Asian And Pacific Economic Review
ISSN: 1000-6052

Unlocking the potential of pharmaceutical supply chain using blockchain technology: A systematic Literature review

[1]Neeraj Sharma, [2]Dr. Neetu Ahmed

[1]Research scholar, GD Goenka University, School of Management-GD Goenka University
[2]Assistant Professor, School of Management-GD Goenka University

DOI: https://doie.org/10.10399/APER.2025118933

Abstract:

This study conducts a systematic literature review (SLR) to evaluate the current structure and challenges of the pharmaceutical supply chain in India and examines the role of blockchain technology (BCT) in enhancing efficiency, transparency, and sustainability. Out of 113 papers identified through five databases, 45 were shortlisted for detailed analysis. Findings suggest that BCT holds significant potential in addressing key issues such as counterfeit drugs, lack of transparency, and inefficient tracking. The review highlights blockchain's utility in drug traceability, data integrity, and automation through smart contracts. However, challenges remain in integration with legacy systems, scalability, absence of standardized protocols, and unclear regulatory frameworks. The paper also discusses current use cases of blockchain by various stakeholders and recent advancements in blockchain architecture and governance models aimed at overcoming existing limitations. The study concludes by emphasizing blockchain's transformative potential in fostering end-to-end visibility and security across the pharmaceutical supply chain through collaborative engagement.

Keywords: Supply Chain, Supply Chain Management, Blockchain technology, pharmaceutical supply chain, counterfeit drugs, PRISMA

1. Introduction

The Indian pharma industry has experienced extraordinary development over the years. In 1969, it shared only 5% of the local market share, and most was dominated by multinational companies (MNCs). In 2020, Indian players had taken up to almost 85% of the market. India now supplies nearly 20% of the world's generic medicine exports and satisfies about 60% of the world's demand for vaccines. The nation has almost 3,000 pharmaceutical firms and around 10,500 manufacturing facilities. The COVID-19 pandemic, however, exposed major weaknesses in the pharmaceutical supply chain, triggering widespread disruptions that affected the availability of critical medicines and negatively impacted public health outcomes. The impact was more profound in India due to its large population and poor last-mile connectivity in rural areas. The Indian pharmaceutical industry like the rest of the world is dependent on China for raw materials and because of this most of the manufacturers were struggling to make formulations of even basic products like Paracetamol, Doxycycline, Amoxicillin, Vitamin C, etc. Lack of transparency and real-time monitoring across the global supply chain hindered effective decision-making and coordination which further aggravated the crisis (Fadojutimi, 2024).

The Indian pharmaceutical supply chain was vulnerable much before the pandemic due to the presence of counterfeit drugs circulating in the market. Counterfeit products can have a crippling effect on the lives of patients and at times can even be fatal. On the business side these products not only affect the revenue of the original manufacturer but also harm the reputation/goodwill in the market. The Indian Ministry of Health assessed that 5% of India's medicines are counterfeit, while 0.3% are spurious. In the US $5 billion pharmaceutical market, 20 % are false medicines (Singh et al., 2017). According to the European Commission India is the hub of approximately 75% of the worldwide cases of fake medicines. A WHO report also confirmed that nearly 35% of spurious drugs are marketed from India (Lokesh et al., 2021).

India is often referred as "The Pharmacy of the World" because of its prominence in the global supply of drugs and medicines. India supplies about 3.5% of the total medicines and drugs provided globally. It is third in volume and fourteenth in value globally. As per the India Brand Equity Foundation (IBEF, 2024), the Indian pharmaceutical industry is likely to expand significantly, to a value of an estimated $120 billion by 2030 and possibly $450 billion by 2047, based on growing global demand, innovation, and government encouragement.

In order to maintain its position in the international pharmaceutical industry, the Indian pharmaceutical industry has to drastically improve its Supply Chain Management (SCM) functions. SCM is a very important function for the success of organizations in various industries and is one of the main sources of competitive advantage. In the drug industry, effective and robust supply chain management is even more essential, as it handles life-saving products that are vital to the health security and well-being of the population. Not only do these products treat and prevent illness, but they also contribute to public health by providing vaccines, control chronic and lifestyle diseases, and enhance general wellness through nutritional supplements such as multivitamins. Strengthening SCM in the sector is hence crucial for assuring uninterrupted availability of quality drugs and upholding confidence in the healthcare system.

Most of the Indian pharmaceutical firms are not supply chain oriented, and therefore not much emphasis is given to SCM by the firms resulting in comparatively low visibility. The concepts of continual improvement are not followed in the industry. There is widespread acceptance of existing service levels when it comes to logistics services. The conventional practices of SCM have become more complicated with the increased pace of technological advancement and globalization (Oguz, 2024). The transactions carried out (invoices, documents, etc.) between various parties engaged in the supply chain (buyers, sellers, banks, etc) are becoming very large in number and are becoming laboriously lengthy which affects the efficiency and speed of the whole process. The centralized nature of the conventional supply chain also makes information an easy target for manipulation and vulnerable to cyber-attacks which, subsequently, can result in unethical practices such as fake goods being introduced into the system.

Blockchain technology (BCT) is a fresh technological idea through which decentralized storage of authenticated information is made possible. Satoshi Nakamoto is regarded as the founder of blockchain technology when he released a paper on bitcoin in 2008 titled "Bitcoin: A peer-to-peer electronic cash system". The essence of the paper was founded on direct online payment from one destination to another destination without depending on a third destination. The paper outlined an electronic system founded on the principle of cryptography and it came up with a solution to the double spending, whereby a digital currency cannot be copied and nobody can spend it twice, thus making the whole process secure and tamper proof (Samrah, 2018). One more significant feature of BCT is programmable contracts referred to as smart contracts which manage the digital assets of the user, create the rights and obligations of participants, and are capable of automatically being executed by computer systems. Such contracts provide an automated mechanism that executes itself when specific conditions are fulfilled thereby significantly automating transactions in supply chain activity. These features of BCT make it particularly suited for a process where speed, transparency and security are of the highest importance.

1.2. Scope of the paper

The pharmaceutical industry is a backbone of a country's health security, and the smooth operation of the industry is essential for making necessary medicines available to the market in time. Such pharmaceutical goods have to adhere to strict regulatory requirements at both production and supply, especially with temperature-sensitive medicines. An efficient, effective, and transparent supply chain is vital to fulfil the core aim of the industry—timely delivery of quality products to the end customer. The following paper attempts to investigate the underlying principles and mission of supply chain management in the pharmaceutical industry,

analyze the organizational structure of pharmaceutical supply chains, and ascertain the most challenging issues they are dealing with. Of great importance, the report explores how current blockchain technology can be maximized to be more transparent and efficient in terms of operations and ensure the stable delivery of the correct medicine, of the proper quality, to the correct buyer, at the correct time.

1.3. Research Questions

In order to investigate how blockchain technology can unleash the potential of the Indian pharmaceutical supply chain, it is important to first know its existing structure, the problems it is facing, and the position of blockchain in solving these problems. This systematic literature review (SLR) will try to study these points in depth. The following research questions will be used to conduct the review:

Q1. What is the structure of Indian pharmaceutical supply chain management and its challenges?

Q2. What are the advantages of blockchain technology in supply chain management?

Q3. How can blockchain technology help in bringing efficiency, sustainability, and transparency to pharmaceutical supply chain management?

2. Methodology

This research utilizes the systematic literature review (SLR) methodology, accessing appropriate literature from peer-reviewed academic databases such as ResearchGate, JSTOR, Scopus, Emerald Insight, and Google Scholar. The literature review concentrates on major themes, namely Supply Chain Management (SCM), pharmaceutical supply chain structure and issues, blockchain technology's (BCT) role, and counterfeit drugs' effects on the pharmaceutical supply chain.

A Boolean search approach was employed to narrow and obtain pertinent literature. The search terms employed were:

- "Supply Chain AND Supply Chain Management OR SCM"
- "Challenges AND Supply Chain Management OR SCM"
- "Pharmaceutical supply chain AND Blockchain Technology OR BCT"
- "Supply chain AND Blockchain Technology OR BCT"
- "Challenges of Pharmaceutical supply chain AND Blockchain Technology OR BCT"

The articles were then filtered, scrutinized, and synthesized to contribute insights that were consistent with the research questions of the study.

Since blockchain is a relatively new technological development, with extensive research only in the last decade, this review concentrated on the literature between 2015 and 2024, specifically within the framework of pharmaceutical supply chain management. The systematic review was structured into eight thematic sub-sections to have a thorough grasp and to clearly link with the structure and issues of the Indian pharmaceutical supply chain. The first four sub-sections give introductory information about supply chain concepts, the purpose of supply chain management, the pharmaceutical supply chain structure, and the issues it encounters. The fifth sub-section discusses the application of blockchain technology in improving pharmaceutical supply chains. The last three sub-sections discuss particular problems in the Indian pharmaceutical supply chain and how blockchain technology can solve these problems efficiently. This format provides for a step-by-step and systematic development from conceptual bases to specific applications of blockchain.

2.1. Inclusion and exclusion criteria

Inclusion	Exclusion
Papers written in English	Papers written in other languages
Must be a research article	Reports, Sections from books, posters
Papers between 2015-2024	Papers before 2015
Papers on blockchain role in Pharmaceutical supply chain, blockchain and supply chain, pharmaceutical supply chain structure and challenges	Papers just discussing Blockchain Technology.

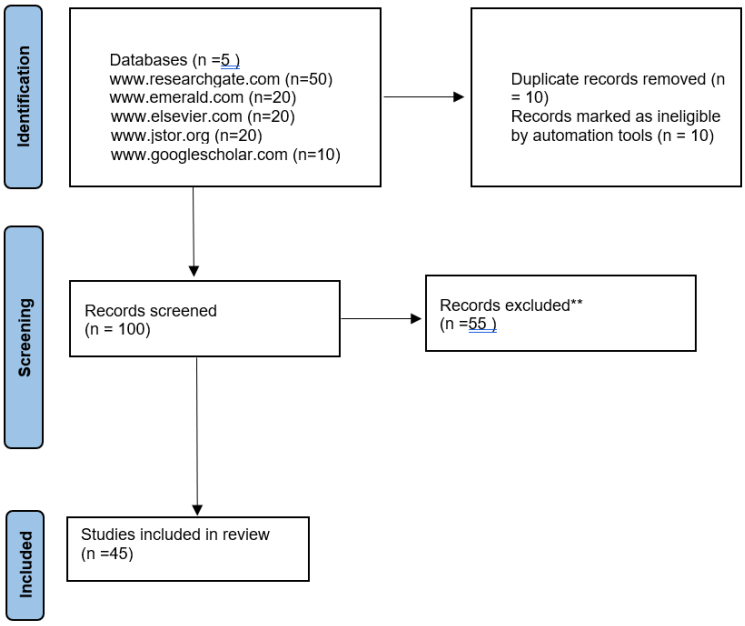
The review was done according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), as adopted up by Haddaway et al. (2022). This systematic process allowed for a strict and transparent selection, screening, and inclusion process of the literature reviewed. The step-by-step flow of such a systematic review process is seen in Figure 3.1.

3. Identification & Selection framework

In this section we have done the analysis Literature review is organized into eight major sections. The first four sections provide the foundation by defining basic terms like supply chain, supply chain management, and supply chain orientation. These sections also provide the fundamental goals of a supply chain, which are essential for establishing significant relationships to the framework and difficulties of the pharmaceutical supply chain.

One is the specially dedicated section about introducing and defining Blockchain Technology with emphasis on its applicability and potential use in the pharmaceutical industry. The last three sections specifically tackle the main research questions of the study—defining how blockchain can fight the global problem of counterfeit drugs, improve operational efficiency with decreased costs, and aid the long-term viability of the pharmaceutical supply chain.

Figure 3.1 Identification of studies via databases



The summary of all the 45 literatures which aided in the targeted SLR can be seen in Table 3.1, the paper numbers in the summary have been picked up from the references given at the end of the paper:

Table 3.1 Summary of the literatures shortlisted

Paper Numbers	Topics discussed
11, 32, 38, 29, 31, 12, 27, 15, 40, 37, 44	Critical factors in pharmaceutical supply chain, its framework and issues
24, 22, 5, 23, 28, 18, 43, 9, 16, 30, 8	Defining supply chain and supply chain management. Supply chain strategies in different industries
6, 4, 36, 33	BCT in supply chain management
7, 10, 17, 2	Indian pharmaceutical supply chain and its challenges
34, 42, 13, 21	Counterfeiting issues in pharmaceuticals and its impact on supply chain
45, 14, 25, 39, 3, 1, 19, 20, 26, 41, 35	BCT role in pharmaceutical supply chain and the solution it provides for mitigating risks and challenges

Source: Developed by the authors

The details of papers reviewed to answer the research questions follows in the subsequent sections:

4. Discussion

As per (Mentzer et al., 2001), Supply Chain and Supply Chain Management (SCM) are two different phenomena. A supply chain at times also known as a distribution channel, exists or is an intrinsic part of a business whether it needs to be managed or is managed, when a supply chain is deliberately coordinated and optimized it is called Supply Chain Management (SCM). The supply chain is defined as a set of three or more entities directly involved in upstream (supply) and downstream (distribution) of products, services, finances, and/or information from a source to a customer.

Supply chains are complex and can have three degrees of complexity:

1. A direct supply chain consists of a company, a supplier, and a customer involved in the upstream (supply) and/or downstream (distribution) flows of products, services, finances, and/or information.

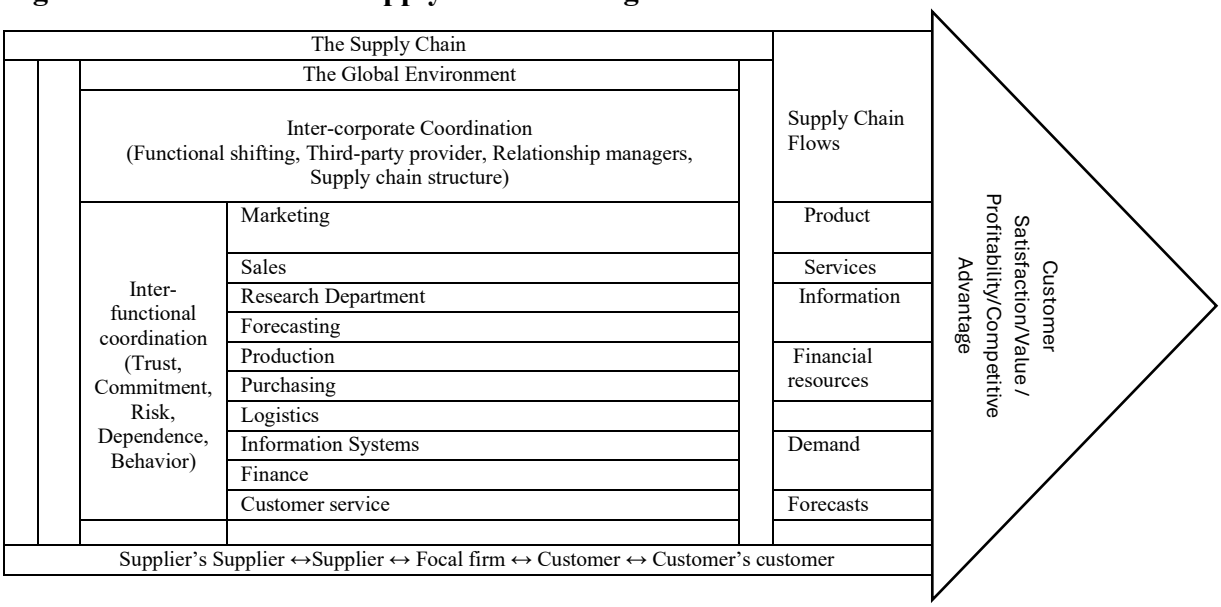
2. The extended supply chain includes suppliers of immediate suppliers and customers of immediate customers involved in upstream and downstream flows.
3. The ultimate supply chain includes all organizations involved in all upstream and downstream flows.

All medium to big-size organizations have extremely complex supply chains or ultimate supply chains and it is here that they need management.

SCM's objective is to manage the complexity that exists within a supply chain through increasing the efficiency, reducing risks and overall cost so that maximum value can be passed on to the end customer i.e., SCM must be customer oriented if it must be considered effective.

After conducting a thorough review of the literature, Mentzer et al. (2001) developed an exhaustive definition of supply chain management (SCM) that attempts to clarify the ambiguities inherent in previous literature. By their definition, SCM is "the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole." The same definition also serves as the basis for the model of SCM presented in Figure 4.1 (Mentzer et al., 2001).

Figure. 4.1. Model of the Supply Chain Management



Source: Mentzer et al., 2001

As it can be seen from the model, the goal of SCM is to provide satisfaction and value to the customer, while increasing the profitability and competitive advantage of the organization. The model also shows that close coordination and clear communication with the organization and among the supply chain partners is of utmost importance.

4.1 Objectives of SCM

Efficiency and transparency are the most critical objectives of SCM. Efficiency aids in optimizing resource utilization, reducing operational cost, and improving overall performance, while transparency is essential for building trust among the stakeholders and ensuring adherence to ethical practices, (Andrew, 2024).

As per (Nakano and Akiyama, 2018) traceability is also an important aspect of SCM that involves tracking the history and movement of the products through various stages of the supply chain as it ensures quality

throughout the supply chain and can also help in finding out at what stage a particular problem arises which impacts the quality of the final product.

Andrade and Silva, (2020), suggested that cost reduction is a fundamental objective of effective SCM, and many companies strive to achieve it by optimizing their operation i.e., JIT (Just in Time) inventory management system minimizes inventory management cost and reduces wastage by aligning production closely with demand. This approach not only improves cash flow but also enhances operational efficiency by reducing the need for large inventory stock.

Effective risk management is essential for addressing potential disruptions and uncertainties in the supply chain. Risk management practices such as assessing geopolitical risk, environmental factors, and supply chain vulnerabilities, mitigate potential disruption. These practices include developing contingency plans and diversifying the supply sources to ensure operational continuity, (Ndlovu and Williams, 2017).

Sustainability is an increasingly important aspect of SCM, focusing on reducing environmental impact and promoting ethical practices. In the United States of America Walmart started investing in energy-efficient technologies and reducing greenhouse gas emissions across the supply chain, which resulted in a 20% reduction in its carbon footprint (Mugoni et al., 2024).

Quality assurance is another crucial aspect of SCM that ensures that the product meets specific standards and ensures safety. (Kumar and Clark, 2019) discussed how GSK's quality assurance measures include comprehensive test and inspection processes that have led to 15% improvement in product quality and regulatory compliance.

SCM must adopt new innovative technologies or innovate itself to enhance performance and achieve competitiveness. Yamaguchi and Tanaka, (2020) highlighted that Sony's integration with AI technology had led to a 25% increase in supply chain efficiencies and a reduction in 5% operational costs.

SCM must strive for collaboration and integration to improve performance and foster strong business relations. As per (Costa and Riberio, 2018) companies like Ambev in Brazil integrated with suppliers and distributors which resulted in a 10% increase in efficiency and 5% reduction in cost.

The primary goal of Supply Chain Management (SCM) is to ensure customer satisfaction and responsiveness, which affects customer perception and loyalty, which in turn impacts the profitability and long-run sustainability of an organization (Andrew, 2024).

4.2 Structure of the Pharmaceutical Supply Chain

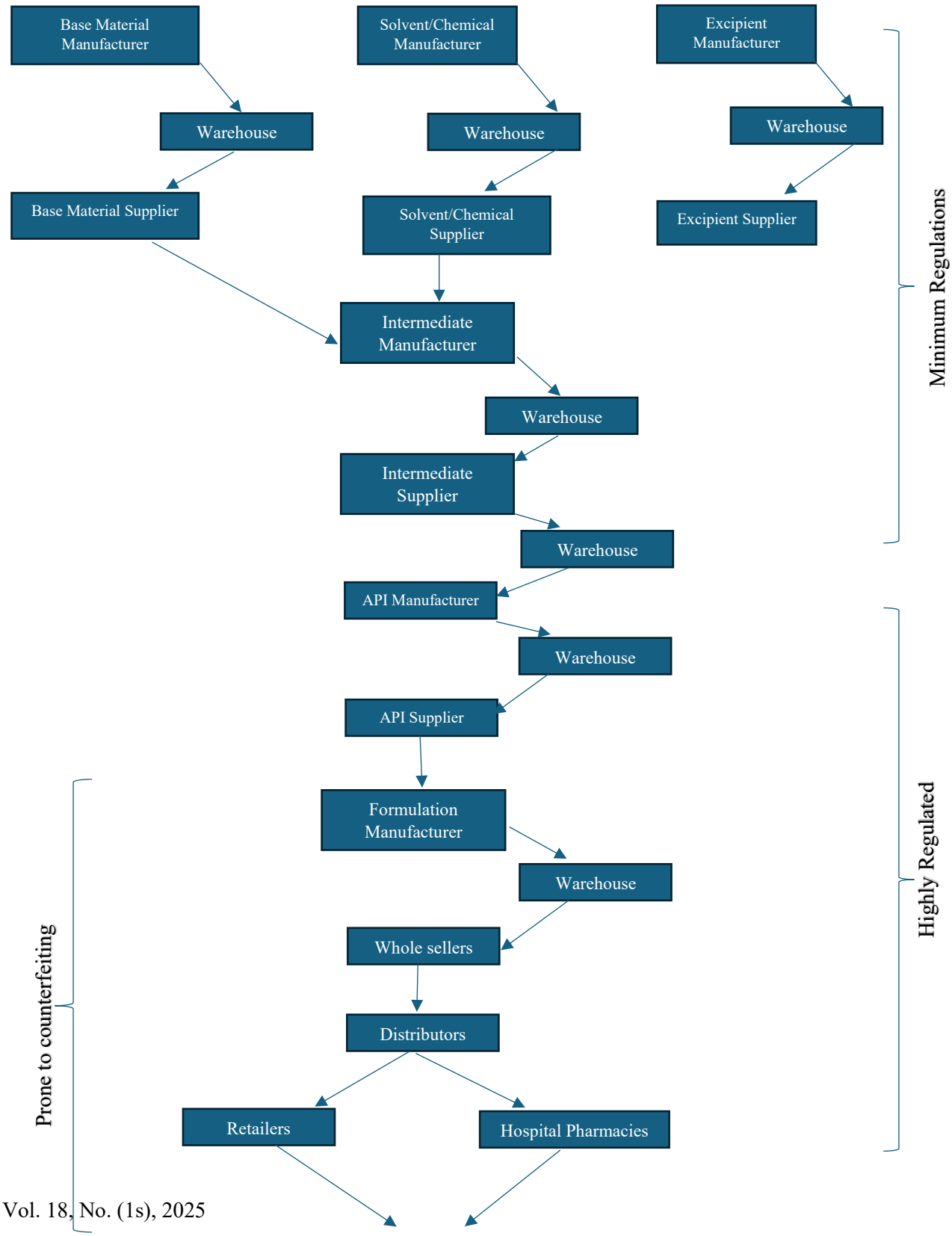
The pharmaceutical supply chain is a complex global network that plays a crucial role in ensuring the availability of essential medicines, vaccines, and medical supplies to healthcare providers and patients (Kayvanfar and Haji, 2023). The complexity of SCM increases because some of the products require cold chain infrastructure to keep the integrity of temperature-sensitive medicines, while the manufacturing requires strict adherence to quality control and regulatory standards to ensure drug safety and efficacy, (Sung, 2022).

The success of a pharmaceutical company not only lies in creating the right medicine but ensuring that it is channeled to the ultimate patients on time. This includes sourcing raw materials, production, inventory, distribution, and delivery to the patient. A typical pharmaceutical supply chain consists of primary manufacturers, secondary manufacturers, distribution centers or warehouses, whole-sellers, retailers, or hospitals (Sangode, 2024), as depicted in Figure. 4.1.

The raw material supplier provides the base materials required for the production of either Key Starting Materials (KSMs) or advanced intermediates, which are essential for the manufacturing of Active

Pharmaceutical Ingredients (APIs). The primary manufacturer converts the raw material to KSMs, or APIs also known as bulk drugs. The secondary manufacturer converts the API into a finished product or formulation and then finally packs it. After the packing of final goods, the material is then transferred to distribution centers or warehouses from where it is supplied down the channels to distributors or wholesalers who are responsible for making the products available at a retail store/hospital/nursing for final usage by the customer/patients. The availability or quality of the final product can be affected by disruption at any stage in this supply chain.

Figure. 4.1 Structure of the Pharmaceutical Supply Chain



End user/Patient

Source: Developed by authors

4.3 Challenges Faced by Indian Pharmaceuticals Supply Chain

SCM has been challenging for Indian pharmaceutical companies due to constant shifting requirements for the short life-cycle of the products, the convergence of industry, and changeable realities on the ground. Indian pharmaceutical firms invest one-third of their revenue in SCM operations because of their relatively weak transport network (Phogat et al. 2022). Drugs that are being halted by one day to reach market cost about US $ 1 million to the industry. Moreover, the cost share of logistics is 45-55% in the context of extra costs by the supply chain making conditions even worse (Parmata, 2016).

Most of the pharmaceutical companies in India lack supply chain orientation, hence not much attention is paid to SCM by the companies leading to relatively low visibility. The continual improvement concepts are not practiced in the industry. There is much acceptance of current service levels when it comes to logistical services (Sangode, 2024).

Some of the challenges faced by the Indian pharmaceutical supply chain are as follows:

1. Multiple manufacturing points: Intense global competition has compelled organizations to have a close and integrated relationship between manufacturers and supply chain partners to ensure a well-integrated supply chain system. However, because India's economy is so fragmented, integrating the different activities that make up the supply chain is complex. The involvement of several policy agencies with partly split roles between core and province cumulates in proprietorship crises (Radwan and Farouk, 2021).
2. Complex and Unequipped Distribution Network: Interruptions in distribution and inventory scarcities have become a regular phenomenon in Indian pharmaceutical SCM. The critical factors behind this issue are a highly decentralized distribution system, inadequate warehouses, and various drug transport requisites, including cold chain storage facilities and augmentation systems (Bolineni, 2016). Insufficient transport facilities and weak road and rail services are other challenges in the distribution network (Dwivedi and Pradhan, 2017; Singh 2019).
3. Long lead time: One of the most critical shortcomings of Indian pharmaceutical SCM is the long lead time, this includes time for new product development, competency acquisition, procurement, manufacturing, delivery, and regulatory process. The long lead time reduces the reliability and responsiveness of supply chain capabilities and might degrade its agility, market share and increase total cost (Moosiv, Ghatari and Rasekh, 2019).
4. Quality issue: Shortage and substandard treatment quality are India's primary concerns (Kokilam et al., 2016). There is also an increasing occurrence of pharmaceutical recalls and reports of counterfeit medicines. India's issue with counterfeit medicine has contributed to negative publicity worldwide. The Indian Ministry of Health assessed that 5% of India's medicines are counterfeit, while 0.3% are spurious. In the US $5 billion pharmaceutical market, 20% are false medicines (Singh et al., 2017). According to the European Commission India is the hub of approximately 75% of the worldwide cases of fake medicines. A WHO report also confirms that nearly 35% of spurious drugs are marketed from India (Das, 2018).
5. Certification and handling issues: International accreditations are needed to export the drugs or even launch them in the domestic market. There is insufficient coordination with the international

accreditation programs and a uniform national accreditation framework. These constraints of certification serve as an obstacle to international trade, (Afshan and Sindhuja, 2015).

6. Poor risk management preparedness: The fragility and vulnerabilities of the pharmaceutical supply chain were exposed during the COVID-19 pandemic, as the availability of even basic medicines such as Paracetamol, Vitamin C, Doxycycline, and Azithromycin were in severe shortage. The vulnerabilities were exacerbated by key factors such as overreliance on a limited number of countries for API, insufficient local manufacturing, and logistical constraints in transportation and distribution networks. Lack of transparency and real-time monitoring across the global supply chain hindered effective decision-making and coordination further aggravating the crises (Fadojutimi, 2024).

4.4 Blockchain Technology and its Role in Pharmaceutical SCM

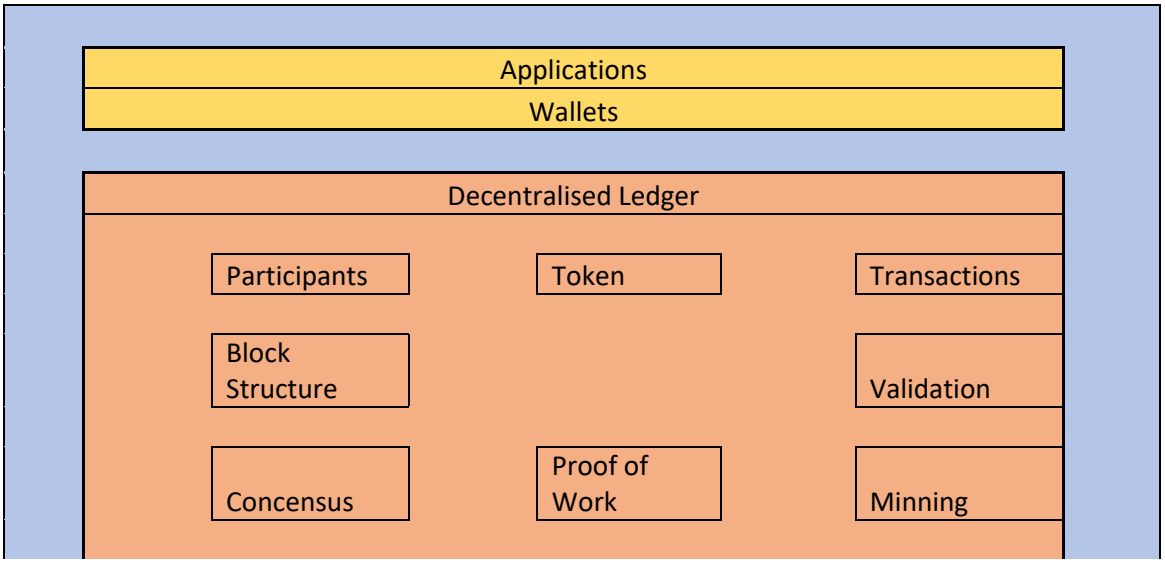
Blockchain is a revolutionary digital ledger system that provides a decentralized, secure, and transparent method for recording transactions and managing data. The decentralized nature ensures that no single entity has control of the entire ledger thereby enhancing security and integrity.

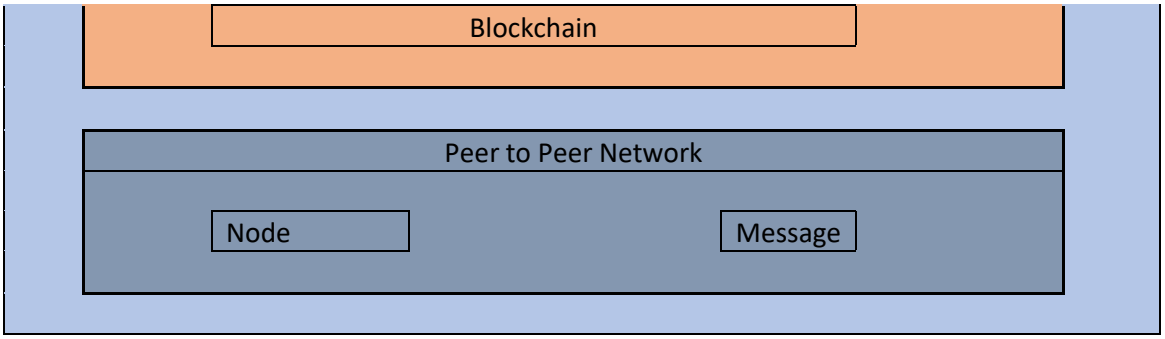
As per Samrah (2018) blockchain architecture can be mainly divided in three layers which are Applications, Decentralised ledger, and peer-to-peer network. Applications is the top layer of the network and it contains the application software of the blockchain i.e. Bitcoin wallet software creates and stores private and public keys enabling users to keep control over the unspent bitcoins. Application layer provides a human readable interface where users can keep track of their transactions.

Decentralised layer is the middle layer in a blockchain architecture that confirms a consistent and temper-proof global ledger. In this layer transactions can be grouped into blocks which are cryptographically linked to one another. Transactions can be defined as the exchange of tokens between two participants and every transaction goes through a validation process before it is considered legitimate. Mining is the process of grouping transactions into a block that is added to the end of the blockchain. Blockchain uses the proof-of-work algorithm to decide the chain that has required the most cumulative effort to build and to assure consensus among all the nodes to determine the blockchain legitimacy.

The bottom layer is the Peer-to-Peer network where node types play a different role and various messages are exchanged to main decentralised layer. The architecture is depicted in Figure 4.2.

Figure 4.2 Architecture of Blockchain





Source: Samrah, 2018

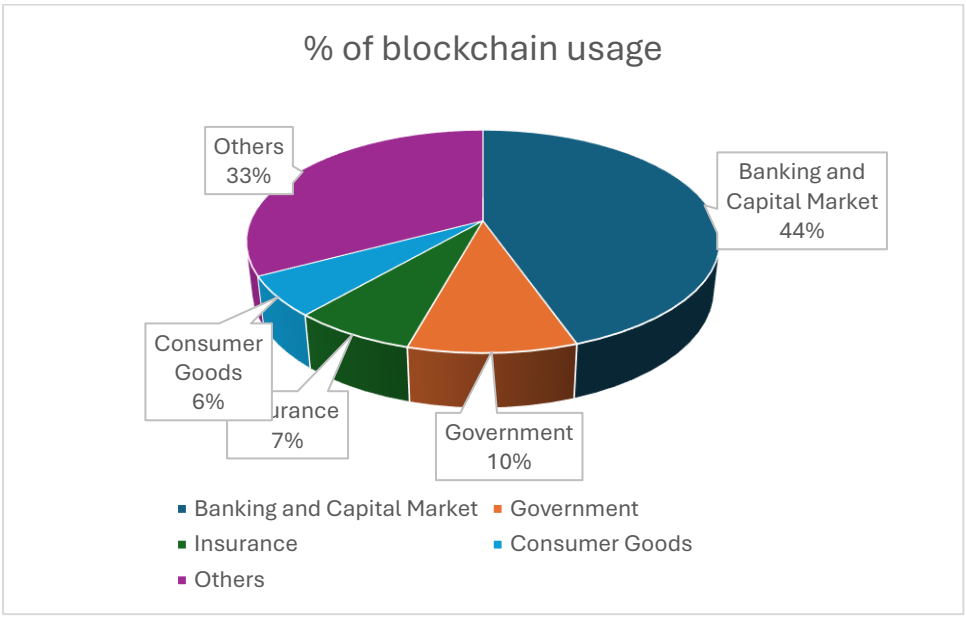
Blockchain is further divided into three tiers which are originally described based on the applications in each category:

4.2.1 Blockchain 1.0 is used for cryptocurrencies and it was introduced with the invention of bitcoins.

4.2.2 Blockchain 2.0 is used in financial services and industries which includes financial assets, options, swamps and bonds etc. Smart contracts were first introduced in this tier.

4.2.3 Blockchain 3.0 offers more security and is highly scalable, adaptable, and provides sustainability. It is used in various industries such as banking, insurance, consumer goods arts, health, justice, etc. The breakup of usage in various industry is given below in figure 4.3.

Figure 4.3. Blockchain usage in various industries



Source: Samrah, 2018

In SCM blockchain technology introduces transformative capabilities that enhance outcomes such as efficiency, transparency, traceability, risk management, and sustainability (Andrew, 2024).

The following are the characteristics of blockchain technology that make it ideal for SCM (Verma, 2024):

1. Immutability: It is a core pillar of blockchain technology ensuring integrity of the digital ledger by making it immutable. The traditional systems allow transaction details to be easily tempered with and

require involvement of third parties to ensure data integrity, however in blockchain each block is intricately linked to its predecessor thereby significantly reducing the likelihood of block alteration.

2. Decentralization: This eliminates the need for a trusted third party or central authority to supervise transactions which helps in overcoming issues such as single-point failures and dependency on third-party
3. Heightened security: Since blockchain relies on irreversible hashes for all its data, any attempt to alter data would need to compromise every block across the entire network and would need to be notified to every party involved, which leads to heightened security.
4. Distributed ledger: Since all the details about a transaction and its participants are distributed across all involved parties any malicious alteration to the transaction can readily be detected, promoting transparency and making system tamper proof.

In SCM Blockchain technology introduces transformative capabilities that enhance outcomes such as efficiency, transparency, traceability, risk management, and sustainability (Andrew, 2024).

4.5 Blockchain in managing counterfeit drugs

The Drug Supply Chain Security Act, originally signed in 2013, challenged the stakeholders of the pharmaceutical supply chain to come together and build an electronic and interoperable system to track prescription drugs along their path (FDA, 2021). These efforts at regulation, as well as other industry actions, have yet to slow the rate of drug breaches, which could be costing the healthcare system billions (Ghadge et al., 2023).

Blockchain, as a shared across nodes and unalterable decentralized database within a peer-to-peer network, could solve this challenge. Every event in the system, which is referred to as a transaction, creates a block, including a timestamp, hash value, and a link back to the last block. These blocks make the chain to uphold the ledger integrity and immutability. Consensus on whether transactions occur uses a proof-of-work process and offers accountability and transparency (Lingyat et al., 2021).

In a pharmaceutical application, a manufacturer might produce a QR code that holds basic product information such as manufacturing date, batch number, expiry date, and active ingredient. The QR code would be placed on primary and secondary packaging, and each transaction would be tracked on the blockchain. Every player in the supply chain manufacturers, warehouses, distributors, wholesalers, retailers, and pharmacies would authenticate the product by scanning the QR code, forming an unbroken chain from source to point of sale. This method minimizes the possibility of counterfeit products reaching the market and enables end-users to authenticate product authenticity through the QR code (Lingyat et al., 2021).

4.6 Blockchain used in cost minimization and improving the efficiency of the Pharmaceutical Supply chain

Traditional supply chains involve multiple intermediaries each adding to their own cost and administrative fees. Blockchain reduces or eliminates the needs of such intermediaries by providing a decentralized ledger where transactions are verified and recorded in real-time which results in lower transaction fees and a reduction in administrative costs. Implementation of Blockchain in shipping has led to significant cost savings by automating documentation and eliminating paperwork (Wang, Lang, and Li 2020).

Blockchain allows for real-time tracking of shipment and automated verification of cargo hence reducing the cost associated with delays, errors, and mutual reconciliation. Blockchain also enhances the efficiency of the supply chain by leveraging smart contracts and automated processes. Smart contracts are programmable agreements that automatically execute predefined conditions when triggered by a specific event, i.e. a minimum inventory level at each stage of distribution can be specified in the form of a smart contract and the

moment the inventory goes below that specific mark it can be notified to the appropriate department to replenish the inventory.

Since the pharmaceutical supply chain is plagued by delays and traceability issues, blockchain provides a workable solution to speed up the transportation issues and delays in decision-making, hence making the supply chain more robust and reactive.

4.7 Blockchain in increasing the sustainability of the Pharmaceutical Supply Chain

Blockchain contributes to sustainability by providing a transparent and verifiable record of the supply chain activities enabling organizations to track and manage their environmental and social impacts more efficiently. This practice has already started in the fashion industry where blockchain is used to trace the origins of materials and verify the adherence to sustainable practices (Caro and Sadr, 2019). By providing consumers with verifiable information about the sustainability of products the companies help in meeting customer demand for ethical and environmentally friendly practices.

The pharmaceutical industry especially manufacturers must be environmentally conscious due to the toxic emissions from manufacturing plants and, the use of huge quantities of water and electricity during the manufacturing of products. A sustainable practice will not only lessen the impact on the environment but also aid in increasing manufacturing efficiency and hence saving costs while providing lifesaving products. Hence it is more than sufficient background for the Pharmaceutical SCM to incorporate blockchain in their supply chain.

5. Conclusion

The objectives of the paper were to analyze the potential of blockchain technology in enhancing the transparency and efficiency of India's pharmaceutical supply chain. By way of a Systematic Literature Review (SLR), it was discovered that the greatest value proposition for blockchain to pharmaceutical supply chain management (SCM) is its capability to solve the universal problems of spurious and counterfeit drugs, which not only invoke serious health threats but also negatively impact the profitability and image of pharmaceutical organizations. Blockchain's decentralized and tamper-proof storage of authenticated data renders it very much tamper-proof, making it a secure and transparent supply chain.

Blockchains capacity for holding transactions in sequence renders it highly suitable for solving traceability and integration issues in the supply chain. By allowing all stakeholders and customers to check the origin of products and their information, including batch numbers and passage through the supply chain, it prevents imitation items from being introduced into the system.

As opposed to conventional supply chains, blockchain eliminates intermediaries, ending multiple transactions among supply chain actors. This simplification process makes the supply chain efficient and affordable, a vital role for every industry. Blockchain also helps with sustainability by creating a clear and verifiable supply chain record, allowing organizations to manage their environmental and social performance more effectively. In the pharmaceutical sector, especially for producers, environmental awareness is crucial because of toxic emissions from factories and high usage of resources like water and electricity. Not only do sustainable practices lower the footprint on the environment, but also increase the efficiency of manufacturing, resulting in cost savings and production of life-saving drugs.

Pharmaceutical companies have historically not had a supply chain focus, resulting in limited visibility. The disintegrated structure of the Indian economy further makes supply chain integration difficult. Blockchain solves this problem by developing an open and integrated platform, getting all the stakeholders on the same page, which enhances the efficiency and trustworthiness of the supply chain.

Nonetheless, scalability issues remain unaddressed. As supply chain players are diverse in size and revenue, applying blockchain to the whole supply chain could be economically unfeasible for smaller players. Small players, including small carriers, will find it hard to appreciate the advantage of blockchain adoption with larger entities. Future research needs to address how much of the burden of blockchain implementation can be distributed among various participants.

Further, research is also needed on the awareness of blockchain technology among medium-sized companies in the Indian pharma supply chain. Management's willingness to implement blockchain for simplifying the supply chain will also be important to know.

References

1. Abass, L. A., Usuemerai, P., Ibikunle, O. E., & Alemede, V. (2024). Optimizing pharmaceutical supply chains for public health resilience. International Journal of Engineering Research and Development.

2. Afshan, N., & Sindhuja, P. N. (2015). Supply chain integration in healthcare industry in India: Challenges and opportunities. Journal for Global Business Advancement, 8(4), 469. https://doi.org/10.1504/JGBA.2015.074161

3. Agarwal, U., Rishiwal, V., Tanwar, S., Chaudhary, R., Sharma, G., Bokoro, P. N., & Sharma, R. (2022). Blockchain technology for secure supply chain management: A comprehensive review. IEEE Access, 10, 85493–85517. https://doi.org/10.1109/ACCESS.2022.3197681

4. Ajayi, A. S. (2025). Blockchain in supply chain. International Journal of Trend in Research and Development. Volume 12(2).

5. Andrade, E., & Silva, M. (2020). Cost reduction and inventory management in aerospace supply chains: A case study of Embraer. *Journal of Supply Chain Management,* 56(3), 45-59.

6. Andrew, D. (2024). Blockchain technology in supply chain management. Journal of Technology and Systems, 6(5), 42–56.

7. Bolineni, P. (2016). The Indian pharmaceutical industry's supply chain management strategies. *Minneapolis: Walden University; Walden Dissertations and Doctoral Studies*. 2394.

8. Caro, F., & Sadr, N. (2019). Blockchain technology in the fashion industry: A supply chain management perspective. Journal of Fashion Technology & Textile Engineering, 7(3), 1-12. https://doi.org/10.4172/2329-9568.1000212

9. Costa, J., & Ribeiro, T. (2018). Collaborative supply chain management: A case study of Ambev. *Brazilian Journal of Operations Management*, 25(4), 567-579.

10. Dwivedi, R., & Pradhan, J. (2017). Does equity in healthcare spending exist among Indian states? Explaining regional variations from National Sample Survey data. International Journal for Equity in Health, 16(1), 15. https://doi.org/10.1186/s12939-017-0517-0

11. Fadojutimi, B. (2024). Exploring the critical factors in pharmaceutical supply chains revealed during COVID-19 and addressing missing links. World Journal of Advanced Research and Reviews, 24(1), 2407–2425.

12. Fernando, E., Meyliana, M., Warnars, H. L. H. S., & Abdurachman, E. (2020). Key strategic issues pharmaceutical industry of SCM: A systematic literature review. Bulletin of Electrical Engineering and Informatics, 9(2), 808–817. https://doi.org/10.11591/eei.v9i2.1814

13. Ghadge, A., Dani, S., & Kalawsky, R. (2012). Supply chain risk management: Present and future scope. The International Journal of Logistics Management, 23(3), 313–339. https://doi.org/10.1108/09574091211289266

14. Gruchmann, T., Elgazzar, S., & Ali, A. H. (2023). Blockchain technology in pharmaceutical supply chains: A transaction cost perspective. Modern Supply Chain Research and Applications, 5(2), 115–133. https://doi.org/10.1108/MSCRA-02-2023-0011

15. Jodlbauer, H., Brunner, M., Bachmann, N., Tripathi, S., & Thürer, M. (2023). Supply chain management: A structured narrative review of current challenges and recommendations for action. Logistics, 7(4), 70. https://doi.org/10.3390/logistics7040070

16. Kochakkashani, F., Kayvanfar, V., & Haji, A. (2023). Supply chain planning of vaccine and pharmaceutical clusters under uncertainty: The case of COVID-19. Socio-Economic Planning Sciences, 87, 101602. https://doi.org/10.1016/j.seps.2023.101602

17. Kokilam, M. B., Joshi, H. G., & Kamath, V. G. (2016). Strengthening the pharmaceutical supply chain management with information communication technology intervention: A windfall to the Indian rural public healthcare system. Journal of Health Management, 18(2), 274–289. https://doi.org/10.1177/0972063416637695

18. Kumar, R., & Clark, A. (2019). Quality assurance in pharmaceutical supply chains: A case study of GlaxoSmithKline. *Pharmaceutical Management Journal,* 37(1), 80-92.

19. Kumar, R., & Tripathi, R. (2019). Traceability of counterfeit medicine supply chain through blockchain. In 2019 11th International Conference on Communication Systems & Networks (COMSNETS) (pp. 568–570). IEEE. https://doi.org/10.1109/COMSNETS.2019.8711403

20. Lakshmi Revathi, K., Vara Lakshmi, T., & Santhosh Kumar Goud, K. (2024). Impact of blockchain technology in supply chain system. International Research Journal on Advanced Engineering and Management (IRJAEM), 2(05), 1670–1672.

21. Lingayat, V., Pardikar, I., Yewalekar, S., Khachane, S., & Pande, S. (2021). Securing pharmaceutical supply chain using blockchain technology. In J. K. R., P. Kommers, A. S., & A. Q. Md (Eds.), ITM Web of Conferences, 37, 01013. https://doi.org/10.1051/itmconf/20213701013

22. Nakano, M., & Akiyama, T. (2018). Traceability systems and quality control in the automotive industry: Toyota's approach. *Journal of Automotive Technology*, 62(5), 675-689.

23. Ndlovu, T., & Williams, P. (2017). Risk management strategies in mining supply chains: A case study of Anglo American. *Journal of Risk Management*, 29(2), 233-247.

24. Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. Journal of Business Logistics, 22(2), 1–25.

25. M. R., L., Ahmed, S. M. N., & Khan, S. (2021). Blockchain based supply chain management for counterfeit drugs in pharmaceutical industry. International Journal of Scientific Research in Computer Science, Engineering and Information Technology, 100–108.

26. Mohammed, S. (2024). Block chain technology in the pharmaceutical supply chain: Enhancing transparency and security. International Journal for Research in Applied Science and Engineering Technology, 12(8), 1336–1341. https://doi.org/10.22214/ijraset.2024.62449

27. Moosivand, A., Rajabzadeh Ghatari, A., & Rasekh, H. R. (2019). Supply chain challenges in pharmaceutical manufacturing companies: Using qualitative system dynamics methodology. Iranian Journal of Pharmaceutical Research.

28. Mugoni, E., Kanyepe, J., & Tukuta, M. (2024). Sustainable supply chain management practices (SSCMPS) and environmental performance: A systematic review. Sustainable Technology and Entrepreneurship, 3(1), 100050. https://doi.org/10.1016/j.stae.2023.100050.

29. Parmata, U. M. D. (2016). Measuring service quality in the pharmaceutical supply chain--distributor's perspective. *International Journal of Pharmaceutical and Healthcare Marketing*, 10(3), 258–284.

30. Pu, S., & Lam, J. S. L. (2021). Blockchain adoptions in the maritime industry: A conceptual framework. Maritime Policy & Management, 48(6), 777–794. https://doi.org/10.1080/03088839.2021.1918953

31. Radwan, N., & Farouk, M. (2021). The growth of Internet of Things (IoT) in the management of healthcare issues and healthcare policy development. International Journal of Technology, Innovation and Management (IJTIM), 1(1), 69–84.

32. Sangode, P. B. (2024). Developing a framework for the India pharmaceutical supply chain: Risks assessment through a FMEA approach. Asia Pacific Journal of Health Management, 19(3), i3171.

33. Sarmah, S. S. (2018). Understanding blockchain technology. Computer Science and Engineering, 8(2), 23–29.

34. Singh, B. R. (2017). Why India failed to penalize those responsible for the circulation of substandard medicines and vaccines while China succeeded? Global Journal of Pharmacy & Pharmaceutical Sciences, 2(5).

35. Sharma, A., & Bansal, M. (2024). Design of a blockchain-based model for secure and effective pharmaceutical supply chain. Nanotechnology Perceptions, 382–391.

36. Sharma, A., Padmavathy, R., Obaid, S., Devi, T. A., Rao, C. M., & Patnaik, C. P. (2024). Blockchain-based smart contracts for enhancing supply chain transparency. In 2024 International Conference on IoT, Communication and Automation Technology (ICICAT) (pp. 1345–1350). IEEE.

37. Singh, R. K., Kumar, R., & Kumar, P. (2016). Strategic issues in pharmaceutical supply chains: A review. International Journal of Pharmaceutical and Healthcare Marketing, 10(3), 234–257. https://doi.org/10.1108/IJPHM-12-2014-0072

38. Sung, C. (2022). Product integrity for patient safety: A Pfizer case study. In Brand Protection and the Global Risk of Product Counterfeits (pp. 218–226). Edward Elgar Publishing.

39. Sylim, P., Liu, F., Marcelo, A., & Fontelo, P. (2018). Blockchain technology for detecting falsified and substandard drugs in distribution: Pharmaceutical supply chain intervention. JMIR Research Protocols, 7(9). https://doi.org/10.2196/10075

40. Takawira, B., Pooe, D., & Samuels, A. (2024). Emerging technologies in the pharmaceutical supply chains: A systematic review of Industry 5.0 challenge. ResearchGate.

41. Tiwari, G., Channakkalavara, P., Singh, G., & Sarella, P. N. K. (2024). Enhancing security, transparency, and efficiency of blockchain technology in pharmaceutical supply chain. International Journal of Pharmaceutical Quality Assurance, 15(2), 1009–1016.

42. Verma, V. (2024). Unveiling the power of blockchain in pharmaceutical supply chains: Strengthening security and improving drug traceability. El-Cezeri Fen ve Mühendislik Dergisi. https://doi.org/10.31202/ecjse.1477526

43. Yamaguchi, M., & Tanaka, H. (2020). The impact of artificial intelligence and robotics on supply chain efficiency: A case study of Sony. *Journal of Technology Management*, 33(4), 400-415.

44. Yousefi, N., & Alibabaei, A. (2015). Information flow in the pharmaceutical supply chain. Iranian Journal of Pharmaceutical Research, 14(4).

45. Zakari, N., Al-Razgan, M., Alsaadi, A., Alshareef, H., Al Saigh, H., Alashaikh, L., Alharbi, M., Alomar, R., & Alotaibi, S. (2022). Blockchain technology in the pharmaceutical industry: A systematic review. PeerJ Computer Science, 8, e840. https://doi.org/10.7717/peerj-cs.840