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Application of blockchain and smart contracts in pharmaceutical cold chain : A systematic literature review

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Abstract

The purpose of this study is to gain valuable insights on the use of blockchain technology and smart contracts in pharmaceutical cold chain systems. The study also intends to identify gaps in existing research on the subject and identifies the opportunities for future research on the same. These articles were selected after deployment of a rigorous filtration process in order to select the most suitable ones that are relevant to the deployment of blockchain and smart contracts in pharmaceutical cold chains. The articles were acquired from the SCOPUS database. This review provides information on the chronological development of the research on the topic by mentioning the trends or patterns related to the top journals, theories applied, methods used, countries of research authors, etc. The study also elaborates the limitations of the existing research papers on the topic and discusses the directions for future research. This article can be used by the future researchers as a summary of currently existing studies on the subject as well as for anyone wishing to actively utilize blockchain technology and smart contracts in the cold chain distribution of pharmaceutical products.

Subject Classification: *Primary 93A30, Secondary 49K15.*

Keywords: *Mathematical modeling, Ordinary differential equations, A duopoly economy, Market share.*

1. Introduction

Pharmaceutical cold chain is the system that facilitates maintenance of low temperatures for special products like vaccines, biologics, etc. The temperatures need to be maintained from the point of manufacture right until it is given to the patient. [1] Blockchain is a decentralised, inflexible and well-established database that enables east trailing and documenting/recording of assets and transactions in a business network. Smart contracts are software applications that run the coded function once the necessary circumstances have been met. These types of contracts are maintained on the blockchain. [2]

This study aims to provide details on how smart contracts and blockchain can be implemented in the current pharmaceutical cold chain system. By integrating these new technologies, an even better performance can be expected out of the pharmaceutical cold chain. [3] Pharmaceutical cold chain is an important element of the healthcare industry and applying newer technologies for its betterment is an essential task. [4] Data from a study estimated that the worldwide cold chain for pharmaceutical market revenue is projected to exceed 7 billion USD by the year 2023 advancing at a CAGR of 9.6% from 2022 to 2030. [5] The market has been growing due to the rising demand for perishable commodities. [6] The advent the Covid-19 pandemic has increased the emphasis on the need for a well-functioning pharmaceutical cold chain systems. [7]

This systematic literature review has been performed to integrate the existing research studies on the topic. The review also classifies the existing research studies into broad themes. The study consists of the Research methodology, findings and discussions followed by future research directions, theoretical and practical implications and lastly the conclusion. This literature review has four research questions. First, it attempts to answer how smart contracts can be implemented in pharmaceutical cold chains. Second, it identifies the drawbacks of smart chain contracts. Third, this review explores the possible ways of overcoming the limitations in implementation of blockchains and smart contracts in pharmaceutical cold chains.

2. Research Methodology

This section discusses the research methodology that was used to conduct this literature review. In order to carry out the systematic review, the relevant articles were obtained from the SCOPUS database. This search yielded innumerable articles on the topic which had to be filtered out to best suit the requirements using keywords as well as inclusion/exclusion criteria. The articles were screened using PRISMA analysis which is elaborated in *Table 1*.

2.1 *Inclusion/Exclusion Criteria*

Table 1 portrays the inclusion and exclusion criteria for this study. These criteria were used while filtering the articles obtained from SCOPUS database.

Table 1

Inclusion/Exclusion constraints (Author)

Sr. no	Inclusion criteria	Exclusion criteria
	Presence of relevant keywords in the research title as well as within the article.	Absence of relevant keywords.
	Papers published from 2017 to 2023.	Papers published outside this timeframe.
	The literature should provide relevant information towards the research question.	Irrelevant information or information that is not necessary.
	The research paper should be written in English.	Any language apart from English.
	Articles that are accessible.	Articles that aren't accessible.

3. Findings and discussions

This section elaborates the findings of the literature review and discusses the insights drawn from the review. More than 8000 articles obtained from the initial search from SCOPUS database were screened using various filters and were funnelled down to 59 articles using PRISMA. These articles were then selected for further analysis using bibliometrics. The outcome of the analysis using bibliometrics are represented in different figures and tables. These analytical results include data based on journals, countries, papers, publication years, authors, trends etc, that will help comprehend the literature to the context.

3.1 *Most cited authors across the countries*

Literature review revealed that 16 cited authors were from China and India, with USA having the no. of cited authors at 6, followed by Canada at 4, Italy at 4, Korea at 4, Australia at 3, UAE at 3 and Egypt with 2 cited authors. If one looks at the number of citations, Brazil was seen to have the highest no. of citations (284) Canada had the second highest number of citations (141) due to the established cold supply chain adopting the blockchain concept. Canada has seen a sudden increase in the number of start-ups working in the area of adopting blockchain into the supply chain. Walmart, a corporate retail giant in Canada recently adopted the blockchain concept in their supply chain, also providing a boom and inspiring other companies to follow. The second highest citations came from Korea (91) as the country is also adopting blockchain throughout its supply chains.

3.2 *Distribution of word frequency-keyword cloud and co word net*

The key word cloud in the *figure 1* represents the most frequently occurring terms. The word frequency-keyword cloud was formed using biblioshiny.

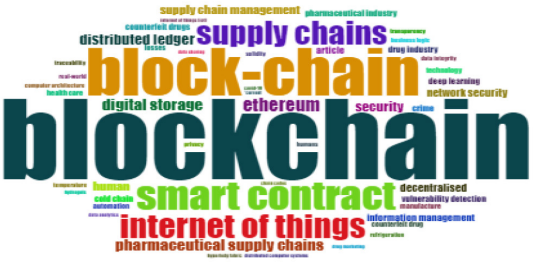

Figure 1

Key word cloud (Biblioshiny)

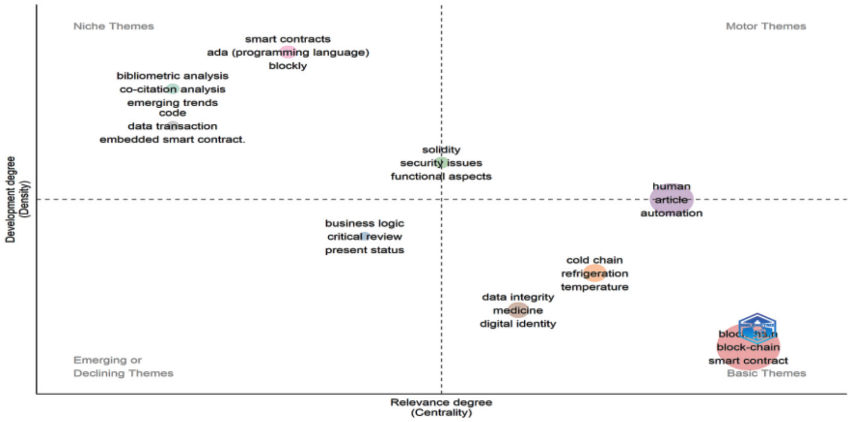

Figure 2

Thematic map (Biblioshiny)

3.3 *Thematic analysis*

Figure 2 portrays the thematic map. It consists of four different themes divided in to 4 quadrants which display the most relevant keywords to the particular theme. [8]

4. Theoretical and practical implications

The amount of research concerning potential advantages of utilization of blockchain and smart contracts in the pharmaceutical cold chain is expanding. [9] Some of the advantages are improved lucidity and trackability combined with enhanced safety, automation of processes, regulatory compliance and improved collaboration. [10] Using the blockchain technology and smart contracts in pharmaceutical cold chain has practical consequences like the requirement for specialised IT infrastructure, data governance, and stakeholder involvement. [11] To create standardised data formats and protocols, parties must cooperate with one another. [12]

Due to its potential to improve the efficacy and transparency of cold chain management, the use of blockchain and smart contracts in the pharmaceutical industry has received a lot of interest recently despite being a relatively young topic of study. [1] In recent years, there has been a noticeable increase in the articles examining the possible advantages of blockchain technology and smart contracts in pharmaceutical cold chain

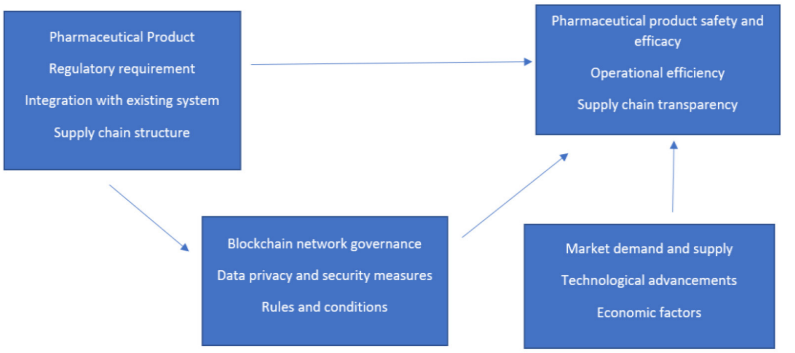

Figure 3

Variables (Author)

management, including subjects like traceability, openness, and security of data. [13]

There are various theories for application of blockchain and smart contracts in pharma cold chain. For example, Distributed Ledger Theory focuses on using a decentralised network to record, share, and store data securely. [14] Smart Contract Theory focuses on using self-executing contracts to automate contract management and enforce the terms of the agreement. [15] Lean management theory aims to eliminate waste and optimise processes to achieve maximum efficiency. [16] Quality management theory focuses on maintaining high levels of quality throughout the process of supply chain management. [17]

Figure 3 depicts such a conceptual framework of application of blockchain and smart contracts in pharma cold chain – as well as IVs (Intravenous), Mediators & CVs (Cardiovascular). To maintain the safety, security, efficiency, and efficacy of the supply chain, the collaborators participating in pharma cold chain logistics can use blockchain and smart contract technology by recognising these factors.[18] By increasing transparency, enhancing efficiency, lowering the risk of errors, enhancing supply chain collaboration, and enhancing compliance, blockchain technology and smart contracts can help business professionals improve the safety, efficacy, and overall quality of these temperature-sensitive pharmaceutical products. [19]

Practical implications

Supply chain and logistics managers working in pharmaceutical industry can leverage this study to understand how blockchain and smart

contracts are applied to improve traceability and accountability to develop strategies for the future. [20] There are several benefits of using conceptual framework for the application of blockchain and smart contracts in pharma cold chain like increased transparency, improve efficiency, reduced risk of errors, improved supply chain collaboration and improved compliance.

The literature synthesis reveals several challenges in the field, such as integration with current systems, data security and privacy concerns, etc. Integrating blockchain and smart contract technology for large pharmaceutical companies with legacy systems can be challenging and time-consuming. [21] The usage of blockchain technology necessitates the sharing of data among numerous parties, which might cause data security and privacy issues. [22] Standardisation can speed up the integration of blockchain technology into current systems by creating standardised protocols for data sharing and storage on the blockchain. [23] Collaboration among pharmaceutical firms, logistics businesses, and regulatory organisations can assist solve data security and privacy concerns while ensuring that all stakeholders in the supply chain adhere to best practices. [24]

5. Future Research Directions

This section focuses on the aspects of future research and developments that can be carried out in the domain of smart contracts and blockchain in the coming years. Most businesses have already adopted supply chain management systems, and it can be difficult to amalgamate blockchain and smart contract technology with conventional systems. To create integration plans that minimise disruptions and maximise the advantages of innovative technology, more study is required. [25] Pharmaceutical organisations produce products such as vaccines and biologics which are known to be highly temperature sensitive, hence temperature monitoring takes high priority. Temperature monitoring is achieved by following cold chain processes.[26] Supply chain of temperature sensitive drugs or biologics must follow a cold chain process, because temperature changes may affect the quality and effectiveness of these pharmaceutical products and thus endanger the health of patients. [27] Future research can address several topics related to pharmaceutical cold chain logistics. Maintaining the uprightness of the cold chain during transportation and storage is one of the most important issues. To achieve this, special tools such as refrigerated trucks, warehouses and packaging materials must be used. Monitoring and tracking techniques are also used to be certain that

temperature requirements are met. [28] Another problem is the lack of uniformity and consistency in cold chain management laws and policies across regions and countries. Due to the resulting differences in procedures and specifications, it can be difficult for pharmaceutical companies and logistics service providers to ensure compliance with different standards.

The pharma sector is strictly regulated, and adopting blockchain and smart contract technology can make it difficult to comply with rules. To ensure that the innovative technologies abide by rules, such as those governing data privacy and medicine safety, more research is required. [29] The scalability of blockchain and smart contract technologies is one of their biggest challenges.[30] A blockchain network grows more slowly and less efficiently as more transactions are added to it. To address this issue, future research can focus on creating new consensus algorithms or improving existing one. Another problem with blockchain technology and smart contracts is privacy. While blockchain technology offers traceability, it also makes private information public.[31] Future research could focus on creating smart contracts that protect privacy and enable secure and private transactions.[22]

Developing cross-chain communication protocols that allow different blockchains to talk to each other may be a topic for future research.[11] Governance is another important area for future research on blockchain. [32] Effective governance systems are needed to ensure the fair and transparent operation of blockchain networks as they become more decentralizedwe argue that blockchains offer a way to enforce agreements and achieve cooperation and coordination that is distinct from both traditional contractual and relational governance as well as from other information technology solutions. We also examine the scope of blockchains as efficient governance mechanisms and highlight the tacitness of the transaction as a key boundary condition. We then discuss how blockchain governance interacts with traditional governance mechanisms in both substitutive and complementary ways. We pay particular attention to blockchains' social implications as well as their inherent challenges and limitations. Our analysis culminates in a research agenda that explores how blockchains may change the way to organize collaborations, including issues of what different types of blockchains may emerge, who is involved and impacted by blockchain governance, why actors may want blockchains, when and where blockchains can be more (versus less.[24] Future research can focus on establishing risk mitigation measures to prevent or reduce future compliance issues, including contingency plans for unexpected events such as natural

disasters or system failures.[33] Code verification is another dimension for research in the future. Developing automated tools for verifying correctness and security of smart contract codes can be a goal for future research.[34] The high energy demands and consumption of blockchain networks is a major problem [35]. Tomorrow, the focus may be on creating consensus algorithms that use less energy or exploring less energy-consuming alternatives to blockchain technology.[36]

Last but not the least, more research is needed on blockchain and smart contract applications. Developing concept-based applications and identifying specific use cases could be key areas for future research to showcase the utility of blockchain and smart contracts.[1]

6. Conclusion

The results of the review show that the use of latest cutting-edge technologies in the pharmaceutical cold chain can be advantageous in terms of speed, safety, stability, efficiency, reliability and robustness. This review provided better understanding of the factors that are to be considered while trying to implement these technologies in the existing pharmaceutical cold chain. Smart contracts can be implemented in pharmaceutical cold chain fairly easily but there are still some challenges like immutability, scalability, complexity and regulatory concerns. These challenges like can be overcome by using different technologies and a better understanding of blockchain but regulatory challenges are still very difficult to deal with and might require further future developments to tackle them. There still needs to be more research on the topic to be able to achieve the best possible amalgamation. A better understanding can be obtained by observing how businesses that have already incorporated blockchain and smart contracts into their cold chain operate.

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