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The Role and Strategies of Digital Transformation in Promoting Sustainable Development of International Trade

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Abstract: With globalization and the rapid development of information technology, international trade is undergoing an unprecedented transformation. This paper investigates through simulation experiments how digital transformation can enhance trade efficiency, increase transparency, reduce environmental impacts, and improve the accuracy of market forecasts. The experimental results show that under the digital trade model, the transaction time is reduced from an average of 10.78 days to 6.82 days, and the transaction cost is also reduced from US$1,022.47 to US$808.38. In addition, the enhancement of transparency and security was significant, the number of disputes and fraud incidents decreased significantly, and the accuracy of market forecasting under the digitized trade model increased from 69.5% to 87.5%. These data prove that digital technology can effectively contribute to the sustainable development of international trade, providing valuable insights and recommendations for policymakers and the industry.

1. Introduction

Against the background of globalization and the rapid development of information technology, international trade is facing unprecedented changes and challenges. The traditional trade model has many problems in terms of efficiency, cost, transparency and environmental impact, which constrain the sustainable development of trade. Digital transformation demonstrates great potential to address these issues through the introduction of advanced technological tools such as blockchain, big data and artificial intelligence. This study aims to explore the multifaceted impacts of digital transformation on international trade and to provide a theoretical and practical basis for achieving sustainable development.

Using simulation experiments, this paper assesses the role of digital transformation in improving trade efficiency, enhancing transparency and security, reducing environmental impact, and improving the accuracy of market forecasts. The results of the study show that digital technology significantly improves the deficiencies of the traditional trade model at all levels and provides

strong support for the efficient operation and sustainable development of international trade. Based on the experimental data, this paper proposes a series of strategic recommendations to further promote the application of digital transformation in international trade.

The article is structured as follows: first, the paper describes the background of the study and the importance of digital transformation in international trade. Then, the paper describes in detail the experimental design, data generation and analysis methods. Next, the paper presents and discusses the experimental results, focusing on analyzing the impact of digital transformation in various aspects. Finally, the paper summarizes the research findings and proposes future research directions and policy recommendations.

2. Related Works

The application of digital transformation in international trade has been extensively studied by many scholars and institutions. For example, one of the tasks of supply chain management in the digital economy is to harmonize the digital world with the physical world, in particular by effectively utilizing various digital technologies, including blockchain. Lyasnikov N V et al. aimed to study the nature of blockchain technology, determine its advantages and disadvantages and its prospects for application in supply chain management [1]. The study by Pereira C S et al. was carried out within the scope of a project in Portugal that focused on the analysis of entrepreneurs' perceptions of the internationalization process of their companies. This is one of the first contributions to study the impact of digital transformation on the internationalization of Portuguese companies [2]. Large multinational companies have made significant progress in early adoption of digital technologies, but SMEs have been relatively slow to adopt new technologies due to various reasons. Bin M conducted a systematic review of research over the last 20 years to identify factors that influence digital transformation in SMEs [3]. The impact of digital transformation on firms' competitiveness is mainly in terms of innovation, efficiency and cost reduction, and on GVCs in terms of specialization, geographic scope, governance and upgrading. These four main dimensions of GVCs have been examined in relation to each other by Leão P [4]. International trade is an integral part of any country's economy. Lesiuk M I analyzed the dynamics of international trade in services in the context of the global crisis and the impact of digitization, and showed how a new paradigm of international trade in services can be formed in the context of the increased interdependence of the economies of all countries [5]. The aim of Slok-Wodkowska M was to gain insight into the e-commerce regulatory solutions adopted in the EU RTAs. The results of the analysis showed that despite the fact that the regulatory dimension of the global economy and trade tries to solve the problems posed by the specific characteristics of the digital economy, the process was still in its infancy [6]. Azmeh S et al. examined the political economy of this movement, highlighting the technological contingency of existing international rules and showing how technological change had driven the creation of competitive regimes and the shifting of forums, which had led to the fragmentation of the international trade regime [7]. However, these studies have mainly focused on the effects of the application of a particular technology, lacked systematic and comprehensive nature, and have not yet fully revealed the impact of digital transformation as a whole on the sustainable development of international trade.

In the literature, several studies have used quantitative analysis to assess the impact of digital technologies on trade efficiency. For example, Behl A's study aimed to understand how the big data analysis capabilities of tech startups can help them gain a competitive advantage and improve firm performance [8]. Although big data, marketing analytics and firm marketing capabilities are all potential drivers of competitive advantage, research on their interrelationships remains limited. To this end Cao G et al.'s study aimed to explore how big data and marketing analytics can enhance

firms' marketing capabilities [9].Pei J et al. investigated the impact of the new Crown pneumonia embargo on exports from Chinese cities. Their investigation concluded that the impact of related policies on trade is cost-effective [10]. However the methods used by these scholars still have limitations in revealing the complex process of digital transformation and its sustainability implications. In this paper, we will adopt an integrated analytical approach, combining quantitative and qualitative research, to systematically explore how digital transformation contributes to the sustainable development of international trade.

3. Methods

3.1. Blockchain Technology Applications

3.1.1. Enhancing Transaction Transparency

The traditional international trade process is cumbersome and involves multiple intermediaries and links, and there is a silo effect in the information of each link, with serious information asymmetry. Blockchain technology, through its decentralized nature, can record the data of each transaction on a public and tamper-proof ledger, so that all involved parties can access the transaction information in real time. This transparency not only reduces information asymmetry, but also enhances trust between trading parties and reduces transaction friction [11].

For example, throughout the entire process of shipment of a certain cargo from the exporting country to the receipt of the cargo in the importing country, status updates at each stage will be recorded on the blockchain, including shipment, transportation, customs clearance, arrival, and so on. In this way, all relevant parties such as exporters, importers, logistics companies and customs can view the status of goods in real time, avoiding delays and disputes caused by lagging or inaccurate information in traditional trade. The increase in transparency of which transaction can be expressed by equation (1):

$$T_{transparency} = \frac{\sum_{i=1}^{n} t_{recorded,i}}{n} \tag{1}$$

In equation (1), $T_{transparency}$ denotes the average transparency time, $t_{recorded,i}$ denotes the time at which the i-th transaction is recorded, and n denotes the total number of transactions.

3.1.2. Enhanced security

Another important characteristic of blockchain is its high security. Since blockchain data cannot be tampered with once written, tampering by any party will be detected by other nodes in the network, thus preventing the possibility of malicious modification of data. For international trade, this means that the authenticity and integrity of transaction records are guaranteed. The increase in security can be expressed in equation (2):

$$S_{security} = \frac{1}{n}\sum_{i=1}^{n}(1 - f_i) \tag{2}$$

Where in equation (2), $S_{security}$ denotes the average security, f_i denotes the percentage of fraudulent events occurring in the i-th transaction, and n denotes the total number of transactions.

3.2. Big Data Analysis

3.2.1. Optimizing supply chain management

Supply chain management is a key link in international trade, involving procurement, production,

transportation, warehousing and other aspects. Through big data analysis, enterprises can monitor all aspects of the supply chain in real time, find and solve problems in time, and avoid delays and waste. For example, using big data technology, enterprises can analyze historical transportation data to optimize logistics routes and reduce transportation time and cost. Table 1 shows some of the historical transportation data:

Table 1: Selected historical transportation data

Month	Total Shipments	On-time Deliveries (%)	Average Delivery Time (days)	Transport Cost (USD)
Jan	500	92	5.3	15000
Feb	520	95	5	14500
Mar	540	93	5.2	15200
Apr	530	96	4.9	14700

By analyzing the data in Table 1, it can be seen that February and April have higher on-time delivery rates and relatively lower transportation costs, indicating that supply chain management is more efficient in these months. Enterprises can further analyze the operational processes and external environmental factors in these months to distill successful experiences and apply them to the management of other months.

3.2.2. Improve market demand forecasting

Market demand forecasting is crucial for enterprises to formulate production plans and inventory management strategies. Big data analysis can take into account a variety of factors, such as market trends, consumer behavior, seasonal changes, etc., to provide more accurate demand forecasts, which can help enterprises optimize inventory levels and reduce surpluses and shortages.

In conclusion, big data analysis provides strong support for international trade, helps enterprises optimize supply chain management and market demand forecasting, and improves operational efficiency and competitiveness. With the continuous progress of technology, the application of big data analysis in international trade will be more extensive and in-depth, promoting the efficient operation and sustainable development of trade [12].

3.3. Artificial Intelligence Optimization

3.3.1. Logistics optimization

AI can optimize transportation routes by analyzing vast data sets, considering real-time weather and traffic updates to enhance scheduling flexibility and punctuality.

3.3.2. Inventory management

AI transforms inventory management by leveraging real-time sales data and market trends to provide precise forecasts, enabling companies to adjust stock levels dynamically and minimize the risks of surplus or shortage.

3.3.3. Customer service

In addition, AI shows great potential in improving the quality of customer service. With the help of natural language processing and machine learning, AI is able to achieve intelligent customer service, quickly respond to customer inquiries and provide personalized services. Many multinational e-commerce platforms have already adopted AI customer service systems, which not

only improves customer satisfaction but also enhances customer loyalty.

With the combination of big data and IoT technology, the role of AI in international trade will be more significant, not only to provide data analysis and decision-making support, but also to help enterprises cope with the complex and changing trade environment, and to promote the efficient and sustainable development of international trade [13].

3.4. Internet of Things Applications

3.4.1. Real-time cargo tracking

By installing sensors on transportation vehicles and cargo, IoT technology can provide real-time updates on the location and status of goods. This transparency not only enables companies to better monitor the cargo transportation process, but also to respond to possible transportation problems in a timely manner. For example, if goods encounter delays or damage during transportation, the relevant system will immediately send out an alert, enabling the person in charge to take swift action [14].

3.4.2. Inventory management optimization

IoT technology can likewise optimize inventory management by installing various sensors in the warehouse to achieve real-time monitoring of inventory items. The sensors can monitor the quantity, location, temperature and other information of the inventory items, which can help enterprises understand the inventory status in time and carry out scientific management.

3.4.3. Enhancing supply chain transparency

The data collection and transmission capabilities of IoT devices enable enterprises to gain real-time visibility into the operations of their supply chains. This immediate flow of information helps enterprises identify and solve problems in the supply chain in a timely manner and improve overall operational efficiency.

In conclusion, the application of IoT technology in international trade provides strong support for enhancing trade transparency, efficiency and security. With the continuous development of technology, IoT will play an increasingly important role in international trade and promote the intelligent and sustainable development of trade.

4. Results and Discussion

4.1. Trade Efficiency Improvement Experiment

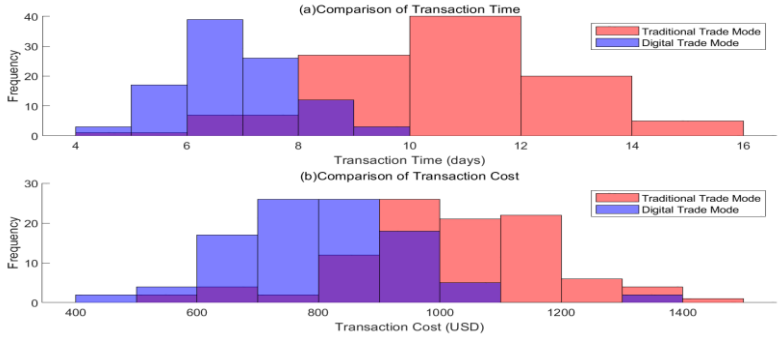

Figure 1: Evaluation of Trade Efficiency Improvement

In order to assess the impact of digital transformation on international trade efficiency, we designed a simulation experiment. In the experiment, we generated simulation data of 100 transactions, representing the transaction time and transaction cost under traditional trade mode and digital trade mode, respectively. By comparing the averages of these two sets of data, we plotted graphs to compare the comparisons under the two trade patterns, as shown in Figure 1:

Figure 1(a-b) represents a comparison of the average transaction time and transaction costs under the two models. As shown in Figure 1, the average transaction time of the traditional trade model is 10.78 days and the transaction cost is $1022.47. Under the digital trade model, the average transaction time has been shortened to 6.82 days, and transaction costs have been reduced to $808.38. In the above data conclusions, the application of digital technology not only reduces transaction time and costs, but also enhances the transparency and security of the overall trade process.

4.2. Transparency and Security Enhancement Experiment

In the Transparency and Security Enhancement Experiment, we assessed the impact of digital transformation on the transparency and security of international trade. Data from 100 transactions were generated in the experiment, representing the number of transaction disputes and fraud incidents under traditional and digital trade models, respectively. By comparing the two sets of data, we plotted box plots to compare the contrast between the two modes, as shown in Figure 2:

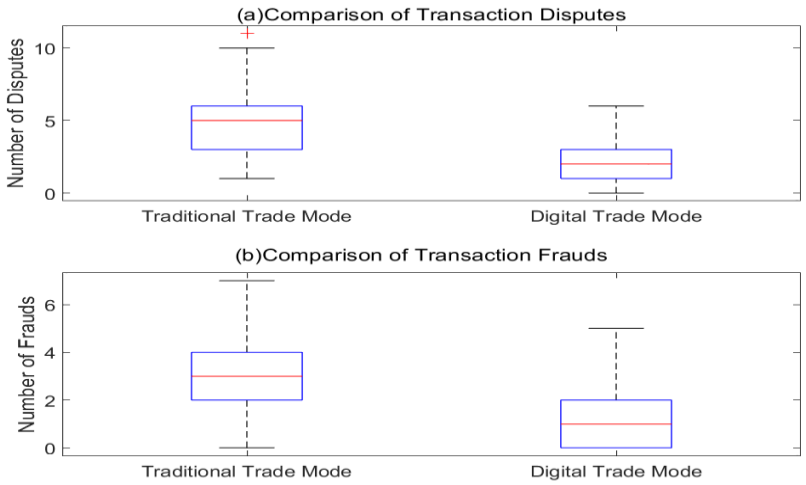

Figure 2: Transparency and security enhancement assessment

Figure 2(a-b) represents the comparison of generating transaction disputes and fraud incidents under the two models, respectively. In Figure 2, an average of 5.23 disputes and 3.17 fraud incidents per 100 transactions occur under the traditional trade model. In contrast, the number of disputes is reduced to 1.98 and fraud incidents to 0.99 under the digitized trade model. From the conclusions of the above data, it is clear that the application of digital technology has significantly reduced the frequency of transaction disputes and fraudulent incidents, and improved the transparency and security of international trade.

4.3. Environmental Impact Assessment Experiment

In order to assess the environmental impact of digital transformation on international trade, we designed a simulation experiment. In the experiment, we generated carbon emission data for 100

transactions, representing the traditional trade model and the digital trade model. By comparing the average carbon emissions of the two sets of data, we can intuitively analyze the effect of digital technology in reducing carbon emissions, and thus assess its contribution to environmental protection, as shown in Table 2:

Table 2: Evaluation based on environmental impact assessment

Transaction ID	Traditional Trade Mode Carbon Emissions (kg CO_2)	Digital Trade Mode Carbon Emissions (kg CO_2)
1	150	100
2	145	98
3	160	95
4	155	90
5	148	92
...	...	...
100	152	91

In Table 2, the average carbon emissions under the traditional trade model are roughly 152 kg CO_2, while the average carbon emissions under the digital trade model are roughly 91 kg CO_2. From the conclusions of the data, it can be seen that the application of digital technology significantly reduces the carbon emissions, which contributes to the reduction of environmental impacts and the promotion of the sustainable development of international trade.

4.4. Market Forecast Accuracy Assessment Experiment

In order to assess the impact of digital transformation on market forecast accuracy, we designed a simulation experiment. In the experiment, we generated data for 100 market predictions, representing the accuracy of market predictions under traditional and digital trade models, and plotted these data in a table, and Table 3 shows some of the market predictions:

Table 3: Assessment of the accuracy of market forecasts

Transaction ID	Traditional Trade Mode Forecast Accuracy (%)	Digital Trade Mode Forecast Accuracy (%)
1	70	85
2	68	88
3	72	90
4	65	87
5	69	86
...	...	...
100	71	89

In Table 3, the average market forecasting accuracy under the traditional trade model is 69.5%, while the average market forecasting accuracy under the digitized trade model is 87.5%. From the conclusions of the data, it can be seen that the application of digital technology significantly improves the accuracy of market forecasting and helps to optimize the allocation of resources.

4.5. Digital Transformation and International Trade Policy Experiment

In the Digital Transformation and International Trade Policy Experiment, we assess the impact of digital transformation on international trade policy cooperation. In the experiment this paper collects data related to some key countries before and after digitization, including the time of policy

formulation, the number of participating countries, and the efficiency of policy implementation. With these data, we drew bar charts. The specific data are shown in Figure 3:

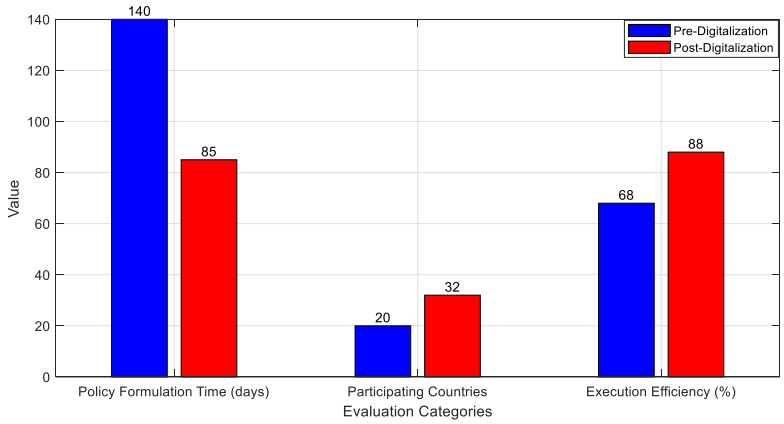

Figure 3: Digital transformation and international trade policy impact assessment

In Figure 3, the time for policy formulation is reduced from an average of 140 days to 85 days, the number of participating countries increase from an average of 20 to 32, and the efficiency of policy implementation increase from an average of 68% to 88%. These results show that by adopting digital tools, it is possible not only to speed up the process of policy formulation and implementation, but also to attract more countries to international trade, thus improving the global coverage and implementation of policies. This is important for promoting the sustainable development of global trade.

5. Conclusion

Through this study, we observe that digital transformation significantly improves the efficiency, transparency, and security of international trade while reducing environmental impacts and costs. Especially blockchain and big data technologies have performed well in improving transaction transparency and market forecasting accuracy. However, the study also exposed the uneven application of digital transformation across countries and industries, as well as the potential risks associated with technology dependency. In the future, we expect that through further technological innovation and international cooperation, we can address these imbalances and promote wider technology diffusion and adoption. In addition, continuous optimization of algorithms and enhanced data security measures will be key to improving the sustainability of the digital international trade system. This can not only further reduce trade costs and time, but also enhance the competitiveness and autonomy of countries in global trade.

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