Research Article

Measurement of Coordination Degree between Economy and Logistics in Hebei Province, China, Based on Fractional Grey Model (1, 1)

Na Zhou, Juan Tan, Xiangyang Ren, and Xinxin Jiang

School of Management Engineering and Business, Hebei University of Engineering, Handan 056000, China

Correspondence should be addressed to Xiangyang Ren; xiangyangren@hebeu.edu.cn

Received 27 January 2022; Revised 17 February 2022; Accepted 18 February 2022; Published 12 March 2022

Academic Editor: Gengxin Sun

Copyright © 2022 Na Zhou et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Modern logistics is the supporting industry of the national economy. The synergy between logistics and economy has been highlighted in northern China’s Hebei Province. This study measures the coordination degree between economy and logistics in Hebei, drawing on the grey system theory. Specifically, the entropy weight-grey correlation method was introduced to evaluate the interplay between economic and logistics factors in Hebei between 2011 and 2020. The evaluation suggests that private car ownership has the most significant correlation with the economy and that the total retail sales of social consumer goods are the leading impactor of logistics. Next, the fractional grey model (FGM) (1, 1) was employed to forecast the economic and logistics indices of Hebei in the next five years. The forecast results show that FGM (1, 1) achieved a higher prediction precision than the conventional GM (1, 1) and discrete grey model (DGM) (1, 1). Based on the original data and forecasted results, the coupling coordination degree (CCD) model was adopted to compute the CCD between the economy and logistics in Hebei during 2011–2025. It was calculated that the coupling coordination exhibited a continuous upward trend. From 2011 to 2025, the CCD between economy and logistics in Hebei evolves from moderate incoordination, mild incoordination, weak incoordination, and weak coordination, all the way to moderate coordination. In the light of the analysis results, several suggestions were presented to promote the coordinated development between economy and logistics in Hebei.

1. Introduction

The regional logistics system depends on the level of economic development of the region and develops gradually into a new growth point of regional economy. The system not only bridges up production with consumption but also links various production sectors in the region, enabling an uninterrupted exchange of materials and information. To stimulate economic growth, it is important to expand the portion of logistics in the industrial structure, clarify the positioning of the logistics industry, and improve the quality of modern logistics, supply chain management, and distribution services.

The emergence of modern logistics is closely associated with economic growth. Kim et al. [1] compared the logistics levels of five South Korean port cities and demonstrated that the logistics industry boosts regional employment and creates trade added value, which in turn stimulates the regional economy. Lan and Tseng applied the entropy method to objectively determine indicators’ weights to precisely evaluate the development level of metropolitan economy and logistics [2]. Through big data analysis (BDA), Yang et al. [3] used the Haken model to quantify the economy-logistics interaction in five cities across China, and the results showed that the economic development is an order parameter and played a key role in the coordinated development of metropolitan logistics and economy. Ma et al. [4] studied how logistics affected international trade by using the entropy method, and empirical results presented that logistics development level had significantly promoted international trade development; in addition, compared with partner countries, China’s provincial logistics development level presented a greater impact on bilateral trade.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2022, Article ID 9539940, 12 pages
https://doi.org/10.1155/2022/9539940
By reviewing the previous literature, it is found that logistics and economic development are closely related and promote each other. However, scholars mainly focused on the relationship between logistics and economy based on historic data or statistical analysis, and few considered the future coordination development through a scientific prediction approach. Therefore, the entropy weight-grey relational model and fractional grey model (FGM) (1, 1) are employed in this study to calculate the coupling coordination degree between economy and logistics in Hebei Province.

As an objective weight defining, the entropy weight method determines the weight of each index according to the uncertainty of the information from each index. The higher the weight is, the larger degree of disorder and the greater the impact of the index on its subsystem [5]. Grey correlation analysis is a flexible method in measuring the similarity of the shape of the curve and can reflect the nonlinear relationship between sequences, so as to achieve the effect of hardness and softness [6]. The application of entropy weight-grey correlation method can effectively obtain the importance of affecting factors of the system under consideration and provide scientific guidance for further optimization of the system [7]. Actually, the entropy weight-grey correlation model has proved its rationality in analyzing correlation degree [8–10].

In 1982, Deng [11] invented grey theory, providing an innovative way to analyze small batches of low-quality uncertain data. The theory has inspired a series of innovative analysis tools. Over the years, Deng’s relational analysis has been extended to absolute and relative correlation analysis and then to the similarity- and proximity-based grey relational analysis (GRA), which is a popular analysis tool nowadays [12]. The GRA has been successfully implemented in many areas. For example, Kose et al. [13] identified the most livable Turkish city through the GRA. With the help of a GRA model, Peng et al. [14] enumerated the health resources that satisfy the public in China.

The grey prediction theory has been modified and bettered continuously. One of the most important branches is the fractional-order grey prediction theory. For instance, Wu et al. [15] relied on fractional-order accumulation to build a novel model for the grey system. The model can effectively reflect the priority of new information, when the accumulation order is relatively small. Grey prediction models have been applied to forecast many things, including oil/gas consumption, air quality, and confirmed cases of infectious diseases [16–19].

Therefore, on reviewing previous literature, this study introduces the entropy weight-grey relational model to examine the data on economy and logistics in northern China’s Hebei Province from 2011 to 2020 and identified the key mutual impactors between the economic system and the logistics system. Then, the fractional grey model (FGM) (1, 1) was employed to forecast the economic and logistics indices in the next five years. Compared with the conventional GM (1, 1) and discrete grey model (DGM) (1, 1), the FGM (1, 1) achieved a relatively high forecast accuracy and close-to-reality fitting values. On this basis, the coupling coordination degree (CCD) model was called to compute the CCD between economy and logistics in Hebei from 2011 to 2015. Overall, the research value of this study is that it assists in realising the coordinated development of logistics and economy in Hebei Province and provides a scientific basis and countermeasures for corporate and government decision-makers.

2. Methodology

2.1. Entropy Weight-Grey Relational Model

2.1.1. Entropy Weight Method. Before the GRA, it is important to assign a proper weight to each index of economy and logistics. To eliminate the impact of subjective factors, the entropy weight method was employed to calculate the index weight of economy and logistics in Hebei Province from 2011 to 2020.

Firstly, the original data of each index is normalized by the following equation:

\[ \bar{x}_{ij} = \frac{x_{ij} - \min \{x_{1j}, x_{2j}, \ldots, x_{nj}\}}{\max \{x_{1j}, x_{2j}, \ldots, x_{nj}\} - \min \{x_{1j}, x_{2j}, \ldots, x_{nj}\}} \]  

(1)

Then, the index value after standardization is transformed to \( p_{ij} = \bar{x}_{ij}/\sum_{m} \bar{x}_{ij} \), and we take matrix \( P = (p_{ij})_{m \times n} \) as the normalized value.

After that, the entropy value of each index \( e_j \) is calculated by the following equation:

\[ e_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij}, \quad j = 1, 2, \ldots, n, \text{ where } k = \frac{1}{\ln m} \]  

(2)

At last, the entropy weight is calculated by the following equation:

\[ W_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)}, \quad j = 1, 2, \ldots, n. \]  

(3)

2.1.2. Weighted-Grey Correlation Degree. Given the interplay between economy and logistics in Hebei, the GRA was selected to evaluate the correlation degree between each economic index and the logistics system and between each logistics index and the economic system, making it possible to identify the leading impactors of the economy and logistics in Hebei.

The correlation degree reflects the collaborative variation of economic and logistics indices in Hebei. The closer the grey correlation degree is to 1, the greater the correlation degree between economy and logistics. The inverse is also true.

Firstly, the grey correlation coefficient is calculated by the following equation:

\[ \zeta_{ij}(t) = \frac{\min_{t} \{Y_j(t) - X_i(t)\} + \rho \max_{t} \{Y_j(t) - X_i(t)\}}{\max_{t} \{Y_j(t) - X_i(t)\} + \rho \max_{t} \{Y_j(t) - X_i(t)\}}, \]  

(4)
where \( t \) is year; \( X_i(t) \) and \( Y_j(t) \) are the mean normalized values of logistics index \( i \) and economic index \( j \) in year \( t \), respectively; \( \rho = 0.5 \) is the resolution coefficient.

Secondly, the original grey correlation degree is calculated by the following equation:

\[
R_{ij}(t) = 1 - \frac{1}{P} \sum_{i=1}^{P} \zeta_{ij}(t). \tag{5}
\]

Finally, the weighted-grey correlation degree is calculated by the following equation:

\[
r_{ij}(t) = \sum_{j=1}^{m} \sum_{j=1}^{m} W_j \cdot R_{ij}(t), \tag{6}
\]

where \( W_j \) is the weight of each index calculated by the entropy weight method.

The levels of correlation degree are given in Table 1.

### 2.2. Construction of Grey Prediction Model

FGM (1, 1), GM (1, 1), as the basic grey prediction model, is only suitable for long-term forecasting based on large stable data. To overcome the deficiency of GM (1, 1), the FGM (1, 1) reduces prediction error through fractional-order accumulation.

**Definition 1.** Let \( X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)) \), \( r \in \mathbb{R}^{+} \), be the original nonnegative series, and \( X^{(r)} = (x^{(r)}(1), x^{(r)}(2), \ldots, x^{(r)}(n)) \) be the \( r \)-order cumulative generating series of the original series. If \( C^{0}_{r-1} = 1 \) and \( C^{k}_{k-1} = 0 \), then \( X^{(r)}(k) = \sum_{i=1}^{k} C^{i-k}_{k-1} x^{(r)}(i) \), where \( C^{i-k}_{k-1} = (k-i+r-1)(k-i+r-2)\cdots(r+1)r/(k-i)! \) \((k=1,2,\ldots,n)\). The nearest mean generating series of \( X^{(r)}(t) \) is

\[
\bar{x}^{(0)}(1) = x^{(0)}(1),
\]

\[
\bar{x}^{(0)}(k) = \sum_{i=1}^{k} C^{i-k}_{k-1} \bar{x}^{(r)}(k) - \sum_{i=1}^{k} C^{i-k}_{k-1} \bar{x}^{(r)}(k-1)
\]

\[
= \sum_{i=1}^{k} C^{i-k}_{k-1} \bar{x}^{(r)}(k) - \sum_{i=1}^{k-1} C^{i-k}_{k-1} \bar{x}^{(r)}(k-1) \quad (k = 2, 3, \ldots, n). \tag{10}
\]

The performance of the FGM (1, 1) can be measured by the mean absolute percentage error (MAPE):

\[
MAPE = \frac{1}{n} \times \sum_{k=1}^{n} \frac{|x^{(0)}(k) - \bar{x}^{(0)}(k-1)|}{x^{(0)}(k)} \times 100%. \tag{11}
\]

When \( r = 1 \), the FGM (1, 1) expresses the same meaning as the GM (1, 1).

DGM (1, 1). To verify its prediction accuracy, the FGM (1, 1) was compared with the conventional GM (1, 1), and the DGM (1, 1). The latter can be established as follows:

Let \( X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)) \) be a nonnegative series, and \( X^{(1)} = (x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n)) \) be the 1-accumulating generation operator (1-AGO). Then, \( x^{(1)}(k+1) = \beta_1 x^{(1)}(k) + \beta_2 \) is called the DGM (1, 1).

If \( \bar{\beta} = (\beta_1, \beta_2)^T \) is a reference series, then

\[
Y = \begin{bmatrix} X^{(1)}(2) \\ X^{(1)}(3) \\ \vdots \\ X^{(1)}(n) \end{bmatrix},
\]

\[
B = \begin{bmatrix} X^{(1)}(1) & 1 \\ X^{(1)}(2) & 1 \\ \vdots & \vdots \\ X^{(1)}(n-1) & 1 \end{bmatrix}. \tag{12}
\]

Then, the column of least square estimates of the DGM (1, 1) \( x^{(1)}(k+1) = \beta_1 x^{(1)}(k) + \beta_2 \) satisfies the following equation:
Discrete Dynamics in Nature and Society

Table 1: Levels of correlation degree.

| Level       | Weak | Moderate | Strong | Extremely strong |
|-------------|------|----------|--------|------------------|
| Correlation degree | $0 < r \leq 0.35$ | $0.35 < r \leq 0.65$ | $0.65 < r \leq 0.85$ | $0.85 < r \leq 1$ |

$$\hat{\beta} = (\beta_1, \beta_2)^T = (B^T B)^{-1} B^T Y.$$ (13)

Suppose $x^{(1)}(1) = x^{(0)}(1)$, then the recursive function can be expressed as follows:

$$\tilde{x}^{(1)}(k + 1) = \beta_1 \tilde{x}^{(1)}(1) + \frac{1 - \beta_1}{1 - \beta_1} \beta_2, k = 1, 2, \ldots, n - 1.$$ (14)

The restored value is as follows:

$$\tilde{x}^{(0)}(k + 1) = \tilde{x}^{(1)}(k + 1) - \tilde{x}^{(1)}(k) = (\beta_1 - 1) \left( x^{(0)}(1) - \frac{\beta_2}{1 - \beta_1} \right) \beta_1^k, k = 1, 2, \ldots, n - 1.$$ (15)

The performance of the DGM (1, 1) can also be measured by MAPE:

$$MAPE = \frac{1}{n} \times \sum_{k=1}^{n} \frac{\tilde{x}^{(0)}(k) - \tilde{x}^{(0)}(k - 1)}{x^{(0)}(k)} \times 100\%.$$ (16)

2.3. CCD Model

2.3.1. Composite Level of Economy and Logistics. The composite level $U_{log}$ of regional logistics and that $U_{eco}$ of regional economy can be respectively calculated by the following equations:

$$U_{log} = \sum_{j=1}^{n} w_{log} X_{ij},$$ (17)

$$U_{eco} = \sum_{j=1}^{n} w_{eco} X_{ij},$$ (18)

where $W_{log}$ and $W_{eco}$ are the index weights of logistics and economy obtained by entropy weight method, respectively; $X_{ij}$ is the normalized value of each index.

2.3.2. Calculation of CCD. The coupling degree $C$, which reflects the degree of interplay between regional economy and regional logistics, can be calculated by the following equation:

$$C = \sqrt{\frac{U_{log} \times U_{eco}}{(U_{log} + U_{eco})^2}}.$$ (19)

The composite coordination index $T$, which reflects the composite level of regional economy and regional logistics, can be calculated by the following equation:

$$T = \alpha U_{log} + \beta U_{eco},$$ (20)

where $\alpha$ and $\beta$ are undetermined coefficients. Assuming that regional logistics and regional economy are equally important in coordinated development, the values of both $\alpha$ and $\beta$ were set to 0.50.

The CCD $D$ can be calculated by the following equation:

$$D = \sqrt{C \times T}.$$ (21)

Table 2 lists the stages of coupling degree $C$ between regional logistics and regional economy. Table 3 lists the different levels of CCD.

3. Empirical Analysis

3.1. Evaluation Index System (EIS). There exists a large amount of literature analyzing the key factors on the coordination development between logistics and economy. Lan and Zhong found that factors like the accessibility of logistics network, logistics infrastructure investment, and logistics cost mainly affected logistics system, and the key factors to economic system were economic aggregate, technological development level, and level of fiscal revenue [20]. Wenjing considered indicators like state of economic development, logistics scale, and information construction into the logistics economy subsystem to study the logistics industry with ecological environment [21]. Yang et al. analyzed the coordinated development path between economy and logistics in large cities along the Belt and Road and found that logistics equipment level, logistics speed/costs, and logistics industrial development were paths to develop metropolitan logistics and economy [22].

Consequently, by considering existing research literature and referring to relevant policy documents of Hebei Province on logistics and economy construction, the factors affecting the coupling coordination degree of logistics and economy in Hebei Province in this work are determined as listed in Table 4.

The EIS of logistics subsystem consists of three parts as follows: logistics demand, logistics supply capacity, and sustainability of logistics. Logistics demand reflects the needs of economic production activities, mainly including cargo turnover, cargo throughput at coastal ports, and a total output of post and telecommunications. Logistics supply capacity indicates the ability of logistics system to provide effective services such as transportation, storage, packaging, and logistics information. The sustainability of logistics is the key factor of regional logistics development. The EIS of economy subsystem includes another three aspects as follows: regional economic aggregate, regional social reproduction level, and regional economic benefits. Added value of tertiary industry, GDP, and public budget revenue well reflect the regional economic development. Regional social
reproduction level measures the ability of social wealth appreciation. Regional economic benefits imply the utilization effect of human, material, and financial resources in various aspects of social reproduction.

### 3.2. Original Data
The original data on the economic and logistics indices (Table 4) were extracted from Hebei Economic Yearbooks (2011–2020), Statistical Bulletin on National Economic and Social Development of Hebei Province (2011–2020), and Hebei Provincial Bureau of Statistics (2011–2020). Tables 5 and 6 present the original data on logistics indices and economic indices, respectively.

| Primary indices | Secondary indices | Tertiary indices | Signs |
|-----------------|-------------------|-----------------|-------|
| Logistics       | Logistics demand  | Cargo turnover (108 ton-km) | X1    |
|                 | Logistics supply capacity | Cargo throughput at coastal ports (108 tons) | X2 |
|                 | Logistics sustainability | Total output of post and telecommunications (108 yuan) | X3 |
|                 |                    | Highway mileage (km) | X4 |
|                 |                    | Private car ownership (104 vehicles) | X5 |
|                 |                    | Fixed asset investment in transportation, warehousing, and postal services (108 yuan) | X6 |
| Economy         | Regional economic aggregate | Added value of transportation, warehousing, and postal services (108 yuan) | X7 |
|                 | Regional social reproduction level | Added value of tertiary industry (108 yuan) | Y1 |
|                 |                    | Gross domestic product (GDP) (108 yuan) | Y2 |
|                 |                    | Public budget revenue (108 yuan) | Y3 |
|                 |                    | Social fixed asset investment (108 yuan) | Y4 |
|                 |                    | Per capita disposable income of urban residents (104 yuan) | Y5 |
|                 |                    | Total import and export trade (108 yuan) | Y6 |
|                 |                    | Total retail sales of social consumer goods (108 yuan) | Y7 |

### 3.3. Weighted-Grey Correlation Degree
The weighted-grey correlation degrees of logistics indices to economic system and economic indices to logistics system are summarized in Tables 7 and 8, respectively.

As listed in Table 8, the weighted correlation degrees of three logistics indices, namely, X4, X5, and X6, to economic system fell in the range of 0.65–0.85, a sign of strong correlation. Meanwhile, the weighted correlation degrees of the other logistics indices to economic system fell between 0.35 and 0.65, a signal of moderate correlation.

The relevance between economy and logistics in Hebei is detailed below:

1. **Influence of logistics factors on economy.** According to formula (6) and Table 7, the logistics indices can be ranked in descending order by their effects on economy as follows: X5, X4, X6, X2, X1, X4, and X7. The highest weighted correlation degree appeared between X5 and economy (0.8161), indicating the strong correlation between private car ownership (X5) and economic development. This is because private car ownership (X5) is closely associated with the annual disposable income of ordinary people, an indicator of economic development level. The second highest value was observed between X5 and economy (0.7627). The thriving post and telecommunications business has a pulling effect on the regional economy in Hebei, and the postal services stimulate online spending and the virtual economy, which accounts for a large portion of regional economy.
Influence of economic factors on logistics. According to formula (6) and Table 8, the economic indices can be ranked in descending order by their effect on logistics as follows: $Y_7, Y_3, Y_1, Y_5, Y_4, Y_2,$ and $Y_6$. The highest weighted correlation degree appeared between $Y_7$ and logistics (0.6978). The reason is that the sales of social consumer goods involve numerous logistics operations, such as packaging, loading/unloading, transportation, and distribution. The higher the total retail sales, the more chances for the region to develop its logistics industry. The second highest value was found between $Y_3$ and logistics system (0.6809), which reflects the strong correlation between the two. The growth of public budget revenue ($Y_3$) provides stronger technical support and financial guarantee for the development of the logistics industry, especially the intelligent logistics system.

### Table 5: Original data on logistics indices.

| Year | X1   | X2   | X3   | X4   | X5   | X6   | X7   |
|------|------|------|------|------|------|------|------|
| 2011 | 9840.5 | 7.1 | 537.56 | 156965 | 832.5 | 2046.2 | 1399.1 |
| 2012 | 10844.84 | 7.6 | 572.69 | 163045 | 957.6 | 2241.1 | 1513 |
| 2013 | 12003.78 | 8.9 | 728.74 | 174492 | 1035.6 | 2377.6 | 2094.3 |
| 2014 | 12968.8 | 9.5 | 825.54 | 179200 | 997 | 2490.1 | 2025.9 |
| 2015 | 12024.94 | 9.1 | 998 | 184553 | 1137.1 | 2479.9 | 2035.7 |
| 2016 | 12339.25 | 9.5 | 1545.2 | 188431 | 1291.7 | 2403 | 2081.3 |
| 2017 | 13383.62 | 10.9 | 1364.5 | 197000 | 1666.7 | 2916 | 2646.43 |
| 2018 | 13876.71 | 11.6 | 3165.4 | 193252 | 1552.5 | 2560.7 | 2581.89 |
| 2019 | 14179.5 | 11.6 | 5300.2 | 197000 | 1666.7 | 2916 | 2646.43 |
| 2020 | 13735.5 | 12 | 6827.1 | 205000 | 1763.1 | 2890.6 | 3048.69 |

### Table 6: Original data on economic indices.

| Year | Y1   | Y2   | Y3   | Y4   | Y5   | Y6   | Y7   |
|------|------|------|------|------|------|------|------|
| 2011 | 8224.4 | 24228.2 | 1737.4 | 16404.3 | 18292.23 | 3461.9 | 8035.5 |
| 2012 | 9387.326575 | 2084.2 | 19661.3 | 20543.44 | 3190.96 | 9154 |
| 2013 | 10038.9 | 28301.4 | 2293.5 | 23194.2 | 22226.75 | 3398.83 | 10516.7 |
| 2014 | 10953.5 | 29421.2 | 2446.6 | 26671.9 | 24141.34 | 3678.3 | 11690.1 |
| 2015 | 11978.7 | 29806.1 | 2648.5 | 29448.3 | 26152.16 | 3206.38 | 12934.7 |
| 2016 | 13276.6 | 31827.9 | 2850.8 | 31750 | 28249.39 | 3074.7 | 14364.7 |
| 2017 | 15039.6 | 35964 | 3233.3 | 33406.8 | 30547.76 | 3375.8 | 15907.6 |
| 2018 | 16632.2 | 36010.3 | 3513.7 | 35310.99 | 32977.18 | 3551.6 | 16537.1 |
| 2019 | 17988.8 | 35104.5 | 3742.7 | 37464.96 | 35738 | 4001.6 | 17934.2 |
| 2020 | 18729.6 | 36206.9 | 3826.4 | 38551.44 | 37286 | 4410.4 | 12705 |

### Table 7: Weighted-grey correlation degrees of logistics indices to economic system.

| X1  | X2  | X3  | X4  | X5  | X6  | X7  | Weight | Weighted correlation degree | Ranking |
|-----|-----|-----|-----|-----|-----|-----|--------|-----------------------------|--------|
| Y1  | 0.8522 | 0.9016 | 0.6296 | 0.8356 | 0.9651 | 0.8384 | 0.9215 | 0.2158 | 0.6796 | 3 |
| Y2  | 0.9621 | 0.9602 | 0.6169 | 0.9486 | 0.9094 | 0.9425 | 0.9155 | 0.0531 | 0.6703 | 6 |
| Y3  | 0.8763 | 0.9267 | 0.6285 | 0.8601 | 0.9708 | 0.8635 | 0.9289 | 0.1786 | 0.6809 | 2 |
| Y4  | 0.8701 | 0.915 | 0.6254 | 0.8686 | 0.9359 | 0.866 | 0.921 | 0.1932 | 0.6755 | 5 |
| Y5  | 0.891 | 0.9387 | 0.6212 | 0.8775 | 0.9719 | 0.8771 | 0.9403 | 0.1510 | 0.6763 | 4 |
| Y6  | 0.9279 | 0.9048 | 0.6042 | 0.9244 | 0.8848 | 0.9435 | 0.8885 | 0.0350 | 0.6524 | 7 |
| Y7  | 0.8823 | 0.9023 | 0.6552 | 0.8765 | 0.9196 | 0.8703 | 0.8981 | 0.1733 | 0.6978 | 1 |

### Table 8: Weighted-grey correlation degrees of economic indices to logistics system.

| Y1  | Y2  | Y3  | Y4  | Y5  | Y6  | Y7  | Weight | Weighted correlation degree | Ranking |
|-----|-----|-----|-----|-----|-----|-----|--------|-----------------------------|--------|
| X1  | 0.5501 | 0.8128 | 0.5884 | 0.5545 | 0.6236 | 0.7277 | 0.5409 | 0.0122 | 0.5875 | 5 |
| X2  | 0.6206 | 0.7748 | 0.683 | 0.6263 | 0.725 | 0.6142 | 0.5497 | 0.0294 | 0.6443 | 4 |
| X3  | 0.7795 | 0.73 | 0.7692 | 0.7612 | 0.7613 | 0.7291 | 0.7544 | 0.8279 | 0.7627 | 2 |
| X4  | 0.5108 | 0.7574 | 0.5471 | 0.5715 | 0.5902 | 0.6992 | 0.5454 | 0.0066 | 0.5667 | 6 |
| X5  | 0.874 | 0.7019 | 0.8912 | 0.7773 | 0.8949 | 0.5753 | 0.725 | 0.0618 | 0.8161 | 1 |
| X6  | 0.461 | 0.7001 | 0.4991 | 0.5075 | 0.5236 | 0.7305 | 0.4841 | 0.0107 | 0.5124 | 7 |
| X7  | 0.7748 | 0.7321 | 0.7769 | 0.7511 | 0.8097 | 0.6812 | 0.6869 | 0.0515 | 0.7551 | 3 |
Table 9: Fitting values and errors of economic and logistic indices.

| Year | Origin | GM (1, 1) | DGM (1, 1) | FGM (1, 1) | Origin | GM (1, 1) | DGM (1, 1) | FGM (1, 1) | Origin | GM (1, 1) | DGM (1, 1) | FGM (1, 1) |
|------|--------|-----------|------------|------------|--------|-----------|------------|------------|--------|-----------|------------|------------|
| 2011 | 9840.5 | 9840.5    | 9840.5     | 9840.5     | 7.1    | 7.10      | 7.10       | 7.10       | 1      | 0.7936    | 3.529      | 3.530      |
| 2012 | 10844.84 | 11459.98  | 11466.12   | 10844.84   | 7.6    | 8.11      | 8.12       | 7.60       | 1      | 0.3858    | 45.57      | 39.15      |
| 2013 | 12003.78 | 11777.87  | 11782.93   | 11718.3    | 8.9    | 8.54      | 8.55       | 8.44       | 1      | 0.00022   | 3.09       | 3.062      |
| 2014 | 12339.25 | 12785.44  | 12786.87   | 13133.33   | 9.5    | 9.99      | 9.99       | 10.27      | 1      | 0.9842    | 3.263      | 3.264      |
| 2015 | 13383.62 | 13140.1   | 13140.17   | 13378.83   | 10.9   | 10.52     | 10.52      | 11.75      | 1      | 0.9999    | 3.247      | 3.247      |

Discrete Dynamics in Nature and Society
### Table 9: Continued.

| Year | Origin | GM (1, 1) | DGM (1, 1) | FGM (1, 1) | Order | MAPE (%) |
|------|--------|----------|-----------|-----------|-------|----------|
| 2011 | 24228.2 | 24228.20 | 24228.20 | 1737.4 | 2.677 |
| 2012 | 26575 | 27244.98 | 27261.88 | 26305.15 | 2.696 |
| 2013 | 31827.9 | 31974.11 | 32055.97 | 3280.8 | 2.388 |
| 2014 | 35964 | 33270.41 | 33274.31 | 33641.96 | 1.991 |
| 2015 | 36010.3 | 34626.81 | 34627.39 | 34648.75 | 1.906 |
| 2016 | 35104.5 | 36038.50 | 36035.49 | 35541.05 | 1.322 |
| 2017 | 36206.9 | 37507.76 | 37500.85 | 3826.4 | 0.9588 |

| Year | Origin | GM (1, 1) | DGM (1, 1) | FGM (1, 1) | Order | MAPE (%) |
|------|--------|----------|-----------|-----------|-------|----------|
| 2011 | 16404.3 | 16404.3 | 16404.3 | 18292.23 | 4.466 |
| 2012 | 19661.3 | 22432.75 | 22462.54 | 22803.64 | 4.461 |
| 2013 | 23194.2 | 24144.8 | 24173.61 | 24189.65 | 0.581 |
| 2014 | 26671.9 | 27907.83 | 27996.83 | 2725.27 | 0.892 |
| 2015 | 31750 | 30105.54 | 30129.3 | 3074.89 | 0.882 |
| 2016 | 33406.8 | 32403.15 | 32424.37 | 3274.62 | 0.613 |
| 2017 | 35310.99 | 34876.13 | 34894.27 | 3301.09 | 0.9655 |
| 2018 | 37464.96 | 37537.83 | 37552.31 | 3718.79 | 0.466 |
| 2019 | 38551.44 | 40402.67 | 40412.82 | 4053.8 | 0.0488 |
| 2020 | 39515.75 | 41767.64 | 41780.92 | 4198.3 | 0.1707 |

### Table 10: Predicted values of logistics indices.

| Year | X1 | X2 | X3 | X4 | X5 | X6 | X7 |
|------|----|----|----|----|----|----|----|
| 2021 | 13979.57 | 12.36 | 10038.54 | 203814.11 | 1895.91 | 2917.90 | 3279.71 |
| 2022 | 14054.52 | 12.71 | 14779.85 | 205979.49 | 2034.15 | 2998.72 | 3565.33 |
| 2023 | 14108.85 | 13.05 | 21778.62 | 207975.91 | 2179.41 | 3081.43 | 3874.03 |
| 2024 | 14145.54 | 13.38 | 32108.67 | 209827.40 | 2332.05 | 3166.10 | 4207.63 |
| 2025 | 14166.99 | 13.70 | 47354.75 | 211553.10 | 2492.42 | 3252.83 | 4568.13 |

### Table 11: Predicted values of economic indices.

| Year | Y1 | Y2 | Y3 | Y4 | Y5 | Y6 | Y7 |
|------|----|----|----|----|----|----|----|
| 2021 | 21196.43 | 23073.23 | 2459.59 | 39818.38 | 40682.43 | 5907.13 | 14857.07 |
| 2022 | 23233.76 | 27653.89 | 4588.95 | 40905.95 | 43716.34 | 6128.23 | 14899.88 |
| 2023 | 25466.91 | 38204.39 | 4942.51 | 41857.37 | 46966.48 | 7670.49 | 14904.16 |
| 2024 | 27914.69 | 38692.29 | 5322.20 | 42687.20 | 50449.43 | 9972.82 | 14878.68 |
| 2025 | 30597.75 | 39124.69 | 5730.07 | 43408.13 | 54182.80 | 13405.83 | 14830.46 |
| Year | Coupling degree C | Coupling stage | Composite level of logistics | Composite level of economy | Composite level T | CCD D | CCD level |
|------|------------------|----------------|----------------------------|---------------------------|-------------------|-------|-----------|
| 2011 | 0.7740           | Running-in     | 0.0151                     | 0.0672                    | 0.0823            | 0.2524| Moderate incoordination |
| 2012 | 0.7806           | Running-in     | 0.0165                     | 0.0716                    | 0.0881            | 0.2623| Moderate incoordination |
| 2013 | 0.8068           | High           | 0.0201                     | 0.0780                    | 0.0981            | 0.2813| Moderate incoordination |
| 2014 | 0.7923           | Running-in     | 0.0206                     | 0.0850                    | 0.1055            | 0.2892| Moderate incoordination |
| 2015 | 0.8066           | High           | 0.0222                     | 0.0865                    | 0.1087            | 0.2962| Moderate incoordination |
| 2016 | 0.8375           | High           | 0.0267                     | 0.0911                    | 0.1178            | 0.3141| Mild incoordination     |
| 2017 | 0.8138           | High           | 0.0267                     | 0.1007                    | 0.1273            | 0.3219| Mild incoordination     |
| 2018 | 0.8914           | High           | 0.0406                     | 0.1078                    | 0.1483            | 0.3636| Mild incoordination     |
| 2019 | 0.9338           | High           | 0.0553                     | 0.1169                    | 0.1722            | 0.4010| Weak incoordination     |
| 2020 | 0.9587           | High           | 0.0669                     | 0.1200                    | 0.1869            | 0.4233| Weak incoordination     |
| 2021 | 0.9794           | High           | 0.0891                     | 0.1341                    | 0.2231            | 0.4675| Weak incoordination     |
| 2022 | 0.9950           | High           | 0.1213                     | 0.1482                    | 0.2696            | 0.5179| Weak coordination       |
| 2023 | 0.9999           | High           | 0.1683                     | 0.1667                    | 0.3350            | 0.5788| Weak coordination       |
| 2024 | 0.9943           | High           | 0.2370                     | 0.1912                    | 0.4282            | 0.6525| Mild coordination       |
| 2025 | 0.9797           | High           | 0.3376                     | 0.2248                    | 0.5623            | 0.7422| Moderate coordination   |

**Figure 1:** Composite levels of economic and logistics development.

**Figure 2:** Coupling degree, composite level, and CCD of economy and logistics.
3.4. Forecast. To predict the coordinated development between economy and logistics in Hebei in the next five years, this study imports the original data on economic and logistics indices of 2011–2020 into the FGM (1, 1) and compares the prediction results with those of conventional GM (1, 1) and DGM (1, 1).

The optimal order of each index was solved through particle swarm optimization (PSO) on MATLAB. Table 9 lists the fitting values and errors of all indices.

As listed in Table 9, the MAPEs of the conventional GM (1, 1), the DGM (1, 1), and the FGM (1, 1) all met the requirements. The FGM (1, 1) achieved the minimum MAPEs among the three prediction models. That is, our model boasts the best prediction accuracy and effect. In addition, the FGM (1, 1) fitted values closer to the actual values than the two contrastive models. Therefore, it is reasonable to use the FGM (1, 1) to predict the future indices of economy and logistics in Hebei. The prediction results of our model are recorded in Tables 10 and 11.

3.5. CCD. The CCD is originally a term in physics. In the realm of system coordination, the term describes the interplay, mutual promotion, and collaborative evolution between two or more independent systems with different properties within a large open system [23]. Based on Tables 10 and 11, the CCDs between economy and logistics in Hebei were solved by the CCD model. The results are recorded in Table 12.

Based on formulas (17) and (18) and Tables 10 and 11, the variation of the composite levels of economic and logistics development in Hebei from 2011–2025 was plotted (Figure 1).

Then, the following conclusions can be drawn.

Overall, the composite levels of economy and logistics in Hebei are on the rise, indicating that the economy and logistics in that province have been improving in the recent decade. Specifically, the composite level of economy rises steadily from 2011 to 2025, that is, the economy develops year by year. The composite level of logistics exhibits an upward trend in the sample period, and the rise picks up speed from 2023 to 2025. In these three years, the logistics industry in Hebei would develop rapidly.

During 2011–2022, the composite level of economy is higher than that of logistics, suggesting that the logistics development in Hebei is not as good as the economic development in this period. However, the composite level of logistics rises sharply, surpassing that of economy, in 2023–2025. In those years, the regional logistics in Hebei would inject new vigor into economic development. By formulas (19)–(21), the coupling degree C, composite level $T$, and CCD $D$ of economy and logistics in Hebei were calculated and prepared into a neat line chart (Figure 2).

As shown in Table 12 and Figure 2, the curve trend of composite level and CCD is almost the same, while the coupling degree between economy and logistics in Hebei has a different shape. Specifically about the coupling degree, despite its fluctuations from 2011 to 2025, it belongs to the running-in stage (0.5–0.8) only in 2011, 2012, and 2014. In these years, the economy and logistics in Hebei are balanced and coordinated. In all the other years, the coupling degrees fall between 0.8 and 1, that is, the high stage. This means the coordinated development between economy and logistics in the province evolves in an orderly and coordinated way.

The CCD between economy and logistics in Hebei moves steadily upward, and the development trend of economy fits well with that of logistics. The province should invest more in the logistics industry and give full play to the mutual promotion between logistics and economy, thereby achieving overall development of both systems. In 2011–2015, the CCDs are within 0.2524–0.2962, belonging to the level of moderate incoordination. In 2016–2018, the CCDs are between 0.3141 and 0.3636, belonging to the level of mild incoordination. In 2019–2021, the CCDs fall between 0.4010 and 0.4675, belonging to the level of weak incoordination. In 2022–2023, the CCDs are between 0.5179 and 0.5788, belonging to weak coordination. In 2024, the CCD arrives at 0.6525, belonging to mild coordination. In 2025, the CCD rises to 0.7422, belonging to moderate coordination. To sum up, the CCD between economy and logistics in Hebei needs further improvement. Our prediction shows that the CCD would reach moderate coordination in 2025, falling short of absolute coordination.

4. Conclusions and Suggestions

4.1. Conclusions. This study firstly constructs an EIS for economic and logistics development in Hebei from 2011 to 2020 and then empirically analyzes the correlation degree between economy and logistics in Hebei, using entropy weight-grey correlation model. The key impactors of the interplay between the two systems were identified through the empirical analysis. Then, the economic and logistics indices of Hebei in the next five years were forecasted by the FGM (1, 1), and the coupling between economic and logistics indices from 2011 to 2025 was analyzed by the CCD model. The results show that

(1) Among economic indices, total retail sales of social consumer goods and public budget revenue exert a huge influence on the logistics industry. Among logistics indices, private car ownership and total output of post and telecommunications are the leading impactors of the economy in Hebei.

(2) Based on the original data of 2011–2020, the FGM (1, 1) was adopted to forecast the economic and logistics indices in Hebei in the next five years and evaluate the coordinated development between economy and logistics in the province. The prediction results of our model were compared with those of conventional GM (1, 1) and DGM (1, 1). The comparison shows that our model achieves the highest prediction accuracy.

(3) According to the original data in 2011–2020 and predicted values of the next five years, the CCD model was adopted to compute the coupling degree and CCD between economy and logistics in Hebei. The results show that the coordination between the two systems belongs to the running-in stage and high
stage; the CCD changes from moderate incoordination, mild incoordination, weak incoordination, and weak coordination, all the way to moderate coordination. The CCD would reach moderate coordination in 2025, falling far behind absolute coordination. Therefore, Hebei should take effective measures to promote the coordinated development between economy and logistics.

The logistics industry is a major driver of economic growth. In return, economic development could create a favorable environment for logistics development. In this research, seven logistics indices and seven economic indices are selected. Then, the CCD was calculated based on the original and predicted values of these indices. This breaks through the limitation of the existing studies: the CCD between economy and logistics is merely computed based on the historical data. The predicted index values help to measure the long-term coupling coordination between economy and logistics in Hebei, clarify the direction for optimizing the coordination between the two systems, and provide a good reference for CCD forecast. However, the economic and logistics systems are so complex that the proposed EIS may not be sufficiently reasonable and effective. Future research will try to further improve the EIS and explore the optimization path of economy and logistics.

4.2. Suggestions

4.2.1. Government Should Guide the Coordination between Economy and Logistics through Macro Policies

(1) Strengthen fixed asset investment in the logistics industry. The government should highlight the role of logistics in economic development, provide financial aid to logistics development, and attract private and foreign investments in logistics. For example, the government could set up a special logistics fund to support the development of regional logistics. The financing restrictions on small and medium logistics enterprises should be relaxed to mitigate their capital and cost pressures. If possible, these enterprises may receive preferential treatment in tax and loans.

(2) Prioritize the development of advantageous logistics enterprises. The government should encourage logistics enterprises to introduce advanced logistics technology and management ideas, pursue technological and industrial innovation, expand the scale of development, and put more efforts to brand building. For example, favorable policies should be laid down for advantageous logistics enterprises, encouraging them to lead the absorption of the latest logistics technology, as well as the transformation and upgrading of the logistics industry.

4.2.2. Expanding Domestic Demand and Promoting Regional Consumption

(1) Develop online business to promote urban real consumption. Logistics enterprises should strengthen cooperation with famous e-commerce platforms to realise quick delivery, creating a good environment for online consumption. Novel online consumption models must be fully utilized to attract consumers, such as community distribution, fixed-point picking, and experience consumption. In addition, more promotion activities should be organized, in association with the holiday activities of e-commerce platforms, trying to drive real consumption, integrate online and offline channels, and facilitate supply chain management.

(2) Build an active rural consumption market. To expand the rural consumption market, it is necessary to improve the quality of rural products, cater to the consumption needs of rural residents, and provide them with better services. At the same time, the relevant parties need to promote the purchasing and supply of commodities in rural supermarkets and fairs and organize more material exchange meetings in villages and towns. The other means to stimulate rural consumption include implementing effective management, relaxing the control of stalls, exempting stall fees, and introducing subsidy policies for the purchase of agricultural means.

4.2.3. Promote High-Quality Development of Logistics

(1) Establish a logistics service information-sharing platform based on the Internet of things (IoT). The commodity circulation needs to be tracked in time to improve the efficiency and speed of cargo turnover in every link of logistics, namely, transportation, warehousing, and distribution. The real-time tracking makes the logistics and transportation information more transparent. On this basis, an IoT-based logistics service information-sharing platform should be established, allowing users to search the order records and place new orders and enabling enterprises to respond to the orders timely, thereby avoiding burst or lost orders.

(2) Develop intelligent logistics. Modern logistics models should be implemented, such as the IoT, big data, and car-free carrier. To this end, it is important to utilize computer technology in overall planning of freight transportation, vehicle routing, vehicle scheduling, etc. For instance, intelligent warehouse management should be realised to update the storage of goods in real time and improve the efficiency of goods sorting, transportation, and packaging. Intelligent logistics can greatly save human resources, improve economic efficiency, and promote the development of modern logistics in Hebei.
Data Availability

The research data used to support the findings of this study are included within the article, and the data used are listed in Tables 5 and 6.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by Project Management Office of Hebei Federation of Social Sciences, Research on the digital transformation of agricultural industry in Hebei Province under the background of Rural Revitalization Strategy, and project no. 20210201333.

References

[1] S.-Y. Kim, H. Park, H.-M. Koo, and D.-K. Ryoo, "The effects of the port logistics industry on port city’s economy," Journal of Navigation and Port Research, vol. 39, no. 3, pp. 267–275, 2015.
[2] S. Lan and M. L. Tseng, "Coordinated development of metropolitan logistics and economy toward sustainability," Computational Economics, vol. 52, no. 4, pp. 1113–1138, 2018.
[3] C. Yang, S. Lan, and L. Wang, "Research on coordinated development between metropolitan economy and logistics using big data and Haken model," International Journal of Production Research, vol. 57, no. 4, pp. 1176–1189, 2019.
[4] W. Ma, X. Cao, and J. Li, "Impact of logistics development level on international trade in China: a provincial analysis," Sustainability, vol. 13, no. 4, Article ID 2107, 2021.
[5] D. Li, J. Chen, and M. Qiu, "The evaluation and analysis of the entropy weight method and the fractional grey model study on the development level of modern agriculture in huizhou," Mathematical Problems in Engineering, vol. 2021, Article ID 554368, 2021.
[6] X. Xiao and H. Guo, "Optimization method of grey relation analysis based on the minimum sensitivity of attribute weights," Advances in Grey Systems Research, Springer-Verlag, Berlin/Heidelberg, Germany, 2010.
[7] Y. Ruan, T. Wu, and J. Chen, "Evaluation of factors influencing energy consumption in water injection system based on entropy weight-grey correlation method," Applied Mathematics and Nonlinear Sciences, vol. 6, no. 2, pp. 269–280, 2021.
[8] Y. Yan, "Identification of low-voltage connection relation in distribution platform based on similarity of voltage curve and grey correlation degree of entropy weight," Journal of Physics: Conference Series, vol. 2137, no. 1, 2021.
[9] C.-L. Gao, S.-C. Li, J. Wang, L.-P. Li, and P. Lin, "The risk assessment of tunnels based on grey correlation and entropy weight method," Geotechnical & Geological Engineering, vol. 36, no. 3, pp. 1621–1631, 2018.
[10] Q. Q. Lu and Q. Zhao, "Data processing in Project supply chain vendor selection based on improved entropy weight-greyscale—TOPSIS," Advanced Materials Research, vol. 1046, pp. 545–549, 2014.
[11] J. L. Deng, Basic Method of Grey System, Huazhong University of Science and Technology Press, Wuhan, Hubei, China, 1987.
[12] S. F. Liu, N. M. Xie, and F. Jeffery, "A new grey relational analysis model based on similarity and proximity," System Engineering Theory and Practice, vol. 5, pp. 881–887, 2010.
[13] E. Kose, D. Vural, and G. Canbulut, "The most livable city selection in Turkey with the grey relational analysis," Grey Systems: Theory and Application, vol. 11, no. 2, pp. 288–308, 2020.
[14] X. Peng, X. Tang, Y. Chen, and J. Zhang, "Ranking the healthcare resource factors for public satisfaction with health system in China-based on the grey relational analysis models," International Journal of Environmental Research and Public Health, vol. 18, no. 3, p. 995, 2021.
[15] L. Wu, S. Liu, L. Yao, S. Yan, and D. Liu, "Grey system model with the fractional order accumulation," Communications in Nonlinear Science and Numerical Simulation, vol. 18, no. 7, pp. 1775–1785, 2013.
[16] K. Xu, X. Y. Pang, and H. M. Duan, "An optimization grey Bernoulli model and its application in forecasting oil consumption," Mathematical Problems in Engineering, vol. 2021, Article ID 5598709, 2021.
[17] W. Zhou, X. Wu, and J. Pan, "Application of a novel discrete grey model for forecasting natural gas consumption: a case study of Jiangsu province in China," Energy, vol. 200, Article ID 117443, 2020.
[18] W. Zhou, X. Wu, S. Ding, X. Ji, and W. Pan, "Predictions and mitigation strategies of PM2.5 concentration in the Yangtze River delta of China based on a novel nonlinear seasonal grey model," Environmental Pollution, vol. 276, Article ID 116614, 2021.
[19] U. Şahin and T. Şahin, "Forecasting the cumulative number of confirmed cases of COVID-19 in Italy, UK and USA using fractional nonlinear grey Bernoulli model," Chaos Solitons & Fractals, vol. 138, Article ID 109948, 2020.
[20] S. L. Lan and R. Y. Zhong, "Coordinated development between metropolitan economy and logistics for sustainability," Resources, Conservation and Recycling, vol. 128, no. 128, pp. 345–354, 2018.
[21] H. Wenjing, "Research on the coordinated development of logistics economy and ecological environment in anhui province," Open Journal of Social Sciences, vol. 09, no. 04, pp. 469–478, 2021.
[22] C. Yang, S. Lan, and M.-L. Tseng, "Coordinated development path of metropolitan logistics and economy in Belt and Road using DEMATEL-Bayesian analysis," International Journal of Logistics Research and Applications, vol. 22, no. 1, pp. 1–24, 2019.
[23] J. Zhan, C. F. Song, and R. R. Deng, "Spatiotemporal evolution of coupling coordination between logistics industry and information industry in Yangtze River economic belt," Hunan Social Sciences, vol. 5, pp. 116–124, 2019.