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A Blockchain and Machine Learning Integrated Hybrid System for Drug Supply Chain Management for the Smart Pharmaceutical Industry

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Abstract

Over the past decade, pharmaceutical businesses have had challenges monitoring their goods across the supply chain, enabling counterfeiters to introduce fraudulent medications into the marketplace. Counterfeit pharmaceuticals are seen as a significant concern for the global pharmaceutical sector. Studies suggest that US pharmaceutical businesses suffer an annual commercial loss of within $200 billion from imitation pharmaceuticals. These medications do not promote patient recovery from the condition but include several hazardous adverse reactions. The World Health Organization (WHO) study data indicates that in underdeveloped nations, one in ten drugs used is fraudulent and of inferior quality. Therefore, a system capable of tracing and tracking medicine distribution at each stage is essential to address the issue of imitation. Blockchain Technology (BCT) can efficiently manage and monitor the Drug Supply Chain (DSC) process. This study proposes and implements an innovative DSC Management System (DSCMS) utilizing BCT and Machine Learning (ML) technologies. The suggested system has two primary components: a BCT-based DSC management engine and an ML-driven drug suggestion system for customers. The initial module implements a DSC monitoring framework utilizing Hyperledger Fabric, designed to monitor and track the drug distribution process inside the innovative pharmaceutical sector. The N-gram and LightGBM algorithms are employed in the ML component to propose the highest-rated medications to pharmaceutical clients. These models have been trained using a widely recognized publicly accessible drug assessment database supplied by an open-source ML library. The ML component is included in this BCT platform via the REST API. The research conducts many assessments to evaluate the efficacy and usefulness of the suggested solution.

Keywords: Pharmaceutical Industry, Drug Supply Chain, Blockchain, Machine Learning.

1 INTRODUCTION

Pharmaceutical firms have encountered challenges monitoring goods across the Drug Supply Chain (DSC) over numerous years (Liu et al., 2021). These deficiencies have facilitated criminals' entry of counterfeit pharmaceuticals into the market. A novel methodology for monitoring and tracing pharmaceuticals is essential to address these issues. Researchers assert that Blockchain Technology (BCT) provides the technological foundation for systems that monitor legitimate pharmaceuticals and inhibit the distribution of counterfeit products (Rana et al., 2021). Imitation pharmaceuticals are classified by the World Health Organization (WHO) as illegally made, mislabelled, of inferior quality, obscure in source information or belonging, and not according to established standards (WHO, 2020).

Although ingested, they induce significant health issues. Counterfeit medication manufacturers employ the trademarks of actual firms to infiltrate the market with their goods (White, 2021). This behavior significantly impacts industrialized nations despite being a worldwide concern. Counterfeit drugs are disseminated through a very intricate network, rendering their removal and detection difficult. A system is required to monitor and trace the shipment of medicines at every level to prevent their spread. BCT is the contemporary breakthrough that pledges to achieve these goals. Figure 1 illustrates the medical sector's Supply Chain Management (SCM) framework (Rizwan et al., 2022).

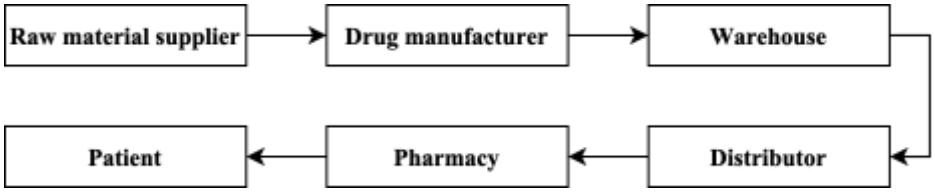


Figure 1: SCM in Pharmaceutical Industries

The medical business is a vital sector that requires regulation for optimization to integrate into the global commerce system. In this context, allocating resources to ensure the financial dominating industry is regulated for optimization is imperative (Xu & Tan, 2020). Despite significant advancements in medicine delivery methods in recent years, it is essential to enhance the accessibility of tablets, identification processes, and the marketplace environment for real-time pricing control. The system allows loopholes to evolve into systemic market inefficiency and failures. This ineffectiveness engenders credibility concerns, medicine shortages, and other complications. This issue is the primary catalyst for market collapses and financial crises. As technology develops, the current social framework needs to accommodate its rapid speed. Therefore, a new measure must be implemented to readjust the dynamics. The proposed design aims to address automation challenges. The healthcare sector self-regulates and derives advantages from BCT (Senbekov et al., 2020). BCT was initially established to function as Bitcoin's transaction ledger. It provides a distributed database for storing data records organized in many "blocks." The gathered data encompasses the respondents, time, date, and price of every exchange. Upon integration into the healthcare supply chain, BCT offers a digital record that allows all network participants to see and authenticate data.

Current Machine Learning (ML) facilitated DSC monitoring and suggestion engines have substantially advanced the effectiveness and security of DSCs (Bashirgonbadi et al., 2024). Several restrictions must be resolved to fully actualize these technologies' promise. This document addresses some constraints. The pharmaceutical sector is extensively regulated, with varying requirements for DSCs across various countries or regions. The absence of standardization complicates the development of globally applicable ML frameworks.

Implementing ML-enabled data SCM and suggestion systems can be costly and require substantial computational resources (Anshari et al., 2023). Expanding the system to accommodate significant data quantities might need some clarification. Most current systems concentrate on enhancing particular

components of the supply chain, such as handling inventory or transportation. End-to-end SCM necessitates a comprehensive strategy encompassing all facets of the supply chain, from production to shipment to the final consumer.

2 RELATED WORKS

The authors introduced and implemented a novel BCT and Machine Learning (ML)-based DSC Monitoring System (DSCMS) (Malik et al., 2023). The proposed solution includes a BC-based DSCMS and an ML-based consumer medication recommending system. Throughout the primary phase, the DSCM technique employed Hyperledger Fabric to continuously monitor and analyze the pharmaceutical distribution process from the intelligent pharmaceutical businesses. The N-gram and Light Gradient Boosting Machines (LightGBM) algorithms are employed in the ML component to offer the most popular or optimal prescriptions to pharmaceutical firms' consumers. Arumugam et al. investigated an Ethereum BCT-based system utilizing innovative contract technology and decentralized off-chain storage to trace products inside the medical sector (Arumugam & Sharma, 2022) efficiently. The intelligent contract verification source of information eliminates the need for intermediaries and provides all stakeholders with a safe, unchangeable record of transactions.

Samadhiya et al. examined the innovative medical governance reliant on the Internet of Things (IoTs) and BCT (Samadhiya et al., 2024). IoT-based BCT is a decentralized ledger technology that maintains immutable transactions, which are susceptible to fabrication and visible to all participants. Implementing an IoT-based BCT approach allows the medical industry to enhance pharmaceutical management across the supply chain, rendering healthcare more dependable and effective.

Huang et al. presented a scenario-based BCT approach for pharmaceutical traceability and regulations called Drugledger, which reconstructs the whole system of services with distinct suppliers as three autonomous service components, guaranteeing data reliability and secrecy (Mishra et al., 2024). Drugledger optimizes its storage, achieving a reliable and appropriate BCT storage solution. Jamil et al. investigated a novel Distributed SCM system employing Hyperledger Fabric based on BCT to manage Distributed SCM data safely (Arun Kumar, 2022). The proposed approach addresses these difficulties by executing medication records on BCT to establish an intelligent healthcare environment with decentralized smart contracts.

Kaladharan et al. developed a BCT-enabled network that allows producers to monitor pharmaceuticals effectively while enhancing safety and openness throughout the SCM process (Kaladharan et al., 2024). The study seeks to reduce the cost and time required for the production company to deliver the drug to customers by employing forward and backward SCM mathematical techniques. The forward chain system ensures prompt medicine supply from the firm to customers via a reliable transportation mechanism. Humayun et al. introduced an innovative monitoring and tracking technology, Medledger, powered by BCT, which utilizes the Hyperledger Fabric BCT environment using chain coding (innovative agreements) (Humayun et al., 2022). The Medledger technique

facilitates the safe and rapid execution of DSC operations from fabric, enabling a secure, permissioned, decentralized system of diverse pharmaceutical players. The chain code is designed, programmed, and implemented using progression diagrams to manage and regulate the interactions among the participating stakeholders from the DSC system.

Albanese et al. created a safe BCT-based Proposal Activity (PA) to issue, sustain, and authenticate medical certifications (Albanese et al., 2020). Singh et al. developed VFChain, a transparent and verified federated learning framework reliant on BCT (Singh et al., 2023). Initially, a committee was selected utilizing the BCT to consolidate procedures and document verifiable evidence within the BCT.

A novel verified information structure was implemented for BC's transparency to enhance the search efficiency of verifiable proof and facilitate the safe rotating of bodies. Ramesh et al. developed an approach utilizing BCT, a privacy-preserving verified data-sharing framework (Ramesh et al., 2022). The author created a unique verified information structure to efficiently validate any segment of the information record provided in a decentralized manner. Ch et al. implemented a Verifiable Query Level (VQL) in the cloud to provide reliable and fast data entry services for BCT systems (Ch et al., 2022). The software layer gathered data from fundamental BCT technologies and efficiently reorganized it into datasets. A cryptography fingerprint can be generated based on all built datasets to prevent the storage of fraudulent databases in the software.

Despite the availability of several ML and DL techniques for diabetes self-care control in this study, it remains crucial to enhance overall effectiveness. The number of attributes in DL algorithms rapidly escalates, resulting in overfitting of the models due to ongoing deeper.

3 PROPOSED BCT AND ML-BASED DSCMS MODEL

The autonomous and distributed characteristics of BCT have enhanced the security and anonymity of the pharmaceutical industry's medication supply chain. The comprehensive DSCMS system is illustrated in Figure 2, depicting respondents and the BCT system, whereby customers oversee and modify all SCM operations.

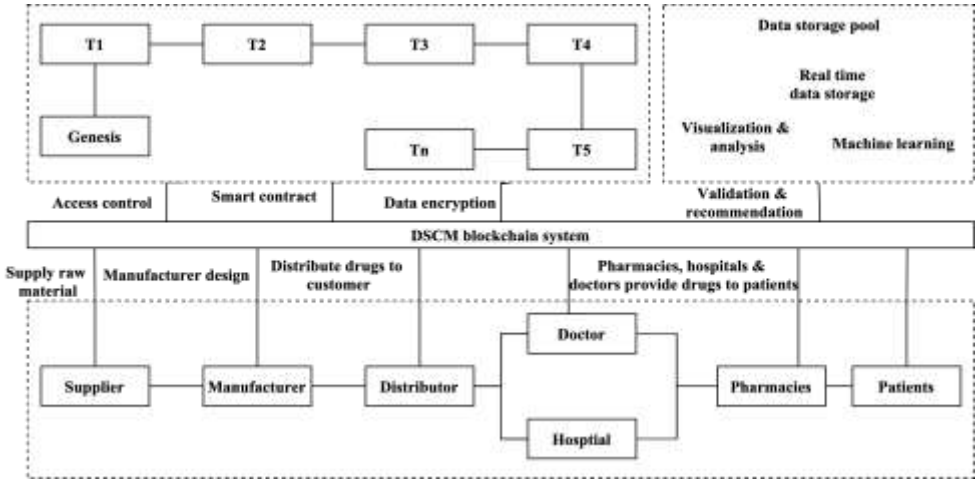


Figure 2: Overview of the DSCMS System

Customer information about system vendors, manufacturers, distributors, pharmacies, hospitals, physicians, and patients is saved in the BCT-based network. The resources of the DSCMS platforms include pharmaceuticals, raw materials, orders, and data repositories. Every system customer has a consumer application-based front-end that facilitates seamless transaction execution and communication with the BCT system. Throughout the whole DSCMS operation, all pertinent system respondents can monitor the progress of medication administration via the patient's software. Conversely, a data storing pool, a distinct data repository, is sometimes called a stored-off BCT. This tool is highly effective for data analysis and representation, which is essential for this platform and healthcare organizations in their work. The platform employs a storing pool for the ML component, which suggests optimal drugs to the consumers. System consumers are granted access to comprehensive facts on pharmaceuticals, ingredients, and other pertinent information such as expiration date, cost, and manufacturing information.

To achieve the reliability of the distributed database, peer nodes in the framework are tasked with executing the consensus method. The first supplier delivers the unprocessed product to the pharmaceutical business. Every system respondent possesses a web-based portal that allows users to log in and execute transactions. When a producer places an order for raw materials, any neighbor node inside the system can authenticate the exchange, and upon validation, the supplier gets the order. When the unprocessed order is prepared for delivery, the vendor executes the order confirmation event.

Conversely, if a consumer thoroughly examines a company's medicinal data, only that individual executes activities delineated by the authorization restrictions inside the BCT system. A physician orders medication from a pharmaceutical business via the suggested BCT structure in a different situation, following the identical procedures outlined in the preceding scenario. Initially, authenticate the doctor, present a transaction suggestion, allow producers to verify the transactions, verify the doctor's transactions, and inform the order status by dispatching an event signal indicating the transaction was approved.

The principal objective of the BCT system is to store data in a decentralized manner, with each block encompassing numerous transactions. These interactions are stored securely by encryption and hashing. The suggested architecture is service-oriented, offering distributed database and intelligent contract functions as services to customers.

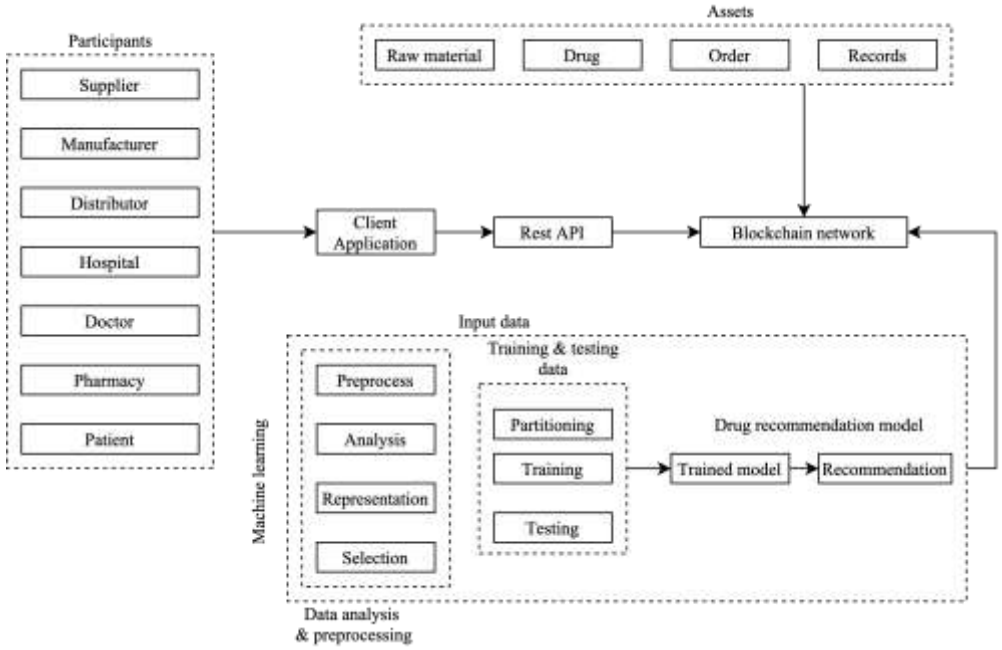


Figure 3: Architecture of the DSCMS System

Figure 3 illustrates the primary architecture of the concept. The suggested system comprises two modules: the DSC monitoring platform and the suggestion platform. This platform enables end-users (vendors, suppliers, pharmacies, physicians, manufacturers, and patients) to execute transactions via a front-end website, facilitating medicine purchases, ingredient availability, data updates for medicines and orders, keeping records, drug delivery, data sharing, tracking of drugs throughout the supply chain, and managing clients, among other functions. The fundamental objective of this framework is to avoid drug counterfeiting and ensure a safe SCM system for end-users. The suggested solution is secure due to BCT technology's integrity and safety control characteristics. For each system, the customer traces the distribution of medicine utilizing the DSCMS platform.

The suggested system executes process (establish, view, modify, and delete) activities among the interconnected peer nodes. The research has implemented channels to enhance privacy among the nodes, creating distinct encrypted networks. This allows nodes inside the same route to communicate data through specific nodes without revealing it to others.

Every respondent can establish a secure connection for security considerations based on the channel's idea. In the platform, customers cannot execute further activities; they can only verify the authenticity of the medication purchased from the pharmacy by reading the barcode affixed to the medicine packaging. Clients are presented with information on the pharmaceutical producer, production date, expiration date, price, and other relevant details. This occurred as a result of the idea of BCT pathways. The research can limit vendors' transactions solely connected to raw materials with the producer. The respondents operate on different paths and utilize the system as a confidential network. Another component of the suggested system is the ML-driven suggestion system, designed to tell the optimal medication to clients of pharmaceutical companies. This module employs ML

techniques Ngram, LightGBM, and psychological evaluation, and it is trained on a collection of customer remarks about the efficacy of the drug, whether positive or negative. According to this instruction, the framework has been advised on the optimal medication for clients, including pharmacies, physicians, healthcare facilities, and individuals.

Customers can utilize this secured BCT network. The agreement method facilitates the connection of the registered user to the private system, enabling transaction execution and management of transaction requests. Every peer node in this BCT-based system possesses an intelligent contract and decentralized ledger inside simulated surroundings, enabling data storage and transaction execution. Due to the intelligent agreement, these nodes verify the exchange post-execution and record the transaction blocks in the database. The primary objective of the agreement method is to preserve a singular transaction history while ensuring that no erroneous transactions are recorded within that record. The agreement technique maintains ledger consistency by generating a unique hashing algorithm and digitally signing all transactions. The altered ledger in the suggested system maintains complete transparency of all action recording pasts, including logs of events of all transactions and activity executed by clients.

4 ML MODEL-BASED SUGGESTION SYSTEM AND RESULTS

This section elucidates the component of the approach, the computerized drug suggestion structure, which utilizes Natural Language Processing (NLP) and ML methodologies. Initially, the research used the publicly accessible drug review dataset to train the algorithms to identify and forecast the most successful and highly rated pharmaceuticals for clients in the pharmaceutical sector. The collection comprises public feedback, feedback, and ratings from several pharmaceutical portals regarding medications, which is favorable or adverse.

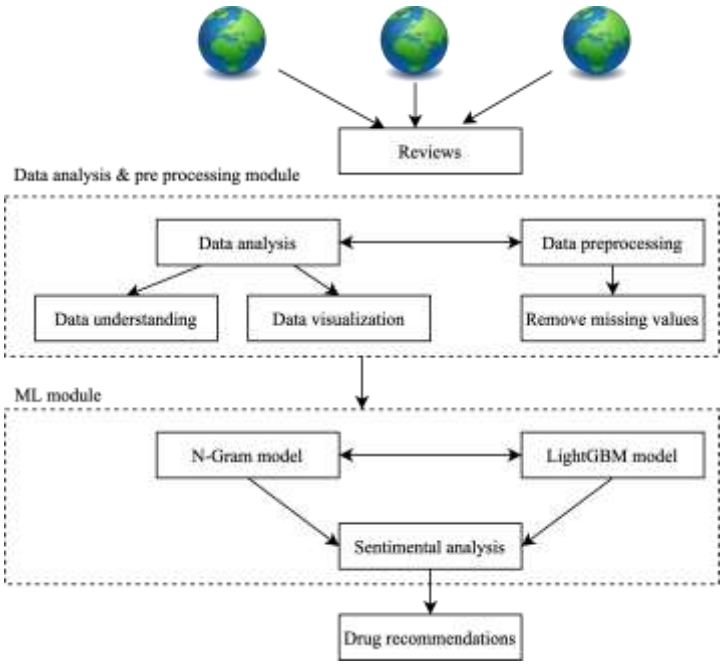


Figure 4: ML-based Drug Suggestion Model

The components of the suggestion method include statistical analysis and preprocessing, ML scenarios, and the suggestion procedure, as seen in Figure 4. The dataset comprises user evaluations and ratings of medications based on patients' medical concerns, such as acne, pain, birth control, and anesthetic. The data evaluation and preprocessing component comprises data analytics and preparation. The research thoroughly comprehends and examines the data using various visualization techniques during data processing. In the preparation phase, the study employed data processing methods to eliminate any missing information from the database, ensuring its cleanliness for further actions.

The module of the suggestion engine encompasses ML and NLP, utilizing the N-gram and LightGBM algorithms with sentiment assessment approaches. These algorithms are trained using the Drug Review database, and an open-source emotional analysis package is utilized to enhance training efficacy. Upon completion of training, the models suggest the most effective and highly-rated medications for specific patient ailments, such as acne, anxiety, and pain. The system for suggestions autonomously enhances performance by assimilating fresh evaluations and remarks from the consumer's usage and then updating the recommended outcomes appropriately. When clients inquire in the DSCMS database for top-rated and pertinent medications based on their condition, the suggestion module activates and suggests the optimal prescription among alternatives. The approach proposes the most productive and optimal medication to stakeholders in the pharmaceutical sector, including pharmacists, physicians, hospitals, and consumers.

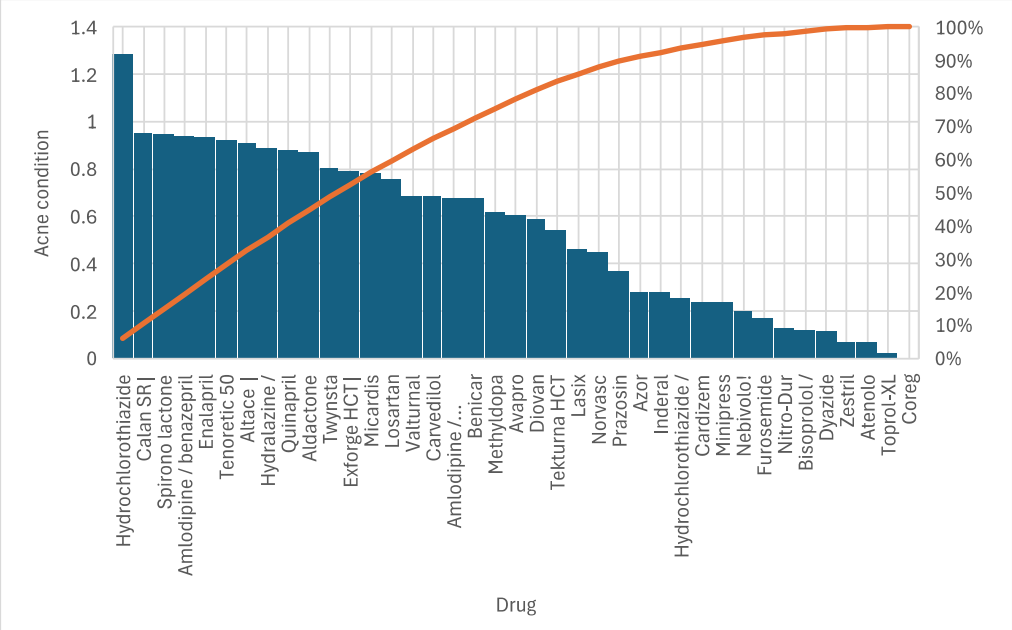


Figure 5: Acne Condition Analysis

Figure 5 depicts the drug suggestion outcomes generated by the suggested method based on particular situations. The medicine names, together with their averages for particular acne conditions, are shown. The system effectively proposes to its users the highest-rated and most effective medications. Clients readily inquire inside the system for recommendations on the most suitable medication for pain, hypertension, and other relevant medical conditions. Patients immediately use the

platform using the customer's usage, while other pharmaceutical clients, such as pharmacists, physicians, and medical facilities, can utilize the system with their identities.

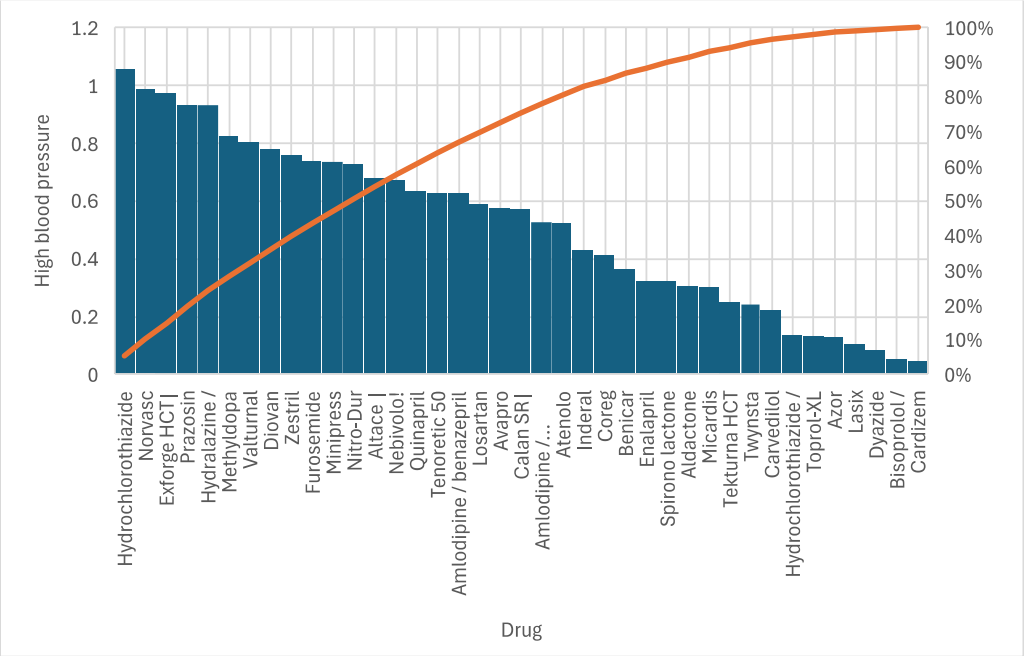


Figure 6: High Blood Pressure Analysis

Figure 6 depicts the medication recommendation outcomes generated by the suggested approach for managing hypertension. The medication names and their mean values for hypertension are shown. The system effectively proposes to its users the highest-rated and most effective medications. While anybody utilizes the medicine suggestion system, only licensed organizations such as pharmacies, manufacturers, hospitals, physicians, and distributors are authorized to execute transactions within the BCT-based platform. Consumers can seek superior medications and monitor the drug's source to verify its authenticity.

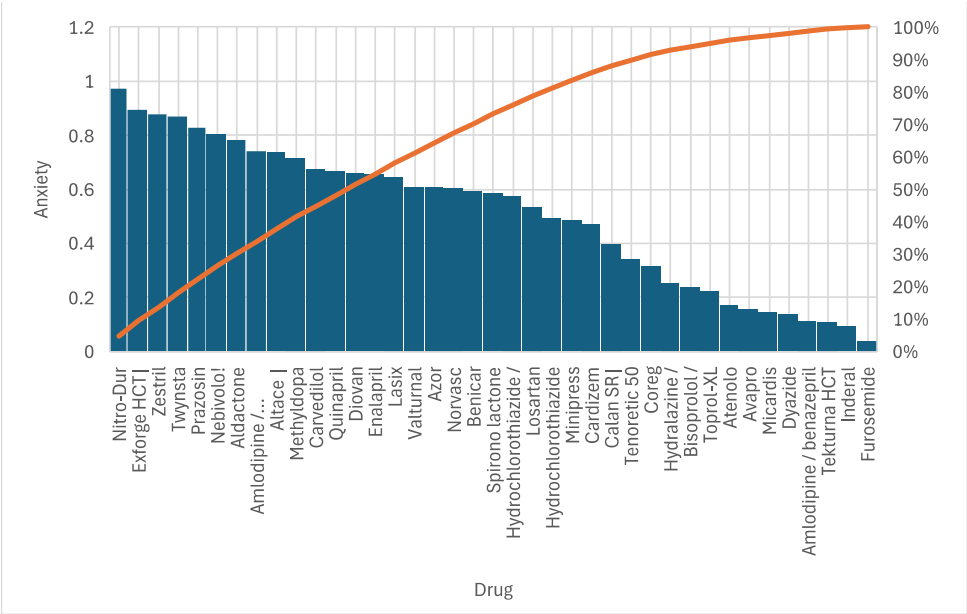


Figure 7: Anxiety Analysis

Figure 7 displays the drug suggestion outcomes for anxiety disorders, with the drug names reflected on the x-axis and their corresponding averages on the y-axis. System users can execute this action by employing the client application's interface to seek optimal medication. The developed model can anticipate the medicine based on learning from the back ends. The optimal advice for anxiousness or any other ailment will be delivered to clients.

5 CONCLUSION

BCT technology has transformed the conventional SCM approach into a more resilient, automated, secure, auditable, and transparent system. It guarantees that the SCM process is infallible and prohibits counterfeit pharmaceuticals from infiltrating the regulatory framework. The suggested plan's primary objectives and innovation involve implementing a BCT and ML-enabled system comprising two components: the drug SCM network and the medication suggestion system. The system has employed ML techniques and BCT technology for medical purposes, yielding exceptional outcomes. Multiple tests were conducted to evaluate the system's efficiency utilizing various performance metrics, including throughput, transaction reaction time, and delay. The simulation outcomes obtained from the technology demonstrate excellent results. This method assists pharmaceutical organizations in eradicating counterfeit medications and substantially enhancing their commercial operations. In future endeavors, the research will expand the system's size and deploy it in real-time for drug companies to evaluate the efficacy and authenticity of the technology. The research will enhance the precision and recommended outcomes of the ML algorithms.

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