A Study on the Gradient Classification of Logistics Development Level in 31 Provinces and Cities Based on Partial Order Set

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Abstract. Logistics in developed areas can pull the remote areas, with very obvious gradient characteristics. To intuitively reflect the gradient characteristics of logistics development level in 31 provinces and cities in China, the partial order set evaluation method is applied to obtain the partial order Hasse diagram that can reflect the evaluation results from the two aspects of logistics development foundation and the degree of logistics development. The Hasse chart shows that 31 provinces and cities are divided into ten levels, with Guangdong, Jiangsu, and Shandong at the top of the ladder, and Tibet and Qinghai at the end of the gradient. Studies have found that the level of logistics development was significantly correlated with the economic GDP of each province, with a correlation coefficient of 0.953.

Keywords: Logistics level · echelon · Partial ordered set · Hasse diagram

1 Introduction

As the basic service industry of national economic and social development of the logistics industry, it has become one of the most important indicators to measure the comprehensive strength of a country or region. From 2001 to 2020, the output value of China's logistics industry increased from 687.13 billion yuan to 4,156.17 billion yuan, an increase of 504.9%; The freight volume increased from 14,011.77 million tons to 47,295.79 million tons, an increase of 237.54%. During this period, for the sake of balanced economic development, the government put forward a series of national economic strategies, such as "Western Development", "Rise of Central China" and "Coordinated Development of Beijing and Tianjin". Logistics can realize the flow of social resources and natural resources, and make developed areas help the development of remote areas, with obvious gradient characteristics.

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Li [1] believes that the development of the logistics industry can not only promote local economic growth but also promote the economic growth of surrounding areas, which has an obvious pulling effect. China's logistics industry has an obvious aggregation effect, and the spillover effect caused by the aggregation effect has effectively stimulated the development of the logistics industry in various provinces [2]. Tian et al. [3] think that the development of regional logistics has a spatial correlation. Based on the evaluation and analysis of the logistics development level of 31 provinces in China, they think that there is an aggregation effect in logistics development. Wang Li et al. [4] believe that the level of logistics development in the eastern, central and western regions of China is highly positively correlated with the level of economic development, and regional logistics cooperation should be strengthened to promote regional logistics development.

China's logistics development level has obvious gradient characteristics. The gradient feature of the logistics development level is that the eastern region is higher than the central region and the western region, among which the eastern region leads the innovation and development of China's logistics industry. The central and western regions take "the belt and road initiative" as an opportunity to strengthen the interconnection with the eastern region and neighboring countries [5]. Ma [6] In the process of Ma's research, it is found that the logistics development level coefficient in the western region is negative, while that in the eastern region is positive. Therefore, strengthening domestic and international logistics construction is not only conducive to the sustainable development of China's future trade but also conducive to the promotion of the eastern and central regions of China to the western region.

Although logistics development is closely related to economic development and has obvious gradient characteristics, at present, the research on logistics evaluation focuses on the ranking of logistics development level, lacking the research on gradient division. Comprehensive evaluation method using current partial order set [7–9]. The partial order Hasse diagram is used to express the evaluation results, which can visually show the hierarchical characteristics of the evaluation objects. The remarkable feature of the partial order method is that the traditional weight vector is replaced by the weight space, so the evaluation result is robust, and the expert experience information can be integrated to solve the problem of weighting. Therefore, based on an in-depth analysis of partial order Hasse diagram stratification, the Hasse diagram is applied to express the gradient characteristics of the logistics development level in 31 provinces and cities based on a mature index system.

2 Partial Sequence Set Evaluation Basis

2.1 Partial Order Set Definitions and Related Theorems

Partial order set evaluation is an evaluation method based on partial order set theory, which belongs to a multi-criteria decision-making method with wider application. This method can not only compare, sort, and optimize but also cluster hierarchically by Hasse graph. This clustering method is different from the statistical clustering method, which can integrate expert preferences and has obvious gradient characteristics among different categories.

Given a set of reviews $M = (A, IC, X)$, where A is the scenario set, $IC = \{c_1, \cdots, c_n\}$ is the set of metrics.scheme a_i In the set of indicators c_j value of is $x_{ij} = c_j(a_i)$, $X = (x_{ij})_{m\times n} \in R^{m\times n}$ is the evaluation matrix. For any $\forall a_i \in A$, The evaluation vector corresponding to this scheme is $(x_{i1}, x_{i2}, \cdots, x_{in})$. Considering the basic role of the function and the convenience of research, the simple linear weighting function, which is most widely used in practice, is adopted as the comprehensive evaluation function, that is

$$f(a_i) = \omega_1 x_{i1} + \omega_2 x_{i2} + \cdots + \omega_n x_{in} \tag{1}$$

Naturally, the comparison of any two schemes is converted into the comparison of comprehensive evaluation function values. However, in practice, when the exact weight is unknown, only the qualitative information of the weight, such as the sequence information of the weight, can be obtained. At this time, the traditional method can't run because the weight is unknown, but the partial order evaluation method solves this problem.

The partial set method uses the weight space to "replace" the weight vector, and the so-called weight space is a set of weight vectors satisfying the weight constraint. For example, the weight space is formed by the weight order.

$$\Lambda = \left\{(\omega_1, \omega_2, \cdots, \omega_n)\middle|\omega_1 \geq \omega_2 \geq \cdots \geq \omega_n \geq 0, \sum \omega_j = 1\right\} \tag{2}$$

Apply a weight space "instead" of weight vectors, specifically, for arbitrary $\forall a_i, a_j \in A, f(a_i)\, f(a_j)$ and the comparison is extended to a comparison of the Λ values of two functions in the weight space, namely

$$\Delta(a_i, a_j) = \left\{f(a_i) - f(a_j)|\omega \in \Lambda\right\} \tag{3}$$

According to Eq. (3), $\min_{\omega\in\Lambda} \Delta(a, b) \geq 0$ if, rule $\forall\omega \in \Lambda$, have $f(a_i) - f(a_j) \geq 0$. On this basis, a partial-order relationship is constructed.

Definition 1 [10]: R is a collection A of a binary relationship, if R satisfied:

(1) Reflexivity: to arbitrary $x \in A$, have xRx;
(2) Antisymmetry (antisymmetry relation): to arbitrary $x, y \in A$, if xRy moreover yRx, namely $x = y$;
(3) Transitivity: arbitrarily $x, y, z \in A$, xRy moreover yRz, have xRz, said R is A for partial order relationship on, Usually remembered" $\succeq$ denote, Pay attention here $\succeq$ refers to "greater than or equal to" in the general sense.

Thus the partial order relation between sets A and A on is $\succeq$ called a partially ordered set, Note as $(A, \succeq)$. Either take two elements x, y, There are several cases in (1) $x \leq y$ or $y \leq x$; (2) $x = y$; (3) x and y not comparable.

Nature 1: while $\min_{\omega\in\Lambda} \Delta(a_i, a_j) \geq 0$, have $a_i \succeq a_j$, then the binary relationship $\succeq$ is a partial order relationship.

Prove: If the binary relationship $\succeq$ three properties in Definition 1 are satisfied, then it is a partial order relationship. For any a_i, obvious $\min_{\omega\in\Lambda} \Delta(a_i, a_i) \geq 0$, So you know $a_i \succeq a_i$, $\succeq$ Satisfying reflexivity.

If $a_i \succeq a_j$, have $\min\limits_{\omega\in\Lambda} \Delta(a_i, a_j) \geq 0$; if $a_j \succeq a_i$, have $\min\limits_{\omega\in\Lambda} \Delta(a_j, a_i) \geq 0$. Both are established at the same time, There must be $\Delta(a_i, a_j) = \{0\}$. That is to any $\omega \in \Lambda f(a_i) - f(a_j) = 0$. Then prove through the method of disproof that there must be for any component $a_{it} = a_{jt}$, If the two are not equal, this $\omega_t = 1$ causes $\Delta(a_i, a_j)$ non-zero elements to appear, Which is contrary to the premise. It can be seen that $a_i = a_j$ the relationship $\succeq$ satisfies antisymmetry.

Let $a_i \succeq a_j, a_j \succeq a_k$, have $\min\limits_{\omega\in\Lambda} \Delta(a_i, a_j) \geq 0, \min\limits_{\omega\in\Lambda} \Delta(a_j, a_k) \geq 0$, According to Eq. (2), it can be seen that,for any, $\omega \in \Lambda$, there is

$$f(a_i) - f(a_j) \geq 0 \tag{4}$$

$$f(a_j) - f(a_k) \geq 0 \tag{5}$$

So it can be $f(a_i) - f(a_k) \geq 0$ obtained, and then $\min\limits_{\omega\in\Lambda} \Delta(a_i, a_k) \geq 0$, it has $a_i \succeq a_k$ and then the relationship $\succeq$ satisfies transitivity.

The above partial order relationship, because the calculation involves the weight traversal problem, the direct operation is difficult. The following theorem gives a simple approach.

Theorem 1 [11] Given the set of evaluations $M = (A, IC, D)$ set the criterion weight, $\omega_1 \geq \omega_2 \geq \cdots \omega_n \geq 0 \sum\limits_{i=1}^{t} x_i \leq \sum\limits_{i=1}^{t} y_i (t = 1, 2, \cdots, n)$ if, then $f(x) \leq f(y)$. Where A are the evaluation matrix, the IC indicator collection, and the D attribute matrix?

According to the literature [12] it is known that theorem 1 can be represented by matrices, given the upper trigonometric matrix E

$$E = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 0 & 1 & \cdots & 1 \\ \vdots & \vdots & \ddots & 1 \\ 0 & 0 & \cdots & 1 \end{bmatrix} \tag{6}$$

When $\omega_1 \geq \omega_2 \geq \cdots \omega_n \geq 0$ the upper triangular matrix $E X$ performs the following operation to obtain the matrix DD

$$D = X \cdot E = \begin{bmatrix} x_{11} & x_{11} + x_{12} & \cdots & x_{11} + x_{12} + \cdots + x_{1n} \\ x_{21} & x_{21} + x_{22} & \cdots & x_{21} + x_{22} + \cdots + x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m1} + x_{m2} & \cdots & x_{m1} + x_{m2} + \cdots + x_{mn} \end{bmatrix} \tag{7}$$

In matrix D, if row i is smaller than row j, then we have $f(a_i) \leq f(a_j)$, One can compare rows of D and create a matrix of partial order relations $R = (r_{ij})_{m\times m}$, where

$$r_{ij} = \begin{cases} 1, & a_i \succeq a_j; \\ 0, & Others. \end{cases} \tag{8}$$

Because of the information redundancy of the partial order relationship matrix, it can be simplified to Hasse matrix H_R. The text [12, 13] gives the conversion formula for both

$$H_R = (R - I) - (R - I) * (R - I) \tag{9}$$

where, the I identity matrix, the operator $*$ is Boolean multiplication, according to which a H_R Hasse plot can be drawn. A Hasse is an intuitive representation of a finite partial order set, and in the mathematical branch order theory, it is a graphical representation of a partially ordered set. Specifically, for a partially ordered set $(A, \succeq)$, each A element is represented as a point on the plane, currently, only y it is overridden x (only and $x \leq y$ not z made $x \leq z \leq y$), and drawn from x the y upward segment or arc, that is, the drawing of the Haas diagram is complete. According to the Hasse diagram, analysis work such as comparison, sorting, optimization, and stratification of solutions can be carried out.

2.2 Hasse Plot Hierarchical Clustering Method

When solving specific problems, a directed acyclic graph (DAG) is usually used to represent a partial order on a set, the elements of the set are represented as nodes, and the direct partial order relationship between elements is represented by directed arcs [14]. A directed acyclic graph depicting a partially ordered set is essentially a Hasse graph. The topological ordering around the Hasse graph is called linear extension in the study of a partially ordered set [15, 16]. Learn from the idea of topological sorting to build a hierarchical algorithm framework. The traditional algorithm framework can be described as [17]: First, select a node without a precursor in the DAG graph and output it, then delete the node and its arc in the graph; Repeat the first two steps until all nodes without precursors are output, and the output order of nodes without precursors is the topological sort results.

Applying the above framework to implement topological sorting, the second step is often faced with multiple nodes to choose from, and they are equally possible to choose from. At this time, there are equal possible nodes, which constitute a graph "layer". For the convenience of expression, the node with zero degrees of penetration (without predecessor) is called the vertex, and the node with zero degrees of penetration is called the bottom. Therefore, there are two methods for layering Hasse graphs: vertex layering method (hereinafter referred to as vertex method) and bottom point layering method (hereinafter referred to as bottom point method). The top (bottom) point method includes the following steps:

Setp1: In the directed graph, select all vertices to form the vertex set, and the vertex set is the topmost layer, that is, the m-layer (select all the vertices to form the base set, and the base set is the bottom, that is layer 1).
Setp2: Remove the points and their associated edges from all the top (bottom) point sets of the first step from the plot to form a new Hasse plot, and the new set of the top (bottom) points of the new Hasse plot is a new layer, i.e. the m-1(2) layer.
Setp3: Repeat the above two steps until the remaining node-set is empty, or all nodes are deleted, and the Hasse graph layering ends.

In practice, the vertex method or the bottom point method is selected according to the evaluator's preference or the demand of clustering. For the same Hasse diagram, the hierarchical results of the vertex method and bottom point method are generally different. For example, aiming at the Hasse diagram with 13 elements in reference [18], the hierarchical results of the vertex method and bottom point method are as follows:

Comparing Fig. 1 with Fig. 2, three elements, N2, N6, and N8, belong to different levels, except that other elements belong to the same level. By comparison, it can be found that N2, N6, and N8 are elements on the non-maximum path. It can be said that

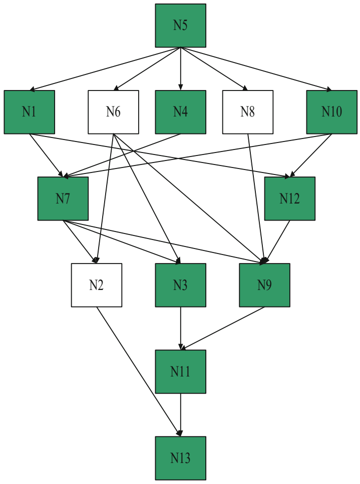

Fig. 1. Vertex method

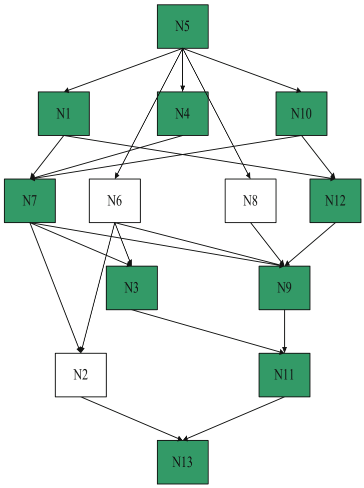

Fig. 2. Bottom point method

the arrangement difference of element positions and layers on the non-maximum path is the key difference between the vertex method and the bottom point method.

To sum up, the operation steps of the sorting method of comprehensive evaluation are as follows:

Step 1: normalizing the original data to obtain a matrix B.
Step 2: According to Eq. (7), the matrix is obtained $Y = \left(Y_{ij}\right)_{m \times n} = B \cdot E$, and the row comparison is constructed to form a partial order relationship.
Step 3: Construct a partial order relationship matrix by Eq. (8).
Step 4: Use Eq. (9) to obtain the Hasse matrix, draw the Hasse diagram, and analyze the ordering and structural relationship between schemes.

3 Horizontal Gradient Analysis of Logistics Development

3.1 Evaluation Index of Logistics Development Level

A set of evaluation index system of logistics development level is established through the collation and integration of existing literature and knowledge [19, 20], in which all data are from the statistical yearbooks of 31 provinces in China in 2020, so as to ensure the availability and authenticity of data, and the weights are arranged from left to right in decreasing order. There are two primary indicators, four secondary indicators and 15 tertiary indicators, including: gross domestic product, disposable income, total retail sales of consumer goods, added value of tertiary industry, density of railroad coverage, density of road coverage, ownership of cargo vehicles, total import and export, freight volume, e-commerce sales, express delivery service, average number of students per 100,000 people in colleges and universities, number of postal workers per 10,000 people, and Internet broadband access. The number of employees in the postal industry, the number of Internet broadband access ports, and the telephone penetration rate (see Table 1).

3.2 Partial Order Hasse Diagram of Logistics Development Level

Operation process.

The raw data were normalized, and $y = x - \min(x)/\max(x) - \min(x)$ was applied to eliminate the effect of magnitude to obtain Table 2. Where y is the value after normalization of x, $\max(x)$ is the maximum value in a column of indicators, and $\min(x)$ is the minimum value in a column of indicators.

The data in Table 2 are calculated by Eq. (7) to obtain the cumulative transformation matrix (see Table 3). The data in Table 2 cannot be compared visually, which province or city is better, but after the cumulative transformation, the relationship between the provinces and cities can be seen more visually.

After the comparison of rows and rows, the bias relationship matrix is constructed according to Eq. (8) (see Table 4). The bias relationship can be understood as a comparative relationship to a certain extent, if the data of each index of study object A are greater than that of study object B, then study object A is better than study object B. For example, in Table 3, the data of each index of Beijing are greater than or equal to that of Tianjin, then Beijing is better than Tianjin.

Table 1. Logistics development indicators

Level 1 indicators	Secondary indicators	Tertiary indicators	code
Logistics industry development foundation	Economic Development Level	Total production value (RMB)	X1
		Disposable income (RMB)	X2
		Total retail sales of consumer goods (million yuan)	X3
		Tertiary industry added value (million yuan)	X4
	Infrastructure Level	Railroad cover density (Km/Km^2)	X5
		Road cover density (Km/Km^2)	X6
		Ownership of cargo vehicles (units)	X7
Degree of development of logistics industry	Related Industry Development Level	Total Import and Export (USD)	X8
		Cargo volume (t)	X9
		E-commerce sales (million)	X10
		Courier business volume (pieces)	X11
	Industrial Development Level	Average number of students per 100,000 people in colleges and universities (persons)	X12
		The number of postal workers per 10,000 people (people)	X13
		Number of Internet broadband access ports (pcs)	X14
		Telephone penetration rate (%)	X15

The final partial order relationship matrix is transformed into the final Hasse matrix by Eq. (9) and the Hasse diagram under this indicator is drawn, so that the level of logistics development in 31 provinces and cities can be analyzed more visually (see Fig. 3).

Hasse chart results interpretation.

The Hasse diagram (Fig. 3) visualizes the structured information among the provinces. The Hasse diagram in Fig. 3 has ten layers, and according to the division principle of 30%, 40% and 30%, the ten layers can be divided into three gradients, and the logistics development level in the first echelon are the first three layers Guangdong, Jiangsu, Shandong, Beijing, Shanghai and Zhejiang; the logistics development level in the second echelon are the fourth to seventh layers: Fujian, Sichuan, Henan, Tianjin, Hebei, Anhui and other provinces and cities; the logistics development level in the third

Table 2. Raw data normalization

region	X1	X2	X3	X4	…	X12	X13	X14	X15
Beijing	0.31	0.95	0.33	0.47	…	1.00	0.94	1.00	0.37
Tianjin	0.11	0.45	0.07	0.13	…	0.75	0.15	0.83	0.28
Hebei	0.31	0.13	0.30	0.28	…	0.31	0.21	0.78	0.14
Shanxi	0.15	0.09	0.15	0.13	…	0.31	0.13	0.72	0.28
Inner Mongolia	0.14	0.22	0.10	0.12	…	0.16	0.15	0.69	0.50
…	…	…	…	…	…	…	…	…	…
Shaanxi	0.22	0.11	0.22	0.19		0.68	0.30	0.12	0.44
Gansu	0.06	0.00	0.07	0.06	…	0.29	0.14	0.08	0.26
Qinghai	0.01	0.07	0.00	0.01	…	0.00	0.02	0.04	0.20
Ningxia	0.02	0.10	0.01	0.02	…	0.31	0.01	0.02	0.30
Xinjiang	0.11	0.07	0.06	0.10	…	0.21	0.10	0.00	0.04

Table 3. Accumulation transformation matrix

region	X1	X2	X3	X4	…	X12	X13	X14	X15
Beijing	0.31	1.26	1.59	2.06	…	5.14	6.08	7.08	7.45
Tianjin	0.11	0.56	0.64	0.76	…	2.06	2.21	3.04	3.33
Hebei	0.31	0.44	0.75	1.03	…	4.16	4.37	5.14	5.29
Shanxi	0.15	0.24	0.39	0.52	…	2.45	2.58	3.30	3.58
Inner Mongolia	0.14	0.36	0.46	0.58	…	3.03	3.18	3.87	4.37
…	…	…	…	…	…	…	…	…	…
Shaanxi	0.22	0.33	0.56	0.75	…	3.01	3.32	3.44	3.88
Gansu	0.06	0.06	0.14	0.20	…	1.56	1.71	1.78	2.04
Qinghai	0.01	0.08	0.08	0.09	…	0.51	0.52	0.56	0.76
Ningxia	0.02	0.12	0.14	0.15	…	0.79	0.79	0.82	1.12
Xinjiang	0.11	0.18	0.24	0.33	…	1.99	2.09	2.09	2.13

echelon are the last three layers: Guizhou, Jilin, Heilongjiang and other provinces and cities.

From the above gradient division, we can see that the level of logistics development in 31 provinces and cities in China has differences, and the areas with higher level of economic development have not lower level of logistics development, in order to find the relationship between the two, the data of gross product of each province in the original data were selected for correlation test. Statistics found that there is correlation between logistics development level and economic development level, the correlation

Table 4. Partial order relationship matrix

region	X1	X2	X3	X4	…	X12	X13	X14	X15
Beijing	1.00	1.00	0.00	1.00	…	1.00	1.00	1.00	1.00
Tianjin	0.00	1.00	0.00	0.00	…	0.00	1.00	1.00	0.00
Hebei	0.00	0.00	1.00	1.00	…	1.00	1.00	1.00	1.00
Shanxi	0.00	0.00	0.00	1.00	…	1.00	1.00	1.00	0.00
Inner Mongolia	0.00	0.00	0.00	0.00	…	1.00	1.00	1.00	1.00
…	…	…	…	…	…	…	…	…	…
Shaanxi	0.00	0.00	0.00	1.00		1.00	1.00	1.00	1.00
Gansu	0.00	0.00	0.00	0.00	…	1.00	0.00	0.00	0.00
Qinghai	0.00	0.00	0.00	0.00	…	0.00	1.00	0.00	0.00
Ningxia	0.00	0.00	0.00	0.00	…	0.00	0.00	1.00	0.00
Xinjiang	0.00	0.00	0.00	0.00	…	1.00	1.00	1.00	1.00

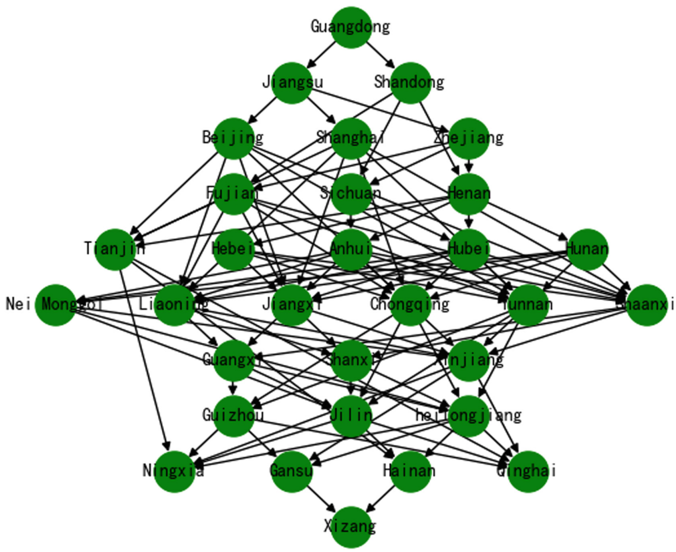

Fig. 3. 31 Sorting of Hasse diagrams of provinces and cities

coefficient is 0.953, and the significant correlation is 0.00 < 0.05, so it shows that logistics development level and economic development level are mutual influence and interaction, that is, the improvement of China's logistics development level can drive the economic development level to improve, and vice versa, the improvement of economic development level can drive the flow development level to improve.

Therefore, the development of the logistics industry can be adjusted appropriately according to the development of the city's economy to promote the common development of logistics and economy. Cities in the first echelon have a high level of economic development and balanced development of various indicators, so they can obtain a more advanced ranking, but still need to start from the whole and develop in coordination with neighboring provinces. Cities in the second and third echelons, most of these cities are inland cities, and there are jagged differences in 15 indicators, especially in the degree of development of the logistics industry, because these areas do not have the same high level of economic development and urbanization as the first echelon cities, but they score higher in certain indicators, such as Xinjiang, in the indicator of car ownership, which is due to geographical factors as well as national policies caused by these advantages, it can rely on these advantages to strengthen infrastructure construction, achieve special development, improve the level of economic development, and then pursue the intelligent and technological development of logistics.

4 Conclusion

The partial-order set evaluation method is applied to study the gradient of logistics development level of 31 provinces and cities in China in 2020 to provide a reference basis for their better development. While improving the robustness of the ranking, this study analyzes and finds that the logistics development level of 31 provinces and cities in China: (1) has a hierarchical character, ten levels are shown by Hasse diagram, and the logistics development level of each level decreases from top to bottom, and is not comparable between the same level. (2) With obvious gradient characteristics, the ten levels can be divided into three echelons, among which Guangdong, Jiangsu and Shandong are the first echelon at the top of the ladder, and Tibet and other places are the third echelon at the end of the gradient. (3) The correlation coefficient between the level of logistics development and the level of economic development is 0.953, and there is a correlation between the two. Although the current study considers 15 three-level indicators of urban logistics development level, it can continue to be improved in the future to build a more comprehensive evaluation system.

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