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Coupling Evaluation and Spatial Analysis of Regional Economy and Logistics Development Based on Digital Twin

Xin Jin[1] *, Young-Soo Choi[2]

[1]School of School of Economics and Management, Kunming University, Kunming 650214, Yunnan, China

[2]Dept. of Tourism Management, Sehan University, Korea 58447, Jeollanam-do, Republic of Korea

jinxin@kmu.edu.cn (Corresponding author), cys0803@sehan.ac.kr

Abstract. With the deepening development of global economic integration, regional economy and logistics development have become important factors driving economic growth and improving competitiveness. In this context, the emergence of digital twin technology provides new methods and tools for the coupling evaluation and spatial analysis of regional economy and logistics development. Based on the digital twin technology, this paper designed the coupling evaluation and spatial analysis method of regional economy and logistics development. This method relied on the modeling, simulation, and data analysis of digital twin technology, and provided precise and efficient decision support for key issues in regional economic and logistics development. At the same time, combining technologies such as GIS (Geographic Information System) and path planning algorithms can further optimize the efficiency and quality of regional economic and logistics development. This article designed five sets of experiments to compare the digital twin model with the traditional model. The experimental results showed that the introduction of the digital twin model for logistics system optimization resulted in an economic growth rate of 7.6% higher than the traditional model's 5%. After combining the digital twin model with intelligent logistics technology, the transportation efficiency reached 0.95 higher than the traditional model's 0.9. Digital twin technology has broad application potential in regional economic and logistics development, which can improve efficiency and efficiency in areas such as economic development, urban planning, manufacturing, and logistics, and provide scientific basis for decision-making and planning.

Keywords: Regional Economy, Logistics Development, Digital Twins, Coupling Evaluation

1. Introduction

With the rapid development of information technology and the popularization of digital transformation, digital twin technology, as an innovative tool and method, is gradually being applied in various fields. Digital twinning refers to the technical means of modeling, simulating and analyzing the entities, processes and systems in the physical world in digital form. It can simulate and predict the behavior and performance of the actual system, provide scientific basis for decision makers and promote economic and social development. In the field of regional economy and logistics, the application of digital twin technology is gradually showing great potential and advantages. Regional economy refers to the economic activities and development within a specific geographical area. Logistics refers to the process of material flow and information flow of goods from the place of production to the place of consumption. The two are closely related and influence each other. Digital twinning technology can establish a virtual model of regional economy and logistics system, and simulate and optimize all links and key nodes of regional economy and logistics activities by collecting and analyzing a large number of data. It can help us better understand the operating mechanism and laws of regional economy and logistics system, reveal the optimization space and potential problems, and provide scientific reference and decision-making basis for the government, enterprises and decision makers. The coupling evaluation and spatial analysis of regional economy and logistics development based on digital twinning aims at comprehensive evaluation and optimization analysis of regional economy and logistics system by using digital twinning technology. By constructing the digital twin model of regional economy and logistics, collecting and integrating relevant data, and using computer simulation and optimization algorithm, the development trend of regional economy and logistics can be predicted and evaluated. The background and importance of this paper lies not only in its academic research value in the field of regional economy and logistics, but also in its guiding significance to the actual economic and social development. Through the application of digital twin technology, we can better understand the operation and development trend of regional economy and logistics system, provide scientific reference for the government to formulate regional planning and development strategy, and provide scientific reference for enterprises to carry out production and logistics management, promote the optimization and upgrading of regional economy and logistics, and promote economic growth and social progress.

The study of regional growth paths is an important theme in economic geography and has significant implications for regional development. Grillitsch and Markku (2020) discussed the interaction between the structural forces of path dependence and the construction and utilization of opportunities through agency processes, and discussed the correlation and interdependence of three institutions with different theoretical roots, namely Schumpeter innovation and entrepreneurship, institutional entrepreneurship, and local leadership, which are the main driving forces of regional structural change . Human capital is considered an important factor in innovation and economic development. However, the long-term impact of human capital on current innovation and economic development remains a black box, especially at the regional level. Therefore, Diebolt and Ralph (2019) connected the past with the present. Using a new dataset on regional human capital and other factors in the 19th and 20th centuries, it was found that past regional human capital was a key factor in explaining the current gap in regional innovation and economic development. Munim and Schramm (2018) conducted an empirical investigation on the broader economic contribution of maritime trade from the perspective of port infrastructure quality and logistics performance. The investment in improving the quality of port infrastructure and its contribution to the economy is often questioned by politicians, investors, and the public. Regional economic resilience attempts to explain why some regions can adapt to recovery and achieve sustained economic development when shocks occur, while others cannot escape the impact of shocks and enter the path of economic recession. Li et al. (2019) summarized the evolution of the concepts of engineering resilience, ecological resilience, and evolutionary resilience through a review of relevant literature both domestically and internationally, as well as the shift from an equilibrium perspective to an evolutionary perspective. Based on this, he redefined the concept of regional economic resilience and believed that regional economic resilience is the ability of a system to resist shocks and avoid deviating from the development trajectory or achieving sustainable economic development through adaptive recovery, It is a constantly evolving process. Tan et al. (2020) quantitatively analyzed the economic resilience of 31 provinces in China during the 1997 Asian Financial Crisis and the 2008 Global Financial Crisis. In addition, the main factors affecting regional resilience were analyzed. There are three main findings. Firstly, in the first economic cycle, the economic resistance in the western region is relatively high, while in the central region it is relatively low; The provinces with higher economic recoverability are mainly concentrated in the central region, while the eastern and western regions have lower economic resistance, and there is a certain negative correlation between economic resistance and recoverability. All regions in the second economic cycle showed good resistance; The main areas with low economic resistance are distributed along the eastern coast and the Yangtze River Economic Belt. Thirdly, in the first economic cycle, the economic resilience of the secondary industry is stronger than that of the tertiary industry, while in the second economic cycle, it is different. Finally, the influencing factors of economic resilience vary between the two economic cycles; Regional advantages, per capita fixed assets investment and per capita GDP have strong explanatory power on economic resilience, but their roles in the two economic cycles are different. The development of China's regional economy in the past 70 years cannot be achieved without the support of scientific and effective regional economic theories. Liu et al. (2021) discussed this and, on the basis of serving the reality of regional economic development and drawing on foreign regional economic theory and methods, the evolution of China's regional economic theory has shown a phased characteristic of solving practical problems, gradually forming a development model of "introduction absorption digestion innovation". Chinese regional economic theory exhibits different characteristics from Western regional economic theory in terms of research perspectives, research paradigms, research content, and development models. Faced with the practical requirements of crossing the middle-income trap and high-quality regional economic development, China's regional economic theory research will make breakthroughs in disciplinary integration, assumptions, research scope, research mechanisms, and regional policies in the future. However, these scholars lacked certain technical arguments for the development of regional economy. Through research, it has been found that digital twin technology is more helpful for the development of regional economy. This article consulted relevant literature on digital twin technology.

The concept of digitalization is based on the dominant position of digital ecosystems and the widespread introduction of artificial intelligence systems, including the physical distribution within trade networks. The implementation of the Internet of Things, artificial intelligence, and machine learning allows for the realization of digital twins. From the perspective of economists, without mathematical models, digital twins are meaningless. Barykin et al. (2021) aimed to develop a logistics digital twin model, with a focus on using it for trade network activity management combined with information cyberspace. Recently, there has been explosive growth in the development of the concept of digital industry. One of the most important elements of this concept is the applied mathematics modeling methods and data mining to create models of production processes and final products, with the aim of making decisions under random uncertainty. Liezina et al. (2020) proposed a method of diversifying investment portfolios in forming digital twins, aimed at reducing total risk by allocating existing assets between analog and digital enterprises. However, these scholars have only explored regional economy and digital twins from a superficial perspective.

In order to promote the growth of regional economy and the development of logistics, this paper conducted a coupling evaluation and spatial analysis experiment on regional economy and logistics development based on the digital twin model. Through experimental results, it was found that introducing the digital twin model can improve logistics efficiency and promote regional economic growth, thereby reducing data management costs. Through the spatial analysis of the digital twin model, it was found that the optimized logistics network and intelligent logistics model can improve the regional spatial distribution characteristics and promote the agglomeration effect of economic activities. These experimental results provided important reference for the decision-making and planning of governments and enterprises in regional economic and logistics development.

2. Evaluation Method for Coupling Regional Economy and Logistics Development Based on Digital Twins

2.1 Digital Twin Technology

Digital twin technology establishes physical systems and processes in the real world as virtual models. By combining sensors and Internet of Things technology with virtual models, real-time monitoring and data collection of the system are achieved. This enables virtual models to dynamically integrate with real-time data, achieving rapid visualization and simulation analysis. The digital twin technology mainly includes four aspects: model building, virtual simulation, data analysis, and reality feedback.

Model establishment is the core link of digital twin technology. By using advanced modeling tools and techniques, key elements in physical systems are extracted, analyzed, and modeled to form high-precision, high-efficiency, and easy-to-use virtual models.

Virtual simulation is an important application of digital twin technology, which involves simulating and analyzing the established virtual model to obtain the operational status and characteristics of the system, and predicting its future development trends.

Data analysis is the fundamental aspect of digital twin technology, which involves collecting, storing, and processing a large amount of data to extract valuable information and features, and integrating, analyzing, and applying them in digital twin models.

Real feedback is the application link of digital twin technology, which optimizes the performance and accuracy of virtual models by comparing and analyzing data from virtual models and actual scenes, and provides reference for decision-making and planning in the next step.

The digital twin technology has the following main characteristics:

High visualization: Digital twin technology adopts advanced 3D (Three dimensional) modeling technology, which can visualize multidimensional information in physical systems.

Strong simulation and prediction performance: Digital twin technology can simulate and predict complex systems in the real world, and improve the understanding and prediction ability of system operation status and future trends, thus making more scientific decisions and planning.

Strong data processing and analysis capabilities: Digital twin technology adopts advanced data processing and analysis techniques, which can efficiently collect, store, process, and apply a large amount of data. It integrates modeling and simulation in the digital twin model, thereby improving prediction accuracy and decision-making efficiency.

2.2 Application of Digital Twins in Regional Economic and Logistics Development

(1) Regional economy

Digital twin technology can provide support for regional economic development. By conducting 3D modeling and simulation of factors such as industry, land use, transportation, and population within a region, comprehensive monitoring and evaluation of the regional economic operation status can be achieved, and future development trends can be predicted (Khan et al., 2020; Liu et al., 2022). The application scenarios of digital twin technology include:

Urban planning and design: Digital twin technology can achieve 3D modeling and simulation of cities, and help urban planners, government managers, and urban residents better understand the operational status and characteristics of cities, thereby optimizing urban planning and design.

Industrial manufacturing: Digital twin technology can help manufacturing enterprises simulate and optimize production processes, thereby reducing production costs and improving quality. At the same time, it can achieve intelligent manufacturing and personalized customization, and enhance the competitiveness of enterprises.

Commercial logistics: Digital twin technology can help logistics companies optimize logistics processes and distribution path planning, and improve logistics efficiency and accuracy, thereby reducing logistics costs and environmental pollution.

(2) Logistics development

Digital twin technology can provide precise and efficient delivery services for the logistics industry, while reducing logistics costs and environmental pollution. The application scenarios of digital twin technology in the field of logistics and distribution include:

Intelligent distribution plan: Digital twin technology can model and simulate the logistics distribution process based on factors such as user needs and product attributes, and combine digital twin and path planning algorithms to develop the optimal logistics distribution plan, thereby improving logistics efficiency and reducing transportation costs.

Intelligent storage management: Digital twin technology enables 3D modeling and simulation of logistics storage facilities, which can help logistics companies better understand the operational status and characteristics of storage facilities, and optimize storage management, thereby improving storage efficiency and safety.

Environmental protection and resource conservation: Digital twin technology can help logistics enterprises predict and optimize transportation energy. Meanwhile, through intelligent distribution and storage and transportation management, logistics costs and environmental pollution can be reduced, achieving sustainable development.

2.3 Logistics Development Coupling Spatial Analysis

(1) GIS

GIS is widely used in the coupling evaluation and spatial analysis of regional economy and logistics development based on digital twins (Mishenin et al., 2018; Coccia, 2018). GIS can provide basic data and analysis tools to support the construction and implementation of digital twin models, and also provide important reference basis for decision-making in regional economic and logistics development. GIS can be used for the collection, integration, and processing of various key data within a region (Beer et al., 2019; Asher and Paul, 2020).

Space distance formula

For two points $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$, the Euclidean distance between them is:

$$d_{Euclidean} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

When considering obstacles between two points, the Manhattan distance can be used:

$$d_{Manhattan} = |x_2 - x_1| + |y_2 - y_1| \quad (2)$$

In the evaluation and spatial analysis of regional economic and logistics development coupling based on digital twin, spatial location information is an important factor (Zhao et al., 2022; Dell et al., 2018). Taking logistics delivery as an example, it is necessary to consider the distance between different logistics nodes in order to reasonably plan logistics routes and vehicle scheduling. At this point, Euclidean distance or Manhattan distance can be used for calculation. Variables x_1, y_1 and x_2, y_2 represent the longitude and latitude coordinates of two logistics nodes, respectively.

Spatial interpolation formula

In spatial analysis, in order to more accurately infer the value of unmeasured points, interpolation is required. The simplest interpolation method is linear interpolation. For a point $Q(x, y)$, if the values of four adjacent points $Q_1(x_1, y_1)$, $Q_2(x_1, y_2)$, $Q_3(x_2, y_1)$ and $Q_4(x_2, y_2)$ are known, the linear interpolation formula is:

$$f(x, y) = aQ_1 + bQ_2 + cQ_3 + dQ_4 \quad (3)$$

Spatial interpolation has a wide range of applications in natural resource evaluation, geological exploration, and other fields. In the coupling evaluation of regional economy and logistics development based on digital twins, spatial interpolation methods can also be used to predict and estimate certain key indicators, thereby providing support for decision-making. For example, when considering the economic development potential within a certain region, spatial interpolation can be used to predict the economic development of other regions in the region based on existing economic indicator data (Doe et al., 2022; Litvinenko, 2020). At this point, a, b, c, and d in the interpolation formula can represent the spatial distance and weight coefficients between each data point and the point to be estimated.

(2) Path planning algorithm

Dijkstra algorithm

In the evaluation of regional economy and logistics development coupling and spatial analysis based on digital twin, Dijkstra algorithm can be used to calculate the shortest path between different cargo warehouses (Winkelhaus and Eric, 2020; Munim and Schramm, 2018). Specifically, the cargo warehouse can be viewed as a node in the graph, and the transportation routes between different cargo warehouses can be viewed as edges in the graph to calculate the shortest path between different cargo warehouses.

The Dijkstra algorithm is used to calculate the shortest path between two points on a graph. Suppose there is an undirected graph G(V, E), where V represents the set of nodes and E represents the set of edges. For node $u \in V$, dist(u) is defined to represent the shortest distance from the starting point to node u. The basic idea of the Dijkstra algorithm is to start from the starting point, traverse all nodes in sequence, and update the shortest distance between each node and the starting point.

The core formula of Dijkstra algorithm is:

$$dist(v) = \min_{u \in N(v)} \{dist(u) + I(u, v)\} \quad (4)$$

Among them, v represents the node currently traversed; $N(v)$ represents the set of nodes adjacent to the node; $I(u, v)$ represents the weight between nodes u and v.

Heuristic search algorithm

Heuristic search algorithm is often used to calculate the heuristic shortest path problem. The basic idea is to add heuristic functions to the Dijkstra algorithm, in order to search more efficiently. Its definition f(u) represents the evaluation function from the starting point to node u, and g(u) represents the actual distance from the starting point to node u. The core formula of the heuristic search algorithm is:

$$f(u) = g(u) + h(u) \quad (5)$$

Among them, $h(u)$ represents the heuristic function from node u to the endpoint. In practical applications, methods such as Manhattan distance and Euclidean distance can be used to calculate h(u).

In the coupling evaluation of regional economy and logistics development and spatial analysis based on the digital twin, the heuristic search algorithm can be used to calculate the cargo transportation path and vehicle scheduling problem (Chen, 2019). The heuristic function h(u) can consider factors such as road congestion and traffic lights to more accurately estimate the actual distance and time cost. This paper aimed at the coupling evaluation and spatial analysis of regional economy and logistics development based on digital twin. Figure 1 shows the overall research framework of this article.

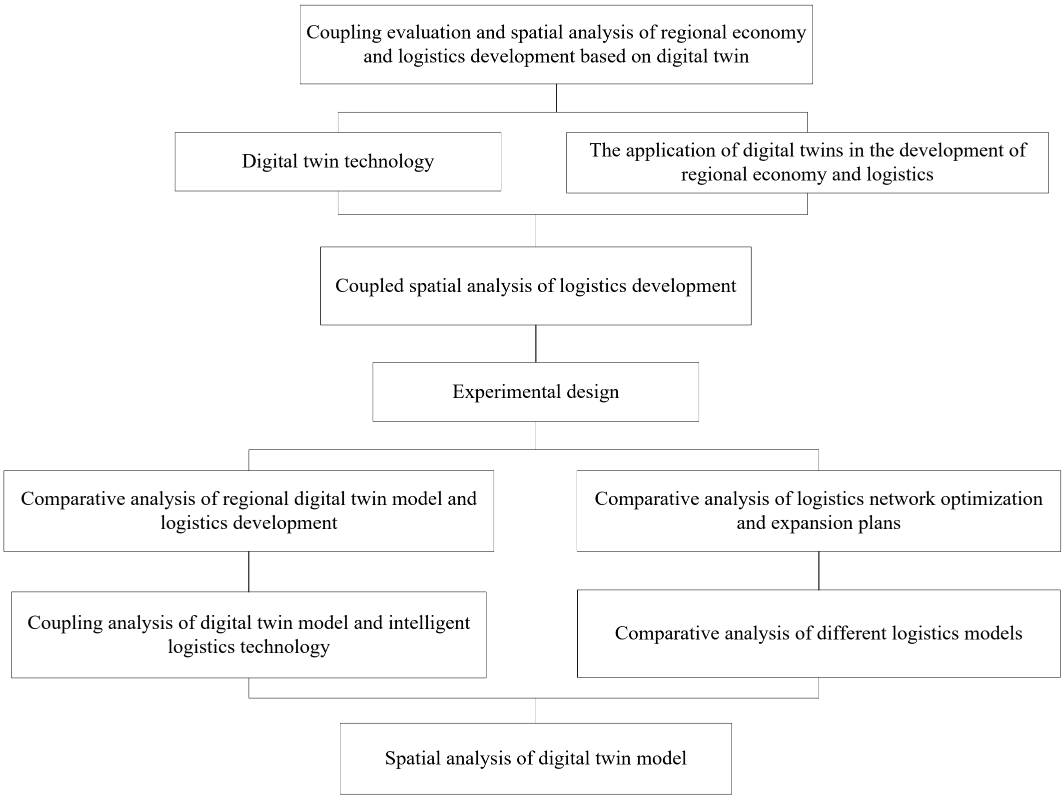

Fig.1: Overall research framework of this article

In order to better promote regional economic growth and logistics development, this article conducts experimental research on the coupling evaluation and spatial analysis of regional economy and logistics development based on digital twin technology. It compares regional digital twin models with logistics development, logistics network optimization and expansion plans, coupling analysis of digital twin models with intelligent logistics technology, and comparison of different logistics models Conduct indicator analysis on spatial analysis and other aspects of the digital twin model. Evaluating the effectiveness and reliability of digital twin models and indicators requires comprehensive consideration of multiple factors, including model accuracy, data credibility, indicator selection, sensitivity analysis, and predictive ability. Through reasonable methods and verification processes, we can obtain a reliable and applicable digital twin model, providing valuable decision-making support for regional economic and logistics development.

3. Regional Economy and Logistics Development Coupling Evaluation and Spatial Analysis Experiment

Digital twin technology is a new type of spatial information technology. It is based on simulation systems in the real world and simulation models in the virtual world, which can more accurately describe and predict the operational status and development trends of actual systems. In terms of regional economic and logistics development, digital twin technology can analyze and evaluate various influencing factors, and help governments and enterprises make better decisions, thereby improving economic efficiency and social welfare. Based on the digital twin model, this paper conducted coupling evaluation and spatial analysis on regional economy and logistics development. This paper selected ten regions in M Province, and divided these ten regions into two groups, using two schemes for research.

3.1 Comparison between Regional Digital Twin Model and Logistics Development

Experimental purpose: The purpose is to compare the impact of introducing digital twin models on system performance in regional economic and logistics development.

Experimental indicator: Regional logistics efficiency: It can evaluate the degree of optimization of the digital twin model on the logistics system, such as logistics transportation time, cost, etc. Regional economic growth: It can compare the growth rate and scale of regional economy after introducing the digital twin model. Data management cost: It can evaluate the cost changes of data management and maintenance after the introduction of the digital twin model.

Experimental design schemes:

Scheme A: Traditional logistics management methods without introducing digital twin models

The logistics system used traditional management methods, based on experience and manual processing. Logistics data collection and management adopted traditional methods, such as manual recording and file archiving. During the experiment, the existing logistics network structure and processes were maintained.

Scheme B: Introducing a digital twin model for logistics system optimization

The digital twin model was introduced as a management and optimization tool for logistics systems. The digital twin model can integrate real-time data collection, simulation, and predictive analysis functions. The digital twin model was used to optimize logistics transportation routes, distribution plans, and resource scheduling decisions.

Experimental data collection method:

Regional logistics efficiency: logistics transportation time was recorded and the difference in time cost of logistics transportation in Scheme A and Scheme B was compared; data on logistics transportation cost, including labor cost, fuel cost, etc., were collected to assess the impact of the digital twin model on logistics cost.

Regional economic growth: Data on regional economic growth, such as GDP (Gross Domestic Product), employment rate, and other indicators were collected, and the growth rate and speed of regional economies in Scenario A and Scenario B were compared.

Data management costs: The data management and maintenance costs after the introduction of the digital twin model were documented, including the costs of hardware, software, and staff training. This scenario was compared with Scheme A and the impact of the digital twin model on data management costs was assessed.

Figure 2 shows a comparative analysis of the regional digital twin model and logistics development; Figure 2 (a) shows Scheme B, and Figure 2 (b) shows Scheme A. In terms of regional logistics efficiency, experimental scheme B introduced the digital twin model, which reduced the logistics transportation time from 8.3 hours to 6.4 hours, indicating that the digital twin model optimized the logistics system and improved logistics efficiency. In terms of regional economic growth, the economic growth rate of Scheme B was 7.6%, which was higher than Scheme A's 5%, indicating that the application of the digital twin model had a positive impact on regional economic growth. In terms of data management costs, the data management cost of Scheme B was 55000 yuan, which was lower than Scheme A's 70000 yuan, indicating that the introduction of the digital twin model can reduce data management costs.

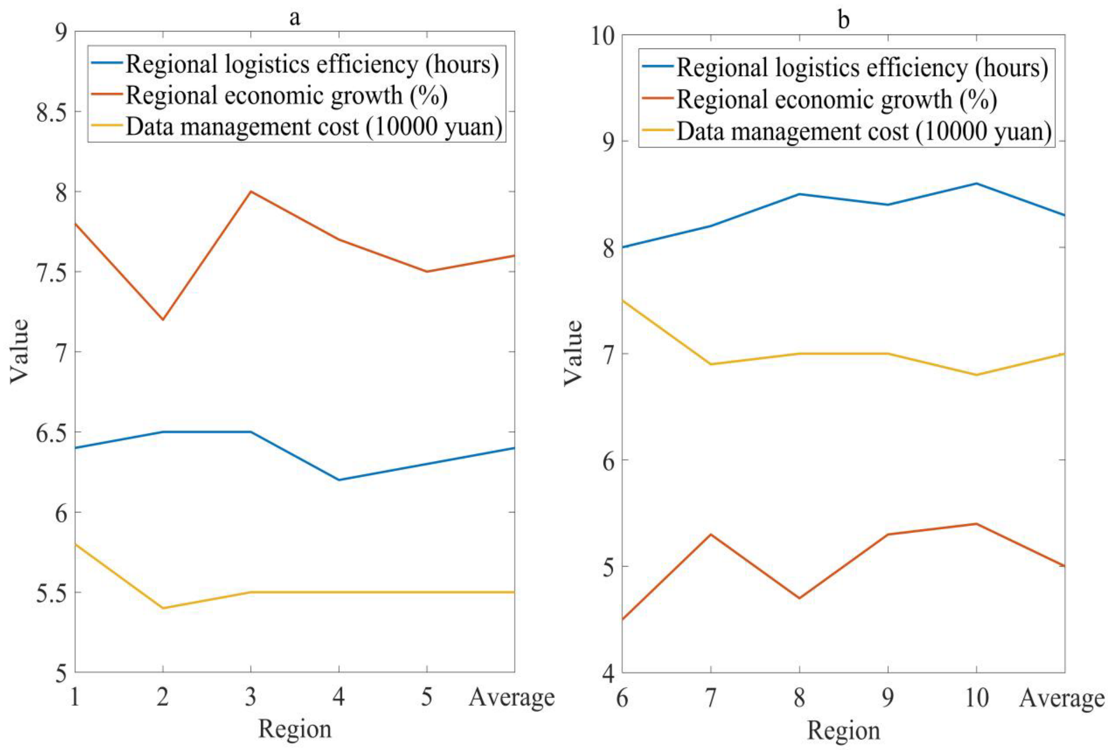

Fig.2: Comparative analysis of regional digital twin models and logistics development

(a) Scheme B (b) Scheme A

In summary, the experimental results indicate that the introduction of digital twin models has significant advantages in regional economic and logistics development, which can improve the efficiency of logistics systems, promote regional economic growth, and reduce the cost of data management. This provides strong support and guidance for future logistics and economic development.

3.2 Comparison of Logistics Network Optimization and Expansion Plans

Experimental purpose: The purpose is to compare the impact of different logistics network optimization and expansion plans on regional economic and logistics development.

Experimental indicators: Scope of logistics services: It can evaluate the coverage of logistics services under different schemes, such as the area and population covered. Transportation cost: It can compare the transportation costs under different schemes, including transportation distance, cost-effectiveness, etc. Logistics resource utilization rate: It can evaluate the efficiency of logistics resource utilization under different schemes, such as vehicle utilization rate, storage facility utilization rate, etc.

Experimental design schemes:

Scheme C: Existing logistics network structure and layout

The existing logistics network structure was maintained, without optimization and expansion. The scope of logistics services was based on the existing coverage range. The transportation cost and logistics resource utilization rate were based on the existing logistics operation situation.

Scheme D: Logistics network optimization and expansion plan

Logistics network optimization and expansion were carried out, including the increase of nodes and optimization of paths. The scope of logistics services was expanded to a wider area, such as increasing the coverage area and population. The transportation cost and logistics resource utilization rate were based on the optimized logistics network operation.

Experimental data collection method:

Scope of logistics services: Data on the scope of logistics services were collected, including indicators such as the area of the area covered by schemes C and D and the number of population; GIS or relevant data sources were used to obtain information on area boundaries and population distribution.

Transportation cost: Transportation cost data were recorded, including transportation distance, fuel consumption, and transportation cost under Scheme C and Scheme D; related data were collected, such as transportation records, fuel consumption data, etc.

Logistics resource utilization rate: data on logistics resource utilization rate under Scheme C and Scheme D, such as vehicle utilization rate, storage facility utilization rate, etc., were collected; resource utilization indexes were calculated based on logistics operation data, storage facility usage, etc.

Figure 3 shows a comparative analysis of logistics network optimization and expansion plans; Figure 3 (a) shows Scheme D, and Figure 3 (b) shows Scheme C. In terms of logistics service scope, the service scope of experimental Scheme D was 802 square kilometers, which was higher than the 497 square kilometers of experimental Scheme C, indicating that the expansion Scheme D can cover a larger area and provide a wider range of logistics services. In terms of transportation costs, the transportation cost of experimental Scheme D was 59000 yuan, which was lower than the 70000 yuan of experimental Scheme C, indicating that optimized Scheme D can reduce logistics transportation costs. In terms of logistics resource utilization, Scheme D achieved a logistics resource utilization rate of 88%, which was higher than 71% of Scheme C, indicating that optimization Scheme D can more effectively utilize logistics resources.

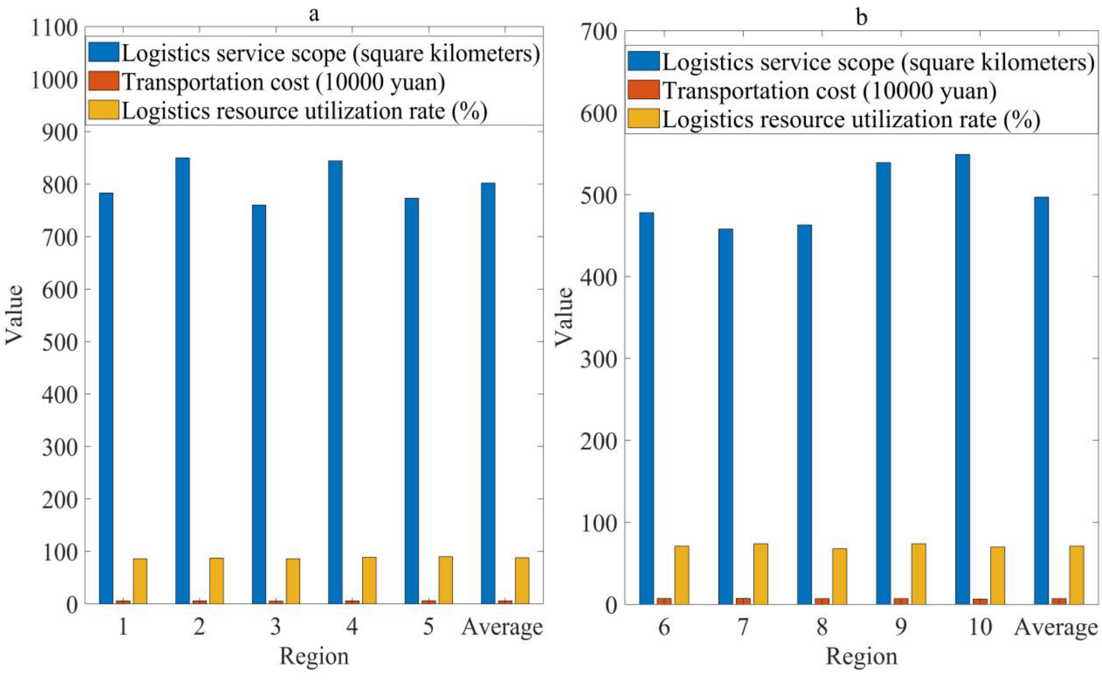

Fig.3: Comparative analysis of logistics network optimization and expansion plans

(a) Scheme D (b) Scheme C

In summary, based on experimental data analysis, the optimization and expansion of logistics network in Scheme D have a more positive impact on regional economy and logistics development. It can expand the scope of logistics services, reduce transportation costs, and improve the efficiency of logistics resource utilization. Therefore, when optimizing and expanding the logistics network, Scheme D is a more optimal choice.

3.3 Coupling Analysis of Digital Twin Model and Intelligent Logistics Technology

Experimental purpose: The purpose is to compare the impact of the combination of digital twin models and intelligent logistics technology on regional economic and logistics development.

Experimental indicator: Transportation efficiency: It can compare the degree of improvement in logistics transportation efficiency after the introduction of intelligent logistics technology. Transportation Safety: It can evaluate the impact of intelligent logistics technology on logistics transportation safety, such as accident rate, cargo loss rate, etc. Human resource utilization rate: It can compare the changes in human resource utilization rate after the combination of digital twin models and intelligent logistics technology.

Experimental design schemes:

Scheme E: Traditional logistics management methods without applying intelligent logistics technology

Traditional logistics management methods were used, including manual scheduling and operations. Logistics data and information were processed manually without intelligent support. Existing human resource utilization patterns and processes were maintained.

Scheme F: Combining digital twin model with intelligent logistics technology

It introduced the digital twin model as a management and optimization tool for logistics systems. It incorporated intelligent logistics technologies such as logistics tracking and automated scheduling. Real-time data and predictive analytics were used for decision support and optimization.

Experimental data collection method:

Transportation efficiency: logistic transportation time and cost data under Scheme E and Scheme F were recorded; the improvement of Scheme F on transportation efficiency was evaluated through logistic transportation records and related data collection.

Transportation security: Data on logistics transportation security under Scheme E and Scheme F, such as accident rate and cargo loss rate, were collected; security incident records and related data were analyzed, and the impact of Scheme F on transportation security was evaluated.

Human resource utilization: Data on human resource utilization under Scheme E and Scheme F, such as employee work hours, task assignment, etc., were collected; based on employee work records and task assignment information, human resource utilization indicators were calculated.

Figure 4 shows the coupling analysis between the digital twin model and intelligent logistics technology; Figure 4 (a) shows Scheme F, and Figure 4 (b) shows Scheme E. In terms of transportation efficiency, the transportation efficiency of experiment Scheme F after the introduction of intelligent logistics technology reached 0.95, higher than 0.9 of experiment Scheme E. This indicated that the combination of digital twin model and intelligent logistics technology can improve the efficiency of logistics transportation. In terms of transportation safety, the safety rate of experimental Scheme F was 0.9, which was higher than 0.8 of experimental Scheme E, indicating that the application of intelligent logistics technology had a positive impact on logistics transportation safety. In terms of the utilization rate of human resources, the utilization rate of human resources in experimental Scheme F was 0.8, higher than 0.7 in experimental Scheme E, which indicates that the combination of digital twin model and intelligent logistics technology can more effectively use human resources.

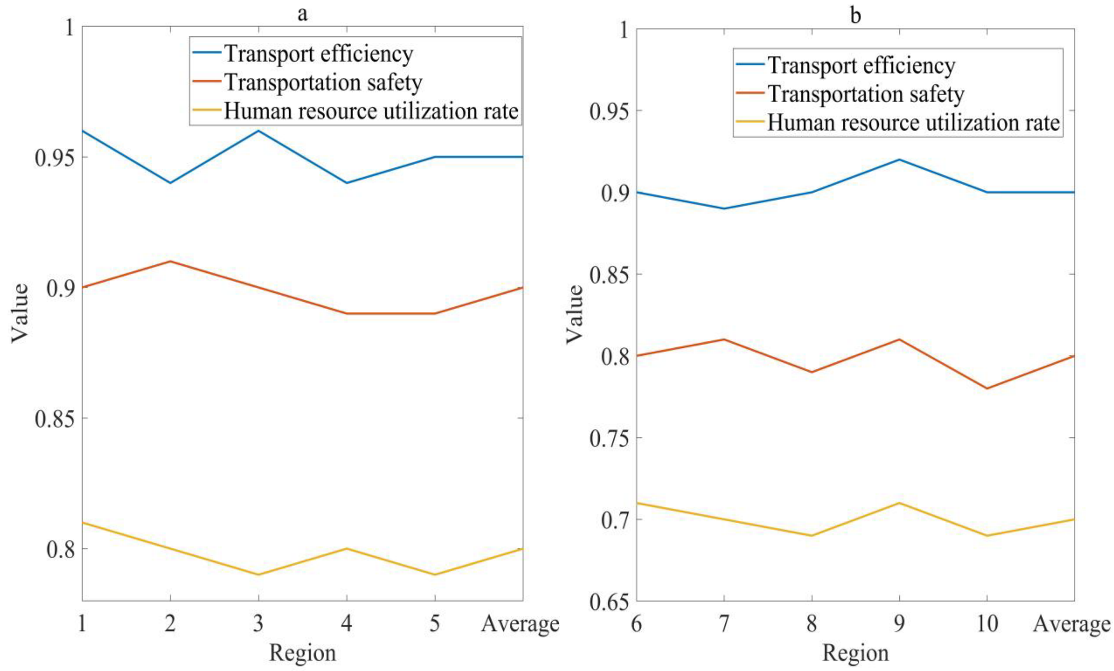

Fig.4: Coupling analysis of digital twin model and intelligent logistics technology

(a) Scheme F (b) Scheme E

In summary, the experimental results show that the combination of digital twin models and intelligent logistics technology has a positive impact on regional economic and logistics development. It can improve logistics transportation efficiency, enhance transportation safety, and optimize the utilization of human resources. Therefore, combining digital twin models with intelligent logistics technology is an effective method in logistics management and optimization.

3.4 Comparison of Different Logistics Models

Experimental purpose: The purpose is to compare the impact of different logistics models on regional economy and logistics development.

Experimental indicator: Transportation efficiency: It can compare the transportation efficiency under different logistics modes, including logistics transportation time, cost, etc. Environmental impact: It can evaluate the degree of impact of different logistics modes on the environment, such as carbon emissions, energy consumption, etc. Customer satisfaction: It can compare the changes in customer satisfaction under different logistics modes.

Experimental design schemes:

Scheme G: Traditional logistics model

It used traditional freight and warehousing methods, such as traditional logistics distribution, warehouse storage, etc. Logistics operations were based on traditional processes and operations. During the experiment, the existing logistics mode and process were maintained.

Scheme H: Innovative logistics model

Innovative logistics models were introduced, such as logistics sharing economy model and intelligent logistics model; advanced technologies and innovative business models were used for logistics operation and optimization; logistics efficiency and service quality were improved through digital and intelligent means.

Experimental data collection method:

Transportation efficiency: logistic transportation time and cost data under Scheme G and Scheme

H were recorded; logistic transportation records and related data were collected, and the transportation efficiency of different logistics modes were compared.

Environmental impact: Environmental impact data such as carbon emissions and energy consumption under Scheme G and Scheme H were collected; the degree of environmental impact of different logistics modes was evaluated based on logistics transportation data and related indicators.

Customer satisfaction: Customer satisfaction data under Scheme G and Scheme H were collected, such as questionnaires, customer feedback, etc.; customer satisfaction research or data collection was conducted to compare the customer satisfaction of different logistics modes. It was scored through a scoring system with a score of 100.

Figure 5 shows a comparative analysis of different logistics models; Figure 5 (a) shows Scheme H, and Figure 5 (b) shows Scheme G. In terms of transportation efficiency, the transportation time of experimental Scheme H was 5 hours, which was lower than the 7 hours of experimental Scheme G, indicating that the logistics mode of Scheme B can improve transportation efficiency. In terms of environmental impact, the carbon emissions of Scheme H were 151 tons of CO2, which was lower than the 201 tons of CO2 of Scheme G, indicating that the logistics mode of Scheme H had less impact on the environment. In terms of customer satisfaction, the satisfaction score of Scheme H was 93, which was higher than the 81 of Scheme G, indicating that the logistics model of Scheme H can improve customer satisfaction.

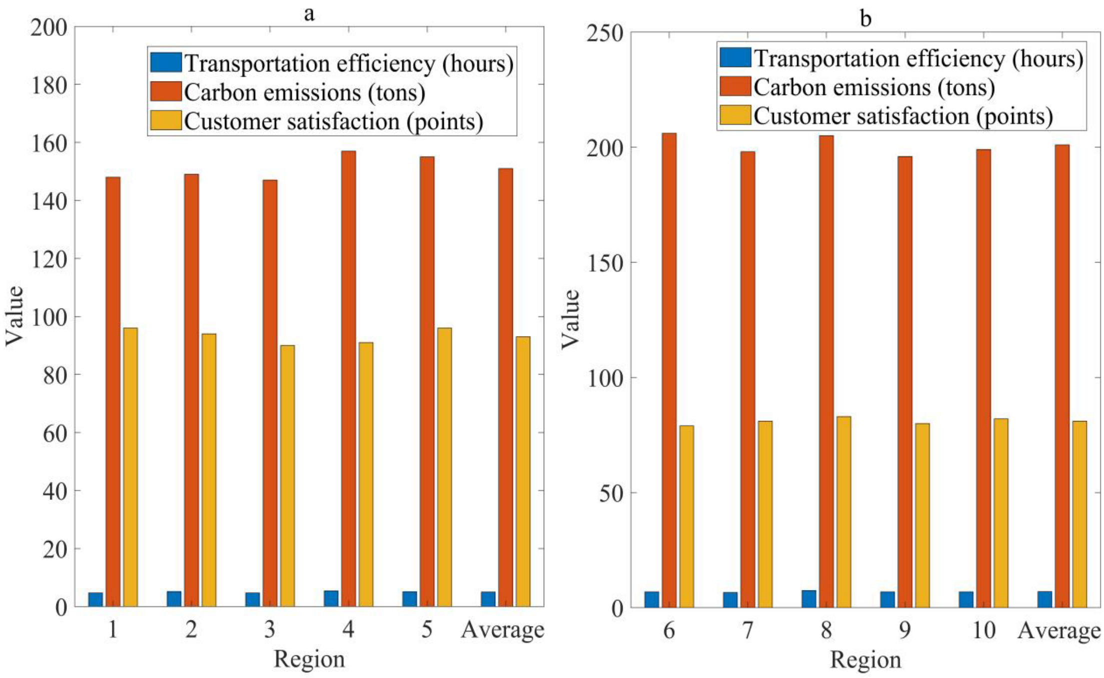

Fig.5: Comparative analysis of different logistics models

(a) Scheme H (b) Scheme G

The experimental results show that innovative logistics models have a more positive impact on regional economy and logistics development compared to traditional logistics models. It can improve transportation efficiency, reduce environmental impact, and enhance customer satisfaction. Therefore, introducing innovative logistics models in logistics management and optimization is an effective strategy.

3.5 Spatial Analysis of Digital Twin Model

Experimental purpose: The purpose is to explore the spatial relationship between regional economy and logistics development through spatial analysis by digital twin model.

Experimental indicator: Spatial distribution characteristics: It can evaluate the spatial distribution characteristics of digital twin models for regional economic and logistics development, such as hot spots, traffic congestion points, etc. Spatial benefit analysis: It can compare the impact of the spatial layout of logistics nodes in different regions on regional economic benefits. Spatial planning suggestions: it can put forward relevant spatial planning suggestions according to the spatial analysis results of the digital twin model, so as to optimize the development of regional economy and logistics.

Experimental design schemes:

Data collection: Data related to regional economic and logistics development were collected, including logistics node locations, economic activity areas, and population distribution; traffic network data were obtained, such as road networks, traffic flow, traffic congestion, etc.

Digital twin model construction: Based on the collected data, a digital twin model was constructed and a spatial simulation of the regional economic and logistics system was established; simulations were conducted using the digital twin model and the distribution of logistics nodes and the spatial characteristics of economic activities in the region were simulated.

Spatial analysis: The spatial distribution characteristics of the digital twin model were analyzed, such as hotspot areas of logistics nodes and traffic congestion points; the degree of influence of the spatial layout of logistics nodes in different regions on regional economic benefits, such as economic growth, was compared; the effect of the digital twin model on spatial planning was evaluated, and relevant spatial planning suggestions were made.

Data analysis and visualization: data analysis was conducted and the spatial analysis results of the digital twin model were tallied; tools such as GIS were used to visualize the analysis results, thus presenting the spatial characteristics and benefit analysis results more intuitively.

Scheme I: Traditional logistics network solution

Scheme I adopted the traditional logistics network structure and layout. The selection and location arrangement of logistics nodes followed traditional experience and planning. The transportation mode mainly relied on traditional freight modes, such as road transportation, air transportation, etc. Logistics information circulation mainly depended on manual operation and traditional information transmission methods.

Scheme J: Intelligent logistics network plan

Scheme J adopted intelligent logistics network optimization and innovative layout. Based on the digital twin model and intelligent logistics technology, the logistics network was optimized and adjusted. Intelligent scheduling and path planning algorithms were adopted, thus improving the efficiency of logistics transportation. Technologies such as Internet of Things and artificial intelligence were introduced, and automation and intelligent management of logistics nodes were realized. A digital information platform was established to achieve real-time monitoring and sharing of logistics information. Table 1 shows the spatial distribution characteristics of regional economy and logistics development based on Scheme J, and Table 2 shows the spatial distribution characteristics of regional economy and logistics development based on Scheme I.

Table 1. Spatial distribution characteristics of regional economy and logistics development based on Scheme J

	Hot spot area density (unit: km^2)	**Traffic Congestion Index (Range: 0-10)**	**Regional economic growth rate (%)**	**Regional logistics service coverage (unit: km^2)**
1	150	5	6	790
2	154	5	6.9	812
3	146	5	6.7	792
4	148	5	6.4	816
5	154	5	6.8	817
Average	150	5	6.6	805

Table 2. Spatial distribution characteristics of regional economy and logistics development based on Scheme I

	Hot spot area density (unit: km²)	**Traffic Congestion Index (Range: 0-10)**	**Regional economic growth rate (%)**	**Regional logistics service coverage (unit: km²)**
6	99	7	3.7	508
7	95	7	3.4	498
8	99	7	3.5	499
9	95	7	3.5	508
10	96	7	3.8	499
Average	97	7	3.6	502

Compared with Scheme I, Scheme J improved the density of hot spots and decreased the traffic congestion index. The increase in density of hotspots indicated that more economic activities and logistics nodes were concentrated in specific areas in Scheme J, which may indicate stronger economic development and logistics activities in the region. The decrease in traffic congestion index indicated that Scheme J can effectively reduce traffic congestion and improve logistics liquidity. Scheme J achieved significant improvements in regional economic growth rate and logistics service coverage compared to Scheme I. The increase in regional economic growth rate indicated that the spatial layout of logistics nodes in Scheme J was more reasonable and efficient, which can bring greater growth potential to the regional economy. The expansion of logistics service coverage meant that Scheme J can cover a wider area and provide more comprehensive logistics services, thereby promoting economic development in various regions within the region.

4. Conclusions

Through digital twin technology, real and dynamic models can be constructed to reveal the internal relationship and development trends of regional economy and logistics systems, providing scientific basis for government and enterprise decision-making. At the same time, digital twins can also provide intelligent management and optimization solutions for regional economic and logistics development, thereby promoting economic growth and sustainable development. Therefore, in-depth research on the application of digital twins in regional economic and logistics development is of great significance. Through the coupling evaluation of digital twin model and spatial analysis experiment, this paper found that the introduction of digital twin model and innovative logistics optimization scheme combined with intelligent logistics technology can improve logistics efficiency, promote regional economic growth, and optimize spatial layout. These experimental results provided important references for decision-making and planning of regional economic and logistics development. Future research directions include further improving the accuracy and practicality of digital twin models, and enhancing the quality and reliability of data. At the same time, it is also necessary to study how to better apply the digital twin model to solve practical problems, such as promoting the development of urban planning, traffic management, and logistics optimization. In addition, the integration of digital twins with other technologies such as artificial intelligence and big data analysis can be explored to further improve the predictive and decision support capabilities of the model. In summary, the digital twin model has broad application prospects in regional economic and logistics development, but it still needs to be continuously studied and improved. By overcoming its limitations, we can better utilize the digital twin model to provide accurate and reliable references for decision-making and planning, and promote sustainable economic and logistics development.

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