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Research on Cross-border E-commerce Import Pharmaceutical Traceability Based on Blockchain

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Master in Digital Technologies for Business

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TECNOLOGIAS
E ARQUITETURA

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Abstract

In this thesis, we delve into the application of blockchain technology in cross-border e-commerce drug tracking and analyze its potential impact on improving supply chain transparency, security, and efficiency. Through detailed analysis of survey questionnaire data, we have demonstrated the significant advantages of blockchain technology in optimizing drug supply chain management, especially in key areas such as business coordination, information sharing, and information security.

Research shows that most participants believe that blockchain technology can significantly improve the response speed and management capabilities of the supply chain, enhance information sharing and transparency, and enhance data confidentiality and integrity through its immutable data records. However, despite the many potential advantages provided by blockchain technology, its practical application still faces some challenges, including technology integration, system adaptability, and initial investment and maintenance costs.

This thesis also discusses the key issues that blockchain technology needs to address in practical applications, such as scalability, interoperability, and integration with other advanced technologies. In addition, we have also explored future research directions in the formulation of relevant regulations, user acceptance, and cost-effectiveness.

In summary, blockchain technology has shown great potential in cross-border e-commerce drug tracking, with the potential to innovate existing supply chain management methods and improve the security and efficiency of global drug supply chains. Future research needs to further explore how to overcome the challenges during implementation and maximize the application value of this technology.

Keywords:

Cross-border E-commerce imported medicine, Blockchain traceability, Evolutionary game.

Resumo

Este artigo aprofunda a aplicação da tecnologia blockchain no rastreamento de drogas de comércio eletrônico transfronteiriço e analisa seu potencial impacto na melhoria da transparência, segurança e eficiência da cadeia de suprimentos. Por meio da análise de dados, as vantagens significativas da tecnologia blockchain na otimização do gerenciamento da cadeia de suprimentos de medicamentos foram demonstradas, especialmente em áreas-chave, como coordenação de negócios, compartilhamento de informações e segurança da informação.

A pesquisa mostra que a maioria dos participantes acredita que a tecnologia blockchain pode melhorar significativamente a velocidade de resposta e os recursos de gerenciamento da cadeia de suprimentos, melhorar o compartilhamento e a transparência de informações e melhorar a confidencialidade e integridade dos dados por meio do registro de dados. No entanto, a aplicação prática da tecnologia blockchain ainda enfrenta alguns desafios, incluindo integração tecnológica, adaptabilidade do sistema e investimento em estágio inicial.

Este artigo também discute os principais problemas que a tecnologia blockchain precisa abordar em aplicativos práticos, como escalabilidade, interoperabilidade e integração com outras tecnologias avançadas. Além disso, futuras direções de pesquisa na formulação de regulamentos relevantes, aceitação do usuário e custo-efetividade também foram exploradas.

Em resumo, a tecnologia blockchain tem enorme potencial no rastreamento de medicamentos de comércio eletrônico transfronteiriço, inovando os métodos de gerenciamento da cadeia de suprimentos existentes e melhorando a segurança e eficiência da cadeia de suprimentos global de medicamentos. Pesquisas futuras precisam explorar ainda mais como superar desafios no processo de implementação e maximizar o valor de aplicação desta tecnologia.

Palavras-chave:
Medicina importada de comércio eletrônico transfronteiriço, rastreabilidade Blockchain, jogo evolutivo.

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Chapter 1 - Introduction

With the accelerated development of globalization, cross-border e-commerce has become an important part of international trade, and cross-border drug supply chain, as a key field, is particularly important for its management and optimization [1]. Cross-border drug supply chain involves many links, including drug production, inspection, transportation, storage, and final sales, and each link needs to ensure the quality and safety of drugs [2]. However, the traditional drug supply chain faces many challenges, such as opaque information, inadequate regulation, and the inflow of counterfeit drugs. These problems not only threaten the health of consumers, but also increase the business risk of enterprises [3]. Therefore, how to effectively manage and trace the cross-border drug supply chain to ensure that every step of the drug from the source to the consumer can be traced and verified has become an urgent problem to be solved.

It is very necessary to introduce blockchain technology into the discussion of cross-border drug supply chain. Blockchain technology, initially widely recognized as the underlying technology of Bitcoin, is a distributed ledger technology that ensures the portability and transparency of data through encryption and consensus mechanisms [4]. The core features of blockchain include decentralized data management, irreversible transaction records, and the ability to automatically execute agreements through smart contracts. These characteristics make blockchain unique in cross-border drug supply chain management [5]. By recording key data in the supply chain - such as the origin of drugs, production batches, transportation routes, etc. - on the blockchain, each record would be encrypted and made available to all participants in the supply chain for verification but not modification. This not only enhances the transparency of information, but also greatly improves the security and reliability of data [6]. In this model, blockchain technology can not only prevent counterfeiting and cross-shipment problems, but also improve the trust of regulators and consumers in the distribution of medicines [7].

The combination of blockchain technology and cross-border drug supply chains opens a new chapter in drug traceability and supply chain management. In the traditional supply chain model, due to the involvement of multiple countries and regions, information is often interrupted or tampered with in multiple links, making supervision more difficult, while the introduction of blockchain effectively solves this problem [8]. By recording every drug movement and transaction in real time on the blockchain, every step from production to consumption is permanently recorded and publicly transparent, giving participants in any supply chain access to this information in real time without having to go through a middleman [9]. In addition, blockchain's smart contract capabilities can also be used to automate the execution of terms in contracts, such as automated payments and quality control, further improving the automation and accuracy of the supply chain. Therefore, blockchain not only

enhances the transparency and security of cross-border drug supply chains, but also greatly improves operational efficiency and compliance, bringing unprecedented changes to drug supply chain management [10]. How blockchain technology specifically improves and enhances all aspects of the cross-border pharmaceutical supply chain, thereby bringing innovation and enhancement to the entire industry.

Although blockchain technology has brought significant improvements to cross-border pharmaceutical supply chains, its implementation and widespread application still face some technical and operational challenges. First, the deployment and maintenance of blockchain technology requires high initial investment and complex technical support, which can be a significant burden for supply chain enterprises in many participating countries. In addition, due to the decentralized nature of blockchain technology, consensus and collaboration among all participants is required, which may be difficult to achieve in practice due to conflicts of interest or differences in management. Technically, the large-scale storage and processing speed of data can also become constraints, especially when large amounts of transaction data are involved, and the scalability and efficiency of blockchain systems can be affected. Finally, imperfect laws and regulations are also an important obstacle, and differences in the acceptance and regulatory standards of blockchain technology in different countries can lead to legal risks and enforcement difficulties. However, many practical problems still need to be solved in the process of comprehensive promotion and application. This provides a new direction and challenge for follow-up research.

The research aims to explore the application of blockchain technology in cross-border e-commerce pharmaceutical traceability and its potential to improve supply chain transparency, security, and efficiency. It seeks to analyze the advantages of blockchain technology in optimizing pharmaceutical supply chain management, particularly in business coordination, information sharing, and information security. It also identifies the challenges faced in practical implementation, such as technology integration, system adaptability, and initial investment and maintenance costs. Furthermore, the research explores future directions, including the formulation of relevant regulations, user acceptance, and cost-effectiveness, with the ultimate goal of promoting the innovative application and maximizing the value of blockchain technology in pharmaceutical supply chain management.

This thesis is divided into six chapters, each chapter has its specific purpose. In the first chapter, we introduce the research background, describe the research theme and objectives. In order to provide a solid theoretical foundation, the second chapter conducts a literature review. We take some relevant researches and data as the theoretical basis to deeply analyze the relationship between cross-border drug supply chain industry. and blockchain technology, and we also try to capture the conclusions reached by contemporary researchers. The third chapter introduces the methodology of

the research, mainly to ensure that the thesis is carried out in an efficient and orderly manner. The fourth chapter analyzes and discuss the research results by means of questionnaire survey and data collection. In the last two chapters, we draw some reliable conclusions through analysis, discuss the limitations of this study, and make some constructive comments and suggestions for follow-up research.

Chapter 2 - Literature Review

This chapter first introduces the background of the global pharmaceutical supply chain, highlighting the challenges and opportunities faced by cross-border pharmaceutical supply chains in the context of globalization and rapid technological development. As a tool to improve supply chain transparency and efficiency, blockchain technology shows great potential for drug tracking, quality assurance, and regulatory compliance. Through specific case studies, as well as the work of other researchers, we have gained an in-depth understanding of how blockchain can help solve information asymmetry, data security, and regulatory efficiency in the pharmaceutical supply chain. It then explores in detail a series of research ideas and findings that not only point to the advantages of blockchain technology, but also to the technical and operational challenges encountered in actual deployment, such as the protection of data privacy, the complexity of technology integration, the limitations of system scalability, and the adaptability of international regulations. Finally, by synthesizing these research results and theoretical analysis, the practical application of blockchain technology in modern cross-border drug supply chain is revealed, and the direction of future research is pointed out. The key role of the technology in improving the efficiency of supply chain management, ensuring drug safety and quality, and strengthening international cooperation was identified, while the importance of addressing implementation challenges to realize this potential was also highlighted.

2.1 Supply Chain

In the context of globalization, cross-border drug supply chains not only need to cope with the growing market demand, but also face strict international regulatory requirements and complex logistics challenges [11]. Pharmaceutical products travel through different political, legal and economic systems from production to end user, which increases the complexity of the supply chain, especially when it comes to ensuring the quality of pharmaceutical products and preventing counterfeiting [12]. In addition, every link in the pharmaceutical supply chain, from raw material procurement, production, packaging to distribution and retail, must strictly comply with national regulatory standards, and any omissions can lead to serious consequences, including public health events and economic losses. The introduction of blockchain technology provides a new solution. Its decentralized nature and encryption ensure enable data to be shared securely across the globe without fear of information being tampered with or leaked. By recording the details of every drug product on the blockchain, everything from the source of the ingredients to the final sale can be tracked and verified. This transparency not only helps to reduce the circulation of counterfeit medicines, but also enhances the supervision and management of all parties in the supply chain. For example, key information such as drug production batch,

expiration date, quality inspection passed, and transportation route can be updated and accessed in real-time, greatly improving regulatory efficiency and consumer confidence [13].

However, the application of blockchain technology to cross-border pharmaceutical supply chains also face many challenges. The deployment of technology requires the collaboration and matching of technical capabilities of all supply chain participants. In addition, the unification of technical standards, the protection of data privacy and compatibility with existing systems are all issues that must be addressed. International cooperation plays a key role in this process and requires international policy makers, industry leaders, and technical experts to work together to ensure effective implementation of technology and regulatory adaptability [14].

By analyzing this background information in depth, we can better understand the potential and challenges of blockchain technology in the global pharmaceutical supply chain and lay a solid theoretical foundation for the discussion of specific application cases and solutions in subsequent chapters.

2.2 Blockchain Technology

Blockchain technology's potential to maintain immutable records is pivotal in preventing fraud and the circulation of counterfeit products in the pharmaceutical supply chain. This assertion, supported by Koulu [15], highlights how blockchain enhances trust among participants and reduces regulatory costs.

Focusing on regulatory compliance for cross-border pharmaceutical shipments, Kshetri [16] introduces a smart contract-based model that automates compliance checks. This model ensures that pharmaceuticals meet the regulatory standards of importing and exporting countries, thus speeding up drug flow and enhancing international regulatory coordination.

The reduction of information asymmetry in cross-border pharmaceutical supply chains is the focus of a study by Kumar & Tripathi [17]. They develop a blockchain framework that allows real-time access to goods movement information for all supply chain participants, enhancing flexibility and reducing risks related to drug delays and expiration.

Exploring data security within the pharmaceutical supply chain, Kumar et al. [18] utilize blockchain's cryptographic features to secure sensitive data. Their research demonstrates blockchain's effectiveness in preventing data breaches and protecting pharmaceutical data from unauthorized access and tampering.

A layered blockchain system to track the full lifecycle of pharmaceuticals is proposed by Kuo et al. [19]. Their research indicates significant improvements in drug safety and a reduction in health risks by ensuring data integrity and traceability from manufacturing to patient delivery.

In the cold chain transportation of pharmaceuticals, Lai [20] implements a blockchain-based temperature monitoring system. The approach to real-time temperature data recording and verification reveals enhancements in the transparency of the drug supply chain and a reduction in drug losses due to temperature anomalies.

Li et al. [21] examine the potential for blockchain to facilitate real-time collaboration between regulators and pharmaceutical companies. They propose a platform that allows immediate access to drug test results and production records, thereby improving regulatory efficiency and market transparency.

Finally, addressing intellectual property issues within the pharmaceutical supply chain, Lieder & Rashid [22] develop a system to manage drug patent information. Their blockchain-based approach helps prevent counterfeiting and ensures that only authorized manufacturers can produce and distribute patent-protected drugs, significantly reducing the circulation of illegal drugs in the market.

Regarding the potential risks of blockchain technology in cross-border pharmaceutical supply chains, several researchers have provided valuable insights. Liu [23] focuses on data privacy, proposing a hybrid blockchain model that combines public and private chains to enhance data protection without sacrificing transparency and efficiency. Narayana et al. [24] explore the compatibility of blockchain technology with existing enterprise resource planning (ERP) systems and supply chain management tools, suggesting middleware solutions to facilitate smooth integration. Ometov et al. [25] address scalability issues, advocating for more efficient blockchain architectures and optimization algorithms to improve transaction processing speed and system performance. Peng et al. [26] examine compliance risks, proposing programmable smart contracts to automatically adjust compliance policies, ensuring legal adherence across different regulatory environments.

These studies collectively demonstrate the diverse applications of blockchain technology in enhancing global pharmaceutical supply chain management, particularly in terms of increasing transparency, safety, and collaborative efficiency, while also highlighting the major risks and challenges faced. Through these theoretical and empirical studies, it is evident that blockchain technology can significantly contribute to improving the pharmaceutical supply chain.

Chapter 3 - Research Methodology

3.1 Research Design and Data Collection

The study utilizes exploratory factor analysis (EFA) to analyze the initial data collected through a structured questionnaire. The questionnaire is designed to explore six key aspects of blockchain technology's impact on cross-border e-commerce: business coordination, information sharing, information security, system adaptability, system reliability, and supply chain costs [27]. The rationale behind selecting these specific aspects and the structure of the questionnaire can be found in Appendix A and B.

3.2 Confirmatory Factor Analysis

Following the EFA, a confirmatory factor analysis (CFA) using structural equation modeling (SEM) is conducted to validate the relationships among the indicators identified. This step confirms the adequacy of the indicator relationship model and the significant relationships between the constructs [28]. These analyses collectively aim to substantiate the significant effect of blockchain technology on the traceability of cross-border e-commerce of imported medicines.

3.3 Challenges and Considerations

While the introduction of blockchain technology shows significant potential benefits, it also introduces challenges related to system adaptability and the costs associated with reconstructing supply chains [29]. These issues are directly explored in the questionnaire to assess their impact on the overall effectiveness of blockchain implementation.

3.4 Evaluation of Questionnaire Responses

The survey results are evaluated using the literature on research methodologies by experts in the field. The semi-structured questionnaire allows for a nuanced assessment of the proposed model and artifact, to draw inferences about a broader population. This method contrasts with a census approach, focusing instead on a representative sample which provides insights into the general population's behavior and perceptions.

3.5 Principles of Artifact Evaluation

In this case, the implementation and impact of blockchain technology, is evaluated based on criteria including completeness, ease of use, fidelity to real-world phenomena, internal consistency, level of detail, simplicity, understandability, importance, accessibility, and suitability, detailed in Table 3.1.

This methodology chapter uses structured questionnaire data, combined with comprehensive factor analysis techniques, to form conclusions based on the survey questionnaires filled out by participants.

Table 3. 1 Semi-Structured Questionnaire for Evaluation

	Criterion	Statement
1	Completeness	The introduction of automation into the audit process contains all the rules and standards of both realms.
2	Ease of use	The impact of blockchain technology on cross-border e-commerce of imported medicines is well-described and easy to verify and implement in both contexts.
3	Fidelity with real-world phenomena	The proposed artifact corresponds to possible solutions.
4	Internal consistency	The findings of the impact of blockchain technology on cross-border e-commerce of imported medicines has an adequate terminology, are well-written, and are justified by the theory.
5	Level of detail	The proposed artifact contains a sufficient level of detail in each mechanism for each area.
6	Simplicity	The proposed artifact contains the necessary practices and it is easy to implement.
7	Understandability	The proposed artifact is easily understood as a good practice for blockchain technology on cross-border e-commerce of imported medicines practitioners.
8	Importance	The proposed artifact is important for both practitioners and academics.
9	Accessibility	The proposed artifact has an understandable terminology with a practical perspective, not only a theoretical one.

	Criterion	Statement
10	Suitability	The proposed artifact of practices is applicable in the practice of both realms.

3.6 Questions

Table 3.2 and 3.3 summarize the structure and content of the survey questionnaires included in Appendix A and Appendix B. These appendices are useful to reflect and transmit information in the e-commerce. The questionnaire captures fundamental demographic information, such as age, gender, and professional background, while also exploring respondents' familiarity and experiences with blockchain technology and pharmaceutical traceability [30].

Table 3. 2 Survey Structure of Blockchain-Based Pharmaceutical Traceability in Cross-Border E-Commerce

Section	Key Information and Questions
Introduction	-Objective: Promote high-quality development of cross-border e-commerce in pharmaceutical imports using blockchain.
Basic Information	1. Familiarity with blockchain technology. 2. Familiarity with cross-border e-commerce in pharmaceutical imports. 3. Familiarity with drug traceability. 4. Concern for quality and safety of pharmaceutical products.
Business Coordination Level	5-7. Agreement on whether blockchain improves responsiveness, management, and business growth in the pharmaceutical supply chain.
Information Sharing Level	8-10. Agreement on whether blockchain enhances shareability, access to information, and information transmission efficiency.
Information Security Level	11-13. Agreement on whether blockchain enhances confidentiality, tamper-proof nature, and integrity of traceability information.
System Adaptability Level	14-16. Agreement on whether blockchain improves acceptability, operability, and scalability of traceability systems.
System Reliability Level	17-19. Agreement on whether blockchain improves availability, authenticity, and traceability of information.

Section	Key Information and Questions
Supply Chain Cost Level	20-22. Agreement on whether blockchain reduces operational, management, and transaction costs.

Table 3.3 outlines the questions and key areas covered in Appendix B, Parts 1 and 2, of the survey. It explores deeper demographic details, professional background, and detailed perceptions of blockchain technology's role in pharmaceutical traceability. The questions aim to gather insights on both general awareness and specific applications of blockchain in the industry.

Table 3. 3 Questionnaire on Professional Background and Blockchain Application in Pharmaceutical Traceability

Part	Section	Key Information and Questions
1	Basic Information	1. Gender 2. Age 3. Occupation 4. Experience purchasing pharmaceuticals via cross-border e-commerce.
	Blockchain Technology Awareness	5-6. Understanding and perceived potential of blockchain in pharmaceutical traceability.
	Traceability in Cross-border E-commerce Pharmaceuticals	7-9. Current traceability rating, attention to traceability information, and critical traceability aspects.
	Application of Blockchain in Pharmaceutical Traceability	10-12. Advantages, challenges, and willingness to pay for blockchain-supported traceability.
2	Basic Information	1. Education level 2. Work experience years 3. Industry
	Awareness of Blockchain Technology	4-5. Initial exposure to blockchain and participation in related training.
	Experience with Pharmaceutical Traceability	6-8. Frequency of pharmaceutical purchases on e-commerce, factors cared about and encounters with suspicious sources.

Part	Section	Key Information and Questions
	Application of Blockchain Technology in Pharmaceutical Traceability	9-11. Aspects where blockchain can increase trust, understanding of data immutability, and impact on counterfeit drug reduction.
	Future Prospects of Blockchain Technology	12-14. Optimism about future blockchain applications in traceability, limiting factors, and willingness to participate in further blockchain training.
	Open-ended Questions	15. Additional suggestions or views on blockchain in pharmaceutical traceability.

Structure and Purpose:

The questionnaire is designed to assess professionals' awareness and perceptions of blockchain technology within their organizations and to understand its impact on management practices in the pharmaceutical import sector. Initial inquiries focus on basic demographic data and general awareness, setting the stage for more detailed questions about specific experiences and attitudes towards blockchain technology in pharmaceutical traceability.

Questionnaire Details:

Appendix A addresses the application of blockchain technology in enhancing the traceability of imported pharmaceuticals, querying participants on their familiarity with various aspects of blockchain, e-commerce, and drug traceability. This section also seeks to understand the respondents' agreement on potential improvements blockchain might bring to business processes and information security.

Appendix B, divided into two parts, goes deeper into personal and professional backgrounds and further explores respondents' detailed opinions on blockchain's role in pharmaceutical traceability. This includes their views on its advantages, challenges, and the potential to improve trust and reduce risks in the supply chain.

Evaluation and Feedback:

Respondents were asked to rate the value of the questions from 0 (not useful) to 5 (very useful) to gauge the relevance of each query in relation to enhancing understanding of blockchain applications in their field. Two optional open-ended questions conclude the survey, allowing for additional feedback on desired solutions and potential improvements in the adoption of blockchain technology.

3.7 Population and Sample

The population under consideration comprises and offers insightful details about the composition of in terms of qualifications, age, roles, and gender. Finally, 100 participants were effectively collected for the questionnaire survey. The Table 3.4 to Table 3.6 illustrate the characteristics of participants.

Table 3. 4 Age Distribution Situation

Age	Ratio （%）	Description
18-25	20	Mainly college students and young professionals entering the workplace for the first time
26-35	30	Most of them are intermediate professionals with certain industry experience and technical background
36-45	25	Usually holding management positions or possessing extensive professional experience
46-55	15	Advanced professionals may be at the peak of their career
56 and above	10	Including retired professionals and long-term practitioners, experience is particularly valuable

Table 3. 5 Professional Background Situation

Career field	Ratio（%）	Describe
Pharmaceutical industry professionals	25	Directly involved in the production, supervision, or distribution of drugs
E-commerce professionals	20	Focusing on the operation, management, and innovation of e-commerce platforms
IT professionals	20	Mainly responsible for technical support, blockchain development, and system maintenance
Academic researchers	15	From higher education institutions, dedicated to researching blockchain technology and its applications in various industries
Other professionals	20	Including legal advisors, business analysts, market experts, etc., providing multidimensional insights

Table 3. 6 Educational Background Situation

Career field	Ratio （%）	Describe
High school and below	10	Provide a perspective on basic education, emphasizing practical experience and direct insights
Junior college	20	Participants typically have professional technical education and are able to provide specific insights into applied technology and operations
Baccalaureate	30	More common in the workplace, representing the combination of professional knowledge and theoretical foundation
Master's degree	30	Means a deeper professional research and analysis ability, as well as a stronger understanding and application ability of new technologies, usually involving deeper research, whose opinions can deepen the scientific and professional understanding of research results
PhD or above	10	Provide a perspective on basic education, emphasizing practical experience and direct insights

Chapter 4 - Results

4.1 Analysis of Research Results

This chapter conducts an in-depth analysis of the survey results, explore the application of blockchain technology in cross-border e-commerce drug tracking, and its impact on various key aspects. The questionnaire covers multiple dimensions, including business coordination, information sharing, information security, system adaptability, system reliability, and supply chain costs. We analyze each dimension in detail and introduce specific viewpoints and suggestions from participants to support the analysis.

1. Business coordination

Figure 4.1 reveals that a significant majority, 78% of respondents, are optimistic about the benefits of blockchain technology in enhancing the drug tracking process. They believe that its decentralized nature facilitates the real-time update and transmission of critical information across the supply chain, leading to improved response speeds and better management capabilities. For instance, one participant highlighted the advantages of blockchain by noting, "Blockchain enables us to respond more quickly to changes in the supply chain and improve management efficiency." This feedback underscores how blockchain can streamline complex coordination processes and boost operational efficiency by eliminating the delays inherent in centralized systems.

Participants in favor of blockchain also pointed out that it enhances transparency and accountability in the supply chain. With each transaction or update being recorded on a blockchain, it becomes easier to trace the origins of drugs and manage inventories more effectively. This can be particularly beneficial in scenarios where quick decision-making is crucial, such as during health crises or drug recalls.

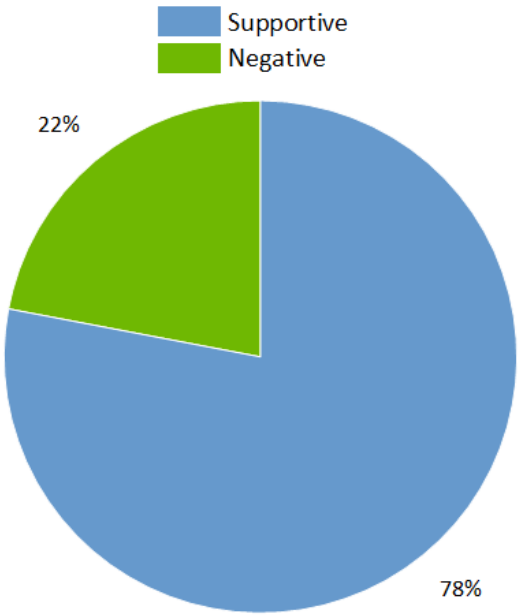
On the other hand, 22% of the respondents expressed skepticism regarding the practical application of blockchain in business coordination. Their concerns primarily stem from issues related to technological acceptance and the reliance on well-established traditional processes. Many in this group feel that while current systems are admittedly less efficient, they have the advantage of familiarity. The transition to a blockchain-based system is seen as a daunting task that involves not just financial outlay but also significant changes to existing workflows. A respondent encapsulated these challenges by stating, "Despite the potential of blockchain technology, our current systems and personnel require extensive training and adjustments, which is a significant challenge for us."

Furthermore, skeptics are wary of the scalability of blockchain solutions and the security challenges that come with digital platforms. They argue that while blockchain could theoretically

streamline processes, the practical challenges of integrating this technology with existing IT systems and ensuring it can handle large-scale operations are significant hurdles.

In conclusion, while there is strong enthusiasm for the potential of blockchain to transform the drug tracking industry by making it more efficient and transparent, reservations about the cost, complexity of implementation, and the readiness of existing systems and personnel also hold substantial weight. Moving forward, addressing these concerns through more detailed feasibility studies, pilot programs, and training can help in achieving a broader consensus on the adoption of blockchain technology in the pharmaceutical supply chain.

Figure 4. 1 Participants' Attitudes Towards Blockchain Technology in Improving Drug Tracking Processes



2. Information sharing

About the role of blockchain technology in enhancing information sharing within the pharmaceutical industry, as shown in Figure 4.2, 85% of respondents, acknowledged the significant benefits of blockchain in promoting transparency. They particularly highlighted its impact on the efficiency and accuracy of information transmission. The immutability characteristic of blockchain not only ensures the authenticity of recorded information but also brings about transformative improvements in tracking drugs across international borders. One participant emphasized this advantage by stating, "Blockchain makes information sharing more reliable, and we can more easily obtain real information about drugs." This comment reflects a general consensus that blockchain

technology plays a pivotal role in facilitating smoother information flows and reducing delays in the availability of critical drug-related data.

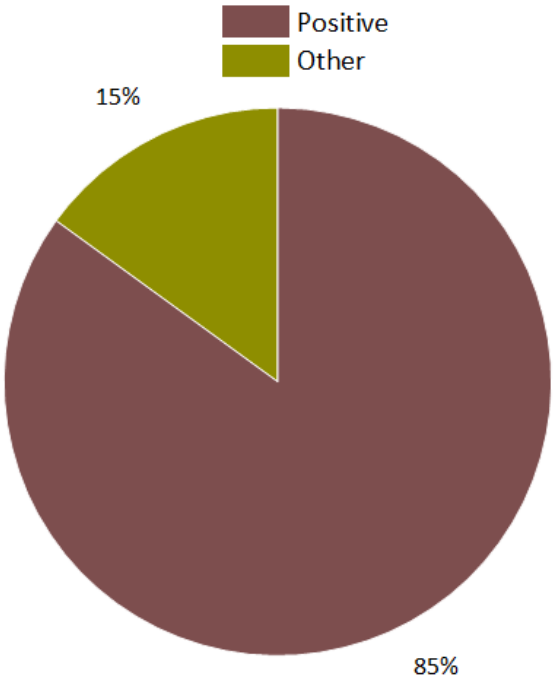
Respondents favoring blockchain pointed out that its application helps in building a robust framework where each entry on the blockchain can be verified by all parties but cannot be altered or deleted. This aspect is particularly valuable in scenarios involving multiple stakeholders across different jurisdictions, as it ensures that all parties have access to the same reliable information, thereby reducing conflicts and misunderstandings. It also enables faster responses in crisis situations, such as during outbreaks or recalls, where time-sensitive, accurate information is crucial for effective decision-making.

However, despite these benefits, the survey also uncovered some concerns among the respondents. A notable 15% expressed apprehensions regarding the potential risks associated with excessive information sharing facilitated by blockchain. Their main concern centers on privacy and security issues that might arise from the accessibility of sensitive data. As one respondent articulated, "Although information transparency has improved, we are also concerned about whether this information would be improperly used, especially when it comes to sensitive data." This statement underscores a critical challenge in the adoption of blockchain technology: balancing the need for transparency with the imperative to protect individual and corporate privacy.

These concerns highlight the potential vulnerabilities that could be exploited if sensitive information, such as patient data or proprietary business information, is not adequately protected. The decentralized nature of blockchain, while preventing tampering, does not inherently limit who can access the information once they are part of the network. This could lead to scenarios where confidential data might be exposed to unauthorized parties.

In conclusion, while blockchain technology offers promising solutions for improving information sharing and transparency within the pharmaceutical supply chain, it also necessitates careful consideration of privacy and security measures. The industry must develop stringent protocols and innovative solutions to ensure that while information is accessible, it remains protected against misuse. Moving forward, fostering a dialogue between technology experts, regulatory authorities, and industry stakeholders are essential to navigate these challenges and harness the full potential of blockchain in enhancing drug tracking processes.

Figure 4. 2 Attitudes of Participants Towards Enhancing Information Transparency Through Blockchain Technology



3. Information safety

In assessing the impact of blockchain technology on information security within the pharmaceutical industry, we can learn from Figure 4.3 that an overwhelming 92% of participants affirmed that blockchain substantially enhances the confidentiality and integrity of data. The respondents attribute this improvement primarily to the use of advanced encryption technologies that blockchain employs to safeguard data against unauthorized access and modifications. One participant specifically noted, "The encryption features of blockchain provide higher security for our data, reducing the risk of data tampering." This comment illustrates the confidence many have in blockchain's ability to maintain data security and integrity, which is paramount in an industry where data breaches can have severe consequences, not just financially but also in terms of patient safety.

Moreover, many respondents pointed out the added benefits of smart contracts, which are self-executing contracts with the terms of the agreement directly written into code. The automation and self-enforcement provided by smart contracts eliminate much of the human error typically associated with manual processes. They also enhance compliance with regulatory requirements by automatically executing transactions that are consistent with pre-established rules and criteria. This is particularly beneficial in the pharmaceutical industry, where adherence to strict regulatory standards is critical.

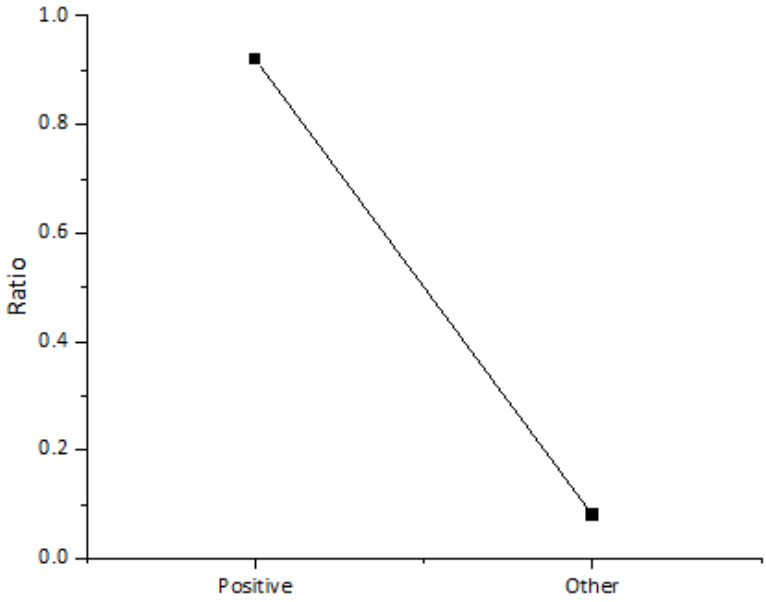
Despite the strong endorsement of blockchain's security features, there are reservations about its broader implementation, highlighted by concerns regarding its technological vulnerabilities and the application environment. As one respondent expressed, "Although blockchain itself is very secure, the

security of its application environment and the compliance with global data protection regulations are still our concerns." This perspective highlights a critical aspect of blockchain deployment—while the technology offers robust security features, the environments in which it operates can present vulnerabilities. For instance, the interfaces or portals through which users interact with blockchain systems can be susceptible to cyber-attacks, potentially exposing sensitive data.

Furthermore, the global nature of the pharmaceutical industry, with its complex supply chains and diverse regulatory environments, adds another layer of complexity. Ensuring that blockchain solutions comply with a myriad of international data protection laws, such as the General Data Protection Regulation (GDPR) in Europe or the Health Insurance Portability and Accountability Act (HIPAA) in the United States, is crucial. Non-compliance can lead to significant legal penalties and damage to an organization's reputation.

In conclusion, while blockchain technology is recognized for its capacity to significantly enhance the security and integrity of data in the pharmaceutical industry, careful consideration must be given to the security of the application environments and the compliance with international data protection regulations. As the industry moves forward with adopting blockchain, ongoing evaluations and enhancements of these aspects are essential to fully leverage blockchain's capabilities and ensure the safety and privacy of sensitive data. Strengthening the security of the application environments and aligning blockchain operations with global data protection standards are vital in mitigating risks and maximizing the technology's benefits.

Figure 4. 3 Attitudes of Participants Towards Enhancing Information Security Capabilities Through Blockchain Technology



4. System adaptability

As for examining the adaptability of blockchain technology within various business environments revealed a notable divergence in opinions among industry professionals. From Figure 4.4, we know that approximately 70% of respondents expressed confidence that blockchain technology could be effectively integrated into their existing business processes. One participant emphasized this positive outlook, stating, "Blockchain technology can be well integrated into our existing processes and improve overall efficiency." This perspective is reflective of a broader sentiment that sees blockchain as a versatile tool capable of enhancing operational efficiencies, streamlining communication, and ensuring more secure and transparent transactions.

These respondents often cited blockchain's ability to seamlessly interact with current systems as a key benefit. They highlighted how blockchain could automate routine tasks, reduce redundancy, and provide a reliable audit trail, which is particularly advantageous in industries requiring strict compliance and traceability. The integration of blockchain is viewed not just as a technological upgrade but as a strategic advantage that could lead to more streamlined operations and improved responsiveness to market demands.

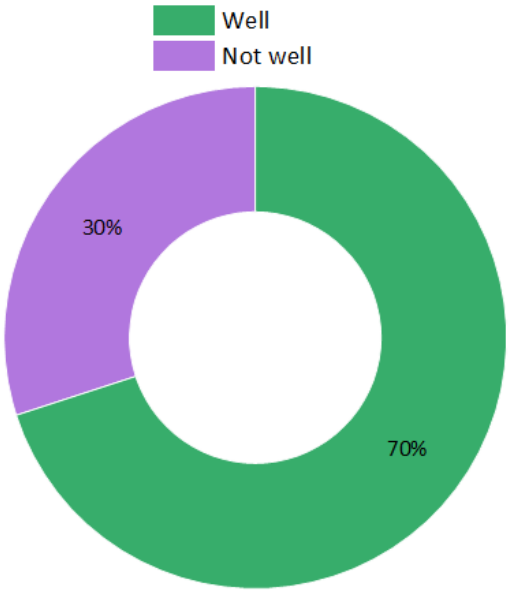
On the other hand, 30% of survey participants indicated that the integration of blockchain technology into existing business frameworks still presents considerable challenges. The most significant of these challenges is the state of current IT infrastructure, which many feel is inadequate to support the complex demands of blockchain applications. A respondent noted, "Our IT infrastructure needs to undergo significant upgrades in order to fully support the application of blockchain technology. This not only involves technical issues but also investment in cost and time." This statement underscores the practical difficulties some companies face, including the need for substantial financial investments and the potential for disruptions during the transition period.

The feedback from this group suggests that while blockchain holds considerable promise, the readiness of an organization's IT environment is a critical determinant of how quickly and effectively this technology can be adopted. Concerns were also raised about the lack of in-house expertise and the need for extensive training of personnel to manage and maintain blockchain systems effectively. These challenges are compounded in sectors where IT systems are outdated or where there is a resistance to change due to the perceived risk and uncertainty associated with new technological adoptions.

In conclusion, while a significant majority of industry professionals recognize the potential benefits of blockchain in enhancing business operations, a considerable proportion also caution against underestimating the practical challenges involved in its integration. For blockchain technology to reach its full potential, companies must not only invest in upgrading their IT infrastructure but also in developing the skills of their workforce to handle new technology. This dual approach is essential for

overcoming the initial barriers to adoption and for realizing the long-term benefits of blockchain in business processes.

Figure 4. 4 Attitudes of Participants Towards the Adaptability of Blockchain Technology Systems



5. System reliability

When talking about the gauging the impact of blockchain technology on system reliability, Figure 4.5 shows that an impressive 89% of respondents attested to improvements in both system stability and data accuracy. This majority views blockchain as a transformative technology that enhances the robustness of systems by making them more resilient against data tampering and errors. A representative comment from one participant encapsulates this sentiment: "Blockchain makes our systems more reliable and significantly improves the accuracy of data." Such feedback highlights the unique attributes of blockchain, including its decentralized nature and cryptographic security measures, which ensure that data is not only secure but also accurate and consistent across different platforms.

Respondents appreciated how blockchain technology maintains a continuous, unalterable record of transactions, which is crucial for sectors where data integrity is paramount. The ledger system that blockchain employs allows for a transparent audit trail, where each entry is time-stamped and linked to the previous one, making unauthorized alterations extremely difficult. This feature is particularly beneficial for industries like finance, healthcare, and supply chain management, where even minor discrepancies can lead to significant issues.

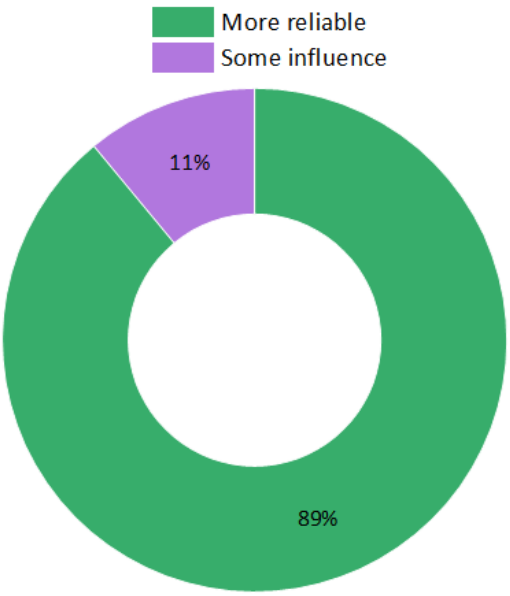
Despite the widespread acclaim for the enhanced reliability and accuracy brought about by blockchain, some respondents voiced concerns over its scalability and performance in large-scale

applications. The decentralized verification process, while secure, can lead to inefficiencies and slower transaction speeds compared to centralized databases, especially when dealing with high volumes of transactions. One respondent articulated this concern by stating, "Although blockchain enhances security and accuracy, we are uncertain if its processing speed is fast enough to maintain efficient operation in large-scale transactions." This concern points to a critical area of focus for the ongoing development of blockchain technology—optimizing performance without compromising on security or accuracy.

The feedback indicates that while blockchain is beneficial for enhancing system reliability, its implementation in large-scale settings poses significant challenges. The technology's performance under heavy loads and its ability to process transactions rapidly without system slowdowns are areas that need further research and development. Industry professionals are looking for solutions that can scale blockchain's capabilities to meet the demands of enterprise-level applications without sacrificing the core benefits that make it appealing.

In conclusion, the survey underscores a strong belief in the potential of blockchain to improve system reliability and data accuracy across various sectors. However, it also highlights the necessity for advancements in blockchain technology to enhance its scalability and performance. As blockchain continues to evolve, finding a balance between maintaining robust security and improving processing speeds is crucial for its broader adoption and effectiveness in handling large-scale, complex applications.

Figure 4. 5 Attitudes of Participants Towards the Reliability of Blockchain Technology Systems

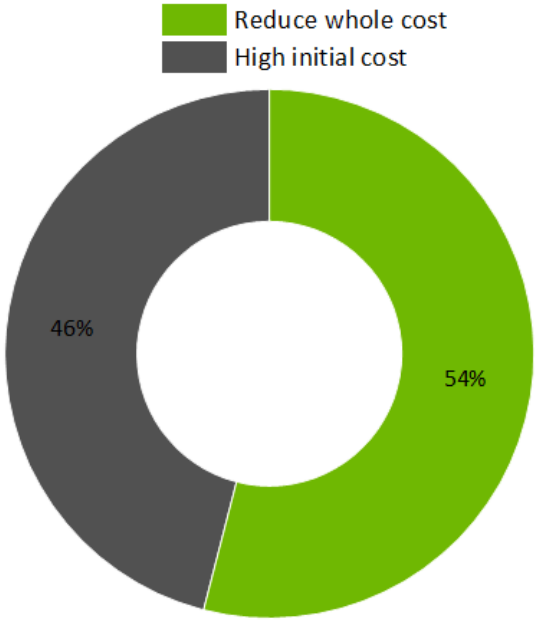


6. Supply chain costs

The supply chain cost is the most divergent item in the survey. From Figure 4.6, there are 54% of respondents believing that blockchain can help reduce operational and management costs, especially by reducing intermediate links and automating transaction processes. For example, one respondent pointed out that "blockchain can reduce intermediate links, make transaction processes more efficient, and thus reduce overall costs." However, 46% of respondents stated that although blockchain can bring long-term operational cost savings, initial investment and maintenance costs are relatively high.

A respondent specifically mentioned, "Although blockchain can save costs in the long term, its initial investment is indeed a significant burden. This includes various expenses such as system construction, personnel training, and daily maintenance." This feedback shows that in the early stages of blockchain technology application, enterprises need to balance costs and benefits and make reasonable budgeting and planning.

Figure 4. 6 Attitudes of Participants Towards the Supply Chain Cost of Blockchain Technology



In order to gain a more intuitive understanding of the application effect of blockchain technology in pharmaceutical supply chain management, this study summarizes multiple key aspects. The Table 4.1 below summarizes these analysis results and shows the positive feedback and challenges faced by blockchain technology in business coordination, information sharing, information security, system adaptability, system reliability, and supply chain costs.

Table 4. 1 The Application of Blockchain Technology in Pharmaceutical Supply Chain Management

Partial	Positive feedback	Negative feedback
Business coordination	78% of business coordinators believe that blockchain can improve response speed and management capabilities, simplify complex coordination processes.	22% believe that there are challenges in the practical application of blockchain, especially in terms of technological acceptance and dependence on traditional processes.
Information sharing	85% believe that blockchain can improve information transparency and transmission efficiency, and enhance drug tracking	Some respondents are concerned that excessive information sharing may lead to privacy and security issues.
Information safety	92% believe that blockchain can significantly improve data confidentiality and integrity, and reduce the risk of data tampering	There are still concerns about the application environment of blockchain and compliance with global data protection regulations.
System adaptability	70% believe that blockchain can adapt to existing business processes and improve efficiency	30% of respondents reported inadequate IT infrastructure and technical support, facing integration challenges
System reliability	89% believe that blockchain has improved system stability and data accuracy	In large-scale applications, the performance and processing speed of blockchain systems may be affected
Supply chain cost	54% believe that blockchain can reduce operational and management costs, especially by reducing intermediaries and automating transaction processes	46% believe that the initial investment and maintenance costs of blockchain are high, which imposes a burden on enterprises

From the analysis, we conducted a detailed analysis of the performance of blockchain in practical applications through survey data and feedback from participants. We found that blockchain technology does have significant advantages in improving information transparency and data security. Most participants believe that blockchain can effectively improve the operational efficiency of the pharmaceutical supply chain and consumer trust, which is consistent with the research objectives. In addition, we also explored the challenges that blockchain faces in technology integration and data privacy protection, which also responds to the applicability issues mentioned in the research objectives

in different regulatory environments. Through these analyses, we can gain a more comprehensive understanding of the application value and future development direction of blockchain technology in pharmaceutical supply chain management.

4.2 Suggestions for Enterprises

Pharmaceutical companies should seize the opportunity in the pilot phase of cross-border e-commerce imports of pharmaceuticals, and actively implement blockchain traceability systems. This is advantageous in establishing a foothold in the early development of cross-border e-commerce imports of pharmaceuticals, increasing consumer acceptance, enhancing corporate image and brand value, and improving operational efficiency through digital transformation.

Strengthen information traceability mechanisms in the enterprise supply chain process. By constructing traceability systems, enhances information sharing and traceability levels. In the traceability of the supply chain links in cross-border e-commerce imports of pharmaceuticals, problems can be identified and responsible parties located in a timely manner, optimizing supply chain management and improving the operational performance of import pharmaceutical enterprises.

Improve the risk warning and protection system for cross-border e-commerce imports of pharmaceuticals. For cross-border e-commerce imports of pharmaceuticals, the quality and safety of imported pharmaceuticals cannot be guaranteed if problems arise in any link of raw material procurement, production processing, warehousing logistics, and sales circulation. Import pharmaceutical enterprises can identify and judge risk factors in a timely manner through traceability, rapidly address issues, and ensure the quality and safety of cross-border e-commerce imports of pharmaceuticals.

Pharmaceutical companies stand at a pivotal moment with the burgeoning opportunity presented by the pilot phase of cross-border e-commerce imports of pharmaceuticals. This juncture offers a strategic advantage for companies to integrate blockchain traceability systems actively. By adopting such advanced systems, pharmaceutical firms can not only solidify their position in the early stages of the cross-border e-commerce market but also significantly enhance consumer trust and acceptance. The deployment of blockchain technology in this context promises to refine corporate image and escalate brand value, positioning these companies as pioneers in digital transformation within the pharmaceutical industry.

Implementing blockchain traceability systems allows these companies to establish a transparent, secure, and efficient supply chain. This technology enables the precise tracking of each step in the supply chain from raw material procurement through to the final sale, ensuring that all stakeholders have access to unalterable data. In the context of cross-border e-commerce imports, where multiple

jurisdictions and regulatory frameworks complicate the supply chain, blockchain provides a unified and consistent method to manage logistical complexities. This capability significantly reduces the risks associated with manual errors and fraud, leading to improved operational efficiency and greater compliance with international standards.

Moreover, strengthening information traceability mechanisms within the enterprise supply chain process is crucial. Constructing robust traceability systems elevates the level of information sharing among stakeholders and enhances traceability across all links of the supply chain. In scenarios where issues arise, such systems can swiftly pinpoint problems and identify responsible parties. This responsiveness not only optimizes supply chain management but also boosts the operational performance of pharmaceutical companies engaged in cross-border e-commerce. Enhanced traceability facilitates the timely resolution of issues, which is essential in maintaining the integrity of sensitive pharmaceutical shipments and in preventing potential health risks associated with compromised medication.

Furthermore, improving the risk warning and protection system is another critical aspect that pharmaceutical companies should focus on. The complexity and scale of cross-border e-commerce in pharmaceuticals bring about various challenges, particularly concerning the quality and safety of imported products. By integrating blockchain-based traceability, companies can quickly identify and assess risk factors at any stage of the supply chain—from raw material sourcing to consumer delivery. This proactive approach in monitoring and addressing potential threats ensures the continuous safeguarding of product quality and safety, crucial for maintaining consumer confidence and regulatory compliance.

In essence, the adoption of blockchain technology in the traceability of pharmaceuticals through cross-border e-commerce not only fortifies the supply chain but also acts as a strategic lever to enhance market competitiveness. It enables pharmaceutical companies to manage risks more effectively, streamline operations, and meet the increasing demands of global trade compliance. As the industry continues to evolve, those who invest in such innovative technologies would likely lead the market, setting new standards for safety, efficiency, and consumer trust in the international pharmaceutical sector.

4.3 Suggestions for Consumers

In an era increasingly influenced by digital transformation, pharmaceutical companies must proactively engage with government initiatives that promote emerging technologies such as blockchain and big data. Understanding and incorporating such technologies into their operational frameworks is crucial for staying at the forefront of the cross-border e-commerce imports of pharmaceuticals. Blockchain,

in particular, offers distinctive advantages in traceability that are indispensable for this sector. By leveraging blockchain's immutable and transparent nature, pharmaceutical companies can enhance the traceability of their supply chains, thereby significantly improving the safety, reliability, and authenticity of drug imports. This not only aligns with government efforts to promote high-quality digital transformations but also propels the pharmaceutical industry towards more secure and efficient operational practices.

Recognizing the role of blockchain traceability can catalyze the adoption of digital technologies among import pharmaceutical enterprises, driving innovation and high-quality development in the cross-border e-commerce market. With blockchain, enterprises can ensure a seamless flow of accurate information, which is crucial for managing the complexities of international pharmaceutical logistics. This includes ensuring compliance with diverse international regulations and standards, which is streamlined by blockchain's capability to provide real-time tracking and verification of drug movement across borders.

In parallel to technological adoption, there is a pressing need for pharmaceutical companies and consumers alike to stay informed about pharmaceutical safety and related information. With the vast amount of information available through various self-media and online channels, consumers and companies need to cultivate a higher level of drug safety awareness. For consumers, this involves learning about the basic safety aspects of medications and being vigilant about the quality of the products they use. Consumers should be equipped to identify products with potential quality risks and recognize signs of counterfeit or substandard products, thus protecting their rights and health effectively.

Furthermore, increasing consumer awareness about traceable products can stimulate market demand for such products, encouraging more pharmaceutical companies to adopt traceability solutions. This awareness is instrumental in pushing enterprises towards transformation and upgrading their systems to integrate advanced digital technologies. By promoting traceable products, companies not only meet consumer demand for transparency but also enhance their own brand trust and market competitiveness.

Overall, the synergy between governmental digital initiatives, corporate technology adoption, and consumer safety education forms a robust framework for the advancement of the pharmaceutical sector. This holistic approach ensures that the benefits of technologies like blockchain are fully realized, leading to a safer, more transparent, and efficient pharmaceutical market. As the industry progresses, continued investment in education, technology, and consumer engagement are key to sustaining growth and ensuring the highest standards of safety and quality in cross-border e-commerce imports of pharmaceuticals.

4.4 Discussion

This thesis delves into the results of the survey questionnaire and explores the potential impact and challenges of blockchain technology in cross-border e-commerce drug tracking from both theoretical and practical perspectives [32]. The discussion in this chapter focuses on several key aspects: how blockchain technology can address existing supply chain pain points, its potential in improving supply chain transparency and efficiency, and the main challenges encountered during implementation.

The immutability and transparency of data provided by blockchain technology solve the problems of information asymmetry and low data credibility in traditional supply chains. According to survey data, the majority of participants acknowledge the important role of blockchain in ensuring drug safety, reducing the circulation of counterfeit products, and strengthening regulatory compliance. The application of this technology not only improves the operational efficiency of cross-border e-commerce, but also enhances consumer trust, bringing significant benefits to all parties in the pharmaceutical supply chain. Although blockchain has revolutionary potential in theory, its practical application still faces many challenges. Technology integration is a major obstacle, especially in terms of compatibility with existing systems. A considerable portion of the respondents pointed out that the existing IT infrastructure and technical support are insufficient, making the integration and optimization process of blockchain complex and costly. In addition, concerns about data security and privacy cannot be ignored. Although blockchain itself is extremely secure, the security of its application environment and compliance with global data protection regulations are still issues that enterprises and policy makers need to pay attention to [33].

With the maturity of technology and the improvement of relevant regulations, it is expected that blockchain plays an increasingly important role in the field of cross-border e-commerce. To achieve this goal, close cooperation between industry leaders, technology developers, and policy makers is needed to overcome existing challenges and promote innovation and application of technology. Continuous education and training, technological innovation, and cross-border cooperation are key factors driving the widespread adoption of blockchain technology in this process [34].

Through the in-depth discussion in this chapter, we not only provide a comprehensive understanding of the application of blockchain technology in cross-border e-commerce drug tracking, but also anticipate the industry changes that this technology may lead. The following is a description of the specific modules:

Enhancing Traceability and Transparency:

Blockchain technology offers an exceptional level of traceability in pharmaceutical supply chains. Each transaction recorded on a blockchain provides an indelible audit trail, facilitating the real-time tracking of drug movement from manufacturer to consumer. This heightened visibility helps in

verifying the authenticity of drugs and in combating counterfeit pharmaceuticals, a significant concern in cross-border e-commerce. Furthermore, blockchain enables all parties—manufacturers, regulators, distributors, and consumers—to access the same information, thereby fostering transparency and trust among stakeholders [35].

Improving Security and Compliance:

The security features of blockchain, including its resistance to tampering and unauthorized access, are critical in managing sensitive information in the pharmaceutical industry. By leveraging cryptographic techniques, blockchain ensures that data exchanges across the network are secure and that access is granted only to authorized individuals. This not only helps in protecting patient data but also ensures compliance with stringent regulatory requirements, such as those stipulated by the GDPR in Europe and HIPAA in the United States.

Operational Efficiency and Cost Reduction:

Blockchain can streamline operations within the pharmaceutical supply chain by automating many processes that are traditionally manual and time-consuming. Smart contracts, for instance, can be used to automatically execute agreements upon the fulfilment of predefined criteria, such as payment release upon delivery confirmation. This automation reduces the need for intermediaries, thereby cutting down operational costs and minimizing delays.

Challenges and Considerations:

While blockchain presents numerous advantages, its implementation is not without challenges. The scalability of blockchain technology, particularly in handling large volumes of transactions typical of the pharmaceutical industry, remains a concern. Additionally, the integration of blockchain with existing IT systems poses technical and organizational challenges that require careful planning and execution.

In conclusion, the application of blockchain technology in the traceability of cross-border e-commerce imports of pharmaceuticals offers significant benefits, including enhanced traceability, increased security, and operational efficiencies. However, careful consideration of the associated challenges is crucial for successful implementation. The next section explores potential solutions to these challenges and outline strategic approaches for leveraging blockchain in the pharmaceutical supply chain.

Chapter 5 - Conclusion

5.1 Final Conclusions

The study delves deeply into the realm of blockchain traceability within the specific context of cross-border e-commerce pharmaceutical imports. From a managerial perspective, it scrutinizes the critical elements of blockchain technology and traceability systems, underlining their pivotal roles in enhancing the integrity and efficiency of pharmaceutical supply chains internationally.

Initiating with a comprehensive review of existing literature, the study encapsulates the myriad challenges and inefficiencies plaguing the current pharmaceutical import and export trade. It identifies key issues such as lack of transparency, risks of counterfeit products, and logistical inefficiencies that can potentially compromise patient safety and trust in pharmaceutical products. The review sets the stage for the exploration of blockchain as a transformative solution capable of addressing these enduring challenges.

Detailed in the study is the design of a blockchain-based traceability system tailored for the cross-border e-commerce environment. This system proposes a multi-layered traceability architecture that ensures data integrity and security while allowing seamless access to authorized entities. The architecture includes:

Data Layer: Responsible for the collection and secure storage of traceability information across the blockchain.

Network Layer: Facilitates the communication between different stakeholders including manufacturers, regulators, distributors, and end-users.

Application Layer: Provides user-friendly interfaces for stakeholders to interact with the traceability system, enhancing usability and accessibility.

Management roles within this system are clearly delineated, ensuring that each stakeholder has defined responsibilities and access rights, which are critical for maintaining the system's integrity and operational effectiveness.

Operational processes are thoroughly outlined, emphasizing the procedural steps from drug manufacturing through to consumer delivery, all underpinned by blockchain technology. These processes ensure that each transaction or movement of goods within the supply chain is recorded, time-stamped, and immutable.

Utilizing evolutionary game theory, the study explores the behavioral dynamics of key entities within the blockchain-enabled traceability system. This theoretical framework helps in understanding how different stakeholders, driven by varying incentives and pressures, evolve their strategies in response to the broader adoption of blockchain technology. The study investigates how cooperative

and non-cooperative behaviors can affect the overall efficacy and trustworthiness of the traceability system.

The empirical component of the research evaluates the actual performance of the blockchain traceability system in operational settings. Through data collected from pilot implementations, the study assesses the system's impact on reducing counterfeit drugs, improving logistical efficiency, and enhancing transparency across borders.

5.2 Contributions and Limitations

The research contribution of this thesis is it explores the application of blockchain technology in cross-border e-commerce drug traceability and analyzes its potential in enhancing supply chain transparency, safety, and efficiency. Through a detailed analysis of the questionnaire data, this thesis demonstrates the significant advantages of blockchain technology in the optimization of pharmaceutical supply chain management, especially in key areas such as business coordination, information sharing, and information security. In addition, the study reveals some of the challenges that blockchain faces in practical applications, including technology integration, system adaptability, and initial investment and maintenance costs, thus comping up with some suggestions. This thesis also contributes to the research on the future development direction of blockchain, covering the formulation of relevant regulations, user acceptance and cost effectiveness. These research results provide important theoretical support and practical reference for industry and academia, and help to promote the innovative application of blockchain technology in pharmaceutical supply chain management, maximizing its application value.

Despite the providing of important insights into the application of blockchain technology in cross-border e-commerce drug traceability, there are still limitations to the study, as it primarily relies on survey data, which may be influenced by respondent bias and thus limit the generalizability of the research findings.

The theoretical models used in this thesis, such as evolutionary game theory, involve certain simplifications and may not fully capture the complexity of real-world scenarios.

Another limitation is the potential supervision of specific challenges faced by the industry, especially in terms of the sensitivity of enterprise information in the traceability process, which requires further research on information sharing mechanisms.

In addition, the study focuses on the early stages of blockchain implementation, which means that long-term impact and scalability issues have not been fully explored. Future research should address these limitations by integrating more diverse data sources, improving theoretical models, and

considering broader industry challenges to gain a more comprehensive understanding of the impact of blockchain on the pharmaceutical supply chain.

Chapter 6 - Future Work

With the continuous maturity and widespread application of blockchain technology, future researches need to focus on several key areas to further promote the practicality and efficiency of this technology in global supply chain management [37].

Future research should focus on improving the scalability and interoperability of blockchain technology. With the expansion of the supply chain network, blockchain systems need to be able to handle larger volumes of transactions and data while maintaining efficiency and security. In addition, in order to achieve seamless data flow across platforms and wider technology adoption, it is necessary to improve interoperability between different blockchain platforms. This involves developing new standards and protocols, as well as improving existing blockchain architectures to support a wider range of business applications [38].

Future research needs to explore the integration of blockchain technology with other advanced technologies, such as artificial intelligence (AI), the Internet of Things (IoT), and big data. This technological integration can further enhance the intelligent monitoring and management capabilities of the drug supply chain, such as optimizing drug distribution paths through AI algorithms, or using IoT devices to monitor the storage and transportation conditions of drugs in real time. This type of integration not only improves efficiency, but also enhances the transparency and security of the pharmaceutical supply chain [39].

The research on regulations and standards related to blockchain technology is also crucial. With the popularization of technology, developing unified regulations and standards has become the key to ensuring technological safety, reliability, and ethical compliance. Especially in the cross-border e-commerce environment, there may be differences in laws and regulations among different countries and regions. Studying how to build an internationally recognized legal framework is of great significance for promoting international cooperation and standardization of blockchain technology.

Future research should also focus on the user acceptance and cost-effectiveness of blockchain technology in practical applications. This includes studying the cost-effectiveness of blockchain solutions and designing user-friendly blockchain systems to lower the threshold for technology adoption and increase their penetration in the supply chain.

Finally, given the importance of data security and privacy protection, future research needs to delve into how to protect sensitive data from abuse while improving supply chain transparency. This may include developing new encryption technologies or improving the privacy protection mechanism of blockchain to ensure data security for all supply chain participants.

Through these research works, we can not only enhance the practicality and popularity of blockchain technology, but also ensure that its role in future supply chain management is more stable

and critical. This brings innovative and revolutionary changes to the pharmaceutical supply chain, improving global health and well-being.

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Appendixes

Appendix A

Part 1

Basic Information

1. Your gender:

   Male

   Female

   Other

2. Your age:

   18-25

   26-35

   36-45

   46-55

   56 and above

3. Your occupation:

   Pharmaceutical industry professional

   Ecommerce professional

   IT professional

   Academic researcher

   Other (please specify)

4. Have you ever purchased pharmaceuticals through crossborder ecommerce?

   Yes

   No

Blockchain Technology Awareness

5. How well do you understand blockchain technology?

   Very well

   Quite well

Moderately well

Slightly well

Not at all

6. How much potential do you think blockchain technology has in pharmaceutical traceability?

Very high potential

High potential

Moderate potential

Low potential

No potential

Traceability in Cross-border Ecommerce Pharmaceuticals

7. How would you rate the current traceability of pharmaceuticals on cross-border ecommerce platforms?

Excellent

Good

Average

Poor

Very poor

8. Do you pay attention to the traceability information when purchasing pharmaceuticals through cross-border ecommerce?

Yes

No

9. In your opinion, which aspects of information need traceability the most when purchasing pharmaceuticals through cross-border ecommerce? (Select all that apply)

Manufacturing information

Transportation information

Storage conditions

Sales records

Other (please specify)

Application of Blockchain in Pharmaceutical Traceability

10. What do you think is the most important advantage of blockchain technology in pharmaceutical traceability?

Immutable data

Increased transparency

Enhanced security

Reduced regulatory costs

Other (please specify)

11. What do you think is the biggest challenge for blockchain technology in cross-border ecommerce pharmaceutical traceability?

High technical costs

Data privacy issues

High technical complexity

Inconsistent regulations and standards

Other (please specify)

12. Are you willing to pay a higher price for pharmaceuticals supported by blockchain technology for traceability?

Very willing

Quite willing

Moderately willing

Slightly willing

Not willing at all

Opened Questions

13. Do you have any other suggestions or views on the application of blockchain technology in cross-border ecommerce pharmaceutical traceability?

Part 2

Application of Blockchain Technology in Cross-border E-commerce Pharmaceutical Traceability

Thank you for your support and assistance in completing this survey. The purpose of this survey is to explore the specific applications and future prospects of blockchain technology in cross-border e-

commerce pharmaceutical traceability. Please fill out each question based on your actual situation. Thank you again for your help.

Appendix B

I. Basic Information

1. Your education level:
   - High school or below
   - Associate degree
   - Bachelor's degree
   - Master's degree
   - Doctorate or above

2. Your years of work experience:
   - Less than 1 year
   - 1-3 years
   - 4-6 years
   - 7-10 years
   - More than 10 years

3. Your industry:
   - Pharmaceutical
   - E-commerce
   - Information Technology
   - Academic Research
   - Other (please specify)

II. Awareness of Blockchain Technology

4. When did you first hear about blockchain technology?
   - Within 1 year
   - 1-3 years ago
   - 4-6 years ago
   - 7-10 years ago

- More than 10 years ago

5. Have you ever participated in blockchain-related training or learning?

- Yes
- No

III. Experience with Pharmaceutical Traceability

6. How often do you purchase pharmaceuticals on cross-border e-commerce platforms?

- Frequently
- Occasionally
- Rarely
- Never

7. What factors do you care most about when purchasing pharmaceuticals? (Select all that apply)

- Price
- Quality
- Traceability information
- Shipping speed
- Other (please specify)

8. Have you ever encountered situations where the source of pharmaceuticals was unclear or suspicious?

- Frequently
- Occasionally
- Rarely
- Never

IV. Application of Blockchain Technology in Pharmaceutical Traceability

9. In which aspects do you think blockchain technology can increase trust in pharmaceutical traceability? (Select all that apply)

- Production
- Transportation
- Storage

- Sales
- Other (please specify)

10. Do you understand how blockchain technology ensures the immutability of traceability information?
- Very well
- Quite well
- Moderately well
- Slightly well
- Not at all

11. Do you think the application of blockchain technology in pharmaceutical traceability can reduce the risk of counterfeit drugs?
- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

V. Future Prospects of Blockchain Technology

12. How optimistic are you about the prospects of blockchain technology in pharmaceutical traceability in the next five years?
- Very optimistic
- Quite optimistic
- Neutral
- Not very optimistic
- Not optimistic at all

13. What factors do you think will limit the promotion of blockchain technology in pharmaceutical traceability? (Select all that apply)
- High technical costs
- Incomplete regulations
- Resistance within the industry
- Low user acceptance
- Other (please specify)

14. Are you willing to participate in more training or seminars on blockchain technology to understand its application in pharmaceutical traceability?

- Very willing
- Quite willing
- Neutral
- Not very willing
- Not willing at all

VI. Open-ended Questions

15. Do you have any other suggestions or views on the application of blockchain technology in cross-border e-commerce pharmaceutical traceability?

Thank you for your participation! Your responses will be very helpful to our research. If you are willing to further discuss or receive the research results, please leave your contact information (optional).