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Quality Evaluation of Rural Logistics Development Based on Partial Order Set-TOPSIS Under Rural Revitalization
A Case Study of 31 Provincial Administrative Regions in China

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Abstract. Rural logistics is a weak link in China's logistics development system, with inadequate supporting infrastructure, a low utilization rate of information technology, and insufficient cross-industry integration, which hinders the sustainable development speed and service quality improvement of rural logistics. Therefore, this article establishes a rural logistics development evaluation system based on data from 31 provinces, with rural economic level, logistics infrastructure, logistics transportation capacity, and rural logistics informatization as evaluation criteria. The combination weighting partial order set method is used to obtain weights and establish Hasse layers to display the performance of each province, and further use TOPSIS analysis to analyze the overall performance of rural logistics development in four regions of China. The data shows that there is a significant imbalance in rural logistics development among different regions in China, and the inadequate construction of rural logistics infrastructure and low level of e-commerce and informatization are important factors hindering the high-quality development of rural logistics.

Keywords: Rural logistics · Infrastructure · Hasse diagram · Informatization level

1 Introduction

In July 29, 2021, the Ministry of Transport and China Post jointly issued an implementation plan to accelerate the development of rural postal logistics system, which aims to promote rural revitalization, improve urban-rural circulation system, expedite e-commerce and express delivery services in rural areas, and achieve smooth "last mile" delivery. Since the issuance of this plan, various provinces have responded positively to it by promoting the development of rural logistics systems. For example, Shanxi Province plans to invest RMB 8 million to construct postal rural logistics infrastructure covering 74 counties under 11 cities by the end of this year. Jiangsu Province has set a goal to achieve full coverage of "last mile" delivery in rural areas by the end of the 14th Five-Year Plan period, and establish a distinctive logistics service model based on transportation, postal delivery, and rural communities. By 2023, eastern provinces

S. H. B. D. M. Zailani et al. (Eds.): ICMSEM 2023, 259, pp. 736–752, 2024.
https://doi.org/10.2991/978-94-6463-256-9_75

will have achieved direct delivery of express services to villages, and the proportion of western provinces with direct delivery to villages will reach 80% and 60%, respectively.

Under these policies, human flow, logistics, and capital flow are further extending to rural areas, creating favorable conditions for sustainable development of rural express delivery and e-commerce. According to data from the Ministry of Commerce, rural e-commerce retail sales from RMB 180 billion in 2012 to RMB 2.17 trillion in 2022, a tenfold increase over a decade. However, it should not be ignored that there are still many difficulties facing rural logistics despite its broad prospects. The quality of rural logistics development varies greatly among different regions in China. Compared with the mature logistics systems in eastern regions, the development of logistics in western inland areas is hindered by problems such as lagging infrastructure and shortage of logistics talents. In particular, remote western areas like Tibet and Qinghai face great challenges in rural express delivery due to severely underdeveloped infrastructure. High logistics construction costs deter third-party logistics companies, which is a major obstacle to rural logistics development. Meanwhile, the low level of e-commerce and informatization in rural areas and the shortage of professional talent in express delivery and logistics distribution systems also constrain the sustainable development of rural logistics. Therefore, studying the current overall development of rural logistics in China is of great significance for achieving coordinated regional and urban-rural logistics industry development, and promoting rural revitalization.

2 Literature Review

Chinese scholars have made rich academic achievements in the evaluation and research of logistics development quality. Wang et al. [1] took eight comprehensive economic zones as an example and established the evaluation system of manufacturing-logistics subsystem efficiency from the perspective of input and output, concluding that the driving effect of China's manufacturing industry on logistics still needs to be improved. Lin [2] evaluated the logistics industry upgrading capabilities of 16 provinces in China based on four primary indicators - output capacity, input capacity, industry upgrading level, and industry upgrading potential, as well as 13 secondary indicators. The conclusion drawn was that there is a significant regional imbalance in the current logistics industry upgrading capabilities in China. Wang and Zhang [3] established a three-level logistics quality evaluation system for 27 cities in the Yangtze River Delta region, focusing on infrastructure construction, logistics development environment, logistics sharing platforms, and smart logistics. Wang [4] evaluated the logistics quality of agricultural products in 21 cities in Guangdong Province based on the development environment, supply capacity, and logistics demand. It was pointed out that there are relatively few agricultural product logistics enterprises in Guangdong Province, the logistics system is not perfect, and the logistics infrastructure is still relatively backward at present. Lu et al. [5] conducted a differentiated analysis of the development of rural logistics in China, using 28 provinces as examples and focusing on five aspects: economic foundation, logistics facilities, logistics market, government policies, and others.

Valuable viewpoints have also been proposed by foreign scholars regarding the problems in the development of rural logistics. For example, Kotliarov [6] analyzed the problems that exist in the production, processing, sales, and logistics distribution of agricultural products in remote areas and pointed out that the development system of agricultural e-commerce needs to be optimized.. Ping et al. [7] believe that the current infrastructure construction in rural areas and the information technology development of agricultural logistics enterprises are far lower than the level of urban areas. Perboli [8] pointed out that high logistics costs are the main reason that restricts the high-quality development of agricultural product logistics. Kumar et al. [9] believe that the construction of highways has widened the gap in production capacity between urban and rural areas, resulting in lower value-added and technological levels of logistics enterprises in rural areas. Meyyappan et al. [10] studied the rural logistics system in India and elaborated that traditional express delivery models cannot meet the development needs of rural areas, and proposed the need for a new type of express logistics model. Many scholars have also put forward countermeasures to improve the quality of rural logistics development. For instance, Murata [11], and Cerina F et al. [12] all believe that changes in transportation costs between rural and urban areas are an important strategy for promoting urban-rural integration. Cárdenas et al. [13] propose that logistics centers are key bridging structures connecting the supply chain upstream and downstream, significantly affecting logistics costs and efficiency, and are therefore crucial to the construction of rural logistics systems.

Overall, the development of rural logistics has become increasingly important, with foreign scholars focusing mainly on the logistics modes of agricultural products, informatization construction, and the role of e-commerce in rural economic development, particularly in constructing the supply chain for agricultural products. In contrast, Chinese scholars place greater emphasis on studying issues related to rural e-commerce development in the context of national policies, such as the rural revitalization strategies, new development pattern of "dual circulation," and the "last mile" logistics problem in rural e-commerce development. However, there is relatively little research on the comprehensive evaluation of the overall quality of rural logistics development. Currently, traditional integrated evaluation methods-regardless of whether they are subjectively or objectively combined - are prone to subjective bias and the influence of sample data, reducing the weighting effect. Therefore, this paper constructs a relatively comprehensive indicator system and evaluates the quality of rural logistics development in 31 provinces, autonomous regions, and municipalities through game theory-based combination weighting and partial order set method. This study provides a new perspective and approach to understanding the overall quality of rural logistics development in various provinces of China, and provides an important reference for relevant policy decisions.

3 Selection and Construction of Quality Evaluation Index System for Rural Logistics Development

3.1 Index System Construction

On the basis of referring to scholars' views and combining with the actual development of rural logistics, this paper screens the indicators layer by layer. With reference to the latest data from the China Statistical Yearbook, China Rural Statistical Yearbook, indicators reflecting rural logistics were screened and sorted. According to the structure of the Analytic Hierarchy Process, the indicators were divided into target layer and indicator layer, and further subdivided into primary and secondary indicators. The overall performance of rural logistics in China was reflected from four dimensions: rural economic level, logistics infrastructure and supply level, logistics transportation capacity, and rural logistics informatization and education level. Considering that some indicators in the evaluation of rural logistics development are too broad and not highly correlated, especially important indicators such as "number of rural logistics service points at the village level in different regions" and "e-commerce turnover of agricultural products in different regions" are seriously lacking in data. Therefore, five indicators such as "number of rural express service outlets", "cross-border e-commerce turnover", "per capita online retail sales of agricultural products", and "top 100 county-level rural e-commerce competitiveness" were removed, and ultimately 19 indicators reflecting the overall quality of rural logistics were retained, as shown in Table 1.

4 The Evaluation Model of Rural Logistics Is Established Based the Combination Weighting Poset-TOPSIS Method

4.1 A Partially Ordered Set Evaluation Method for Rural Logistics Dynamics

The Partially ordered set evaluation method is an applicable multicriteria and multiobjective evaluation method, and the definition of the partially ordered sets is as follows:

Let R be a binary relation on a nonempty set A. If R satisfies self-reflexivity (for any $x \in A$, there is XRX), antisymmetry (for any $x,y \in A$, if xRy and yRx, then $x = y$) and transferability (for any $x,y,z \in A$, if xRy and yRz, then xRz), then R is said to be a partial order relation on A, denoted as $(A, \preceq)$.

Determining the decision function as the objective function, constructing the weight space as the constraint, and building a linear programming model from it is the key to converting the multicriteria decision problem into a partial order problem, and the specific conversion process can be referred to [14, 15], whose main process is as follows.

(1) Determine the feature weight size ranking, and if the weights express preferences, then specify the sequence of decision-maker preferences. One of the advantages of biased order expression is that the decision can be made without exact weights and only the order of weights, and it has strong robustness. For n features, let the order of weights be $\omega_1 \geq \omega_2 \geq \cdots \omega_n \geq 0$.
(2) For each column of the sample data, the full arrangement is made in the order of the weights from left to right, from largest to smallest, and noted as X. The rearranged matrix is transformed to obtain the cumulative matrix $Y = D * E$, where E is the upper triangular matrix.

$$Y = \begin{bmatrix} a11 & a11 + a12 & \cdots & a11 + a12 + \cdots + a1n \\ a21 & a21 + a22 & \cdots & a21 + a22 + \cdots + a2n \\ \vdots & \vdots & \ddots & \vdots \\ am1 & am1 + am2 & \cdots & am1 + am2 + \cdots + amn \end{bmatrix}$$

Table 1. Evaluation index system of rural logistics development vitality.

	Level 1 Indicators	Level 2 Indicators	Unit	Attribute	Data source
Target layer	Economic level of rural areas (A1)	Per capita disposable income of rural residents (B1)	(RMB)	Positive index	《China Statistical Yearbook 2021》
		Per capita consumption expenditure of rural residents (B2)	(RMB)	Positive index	《China Rural Statistical Yearbook 2021》
		Transportation, warehousing, postal business value added (B3)	(hundred million RMB)	Positive index	《China Statistical Yearbook 2021》
		Retail sales of social consumer goods per capita in rural areas (B4)	(hundred million RMB)	Positive index	《Statistical Yearbook of China Foreign Trade and Economics 2021》
		Rural agriculture, forestry, animal husbandry and fishery products per 10,000 people (B5)	(Ten thousand Yuan)	Positive index	《China Statistical Yearbook 2021》
	Rural regional logistics foundation And facilities supply level (A2)	Local financial transportation expenditures (B6)	(hundred million RMB)	Positive index	《China Statistical Yearbook 2021》
		Rural transportation per 10,000 people on the number of postal business employees (B7)	(person)	Positive index	《China Statistical Yearbook 2021》

(*continued*)

Table 1. (*continued*)

	Level 1 Indicators	Level 2 Indicators	Unit	Attribute	Data source
		Rural per capita express business income (B8)	(hundred million RMB)	Positive index	《China Statistical Yearbook 2021》
		Length of rural delivery route (B9)	(10000 km)	Positive index	《China Statistical Yearbook 2021》
		Road density by region (B10)	(100 square kilometers)	Positive index	《China Traffic Statistics Yearbook 2021》
	Transportation capacity (A3)	Total post and telecommunications business (B11)	(10 kilo-tons)	Positive index	《China Statistical Yearbook 2021》
		Transit volume per capita (B12)	(hundred million RMB)	Positive index	《China Statistical Yearbook 2021》
		Freight volume per capita (B13)	(t)	Positive index	《China Statistical Yearbook 2021》
		Rural per capita express volume (B14)	(piece)	Positive index	《China Statistical Yearbook 2021》
	Rural regional logistics informatization level (A4)	E-commerce sales per capita (B15)	(Ten thousand Yuan)	Positive index	《China Statistical Yearbook 2021》

(*continued*)

Table 1. (*continued*)

	Level 1 Indicators	Level 2 Indicators	Unit	Attribute	Data source
		Mobile Internet users per capita in rural areas (B16)	(households)	Positive index	《China Statistical Yearbook 2021》
		Percentage of rural undergraduate degree or above (B17)	(%)	Positive index	《Yearbook of China's Population and Employment Statistics 2021》
		Online retail sales per capita (B18)	(Ten thousand Yuan)	Positive index	《Statistical Yearbook of China Foreign Trade and Economics 2021》
		Number of e-commerce companies (B19)	(ten thousand households)	Positive index	《China Statistical Yearbook 2021》

Note: According to China Statistical Yearbook 2021 and China Rural Statistical Year 2021, the income is calculated and sorted out.

$$D = \begin{bmatrix} a11 & a12 & \cdots & a1j & \cdots & a1m \\ a21 & a22 & \cdots & a2j & \cdots & a2m \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ ai1 & ai2 & \cdots & aij & \cdots & aim \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ am1 & am2 & \cdots & amj & \cdots & amm \end{bmatrix}$$

$$E = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 0 & 1 & \cdots & 1 \\ \vdots & \vdots & \ddots & 1 \\ 0 & 0 & \cdots & 1 \end{bmatrix} \tag{1}$$

(3) The rows of the cumulative transformation matrix Y are compared pairwise. If each value of the $m - 1$ row is greater than or equal to the value of the corresponding position of the m row, then the $m - 1$ evaluation object is better than or equal to the m evaluation object. For a given partial order set $(A, \preceq)$,$\forall\, i\,, j \in A$, where if the components of a row i are greater than or equal to the components of a row j, then $r_{ij} = 1$, if $\alpha_i \leq \alpha_j$ or α_i and α_j are not comparable, $r_{ij} = 0$, Then $R = (r_{ij})$ is called the comparison relation matrix of $(A, \preceq)$.

(4) The HASSE matrix, obtained by transforming the computed comparison matrix, can be used to draw the HASSE diagram. The HASSE diagram is a specially directed graph that can intuitively show the partial order relations between evaluated objects, making it a powerful tool for presenting transitive and structural relationships. The conversion formula between the two is as follows:

$$H_R = (R - I) - (R - I) * (R - I) \tag{2}$$

4.2 TOPSIS Evaluation Method for Rural Logistics Vitality

This article constructs an evaluation model for rural logistics development based on entropy weighting partial order set-TOPSIS. The evaluation steps of the model are as follows:

first, determine the set of evaluation indicators;
second, normalize the indicator data;
third, we use AHP, entropy weighting, and CRITIC to calculate the subjective and objective weights, and rank the evaluation indicators according to the weight size;
fourth, establish a comparison relationship matrix according to the weight order, convert it into a Hasse matrix, draw a Hasse diagram, and rank the evaluation samples in layers;
fifth, we further use TOPSIS to obtain the score and ranking results, and conduct analysis.

5 Empirical Research

5.1 Data Preprocessing

Based on the rural regional logistics development quality evaluation indicator system established above, this article selects 31 provinces (autonomous regions, municipalities) such as Beijing, Tianjin, and Zhejiang as the direct research objects, and conducts

Table 2. Normalized data.

Region	B1	B2	B3	B4	B5	…	B15	B16	B17	B18	B19
Beijing	0.055	0.049	0.020	0.077	0.008	…	0.254	0.050	0.091	0.179	0.035
Tianjin	0.047	0.039	0.020	0.020	0.021	…	0.064	0.036	0.038	0.049	0.019
Hebei	0.030	0.029	0.070	0.024	0.028	…	0.012	0.032	0.017	0.014	0.028
Shanxi	0.025	0.024	0.026	0.029	0.016	…	0.013	0.031	0.041	0.007	0.017
…	…	…	…	…	…	…	…	…	…	…	…
Gan Su	0.019	0.023	0.010	0.017	0.021	…	0.004	0.031	0.032	0.005	0.008
Qinghai	0.022	0.028	0.003	0.022	0.029	…	0.007	0.033	0.026	0.008	0.002
Ningxia	0.025	0.027	0.004	0.022	0.029	…	0.007	0.033	0.038	0.012	0.003
Xinjiang	0.025	0.025	0.015	0.012	0.038	…	0.007	0.030	0.034	0.005	0.012

Note: According to China Statistical Yearbook 2021 and China Rural Statistical Year 2021, the income is calculated and sorted out.

horizontal and vertical comparative analysis. The latest 2021 China Statistical Yearbook 2021, China Rural Statistical Yearbook 2021 were used as data sources to obtain the original information on rural logistics in 31 provinces and municipalities of China, ensuring the authenticity and reliability of the data.

To facilitate subsequent evaluation research, preprocessing of the original data is necessary due to the issue of different measurement units for the indicators. As all data in this study are benefit-type indicators, normalization using formula (5) was applied. Additionally, the 19 evaluation indicators were sequentially numbered as B1, B2, B3,…,B19. The preprocessed data are shown in Table 2.

5.2 Calculate the Objective Weight Index

First, calculate the subjective weight. In order to evaluate the quality of rural logistics development, 20 scholars and related practitioners in the field of rural logistics were invited to form an expert group. Through the questionnaire survey, the index system is judged layer by layer, and the subjective weight ω_1 of each index is obtained, as shown in Table 3.

Using the normalized data in Table 2, the entropy weight ω_2 and the CRITIC weight ω_3 are obtained in turn, as shown in Table 3. According to, the weighted results of game theory combination are obtained: $\omega_1,\ \omega_2,\ \omega_3$. From this, the game theory combination weight value $\alpha_1^* = 0.4135, \alpha_2^* = 1.168, \alpha_3^* = -0.582$ of each index can be obtained, and the indexes are sorted according to the obtained weight value, as shown in Table 3.

Table 3 shows that rural logistics infrastructure and supply level have the greatest impact on rural logistics development among the primary indicators, which is in line with the current situation of serious shortage of rural logistics infrastructure in China. Secondly, the current economic development level of rural areas is also very important. In the secondary indicators, rural per capita express delivery revenue ranks first, reflecting the inseparable relationship between rural logistics infrastructure and supply level and

Table 3. Combination weight and ranking of indicators

AHP	0.10	0.05	0.09	0.04	0.03	0.10	0.03	0.11	0.03	0.06	0.04	0.01	0.02	0.06	0.07	0.02	0.02	0.08	0.03
entropy method	0.03	0.03	0.04	0.04	0.02	0.02	0.03	0.13	0.04	0.03	0.04	0.03	0.02	0.10	0.13	0.03	0.05	0.13	0.06
CRITIC	0.02	0.01	0.05	0.03	0.05	0.04	0.05	0.11	0.05	0.04	0.05	0.06	0.04	0.08	0.12	0.01	0.04	0.09	0.06
Combination Weighting	0.07	0.04	0.05	0.05	0.01	0.05	0.03	0.14	0.03	0.04	0.04	0.00	0.01	0.09	0.11	0.04	0.04	0.13	0.04
sort	5	9	6	8	18	7	16	1	15	14	12	19	17	4	3	13	11	2	10

the quality of logistics development. At the same time, in the index of rural area economic level, rural per capita disposable income, transportation value added ranking are also high. Spearman's p test was used to test the consistency of the three weighting methods and the combined weighting results, and it was found that the correlation coefficient of the game theory combined weighting method was the best (0.920), while the correlation coefficient values of the objective weighting method and the AHP method were relatively low and the correlation was not obvious enough. The reason for this phenomenon is that there is ambiguity in the ranking of some indicators when calculating their weights, resulting in significant controversy over the ranking produced by subjective and objective weighting methods. To solve this problem, a game theory optimization method was introduced to ensure the ordinality of the weights by balancing the weights corresponding to each indicator. This method is consistent with the partially ordered set model, thus creating conditions for the transformation of partial order relations.

5.3 Establishing the Relational Matrix to Obtain Hasse Diagram

Furthermore, a partial order set evaluation was utilized to evaluate rural logistics in 31 provinces. Firstly, based on the results of the game theory combinatorial weighting method, 19 secondary indicators were ranked in order of importance from high to low:

$$\omega_{\mathrm{B8}} > \omega_{\mathrm{B18}} > \omega_{\mathrm{B15}} > \omega_{\mathrm{B14}} > \omega_{\mathrm{B1}} > \omega_{\mathrm{B3}} > \omega_{\mathrm{B6}} > \omega_{\mathrm{B4}} > \omega_{\mathrm{B2}} >$$
$$\omega_{\mathrm{B19}} > \omega_{\mathrm{B17}} > \omega_{\mathrm{B11}} > \omega_{\mathrm{B16}} > \omega_{\mathrm{B10}} > \omega_{B9} > \omega_{\mathrm{B7}} > \omega_{B13} > \omega_{\mathrm{B5}} > \omega_{\mathrm{B12}}$$

In the second step, the cumulative matrix is obtained according to Eq. (1).

In the third step, the rows of the cumulative transformation matrix are compared two by two to obtain the comparative relationship matrix R. In the fourth step, transforming the interprovincial relationship matrix into a HASSE matrix according to Eq. (2), and drawing the HASSE diagram of the partial order set of the HASSE matrix, as shown in Fig. 1. The HASSE diagram is an intuitive sorting tool that visually reflects the clustering information and hierarchical relationships of rural logistics development among provinces at the current stage, facilitating direct classification and result analysis.

5.4 Analysis of Results

Figure 1 shows the "overall picture" of rural logistics development in 31 provinces (autonomous regions and municipalities). The higher a sample is positioned on the Hasee chart, the better its performance in terms of logistics development quality. For example, Shanghai is positioned above Beijing in the chart, indicating that its performance is better than that of Beijing. At the same time, the security of each sample has the characteristic of mutual transmission. For instance, if Shanghai performs better than Beijing and Beijing performs better than Tianjin, it can be concluded that Shanghai performs better than Tianjin. This chart divides the 31 provinces (autonomous regions and municipalities) into four levels, corresponding to excellent, good, moderate, and poor levels.

Provinces in the excellent level include: {Shanghai, Beijing, Zhejiang, and Guangdong};
Provinces in the good level include: {Tianjin, Fujian, Jiangsu, and Shandong};

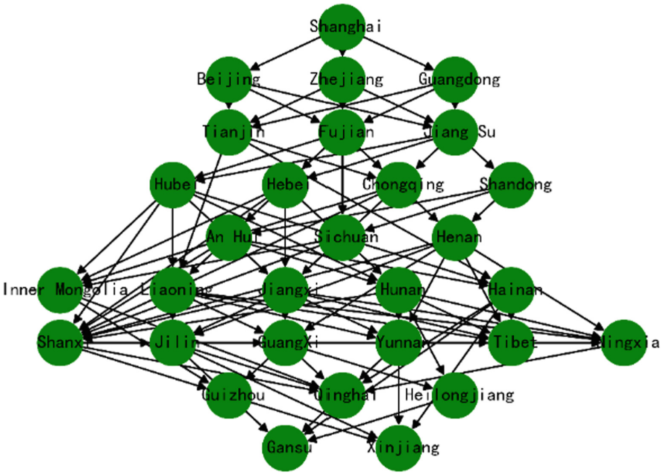

Fig. 1. Hasee diagram.

Provinces in the moderate level include: {Hebei, Chongqing, Anhui, Hubei, Sichuan, Henan, Inner Mongolia, Liaoning, Jiangxi, Hunan, Hainan, Shaanxi, Shanxi, Guangxi, and Yunnan};
Provinces in the poor level include: {Jilin, Ningxia, Guizhou, Qinghai, Heilongjiang, Tibet, Gansu, and Xinjiang}.

From the output results, the Hasee chart presents a characteristic of being narrow on both sides and wide in the middle. In this structure, the proportion of provinces in the good and moderate levels is the highest, while those in the poor and excellent levels are the least. Developed provinces such as Shanghai, Beijing, Zhejiang, and Guangdong rank top four, with their rural logistics development quality significantly higher than other provinces. Most provinces (5–20) have good or moderate levels of rural logistics development, indicating great potential for further growth. In contrast, 10 provinces such as Tibet, Gansu still lag behind the developed eastern regions in terms of rural logistics development quality. To further conduct detailed horizontal comparison analysis, the TOPSIS method was used to calculate the comprehensive scores of rural logistics development quality for each province (autonomous region and municipality) based on the weightings derived from the game theory combination weighting method. Combined with the Hasee chart and based on the comprehensive scores of each province, they were divided into four levels: 0–0.15 points represent underdeveloped provinces in logistics development; 0.15–0.3 points represent provinces with underdeveloped logistics development; 0.3–0.45 points represent provinces with relatively developed logistics development; and above 0.45 points represent provinces with developed logistics development. The results are shown in Fig. 2. Furthermore, according to the provincial administrative regions of the eastern, central, northeastern, and western regions, the overall performance of the four regions was further obtained (see Table 4).

(1) Overall, the quality of rural logistics development in the eastern region is significantly higher than that in other regions, with a decreasing trend from east to west. The overall

performance in the eastern region is relatively good (0.272), significantly higher than the national average (0.166), reflecting the relatively mature development of rural logistics in the eastern region. The mean score in the central region (0.257) is slightly lower than the national average, while the scores in the northeastern region (0.166) and western region (0.168) are far lower than those in other regions, especially with a significant gap compared to the eastern region. Specifically, Shanghai has the highest score at 0.411, followed by Zhejiang (0.578) and Beijing (0.549). Tibet has the lowest score at only 0.046, ranking last. It is worth noting that all provinces in the eastern region except Hainan have comprehensive scores higher than the national average. In the central region, the performance of all provinces except Jiangxi (0.215) and Shanxi (0.206) is slightly better than the national average. However, only Chongqing and Sichuan in the western region have slightly higher comprehensive scores than the national average, and other indicators rank very low except for government policy indicators.

(2) Inadequate rural logistics infrastructure and low levels of e-commerce and informatization are key factors constraining high-quality rural logistics development. Among the data calculated for 31 provinces (municipalities and autonomous regions) in China, the coefficient of variation for rural economic development scores is 0.307, with a weighting of 0.509, indicating that the contribution rate of economic development to regional differences in rural logistics development quality is 8.76%. Meanwhile, the contribution rate of rural e-commerce and informatization (A4) is the highest, reaching 14.21%. In addition, rural regional economic development (A2) also has an important impact on regional differences in rural logistics development

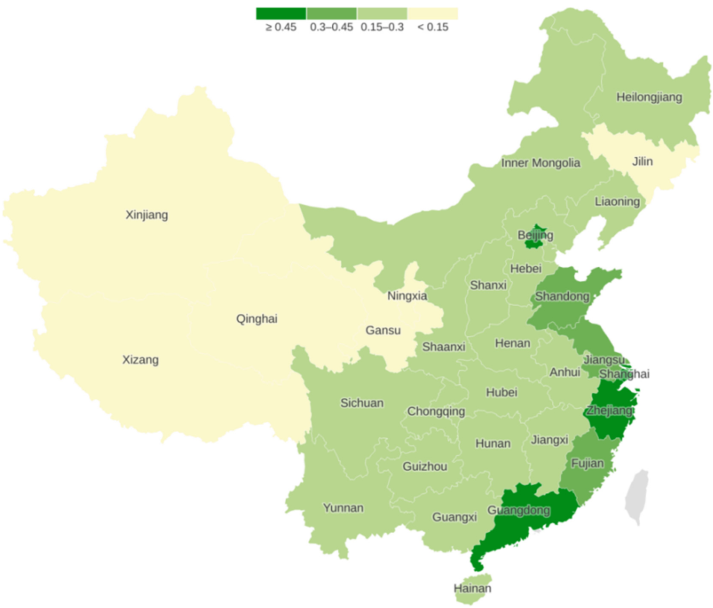

Fig. 2. Performance of Rural Logistics Development in Provinces.

Table 4. Regional Performance of Rural Logistics Development Quality.

		Level of aggregation		Economic level (A1)		Logistics infrastructure level (A2)		Logistics transportation capacity (A3)		E-commerce and informatization level (A4)	
	Zone	index value	Proportion of the whole country	index value	Proportion of the whole country	index value	Proportion of the whole country	index value	Proportion of the whole country	index value	Proportion of the whole country
score average/mean value	whole country	0.26	-	0.35	-	0.36	-	0.21	-	0.19	-
	eastern region	0.41	1.56	0.54	1.56	0.44	1.22	0.33	1.57	0.36	1.90
	middle	0.26	0.98	0.34	1.00	0.44	1.23	0.19	0.90	0.12	0.62
	Northeast region	0.17	0.63	0.26	0.76	0.24	0.66	0.10	0.49	0.10	0.55
	western region	0.17	0.64	0.20	0.59	0.29	0.79	0.15	0.70	0.11	0.56
variable coefficient	whole country	0.54	-	0.52	-	0.48	-	0.73	-	0.93	-
	eastern region	0.37	-	0.27	-	0.47	-	0.66	-	0.65	-
	middle	0.15	-	0.24	-	0.19	-	0.21	-	0.13	-
	Northeast region	0.17	-	0.24	-	0.12	-	0.60	-	0.17	-
	western region	0.36	-	0.46	-	0.52	-	0.39	-	0.30	-

quality, with a contribution rate of 8.83%. However, logistics transportation capacity (A3) only contributes 3.45% to regional differences. This indicates that there is a significant regional difference in the rural logistics and informatization level among provinces, which has the most significant impact on the quality of rural logistics development. Furthermore, from the mean scores, it can be seen that the western region performs poorly, with rural regional economic development only reaching 59.1% of the overall national development quality, and rural logistics and informatization levels only reaching 55.6% of the average level. This indicates that the western region still faces significant gaps in the quality of rural logistics development due to weak economic strength and geographical limitations, requiring improvements in rural logistics infrastructure and supply levels, as well as the development of regional logistics e-commerce and informatization.

6 Conclusions and Future Research

With the rapid development of China's economy and the acceleration of urbanization, rural logistics has become an important carrier for connecting urban-rural economies and promoting sustainable rural economic development. It is of great significance for accelerating the pace of rural revitalization and driving rural industrial upgrading. In this study, based on the combination weighting-partial order set method, comparative analysis of rural logistics development in 31 provinces (municipalities and autonomous regions) was conducted. The results showed that China's rural logistics development presents a trend of decreasing levels from east to west regions, with significant regional imbalances; inadequate rural logistics infrastructure construction and low level of rural e-commerce and informatization are critical factors restricting high-quality rural logistics development; the internal disparities between the western and eastern regions are particularly prominent, while the internal differences in the central and northeastern regions are relatively small.

To address the key issues in rural logistics development in different regions, the following measures need to be taken: Inadequate rural logistics infrastructure necessitates increased investment from the government in infrastructure construction. Especially in the western region, where logistics transportation capacity and economic foundation are relatively low, rural logistics transportation faces significant difficulties. Therefore, there is a need to strengthen the construction of transportation infrastructure, including roads, railways, and airports, improve the accessibility of rural roads, and shorten logistics delivery time. At the same time, establish a rural logistics service network, encourage enterprises to invest in logistics parks, agricultural markets, distribution centers, and other logistics platforms, drive local residents' entrepreneurship and employment, boost local economic vitality, and enhance rural logistics delivery capacity and service quality in the western region. Additionally, cooperation and communication between the central and western regions and other regions should be strengthened to promote rural logistics development. Specifically, cooperation can be enhanced in talent training, technological innovation, market expansion, and information sharing, among others, to create a cross-regional logistics service system, improve the overall development quality and service quality of rural logistics.

This article evaluates the overall development quality of rural logistics in 31 provinces (autonomous regions and municipalities) using the game theory combination-partial order set-topsis model. However, there are some shortcomings in this article. Firstly, the evaluation index system for rural logistics development needs to be further improved, and the sample data needs to be expanded. Secondly, the application scenario of the model needs to be expanded. This article evaluates the development quality of rural logistics for a single year using a combination method, but the development of rural logistics changes dynamically over time, so it is necessary to conduct a horizontal comparison analysis of provinces based on historical data. In the future, it is necessary to solve the problem of partial order expression of two weights, indicator weight and time weight, and then clarify the method of using partial order expression of panel data.

Acknowledgments. The work described in this paper is supported by the fund of the Liaoning Provincial Department of Education LJ2020JCL028.

References

1. Wang Zhenzhen. (2017). Evaluation of the Efficiency of Linkage Development of Manufacturing and Logistics Industry in China—Based on the Super-efficiency CCR-DEA Model. China Circulation Economy (02), 20–30. https://doi.org/10.14089/j.cnki.cn11-3664/f.2017.02.003.
2. Lin Peng, Yang Xiaohui & Guo Zixue. (2020). Improved TOPSIS method and application research for logistics industry upgrading capacity evaluation. Contemporary Economic Management (11), 24–28. https://doi.org/10.13253/j.cnki.ddjjgl.2020.11.004.
3. Wang Peng, Zhang Ruqi & Li Yan. (2021). Measurement and Evaluation of High-quality Development of Logistics in the Yangtze River Delta: On the Construction of a New Logistics System in the Post-epidemic Period. Industrial Technological Economics (03), 21–29. https://doi.org/10.3969/j.issn.1004-910X.2021.03.003.
4. Wang Xiumei & Qi Li. (2017). Comprehensive evaluation and policy promotion of agricultural product logistics development level in Guangdong Province. China Agricultural Resources and Regional Planning (06), 230–236. https://doi.org/10.7621/cjarrp.1005-9121.20170633.
5. Lu Zheng, Huang Weiru & He Juice. (2021). Evaluation of China's rural logistics development level and analysis of regional differences: Based on the data of 28 provincial-level administrative regions. Journal of Chongqing Technology and Business University (Social Science Edition) (04), 36–45. https://doi.org/10.3969/j.issn.1672-0598.2021.04.005.
6. Zhai Xiaoke & Wu Qizong. (2019). Research on rural e-commerce logistics service quality evaluation based on AHP-fuzzy comprehensive evaluation. Mathematics in Practice and Cognition (05), 121–127. https://CNKI:SUN:SSJS.0.2019-05-013.
7. Ping H, Wang J, Ma Z, et al. (2018).Mini-review of application of IoT technology in monitoring agricultural products quality and safety [J]. International Journal of Agricultural Biological Engineering (05), 11: 35–45. https://doi.org/10.25165/j.ijabe.20181105.3092.
8. Perboli G, Musso S, Rosano M. (2018). Blockchain in logistics and supply chain: A lean approach for designing real-world use cases [J]. Ieee Access (6), 62018–62028. https://doi.org/10.1109/ACCESS.2018.2875782.
9. Kumar I, Zhalnin A, Kim A, et al. (2017). Transportation and logistics cluster competitive advantages in the US regions: A cross-sectional and spatio-temporal analysis [J]. Research in Transportation Economics (61), 25–36. https://doi.org/10.1016/j.retrec.2016.07.028.

10. Meyyappan R S, Nivash T N, Ariharan J. (2019). Rural E-Commerce and Last Mile Delivery: Challenges and Solutions in the Indian Context [J]. International Journal of Management, IT and Engineering (9), 9: 164–170. https://www.indianjournals.com/ijor.aspx?target=ijor:ijmie&volume=9&issue=9&article=016.
11. Murata, Y. (2008). Engel's law, Petty's law, and agglomeration. Journal of Development economics, (1) 87: 161–177. https://doi.org/10.1016/j.jdeveco.2007.06.001.
12. Cerin a F, Mureddu F. (2013). Structural Change and Growth in a NEG Model[J]. Review of Development Economics (2), 17: 182–200. https://doi.org/10.1016/j.jtrangeo.2021.103095.
13. Yufeng Zhuang, Bin Zhang. (2018). Research on the Rural Express Alliance based on ANP improved profit Allocation [J]. IOP Conference Series: Earth and Environmental Science (03), 108: 032028. https://doi.org/10.1088/1755-1315/108/3/032028.
14. YUE Li-zhu, ZHANG Zhi-jie, YAN Yan. (2018). Multi Criteria Decision Making Method of Poset with Weight [J]. Operations Research and Management Science (2), 27: 26–31. https://doi.org/10.12005/orms.2018.0031.
15. Yue Lizhu, Yan Yan. (2015). A method for determining attribute weights based on ordinal information [J]. Statistics and Decision-making (13). https://doi.org/10.13546/j.cnki.tjyjc.2015.13.02.