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Research Article

Revolutionizing Healthcare Supply Chains: The Synergistic Power of IoT and Blockchain

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ABSTRACT

In spite of dramatic advances in healthcare informatics and management, little yet has been done to eliminate supply chain related problems. The product recalls, supply shortage monitoring and management, preventive expiration date management, and counterfeit product detection are essential healthcare supply chain activities that are also deeply affected. Because of the fragmented structure of healthcare supply chains, it is difficult to implement these operations securely, efficiently, globally accessible, and traceably, and are prone for systemic mistakes and redundancies. This can result in patient safety issues as well as negative health outcomes. The conjunction of blockchain technology and Internet of Things (IoT) provides a feasible way to deal with these problems. IoT empowered blockchain solutions provide a safe, decentralised peer to peer ledger for monitoring and tracing products. In this study, there is a study of how the healthcare supply chain faces imminent and significant challenges, and how IoT blockchain technology could help solve these challenges in the present and near future.

Key words: blockchain; counterfeits; expiration; healthcare; Internet of Things (IoT); supply chain

1. Introduction

SCM and related operations represent the second biggest expense category in healthcare (Scalise, 2005; Kowalski, 2009). Prompt delivery and monitoring of such commodities along the supply chain till its usage with patients constitutes very wide range of healthcare supply chain management operations. Research in both the retail and manufacturing arenas has measured the strategic and competitive benefits of well managed supply chains, but healthcare provider organizations have had difficulty attaining these gains in their entirety (Benzidia et al., 2021). Some of the major obstacles towards effective implementation of supply chain management in healthcare, point out McKone-Sweet et al. (2005), include misaligned incentives with for-profit and not-for-profit entities within the supply chain, limited awareness of supply chain issues, potential conflicts amongst group purchasing organisations and the rest of the supply chain partners, inadequate data collection and performance metrics (Doolun et al., 2018). Also, utilisation of different information systems and applications with limited interoperability exacerbates these issues. Knowing dependence on ineffective, manual and improvised product tracking and traceability techniques, it is high time to have solutions based on automation and machine learning (Lamba and Singh, 2016).

Similarly, the healthcare supply chain literature highlights the need for integrated, information technology systems and electronic data interchange systems in order to enhance product visibility and traceability. Ford and Scanlon (2005) argue that supply chain techniques can radically improve quality and cost management in healthcare provisioning. The reengineering of hospital logistics with activity-based costing is proposed by Landry and Philippe (2004), and the complexity of internal supply chain management in hospital systems is studied by Landry and Beaulieu (2013). According to De Vries (2011), there are multiple, and sometimes contradicting, objectives of the healthcare stake holders that significantly drive inventory management decisions. According to Privett and Gonsalvez (2014), the global pharma supply chain is inadequate: there is poor coordination among stakeholders, inventory and ordering systems are tenuous, demand forecasting is underdone, and storage and transportation temperature control is not optimal; shipment visibility is poor, and tracking systems fail to preclude shortages and expired products (Gupta et al., 2019).

However, the absence of a dependable data sharing platform increases systemic inefficiencies, interoperability difficulties and disjointed data exchange amongst healthcare systems. The data storage, exchange, and sharing between many systems and many stakeholders requires improvements (Dubey et al., 2019). The costs for healthcare products and services are becoming more costly, the need for implementation of new technology to remedy such inefficiencies is necessary (Boone et al., 2019). Several ongoing challenges in healthcare supply chain management include inadequate product recalls, suboptimal expiration monitoring, the lack of product shortages, constrained counterfeit detection, disparate logistics, and disjunction among information systems (Bag et al., 2021). However, IoT blockchain technology emerges as the last revolutionary solution that can unite many stakeholders in healthcare supply chain operations (Mishra and Singh, 2020). It enables it to track items in its entirety, from raw materials all the way to its eventual consumption through a secure, decentralized, peer to peer (P2P) ledgers system (Hazen et al., 2016). This design helps product traceability and visibility which manage recalls, expirations, shortages, and counterfeit parts (Lamba et al., 2019).

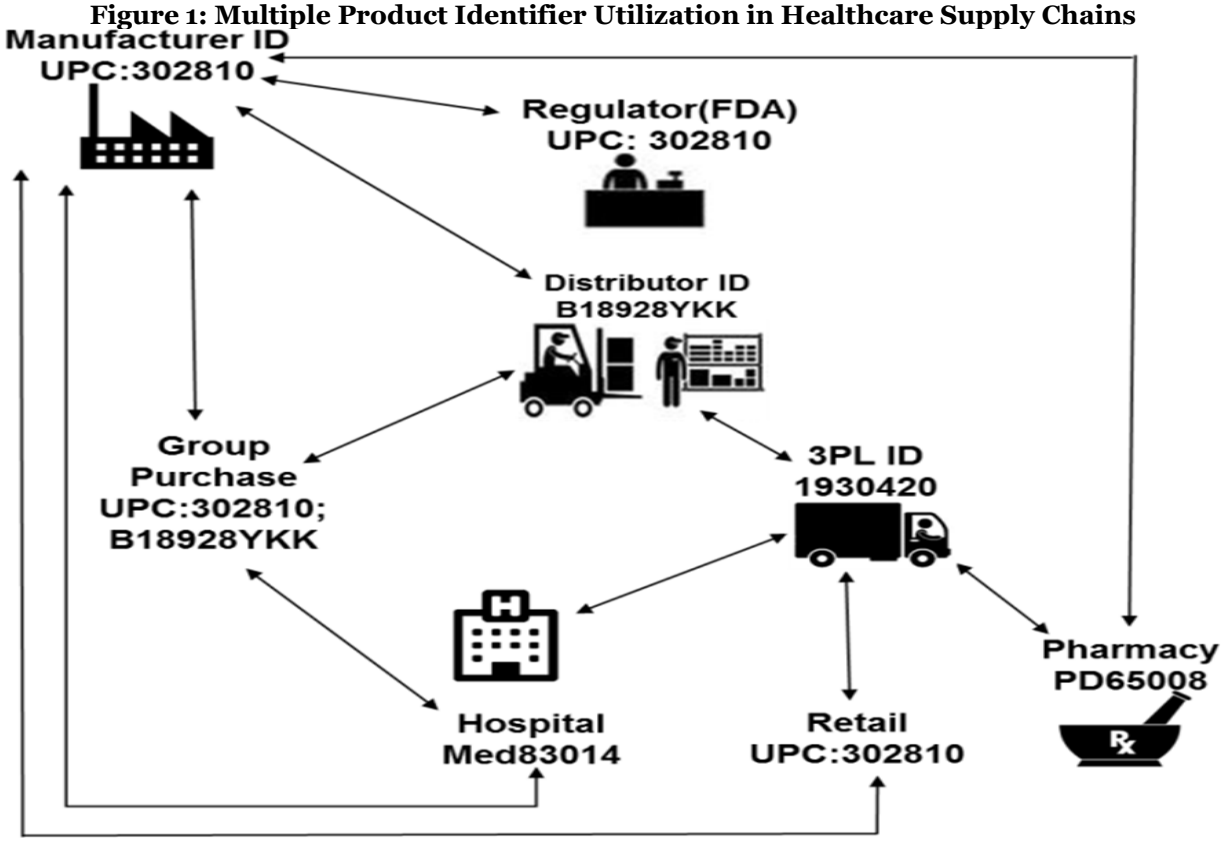
The implementation of Internet of Things blockchain technologies in the healthcare business is complex and needs to be well scoped to address the specific problems that the industry has. An IoT blockchain platform which aims to solve some of the most salient challenges of healthcare product management (product recalls, expiration monitoring, inventory shortages, and counterfeit detection) is introduced in this paper. Initial research includes examination of data in healthcare supply chains and appropriate distribution methods for products in healthcare supply chains (Raghupathi and Raghupathi, 2014). This research contributes to address the lagging literature on supply chain processes through an IoT blockchain as an innovative solution. The research seeks to study novel supply information management techniques and assess blockchain technology applied to IoT and its effectiveness in enhancing the healthcare supply chain operation (Lamba and Singh, 2018).
The paper is structured as follows: Section 2 describes some major challenges in data monitoring in healthcare supply chain continuum. Section 3 describes contemporary data collection technologies and methods for overseeing product distribution in the areas related to recalls, expirations and shortages in healthcare. In Section 4 a conceptual framework for integration of IoT and blockchain technology within the supply chain operations is presented, and the current literature about blockchain applications in healthcare is reviewed. Finally, in Section 5, contemporary IoT blockchain applications for healthcare are analyzed and prospective research avenues are discussed.

Challenges in the Healthcare Supply Chain

The current information and product flow throughout the healthcare supply chain is interrupted due to a substantial obstacle, the data fragmentation that impacts the critical supply chain activities. In healthcare supply chains, the prevalent utilisation of non-standard product identifiers hampers the ability to identify products clearly and certify procurement transactions (Arunachalam et al., 2018). Beyond a reliance on many product IDs, the global sourcing, transporting, storing, and consuming of items means that the establishment of efficient track-and-trace systems is inhibited by the dependence of various stakeholders on a wide range of multidimensional IDs (Patel et al., 2017). Figure 1 illustrates how bespoke product identifiers are utilized by various stakeholders along the course of healthcare supply chain. Unique numbering systems for internal product identification are currently used by manufacturers, distributors, and third-party logistics (3PL) providers (Zhang et al., 2017). Subsequently, these identifiers need to be converted into the identifiers used by transacting parties in supply chain transactions, e. g., purchase orders, invoices or advanced shipping alerts. Manufacturers, distributors, and third-party logistics providers utilize internal identifiers, such as stock keeping units (SKUs) or warehouse IDs, while hospitals, pharmacies, and retailers, must also map their proprietary identifiers (e. g., hospital IDs) to their own proprietary identifiers (antecedent), such as Universal Product Codes (UPCs) or National Drug codes (NDCs) (Khan et al., 2018; Verma and Gupta, 2018).

Furthermore, the lack of documentation and retaining the secondary product qualities like batch numbers, lot numbers, serial numbers and expiration dates has been a big limitation across all organisations that make up the healthcare supply chain (Singh et al., 2020). Much of the difficulty in this stems from limitations in information systems (IS) and information technology (IT), and the large volume and variety of things passing through the supply chain (Zhou et al., 2016). Lacking these fundamental data points make it impossible to create efficient traceability and transparency on the supply chain. However, this difficulty is made worse when considering product formulations that are complex, like surgical kits or pharmaceutical compounding (Sharma and Joshi, 2017). Specifically, when in a kit, such components are, for the most part, not disclosed to the other parties in the transaction. Lack of visibility severely inhibits supply chain oversight while restricting the assurance of product integrity, authenticity, and on time availability. Failing to record these properties along the supply chain can cause efficiency and error problems, and even create patient safety issues: recalls, counterfeit identification and supply problems (Patel et al., 2019).

Figure 1: Multiple Product Identifier Utilization in Healthcare Supply Chains



Information disaggregation and data fragmentation in healthcare SC are present due to a secondary cause, the delivery of mixed lot products. A streamlined three tier supply chain scenario is shown in figure 2 with producers, distributors and providers. Here product flow starts at manufacturing phase and product is made in batches and then segregated into smaller quantity to allow for easier inspection, better quality control, or different packaging (Jebaraj et al., 2019; Rajput et al., 2017). The cassettes of each lot are then re packaged into a number of cartons and subsequently consolidated into one, or more generally, a number of shipping pallets that the following supply chain stage orders (e. g., a distributor).

Products in healthcare supply chains, typically with medical devices and medicines, often bear a unique serial number, among other key identifiers such as manufacture's batch number, lot number and expiry date. These are also important for differentiating the product on its own and traceability of it along its journey (Choi et al., 2016). The serial number is allocated at the lowest unit of measurement, e. g. one medical gadget or one vial of medicine, in order to track serial number backwards from the moment of manufacture to the end user's consumption (Zhou et al., 2018) (Sarkar et al., 2018).

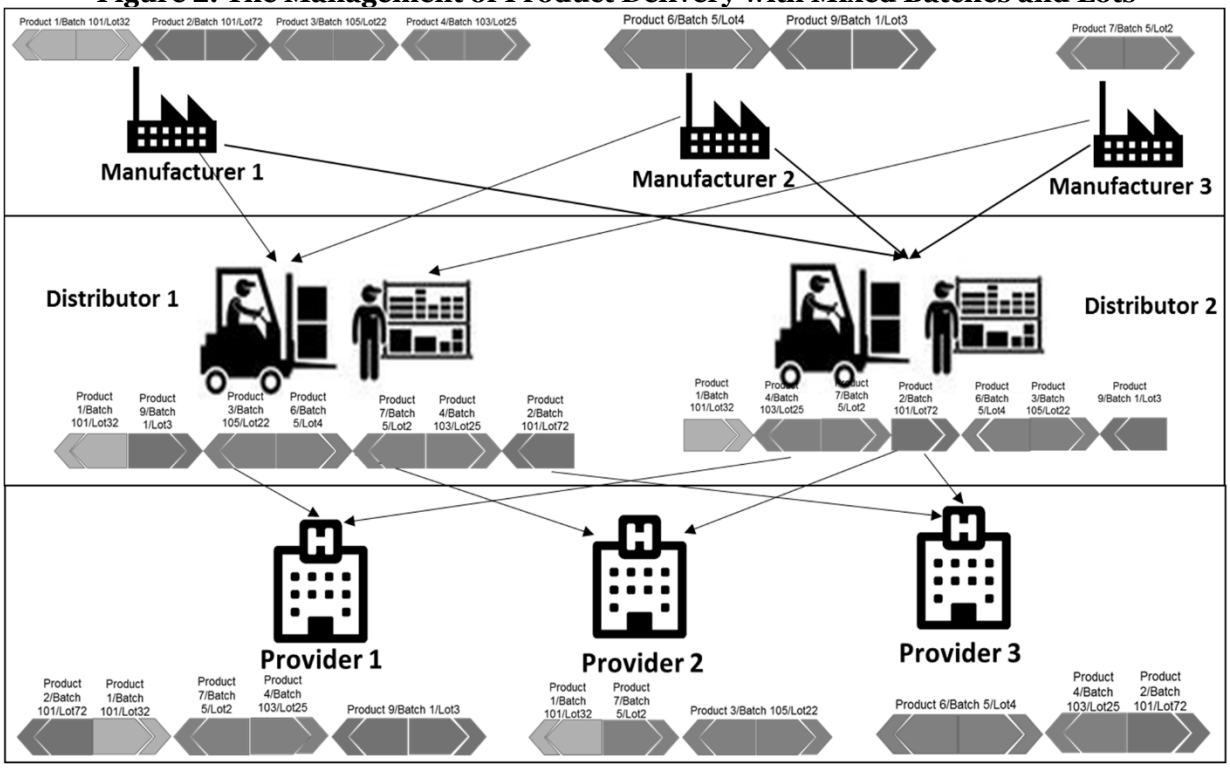
Individual product identification is precisely delineated by associating the product with some specific production information as the manufacturer's catalogue number, batch number, and lot number (Sharma et al., 2021). The batch and lot number identify the precise product production batch, while their catalogue number gives a reference assigned by the manufacturer referring to these within their inventory system (Gupta and Sharma, 2019). These are essential instruments for quality assurance and traceability. For instance, if there is a problem with a particular batch or lot of products, be it defective, contaminated or requiring a recall, these unique identifiers allow stakeholders to immediately identify the affected units and take the necessary actions like removal from the market, recall, or extra inspection (Wang et al., 2016). Together these variable numbers ensure that health care products are completely traceable, a critical requirement to assure regulatory compliance and patient safety. They help preserve a clear and traceable record of how every product is made, stored and used. In scenarios such as product recalls it's necessary to have the capacity to monitor every product at this level of detail to ensure that only the affected units are taken out of market, minimizing the chance of widespread alarm or unnecessary product removal (Agarwal et al., 2017). These IDs also enable preservation of the integrity of the healthcare supply chain ensuring that items remain untampered and authentic, used within the stipulated time limit. When there are twelve different goods, they may be individually identified with serial numbers, all located in a single carton. Cartons from the same lot could be transported on pallets to intermediaries including distributors and even third-party logistics (3PL) providers. Although 3PL providers are not required to monitor lot information, except for specialised products such as medical equipment or vaccinations, they must work productively to verify quantities dispatched and received (Kumar et al., 2019).

First, manufacturers start using carton barcodes as one item of internal inventory management where, after this phase it becomes not productive to monitor individual goods. They usually break down pallets into smaller units,

holding cartons in storage for a while until a wholesaler or healthcare provider places a purchase order (Sahu et al., 2020). When an order is received by a distributor they then combine and ship to the necessary quantity of cartons to a pallet or another box depending on the order's size and dimensions. Consequently, this procedure is done in a first in first out (FIFO) manner which may result in shipments comprising cartons from different lots. When distributors scan the barcode on a shipping carton, they don't usually keep records of batch numbers, lot numbers or expiration dates (Alharkan et al., 2019; Arunachalam et al., 2018).

Individual cartons may be scanned in mixed lot shipments; however, it is more common that volumes are counted to ensure the fulfilment of the pertinent purchase order. These shipments are kept temporarily in central storage by the providers until requisitioned by the clinical units or shipped during replenishment (Choi et al., 2016). Thus, data disaggregation becomes worse since items are often extracted from boxes and amalgamated with current inventory. In addition, the internal distribution at the provider level also employs the FIFO method in which the items are extracted without paying attention to batch or lot identifiers (Rajput et al., 2017). Consequently, items delivered to clinical facilities may be composed of items resulting from different lots and batches, increasing complexity of traceability and monitoring procedures.

Figure 2: The Management of Product Delivery with Mixed Batches and Lots



On the other hand, internally among providers, and externally among supply chain stakeholders, information disconnection and intractability may occur. Documenting product consumption at the patient level is essential to establishing an effective and traceable solution such as product provenance (Jebaraj et al., 2019). If providers want to track batch, lot, expiration, and other product characteristics that are relevant, then they must re barcode each good with a unique identifier with dynamic properties. Despite this, other than performing periodic manual inventory counts or setting up custom identifiers, providers have few means of tracking inventory efficiently (Beck et al., 2017).

Product management in healthcare supply chains relies heavily on bespoke identities, mixed lot shipments, and does not provide effective mechanisms for storing secondary identifiers (Zhou et al., 2016). The exclusive use of standard identifiers, such as Universal Product Codes (UPCs) or National Drug Codes (NDCs), presents multiple challenges:

- The batch, lot, and expiration dates for these dynamic product attributes, are physically inscribed on the objects but the information is not documented by any transacting entity in the supply chain.
- Most shipments consist of items from multiple batches or quantities.
- At each stage of the supply chain, shipments are very often received in the form of mixed batches.
- This exacerbates the problem because specific commodities can be obtained by clinical units of the health service provider from different lots.

However, this is why sophisticated traceability solutions are essential to remedy current inadequacies with healthcare supply chain procedures.

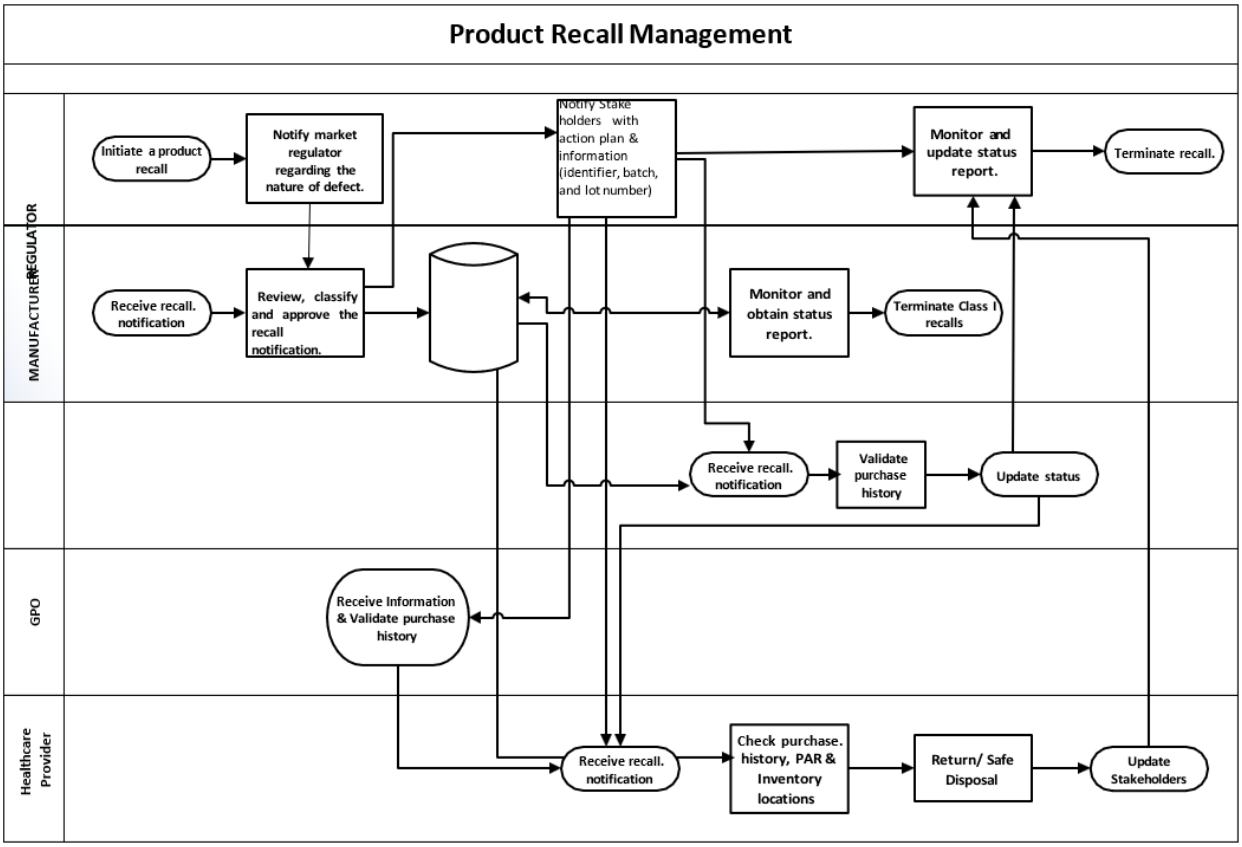
Product Recalls, Expiration, Shortages, and Counterfeits

This chapter examines the current product and information flow regarding the management of recalls, expirations, shortages, and counterfeits as they occur within the healthcare supply chain. Current practices need to be evaluated to delineate process specifics, to identify deficiencies and to understand the order in which information is processed and accessed by different stakeholders (Dash et al., 2019; Sharma and Joshi ,2017). Whether designed for a customized product identity or combining shipments of various items, the use of bespoke product identities and mixed Lot shipments create implications for healthcare supply chains that include pricing inconsistency, poor inventory management and incorrect medical record data (Drozda et al., 2016). The tagging of products with standardised identification systems (e. g. Universal Product Codes (UPCs) coupled with GS1 healthcare standards or the Health Industry Business Communications Council (HIBCC) standard) and the automation of operations, allow for products to have their tag information propagated seamlessly up and down the supply chain (Patel et al., 2019) Literature has extensively recognised the benefits of implementing healthcare supply chain standards (e. g., Wilson et al., 2015 and Bayrak & Copur, 2017). These standards ensure greater traceability and transparency which minimise inefficiencies and promote a better system of supply chain management.

1.1 Managing Product Recalls

In the healthcare sector, effective recall management involves quickly and precisely disseminating information to all participants in the supply chain. One of the biggest problems care providers and distributors face during a recall event is lack of accessible and searchable product purchase records. This is often due to the constraints imposed by rigid existing data storage systems, typically Enterprise Resource Planning (ERP) Systems and Materials Management Information Systems (MMIS) (Raghupathi and Raghupathi, 2014). While these systems perform very well at inventory and procurement tasks, they are not always optimized for real time product movement tracking or full transaction history.

Figure 3: Improved Product and Information Flow in Recall Management



In the event of a problem, the inability to search or trace product histories makes it hard to quickly identify and halt the spread of contaminated goods. When the health care system recalls hazardous or defective items, stakeholders (such as manufacturers, even distributors and health care practitioners) need to be able to access accurate, up to date records quickly (Chen et al., 2020; Verma and Gupta ,2018). However, conventional ERP and MMIS systems often separate data into different compartments, making important supply chain information difficult to retrieve quickly among a wide range of stakeholders. The limitation to the already backlogged recall process also increases the likelihood that such aged, contaminated, or defective products are used in patient care, with dire consequences. If there is no system to trace the defective products, it means

there is a possibility that healthcare personnel continue using items that are supposed to be recalled thereby endangering the patient safety (Dash et al., 2019). One large obstacle to efficient product recall management in healthcare is the lack of searchable, real time, or traceable product purchase history. New technologies such as blockchain and IoT may help to solve these challenges by creating a more transparent and accessible product transaction record in the supply chain (Roski et al., 2014).
Healthcare providers are the most involved stakeholders in product recalls, thanks largely to the threat to patient safety. The recall of several healthcare items requires an important exchange of information between the manufacturers, distributors, and healthcare providers in the healthcare supply chain (Chen et al., 2020). Figure 3 illustrates, the flow of information is complex when established coding procedures and secondary data, including batch numbers, lot numbers, serial numbers, and expiration dates, are missing or not followed. In the absence of these important identifiers, there are very few ways for the product to be accurately tracked and identified if a recall event occurs (Raghupathi and Raghupathi, 2014).

Over the past few years, the incidence of recalls with healthcare products has increased, a fact that leads to considerable concern for patient safety and treatment efficacy. In the United States, after a health care product has been recalled, the producer must inform the appropriate regulatory body how his health care product posed a risk, as well as how he removed it from the health care supply system (Lamba and Singh, 2018). Locating the recalled product inside of a provider's internal inventory is usually laborious and protracted, sometimes taking weeks before any action can be taken. Delays in notice to a patient or finding the recalled products in the system can result in patients being exposed to potentially dangerous items for too long (Lamba and Singh, 2018).
Another challenge that workers must face in providing adequate care is misdirection or lack of recall communication. Recall warnings are often sent to the wrong clinical or commercial units or in some cases (Dash et al., 2019). Notifications to the sector on recalls are normally initiated by the FDA through its safety information and adverse event reporting systems (e. g., MedWatch), or subscription based alert services (e. g., RASMAS, ECRI AlertTracker), by the manufacturer or distributor directly, or infrequently by intermediaries (logistics service providers). According to Hall et al. (2016), between June 2012 and December 2014, the FDA initiated 21,120 recalls, and 3,045 (14. 4%) of these recalls pertain to healthcare related items. The predominant causes of product recalls they found to be contamination, mislabeling, adverse reactions, product faults and wrong potency.

Recalls also pose huge financial implications, besides being safety related. Based on this, Tirumalai and Sinha (2011) explored the financial impact of product recalls, focusing only on the medical device sector, by presenting the enormous direct and indirect costs borne by manufacturers and healthcare providers to discontinue defective or hazardous items. In these situations, recovery costs, business interruption costs, legal costs and potential damage to brand reputation are incurred (Kong et al., 2015). The current form of recall management in healthcare shows the need for better systems to overcome these problems. Improved visibility into data, real time monitoring and advanced communication processes are critical to guarantee delivery of recall notices in a timely manner to the right people, as well as the rapid, precise identification and withdrawal of implicated items from circulation to prevent patient risk (Galetsi et al., 2019).

1.2 Managing Product Expiration

Currently, there is no single solution for how to properly control product expiration along the entire supply chain for the healthcare industry. Product expiration is something to oversee so that we don't impede on supply chain operations and avoid wasting supplies that are expired. In the healthcare supply chain, each participant improvises his own strategy to manage expiry. Distributors typically tell care providers they must return products nearing their dates of expiration within 30 days of the date of expiration for replacement or refund. While these approaches work, they are inconsistent and may cause inventory management and product utilization inefficiencies (Sharma et al., 2021).

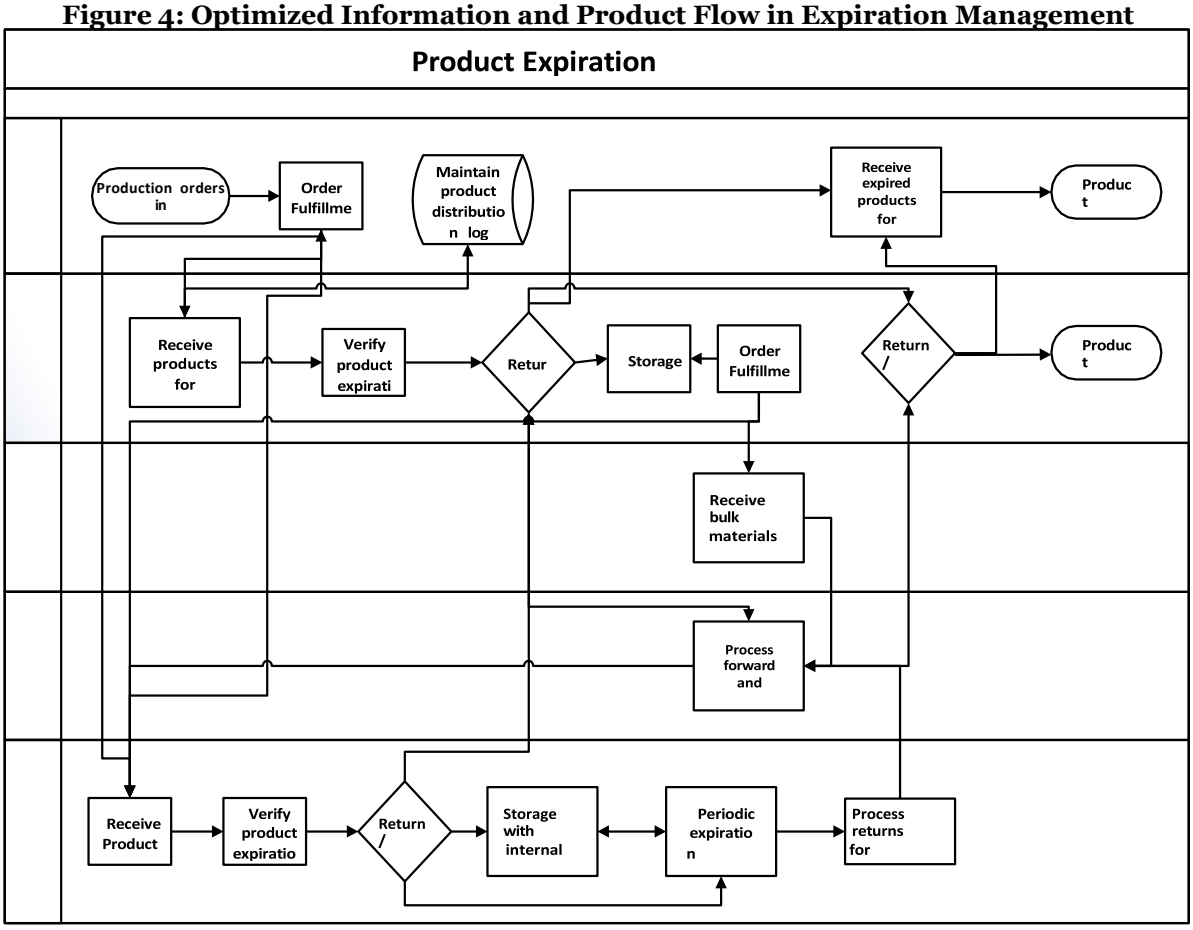
Healthcare practitioners are required to assume responsivity for both proactive inventory oversight and systematic product rotation for expiration management to ensure drug safety and to ensure the continuous efficacy of a therapy. Expiry management current process flow across some healthcare supply chain partners being depicted on figure 4. At many periodic automatic replenishment (PAR) sites today, care providers detect products nearing expiration by human inspection of inventories. In these cases, they either label them for initial use (stock rotation) or start a return process (Alharkan et al. 2019). This manual tracking technique has challenges though, especially with large stocks consisting of thousands of stocks keeping units (SKUs), and effectively tracking each and every product in a healthcare institution will be effectively untenable (Sahu et al., 2020).
This worsened by the nonexistence of a unified system that connects product acquisitions with product usage. Karaesmen et al. (2011) argue that improvements in automated inventory management systems such as materials management and information systems (MMIS) coupled with advancements in auto identification technologies are essential to reducing expiration losses. Today, most techniques to reduce expiry involve increasing volumes and quantities bought in buy orders to ensure products are available, thereby missing the

core inefficiency in product shelf life. Furthermore, the information which manufacturers need to maintain regarding dispersed products expiring dates past the manufacturer's shipping point to unarticulated between supply chain participants (Wang et al., 2016). These largely result in substantial deficiencies in the traceability of product expiration, which complicates healthcare providers' ability to manage inventories efficiently and prevent waste in outdated items.

1.3 Managing Product Shortages

The impact of product shortages in healthcare is substantial and affects treatment outcomes and patient safety creating additional stress to supply chain players to promptly find alternative products.

Figure 4: Optimized Information and Product Flow in Expiration Management



Shortages are caused from a number of sources and can disrupt the constant flow of items in the healthcare supply chain. These sources include production disruptions, manufacturing quality deficiencies, unanticipated demand surges, raw materials shortages, and even unexpected disasters. But Fox et al. (2014) and Rosoff et al. (2012) report that these are among the common causes of supply chain interruption, certainly not an exhaustive list. These shortages in various aspects show the intricacy associated with handling the availability of the products in the health sector. Though they are not factors that companies can 100 percent control, such as raw material shortages or unforeseen disasters, others, like poor inventory practices or bad demand forecasting, are internal issues companies can take steps to prevent with better planning and transparency (Agarwal et al., 2017).

The problem of product shortages is exacerbated by inventory transparency being missing among supply chain partners currently. When inventory levels are opaque to supply chain stakeholders at various points, they cannot anticipate or react to demand for products as accurately as they should. Such lack of transparency often results in the artificial or 'fake' demand where stakeholders grow the inventory needs artificially to secure themselves from any eventual shortages (Khan et al., 2018). However, such actions can distort real product demand for things, leading to a stockpiling that upsets the entire supply chain equilibrium. The situation is complicated further by inconsistent pricing, generated from a lack of standard pricing models or agreements between the different parties involved, which adds uncertainty to what products are available and their cost (Chen et al., 2020).

In figure 5, when a product shortage is identified in the healthcare supply chain, the information flow is explained. Management of shortages depends on the smooth flow of information among manufacturers,

distributors, healthcare providers and the other stakeholders. Through the transparent data exchange, stakeholders are better able to anticipate the shortages and take corrective action e. g. modification of production schedule, resource reallocation, etc. or inventory level management (Rehman et al., 2016b). In the existing environment of fragmented and not shared in real time inventory data, however, the healthcare supply chain is still prone to disruption from foreseeable as well as unforeseeable events. Minimizing these shortages and delivering products that are crucial to patient care in a timely manner requires improving visibility, across the supply chain, of inventory levels and demand trends (Zhang et al., 2017).

This allows inventory to be seen and proactive exchanges of information with stakeholders to occur which is the best way to manage inventory shortages. The healthcare providers are usually the most hit by shortages, there is a need for considerable adjustment to the information systems (IS/IT) to allow for help supplies, changes in dispensing strategies and improved inventory management (Singh et al., 2020). Effective dealing with shortages and safeguarding patient care requires a multidisciplinary team comprising chemists, medics, and nursing personnel, and supply chain managers (Chen et al., 2020).

1.4 Managing Product Counterfeits

Now, healthcare providers and other SC stakeholders are now globally challenged to manage counterfeiting in the SC. The presence of a growing number of items with different characteristics of healthcare complicates the evaluation of the effects resulting from counterfeits in the healthcare industry. Worldwide fake detection has become extremely complicated due to the proliferation of new items (Kumar et al., 2019). The lack of rigorous regulatory supervision is itself a very critical aspect contributing to counterfeiting; unregulated internet pharmacies aid the infiltration of counterfeit products into the market (Blackstone et al., 2014).

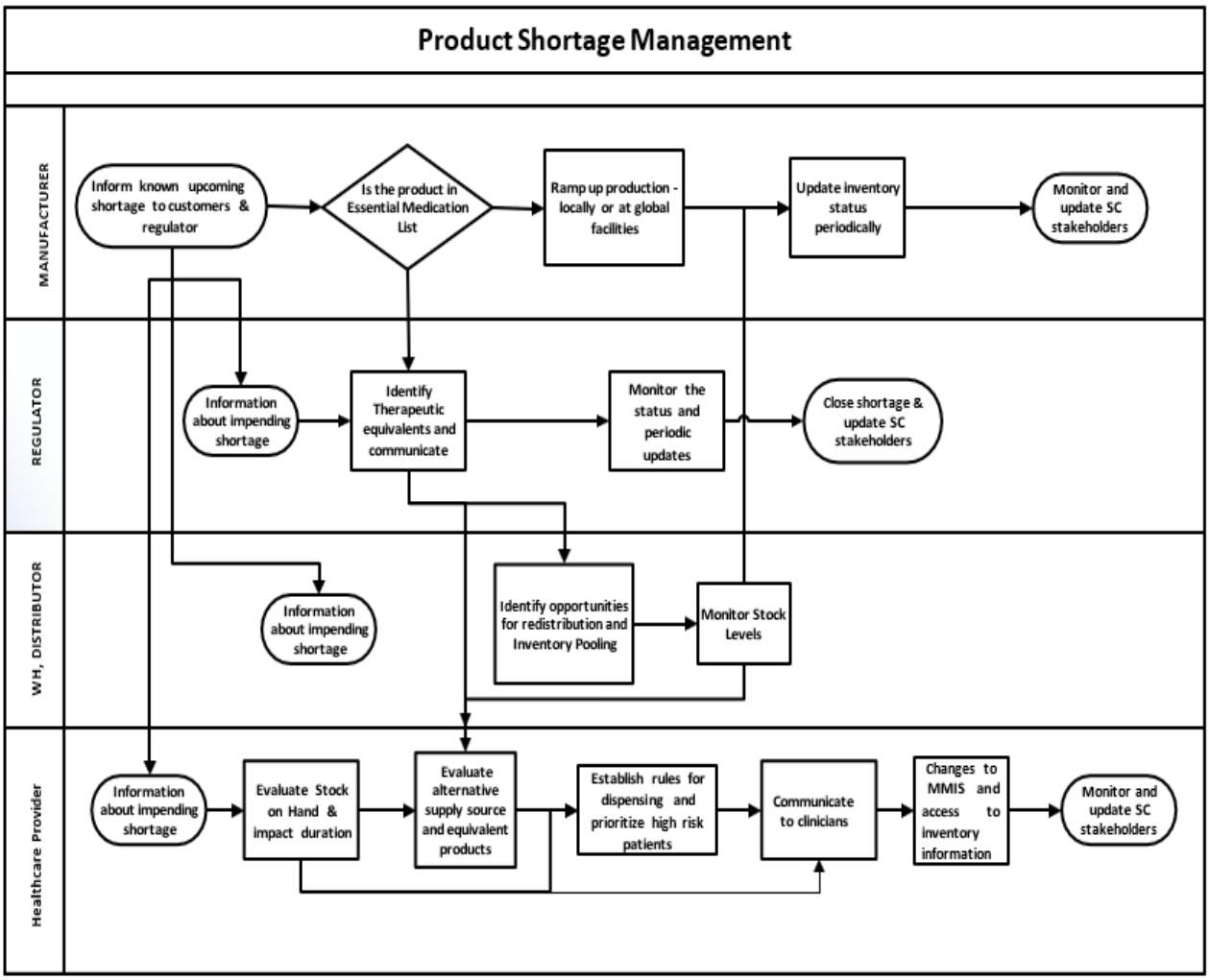
Thus, the implementation of information systems (IS) and information technology (IT) solutions, supporting traceability and product verification on several levels of the supply chain (SC) becomes crucial in combating counterfeits in healthcare (Mackey & Liang, 2011). A comprehensive review of a pool of tactics and anti-counterfeiting solutions is made by El-Jardali et al. (2015). In a pharmaceutical sector perspective, Bansal et al. (2013) discuss how the need for track and trace solutions as well as serialization are prime moves to counteract counterfeiting. Various European pilot initiatives into product verification methods to stop counterfeit infiltration into the healthcare supply chain are highlighted by Jackson et al. (2012).

Both established and novel technologies to counter the problem of counterfeiting have been reviewed by Mackey and Nayyar (2017). Due to the complex, multifaceted procurement process, which is further complicated by the lack of a product pedigree, the healthcare supply chain is uniquely susceptible to counterfeits. To counteract counterfeiting after the supply chain, Toyoda et al., (2017) propose a blockchain based system for the management of ownership of products. This approach could be easily scaled up across the supply chain to monitor counterfeit healthcare products.

Leveraging IoT Blockchain Technologies in Healthcare Supply Chains

Blockchain is gradually accepted as a transformative technology in healthcare and arouses much interest among both the academics and professionals. The reason for this rise in interest is that blockchain has the ability to upend many areas of healthcare, including contract administration, clinical trial data sharing and electronic health record (EHR) management. As a decentralized and distributed technology, blockchain has strong data management capabilities to make sure of safe and transparent real time transactions. It provides decentralization, no central authority is required, and numerous stake holders can access and authenticate data concurrently in a trustworthy and safe fashion.

Figure 5: Streamlined Distribution of Information for Scarcity Management



Blockchain in health care has plenty of use cases. One highly promising use is in the distribution of clinical trial data. With blockchain, clinical data can be securely, real—time shared in real—time among researchers and healthcare practitioners, and its integrity maintained. Additionally, blockchain enables contract administration since it offers a secure record of all transactions, and agreements will be fulfilled as agreed without intermediaries. One example of the potential of blockchain is its implementation into electronic health records (EHRs). Due to the security and immutability properties of blockchain, medical records, which are electronic health records (EHRs), can be administered for patients to secure privacy between them and enable smooth and secure transfer of their records between healthcare professionals.

Its ability to provide real time and traceable transactions, securely accessible by all parties on the supply chain, makes blockchain a value proposition in enhancing healthcare product management. In particular, healthcare stands out, as the products involved (medications and medical devices) present high risk of counterfeiting, expiration and shortages and thus require rigorous regulation. Blockchain can also provide decentralized ledger for healthcare supply flow monitoring and verifications, and increase transparency of supply chain flow. The enhanced traceability will facilitate the fast identification and removal of these products during a recall, assuring product safety and improving product management efficiency of the healthcare profession.

Blockchain technology can solve many of the problems in the healthcare sector, particularly around the handling of data, product traceability, and efficiency in supply chains. While still in an early stage of development, the technology can already be seen to make a difference when it comes to optimizing health care operations and improving outcomes. With continued advancement in blockchain technology the healthcare industry will call for more research and development to maximize the potential that the application of blockchain technology can bring to healthcare product management and other sides of the healthcare industry.

Blockchain Applications in Healthcare

The literature on blockchain applications in healthcare is growing and, in this area, blockchain has the potential to change many aspects of the healthcare sector such as data management and product tracking. In an in-depth analysis of blockchain technology and its possible advantages and weaknesses, Kuo et al. (2017) look at its uses in the biomedical and healthcare sectors. Then, we consider the Medrec project from MIT Media Labs using blockchain for electronic medical records (EMR) management to enhance authorized accessibility and

interoperability across healthcare providers (Azaria et al. 2016). Nugent et al. (2016) explore the advantages of the open source Ethereum platform, through its implementation in the context of decentralized distributed applications such as smart contracts, for the management of clinical trial data to provide greater transparency and access to data. In 2016, the U. S. Department of Health and Human Services (HHS) and the Office of the National Coordinator for Health Information Technology (ONC) identified health information technology blockchain applications by launching a blockchain challenge (Rehman et al., 2016b) (Zhang et al., 2017). In particular, they analyzed blockchain applications in cases of great scale and impact in its application to electronic health records (EHR), development of an alternative payment system, and revision of reimbursement claim processes, illustrating the potential magnitude of influence blockchain is contributing to healthcare (Singh et al., 2020).

Despite these gains, the most significant obstacles to interoperability in the exchange of healthcare data in terms of privacy issues over secure exchange of patient data still remain. Zyskind and Nathan (2015) propose a decentralized data management system using blockchain technology to address secure interchange of data which is the ultimate issue of patient confidentiality. To enable patients to securely manage, control, and exchange their medical information, Yue et al. (2016) propose a blockchain enabled data gateway. This idea was further explained by Xia et al. (2017) who proposed a blockchain based framework for electronic medical records (EMRs) dissemination with the use of permissioned blockchain and cloud storage to enhance security and security and management of access. In Benchoufi and Ravaud (2017), blockchain is examined as a potential means of sharing clinical trial data while maintaining secure and transparent reproducibility at the research level. Privacy protection challenges in healthcare blockchain are examined by Zhao et al. (2017) with focus on efficient key management and convincing body sensor network implementation for practical data exchange.

We can use blockchain to provide privacy preserving administration of healthcare information. The system proposed by Al Omar et al. (2017) ensures patient privacy using the cryptographic techniques based on blockchain. Since these blockchain systems are designed with the patient in mind, they will be used to protect sensitive medical information that will be shareable only among authorized individuals and with integrity guaranteed. Industry initiatives have noted numerous opportunities blockchain may have in the healthcare value chain (Chen et al., 2020). BlockRx looks to use blockchain to improve visibility, verification, and validation in drug research by fixing the problems in the pharma supply chain. In the United Kingdom, Google's DeepMind, which is investigating blockchain technology, is using its capability to enhance data accessibility at both hospital and individual levels by studying blockchain technology to monitor personal health records in real time.

In the meantime, IBM and its Hyperledger effort are starting a working group to find answers to open-source software development issues in the healthcare sector (Kumar et al., 2019). Working with the Food and Drug Administration, IBM Watson Health is piloting blockchain technology for the exchange of cancer data from a variety of sources, such as genetics, patient records, clinical trials and wearables. These applications are indicative of increasing importance of blockchain in maneuvering the healthcare systems. Blockchain can fundamentally revolutionize healthcare data management by working to bolster data security, interoperability and transparency – thus enabling strengthened supply chain visibility and ensuring the integrity of medical records and clinical trials. As research and industry initiatives evolve, blockchain technology is still being looked at as a possible solution to longstanding issues in healthcare (Chen et al., 2020).

Proposed Blockchain Implementation for Healthcare Supply Chains

This is always the case when a product producer within the supply chain (SC) produces a product and markets that product within the SC creating a block and recording all transactions of that products product. The block contains the dynamic product attributes such as batch, lot, serial number, amount, unit of measure, and expiration date (Malaka and Brown, 2015). As shown in Figure 6, business partners acting as transacting nodes are available and verify transaction blocks. The blockchain records and the nodes have the complete history of all transactions related to the product, in real time. In case of a sales transaction with the healthcare providers by a distributor, supply chain participants can trace and authorize these activities. In addition, all transactional data is stored and creates an immutable ledger (Zhou et al., 2018). It ensures that a verifiable record is preserved (for validating previous transactions). The block information is confirming that any attempt to change or delete that information is infeasible, this will increase the trust of transacting parties (Sarkar et al., 2018). The blockchain documentation of healthcare transaction data enables easy tracking of these transactions ensuring visibility into inventory information, with unparalleled integrity, precision, and reliability (Patel et al., 2017). As seen in Figures 4 and 5, lack of inventory visibility stems from lack of supply chain information and product flow in presenile systems. This can be improved with a blockchain enabled supply chain to authenticate real time inventory availability along different levels in the supply chain to solve problems such as product diversion, failures of authentication of origin, shortages etc.

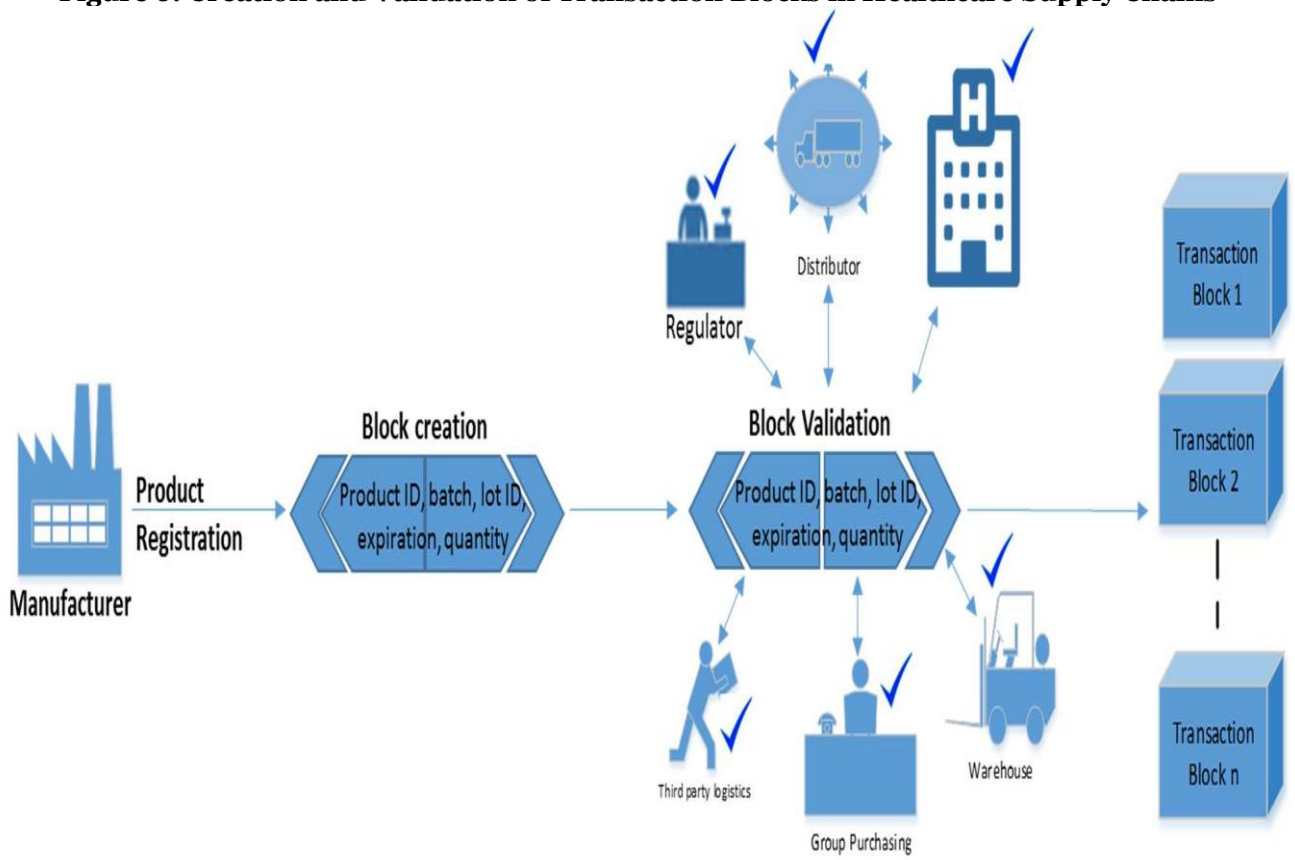
The potential Blockchain enabled healthcare supply chains offer to efficiently facilitate inventory sharing and resource aggregation among stakeholders is tremendous and a more cohesive, responsive system. Blockchain technology will help producers identify exactly which trading partners need to be notified in the event of a product recall (Sahu et al., 2020). With this specific strategy, disruptions are kept at a minimum throughout the supply chain, making sure unaffected items get pushed with few superfluous disruptions. By using blockchain technology in recall we can shorten recall durations and advance proactive product management and patient safety while earning financial savings. One of the distinctive features of blockchain technology is its ability to authenticate and validate products traded across the healthcare supply chain (Wang et al., 2016). Blockchain can give the guarantee to keep in check the integrity of the circulating products by maintaining an immutable, transparent database of transactions. The absence of a verified database in existing systems usually leads to the exploitation of counterfeit products. When there is no centralized or shared record, stakeholders lose the vital view to authenticate products and strictly keep track of inventory, making the supply chain more vulnerable (Agarwal et al., 2017; Khan et al., 2018).

Block chain technology based smart contracts are formidable solution to these difficulties. These programmable contracts can be engineered to automatically enforce agreements among stakeholders of interest (such as the group purchasing organization and manufacturers). With the introduction of authentication procedures and eligibility criteria in smart contracts, the system can authenticate suppliers, as well as validate pricing agreements in real time (Chen et al., 2020). It insures that terms agreed upon are followed and decreases risk associated with unconfirmed transactions. In addition, smart contracts automatically execute conditions which are predetermined e. g. payment release upon goods delivery confirmation or inventory adjusted based on shipment tracking information (Rehman et al., 2016b). The skill of these skills enhance operational efficiency and encourage trust and accountability among supply chain actors. To sum up, blockchain technology, being secure, transparent and properly managed can have an all round impact on healthcare supply chains in terms of guaranteeing product authenticity, optimizing the need of recalls and improving communication between buyers and sellers (Zhang et al., 2017).

Product tracking in healthcare supply chains via IoT blockchains can be executed through two primary methods: volume-based tracking and tracking using the second-degree parameters such as a batch and lot numbers. These enhance recall of administration, expiry control, deficiency prevention, and counterfeiting. The first blockchain application area is focused on tracking the sales of goods by volume (Singh et al., 2020). For instance, when a manufacturer produces 1000 units of a product and puts on the market, other transactional organisations such as distributors or other downstream supply chain players like healthcare givers are denied the right to transact more than 1000 units.

Blockchain ledgers ensure that all nodes in the network have information that the quantity is limited. In an instance where the number of units being transacted rises beyond ten hundred, the transaction is considered null and void. Transaction parties can verify the authenticity of a batch or lot number and be assured by the manufacturer that they have released more quantities in back-order deliveries to prevent the entry of counterfeit products in the supply chain. Besides, inventory status can be evaluated at every stage in the supply chain to avoid shortages in the future or to keep track of products that are nearing their deadline (Chen et al., 2020). This system allows all involved nodes to disseminate product information effectively, thereby minimizing wastage due to expiry and shortages. The second strategy springs from the attempt to enhance product traceability by means of secondary features. This method identifies different transactional entities which ordered and received certain products by using the universal product codes coupled with attributes such as batch, lot, or serial numbers.

Figure 6: Creation and Validation of Transaction Blocks in Healthcare Supply Chains



In case of a recall, the manufacturer is in a position to match batch and lot numbers to all the transaction nodes. This procedure assists to identify all transaction blocks related to the merchandise, to track possessor of the products at the current date for a specific focused recall.

Besides, product monitoring, the blockchain technology can also prove the medical gadgets' origin and support the organ donation registers (Kumar et al., 2019). For the purchasers, it allows the information interchange of purchase trends with other healthcare providers and stakeholders and keeps inexpedient information from the third party.

This means that using block chain, real consumption data culled from patient's record could be incorporated into the efficiency of the healthcare supply chain. Another use case indicates that the management of procurement data, purchase orders and the invoices along with the patient record systems has many benefits (Galetsi et al., 2019). The above relationship can serve to improve integration with procurement, financial, and clinical management systems, which places blockchain as a powerful solution to address operation challenges across the continuum of the healthcare supply chain (Chen et al., 2020).

Blockchain Technology for Healthcare Supply Chain Management in IoT

Origins of Blockchain technology as the basis for Digital Currencies such as Bitcoin, has however expanded to become a revolutionary solution to many industry issues. It also boasts unique characteristics, including secure decentralized data management and real time transaction validation, which are currently found to be useful in areas such as banking, insurance, logistics and food safety. Blockchains can play an important role in healthcare which has a very complex supply chain and some major issues: product recalls, supply shortages, counterfeit detection, and items like drugs time management process (Kong et al., 2015). When blockchain is integrated into the internet of things (IO7), a network of connected devices and sensors, it provides the foundational element of modern healthcare supply chain management (SCM). In this research the amalgamation of blockchain and IoT for transformation of healthcare supply chain management through increased traceability, data security, and operational efficiency is analyzed (Kumar et al., 2019).

Blockchain is an information exchange between participants, without relying on a bank or other third party. A header of each block in blockchain contains the hash of the previous block and this dictates an irreversible sequence of records. Due to its unchangeable framework, with no exception, this framework guarantees that transaction has been verified and is dependable for the healthcare supply chain to operate effectively. For instance, in healthcare, blockchain's immutability makes tracking of products through their cycle transparent. With this, stakeholders can view product movement in real time, verify authenticity, and guarantee product compliance to the most stringent regulatory standards (Sahu et al., 2020). These capabilities are important for

addressing major supply chain challenges such as authenticating fake products, inventory shortfalls and recall. The decentralized aspect of blockchain negates intermediaries, thereby reducing expendable cost on operations and increase members' confidence in a supply chain network. Blockchain cuts out intermediaries and solves the problems of a fragmented system and disjointed communication channels by linking stakeholders directly in one unified and secure platform (Alharkan et al., 2019). This efficient method boosts credibility along the supply chain to certify that products withstand quality and safety standards and maximize the entire efficacy of healthcare actions (Arunachalam et al., 2018).

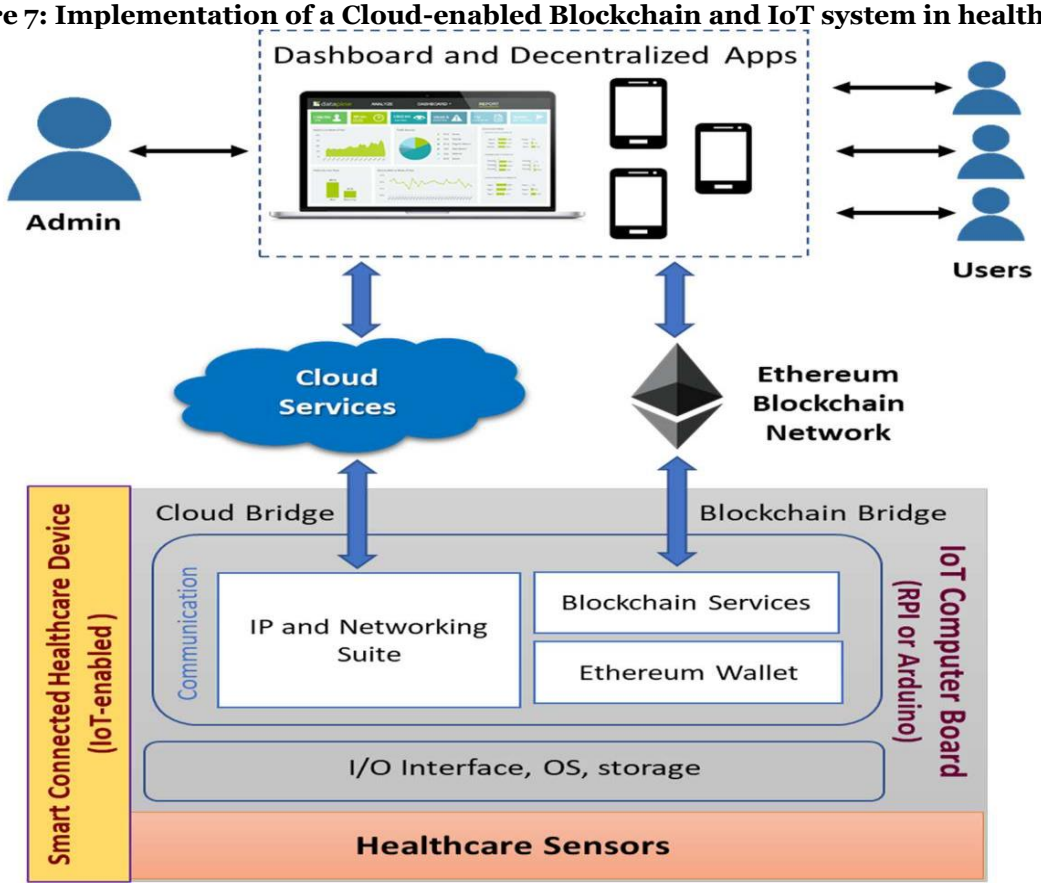
The Internet of Things (IoT) is an extensive network of interconnected sensors, devices and apps delivering real-time data collection and analysis. IoT has wide applications scenarios in healthcare supply chain management including the advanced functionality such as remote monitoring of medical devices, real time alerting systems and optimization of process and device interoperability (Choi et al., 2016). By enabling sensors that are IoT enabled, conditions of healthcare supplies, including temperature-sensitive pharmaceutical products, can be continuously monitored to ensure stored and delivered products are purified and remain efficacious. In addition, IoT enables electronic health record (EHR) data to seamless integrate with supply chain data, promoting a better coordinated and patient centered healthcare delivery (Rajput et al., 2017).

Block chain and IoT synergy can be used to settle many important challenges that are part of a healthcare supply chain. While blockchain provides a solid and immutable layer for recording and validation of data, the IoT allows for real time collection and analysis of data. Together these technologies contribute to supply chain transparency, where a range of stakeholders can monitor inventory, track product origins and confirm the integrity of a transaction. The combination of this together with batch tracking is important to product recall management as it allows the producers to identify which specific batches have been affected and to inform all the relevant stakeholders quickly, eliminating delay and limiting the effect of faulty products (Jebaraj et al., 2019). The ability of IoT devices to monitor in real time and the transparency of blockchain help early detection of supply shortage or expiration of medical supply, thereby reducing waste, and assuring timely availability.

The following architecture for blockchain and IoT integration in healthcare supply chain management is a hypothetical system in which items, and medical devices are fitted with IoT sensing devices that are linked to an IP network and a blockchain platform. Ethereum blockchain is a brand-new ledger on the blockchain that documents product transactions securely and decentralized. These sensors interact with the hardware boards excelled with processing and networking capabilities to acquire and transfer data in real time over the IoT infrastructure (Zhou et al., 2016). This data, once placed on the blockchain, is immutable, making it safe and transparently recorded product movement throughout the supply chain. This system guarantees complete traceability throughout the product life cycle, i. e., from production to final delivery, so that all the stakeholders can monitor the entire lifetime of healthcare items (Dash et al., 2019).

However, the integration of blockchain and IoT in healthcare supply chain management heralds' significant potential for addressing existing inefficiencies and vulnerabilities in this area. These improvements to traceability allow for the accurate tracking of product and identification of counterfeits, allowing for assurance of patient safety. While Blockchain enhances Iles supply chain stakeholders' confidence by its transparency, IoT with real time data capabilities further improves decision making and operational efficiency. Additionally, the ability of the system to integrate supply chain data with clinical and financial records offers a coherent and cost-effective approach to driving healthcare delivery (Zhou et al., 2016).
Blockchain and IoT technology integration leads a transformation towards new development in healthcare supply chain management. They combine the strengths of decentralized, secure data management with real time, intelligent decision assistance for important problems such as product traceability, recall efficiency, and counterfeit protection. While healthcare is currently undergoing aggressive digital transformation, however, the combination of the Internet of Things (IoT) and blockchain is a possible approach to creating a more transparent, efficient, and patient centered supply chain ecosystem (Sharma and Joshi, 2017).

Figure 7: Implementation of a Cloud-enabled Blockchain and IoT system in healthcare



The convergence of IoT enabled devices and blockchain technology which enables operations along the healthcare supply chain in a cheaper, faster, more transparent, more secure and a more traceable manner. However, the rapid evolvement of IoT hardware environment is the prevalent platform such as Arduino microcontroller and Raspberry Pi (RPI) which offers open hardware and (open) software programmability (Al-Fuqaha et al., 2015). These systems can be customized to be used to aid blockchain and cloud capabilities and be made capable of talking to decentralised networks like Ethereum. Blockchain technology integrates with IoT devices to help in controlling the management of data which is done using application protocols like the Constrained Application Protocol (CoAP) and MQTT that have been developed for efficient IoT communication because they're fit for the specific tasks (Al-Fuqaha et al., 2015).

IoT integrated blockchain systems receive data from smart devices, stores, analyses and then displays through intuitive dashboards or decentralized applications. We can also incorporate Ethereum based services and wallets into the embedded software of IoT devices so that we can directly engage with blockchain network safely and transparently for safe and transparent data management (Buterin, 2014; Christidis and Devetsikiotis, 2016). Functionality is augmented by open source libraries and blockchain explorers which enable real time traceability and visibility into supply chain data. These interfaces provide the healthcare supply chain management administrators with meaningful information about the product and device lifecycle from manufacture to end use (PFA Health Signs, 2007).

Blockchain networks are smart contracts, namely, the execution of algorithmic logic based on which the functionality of smart equipment and gadgets are regulated. These contracts are implemented on the Ethereum blockchain, and provide a form of automated, verified, and accurate governance over identifying, accessing, collecting data from, and overseeing lifecycle of the devices (Buterin, 2014; Christidis & Devetsikiotis, 2016). Because the smart contracts are secure and straightforward in monitoring the device transaction, movement, and ownership, it is easier to govern the supply chain operations efficiently.
The proposed approach mitigates privacy issues by utilizing both public and private blockchain infrastructures. Global supply chains touching multiple geographically dispersed parties are suitable to get implemented on a Public (permissionless) blockchain network such as Ethereum. These are networks which provide transaction records in an open manner, making it easier to monitor and track the healthcare products. On the other hand, private (permissioned) blockchain networks, like HyperLedger, are applied in private usage, for example in case of batch and serial numbers. Blockchains permissioned at least restricts access to authorized users just in order to protect the privacy of data and confidentiality of that data (Patel et al., 2019). A versatile framework that satisfies diverse operational and regulatory needs in healthcare supply chain management is presented by

the combined utilisation of both public and private blockchains (Jebaraj et al., 2019).
There are unique advantages of blockchain technology for IoT in healthcare supply chain management. It first provides us Global Unique Identifiers (GUID) for things, using a much larger 160-bit address space over than 128-bit address space of IPv6. Having this functionality, the effective and conflict free distribution of the various addresses to the healthcare goods is guaranteed. Second, blockchain cryptographic validation inherent in its architecture certifies that all reads and writes of data from IoT devices is signed securely by the rightful sender utilizing a distinct public key and GUID to validate (Rajput et al., 2017). This offers validity and the integrity of the transmitted data. Third, on the Ethereum blockchain, smart contracts provide for decentralized administration, monitoring, and access management of IoT devices. Taken together these capabilities allow for full product tracking, enabling responsible management of recalls, expiry management and counterfeiting deterrence. Besides, blockchain's decentralized nature frees mandate on centralized authorities thereby cutting down costs and enhancing stakeholders' confidence (Choi et al., 2016). Using the knowledge of blockchain with IoT, it offers difficult challenges in healthcare supply chain management solutions which are exceptionally efficient. The ability to trace items throughout their entire lifecycle brings accountability and transparency, whilst the secure management of the data ensures against counterfeiting and enhanced unauthorized access (Zhou et al., 2018). These smart contracts preserve the exact function regulation of device functions and the automation of management and supply chain efficiency.

By bringing IoT's real time data collection and blockchain's secure and decentralized ledger together, healthcare supply chain management can benefit from greater operational efficiency and dependability. Blockchain and IoT technology were integrated to effectively deal with difficult problems that exist associated with product recalls, supply shortage, expiration and product authenticity and traceability verification (Sarkar et al., 2018). Combining secure, decentralized, and transparent blockchain features with IoT's functionalities for near real-time data acquisition and analysis, this strategic framework ameliorates inefficiencies in traditional healthcare supply chain systems. The collaboration ensures that healthcare commodities are accurately tracked through their entire lifespan, leading to rapid and focused responses to recall events and lowers the threats of counterfeiting, as well as making inventories more manageable to avoid shortages or losses through expiration (Sharma et al., 2021). The addition of blockchain and IoT technologies into the healthcare supply chain drastically improves data integrity and efficiency of operations, in addition to enhanced stakeholder trust, from manufacturers through healthcare providers (Gupta and Sharma, 2019). The solution takes advantage of blockchain's immutable ledger and the real time data collection capabilities of the IoT, to ensure supply chain processes are transparent, reliable, and efficient.

An integrated technical strategy that can adjust efficiently to the market's dynamic character and enhance the durability and agility of healthcare supply chains is proposed. IoT devices allow for real time monitor and track, while blockchain ensures secure and verified transfer of this information among the concerned stakeholders. This collaboration eliminates inefficiencies, reduces errors, and allows for faster responses to issues like product recalls, expiration management, and counterfeit protection (Wang et al., 2016). This integrated strategy works in line with current regulatory standards and stakeholder expectations to improve transparency and security of healthcare systems. Enhanced patient outcomes are offered through an assurance of timely delivery of both safe, genuine, and high-quality products through this improved supply chain infrastructure, and extrinsic stakeholders benefit with reduction of costs and greater trust (Agarwal et al., 2017).

Concluding Remarks & Future Research Directions

This article discusses the possibility of using blockchain technology to build a distributed ledger system that can be used for the purpose of revolutionizing the healthcare supply chains (SC). These are difficulties in streamlining product recalls, overseeing expiration dates, and getting rid of prescription shortages. The study illustrates the importance of using Blockchain technologies attributed to IoT in the product monitoring and tracing and provides this an approach holistic system with the ability to link otherwise unconnected parties across the whole healthcare supply chain. This solution proposes using the blockchain based distributed ledger as an auxiliary system which will be an addition on current procurement and supply management framework. Its capability allows for precise management of the product inventory, such as product quantities, batch numbers, lot numbers, and expiry dates, for each product coming down the supply chain. It takes a blockchain technology in the healthcare supply chain ecosystem to understand potential advantages: they are an improved traceability, data integrity and better collaboration for stakeholders (Kumar et al., 2019). Through the analysis of a wide range of use cases, the research shows how various functionalities of distributed ledger technology in particular end-to-end product tracking can be tailored to satisfy specific supply chain requirements.
The critical issues such as product recalls, supply shortage, expiration monitoring and counterfeits prevention discussed in this paper are the factors that continue to a negative impact on the healthcare supply chain. Then it touches on innovative technology which is IoT enabled blockchain solutions, with smart contract functionality as a tool to efficiently handle these issues. The strong structure of these technologies complies with product traceability and safe information interchange among supply chain participants. The achievement of this is through the integration of IoT and blockchain that transforms healthcare supply chain operations by ensuring data integrity, security, and stakeholder confidence without having the need for intermediaries (Sahu

et al., 2020). Yet, the integration of the IoT and blockchain technologies is still early stage with a concentration of such attempts at experimental applications, prototypes, and proof of concept stage. To achieve all their potential, they need comprehensive research and development combined with cooperation between researchers, industry leaders, and practitioners. Some of the current issues in IoT driven blockchain system include scaling issues (elevated energy usage), regulatory and compliance issues and security of the IoT devices. In addition, as data management, access control, trust, and governance are also substantial barriers, especially in the healthcare supply chain where efficient and safe data exchange among stakeholders is required for effective data exchange among different stakeholders in the healthcare supply chain (Choi et al., 2016). However, this paper argues that, with the ability to overcome these challenges, the integration of IoT and blockchain can improve the transparency, efficiency, and reliability of healthcare supply chains leading to better patient outcomes and stakeholder trust.

Main challenges for implementation of blockchain systems include scalability, latency, transaction privacy, regulatory compliance, and governance. Some of the constraints have been overcome with new blockchain variations such as IOTA and Algorand. However, these new blockchain varieties still need further review and consideration to adequately assess their functionality and appropriateness to healthcare supply chain systems (Rajput et al., 2017). This article articulated the ongoing difficulties of overcoming these challenges in IoT driven blockchain systems and put forward the need for constant innovation and research, to ensure IoT driven blockchain systems fulfill their transformative promise in healthcare supply chain management.

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