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Integrating Blockchain Technology in Pharmaceutical Supply Chains

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Abstract:

This paper presents a transformative approach to enhancing transparency, security, and traceability. By utilizing a decentralized ledger system, stakeholders can access real-time data about drug provenance and distribution, thereby increasing consumer confidence and improving regulatory compliance. Existing pharmaceutical supply chains face significant challenges, including counterfeit drugs, lack of visibility, and inefficiencies in tracking products through complex logistics networks. These issues lead to financial losses, compromised patient safety, and regulatory penalties. This study proposes a novel framework, the Pharmaceutical Supply Chain using Blockchain Technology (PSC-BCT), designed to address these existing challenges. The PSC-BCT framework leverages smart contracts, distributed ledgers, and IoT integration to create a secure, transparent, and efficient supply chain ecosystem. This framework enables all participants, from manufacturers to pharmacists, to share and verify transaction data, thereby enhancing accountability and reducing the risk of fraud. The proposed method is utilized to streamline operations, reduce delays, and enhance data integrity within the pharmaceutical supply chain. By ensuring that every transaction is recorded immutably, stakeholders can verify product authenticity and track the drug's journey from production to the end consumer. The findings indicate that the PSC-BCT framework significantly improves supply chain transparency and efficiency while reducing instances of counterfeit drugs. Furthermore, the implementation of blockchain technology fosters trust among stakeholders and enhances compliance with regulatory standards, ultimately leading to improved patient outcomes and safety.

Keywords: Decentralized Ledger, Supply Chain, Pharmaceutical, Blockchain Technology, Logistics Networks..

1. INTRODUCTION

Within the last few years, both scholars and practitioners have also been taken up by the growing number of activities, discussions, and studies associated with blockchain [1]. This technology is a distributed system known for its capability of recording financial operations reliably, quickly and in a secure and verifiable manner [23]. In the same way, it is a centralized database but one that can support a growing number of records, or nodes [3] [6]. The fact that all contracts and execution of transactions which are saved on the ‘blockchain’ technology is almost impossible to change is one of the best advantages of this technology Since all records are transparent and cannot be altered [17]. Many industries such as healthcare and medical research, military, banking and finance, and even insurance are likely to benefit from the introduction of Blockchain despite the limitations of this technology [5][12].

It can be applied even to any undertaking that requires some kind of verification as well as documentation. Fake medicines are produced not in line with appropriate drug manufacturing practices, which is why they are dishonest [24]. Counterfeit drugs can be hard to detect as they even humidity. Since they are made precisely to the genuine article, no defects manufactured [7]. They are passive most often and do not cause any serve effects and are designed to mimic the genuine article rather too much.

On the other hand, they could include dangerous and even poisonous substances, or they don't work as well as advertised in treating the intended sickness or condition[19]. Additionally, pharmaceutical medications are used for the purpose of illness prevention, treatment, and diagnostics [9]. Legitimate pharmaceutical companies lose credibility and money when counterfeit pharmaceuticals hit the market [20]. However, there is an immediate need to stop counterfeits from reaching the market so that patients are protected [11].

The main contribution of the paper is as follows:

- To combat fake medications and improve product traceability, the PSC-BCT framework uses blockchain technology to permanently record all transactions in the pharmaceutical supply chain. This gives stakeholders access to up-to-the-minute information regarding the origin, authenticity, and distribution of drugs.
- The framework improves operational efficiency throughout the pharmaceutical supply chain by automating procedures, reducing delays, and optimising logistics via the use of smart contracts and Internet of Things devices.
- The PSC-BCT framework's decentralised design promotes confidence among producers, suppliers, dispensaries, and authorities by strengthening adherence to industry norms and safeguarding data integrity; this, in turn, improves patient safety and results [14].

The remaining of this paper is structured as follows: In section 2, Pharmaceutical Supply Chains is studied. In section 3, the proposed methodology of PSC-BCT is explained. In section 4, the efficiency of PSC-BCT is discussed and analysed. Finally, in section 5 the paper is concluded[18].

2. RELATED WORK

Blockchain technology is changing the game for pharmaceutical business transparency and traceability. Here explores the intriguing interplay between blockchain technologies and quality management techniques, shedding light on how these two domains work together to tackle pressing issues in the pharmaceutical and healthcare industries [2]. This article will walk you through the many ways in which the immutable ledger technology known as blockchain is improving healthcare, supply chain management, and data security [10]. So, let's set out on this adventure to see how blockchain technology may usher in a new age of transparency and responsibility in the pharmaceutical industry [8].

Pharmaceutical Supply Chain using Analytic Hierarchy Process (PSC-AHP)

In nations where domestic pharmaceutical businesses provide the majority of the pharmaceuticals, the pharmaceutical supply chain plays a crucial role in the health system [4]. Prior research on the pharmaceutical supply chain has not included an evaluation of the risks and interruptions faced by pharmaceutical businesses. Disruptions to the supply of medications and the efficiency of the health system might result from any threats impacting pharmaceutical businesses. Risk assessment in Iran's pharmaceutical business with an eye on process priority, hazard, and probability was the focus of this research by Jaberidoost, M. et al.,[21].

Support Vector Machine based Pharmaceutical Supply Chain (SVM-PSC)

Liu, P. et al., [13] builds a credit risk assessment system using financial data from 80 listed pharmaceutical SMEs and compares the effectiveness of the Logistic model and the support vector machine model for risk evaluation using factor analysis. With a first-type error rate of 12.3% and an overall prediction accuracy that is 3.7% higher than the Logistic model, the results demonstrate that the SVM model is superior and effective when applied to the credit risk evaluation of the pharmaceutical industry under the supply chain finance (SCF) mode.

Big Data Analytics in Pharmaceutical Supply Chain (BDA-PSC)

Ziaee, M. et al., [22] aims to provide improved business intelligence by exploring the use of BDA in the pharmaceutical supply chain using the information processing perspective theory. It can find and talk about the probable advantages of BDA adoption in the five steps of the supply chain operations reference model: planning, sourcing, making, delivering, and returning. Managers from pharmaceutical companies, wholesalers/distributors, and public hospital pharmacies participated in semi-structured interviews. Thematic data analysis was conducted using NVivo software. The results showed that PSC's planning, delivery, and return processes would benefit more with BDA capacity. Fewer people see the value in the sourcing and producing processes.

Pharmaceutical Supply Chain in Machine Learning (PSC-ML)

When it comes to recovery planning and supply chain design, demand foresting is king. The recovery strategy and SC's resilience are both enhanced by precise demand forecasts. This study is to examine the use and impact of ML algorithms on demand forecasting since there is a lack of literature on the topic and because the pharmaceutical sector is in need of innovative approaches. To be more precise, the research evaluates the efficacy of ML-based forecasts in the pharmaceutical SC and identifies ML-based algorithms that may be used for demand forecasting by Yani, L. P. E. et al., [15]. The influence of information technology acquisition and the study's purpose were both investigated using an exploratory technique.

In summary, focusses on several methods for enhancing pharmaceutical supply chains. Risk evaluation in Iran's pharmaceutical industry is the primary emphasis of the PSC-AHP paradigm. Using support vector machines, the SVM-PSC model improves the assessment of credit risk for small and medium-sized pharmaceutical enterprises. The BDA-PSC model investigates how supply chain management, shipping, and returns may all profit from big data analytics. Lastly, PSC-ML explores how supply chain resilience and recovery planning may be improved by the use of machine learning algorithms for demand forecasting [16].

3. PROPOSED METHOD

There are always going to be new ailments, a plethora of medications with different names and labels are flooding the market daily. The patient has temporary relief from excruciating pain with the aid of these drugs. The manufacturing organisations are not recognised or registered, therefore there are no benefits from these pharmaceuticals. What's more, they do not follow the set requirements, and there are numerous downsides. In underdeveloped nations, the use of these counterfeit narcotics is a leading cause of mortality, with children being the most vulnerable victims. Although these medications may not aid in illness recovery, they come with a plethora of additional harmful side effects. There is a grave danger to human health from these medications. The delivery of these counterfeit pharmaceuticals occurs via several intricate networks, making their detection a challenging task.

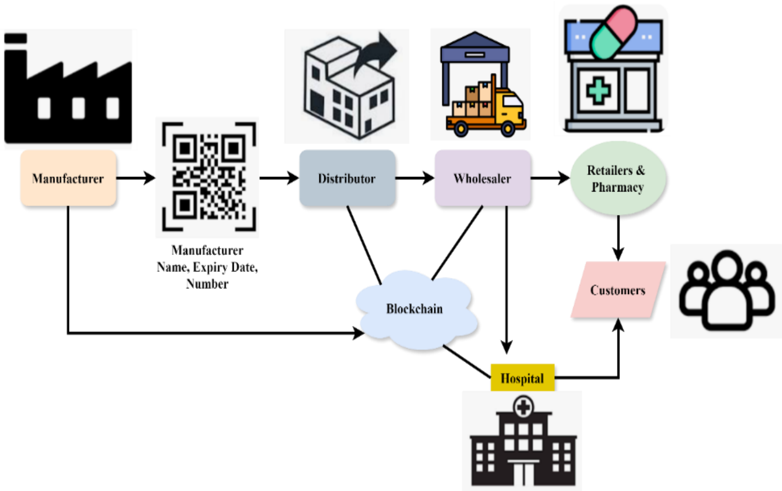

Figure 1: The Architecture of Blockchain in Drug Supply

To begin, the maker will design a quick response (QR) code that includes their name, the date of production, the expiration date, and the number of the transaction. To better identify the medication on the blockchain, the transaction number is useful. After that, the distributor will verify its legitimacy by scanning the QR code. The distributor should add his signature data to the medicine's record when the shipment leaves their storage. All three parties involved—wholesalers, merchants, and pharmacies—will perform the same function. The medication supply chain may be made traceable and trackable by documenting the transactions at each step of the chain. A hash, a timestamp, and the hash of the previous square are all included in each square. Modifying blocks in the middle is prevented by past hash. In this way, the organisation is transformed, uncomplicated, and everlasting. Blockchain, in its simplest form, is a decentralised ledger that ensures the integrity of an organisation by facilitating consensus using algorithms such as Proof of Work, Evidence of Authority, or the organization's own specific algorithms is shown in figure 1.

$$D\{Zx(nb-2q) = Ngt\{Y, M\{\partial + nF\}\} \quad (1)$$

The drug's distribution and purchase variables can be represented by equation 1,$D\{Zx$, delays and inefficiencies can be represented by $(nb-2q)$, the interaction among nodes (such as manufacturers and distributors) can be captured by Ngt, and factors like blockchain identification$\{\partial + nF\}$ and fraud prevention can be entailed by Y, M. By integrating blockchain technology, this equation 1 shows how supply chain efficiency is optimized via the simplification of medication delivery and the reduction of fraud.

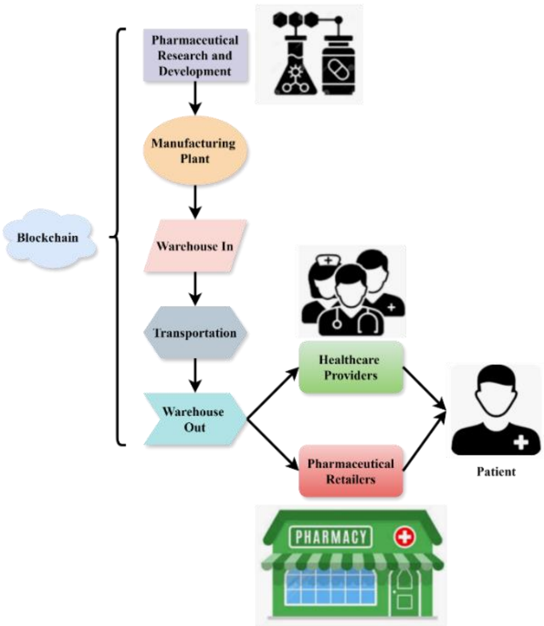

Figure 2: Supply Chain Management in Block Chain

Figure 2 shows the PSC-BCT flow diagram, which is a representation of the pharmaceutical supply chain. The process starts with the original ideas and formulation of the pharmaceuticals in Pharmaceutical Research and Development. The next stop is the manufacturing plant, where the meds are mass-produced. Warehouse In is the first stop in the supply chain as it is where the finished goods are kept. With the movement of the drugs through the Transportation step, the final touch is the movement of the drugs from the manufacturing sites to the distribution system. The products are now in a final distribution stage which is however only accessible after they have been received in the Warehouse Out. It is established that the cut-through of such supply chain imbalances and unethical unbelievable controversies is contributed by the supply chain in more than a reasonable way in as much as all decisions, all monitoring and all transactions are performed and recorded on the same growser. This data is provided to key players such as medical service providers and drug stores in a real time basis which is useful in maintaining the authenticity and the quality of the products. Finally, the products are delivered to the community pharmacies where they are put within the reach of the end users. This concludes the supply chain and ensures that access to the medicines is effective and safe..

$$E(\partial r - 2sw'') + V\{\gamma + \nabla'' Em - 2\} = Bd\{Mt, y - ew''\} \quad (2)$$

The energy expenditure and delays in data processing among blockchain nodes are represented by equation 2 $(\partial r - 2sw'')$, and the verification and agreement mechanism between stakeholders is captured by $Bd\{Mt, y - ew''\}$. Shows how blockchain guarantees safe, real-time verification while lowering inefficiencies, $V\{\gamma + \nabla'' Em - 2\}$ connects verifying transactions and data immutability for the analysis of efficiency.

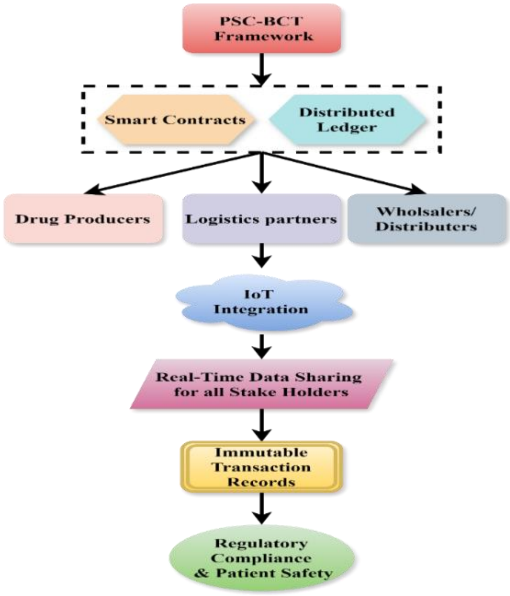

Figure 3: Pharmaceutical Supply Chain using Blockchain Technology

The PSC-BCT architecture uses blockchain technology to make the pharmaceutical supply chain more transparent, secure, and traceable. At its core, this system relies on Smart Contracts and the Distributed Ledger to streamline processes, verify information, and provide an unchangeable log of all operations. Drug producers, logistics partners, and wholesalers/distributors are all involved in these parts since they are in charge of the production, transportation, and distribution of pharmaceuticals. Internet of Things Integration is a critical component of the system that uses sensors, radio frequency identification, and global positioning systems to monitor the delivery, status, and origin of drugs in real-time. With the ability to create immutable records for every product transaction, any assumptions can be made that compliance by the regulations is expected as well the safety of the patients due to the traces of the products and their distributions. This is instrumental in reducing the occurrence of fake drugs substances. The PSC-BCT model brings about effectiveness in operations and better results for the patients as this establishing authority and accountability is illustrated in figure 3.

$$Tew(Max) = BsinH < Fd, mt(y - er'') > +Sk'' \quad (3)$$

The maximum transaction efficiency is represented by the equation $Tew(Max)$, which describes the relationship between data flow $y - er''$, activity frequency Fd, mt, and verification delays. The overhead $+Sk''$ in blockchain validation procedures is captured by $BsinH$. Equation 3 exemplifies the PSC-BCT's data flow optimization, which reduces delays and improves supply chain throughput and security in general for the analysis of patient outcomes.

Due to the permanent data recording of the transactions and the ability to transfer information in real time, the efficiency of the supply chain activities is significantly improved through the PSC-BCT framework. This ensures regulatory compliance, enhances accountability and reduces the risks of counterfeit drugs. Ultimately, the framework optimizes the pharmaceutical supply chain efficiency, bolsters the safety of patients, and sustains the confidence of the parties involved..

4. RESULT AND DISCUSSION

There has been a paradigm shift in the management of issues regarding the tracking, securing and handling of the transit chain with the Pharmaceutical Supply Chain through Blockchain Technology Architectural Design. Existing systems are threatened by rogue drugs, resource wastage and regulatory loopholes. Using PSC-BCT, a more secure, transparent and efficient system can be established by leveraging on distributed ledgers, smart contracts and IoT. The system provides for the sharing of information in an appropriate manner, management of operations and enhancement of patient safety by establishing processes to be completed in real time, automating those processes and increasing the scope of the products for tracking.

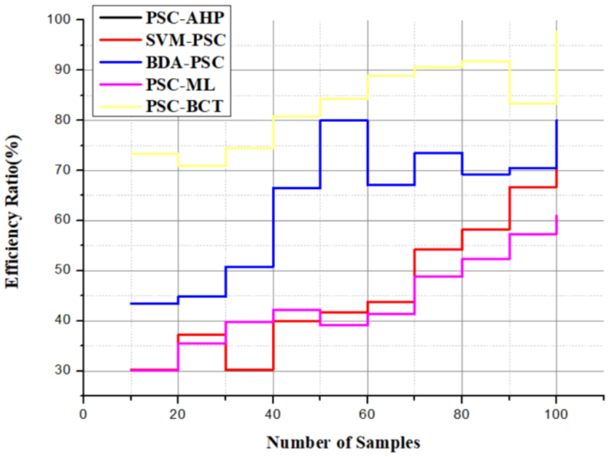

Figure 4: The Analysis of Efficiency

The PSC-BCT methodology assesses efficiency by focusing on the elements of supply chain operations that benefit from the application of blockchain technology in terms of enhanced visibility, security and auditability. Due to the availability of a decentralised ledger, real-time exchange and checks on an operation are possible while at the same time minimising the time lost in completing lengthy bureaucracies and decreasing the risk of an operational error. In the system, smart contracts handle such functions as product and payment audits without requiring any third party in the process, thus facilitating effective and efficient transactions. Due to the help of IoT integration in the medical center, stakeholders are able to quickly track product movement throughout the supply chains due to constant drug tracking. This assures that no resources are wasted within the supply chain, hence optimization of the entire supply chain within its periphery. Other than that, the reliability of the database is enhanced since the information is permanent and cannot be altered, thus decrying the likelihood of corruption or falsification of information. The PSC-BCT framework enhances the operational cost effectiveness while the security and regulatory compliance remains high using equation 2. The efficiency ratio is improved by 98.43% is shown in figure 4.

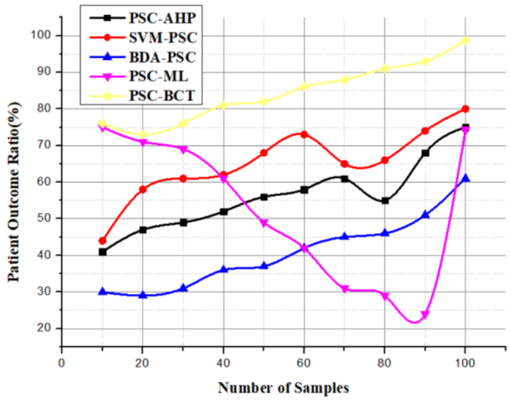

Figure5: The Analysis of Patient Outcomes

Through a PSC-BCT framework, figure 5 show advances in the blockchain technology are increasing the health and safety of patients. The PSC-BCT framework makes certain that counterfeit medicines are limited and only quality medicines reach the patients through enhancing visibility and accountability of the pharmaceutical products, thus limiting the availability of the forged pharmaceuticals. Counterfeit and inferior quality medicines are a big health risk and this helps reduce that risk. How drugs are sourced, made, and how they are distributed is also accessible to healthcare providers because of the timely and secure exchange of data capabilities that the blockchain provides. This makes sure that the medicines which are supplied to the patients have not been contaminated, they have not reached their expiry dates, and they are in the right places for storage. Due to the more visibility correction needs of defective products are quicker, the risk of the patients is reduced because of the correctability of attributes of the faulty features of an item. Better adherence to regulatory requirements has a positive effect on management and the delivery of healthcare services. Patients benefits in terms of safety and outcomes of care are enhanced by the PSC-BCT framework by fostering confidence and reinforcing the pharmaceutical supply chain. The patient outcomes was improved by 97.46% using equation 3..

Enhancement in the efficiency of the PSC-BCT architecture enhances patient outcome, in terms of improved patient safety, by the reduction of delays and fraud in the supply chain management system. This ensures that the entire supply chain is made efficient and such problems like shipping delays and product loss are eradicated. The block chain records are of higher assurance to the users since they cannot be modified thus making the accountability of the transactions and less susceptible to fraud prudent than conceiving.

5. CONCLUSION

The new technology called blockchain is showing great promise to transform a number of different industries. The latest application of blockchain technology in pharmacy industry was the main area of this study. It was reported that systematic review covered 38 publications on the topic under review. The documents that were in the PSC-BCT, were able to, amongst others, handle issues on safety & security, drug delivery, tracking & tracing, and anti-counterfeiting of drugs. It provided a description of each category and discussed its boundaries so that scholars in the future can attempt to bridge the gaps in such a novel area of study. The focus of this PSC-BCT were the blockchain based proof of concept business models for the pharmaceutical industry. It also made a lot of excess talking about vision papers and white papers that have provided ideas and mechanisms as to how the pharmaceutical industry can implement the blockchain technology. In addition, the PSC-BCT pointed out the limitations of the studies of the pharmaceutical industry regarding the issue of blockchain. Discussing the issues of blockchain technology adoption in complex environments, such as, for instance, software defined networks, big data, and edge computing, is one such integral aspect of this PSC-BCT. It continued by talking about where things are headed and how adaptive blockchain designs are needed to handle the computational complexity of cloud computing and large data. The pharmaceutical supply chain business with a solution based on the design science research paradigm. Using Internet of Things sensors and blockchain technology driven by smart contracts, the suggested framework would ensure the end user receives trustworthy pharmaceutical supplies. While the pharmaceutical supply chain is the primary emphasis of our proposed framework, PSC-BCT might benefit from our solution structure, smart contract code, and algorithms.

Future Work: Further optimisation of supply chain efficiency and forecasting of demand changes will be the focus of future work that expands the PSC-BCT framework via the integration of powerful AI-driven predictive analytics. Furthermore, investigating blockchain-based cross-border regulatory compliance methods would boost the framework's worldwide acceptance. The precision of real-time tracking may be enhanced by including additional sensors and devices that are enabled by the Internet of Things. This will result in a more robust monitoring system. Finally, to make sure blockchain platforms are widely used, especially in areas with limited resources where supply chain issues are more common, it is vital to study their scalability and interoperability across different pharmaceutical networks.

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