

# Blockchain Technology to Combat Counterfeiting of Drugs in the Pharmaceutical Industry

Anusha Thakur

University of Petroleum & Energy Studies, Dehradun, Uttarakhand, India.

Email: [anushathakur89@yahoo.com](mailto:anushathakur89@yahoo.com)

**Abstract:** Counterfeiting is an ever-growing issue intensified by the increasing ease of access via e-commerce activities. The amalgamation of misinformation-driven panic, economic distress, and public health emergency contributes to the challenges related to the accessibility and supply of better and essential quality of medicinal products, leading to price volatility, uncertainty, quality of issues, and drug shortages. The adoption of state-of-the-art technologies paves the way for the digital transformation of the pharmaceutical industry. Incorporating blockchain technology augments the safety of drugs, with easy detection of falsified drugs, thereby leading to minimized mortality rate and improved safety. Blockchain-based architectures enable the systems to offer a platform to substantially cater to the changing need for pharma-data privacy, data storage, quality assurance, and material traceability. This paper discusses the different technologies in the counterfeiting of drugs, with the prime focus being on blockchain technology. It emphasizes on the strategic decisions and models adopted by the key players in their supply chain processes to make these an efficacious one. The article also focuses on the relevant information regarding blockchain architectures and the challenges being faced in the implementation of this technology in combating counterfeiting in the pharmaceutical industry.

**Keywords:** Blockchain, Counterfeiting, Drugs, Pharmaceutical, Technology.

## I. INTRODUCTION

Technological infusion has shown an enormous transformation in the pharmaceutical business. Major highlights of the pharmaceutical & life sciences

industry include the consistent discovery of generic drugs, orphan drugs, next-generation gene & cell therapies, and biosimilars. The increasing superiority of the illicit manufacturers acts as an impetus for the latest combination of technologies and innovations.

Companies nowadays, emphasize on monitoring their suppliers and verifying the authenticity and efficacy of their supply chain process. To alleviate the risks related to health from the trade across, the organizations are focusing on technology-centric solutions.

The trust with falsified drugs is no different, with the business of these products tarnishing the image of the companies. Counterfeiting products that are not as per the production norms for legitimate products and the regulatory standards for the same are dangerous if consumed, and pose a threat to the health of an individual. The increasing prevalence of counterfeit products can be attributed to the increasing demand for inexpensive drugs, lack of law enforcement, complex import-export mechanisms, non-stringent regulatory policies, and growing international free trade [1].

Although counterfeit and falsified medicines have increasingly affected all countries, however, the problem seems to be more visible in the countries wherein, the standard of living is low, and the process of making, supply, distribution, and sales are less scrutinized, owing to the fact, that, the forged medicines are considerably the cheapest [2] [3]. The growing investments in the pharma sector by various governments, the rise of communicable and non-communicable diseases, and the availability of

diverse medicine-tracking software/systems, among others, are set to drive the market for counterfeiting solution providers.

Growing automation is paving the way for continual upgradation of the pharmacy medicine tracking software system. These systems work in sync with the drug/medicine codes and other minute details, thereby increasing the scope of technological solutions for these drugs/medicines in modern-day situations. Changes such as the inculcation of the UDI (Unique Device Identification) system by the EU Medical Device Regulations push for sufficient traceability of medical devices throughout the supply chain [4]. The system enhances the effectiveness of the market-related activities for the devices and enables better monitoring of the products by skilled professionals, thereby minimizing errors and catering against counterfeit devices.

To combat against falsified and counterfeit medicines, several areas need to be catered to such as ensuring integrity and traceability of the medical products supply chain, securing the drugs and their packaging, easy traceability solutions for the drugs over the supply chain, increasing awareness among the individuals, and introduction of stringent regulatory measures to combat the same. Technological advancements are expected to enable the companies to adopt features such as unique packaging, and serialization, thereby creating consumer-focused awareness and content, being looked for.

The article emphasizes on the research opportunities to enable the prevailing initiatives to combat the counterfeiting of drugs such as exploring emerging technologies, possible use cases of the implementation of blockchain to minimize the market for counterfeit and falsified medicines, and the surge of the blockchain-based systems for the same.

## II. LITERATURE REVIEW

The siloed and fragmented supply chain network of the pharmaceutical industry paves the way for numerous entry and exit points which make the products susceptible to the usage of substandard type, contamination, and adulteration processes [5].

Designing digital platforms with market-ready solutions to cater to the changing market paradigm is gaining traction. The growing emergence of organized trade, rising purchasing power, coupled with a shift towards digitalization are changing the market dynamics of customer opportunities across the different regions of the world. Problems related to a product's quality and safety are not only prevalent in developing countries but in developed countries as well. Counterfeiting products poses a worldwide issue, with the situation worsening in developing countries. At times, it becomes difficult for businesses to detect drug counterfeiting owing to their movement across the complex distributed networks, thereby creating entry opportunities for the counterfeits in the supply chain [6]. Such fraudulent activities can be valid for both generic and branded products.

Unreliable or unsafe counterfeit products are expected to negatively impact the market perception of the genuine products that are being copied, thereby reducing the potential sales of the same. Increasing consumerism is expected to bolster counterfeiting trade activities. The manufacture and sale of counterfeiting products are expected to impact retailers, distributors, and manufacturers.

In certain situations, adverse publicity, and counterfeit products might extend to the companies that manufacture legitimate products or sell the same, further damaging the industry's identity and reputation. The incorporation of different methods to curb counterfeiting across different product categories are thereby a necessity.

The rising trends towards anti-counterfeiting solutions are anticipated to add another level of complexity to the various coding necessities such as the usage of UV inks and serialization codes. Pharmaceutical companies nowadays are emphasizing on the implementation of seamlessly trackable technologies throughout the supply chains without the involvement of duplication risks. The companies are inevitably engaged in offering products that help enhance patient safety, combat counterfeiting, and cater to regulations as well as several industry concerns. Counterfeiting and traceability measures are expected to witness

an improvement due to the usage of variable data on labels, such as unique coding and marking on the packages. These measures or solutions include the application of overt and covert security coding, usage of holographic labels, and employing special color schemes to identify specific product types. The two types of anti-counterfeiting packaging strategies being incorporated include covert and overt strategies.

- The *overt* packaging technologies include uneven package designs (such as holograms and color-shift inks) which can be verified at different angles, enabling quick authentication without sophisticated devices.
- The *covert* packaging technologies require special detection devices, posing a challenge for counterfeiters to duplicate. This includes biological tracers, molecular markers, micro-text, ultraviolet inks, and taggant systems comprising of radio frequency microchips [7].

In today's scenario, the companies emphasize implementing full traceability, visibility, and serialization programs, offering them a competitive advantage over other pharmaceutical vendors. Implementation of serialization codes and barcodes is expected to help identify individual products, shipments, and packaging, thereby favorably impacting factors such as visibility and authentication. One vital way to reduce counterfeiting is to ensure that medicine packs carry unique identifiers. Serialization in the pharmaceutical industry focuses on assigning an exclusive code to every single unit or package of medicine, which is then tracked in the supply chain. Simple and effective data structure communication between logistics, sales, and production, plays a vital role in delivering a significant level of security, traceability, and accountability. The drug distribution system comprises several entities, which include wholesale distributors, manufacturers, and pharmacies before the products reach the end-users [8].

With the implementation of tracing and tracking capabilities across touchpoints in the supply chain

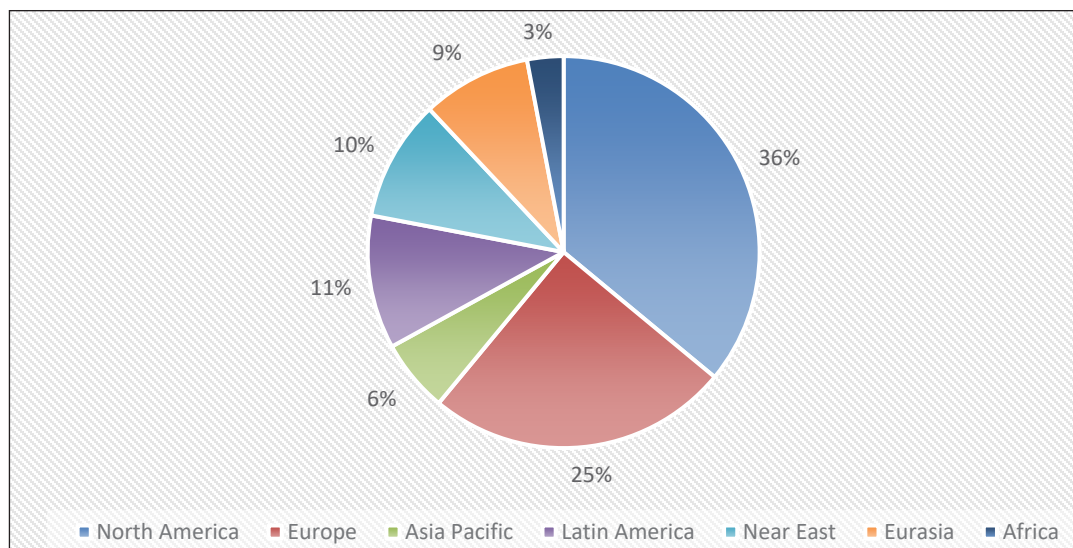
process, various challenges and bottlenecks can be overcome. The process of traceability offers excellent benefits such as the ability to troubleshoot and investigate the issues associated with a product. A few of the issues faced by manufacturers across different verticals include product recalls and replacements. Implementation of an appropriate drug product-coding scheme can be attained by generating unique serial numbers for tracking and marking, thereby enabling a seamless tracking process across the supply chain, and blocking the progress of illegitimate serial numbers. Traceability via the entire supply chain is vital in any quality defects or manufacturing, particularly those necessitating a recall from the producer [9]. With the incorporation of efficient tracking systems, the company can easily track the finished goods, and the processes relevant to product handling in the distribution and manufacturing systems. Hence, keeping track of the entire supply chain process is one of the critical areas manufacturers should focus on.

### III. GLOBAL DRUG COUNTERFEITING SCENARIO

Counterfeiting of drugs has increasingly become a major health issue in both industrialized and developing countries [10] [11]. Nearly 15 percent of the drugs sold in the world are counterfeit [12].

The developing nations account for a substantial part of the forged drugs being distributed in the world. According to the World Health Organization, nearly 1 out of 10 medical products in developing countries are spurious or counterfeit [13]. Increasing incidences of drug counterfeiting can be attributed to the complexity of the drug counterfeiters due to the limited enforcement capability and regulations in developing countries. People in underdeveloped countries emphasize on reasonably priced alternatives due to the unavailability and high pricing of medicines.

Increasing incidents of counterfeiting concerning pharmaceutical companies across the world, region-wise, are illustrated in the graph mentioned below:



Source: [14]

Fig. 1: Number of Counterfeit Incidents Region-Wise, 2022

Counterfeiting of the drugs in different segments is gaining significant traction across the different regions of the world. For instance, the drugs fitting in the therapeutic categories are significantly being forged across the globe. The anti-infective drug category, such as antivirals, antibiotics, antimalarials, and antifungals account for most of the drugs being counterfeited, ranging from approximately 10 percent to nearly 50 percent [15]. Further, in the anti-infective drug segment, the antibiotics are expected to be highly falsified [16].

Although low-income and developing countries are witnessing a surge in counterfeiting incidents, developed nations such as the regions of the US, Europe, and Canada also hold a significant share in the same, thereby increasing the need to combat the same.

#### IV. IMPACT OF COUNTERFEITING ON THE GLOBAL ECONOMY

Scammers nowadays are increasingly replicating the products at a larger level, thereby turning illegal fraud into an enterprise-level industry. The unawareness of supply chains with forged goods is expected to make the companies unattractive and volatile targets for investors, thereby leading to severe damage to the corporate Environmental, Social, and Governance (ESG) aspects.

Counterfeit products contribute nearly 3.3 percent of the value of the global economy annually [17]. The rising counterfeiting and piracy issues on legitimate economic activities increase the economic costs, which further drives fiscal losses. This refers to manufacturers facing competitors that are taking away their intellectual property (IP) rights without complying with the regulatory standards or payment of taxes. Counterfeiting is also expected to impact the foreign direct investment (FDI) scenario of a country, thereby failing to attract multinational innovators to that region.

#### V. TECHNOLOGICAL INNOVATIONS TO COMBAT COUNTERFEITING

Increasing advancements in simple field tests and forensic chemical analysis are expected to augment drug quality monitoring, access to low-cost genuine medicines, cooperation with determined political management, and stringent law enforcement, as well as support the drug regulatory authorities, to combat the counterfeiting threat.

Using a forged medicine is significantly substandard, comprising of inactive or fewer ingredients in an appropriate measures leading to treatment failure [18]. The concern to reinforce intellectual property rights and ensure brand protection for pharmaceutical companies, with the possibility for counterfeit drugs

to cause mortality is witnessing an increase. The overtly visible markers on a drug's packaging are gaining traction owing to its potential to identify fake products. However, distinguishing markers and holograms, when applied to the paper substrates, film, or blister foils can be copied to a higher extent with much accuracy. The rising sophistication of illegal manufacturers thereby, plays a pivotal role in the launch of advanced technologies. To avoid counterfeiting, the manufacturers, and suppliers link on a single blockchain platform with the usage of exclusive cryptographic identifiers "smart tags" to track and approve the provenance and position of each item. The tags can be of different forms, such as security labels with unique RFID, and QR codes that comprise of a customized software component. A few technological innovations can be illustrated as:

*Smartphone Applications:* Increasing smartphone applications enables customers to instantly check the authenticity of the products before making a purchase. The applications allow the brand owners to recognize, avert, and track brand invaders from selling counterfeit products. Advancements in smartphone technologies are expected to boost the integration of anti-counterfeiting solutions in terms of product authenticity, thereby enabling the owners to prevent infringing on any type of drug. For instance, Unique Product Identifier (UPI), in retail outlets helps the consumers comprehend the authentication of the product, and accordingly inform the customers about the counterfeiting of the same.

*Radio Frequency Identification (RFID):* Technologies such as RFID offers strategized labeling solutions, inventory control, and automatic tracking. It generates significant impacts with a unique selling proposition, such as secure supply chains, quality monitoring, cold chain, anti-counterfeiting, and improved information for the decision-makers [19]. Technology also plays a crucial role in the packaging of pharmaceutical products, protecting them from getting tampered with, and, defending against monetary crimes [20]. Incorporation of RFID in the pharmaceutical industry thereby enables businesses to seamlessly cater to difficulties such as diversion, theft, and counterfeiting and ensures the legitimacy of the medications arriving at the pharmacies.

Companies are increasingly emphasizing on enabling safe, secure, and transparent sharing of information, thereby saving businesses from offering forged products. In addition to this, in the pursuit to gain continual confidence in the exported drugs, the regulatory bodies of organizations, nowadays are focusing on improvising on mechanisms to attain real-time visibility into all the pharmaceutical products being manufactured and exported. Various advanced technologies such as RFID, image processing, blockchain, pattern recognition, and others are thereby, significantly gaining traction to address the changing scenario.

However, businesses incorporating state-of-the-art technology such as blockchain, offer, unprecedented scalable solutions catering to the existing challenges in the dynamic marketplace. In addition to collaborating the QR codes and Distributed Ledger Technology, the blockchain solutions also poses to be significantly compatible with other technologies, such as GPS, RFID, or NFC, based on the contactless relocation of data.

## VI. BLOCKCHAIN TECHNOLOGY TO COMBAT DRUG COUNTERFEITING

Blockchain technology enables a revolutionary level of supply chain transparency in businesses. A blockchain-based supply chain of drugs depends on the inclusion of entities such as pharmacists, distributors (3PL), and manufacturers on a reliable system powered by blockchain. Organizational and multi-stakeholder involvement poses to be an integral part of the drug supply chain.

A supply chain comprising of partners, distributors, vendors, and suppliers is created, at the time when the drug bottles are labelled, scanned, and documented on the blockchain at every stage, from the plant to the pharmacy. The distribution points in the supply chain processes supply the medical products to the customers in bulk quantities. There are several unsecured, and unverified points of contact, which significantly pose as an entry point for the lethal forged drugs. The medical product supply chain process comprises of several parties such as wholesalers, patients, pharmacies, supermarkets,

suppliers, and manufacturers. Understanding the way how counterfeit drugs make their way in the supply chain processes, plays a crucial role in the implementation of the technology. This includes the ways:

- The probability of the key players being corrupt in the supply chain processes (mislabelling, substituting, or contaminating).
- Possibility among the manufacturers of not being aware of the source of the ingredients.
- The drug or ingredient manufacturers posing as legitimate companies due to incorrect papers [21].

With no secure or robust system and several points of entry, tracking the drugs in supply chain processes is significantly challenging. Blockchain, based on DLT empowers the storage of data in a decentralized manner, rather than in a central database. Every entry is independently encrypted and every change needs to be verified by all the distributed nodes in the system, making it virtually unbearable to address a blockchain. When stored, the data becomes difficult to be tampered with, owing to the easy identification of weak points and detection of fraudulent activities, thereby offering enhanced counterfeiting protection to the companies [22].

Keeping track of the activities associated with medical products poses to be considerably difficult with the increasing complexity of the processes, thereby limiting the data provenance and transparency checks for the same [23].

Blockchain helps in tackling the issues of counterfeiting by focusing on the identification of proof-of-origin of the product and offering a trusted and secure tracking system from one end to the other end of the supply chain. The pharmaceutical products are systematically serialized and assigned the security features, which are easily differentiated and verifiable by the consumers from counterfeits. Serialization of the drugs caters to the security threat of false medications, via digital signatures, health information, and blockchain codes [24]. Incorporation of this technology enables the security via transparent and chain code-based transactions. This can be largely attributed to the features offered

by blockchain technology, such as decentralization, immutability, decentralization, distribution, and transparency, which can address the issues of trustless between parties, tracking and monitoring all processes of the drug supply chain.

## VII. BLOCKCHAIN-BASED ARCHITECTURES FOR DRUG TRACEABILITY

Counterfeit drugs contribute to major health concern severely impacting the treatment outcomes and lives of the individuals. Growing access to the medicines via unauthorized distributed channels and online pharmacies makes it difficult to guarantee the safety of products in the supply chain process.

The traceability of drugs based on blockchain technology helps create a distributed shared platform for a transparent, accountable, trustworthy, and immutable system in the supply chain process. The two potential blockchain-based architectures include hyperledger fabric and hyperledger besu, which offer a higher degree of transparency, decentralization, trust, data integrity, scalability, modularity, security, deployment, and privacy in comparison to the other platforms based on blockchain. These act as the enablers for generating private permissioned ecosystems, wherein, the pharmaceutical end-users and stakeholders are listed, and controlled by a group of stakeholders.

*Hyperledger Fabric Architecture:* This architecture is a platform offering disseminated ledger solutions, derived by a modular architecture remitting higher degrees of scalability, resilience, and confidentiality. This enterprise-grade DLT is based on technology that uses smart contracts to carry out the trust between several parties and offers higher transaction throughput, up to nearly a thousand transactions per second [25].

*Hyperledger Besu Architecture:* This architecture has gained significant traction among enterprises, owing to the fact, that it backs the building networks supporting both integration with the public blockchains (Ethereum) and private transaction processing while upholding the high transaction throughput and architectural flexibility.

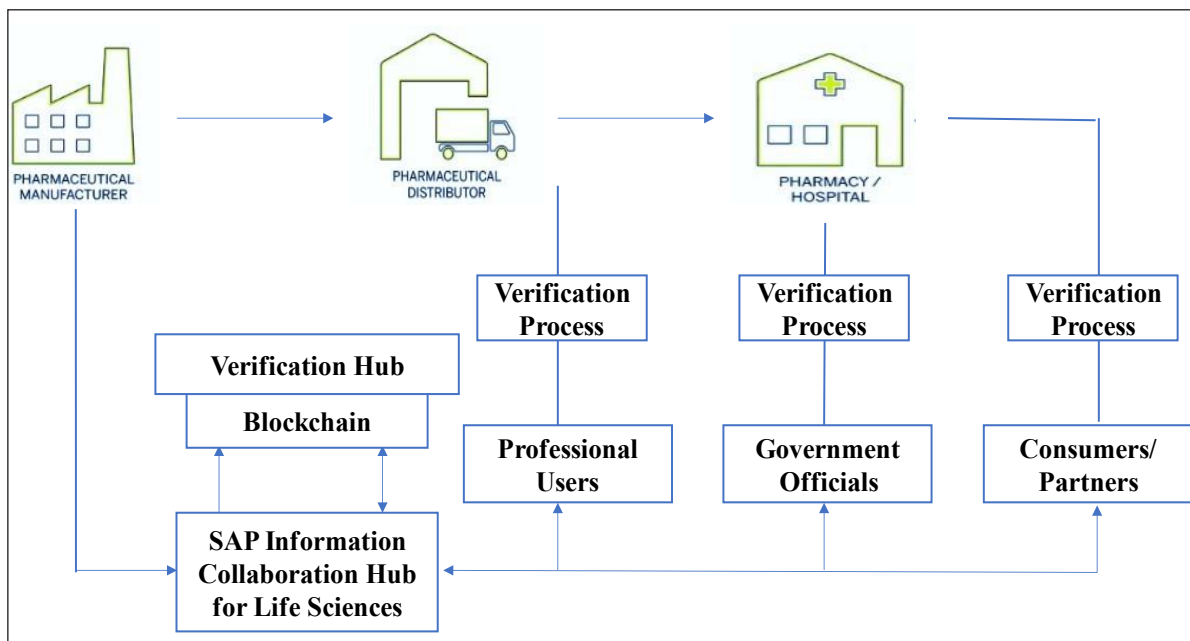
### VIII. USE CASES OF BLOCKCHAIN IN DRUG COUNTERFEITING

In 2019, in reaction to the FDA’s call to form trial projects, in order to test the automated inter-operable systems, the pharmaceutical companies, announced the development of a blockchain platform such as MediLedger Network, to trace forged drugs and prescriptions and eliminate them subsequently [26].

- *HCL Technologies Limited*

HCL Technologies Ltd. announced the launch of strategies to combat the counterfeiting of drugs with blockchain and SAP. In 2017, SAP teamed up with leading pharmaceutical firms such as Boehringer

Ingelheim, AmerisourceBergen, GlaxoSmithKline, and, Merck to develop distributed ledger and blockchain-based decentralized solutions to cater to legal compliance necessities. In 2019, SAP announced an “Information collaboration hub for Life Sciences blockchain solutions”, supporting the eradication of counterfeit drugs through the supply chain processes in the pharmaceutical industry. The developed solutions are designed to minimize drug counterfeiting as per the government by keeping to the directives necessitating the serialization of drugs. The SAP ICH offers its partners/customers with different connectivity choices as per the technological specifications and business needs.



Source: [27]

Fig. 2: Model for SAP – Blockchain Solution by HCL Technologies Limited

The SAP information collaboration hub for the life sciences connects the supply chain partners, such as Contract Manufacturing Organization (CMO), Marketing Authorization Holder (MAH), Third-Party Logistics service provider (3PL), and wholesaler.

SAP announced the launch of the solution known as “Advanced Track and Trace for Pharmaceuticals (ATTP)” which creates exclusive identifiers for the packaging of the drugs. The solutions help store the information into four subsets: batch number, serial number, expiry date, and item number on the basis,

of the GSI standard. Immediately upon the shipment of the box, the items get registered, and stored.

The items get registered on the blockchain when a manufacturer ships a box, and this is stored transparently. With the specific code recognition technology, SAP has the capability to track and monitor the packages efficiently at any point, thereby making the process seamless.

*Benefits Offered:* The benefits offered by the implementation of SAP blockchain solutions in businesses include transparency to enhance

accountability, end-to-end traceability of drug products, minimal losses related to counterfeiting, and efficient recall management.

- *Vault Security*

Vault Security, the US-based company is engaged in addressing the security challenges with cutting-edge applications backed by technologies such as Blockchain. The ivault solutions offered by the company are incorporated into the businesses to augment the logistics management and supply chain networks, with advanced security.

*For Businesses:* The company offers ivault.verified, which is a smart anti-counterfeiting technological solution incorporated in businesses, to enhance the future of blockchain in supply chain processes. The solutions offered are sustainable, scalable, affordable, and effective, that caters to the needs of the individuals effortlessly.

*For Customers:* The company is the provider of solutions that protect individuals from being duped in the purchase of fake or counterfeit medications, leading to death, illness, or other harmful effects [28].

The ivault™ blockchain technology is engaged in applications such as anti-counterfeiting technology, distributed computing, blockchain architecture, cloud elasticity, and data warehousing, thereby making the supply chain process an efficacious one. Incorporation of this technological solution, offered by Vault Security offers a revolutionary level of transparency in the supply chain process, thereby ensuring complete protection of the same.

- *Pfizer*

Pfizer, a pharmaceutical giant, is increasingly emphasizing towards the adoption of blockchain technology, to augment medical services. The company announced its partnership with Aimedix, a healthcare startup, to implement the latest technological innovations in the healthcare industry. The company emphasizes on researching and developing the latest therapies, and solutions to improve the lives of individuals across the world. Pfizer operates with nearly 86,000 blockchain

projects, to track the health of patients and improve pharmacovigilance [29].

*Pfizer's Anti-Counterfeiting Program:* Pfizer has announced the introduction of a focused and aggressive campaign to deter, disrupt, and detect the key manufacturers and suppliers of counterfeit drugs in the industry. The company is engaged in working with law enforcement agencies, customs offices, pharmacies, and wholesalers to augment the surveillance of re-packagers and distributors, monitor the distribution channels, and increase inspection coverage. Pfizer also emphasizes on efficacious conduct and management of proactive investigations from the professionals, patients, along with confidential information related to the sales trends and volumes from the enforcement authorities [30]. The anti-fraud measures offered by Pfizer are patient-centric and are designed to identify and disrupt the fraud affecting the operational activities and accordingly address the breakthroughs to save lives.

- *Novartis*

Novartis announced the adoption of blockchain technology in 2016, with various proofs of Concepts (PoCs) [31]. The company emphasizes on securing the supply chain processes, with the tamper-evident and serialization features on the medical products.

Authentifield, under the brand name Novartis, offers anti-counterfeit solutions for testing and rolling out a new generation of mobile spectrometers, to efficaciously monitor the portfolio of drugs, and prevent individuals from being misled to purchase the falsified products [32]. The company is an industry leader in establishing a 29-member blockchain consortium for the European pharmaceutical industry and the European Union, known as Pharmaledger [33].

## IX. CHALLENGES IN THE IMPLEMENTATION OF BLOCKCHAIN TECHNOLOGY TO COMBAT DRUG COUNTERFEITING

The notable challenges in implementing blockchain based track and provenance solutions in the pharmaceutical industry are illustrated as:

*Interoperability:* The prevailing drug traceability solutions such as e-pedigree, bar codes, serialization, blockchain-based platforms, and solutions, as well as RFID tags lack full interoperability, considering the fact, that, there are no homogenous solutions to make the implementation, adaptability, and integration of the same a seamless one [34]. The various platforms under the hyperledger umbrella are catering to the issues to ensure maximum adaptability, scalability, and interoperability as well as enable external and internal communication between the organizations.

*Implementation and Cost:* Designing of an application based on blockchain poses to be a difficult task, because majority of the prevailing solutions are under development. The interoperability, scalability, and privacy tests contribute significantly to this problem. The energy and implementation costs are one of the leading problems being faced by the supply chain processes of the drugs. In addition to this, the existing legacy software systems and platforms are centralized and poses to be inefficient at the time of executing the transactions, thereby leading to higher maintenance and implementation costs. For instance, the hyperledger fabric owes the potential to execute nearly 3500 transactions per second with less power consumption in comparison to Ethereum, owing to the different consensus protocols [35].

## X. CONCLUSION

Counterfeiting acts as a menace to the businesses, with the need to be countered effectively and actively [14]. Lack of stringent regulations and growing international free trade contribute significantly to the rise of counterfeit products. The pharmaceutical segment nowadays, is increasingly being vulnerable to the counterfeiting issues.

Combating these challenges is thereby gaining traction. The drug companies across the different regions in the world are inevitably engaged in offering products which helps in enhancing the patient safety, combating counterfeiting, and caters to regulations, as well as several industry concerns. Cutting-edge technologies such as blockchain unfold unusual opportunities to minimize the scam in the pharmaceutical industry, owing to its unparalleled

features such as transparency, distribution, decentralization, and immutability [36].

Several studies have been conducted on a decentralized supply system with immutable and secure tracking capabilities via blockchain technology. This article discusses the different technology-based approaches, that help in averting the counterfeiting of drugs. It emphasizes on the ways blockchain technology helps in combating the counterfeiting of drugs in the pharmaceutical industry, with the inclusion of a few use cases of the businesses incorporating the same.

## REFERENCES

- [1] K. S. Ziavrou, S. Noguera, and V. A. Boumba, "Trends in counterfeit drugs and pharmaceuticals before and during COVID-19 pandemic," *Forensic Sci International*, vol. 338, p. 111382, 2022.
- [2] M. Amusa, and B. Oluwade, "A historical background of some basic ICT tools used in counterfeit drug control," *African Journal of Computing*, vol. 13, no. 1, pp. 52-61, 2020.
- [3] H. Isah, "Information and communication technology in combating counterfeit drugs," *Int. J. Eng. Technol.*, vol. 2, 2012.
- [4] European Union, "Unique device identification (UDI) system: Under The EU medical devices regulations, 2017/745 and 2017/746," *European Union*, p. 6, 2020.
- [5] P. Sikri, "Counterfeit and fake medicines: challenges for supply chain," Jul. 20, 2022. [Online]. Available: <https://www.financialexpress.com/healthcare/pharma-healthcare/counterfeit-and-fake-medicines-challenges-for-supply-chain/2600555/>
- [6] F. Jamil, L. Hang, K. Kim, and D. Kim, "A novel medical blockchain model for drug supply chain integrity management in a smart hospital," *Electronics 2019*, vol. 8, no. 5, p. 505, 2019. [Online]. Available: <https://doi.org/10.3390/electronics8050505>
- [7] S. V. Nair, "How technology can tackle counterfeiting in the pharmaceutical industry," Apr. 19, 2022. [Online]. Available: <https://>

- www.healthcareradius.in/features/pharma/how-technology-can-tackle-counterfeiting-in-the-pharmaceutical-industry
- [8] S. Deakins, "Serialization: Reducing counterfeit drugs and increasing sales," Aug. 3, 2021. [Online]. Available: <https://www.pharmtech.com/view/serialization-reducing-counterfeit-drugs-and-increasing-sales>
- [9] S. Kabra, "Fighting the issue of counterfeiting in india's pharmaceutical industry," May 8, 2022. [Online]. Available: <https://timesofindia.indiatimes.com/blogs/voices/fighting-the-issue-of-counterfeiting-in-indias-pharmaceutical-industry/>
- [10] O. Buowari, "Fake and counterfeit drug: A review," *Afrimedical Journal*, vol. 3, no. 2, pp. 1-4, 2012.
- [11] A. Chika, S. O. Bello, A. O. Jimoh, and M. T. Umar, "The menace of fake drugs: Consequences, causes and possible solutions," *Research Journal of Medical Sciences*, vol. 5, no. 5, pp. 257-261, 2011.
- [12] "Fighting fake drugs: The role of WHO and pharma," *The Lancet*, vol. 377, no. 9778, p. P1626, May 14, 2011.
- [13] D. Bagozzi, and C. Lindmeier, "1 in 10 medical products in developing countries is substandard or falsified," Nov. 28, 2017. [Online]. Available: <https://www.who.int/news/item/28-11-2017-1-in-10-medical-products-in-developing-countries-is-substandard-or-falsified>
- [14] R. Pathak, V. Gaur, H. Sankrityayan, and J. Gogtay, "Tackling counterfeit drugs: The challenges and possibilities," *Pharmaceutical Medicine*, vol. 37, pp. 281-290, 2023.
- [15] P. Newton, M. D. Green, F. M. Fernandez, and N. P. John Day, "Counterfeit anti-infective drugs," *The Lancet Infectious Diseases*, vol. 6, no. 9, pp. 602-613, 2006.
- [16] A. Delepierre, A. Gayot, and A. Carpentier, "Update on counterfeit antibiotics worldwide; public health risks," *Medecine et Maladies Infectieuses*, vol. 42, no. 6, pp. 247-255, 2012.
- [17] R. Jones, "The impact of counterfeits on environmental, social and corporate governance agendas," May 10, 2022. [Online]. Available: <https://www.forbes.com/sites/forbesbusinesscouncil/2022/05/10/the-impact-of-counterfeits-on-corporate-environmental-social-and-governance/?sh=88bd85f4dc21>
- [18] C. Hall, "Technology for combating counterfeit medicine," *Pathog Glob Health*, vol. 106, no. 2, pp. 73-76, 2012.
- [19] I. Ungurean, C. Turcu, V. Gaitan, and V. Popa, "An RFID-based anti-counterfeiting track and trace solution," in *Designing and Deploying RFID Applications*, IntechOpen, 2011.
- [20] S. Hsia, "How is RFID used for anti-counterfeiting?," Mar. 4, 2022. [Online]. Available: <https://nexqo.com/2022/03/rfid-for-anti-counterfeiting/>
- [21] D. Nandan, "How blockchain can help fight counterfeit drugs in India," Jul. 26, 2018. [Online]. Available: <https://www.forbesindia.com/blog/technology/how-blockchain-can-help-fight-counterfeit-drugs-in-india/>
- [22] P. Sinistra, "Counterfeit drugs 2021 statistics and facts or: How blockchain can fight the pandemic," Feb. 4, 2021. [Online]. Available: <https://vaultsecurity.io/counterfeit-drugs-2021>
- [23] V. Mani, M. Prakash, and W. C. Lai, "Cloud-based blockchain technology to identify counterfeits," *Journal of Cloud Computing*, vol. 11, 2022, Art. no. 67.
- [24] W. Alshahrani, and R. Alshahrani, "Assessment of blockchain technology application in the improvement of pharmaceutical industry," in *International Conference of Women in Data Science at Taif University (WiDSTaif'21)*, 2021.
- [25] C. Gorenflo, S. Lee, L. Golab, and S. Keshav, "FastFabric: Scaling hyperledger fabric to 20,000 transactions per second," in *International Conference on Blockchain and Cryptocurrency (ICBC'19)*, 2019.
- [26] N. A. Beaver, J. D. Lanza, G. B. Solomon, E. Wang, and K. E. Wegrzyn, "Get real: Preventing counterfeit product with blockchain," Oct. 13, 2021. [Online]. Available: <https://www.foley.com/en/insights/publications/2021/10/preventing-counterfeit-product-with-blockchain#:~:text=In%20response%20>

- to%20the%20FDA%E2%80%99s%20call%20in%202019,globe%20in%20hopes%20of%20eliminating%20counterfeit%20medicines.%2011
- [27] S. Mahajan, "Combating counterfeit drugs with SAP and blockchain," Apr. 1, 2021. [Online]. Available: <https://www.hcltech.com/blogs/combating-counterfeit-drugs-sap-and-blockchain>
- [28] V. Security, "Vault security," 2018. [Online]. Available: <https://vaultsecurity.io/ivault-blockchain-applications>
- [29] W. McCormick, "Pfizer is latest multinational giant to explore blockchain," Jul. 25, 2018. [Online]. Available: <https://cryptobriefing.com/pfizer-multinational-explore-blockchain/>
- [30] Pfizer, "Combating counterfeit medicine," [Online]. Available: <https://www.pfizer.com/products/medicine-safety/counterfeiting>
- [31] N. Morris, "Novartis explores blockchain's potential for pharmaceuticals," Aug. 22, 2018. [Online]. Available: <https://www.ledgerinsights.com/novartis-pharma-blockchain/>
- [32] Novartis, "Novartis." [Online]. Available: <https://live.novartis.com/article/fighting-fake-medicines/fighting-fake-medicines-4-digital-technology-boost#!>
- [33] A. Takyar, "Blockchain in pharma supply chain - Reducing counterfeit drugs." [Online]. Available: [https://www.leewayhertz.com/blockchain-in-pharma-supply-chain/#blockchain\\_supply\\_chain\\_use\\_cases](https://www.leewayhertz.com/blockchain-in-pharma-supply-chain/#blockchain_supply_chain_use_cases)
- [34] G. G. Dagher, J. Mohler, M. Milojkovic, and P. Babu Marella, "Ancile: Privacy-preserving framework for access control and interoperability of electronic health records using blockchain technology," *Sustainable Cities and Society*, vol. 39, pp. 283-297, 2018.
- [35] M. Uddin, K. Salah, R. Jayaraman, S. Pesic, and S. Ellahham, "Blockchain for drug traceability: Architectures and open challenges," *Health Informatics Journal*, vol. 27, no. 2, 2021.
- [36] A. Quzmar, Mohd. Qatawneh, and S. Al-Maaitah, "Reducing counterfeit drugs with blockchains: A survey," in *International Conference on Information Technology (ICIT'21)*, Amman, Jordan, 2021.