SUPPLYDECK – A Blockchain-Based Pharmaceutical Supply Chain Management

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***Abstract*— With the rising competition among pharmaceutical companies, the current drug supply chain market has become more competitive with high-quality product segments. The rapid growth of internet pharmacies has made it more difficult to standardize drug safety throughout in complex distributed supply chain networks. There is a high chance of introducing counterfeit drugs which are almost the same as the original pharmaceuticals. Due to the lack of transparency the possibility of tampering with drugs in the current manual and web-based pharmaceutical systems is extremely high. Throughout the past recent years, these counterfeit drugs were recognized as the one of major worldwide problems. This situation is worse in developing countries. The unavailability of verifying the legitimacy of drug suppliers and poor mechanisms to trace the drugs were identified as critical points that need to be resolved. SUPPLYDECK comes as a solution for the critical scenario mentioned. This solution addresses the above problems using blockchain technology, as a distributed digital ledger that ensures transparency, traceability, and security. This can show promise for solving some global supply chain management problems using smart contracts and user authentication along with IoT technology and machine learning concepts that are critically examined with this potential application.**

Keywords*— *drug supply chain, pharmaceutical, blockchain, smart contracts, user authentication, IoT, AWS, API

I. INTRODUCTION

Modern day healthcare systems are complex networks consisting of several independent entities. That includes the origin point as manufacturer companies and the end user as the drug consumer who is the best priority. In this process, many organizations, transportation modes, and stakeholders such as distributors, producers, wholesalers, drivers, and pharmacists are actively involved in the pharmaceutical supply chain under various situations. While doing this delivery process it has been identified that in public health, the safety of the pharmaceuticals throughout the supply chain is one of the major concerns, which is a collective process. When it is considered deeper on the safety approach, the security threat is the most significant safety violation that is happening in the current drug supply chain. Prevention of counterfeit pharmaceuticals and managing the access privileges to the stakeholders are identified as the major precautions needed for the advanced security approach in the supply chain. The next main safety related violation that can ordinarily happen in the pharmaceutical supply chain is cold chain management with parameter monitoring in the stored environments. Once the drug is purchased a proper mechanism should be there to share the customer feedback with the audience. In the current supply chain, there is no existing customer satisfaction monitoring.

According to the World Health Organization (WHO), taking counterfeit drugs could have serious side effects [1]. The unavailability of the an automated mechanism to verify the quality of the drugs that are consumed in the day to day life is very challenging to overcome because fake drugs are introduced to consumers with the same look that is totally like the original product and even the brand names logos are also the same as the original pharmaceutical [2]. This will mislead the patients to consume fake products. Because of this counterfeit drug consumption, people are experiencing various side effects and unfortunately died as well.

In addition to the safety, existing drug supply chains have many disruptive such as lack of transparency, loss of records, manual data recording, the untrustworthiness of the stakeholders, tampering drugs, and the same drug under different brand names [3]. Due to the lack of transparency, the participants cannot verify whether the received drug has come from a legitimate supplier and there is no proper mechanism to track and trace whether the pharmaceutical is legit, how the drugs were delivered, and how much quantities of dug lots were delivered within a period. Most organizations still follow the recording of the manual drug, and some are using web-based systems with limited administrator access. But these types of data recording can be altered and deleted by an external third-party involvement. In web-based systems some untrustworthy administrators can misbehave and go wrong, finally causing a data loss.

This research proposed a working real-time solution to envision a robust and transparent traceability system for the modern pharmaceutical supply chain. The solution designed using blockchain-based drug supply chain tracking and monitoring provides a better solution to build the trust of the participants. SUPPLYDECK provides a web-based system integrated with mobile apps to scan a QR code placed outside of the drug package which allows the consumers to access the most current updated and accurate information related to the specific drug. The data is injected into the system in two ways.

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1. Manual data entry via mobile app.
2. Automatic feed from the sensors.

Once the data is entered into the system, it is signed at the origin and is hashed, and time stamped. Only the hashes along with metadata go to the blockchain [4]. The data ledger in the blockchain is immutable. It can provide proof that traceability data added to the system have not been altered afterward due to the high security in the blockchain system. The supply chain flow diagram, Fig. 1 shows the way of interconnecting supply chain nodes with the blockchain.

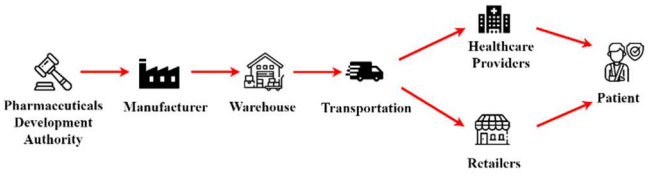

Fig. 1. Supply Chain Flow Diagram

Decentralized technology that offers self-controlled identity with a higher degree of privacy among all the nodes of the large network. The decentralized database enables stakeholders in the drug supply chain to expose only necessary information without compromising confidential business data. Using smart contracts and user identification with varied access privileges, blockchain technology which acts as a distributed digital ledger system while showing promise for reducing some global supply chain management issues. This research enables of monitoring the counterfeit drugs entering the supply chain, with more accuracy using blockchain to become the journey of the drug more secure and streamlined.

II. Background And Literature Survey

The pharmaceutical supply chain is a network of nodes that connects organizations, individuals, technology, and resources involved in pharmaceutical production. SUPPLYDECK provides functionalities using the technologies of AWS, Ethereum, Solidity, IoT, and Natural Language Processing. The followings are the literature survey done in this research. The efforts to identify relevant literature that addressed the existing work are proposed in this study through the literature search.

A. User Authentication with RFID Solution

To register users for the system some research used Hyperledger Fabric drug traceability architecture that allows all stakeholders for participating organizations to end users registered by the Health Authority using a design known as Membership Service Provider [5]. Using MSP, rules and regulations for various stakeholders are governed, authenticated, validated, and granted access to the blockchain resources. Some have applied Hyperledger Fabric blockchain based biomedical engineering supply chain that has nodes as the supplier, manufacturers, warehouses, hospitals, and admin. Each entity is designed to acquire a copy of the central ledger [6].

When considering the tagging solution much research has used Near Field Communication (NFC) tags to achieve visibility and authenticity across the pharmaceutical supply chain. Each drug is registered and authenticated using a key value and an NFC tag is attached to it [7]. The end users can verify the origin and authenticity of the drug by scanning the attached NFC tag through a mobile application. The Radio Frequency Identification (RFID) technology for tracking and tracing products have proposed by a study in 2014, and they discovered that allowing an RFID barcode hybrid technology improves the speed and accuracy of product location within the hospital, which is useful during product recalls [8].

B. Decentralized Blockchain with Smart Contracts

There are some product traceability difficulties in the pharmaceutical supply chain, and it might consider the way of providing provenance, track, and trace solutions to reduce counterfeit pharmaceuticals using blockchain technology as a current need. The Hyperledger Fabric blockchain architecture provides a shared, trusted, permissioned, and decentralized platform for storage and communication across various nodes [5]. A system called Drug ledger, a practical blockchain system for drug regulation and traceability that reconstructs the entire service architecture by separating the service provider into three independent components [9]. The solution is cost-effective in terms of the gas fee required to carry out the numerous operations triggered by the smart contract. The suggested approach protects against malicious attempts to target the integrity, availability, and nonrepudiation of transaction data in a complex multi-party scenario [7].

The numerous workflows in the healthcare ecosystem that use blockchain technology for better data management were analyzed while considering the existing literature of blockchain applications in healthcare sector [10]. Ethereum based for clinical trials and basic outpatient surgical procedure using smart contract [11]. An article has proposed a new blockchain based medicine supply chain management system by creating a system based on the permissioned supply chain [12]. The performance of several types of requests and the quantity of clients has been assessed to acquire tolerable efficiency [13]. The decentralized blockchain architecture was validated through smart contract to achieve the permissioned supply chain.

C. Cold Chain Management

Considering the literature associated with cold chain management using blockchain technology, the approach of the review is chronological and theoretical. There is much existing research completed to track temperature sensitive pharmaceuticals in several stages. They have used different technologies and tried to increase the accuracy and the detection of the sensor data. When reading papers regarding cold chain management and tracking using various technologies, common problems, and methodologies can be identified. To control the risk assessment variables and quality management, research has been [14] proposed a detailed framework for the cold chain management while monitoring temperature and distribution procedures. They suggested that the pharmaceutical drug supply chain currently needs to develop a temperature and humidity monitoring system.

In 2017, the mean availability of essential cold chain products was 72.1 ± 14.8% while the pharmaceutical wastage rate due to expiration was 9.2 ± 7.8% and due to improper storage conditions 63.8 ± 36.2%. The cold chain management using blockchain technology along with the IoT has been conducted by Modum.io and they released a pilot operation in 2016. Consequently, 52 shipments were accomplished successfully, and temperature readings were taken. A total of 7576 temperature points were collected, with sensors taking reading every ten minutes [15]. Also, a blockchain-IoT based supply chain management system was proposed by properly monitoring the cold chain for temperature specific drugs [16].

Finally, they show full implementation to deploy the system and conduct rigorous performance evaluation with detailed security analysis of a scalable blockchain network. Another blockchain based framework to handle the drug supply chain was proposed by utilizing the blockchain and smart contracts-based system [17]. They have not properly analyzed the supply chain management of vaccines that have special temperature and weather requirements which is one of the common issues nowadays.

D. Automated Drug Rating

Over the years, much research has been drawn to the way of determining helpful drug reviews and used a variety of methods to predict the usefulness of drug reviews. For this, some used a machine learning approach while others used a statistical approach [18]. Research published in 2020, proposed a drug rating and recommender framework to generate drug ratings based on the reviews. The usefulness of the drug reviews for the users and the sentimental polarity of the reviews have been obtained at the end of the research [19]. In 2019, a team presented a drug rating system with a weekly supervised mechanism, whose main objective was to recognize the sentiment inclination of drug review by sentiment analysis [20]. Chua and Banerjee [21] tested a machine learning model utilizing Amazon.com reviews to determine the association between review sentiment and helpfulness. They discovered that the usefulness of the reviews was independent of the type of the product and the review helpfulness can vary as a function of review sentiment.

Using social media sites to collect data on customer reviews and discussions about drugs another study was conducted [22], and they analyzed the collected data using a data mining technique that classify those filtered data under specific aspects. As the final output received was revealed as 62% positive reviews and 38% were negative responses and the system accuracy was 85%. When considering ecommerce customer reviews, a system was proposed that mines topics and sentiment orientation that can be used to track and manage customer reviews [23]. They were created to capture the reviews in both Chinese and English languages, and they could recognize the offensive words as well. That was to provide data to ecommerce enterprises and product manufacturers to improve their product quality and service.

III. Research Objectives

The main goal of this research is to improve the overall security and transparency of pharmaceutical drug authenticity and supply while ensuring secure interoperability among healthcare organizations at several stages of the supply chain. With the aim of developing a patient-centric pharmaceutical supply chain while maintaining the good name of the pharmaceutical suppliers, research has been designed with the minimum resources. SUPPLYDECK supports the following sub-objectives.

- Provide user authentication and to allow retrieving of traceability data easily with the use of RFID tags.
- Apply smart contracts to the blockchain to perform transactions without an intermediary.
- Review cold chain management to track the cold chain process of temperature sensitive pharmaceuticals.
- Classify user ratings of drugs and measure review quality metrics to summarize review results.

These sub functionalities are deeply researched as individual functionalities to achieve the final SUPPLYDECK decentralized blockchain based platform.

IV. Methodology

SUPPLYDECK is a combined system of web applications and mobile applications which are used along with IoT technology for tracking and tracing the pharmaceutical drug supply chain. SUPPLYDECK web portal is mainly for visualizing the entered pharmaceutical data, traceability data, and sensor data of the temperature-sensitive drugs. In addition to that, a mobile application for pharmacists and a separate application for consumers to view the traceability data are designed.

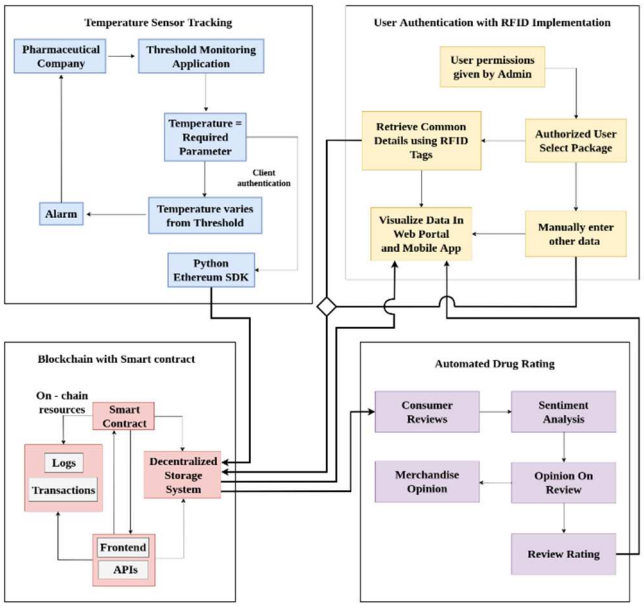

Fig. 2. System Overall Diagram

SUPPLYDECK consists of four sub-parts to achieve the fully combined system as in the above Fig. 2. The four main functionalities of the system are user authentication with RFID tagging solution, decentralized blockchain network with smart contracts, cold chain management for temperature-sensitive drugs, and automated drug rating system based on consumer reviews. Figure 2 demonstrates the way of blending four main functionalities to create an overall SUPPLYDECK system. All four different functionalities combine into one canvas which came out as one single blockchain platform to prove the concepts in the pharmaceutical drug supply chain underlying a decentralized blockchain network.

A. User Authentication with RFID Solution

In a decentralized blockchain network to enable security for each participant and their transactions, user authentication will be enabled to the SUPPLYDECK participants to increase the confidentiality and security. For anonymous user authentication functionality AWS user pools have been used to provide high security and different access privileges to the users. Once the company administrator created the blockchain account in SUPPLYDECK he can assign distinct roles for the users according to their company business requirements. These user roles have different tasks for each user level, permissions and limitations that are needed to be given to each user level and the different inputs that each user level adds to the blockchain. When implementing this in the application

creation of user groups and granting different user permissions for different user levels using AWS user pools using Identity and Access Management web service. This process of user account creation and RFID tagging solution is explained in the below diagram Fig. *3*.

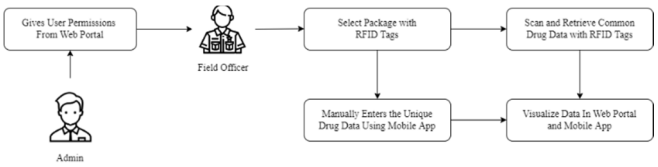

Fig. 3. User Authentication with RFID Solution

Once the stakeholders are registered to the system while creating AWS users and next assign each user to a specific user level. Then those permissioned users can enter the data into the blockchain and for this data entering purpose RFID tags will be used. This can easier the process of data entering the blockchain rather than entering data into the system manually. RFID tags will be placed on top of the drugs and that can be scanned through a mobile application and those data will be captured and sent to the blockchain. The unique data related to a certain drug can be entered to the mobile app using the SUPPLYDECK mobile application.

B. Decentralized Blockchain with Smart Contracts

Throughout the supply chain smart contracts are used to track the location of the drug. This can be done when the manufacturer provides a unique code which cannot be tampered with or removed. This process includes enabling smart contracts to track pharmaceuticals, Web 3.0 for the decentralized blockchain architecture, and a private blockchain explorer built on Ethereum. Ethereum relies on key storage, user account creation, transaction signing, and queries to the Ethereum database. The Private blockchain explorer lies on top of the Ethereum to track and trace all the transactions happening in the drug supply chain and those data records are displaying in blockchain explorer. The blockchain module mainly designed to create a reliable application that can explore relevant information stored in the ledger. The following diagram, Fig. 4 displays how the blockchain works on the SUPPLYDECK application.

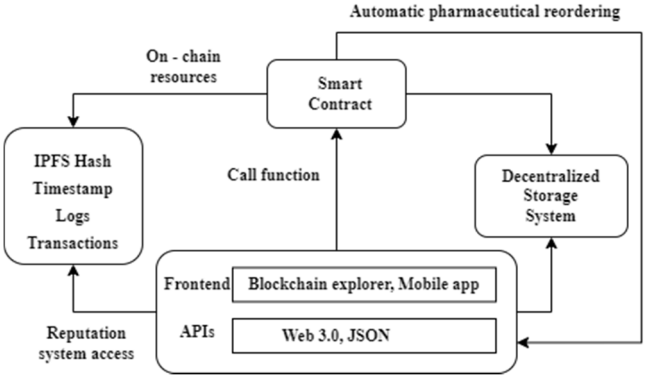

Fig. 4. Decentralized Blockchain with Smart Contracts

The blockchain traceability data can be retrieved to the clients via a Gateway and inside the Gateway the API's, Routes, running transactions are relies. The gateway is directly connected to the blockchain, and decentralized storage system connects and enables smart contracts as shown in the diagram, Fig. 5 . Once the transaction is completed all participants can verify their transactions using the blockchain explorer.

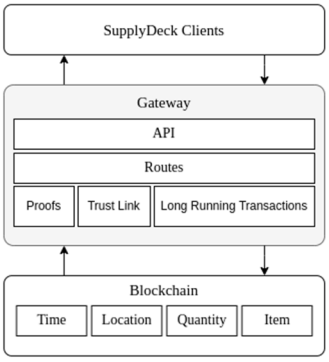

Fig. 5. Blockchain Architecture

C. Cold Chain Management

This research has a sub feature to analyze the tracking of the temperature, humidity and the location of temperature sensitive pharmaceuticals and find the most suitable mitigation for temperature-controlled warehouses. Using temperature and humidity sensor tracking using IoT-based technologies, cold chain management will be focused on the degree to which storage conditions in the pharmaceutical drug supply chain comply for storage and handling of temperature sensitive medicines. In this research for the pilot implementation Insulin is used as the temperature-controlled drug. Using the sensor system, it has a capability of tracking and store temperature and humidity readings of the storage devices for a period and able to retrieve those data through sensors to track live data that needs to be stored under special temperature conditions. For the storing process pharmaceutical organizations commonly use refrigerators and cooling containers. The process of tracking storage conditions from the warehouse to the live data interpretation on the SUPPLYDECK web portal is shown in the below Fig. 6 .

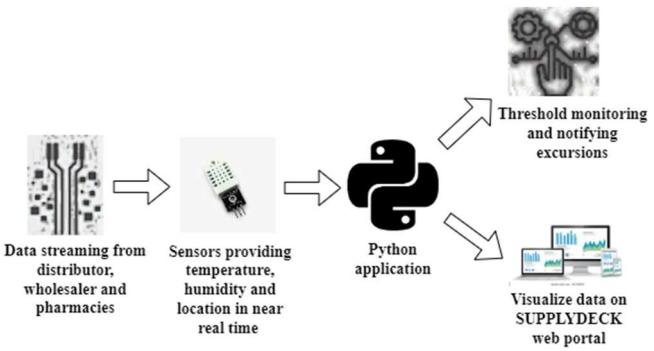

Fig. 6. IoT-based Cold Chain Management

As shown in the above diagram the proposed IoT system can track any drug that needs to be stored at a specific temperature to retrieve whether they are in required environmental conditions such as temperature, humidity. An apparatus consisting with a DHT22 temperature and humidity sensor along with a Raspberry Pi device is used to capture the storage data in real time and those captured data will be sent to the blockchain. Blockchain will show the sensor data of the pharmaceuticals using a Backend API throughout various stages of the supply chain.

D. *Automated Drug Rating*

In automated drug rating, it enables customers to submit reviews for the pharmaceutical products they purchased and implements a model for gathering both positive and negative feedback. Negative reviews won't be removed in that model, while increasing the products' credibility as a result. Using an ecommerce website, it has the capability of exporting reviews to a delimited text file which facilitates the analysis for collecting the customer reviews. Another model needs to be trained to achieve the preprocessing for review text files. For that text mining is used for classification for the reviews while one part of the reviews goes to the mobile application while other one is for the drug. Furthermore, this model implementation includes word segmentation, of speech tagging, feature representation, semantic categorization, and sentiment analysis. The concept of this review training model illustrates in the below Fig. 7.

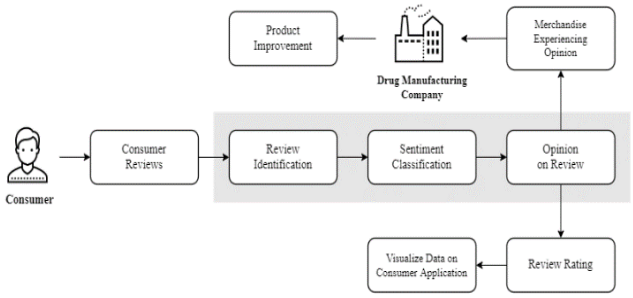

Fig. 7. Process of Customer Feedback and Review Rating

The process of word segmentation will initially be used to separate written text into understandable pieces like words, phrases, or subjects. The provided words are then highlighted in a text as belonging to a specific part of the speech. To determine the subjects that customers communicate about the most, a semantic analysis is conducted. This can categorize the reviews as positive or negative automatically. Finally, the SUPPLYDECK mobile application can render the reviews accessible to drug buyers.

V. Results And Discussion

The SUPPLYDECK team surveyed individuals involved in the pharmaceutical supply chain when the research was initiated. The study's primary data collection tools, including the questionnaire and interviews, combine quantitative and qualitative data. The next phase of the study was to analyze the survey results obtained. According to the consumer responses they need SUPPLYDECK kind of a system. Additionally, the team connected with pharmacists, drug distributors, and the appropriate drug authorities in person. Since the mentioned parties are the participants throughout the supply chain, our team interviewed them as considering them all as the organizations. Therefore, on the organizations perspective they are also revealed that the need of a SUPPLYDECK kind of a system is very high.

In customer review mining to select the most accurate review rating algorithm for the model Multinominal Naive Bayes, Logistic Regression, Support Vector Machine, Decision Tree, and Random Forest algorithms were tested. The following table, TABLE I illustrates the results for accuracy.

TABLE I. Review Rating Accuracy Results

Testing Model	*Accuracy*
Random Forest	0.9350
Logistics Regression	0.9392
Decision Tree	0.9016
Support Vector Machine	0.9393
Multinomial Naïve Bayes	0.9344

Among the above algorithms, the Support Vector Machine model was selected as the most accurate model for the review results prediction.

Fig. 8. Transaction Log of a Smart Contract

The above figure, Fig. 8 illustrates how transactions can be verified using EtherScan after a successful smart contract execution. This process allows participants to access the transaction id, encrypted blockchain data, and transaction timestamp.

In sensor data application testing the number of sensor clients had an impact with the response time to retrieve and store sensor data sent by simultaneously. However, taking use of scalability support by adding more servers might improve in achieving a lower response time as compared to a single server. And the ability of blockchain to connect with IoT without human interaction enabled more convenience.

After the implementation phase, a pilot version has been tested using stakeholders. This concept and this tool impressed all these stakeholders. The results were obtained as in the below chart Fig. 9. With these findings gathered that the implementation of blockchain to the current drug supply chain would benefit the pharmaceutical industry.

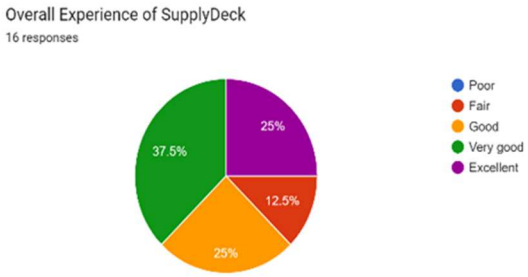

Fig. 9. Participants' Feedback Results

SUPPLYDECK envision a robust and transparent traceability system for the pharmaceutical drug supply chain. In this article, we are presenting how blockchain technology can be applied to the pharmaceutical supply chain in need of

drug traceability. Blockchain architecture based on Ethereum deployed with smart contracts to establish a peer-to-peer network. These architectures offer a shared, trusted, permission able, and decentralized platform for communications and data storage and sharing among various stakeholders in the pharmaceutical supply chain, and individuals that can satisfy important requirements and features like security, privacy, accessibility, transparency, and scalability.

In this paper, we discussed the major drawbacks of the existing current pharmaceutical supply chains, and the goal of this research was to introduce a streamlined process for reliable medication tracing without tampering the data with an organized approach in a cost-effective manner. We intend to research deeper on improving the efficiency of pharmaceutical supply chains and to emphasize future works on enhancing the suggested system to achieve a complete end to end transparency and verification of pharmaceuticals with having more features such as proof of work while increasing the system performance for increasing supply chain nodes.

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