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Design of international trade network optimization and regional economic synergy model based on evolutionary algorithm

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ABSTRACT

This paper synthesizes relevant theoretical knowledge and construction principles, selects 20 evaluation indicators to constitute the evaluation system, and divides the evaluation system into two subsystems in order to more intuitively demonstrate the relationship between international trade network optimization and regional economic synergy. Setting the source of research data, due to the initial data outline is not uniform, the research data for the dimensionless processing. Then the weight values of each index are calculated with the help of entropy weight method, and their values are substituted into the coupled synergy model of the fusion evolutionary algorithm. It is calculated that the synergy level of international trade network optimization and regional economy is medium in the period of 2014~2016, the coordination level of the two has been significantly improved in the period of 2017~2021, and the coordination level is good, and the coordination level of international trade network optimization and regional economy rises to excellent in the period of 2022~2023.

Keywords: evolutionary algorithm, international trade, regional economy, synergy model

1. Introduction

In today's era of globalization, the formation and development of international trade networks provide a more convenient and broader platform for trade cooperation among countries [1-2]. Trade network refers to the complex trade relations and network structure established between countries, involving the trading of goods and services, the cooperation of multinational corporations and the coordination of international trade policies [3-5]. The formation of trade networks makes it possible to carry out trade activities between countries more conveniently and effectively. Through the establishment of trade networks, the exchange of goods and services between countries can be realized to meet the needs of different countries [6-8]. The trade network connects the markets in all corners of the world

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and promotes the efficient allocation and coordination of resources. At the same time, trade networks also provide a broader cooperation platform for transnational corporations (TNCs) and promote the development and expansion of TNCs [9-12].

With the deepening of economic globalization, regional economic cooperative development has become an important way to promote economic growth and social progress [13-14]. Regional economic cooperative development is an important way to promote economic growth and social progress. Through the complementarity of resource advantages, the interconnection of industries, the integration of markets, the sharing of public services, and the balanced development of society, different regions can realize mutual benefits and win-win situation and common development [15-18]. Regional economic synergistic development requires joint efforts and policy support from all parties in order to give full play to its potential and value, and inject new impetus and vitality into economic and social development [19-21]. Evolutionary algorithm, as an algorithm simulating the biological evolution process in nature, has been widely used in the solution of optimization problems by simulating the operations of selection, crossover and mutation to carry out and optimize the problem space. Optimal design methods based on evolutionary algorithms are used to model and solve design problems by combining evolutionary algorithms and design principles in order to obtain better design solutions [22-25]. Therefore, the design of international trade network optimization and regional economic synergy model based on evolutionary algorithm is of great significance.

In this paper, under the requirements of scientific principle, digital principle, hierarchical principle and importance principle, the evaluation index system is determined, which consists of international trade network optimization sub-system and regional economic sub-system, and each sub-system is composed of 10 evaluation indexes. From the many weight calculation methods, the entropy weight method is chosen to calculate the weight value of each index, and then it is found that the original coupled synergistic model has the problems of high similarity of results and low precision, accordingly, it is proposed to use the evolutionary algorithm to construct the synergistic model of international trade network optimization and regional economy. Set the research data sources, combined with the corresponding research data to empirically analyze the model of this paper.

2. Model of international trade network optimization and regional economic synergy

2.1. Relevant theoretical foundations

2.1.1. International trade networks. International trade is a very complex activity, there are many countries involved in the activity, the relationship between each country is also intricate, at the same time, the development of international trade is also affected by a lot of factors, such as national political stability, the supply and demand situation of the whole market, the overall economic situation and so on. In order to study the trade links between countries, there is a new term of international trade network. International trade network is the most representative part of the economic network, international trade network will be the country as a node, the import and export trade relations between countries as a link, it can provide us with a new way of describing the world trade in addition to the traditional economic and trade analysis for specific countries. With the development of economic globalization, in the information technology and transportation environment, whether it is the trade activities between countries or regions have formed an inseparable, interactive, interdependent social and economic network, the international trade network can not only reflect the degree of trade dependence can be reflected in the degree of openness of the economy, but also reflect the economic relations between the economies and the overall international economic development trends and patterns. Trends and patterns of international economic development as a whole.

2.1.2. Regional economies. The regional economy, also known as the regional economy, is the result of the division of labor and collaboration in society, and is an important component of the national economy, displaying obvious regional characteristics and comprehensive features. Regional economy is the result of the interaction between internal factors and external conditions of economic development in a specific region. At the same time, there are differences in regional economy, and the geographical environment, population distribution, consumption level and political system of a region all have an important impact on the development of regional economy, and the economic development of each region has its own characteristics. At present, regional economic development shows large differences, the economic development excellence of a region does not represent the overall economic level of the country, so the coordinated development of regional integration is very important. Regions with higher economic levels can play a radiation-driven role for their neighbors, and each region, on the basis of its own comparative advantages, focuses on the division of labor and strengthens exchanges, which contributes to the coordinated development of the inter-region.

2.2. Principles of the evaluation indicator system

The evaluation system of international trade network and regional economic indicators is a unified whole that evaluates the synergy between international trade network and regional economy, and its establishment is not a simple stack of related indicators. The establishment of international trade network optimization and regional economic synergy indicator evaluation system should follow the four principles of scientific, digital, hierarchical and importance, and only by adhering to the above construction principles, can we establish a complete set of scientific and practical international trade network optimization and regional economic synergy indicator evaluation system.

2.2.1. Scientific principles. The scientific principle followed in the evaluation system of international trade networks and regional economic indicators is that the indicator evaluation system can truly and effectively reflect the degree of trade facilitation of the countries evaluated. For this reason, the selection of each indicator and the definition of the name of the indicator should have a scientific basis, and the calculation of the weights of the indicators and the categorization of the indicators should follow the scientific calculation and categorization methods.

2.2.2. Principles of digitization. The digitalization principle followed by the evaluation system of international trade networks and regional economic indicators is that the selection of indicators should be easy to measure, analyze and predict. To this end, statistical data that are more readily available should be selected, and the statistical data should be real and effective, with a certain degree of authority, and the appearance of virtual data should be avoided as much as possible, which will affect the results of the analysis.

2.2.3. Hierarchical principles. The hierarchical principle followed by the evaluation system of international trade network and regional economic indicators is that the evaluation system should be constructed in a hierarchical manner, so that it is easy to use and analyze. The evaluation system of international trade network and regional economic indicators is a comprehensive evaluation system, which involves all aspects of the main body of the study, so when establishing the evaluation system, it should follow the principle of clear structure and clear hierarchy, and should not make the evaluation system too large and complex.

2.2.4. The principle of materiality. The principle of importance followed in the evaluation system of international trade networks and regional economy indicators is that the evaluation system constructed should be a centralized representation of the important factors affecting international trade networks and regional economies. Factors affecting the international trade network and regional economy are very extensive, and some of these factors are important and some are not so important, therefore, in the selection of evaluation indicators, we should try to select the data of the important factors affecting the international trade network and regional economy, and seize the main factors affecting the international trade network and regional economy to evaluate, and better reflect the degree of influence of the international trade network and regional economy.

2.3. *Construction of evaluation index system*

The evaluation index system is shown in Table 1. In order to construct the evaluation index system of international trade network optimization and regional economic coupling and coordination in a more detailed way, we can divide it into two main subsystems, which are the international trade network optimization subsystem and the regional economic subsystem, and the specific evaluation indexes of each subsystem are shown below:

Table 1. Evaluation index system

Subsystem	Symbol	Evaluation index	Symbol
International trade network optimization	A	Trade cost word count	A1
		Market access index	A2
		Supply chain diversity	A3
		Trade facilitation index	A4
		Digital trade development level	A5
		Proportion of trade in services	A6
		Environmental Sustainability Index	A7
		Attractiveness of foreign direct investment	A8
		Technological innovation ability	A9
		Participation in multilateral trade agreements	A10
Regional economy	B	Economic growth rate	B1
		Employment rate	B2
		The Income Inequality Index	B3
		Industrial structure advanced index	B4
		Availability of financial services	B5
		Policy coordination and consistency	B6
		Infrastructure connectivity Index	B7
		Human Capital Development Index	B8
		Social Stability Index	B9
		Environmental Sustainability Index	B10

2.3.1. International trade network optimization subsystems:

1) Trade cost word count: measures total trade costs including transportation, tariffs, and non-tariff barriers.

2) Market Access Index: Assesses the degree to which countries' markets are open to foreign goods and services.

3) Supply Chain Diversity: Measures the degree of supply chain diversification in trade networks to reduce dependence on a single source.

4) Trade Facilitation Index: Reflects the efficiency of customs degree, quality of trade-related infrastructure, etc.

5) Level of digital trade development: including the share of e-commerce transactions and the utilization rate of digital payments.

6) Share of trade in services: the share of trade in services in total trade, reflecting the advanced structure of the economy.

7) Environmental sustainability index (trade perspective): e.g. real-time green trade policy, share of trade in low-carbon products.
8) Foreign Direct Investment Attractiveness: Measures the confidence of foreign investors in the economies of the region and the scale of investment.
9) Technological Innovation Capacity: Measured through indicators such as technology imports and international technological cooperation.
10) Multilateral trade agreement participation: the number and depth of participation in regional and global trade agreements.

2.3.2. Regional economic coordination subsystems:
1) Economic growth rate: measures the rate of growth of GDP or GDP per capita in the region
2) Employment rate: reflects the health of the labor market in the region
3) Income inequality index: such as the Gini coefficient, which measures the fairness of income distribution in the region
4) Index of advanced industrial structure: reflecting the degree of transformation from primary industries to high value-added industries in the region.
5) Accessibility of financial services: assesses the ease or difficulty for enterprises and individuals to access financial services such as credit and insurance.
6) Policy Harmonization and Coherence: Measures the consistency and systematic efficiency of economic policies and regulations of countries in the region.
7) Infrastructure connectivity index: assesses the connectivity of regional transportation, communication and other infrastructure.
8) Human Capital Development Index: Reflects the level of education, skills training and mobility of talents in the region.
9) Social Stability Index: Reflects the stability of the social environment through indicators such as crime rate and political stability.
10) Environmental sustainability index (regional perspective): including air quality cooking, forest coverage, water resource management, etc.

2.4. Construction of the model

The variation operator is an important part of the evolutionary algorithm, which consists of a target vector and a difference term. At present, many researchers have proposed a variety of improved variation operators and achieved good results. However, in the improved variation operator about the difference term, the individual selection of the difference term is mainly based on its fitness value, and this single selection may weaken the perturbation performance of the stochastic difference term and reduce the population diversity. Based on this consideration, this paper proposes a coupled synergistic model based on evolutionary algorithm. The weights of the evaluation indexes of the two subsystems are calculated using the entropy weight method, and on the basis of knowing the weights of the evaluation indexes, the coupling and synergy of the two subsystems are calculated using the evolutionary algorithm. The detailed process is as follows:

2.4.1. Calculation of weights. Because of the differences in the magnitude of each indicator, there are differences in the order of magnitude, so in order to eliminate the impact of the evaluation results due to the different magnitude, this paper standardizes the indicators, and at the same time, in the process of constructing the indicator system, the selected indicators are positive indicators, so the following formula is used:

$$x'_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} x'_{ij} \in [0,1] \tag{1}$$

The standardized indicator data were processed using the linear dimensionless weighting method:

$$Y_{ij} = \frac{x'_{ij}}{\sum x'_{ij}} \tag{2}$$

The formula for calculating the information entropy value of the jth indicator is:

$$e_j = -K \sum Y_{ij} Ln Y_{ij} \;\; Which\ K = 1/\ln(m) \tag{3}$$

The information utility value of an indicator depends on the gap between the information entropy value of the indicator e_j and 1, its value is the utility value d_j, $d_j = 1 - e_j$, which directly affects the size of the weights, the greater the information utility value, the greater the importance of the evaluation.

The use of entropy value assignment method to calculate the weight of each indicator, its essence is to use the value coefficient of the information of the indicator to calculate the value coefficient, the higher its value coefficient, the greater the importance of the evaluation. The weight of the jth indicator is:

$$W_j = \frac{d_j}{\sum d_j} \tag{4}$$

2.4.2. Evolutionary algorithms. JADE is an improved evolutionary algorithm with excellent performance. In this algorithm, firstly, a new mutation operator DE/current-to-pbest/1 is proposed, which takes the individual with better fitness value as the target vector as a way to balance the search and convergence of the algorithm, in addition to that an external archive concept is proposed, which takes the failed parent individuals as the alternative set of posterior terms in the difference term, so that the target vector can be kept away from those eliminated individuals, increasing the convergence of the algorithm.DE/current-to-pbest/1 is represented by equation (5):

$$v_i^g = x_i^g + F * \left(x_{pbest}^g - x_{r1}^g\right) + F * \left(x_{r2}^g - \tilde{x}_{r3}^g\right) \tag{5}$$

In addition to this, JADE proposes a complex parameter adaptation mechanism. Let F_i and Cr_i be generated separately and independently based on the successful parameters of the previous generation, and the formula for Cr_i is as follows:

$$Cr_i = rand_i\left(\mu_{Cr}, 0.1\right) \tag{6}$$

Where $randn_i\left(\mu_{Cr}, 0.1\right)$ is a random number generated by a uniform distribution. 0.1 is the standard deviation, μ_{Cr} represents the mean, and μ_{Cr} is given by the following formula:

$$\mu_{Cr} = (1-c) * \mu_{Cr} + c * mean_A\left(S_{Cr}\right) \tag{7}$$

Here S_{Cr} is the set of successful crossover probabilities from the previous generation; $mean_A(x)$ is the commonly used arithmetic mean; c is a constant between 0 and 1.

F_i and Cr_i are similar, as follows:

$$\begin{cases} F_i = rand_i\left(\mu_F, 0.1\right) \\ \mu_F = (1-c) * \mu_F + c * mean_L\left(S_F\right) \\ mean_L\left(S_F\right) = \sum_{S_F} \dfrac{F^2}{\sum_{S_F} F} \end{cases} \tag{8}$$

where $rand_i(x,y)$ denotes the random value of the Cauchy distribution generated according to parameters x and y; $mean_L(x)$ denotes the arithmetic mean; and S_F denotes the set of mutation factors that were successfully replaced with their parents.

2.4.3. Mathematical modeling. The coupling coordination model is used to analyze the level of coordinated development of things, and consists of two parts: the coupling degree and the coordination degree. The coupling degree refers to the dynamic correlation relationship between two or more systems that interact and influence each other to realize coordinated development, which can reflect the degree of interdependence and mutual constraints between systems [26-28]. The degree of coordination refers to the size of the degree of benign coupling in the coupled interaction relationship, which can reflect the good or bad coordination status. The concept of coupling degree comes from the field of physics, and is later widely used in the field of social science. Coupling degree is used to characterize the degree of mutual influence between multiple systems (indicators), which can reflect the trend of the system (indicators) from disorder to order. The formula for calculating the degree of coupling is as follows:

$$C_1\left(U_1,U_2,\cdots,U_n\right)=n\times\left[\frac{U_1U_2\cdots U_n}{\left(U_1+U_2+\cdots+U_n\right)^n}\right]^{\frac{1}{n}} \tag{9}$$

$$C_2\left(U_1,U_2,\cdots,U_n\right)=2\times\left[\frac{U_1U_2\cdots U_n}{\prod_{i<j}\left(U_i+U_j\right)^{\frac{2}{n-1}}}\right]^{\frac{1}{n}} \tag{10}$$

Where: C_1 and C_2 denote the two coupling degrees. U_n indicates value $(n\geq 2)$ for the nth indicator. Note that the coupling degree is 0 when any one of the indicator values is 0, but the coupling degree is meaningless when all the indicator values are 0.

The formula for calculating the degree of coordination is as follows:

$$T=\beta_1U_1+\beta_2U_2+\cdots+\beta_nU_n \tag{11}$$

Where: T is the degree of harmonization. U_n is the value of the nrd indicator $(n\geq 2)$. β_n is the weight of the nth indicator $(n\geq 2)$.

After determining the degree of coupling and the degree of coordination, the degree of coupling coordination can be calculated, and its formula is as follows:

$$D=\sqrt{C\times T} \tag{12}$$

Where: D is the degree of coupling and coordination, C is the degree of coupling and T is the degree of coordination.

For the problem of similarity between the coupling degree and coordination degree of these two indicators, an evolutionary algorithm can be used to solve the problem. The specific operation consists of three parts:

In the first part, the difference in fitness between individuals is taken as the first index in the coupling and coordination degree U_1. Firstly, the difference in fitness between two individuals in the population is calculated. The specific calculation formula is as follows:

$$\Delta f_{i,j}=\left|f_i-f_j\right|,i,j\in\{1,2,\cdots,NP\} \tag{13}$$

Where: $\Delta f_{i,j}$ is the difference in fitness between the ind individual and the jrd individual. f_i is the fitness value of the ith individual. f_j is the fitness value of the jth individual.

Since the result of calculating the coupling coordination degree between individuals needs to be controlled at $[0,1]$, it is necessary to standardize $\Delta f_{i,j}$. The standardization method is as follows:

$$U_{1i,j} = 1 - \frac{\Delta f_{i,j}}{\max_{i,j}\left(\Delta f_{i,j}\right)}, i,j \in \{1,2,\cdots,NP\} \tag{14}$$

Where: $U_{1_{i,j}}$ is the fitness difference between the i nd individual and the j rd individual obtained through normalization means $\max_{i,j}\left(\Delta f_{i,j}\right)$ is the maximum value of the fitness difference between any two individuals in the current population.

In the second part, the positional distance between two individuals is used as the second index of the coupling coordination degree U_2. The distance between two individuals in the population is first calculated using the Euclidean distance. The specific calculation is as follows:

$$d_{i,j} = \left\| X_i - X_j \right\|_2, i,j \in \{1,2,\cdots,NP\} \tag{15}$$

Where: $d_{i,j}$ is the Euclidean distance between the i nd individual and the j rd individual. Where X_i is the coordinate position of the i th individual. X_j is the coordinate position of the j th individual. Similarly, $d_{i,j}$ is then normalized:

$$U_{2_{i,j}} = 1 - \frac{d_{i,j}}{\max_{i,j}\left(d_{i,j}\right)}, \quad i,j \in \{1,2,\cdots,NP\} \tag{16}$$

Where: $U_{2i,j}$ is the metric obtained by normalizing the Euclidean distance between the i nd individual and the j rd individual. $\max(d)$ is the maximum value of the Euclidean distance between any two individuals in the current population.

In the last part, the coupling coordination degree is calculated, and in this paper, C_2 coupling degree is used for calculation. Namely:

$$C_{2_{i,j}} = 2 \times \left[\frac{U_{1_{i,j}} \times U_{2_{i,j}}}{\left(U_{1_{i,j}} + U_{2_{i,j}}\right)^2} \right]^{\frac{1}{2}}, i,j \in \{1,2,\cdots,NP\} \tag{17}$$

$$T_{i,j} = \beta_1 U_{1i,j} + \beta_2 U_{2_{i,j}}, i,j \in \{1,2,\cdots,NP\} \tag{18}$$

$$CCD_{i,j} = \sqrt{C_{2_{i,j}} \times T_{i,j}}, i,j \in \{1,2,\cdots,NP\} \tag{19}$$

Where: $C_{2_{i,j}}$ is the coupling degree of the i nd individual with the j rd individual. $T_{i,j}$ is the degree of coordination between the i th individual and the j th individual, and in this paper, we make $\beta_1 = \beta_2 = \frac{1}{2}$, which means that the value of visual adaptation and distance are equally important, and $CCD_{i,j}$ is the degree of coupling coordination between the i th individual and the j th individual.

3. Model empirical analysis

3.1. Data sources and descriptive statistical analysis

3.1.1. Data sources. The data for the above indicators are mainly derived from the 2014-2023 Statistical Yearbook of a Region, supplemented by data from the websites of government departments; for data without indicators, they are obtained by using relevant data collation, and missing data for individual years are processed by the linear interpolation method. In the process of comprehensive evaluation of multiple indicators, the data need to be dimensionless due to the fact that it is impossible to evaluate each indicator directly because of the different units and magnitudes (i.e., the order of magnitude of the measurement indicators), so the data need to be dimensionless. There are three methods for dimensionlessness in the indicator system, the mean value method, the extreme difference regularization method and the standardization method, and the mean value method is used in this paper. Because the data in this paper all belong to objective data, the use of homogenization method can correctly reflect the information contained in the original data, making the evaluation results more accurate.

3.1.2. Descriptive statistics. Descriptive statistical analysis of the research data of the above indicators, descriptive statistical analysis results are shown in Table 2. It can be seen that the data distribution of each indicator from 2014 to 2023 is within 20, in addition, it is also found that the data difference of each indicator is too large (at the same time, there are problems such as non-uniformity of the quantitative outline, etc.), and the next step is to carry out a dimensionless processing of the research data.

Table 2. Descriptive statistical analysis results

Index	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
A1	18.92	7.02	17.96	18.37	10.33	14.73	12.95	11.36	1.07	15.13
A2	6.83	15.23	6.53	11.02	10.51	19.17	5.33	12.97	13.76	15.23
A3	9.27	2.47	12.87	4.07	3.61	2	3.41	19.58	5.28	11.46
A4	10.83	9.88	15.92	17.06	19.01	8.15	5.75	0.33	12.3	18.42
A5	14.55	9.81	8.72	17.21	10.11	4.46	9.67	4.86	6.73	16.03
A6	8.1	3.31	0.38	4.94	16.05	14.37	9.51	3.17	3.38	15.75
A7	11.32	5.96	8.45	19.3	13.46	18.66	18.87	13.84	9.21	1.66
A8	9.26	11.41	5.89	4.02	1.45	19.35	6.75	11.64	3.81	6.15
A9	5.97	8.4	15.25	8.94	4.42	11.36	15.07	8	8.8	13.83
A10	13.69	19.41	7.51	17	6.56	6.06	2.26	8.34	10.44	6.92
B1	3.45	0.84	15.47	14.61	16.69	1.4	12.86	1	2.13	13.96
B2	7.77	14.19	18.75	2.16	7.43	1.34	6.56	4.9	8.56	4.74
B3	4.09	17.28	14.48	17.1	6.6	18.91	3.68	0.25	18.2	3.33
B4	4.56	9.77	7.67	14.92	12.53	19.58	18.06	19.84	11.27	11.62
B5	10.55	1.75	18.22	15.57	8.77	14.21	16.29	3.09	6.59	15.3
B6	9.76	4.29	6.11	15.39	9.53	4.09	7.63	16.19	7.79	6.69
B7	10.67	0.54	15.04	18.22	2.08	16.81	15.81	7.1	5.71	11.66
B8	12.4	13.68	15.56	16.66	3.27	2.87	10.23	7.24	10.05	2.33
B9	6.84	19.47	19.8	2.93	13.02	18.97	12.37	19.26	12.36	3.46
B10	16.65	13.5	16.05	3.57	5.26	15.38	0.62	17.93	17.77	3.06

Based on the above theoretical approach, the research data of each evaluation index is processed without dimension, and the dimensionless results are shown in Table 3. It can be clearly seen that the data of each index is less than 1, which lays a theoretical foundation for the subsequent calculation of index weights.

Table 3. Dimensionless processing of research data of each evaluation index

Index	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
A1	1.00	0.33	0.95	0.97	0.52	0.77	0.67	0.58	0.00	0.79
A2	0.11	0.72	0.09	0.41	0.37	1.00	0.00	0.55	0.61	0.72
A3	0.41	0.03	0.62	0.12	0.09	0.00	0.08	1.00	0.19	0.54
A4	0.56	0.51	0.83	0.90	1.00	0.42	0.29	0.00	0.64	0.97
A5	0.79	0.42	0.33	1.00	0.44	0.00	0.41	0.03	0.18	0.91
A6	0.49	0.19	0.00	0.29	1.00	0.89	0.58	0.18	0.19	0.98
A7	0.55	0.24	0.38	1.00	0.67	0.96	0.98	0.69	0.43	0.00
A8	0.44	0.56	0.25	0.14	0.00	1.00	0.30	0.57	0.13	0.26
A9	0.14	0.37	1.00	0.42	0.00	0.64	0.98	0.33	0.40	0.87
A10	0.67	1.00	0.31	0.86	0.25	0.22	0.00	0.35	0.48	0.27
B1	0.16	0.00	0.92	0.87	1.00	0.04	0.76	0.01	0.08	0.83
B2	0.37	0.74	1.00	0.05	0.35	0.00	0.30	0.20	0.41	0.20
B3	0.21	0.91	0.76	0.90	0.34	1.00	0.18	0.00	0.96	0.17
B4	0.00	0.34	0.20	0.68	0.52	0.98	0.88	1.00	0.44	0.46
B5	0.53	0.00	1.00	0.84	0.43	0.76	0.88	0.08	0.29	0.82
B6	0.47	0.02	0.17	0.93	0.45	0.00	0.29	1.00	0.31	0.21
B7	0.57	0.00	0.82	1.00	0.09	0.92	0.86	0.37	0.29	0.63
B8	0.70	0.79	0.92	1.00	0.07	0.04	0.55	0.34	0.54	0.00
B9	0.23	0.98	1.00	0.00	0.60	0.95	0.56	0.97	0.56	0.03
B10	0.93	0.74	0.89	0.17	0.27	0.85	0.00	1.00	0.99	0.14

3.2. Numerical analysis of indicator weights

3.2.1. Weighting analysis of indicators for the international trade network subsystems. On the basis of the dimensionless processing of the indicators, the weight values of the 10 indicators in the international trade network subsystem are calculated using the calculation method mentioned above, and the results of the weights of the indicators of the international trade network subsystem are shown in Table 4. Based on the data in the table, it can be seen that the environmental sustainability index (A7: 0.0126) < attractiveness of foreign direct investment (A8: 0.0292) < proportion of trade in services (A6: 0.0491) < number of words of trade costs (A1: 0.0693) < trade facilitation index (A4: 0.1009) < participation in multilateral trade agreements (A10: 0.1077) < Supply Chain Diversity (A3: 0.1167) < Level of Digital Trade Development (A5: 0.1463) < Market Access Index (A2: 0.1701) < Technological Innovation Capacity (A9: 0.1981).

Table 4. Index weight results of international trade network subsystem

Subsystem	Symbol	Evaluation index	Symbol	Weight
International trade network optimization	A	Trade cost word count	A1	0.0693
		Market access index	A2	0.1701
		Supply chain diversity	A3	0.1167
		Trade facilitation index	A4	0.1009
		Digital trade development level	A5	0.1463
		Proportion of trade in services	A6	0.0491
		Environmental Sustainability Index	A7	0.0126
		Attractiveness of foreign direct investment	A8	0.0292
		Technological innovation ability	A9	0.1981
		Participation in multilateral trade agreements	A10	0.1077

3.2.2. Analysis of indicator weights for regional economic subsystems. Consistent with the above, the weight values of the 10 evaluation indicators in the regional economic subsystem are calculated, and the weight values of the indicators in the regional economic subsystem are shown in Table 5. According to the relationship between the weights, it can be concluded that the index of infrastructure connectivity (B7: 0.0126) < index of human capital development (B8: 0.0292) < index of policy coordination and consistency (B6: 0.0491) < index of economic growth rate (B1: 0.0693) < index of advanced industrial structure (B4: 0.1009) < index of environmental sustainability (B10: 0.1077) <Income inequality index (B3: 0.1167) <Accessibility of financial services (B5: 0.1463) <Employment rate (B2: 0.1701) <Social stability index (B9: 0.1981).

Table 5. Regional economic subsystem index weight value

Subsystem	Symbol	Evaluation index	Symbol	Weight
International trade network optimization	B	Trade cost word count	B1	0.0693
		Market access index	B2	0.1701
		Supply chain diversity	B3	0.1167
		Trade facilitation index	B4	0.1009
		Digital trade development level	B5	0.1463
		Proportion of trade in services	B6	0.0491
		Environmental Sustainability Index	B7	0.0126
		Attractiveness of foreign direct investment	B8	0.0292
		Technological innovation ability	B9	0.1981
		Participation in multilateral trade agreements	B10	0.1077

3.3. Coupling synergies

Under the premise of knowing the weights of the indicators of the two subsystems, for the traditional coupling coordination degree calculation is prone to similar high, low precision and other problems, in this regard, it is proposed to use the differential evolution method for international trade network optimization and regional economic coupling synergies to calculate the coupling degree of the two subsystems, the coupling degree of the two subsystems is shown in Table 6, where C indicates the degree of coupling, T indicates the degree of synergy, and D indicates the degree of coupling synergies, 0<D < 0.1 indicates extreme dissonance, 0.1<D<0.2 indicates severe dissonance, 0.2<D<0.3 indicates moderate dissonance, 0.3<D<0.4 indicates mild dissonance, 0.4<D<0.5 indicates on the verge of dissonance, 0.5<D<0.6 indicates barely coordinated, 0.6<D<0.7 indicates primary coordinated, 0.7<D<0.8 indicates intermediate coordinated, 0.8<D< 0.9 indicates good coordination, and 0.9<D<1.0 indicates quality coordination. It can be clearly seen that international trade network optimization and regional economy show intermediate coordination during the period of 2014~2016, with the progress of science and technology, both of them show good coordination level during the period of 2017~2021, and finally international trade network optimization and regional economy show high quality coordination level during the period of 2022~2023 to achieve the goal of common development of both of them, and this paper accurately reflects the then international trade network optimization and regional economic development, verifying the effectiveness of the model of this paper.

Table 6. The result of coupling coordination degree of two subsystems

Year	C	T	D	Coordination level
2014	0.803	0.623	0.707	Intermediate coordination
2015	0.811	0.647	0.724	Intermediate coordination
2016	0.812	0.673	0.739	Intermediate coordination
2017	0.815	0.801	0.808	Good coordination
2018	0.816	0.809	0.812	Good coordination
2019	0.842	0.822	0.832	Good coordination
2020	0.843	0.829	0.836	Good coordination
2021	0.902	0.844	0.873	Good coordination
2022	0.909	0.908	0.908	Quality coordination
2023	0.927	0.977	0.952	Quality coordination

4. Conclusion

In this paper, on the principle of the construction of evaluation index system, the evaluation index system is constructed and divided into two main subsystems, which are the international trade network optimization subsystem and the regional economy subsystem. The entropy weight method is used to calculate the weight value of each evaluation index, and then the evolutionary algorithm is used to define the calculation formula of the coupling synergy degree and finally complete the design of the synergy model. Based on the initial data of each evaluation index from 2014 to 2023, the model of this paper is empirically analyzed. During the period of 2014~2016, the synergy level of international trade network optimization and regional economy is medium, with the development of science and technology, the synergy level of the two rises to good in the period of 2017~2021, and when the technology becomes more and more mature, the international trade network optimization and regional economy show a high-quality level of coordination in the period of 2022~2023, which indicates that the situation described by this paper's model and the reality of the development situation coincide, confirming the practical application effect of the synergy model in this paper.

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