monitoring System (BLMS). The functionality of the system enables customers, logistic operators and all other participants to track and trace their parcel packages within the ecosystem. Ethereum blockchain network is selected for implementation and testing of the developed system. As an extension to the framework proposed here, CEP sector can further incorporate blockchain for managing customer returns. But, blockchain frameworks for reverse supply chains are absent in the literature.

2.4 Luxury supply chain

Blockchain-based traceability solutions have applications in luxury supply chains. Choi (2019) explained the benefits in trading jewellery items through Blockchain Technology Supported (BTS) platforms such as Everledger. Certification and authorization of luxury products such as diamonds using BTS platforms is beneficial for manufacturers as well as customers. In retail shops, salespeople need to present the details of items to the customers and it consumes a lot of time. Again, the proof of purity provided to the customers will be mostly paper based which can be easily manipulated. Retail trading of high value jewellery items through BTS can eliminate all these issues. Information of jewellery items added to the blockchain will remain permanently as immutable. End customers of luxury supply chains will be highly concerned about the genuineness and purity of the products.

2.5 Consumer electronics supply chain

The Consumer Electronics (CE) industry is a pool of companies, which work on designing and manufacturing of products like television, laptops, smartphones, etc. By addressing the issue of counterfeiting, Lee & Pilkington (2017) reported the scope of blockchain technology in the CE industry. As far as CE industry is concerned, transfer of ownership of items is an important process. This is to be thoroughly monitored to avoid the entry of counterfeit or duplicate products into the market.

2.6 Manufacturing supply chain

For the first time, Westerkamp, Victor, & Küpper (2019) presented a blockchain-based solution for tracing manufactured products and its parts/ingredients. The system was capable to track and trace various input items essentially required for manufacturing a product and their transformation during the manufacturing process. Suppliers, producers, logistics providers, certifier and consumers are the major actors in the designed system. In order to keep the connection between a product and its part, the idea of token receipt is incorporated with the system. A prototype implementation of the concept was done on Ethereum blockchain using smart contracts.

2.7 Automobile supply chain

Miehle, Henze, Seitz, Luckow, & Bruegge (2019) presented PartChain, a decentralized application for the automobile industry to ensure the traceability of automobile parts which are manufactured at various regions of the world and distributed via global supply chains. Original Equipment Manufacturer (OEM), suppliers and logistic service providers are the major participants of this supply chain. Though much effort is needed for the implementation, this application will facilitate the option to trace the defective parts and to avoid consequences without calling back the entire batch of sold out vehicles. This application can also eliminate the counterfeit parts. Business logics within the supply chain were incorporated with smart contracts. While PartChain is proposed for automobile supply chains, the same solution can be applied to any product manufactured with a large number of parts and its supply chains.

2.8 Textile supply chain

Agrawal, Sharma, and Kumar (2018) introduced a blockchain-based traceability solution for the textile industry. Proposed concept considers a use case in the textile industry in which the participating entities are cotton producer, manufacturer, wholesaler, distributor, customer, registrar and auditor. Blockchain traceability concept presented in this work can drastically improve visibility because customers, retailers and auditors can trace the history of the product. Such a traceability solution can increase the confidence of customers in buying the textile products.

2.9 Wood supply chain

In a recent study, Figorilli et al. (2018) introduced an information sharing system via RFID technology with blockchain to track the journey of precious wood along the whole supply chain and to trace it back in order to ensure the quality and authenticity. Journey of the timber throughout the supply chain until it reaches the customer side in the form of end products, was simulated. Further, the proposed blockchain architecture is implemented as a prototype in the simulated scenario. To perform the implementation, Microsoft Azure Blockchain Workbench was used.

2.10 Dangerous goods supply chain

Supply chains of dangerous goods (for example, explosives) are to be treated in a much secured way. Advanced care is needed while transporting dangerous goods. Imeri & Khadraoui (2018) proposed a novel blockchain-based solution to track and trace the dangerous goods while it is in transit. With this, all the stakeholders involved in the supply chain of dangerous goods can get the relevant information. Manufacturer of dangerous goods creates the smart contract with all the fundamental details of the goods to be transported. This information will be accessible to all the peers or network participants including regulatory authorities. In case of an emergency, authorities can take immediate actions and instantly trace the causes by investigating the history of events. In this way, transparency created by blockchain in the dangerous good supply chain helps to manage hazardous situations. Similar kinds of concepts can be experimented in the supply chain of weapons as well. Military can make use of such solutions to keep tracking the availability of weapons at different locations.

2.11 Others

originChain is a blockchain-based traceability system for ensuring the traceability of imported items (Xu et al., 2019). As a pilot study, originChain has been tested in the real company environment. originChain is a multi-party system and other organizations can use its traceability service. All the parties won't be financially capable to set up their own traceability systems. They can depend on these kinds of services facilitated by third party organizations. Dasaklis & Casino (2019) explained a novel concept of vendor managed inventory (VMI) system incorporated with blockchain traceability. According to the proposed system, the vendor will continuously monitor the inventory details added by the retailer into the blockchain and create smart contract by adding the details of the products to be delivered with appropriate specifications. The retailer should agree on this smart contract to get the shipment released. Vendor will monitor the status of the shipment until it reaches the retailer side. A blockchain-based vendor managed inventory system can be implemented between any two actors in a supply chain. Di Ciccio et al. (2018) recently presented an application of blockchain in inter-organizational business processes to ensure traceability. Information evolved in a business process scenario can be added to the blockchain and these instances can be traced to make use of it. Most of the business environments are highly decentralized and blockchain-based traceability solutions can create collaborative environments for better performance. These cases showcase the potential of blockchain-based traceability solutions in managing the internal activities of a supply chain. Also, they exhibit the role of blockchain traceability in offering operations transparency.

Table 2 encapsulates the content of the important literature reviewed in this section, and infer certain key points. Details about the specific methods and tools devised for enabling traceability in each of the use-cases are briefly pointed out in the table.

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Table 2: Summary of blockchain-based traceability solutions

Sl. No.	Authors	Area (Product/ Service)	Distribution network design	Purpose	Method/tools used for traceability
1	Tian (2016)	Food supply chain (Fresh fruit, vegetable and meat)	Retail storage with customer pick-up	To ensure food safety and quality	RFID tags
2	Biswas et al. (2017)	Food supply chain (Wine)	Retail storage with customer pick-up	To prevent counterfeiting	Unique ID number
3	Bocek et al. (2017)	Pharmaceutical supply chain (Medical products)	Distributor storage with carrier delivery	To prevent substandard medicines	Smart contract, QR code, IoT sensors and smart devices with Bluetooth
4	Lee & Pilkington (2017)	Consumer Electronics (All sorts of electronics goods)	Retail storage with customer pick-up	To prevent counterfeiting	Not clearly mentioned
5	Tian (2017)	Food supply chain (All sorts of food items)	Retail storage with customer pick-up	Rebuild public confidence in the food supply chain using HACCP	IoT devices, RFID tags, smart contract, HACCP
6	Agrawal et al. (2018)	Textile supply chain (Textile Products)	Retail storage with customer pick-up	For better customer experience	Unique identity (barcodes, serial numbers and digital tags), IoT, smart contract
7	Archa et al. (2018)	Pharmaceutical supply chain (Drug)	Distributor storage with carrier delivery	To prevent counterfeiting	GDP IoT framework, RFID tags, sensors (RFID reader, barcode scanner, smartphones)
8	Caro et al. (2018)	Food supply chain (Agro-food products)	Retail storage with customer pick-up	To prevent food safety hazards	Traditional software like ERP, Customer Relationship Management (CRM), smart

					contract, GPS, IoT devices, Smart tags
9	Di Ciccio et al. (2018)	Pharmaceutical (Inter-organizational business process management)	Retail storage with customer pick-up	To trace process instances of execution	Smart contract, QR code
10	Figorilli et al. (2018)	Forestry (Wood)	Retail storage with customer pick-up	To prevent products of illegal origin	Specially designed mobile application, RFID, QR code and Near Field Communication (NFC) tags, sensor devices
11	Haq & Muselemu Esuka (2018)	Pharmaceutical (Drug)	Retail storage with customer pick-up	To avoid counterfeiting of medicines	Unique hash ID, specially designed mobile application
12	Hirbli (2018)	Agricultural supply chain (Palm oil)	Retail storage with customer pick-up	For better customer experience	Geospatial imagery classification, IoT technologies, and smart tags
13	Imeri & Khadraoui (2018)	Dangerous goods supply chain (Any sorts of authorized dangerous goods)	Retail storage with customer pick-up	For more secure transportation	Smart contract, smartphone for location data
14	Kamath (2018)	Food supply chain (Pork, Mango)	Retail storage with customer pick-up	For better customer experience	IoT sensors, GPS, Geographic Information Systems (GIS), QR code, GTIN
15	Lin et al. (2018)	Food supply chain (Agro-food)	Retail storage with customer pick-up	To tackle the food safety issues	2D bar code, ERP, LPWAN IoT system
16	Rejeb (2018)	Food supply chain (Halal meat)	Retail storage with customer pick-up	Higher transparency and assurance of halal compliance	HACCP, IoT, RFID tags and readers, 2D barcode

17	Tseng et al. (2018)	Pharmaceutical (Drug)	Retail storage with customer pick-up	To prevent counterfeiting	QR code, smart contract, smart devices
18	Visser & Hanich (2018)	Food supply chain (Tuna fish)	Retail storage with customer pick-up	To prevent illegal and unregulated fishing in the tuna industry	Reusable RFID and QR code tags, scanning devices
19	Chandra et al. (2019)	Food supply chain (Halal food items)	Retail storage with customer pick-up	Higher transparency and assurance of halal compliance	IoT devices, smart contract, QR code, RFID
20	Choi (2019)	Luxury supply chains (Diamond)	Retail storage with customer pick-up	For authentication and certification	Digital thumb-print system
21	Dasaklis & Casino (2019)	Inventory management-Vendor Management Inventory (VMI)	Not clearly mentioned	For governing the relationship between the vendor and the buyer	Smart contract, IPFS, IoT
22	Hasan et al. (2019)	Pharmaceutical (Vaccine)	Manufacturer storage with direct shipping	To avoid counterfeiting of medicines	GPS, smart contract, IoT devices
23	Helo & Hao (2019)	Courier express parcel (Parcel tracking)	Distributor storage with last-mile delivery	For better customer experience	GPS, RFID, Sensors, barcode, smart contract
24	Miehle et al. (2019)	Automobile supply chain (Auto mobile parts)	Distributor storage with last-mile delivery	Identification of defective parts and detection of counterfeit parts	Specially designed mobile application
25	Salah et al. (2019)	Agro-food (Soybean)	Retail storage with customer pick-up	Better customer experience through ability to trace origin of product	IPFS, GTIN, smart contract, GPS, IoT
26	Westerkamp et al. (2019)	Manufacturing (Manufactured goods, including their components)	Retail storage with customer pick-up	To provide better customer experience	Tokenization, smart contract

27	Xu et al. (2019)	Global trading/Procurement (Traceability service)	Not clearly mentioned	To check the originality and authenticity of the imported products.	Smart contract

2.12 More real-world use-cases

Apart from the few real-world pilot initiatives mentioned, many enterprises, individually and collaboratively, have started real world studies to explore the potential of blockchain-based traceability in creating transparency. T-Mining, a start-up firm in Antwerp collaborated with Port of Antwerp as part of the programme called 'Smart Port' and developed blockchain-based solutions for the container release operation. Maersk and IBM jointly developed a trading platform called 'TradeLens' for the maritime shipping industry. It helps parties to exchange relevant information without any delay. Similarly, Accenture, a multinational professional services company associated with firms like APL, Kuehne + Nagel, and AB InBev to test blockchain-based solutions for the maritime industry. United Parcel Service has framed a blockchain-based traceability system to track and trace their packages. Leading French based retailer Carrefour has launched a blockchain-based food traceability system. This system captures all the relevant information about the supply chain actors and their activities so that customers can trace them just by scanning a QR code. 'MediLedger', 'SAP Advanced Track and Trace' are two important pilot initiatives aiming for transparency in pharmaceutical supply chains (Chang, Iakovou, & Shi, 2020).

Tracr, Provenance Proof and TrustChain are some of the important blockchain based traceability initiatives in the area of luxury supply chains (Cartier, Saleem, & Krzemnicki, 2018). These initiatives serve customers in satisfying their demand for revealing the source information of jewellery items. Also, they help to identify and disclose treated and synthetic jewellery materials throughout the supply chains. Everledger, a firm headquartered at London, United Kingdom has associated with famous wine maker Maureen Downey for developing a blockchain-based provenance tracking system to prevent the theft of fine wine (Finextra, 2016). Abu Dhabi National Oil Company (the state-owned oil company of the United Arab Emirates) has collaborated with IBM for a pilot project and developed a blockchain-based supply chain traceability system to track oil from its origin to customers (Yafimava, 2019). Provenance united with Martine Jarlgaard for a blockchain oriented traceability solution to bring more transparency in the fashion industry. They aim to track every aspect of a garment's life through all the development phases (Skender & Zaninović, 2020). As part of a study on the influence of blockchain on future supply chains, Wang, Hugh Han, & Beynon-Davies (2019) have detailed several other real-world pilot studies initiated by reputed organizations.

This section extensively highlighted the applications of blockchain-based traceability solutions in various supply chains. Blockchain-based traceability solutions have scope in a wide range of supply chains; irrespective of the types of distribution network design. Next section practically demonstrates how these solutions bring transparency in a supply chain.

3. Penalty-Based Blockchain Traceability Solution for Cold Chain Management: A Proof of Concept (PoC)

3.1 Background

Substandard and counterfeit medicines are harmful to the general public. Substandard medicines are those which failed in meeting the required specifications whereas latter are fake items. Both these categories can create potentially dangerous health issues among the consumers. Medicines can get substandard due to manufacturing defects, improper storage and inefficient transportation or because of the combinations of these factors (Johnston & Holt, 2013). According to the definition proposed by the World Health Organization at Seventieth World Health Assembly, substandard, also called "out of specification" products, these are authorized medical products that fail to meet either their quality standards or specifications, or both (World Health Organization, n.d.). Manufacturers and other government agencies are responsible for periodically reviewing and monitoring these sub-standard products. The issues due to the entry of substandard medicines in the market can be eliminated by improving the transparency in supply chains.

Most of the pharmaceutical supply chains are cold chains. A cold chain is a kind of supply chain where temperature of the products should be maintained in a specified range throughout the journey (Hulea, Roşu, Miron, & Aştilean, 2018). Traditional cold chain is inherently vulnerable to many critical points at various stages. After the production, till the dispatching of medicines the temperature and humidity should be maintained in the storage areas as per the specifications. While the medicine is in transit, the refrigerated carrier vehicle should be properly equipped to meet the medicine specification. Again, at the time when it enters into an intermediate warehouse facility, there also temperature and humidity control is needed. Traditional cold chains fail in monitoring these critical points and thus it is very difficult to trace the party who violated the specifications. None of these critical points are visible to the end customers and they are forced to buy the medicines even if it is substandard. Combination of blockchain smart contract and IoT is a promising solution for this. Following subsections covers the details about the cold chain scenario considered, description of the proposed blockchain-IoT framework, exposition of the development of proof of concept and overview of the smart contract.

3.2 Cold chain scenario considered

For the purpose of this work the following scenario is considered.

3.2.1 Members

Cold chain scenario considered in this work consists of five members which are manufacturer or owner, buyer, carrier 1, carrier 2 and warehouse. Manufacturer manufactures a particular medicine. This is to be reached at the buyer's spot as per the agreement. Carrier 1 is responsible for transporting medicine from the manufacturing plant to an intermediate warehouse. Similarly, carrier 2 transports it from warehouse to the final destination. Warehouse is a temporary storage facility. Carriers and the warehouse are managed by independent third parties. Owner and other participants are equally responsible for monitoring the flow of medicines till it reaches the buyer's facility. Beyond that point, they can only indicate to other distributors and users about how to store and handle the products based on the compliance rules and conditions. Here, we assume that the manufacturer is trustworthy and always keeps medicines in the plant, within the range of specifications. Figure 1 shows the structure of the cold chain considered.

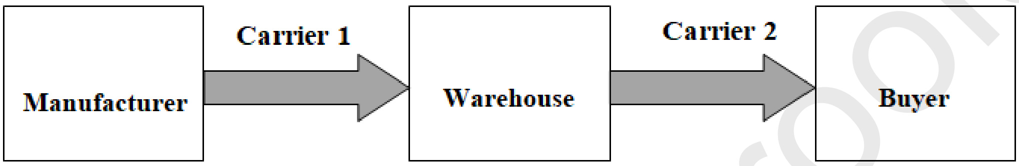


Figure 1: Structure of the Cold Chain

3.2.2 Quantity and quality of the shipment

A single shipment can transport 1000 boxes of medicine weighing 5 kg each. To keep the quality of the medicine, the temperature and humidity are to be maintained in a specific range. Here, the specified range of temperature is assumed to be 4°C to 10°C and the specified range of humidity is 10% to 25%. A tolerance limit of ±2 is provided for flexibility in the temperature and humidity range. That is, if the temperature goes to a lower level of 2°C from 4°C or if the temperature increases to 12°C from 10°C, then also the product is acceptable with a penalty.

3.2.3 Payment and penalty

After the successful delivery of the shipment, the buyer will pay the full amount to the owner and it is assumed that all the other parties will get paid by the owner. Penalty point is the moment at which temperature or humidity goes out of the specified range. If the parameters are not within the specified range; but within the tolerance limit, a penalty will be charged against the party holding the shipment at that time. Penalty will be based on the number of penalty points made by a party. For example, assume that the temperature exceeds the specified maximum temperature and it remains within the tolerance limit while the shipment is in transit from warehouse to the final destination. In this case, carrier 2 will be responsible for it and penalty will be charged against the firm managing carrier 2. Number of penalty points allowed to a party is limited and the buyer can terminate the contract if the penalty point exceeds this limit. In our case, allowable number of penalty points is three. Again, if temperature or humidity exceeds the tolerance limit buyer will get the authority to terminate the contract and the respective party (ies) responsible for contract breach will bear the loss. Once the shipment is rejected by the buyer under the above-mentioned conditions, the shipment will get returned to the owner.

3.3 IoT-blockchain framework for preventing substandard cold chain medicines

Cold chain network considered in this paper is a closed one consisting of a limited number of known participants. For this scenario, private blockchain will be feasible. All the supply chain actors have equal responsibility for monitoring the quality of medicines till it reaches the final destination. An IoT device capable of measuring temperature and humidity is attached with the shipment. These devices will facilitate real time monitoring of the environment in which medicine is kept. Data gathered from this device will get appended to the blockchain network then and there. If the products are out of compliance, the network will treat it as a penalty point. Figure 2 represents the proposed framework.

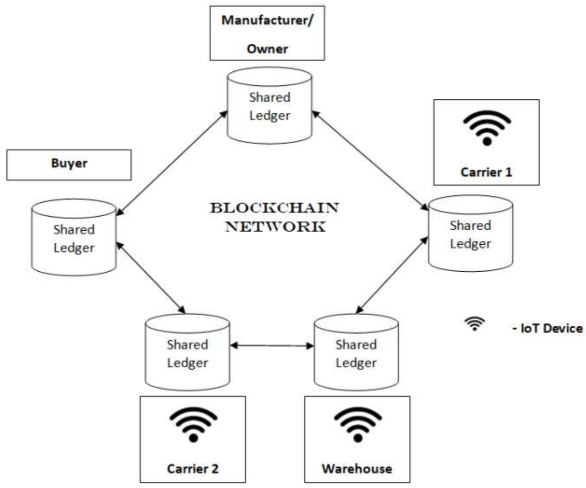


Figure 2: Proposed Framework

3.4 Proof of concept

PoC is an effective way to realize ideas basically for understanding their feasibility. PoC is capable of demonstrating a method or concept in a complete or incomplete form. PoC can be used to demonstrate the feasibility and practical potential of any blockchain project in any fields such as energy, communication, services, insurance and healthcare. Here, an application prototype is developed to perform the PoC. A real IoT device is not incorporated in this work and instead, the role of adding temperature and humidity details into the blockchain is done manually by the supply chain actors themselves. Following assumptions were considered for the PoC.

(1) All boxes in the shipment are assumed to have the same temperature and humidity.

(2) An IoT device is attached with the shipment and it monitors the entire boxes of medicine.

3.4.1 Development of application prototype

Microsoft Azure Blockchain Workbench is a cloud platform for the development of blockchain-based application prototypes. It can eliminate the difficulties in creating hardware nodes by dynamically facilitating all the requirements for making decentralized applications. Azure Blockchain Workbench provides a Proof of Authority (PoA) Ethereum network, off-chain Structured Query Language (SQL) storage, message routing, and sample user interface. PoA is a consensus protocol which is more suitable for permissioned networks where all participants involved in the consensus mechanism are known. PoA doesn't need any mining as in Proof of Work (PoW) consensus of Bitcoin blockchain and consumes less resources. Figorilli et al. (2018) has explained the benefits of Microsoft Azure Blockchain Workbench as a cloud platform to instantly create blockchain applications. Since the cold chain scenario considered in this work is more or less similar to a private network, Azure Blockchain Workbench is opted to develop the application prototype. To create an application in Microsoft Azure two files are required; a JSON configuration file and a Solidity smart contract code file (Wang et al., 2018).

3.4.2 Overview of the smart contract

In this work, the smart contract for the cold chain is developed using Solidity language. The business process along with the transportation details discussed in Section 3.2 is coded as a smart contract. The contract deals with eight main stages. As the first stage, the medicine manufacturer has to initiate the contract. Details such as description of the medicine, temperature & humidity range, price, quantity, etc. is to be appended by the manufacturer into the contract. Manufacturer initiates the blockchain by deploying the smart contract into the first block. Smart contract contains the terms and conditions for all the participating members. Manufacturer can add participants into the network. Acceptance of terms and conditions appended in the smart contract by the parties is necessary to avoid disputes in future. Details about the acceptance of smart contract by each party will be added into the blockchain. Once all members agree to the smart contract terms and conditions, the contract is said to be active. Algorithm 1 describes the process for signing the terms and conditions in the contract. While the contract state becomes 'Contract Active', the manufacturer can hand over the shipment to carrier 1. Algorithm 2 shows the process of transferring the responsibility of shipment to carrier 1. Once the responsibility is transferred, the state of the contract is 'In Transit 1'. The IoT device attached to the shipment will track the temperature and humidity details in real time and that information will be added to the blockchain then and there till the shipment reaches the buyer's plant. Processes to be executed during 'In Transit 1' and 'In Storage Facility' states are given in Algorithm 3(A) and 3(B). 'In Storage Facility' means that the shipment reached the warehouse. Based on the information from IoT device penalty is determined as per the Algorithm 4. Warehouse can change the contract state to 'In Transit 2' by transferring the shipment responsibility to carrier 2. Carrier 2 has to deliver the shipment to the buyer. Once the shipment is reached, the contract state will become 'Shipment Received by Buyer'. Owner can either accept or terminate the shipment after verifying the details captured by the IoT device in the blockchain. Shipment acceptance and payment procedure are according to Algorithm 5. Figure 3 shows the state transition diagram which represents the workflow in the smart contract. Finally, the owner can complete the contract by acknowledging the payment made by the buyer.

ALGORITHM 1: SIGNING TERMS AND CONDITIONS IN THE CONTRACT

```
Input: Weight, Number of units, Tolerance limits, e and E
(e is member role and E is set of all members participating in contract)
if contract state = Pending Initiation and Acceptance of Contract
    for each e ∈ E
        Sign the contract
        Create a block by stating that contract has been accepted by all parties
        Change contract state to 'Contract Active'
    end
else
    Revert the contract and show an error
end
```

ALGORITHM 2: INITIATING TRANSFER RESPONSIBILITY OF PRODUCT

```
Input: e
if contract state = Contract Active
    for e = Owner
        Transfer the shipment to Carrier1
        Create a block about the successful transfer of shipment
```

```
                Change contract state to 'In Transit 1'
        end
else
        Revert the contract and show an error
end
```

ALGORITHM 3(A): SHIPPING*

```
Input: e
if contract state = In Transit 1
        for e = Carrier 1
                Transport the shipment from owner to the warehouse
                Keep the temperature and humidity within the specified range
                Change contract state to 'In Storage Facility'
                if (penalty points > 3 || Temperature or humidity crosses the tolerance limit)
                        for e = Buyer
                                Terminate the contract
                                Respective member should bear the incurred loss
                        end
                end
        end
else
        Revert the contract and show an error
end
```

*Same logic can be applied for the contract state 'In Transit 2'

ALGORITHM 3(B): SHIPPING

```
Input: e
If contract state = In Storage Facility
        for e = Warehouse
                Store the shipment under required specifications
                Change contract state to 'In Transit 2'
                if (penalty points > 3 || Temperature or humidity crosses the tolerance limit)
                        for e = Buyer
                                Terminate the contract
                                Respective member should bear the incurred loss
                        end
                end
        end
else
        Revert the contract and show an error
end
```

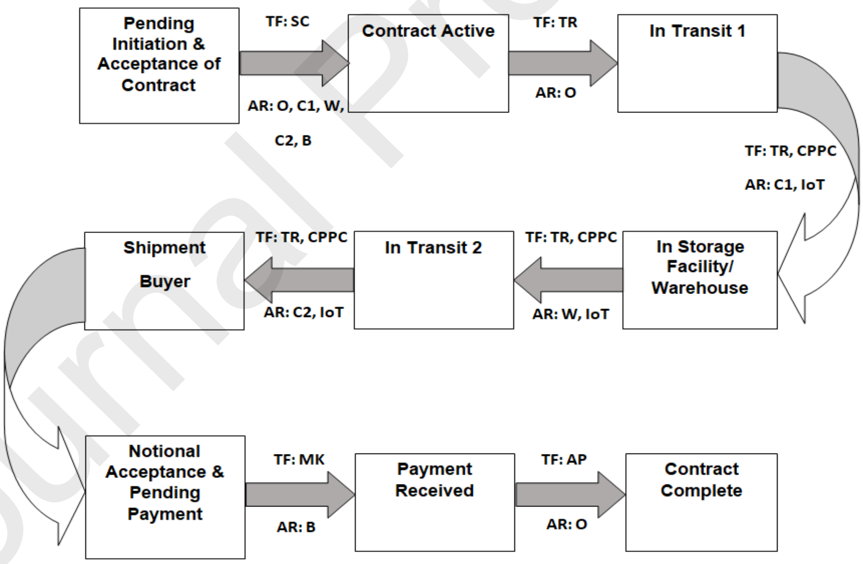
ALGORITHM 4: MONITORING THE REQUIRED SPECIFIC CONDITIONS

```
Input: e
if contract state = In Transit 1 || In Storage Facility || In Transit 2
        for e= Device
                Calculate the number of penalty points
                Change the current contract state into the next
        end
else
```

```
7.      Revert the contract and show an error
8. end
```

ALGORITHM 5: SHIPMENT RECEIVED AND PAYMENT PROCEDURE INITIATED

```
Input: e
1. if contract state = Shipment received by Buyer
2.      for e = Buyer
3.              Acknowledge that the shipment has been received
4.              Verify all the specifications of the shipment
5.              Initiate the payment procedure to owner
6.              Change contract state to Payment Received
7.      end
8.      if contract state = Payment Received
9.              for e = Owner
10                      Acknowledge that the payment has been done
11.                     Sign off the contract, i.e., contract is complete
12.             end
13.     end
14.     else
15.             Revert the contract and show an error
16.     end
17. else
18.     Revert the contract and show an error
19. end
```



Legend: TF - transition function, SC- sign contract, TR - transfer responsibility, CPPC- calculate penalty points and characteristics, AS - accept shipment, MK - make payment and AK- acknowledge payment. AR - application role, O – manufacturer/owner, C1 – carrier 1, C2 – carrier 2, W – warehouse, B – buyer

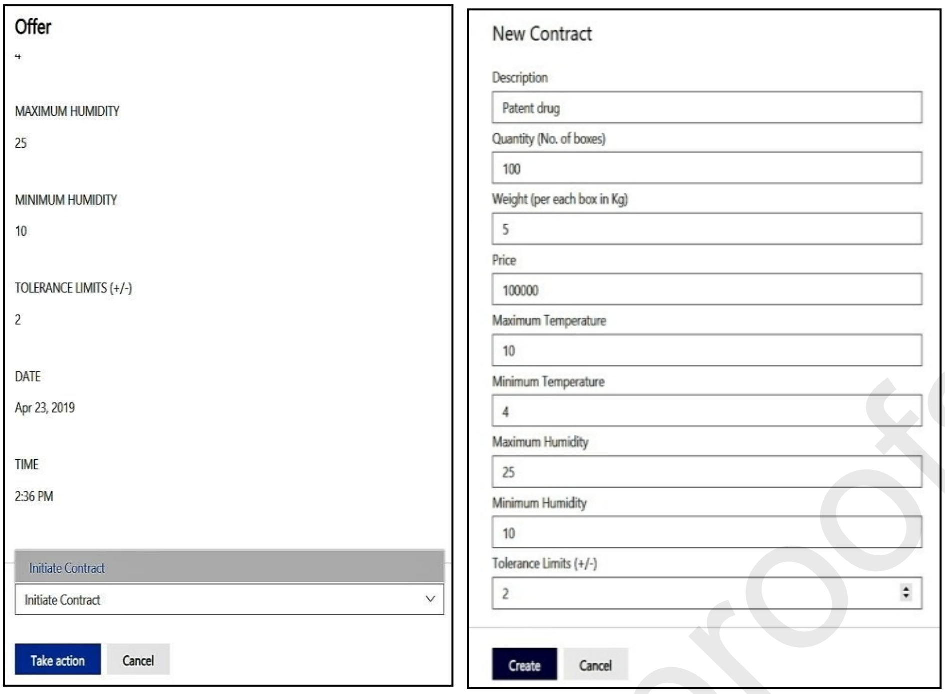
Figure 3: State transition diagram

In Figure 3, TF represents transition functions. Different transition functions involved in the workflow are SC - sign contract, TR - transfer responsibility, CPPC - calculate penalty points and characteristics, AS - accept shipment, MK - make payment and AK - acknowledge payment. AR stands for application roles. As mentioned in Section 3.2.1, manufacturer/owner (O), carrier 1 (C1), carrier 2 (C2), warehouse (W), buyer (B) and the IoT device are the members in the cold chain scenario. Description for the various contract states are given in Table 3.

Table 3: Descrption of states

State	Description
Pending Initiation & Acceptance of Contract	Contract has been created and waiting for initiation & acceptance from all the parties
Contract Active	All parties have signed the contract (initiated by the owner/manufacturer) and agreed to all the terms and conditions
In Transit 1	Owner has handed over the drug to carrier 1 and it is in transit to warehouse
In Storage facility/Warehouse	Warehouse has received the medicines from carrier 1 and it is stored in the storage facility. Waiting for pick-up by carrier 2
In Transit 2	Carrier 2 has collected the medicine from warehouse and it is currently in transit to the buyer's facility
Shipment Received by Buyer	Buyer has received the shipment from carrier 2
Notional Acceptance and Pending Payment	Waiting for payment from buyer and acceptance from owner
Payment Received	Buyer has completed the payment and waiting for further confirmation from owner
Contract Complete	Owner has acknowledged the payment and completed the contract
Terminated	Failed to meet the terms and conditions of smart contract

Once the number of penalty points cross the accepted limit, the network will treat the product as substandard as per the agreed terms & conditions and then the state of contract will become 'Terminated'. Blockchain ledger is immutable, and no one can change the data once it has been added. With the traceability offered by blockchain technology, it will be easy to trace the party who violated the agreement and caused the contract termination. As per the smart contract signed, the party (ies) responsible for the contract termination has to bear penalty. This mechanism can significantly reduce the presence of substandard cold chain medicines in the market. Figures 4-7 show the screenshots from the developed application prototype.



a) Creating a new smart contract　　　b) Initiating a smart contract

Figure 4: Windows for creating and initiating a smart contract

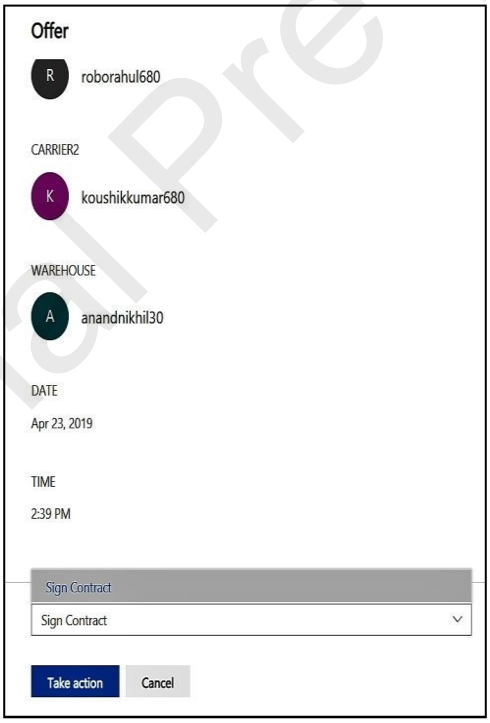
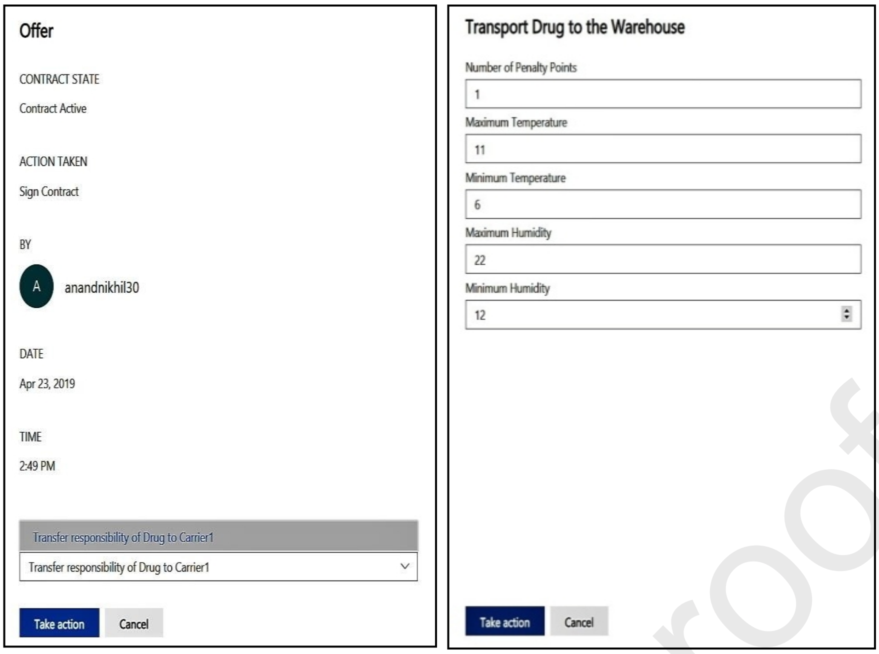
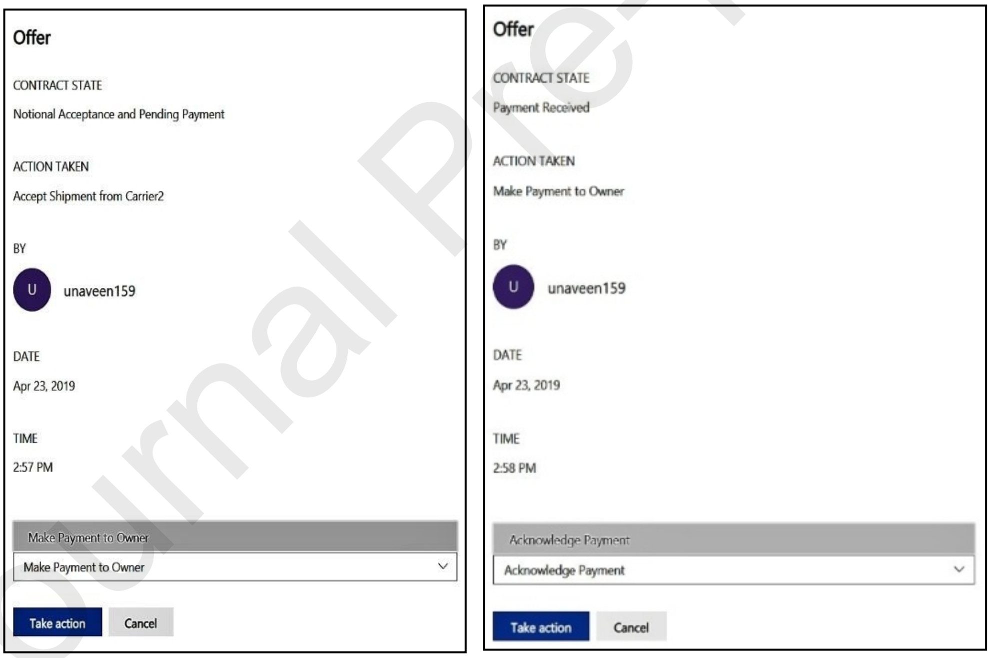


Figure 5: Window for signing a smart contract



a) Transfer of responsibility to Carrier 1   b) IoT inputs (penalty points, maximum temperature, minimum temperature, etc.)

Figure 6: Windows showing responsibility transfer to Carrier 1 and IoT input



a) Making the payment   (b) Payment acknowledgement

Figure 7: Windows for making the payment and payment acknowledgement

Readers can access the configuration and Solidity smart contract code files of the penalty-based blockchain traceability system from the link given in the Appendix.

4. Discussions

Articles in the literature reviewed in Section 2 derive several valuable conclusions. Most importantly, blockchain traceability solutions have a wide range of applications in different supply chains irrespective of the products and services they handle. This trend is relatively high in food supply chains and pharmaceutical supply chains. Notably, a good percentage of traceability solutions are proposed for food supply chains. In general, supply chains prefer traceability solutions mostly for elimination of counterfeit products, monitoring of safety and quality, management of business processes, etc. Interestingly, the distribution network designs discussed in most of the literature are retail storage with customer pick-up. This reveals the fact that blockchain-based traceability solutions have wide applications in supply chains with larger numbers of participants. In reference to Table 1, order visibility is trivial in retail storage with customer pick-up type distribution network, in the case of in-store orders. On the other side, it will be difficult to achieve the order visibility for online or phone orders. Here, blockchain-based traceability solutions can further enhance the order visibility and thus increase the customers' purchase confidence. Few of the use cases deal with manufacturer storage with direct shipping or drop shipping distribution network. It is very difficult to achieve visibility in this type of network design. Blockchain traceability solutions crack this constraint through instant notifications and an immutable ledger of logs. Irrespective of the type of distribution network designs, blockchain traceability solutions have positive influence on them. From the customer point of view, blockchain traceability solutions enhance their purchase confidence. It can provide better shopping experience through improved order visibility without significant hike in the price. Hence, blockchain-based traceability solutions add value to the products and services through enabling functionalities for trace and track.

Participants in a blockchain network can track the journey of an asset from its origin to destination with the information appended on the blockchain. In order to capture this asset related information (location, properties, etc.), blockchain needs to depend on existing methods (example: IoT, RFID, GPS, etc.). Once the data is available in the blockchain, participants can trace it. Notably, a good number of frameworks presented in Section 2 incorporate IoT or other technologies with blockchain. All these technologies were part of centralized traceability solutions and blockchain is not completely replacing them in any of the use cases. In short, blockchain technology will not supplant the currently available means for traceability, but rather complement them.

Smart contract is a powerful extension to blockchain technology. It automates actions when a given condition is satisfied. Smart contracts further enhance the experience of traceability. They can monitor the quality of physical items; verify the identity of supply chain actors; control the access of members to blockchain and so on. The literature review underscores the fact that traceability solutions framed by combining IoT, smart contracts and blockchain are suitable for complex supply chains involving many stages.

It will be worth noting that blockchain technology has several downsides as well. Most importantly blockchain is unable to detect intentionally corrupted data. For instance, genuineness of the data uploaded by the supply chain actors into the blockchain is always subjective. In the worst case, some actors may upload false data for their own benefits. Blockchain provides no protection against such attempts. Without getting benefits, none of the actors will take the effort in sharing data. Exclusive studies are required for conveying the additional benefits that members can gain while sharing genuine information. Most of the blockchain protocols and consensus mechanisms require huge computation and consume a lot of energy. For instance, Bitcoin blockchain deals with Proof of Work consensus mechanism and it requires a lot of computation power and hardware resources (Mora et al., 2018). This breaks environmental sustainability. As another potential downside, blockchain always requires participants to share at least a certain degree of their information. In business perspective, privacy is equally important as transparency and the majority of the firms won't be ready to share their sensitive information with others.

Blockchain traceability solutions proposed in literature are effective, but its implementation will not be that much easy. Common people like farmers will not be familiar with sophisticated technologies. Again, it will not be feasible for them to buy expensive smart devices to interact with blockchain networks. For convenience, simple user interfaces (UI) have to be developed and the process of data entry is to be made simple. To overcome this, upstream members can facilitate the required training and resources to the downstream members. It will be a great challenge to convince farmers that the overall improvements with the transparency and security offered by blockchains will create benefits and value to their respective roles in the supply chain. While researchers prefer application of IoT devices in the majority of blockchain traceability frameworks, its feasibility remains as a question mark. For instance, the effectiveness of IoT in capturing the details of animals and slaughtering tools in halal food supply chain. While the number of participants exceeds, the practical implementation of blockchain traceability solutions becomes problematic due several challenges.

In order to adopt blockchain applications into an ongoing business process, a severe transformation is needed in the work culture. This transformation will be extremely difficult for large supply chains as they hold many participants. Several articles of the literature highlight the scope of integration of blockchain traceability solutions with existing technologies, for instance, ERP. Recently, Banerjee (2018) has underlined the scope of blockchain based ERP consortiums for better supply chain performance. With this approach, organizations can experiment the feasibility of blockchain technology in their operations without building a system from scratch.

Several organizations have already started real-world pilot studies on the applications of blockchain in supply chain management. As far as these pilot initiatives are concerned, they clearly exhibit the potential of blockchain traceability solutions; but they are not sufficient to prove the capabilities of blockchain. Such efforts can be continued to the next levels as they are essentially required to create more evidence on the feasibility of blockchain technology in various contexts. It is to be noted that downstream members cannot take-up these kinds of research efforts as they are not economically affordable for them. Lack of proper infrastructure facilities will surely be a threat to blockchain traceability solutions, for example, lack of proper internet connectivity while collecting data from the field. Blockchain traceability solutions require genuine information as input, and are quite impossible in the absence of proper internet connectivity. While blockchain traceability systems coupled with other technologies are far better than conventional centralized traceability systems, still they are not perfect. Lack of security at product level is an important limitation of blockchain-based traceability solutions. Traceability markers like IoT, RFID, NFC, etc. are always exposed to attacks. Sometimes these devices themselves or their parts may fail. Intake of corrupted data can create issues in the entire traceability system. Hence, thorough testing is necessary for devices before the integration with blockchain. Regular inspections and maintenance are also important.

It is a fact that integration of blockchain traceability solutions essentially requires considerable investment and this will increase the total cost in the supply chain. There is no meaning in designing a framework that extremely amplifies the product price. On the other side, opportunity for traceability will definitely increase the value of products and services. Customers may be ready to pay more if they can know the provenance of the products. Customers of high value products like jewellery products or branded wine will be always willing to pay more on getting more services. But this response cannot be expected from normal customers who purchase vegetables, fruits and groceries on a daily basis. Hence, while integrating blockchain traceability solutions into a supply chain, the nature of the end customers should be seriously considered. Approaches like reuse of smart tags can be considered for reducing the cost of implementation of blockchain traceability solutions. This is a topic for further research.

Majority of the use cases reported in literature are conceptual in nature. This is due to the novelty of blockchain technology. Their viability in real world situations is yet to be analyzed. Literature lack clear evidence on the benefits of blockchain traceability solutions in supply chain management. Research is further needed for the empirical evidence on the benefits of these traceability solutions. Large scale companies can conduct more intensive experimental investigations in this aspect as part of their research and development activities. It may be observed that a good number of traceability solutions reported in literature are on Ethereum based blockchains. This may be due to the simplicity in setting up the development environment and good compatibility with smart contracts. Also, community support is relatively easy for Ethereum.

Although blockchain pilot studies initiated by enterprises underline the possibilities of blockchain traceability in elevating the supply chain transparency, it is a fact that the complete potential of blockchain is yet not completely fulfilled. Several reasons are behind this. One of the most important facts is lack of scalability. Compared to other popular transactions networks, the transaction rate of blockchain systems is extremely low, which is not at all favorable for many applications. Big enterprises deal with a large number of suppliers and clients, and they may have thousands of transactions per second. Current level of scalability offered by blockchain will not be sufficient for this. It is true that private blockchains can manage the scalability issues up to a limit as it deals with only trusted parties. Consensus mechanisms like PoW are technically complex and cause delay in transactions. In the near future, ongoing research works around lightning networks (Poon & Dryja, 2016) and sharding (Yu et al., 2020) may bring a permanent solution for this. Again, it is obvious that firms will not be ready to replace their current data management systems, which are currently well established in terms of functionality. In such a context, blockchain-based systems should be flexible enough to integrate with the current systems, in the form of a pluggable module. Definitely this will prompt the firms to try blockchain solutions at least for checking its feasibility. Absence of a standard blockchain protocol is another issue. A wide range of blockchain protocols is already available and many are under development. This creates interoperability issues which is quite unfair for a supply chain network dealing with large organizations, which are geographically decentralized. Trained workforce is necessary for the design and development of blockchain oriented systems, and unfortunately it is not sufficiently available.

Demonstration presented in Section 3 exhibits how blockchain-based traceability improves the transparency in a supply chain. In the cold chain scenario considered, a private blockchain deployed by the manufacturer captures each and every event. The IoT device attached with the shipment captures the temperature and humidity details in real time and appends to the blockchain ledger with timestamps, which is accessible to everyone in the supply chain. This offers the opportunity to track the journey of medicines right from the beginning till it reaches the buyer. Also, at any point of time, members can trace these digitally recorded events for the purpose of review and analysis. Data captured by a secure IoT device is completely objective in nature. Presence of IoT reduces or eliminates the need of human involvement in capturing the relevant information to be inputted on to the blockchain. User interface of the traceability system is very simple and even parties not having technical knowledge on blockchain can easily interact with it. Integration of a smart contract automates the quality check by closely monitoring the parameters (temperature and humidity) with respect to the specifications. Additionally, conditions programmed in the smart contract will assess the performance of each intermediary in terms of penalty points. Higher the penalty points, poor will be the performance. The logic of penalty points prompts the supply chain actors to safely handle the shipment. The proposed PoC clearly conveys the role of IoT and smart contracts in blockchain-based traceability solutions. As far as a cold chain is concerned, the introduction of such a blockchain-based traceability solution can bring a high level of transparency. Higher transparency helps to identify parties violating the contract clauses and impose penalty over them. This will be helpful for mitigating the entry of sub-standard medicines into the market, which is a severe threat to the public.

5. Conclusions and Scope for Future Work

This paper mainly provides an insight on the capabilities of blockchain-based traceability solutions by reviewing the currently available literature. Application of blockchain-based traceability solutions can create better transparency in supply chains both via tracking and tracing. An overview of the articles reported in the literature reveals that blockchain oriented traceability solutions are gaining popularity in almost all the supply chains. In view of the literature considered in this work, as of now, the majority of these applications are in food and pharmaceutical supply chains. Integration of IoT and smart contract is drastically uplifting the applications of blockchain. Remarkably, blockchain cannot completely eliminate the existing technologies. In order to demonstrate the potential of blockchain-based traceability in elevating the supply chain transparency, a framework for cold chain management has developed and a proof of concept was performed using Microsoft Azure Blockchain Workbench platform.

Though countless applications are reported in the literature, most of them are conceptual in nature. Real implementations of blockchain traceability solutions are very rare. Research attempts in aiming empirical evidence on the benefits of blockchain-based solutions are in high demand. Small scale experiments can be conducted to quantitatively emphasize the need of blockchains in supply chains. Blockchain technology is still in its infancy and further research is needed for nurturing brand-new traceability applications.

The findings of this study have to be seen in light of two limitations. First, the selection process of literature was not purely systematic. For the overview, this study considered the keywords ‘blockchain’, ‘transparency’, ‘traceability’, ‘trace’, ‘track’, and ‘supply chain’ in different combinations, and focused on the articles reported in the literature since 2016. Second, due to the unavailability of sufficient information, some of the use-cases are not well scrutinized.

Appendix

Link to access the files for replicating the PoC:

https://drive.google.com/file/d/1KD90G2ola8Iy_g0u64dC0OwpByoOXGgI/view?usp=sharing

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Highlights

1. Blockchain-based traceability solutions bring better transparency in supply chain
2. Literature on blockchain-based traceability solutions are mostly conceptual
3. Blockchain cannot supersede the existing technologies, but can complement them
4. Smart contracts make blockchain traceability solutions more effective
5. Blockchain based traceability systems are not free from shortcomings