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Distributed Ledger of Blockchain Enhance API Supply Chain Social Economical Resilience

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Abstract: The application of Blockchain to enhance the industry's social economic resilience is widely of concern in the science, technology, and pharmaceutical industries. The research discusses the resilience of the Active Pharmaceutical Ingredient (API) in the face of global health challenges and how blockchain can improve supply chain transparency and efficiency through its unique distributed ledger (DLT) technology. The report uses literature review methods to analyze the application of blockchain technology to real-time data sharing in the API supply chain and its impact on improving API supply chain adaptability, optimizing resource allocation, and enhancing risk management capabilities. As can be seen from the result, through the real-time data sharing by the distributed ledger (DLT), the API supply chain can more effectively respond to the fluctuation of the environment and market to enhance its social and economic resilience. This research demonstrates the potential of blockchain technology in optimizing pharmaceutical supply chain management to safeguard human health and well-being.

Keywords: API Supply Chain, Supply Chain Resilience, Blockchain

1. Introduction

Based on the globalization background, the Active Pharmaceutical Ingredient (API) supply chain management is the main factor in ensuring global health security, especially the breakout of COVID-19 emphasis on enhancing the stability and resilience of the API supply chain. The essay uses the literature review method to discuss the main function of blockchain in the API supply chain and analyze how to use its unique function called distributed ledger (DLT) to enhance the social-economic resilience of the API supply chain. The analysis will review the fundamental capabilities and APIs in the global pharmaceuticals industry and their importance in a global health crisis. It will also discuss the different perspectives on supply chain resilience and the importance of social and economic resilience to the current API supply chain. Through a detailed literature review and analysis, the essay aims to discuss the application of DLT of blockchain technology in the API supply chain to enhance its social-economic resilience and respond more effectively to uncertain future health crises and the market environment.

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2. API and API Supply Chain

Active Pharmaceutical Ingredients, so-called API as an abbreviation. According to the official website of Biocon, in 2024, API will be the biologically active ingredient for pharmaceutical products, which services tablets, capsules, creams and injections and can also treat drugs in clinical medical specialties [1]. As can be seen, this ingredient can ensure the medicine can effectively treat a disease and is an indispensable part of ensuring the quality and efficacy of the medicine.

Besides the pharmacological properties of API, which will determine the medical effect, the demand for API will get higher in the current global fickle situations due to the unforeseen public sanitation emergency, which will also contribute to the role of API becoming more important. As can be seen, the Centers for Disease Control and Prevention pointed out there have been several outbreaks of disease across the globe in 2024 [2], which emphasizes the importance of API:

Chikungunya in Timor-Leste and Yellow Fever in Nigeria: These two viruses are transmitted by mosquitoes. The former is the outbreak across Africa, the Americas, Europe, the Caribbean, the Indian Ocean, and the Pacific, and the latter is the outbreak in Nigeria. The number of cases has been high since the virus was first reported in 2020. These two viruses have no specific treatment method but can be prevented through the intake of vaccines [3, 4].

Global Measles: This is a highly contagious virus across the globe; this virus is serious in all age groups and can lead to serious complications resulting in death. Taking a vaccine is the best method to protect people and reduce the risk of infection [5].

Based on API, it makes up the core functional components of vaccines to activate the body's immune system to fight specific pathogens. Hence, the high quality of API directly determines the efficiency of vaccines. Based on the high demand for global health management, especially in response to current and future infectious disease outbreaks, on-time and high-quality API supply is essential, which can illustrate the importance of a stable API supply chain to ensure rapid distribution of the medicines and vaccines in sufficient quality and quantity to achieve agility under emergency circumstances.

3. Challenges of API Supply Chain

To achieve a stable API supply chain to rapid response if the demand for API sharply increases due to a public health emergency, resilience is a critical criterion to measure the supply chain successfully to deliver the API to the affected areas, advanced intervention to avoid infection and maximize the negative impact by the pandemic to people. The consideration of 'Resilience' is more likely to describe the delivery process to achieve "stability".

Nagu, Kumar and Purani 2020 pointed out that APIs highly rely on globalization, especially mass production concentrated in India, China and other very few countries. Because these countries can produce large and diverse API efficiency at lower cost with specialized production facilities and technical express. For example, the USA imports approximately 80 percent of API from China and India. This dependence makes the supply chain of API very fragile if America experiences fluctuating international markets, geopolitical tension or trade policy changes [6].

Based on the globalization of the API supply chain, Narendra et al. 2020 pointed out that COVID-19 disturbed the API supply chain to a big extent, which resulted in the Chinese factory shutting down due to the supply amount decrease, the price of API increased sharply and shortage of inventory if China lockdown to export API [7]. As can be seen, although most countries have adapted to COVID-19 already and adjusted their policy for post-covid, based on the globalization-independent situations, outsourcing by other countries of origin is still the mainstream in this industry, the risk of interruption will intensify again if the pandemic breaks out again. The interaction with different supply APIs can be imagined as numerous intertwined threads. According to Sourav Adak, in 2024, four years later

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already, the issue of heavily relying on a small number of countries of origin remains; supply chains from multiple countries can interfere with each other [8].

Also, not just the external factor, the challenge of the API supply chain resilience is also attributed to its chemical character as an internal factor. The API supply chain has highly complex logical and cold chain management requirements. As Nagu, Kumar, and Puranik pointed out as biopharma components, the challenge of API transportation is due to its highly sensitive characteristics and strict environmental requirements. Transportation across borders must control temperature and prevent contamination to ensure API stability and effectiveness in exerting drug properties effectively [6]. As can be seen, the cooperative works with other countries to achieve supply chain consistency, which refers to real-time API monitoring, improving the transparency of the supply chain, delivering API on time, and preventing supply delay and product quality decline from becoming a challenge.

As can be deduced, the risk of the supply chain across borders is bigger than that of domestic delivery because, compared with the former, a supply chain across borders will not just consider the risk of shutting down the supply chain link due to the pandemic. Moreover, the compatibility issues between different countries, the high dependence on other countries, and the high requirement for API delivery are potential risks that result in API supply chain disruption. The API supply chain distribution will result in medicine shortages in disaster areas, resulting in treatment delays and medical costs rising sharply due to shrinking supply, ultimately increasing public health risks. From a macro perspective, Ponomaror and Holcomb 2009 claim that a resilience supply chain is not just able to respond quickly to an emergency but can also revert to the previous state or better after the disruption through precondition and contingency plan to enhance its capacity to respond to future challenges [9]. Hence, resilience is a criterion to motivate the stakeholders to meet the requirement of a stable API supply chain to prevent human beings from being infected by the virus and minimize the suffering of those affected by the virus outbreak.

4. Social Economical Resilience of API Supply Chain

Wieland and Duranch, in 2021, claim that supply resilience has two perspectives: engineer resilience and social-economic resilience [10]. To the extent that these two kinds of resilience are the same, in supply chain management, engineer resilience and social and economic resilience focus on how to enhance the supply chain capacity to respond to interference and emphasize the core of supply chain resilience is to deal with the unforeseen events and ability to maintain operational continuity.

For differentiation, engineer resilience is focused more on the capacity of the system to get back to a steady state with efficiency and control. This tends to use clear risk management and quick recovery strategies to achieve the goal of minimizing interference. Engineering resilience is suitable for situations where it is relatively stable and predictable with controllable risk situations [10].

By contrast, social and economic resilience is more tending. It focuses on the system's capacity to return to a stable state quickly, but it is also possible to persuade it to reach a new optimal state. This perspective believes that the supply chain is an open and dynamic state to adapt to the constant change of the external environment. This perspective can be applied to situations where the environment constantly changes and requires highly adaptable innovation [10].

Compared with the other general consumer goods, like cars, furniture, and household appliances, the demand for elasticity is relatively lower than API. Leaving out the supply chain theory first, API has a higher health dependence and global impact with tighter regulation to prevent and treat the spread of disease. Greater importance to the product reflects greater elasticity to its supply chain resilience than other products. As can be seen, the API supply chain has a high requirement of compatibility based on the globalization circumstance, involving transnational policy adjustments, handling methods in transit to adapt to the climate of the route and further adjustments made by the stakeholder due to the interruption of the pandemic etc. Hence, the API supply chain needs to consider

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social-ecological resilience because it allows for the adaptation to regulatory changes, technology advantages and shifting market demands, ensuring continuous supply and innovation in a rapidly changing global health landscape.

5. Blockchain and Social Economical Resilience of API Supply Chain

Chang and Chen, 2020, claim that the current application of blockchain in the supply chain focuses on enhancing transaction transparency and traceability, which can be useful in solving the trust issue. Because blockchain can provide a decentralized and immutable record system, all supply chain participants can view the transaction history to reduce fraudulent conduct and enhance the whole supply chain efficiency [11]. The transparency effect of blockchain can ensure that the raw material of API and the final product of API can be traced. Through the monitoring and data sharing in each link of the supply chain between the participants, it can recognize the external disturbances and risks to make the rapid response to maintain the function and adapt the changes of the supply chain to keep effective operation, To improve the API supply chain stability and resilience, achieve the optimize, can accomplish the social, economic resilience.

5.1. The Unique Function of Blockchain

Distributed Ledger Technology (DLT), highlighted by researchers such as Sunny, Undralla, and Pillai in 2020, is crucial in enhancing supply chain transparency [12]. DLT, a core aspect of blockchain, operates by recording and sharing transaction data across a decentralized network of nodes, as Roeck, Sterberg, and Hofmann stated in 2019 [13]. Unlike centralized systems, DLT ensures transaction records are stored on multiple nodes, promoting reliability and transparency. One key function of DLT, emphasized by Sunny, Undralla, and Pillai, is its ability to facilitate real-time data sharing, enabling stakeholders to access up-to-date information about product flows. This transparency allows for swift decision-making and facilitates efficient supply chain participant collaboration [12]. In the subsequent paragraph, the function of DLT and its application in the API supply chain will be examined, along with an analysis of how these applications bolster the socio-economic resilience of the API supply chain.

The function of DLT in improving transparency through real-time data sharing is pivotal. Sunny, Undralla and Pillai 2020 pointed out that DLT is the main framework of the blockchain, which provides the visibility of each part of the supply chain to make sure that each stakeholder can visit and share the product flow information, which means allowing all participants in the supply chain to access the latest information in real-time facilitates rapid decision making and efficient collaboration, to improve the supply chain transparency [12].

5.2. The Application of DLT Function in API Supply Chain

They enhanced regulatory compliance. Through the DLT, all parts of API transaction data, involving production records, order transactions, real-time quality and so on, can be updated for the related stakeholders.

Enhance the inventory management. The DLT allows all the parts of the API supply chain to access the inventory level. The downstream can, based on the real-time market analysis, predict the future demand of API, hence can coordinate the production plan and the inventory level to avoid overstocking and shortage, therefore can increase the flexibility of transportation in different regions and adjust the quantity according to the demand to make sure the accurate transportation to the disaster area.

Improve the response time. Due to the high amount of information transactions between each stakeholder, the API quality issue and any potential risks will result in the distribution being

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recognized quickly and updated by the corresponding department. The downstream part will take appropriate countermeasures to minimize the impact of various factors that have the risk of supply chain disruption on the final delivery of API.

Risk management. Through the review of blockchain applied in the supply chain review by Hu and Ghadimi, the blockchain allows the real-time monitoring of the whole supply chain through the supply chain stakeholders participating in the real-time sharing and visiting data. This enables organizations to promptly identify potential supply chain risks and anomalies, such as delays or resource shortages, and send immediate alerts. This immediate flow of information helps managers make quick decisions and take preventive or corrective actions to avoid or minimize the impact of risk [14]. Through the blockchain, it is divided into a supply chain network and managed in a regionalized way. It can be divided into different parts of the supply chain for monitoring and information sharing in real-time: purchasing and procurement of API raw material, production process, quality, etc. This solution can ensure that each of the parts in the supply chain achieves information transparency and meets the production requirements. Hence, it can help the managers predict the possible risks and announce how upstream and downstream will react.

5.3. API Social and Ecological Resilience and DLT Applications

Based on the following application, to improve transparency through real-time data sharing by DLT, social-ecological resilience is achieved mainly by improving the supply chain capacity reactively and adaptively and minimizing resource waste.

Enhance the supply chain's reaction capacity and adaptability to environmental change. According to the data of API in the supply chain, real-time sharing between each stakeholder inside by DLT enhances the transparency of the supply chain, can help each part of the supply chain rapidly and accurately recognize the specific part of the issue then through the participants can quickly adapt and based on the current situations to find the optimization by reallocated resources production and delivery, to response to the external stocks such as the market change, demand of API surges or decrease for short period due to the pandemic. Overall, the rapid reaction and the accuracy of action can minimize the duration of production and delivery disruption and speed up the retirement of the operation.

Optimize the allocation of resources. Though the DLT allows every participant to check the inventory and logistics data, it can help each part of the API supply chain access the data of inventories of raw materials, work in progress, and the final product data. At the same time, through the downstream analysis and prediction of the current situation of market demand, different delivery quantities are adjusted as needed to avoid shortage and overstocking in the supply chain through sharing the real-time data to the API supply chain, which can prevent over-purchase of the raw material and overproduction.

Also, efficient resource allocation management optimizes the API supply chain structure and achieves social and environmental sustainability by reducing waste.

Overall, the API supply chain utilizes DLT features of high information transparency through real-time data sharing to enhance the trust and collaboration between the participants by accessing and sharing real-time and accurate data. Following the transparency improvement of data can also make the repaid adjustment, boost decision-making, and enhance response to surges or declines in API demand due to market volatility and exogenous shocks. Also, DLT optimizes resource allocations by tracking the inventory level and logistics data to reduce misallocation and resource wastes, supporting economic and environmental sustainability. In conclusion, improving transparency through real-time data sharing by DLT can enhance the API's social and economic resilience by constantly adapting to changes brought about by the uncertainty of the future.

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6. Conclusion

This study discusses the DLT of blockchain applications to enhance the social and economic resilience of the API supply chain. DLT, through the high level of real-time data sharing function, enhances the API supply chain coordination and quick response capability. This technology achieves the precise monitoring and management of each link inside the API supply chain to reduce the interruption risk of market volatility and public health emergencies.

In the future, the research should further consider the operation and effects of DLT in different medical supply chain services for healthy demand, especially in the background of the uncertainty of the global health crisis. At the same time, challenges also appear, mainly involving the efficient application of the technology in the premise of data privacy and security to prevent data abuse; at the same time, we also need to consider how to coordinate the complex international legal and policy environment to support technology implementation.

Overall, the DLT of blockchain is not just a new technology that is appearing in the supply chain. Moreover, this is the key to motivating the global API supply chain for more efficiency, transparency and sustainability. Based on the potential contribution of DLT to enhance global public health response capacity through analysis of the impact on the API supply chain, the application of DLT in the supply chain of industries highly dependent on raw materials deserves continued attention and further study. Its in-depth research and roll-out have the potential to fundamentally change the supply chain. These industries face challenges in balancing today's changing environment, resulting in broader socio-economic benefits and improved human well-being.

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