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Early-warning of socioeconomic-traffic resource-environment compound system carrying capacity in Yangtze River Economic Belt

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Abstract. Socioeconomic, traffic resources and environment have mutual effects on each other and constitute a dynamic open compound system. Based on principles of indicator selection, this paper built an early-warning indicator index of Socioeconomic-Traffic Resource-Environment compound system carrying capacity, used relative entropy to carry out weights of indicators and established a complex matter-element model. This paper took nine provinces and cities in Yangtze River Economic Belt for example and judged the early warning status of carrying capacity of the compound system and its subsystems in 2016. The results could commendably reflect the actual situation of regional carrying capacity status. The indicator index and model could be regarded to be reasonable. The early warning results may indicate directions for formulating regional policies and measures to deal with the various problems of inadequate carrying capacity.

1. Introduction

The Yangtze River Economic Zone spans three major regions of China, including Shanghai, Chongqing and other provinces and cities. The population and GDP of this region are both over 40% of the total amounts, and it has become one of the regions with the strongest comprehensive strength and the most powerful strategic support in China. At present, the concept of "Ecological Priority and Green Development" has become a consensus in the development of the Yangtze River Economic Zone. It can be regarded as a dynamic and open composite system composed of the interaction of social economy, traffic resources and environment subsystems. From the perspective of green development, it is urgent to study the carrying capacity of each subsystem and the compound system.

About the compound system of social economy, resources and environment, scholars have studied it mainly from the perspectives of system coordination, sustainable development and carrying capacity of resources and environment system. Lu[1], Li[2] and others used grey relational entropy model and ARIMA model to predict the coordination degree between economy, resources and environment. Ma [3], Grossman[4], Slessor[5], Fan[6] and so on have studied the correlation between resources and population, economy and environmental pollution; Li[7], Daniel[8], Shi[9], Jiao[10], Jiang[11] have respectively studied the water environment, tourism resources, water and soil resources, port traffic resources, comprehensive traffic resources and environmental carrying capacity. It can be seen that there are few studies on the carrying capacity of socioeconomic, transportation resources and environmental compound system, and the early warning research on the carrying capacity is even



more rare. Therefore, this paper combines the complex matter-element analysis with the correlation entropy theory to construct an early warning model of the carrying capacity of the socioeconomic, transportation resources and environment compound system.

2. Index system construction and early warning level setting

2.1. Construction of index system






In order to carry out early warning research on the carrying capacity of socioeconomic, transportation resources and environment compound system, we should establish the index system first. Based on the principles of scientific, completeness, objectivity, data comparability and data availability, and referring to other scholars' research results on DPSIR[12] model, PSR[13] model and other related research results[14], this paper selects 16 indicators (seen in Table 1). The index type "+" represents the benefit index (the greater the better), and "-" represents the cost index (the smaller the better).

Table 1. Early warning index system.

	Index	unit	Code	Index type
Social economic system	GDP per capita	yuan per capita	C ₁	+
	GDP growth rate	%	C ₂	+
	Density of Population	population per km ²	C ₃	-
	Growth Rate of Population	%	C ₄	-
Transportation resource system	Road area per capita	m ²	C ₅	+
	Proportion of roads above grade two	%	C ₆	+
	Public transport vehicles owned by every 10000 people	standard vehicles	C ₇	+
	Urban road network density	km per km ²	C ₈	+
	Vehicle ownership density	vehicle per km	C ₉	-
Environmental system	Nitrogen oxides emissions per vehicle	ton per car	C ₁₀	-
	Carbon monoxide emissions per vehicle	ton per car	C ₁₁	-
	Carbon hydride emissions per vehicle	ton per car	C ₁₂	-
	Average equivalent sound level of traffic environment	dB(A)	C ₁₃	-
	Green coverage rate	%	C ₁₄	+
	Greening area per capita	m ² per capita	C ₁₅	+
	Percentage of environmental investment to GDP	%	C ₁₆	+

2.2. Warning level setting

Table 2. Warning level setting.

Carrying capacity	unbearable	weak unbearable	weak bearable	bearable	strong bearable
Early warning Degree	giant	heavy	middle	light	no
Early warning Index	[8,10]	[6,8)	[4,6)	[2,4)	[0,2)
Early warning Color	Red	Orange	Yellow	Blue	Green
Early warning Sign					
Benefit Index	$\leq S_4$	$(S_4, S_3]$	$(S_3, S_2]$	$(S_2, S_1]$	$> S_1$
Cost Index	$\geq S_1$	$[S_2, S_1)$	$[S_3, S_2)$	$[S_4, S_3)$	$< S_4$

Setting warning level is important when judging the early warning status of carrying capacity. In this paper, the status is divided into five grades: unbearable, weak unbearable, weak bearable, bearable and strong bearable. The corresponding warning levels are giant, heavy, middle, light and no warning. The warning index is between [0,10]. The warning colors and symbols are shown in Table 2. Referring to the Evaluation Index System of Urban Road Traffic Management (2012 edition) and relevant research results, this paper sets the early warning levels for each index, as shown in Table 3.

Table 3. Warning level standard of each index.

Index Code	giant	heavy	middle	light	no
C ₁	≤10000	(10000,15000]	(15000,30000]	(30000,50000]	>50000
C ₂	≤4	(4,6]	(6,8]	(8,10]	>10
C ₃	≥1000	[800,1000)	[500,800)	[200,500)	<200
C ₄	≥12.5	[11,12.5)	[9,11)	[5,9)	<5
C ₅	≤4	(4,8]	(8,12]	(12,16]	>16
C ₆	≤3	(3,9]	(9,15]	(15,20]	>20
C ₇	≤6	(6,9]	(9,12]	(12,15]	>15
C ₈	≤0.5	(0.5,0.9)	(0.9,1.2]	(1.2,1.5]	>1.5
C ₉	≥400	[270,400)	[180,270)	[100,180)	<100
C ₁₀	≥120	[80,120)	[50,80)	[30,50)	<30
C ₁₁	≥380	[300,380)	[240,300)	[180,240)	<180
C ₁₂	≥60	[45,60)	[30,45)	[25,30)	<25
C ₁₃	≥75	[70,75)	[65,70)	[60,65)	<60
C ₁₄	≤25	(25,30]	(30,35]	(35,40]	>40
C ₁₅	≤3	(3,6]	(6,9]	(9,12]	>12
C ₁₆	≤1	(1,2]	(2,3]	(3,5]	>5

The actual value of each index should be properly handled to make it within the warning levels. This paper defines S_1 、 S_2 、 S_3 、 S_4 as critical values of warning levels of each index($S_1 > S_2 > S_3 > S_4$).

Taking the benefit index for example, the calculation formulas of each index are as follows:

$$\begin{cases} u_{ij} = 8 + 2 \times (S_4 - x_{ij}) / S_4, (x_{ij} \leq S_4) \\ u_{ij} = 8 + 2 \times (S_4 - x_{ij}) / (S_3 - S_4), (S_4 < x_{ij} \leq S_3) \\ u_{ij} = 6 + 2 \times (S_3 - x_{ij}) / (S_2 - S_3), (S_3 < x_{ij} \leq S_2) \\ u_{ij} = 4 + 2 \times (S_2 - x_{ij}) / (S_1 - S_2), (S_2 < x_{ij} \leq S_1) \\ u_{ij} = 2 + 2 \times (S_1 - x_{ij}) / S_1, (x_{ij} > S_1) \end{cases} \quad (1)$$

Where x_{ij} is actual value of the index, u_{ij} is the results. If $u_{ij} < 0$, then u_{ij} is 0, if $u_{ij} > 10$, then $u_{ij} = 10$.

3. Model construction of early warning for carrying capacity

3.1. Correlation entropy

Correlation entropy theory can be used to determine weights and the index value should be normalized. The processing methods of benefit and cost indexes are as follows:

Benefit index:

$$\xi_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad (2)$$

Cost index:

$$\xi_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad (3)$$

Where ξ_{ij} is the standardized index, $\max_i x_{ij}$ 、 $\min_i x_{ij}$ are the maximum and minimum values of indicators i respectively. When $y_j = \max_{1 \leq i < m} \xi_{ij}$, $j = 1, 2, \dots, n$, and at that time there was a reference sequence $Y = \{y_1, y_2, \dots, y_n\}$, then the correlation coefficient is:

$$\delta_{ij} = \frac{\min_i \min_j |\xi_{ij} - y_j| + 0.5 \max_i \max_j |\xi_{ij} - y_j|}{|\xi_{ij} - y_j| + 0.5 \max_i \max_j |\xi_{ij} - y_j|} \quad (4)$$

The information entropy is:

$$F_j = -(\ln n)^{-1} \sum_{i=1}^m \left(\frac{\delta_{ij}}{\sum_{i=1}^m \delta_{ij}} \times \ln \frac{\delta_{ij}}{\sum_{i=1}^m \delta_{ij}} \right) \quad (5)$$

The variation coefficient is $k_j = 1 - F_j$, then the weight of indicator j is:

$$w_j = k_j / \sum_{i=1}^n k_j \quad (6)$$

3.2. Complex matter-element model

Matter-element is the basic element described by three elements: objects(M), characteristics(C) and values(V) [15].

$$R = \begin{bmatrix} M \\ C \quad u \end{bmatrix} \quad (7)$$

Suppose that the amount of characteristics of object is n , recorded as C_1, C_2, \dots, C_n respectively. The corresponding values of each characteristic are u_1, u_2, \dots, u_n respectively, then R_n is called n -dimensional matter-element.

$$R_n = \begin{bmatrix} M \\ C_1 \quad u_1 \\ C_2 \quad u_2 \\ \dots \quad \dots \\ C_n \quad u_n \end{bmatrix} \quad (8)$$

If the amount of objects is m , and u_{ij} stands for the characteristic(j) value of the object(i), then R_{mn} represents the complex matter-element:

$$R_{mn} = \begin{bmatrix} M_1 & M_2 & \dots & M_m \\ C_1 & u_{11} & u_{21} & \dots & u_{m1} \\ C_2 & u_{12} & u_{22} & \dots & u_{m2} \\ \dots & \dots & \dots & \dots & \dots \\ C_n & u_{1n} & u_{2n} & \dots & u_{mn} \end{bmatrix} (i = 1, 2, \dots, m; j = 1, 2, \dots, n) \quad (9)$$

3.3. Early warning model of carrying capacity

According to the index weight coefficient and the complex matter-element model, the early-warning degree can be calculated:

$$V = w_j \times R_{mn} = \left(\sum_{j=1}^n w_j \delta_{1j}, \dots, \sum_{j=1}^n w_j \delta_{mj} \right) = (V_1, V_2, \dots, V_m) \quad (10)$$

According to the early warning interval, the early warning status can be judged.

4. Empirical study of the Yangtze River Economic Belt

In this paper, seven provinces and two cities in the Yangtze River Economic Belt (Shanghai: coded by M_1 , Jiangsu: M_2 , Hubei: M_3 , Anhui: M_4 , Hunan: M_5 , Jiangxi: M_6 , Sichuan: M_7 , Chongqing: M_8 and Yunnan: M_9) were selected. The indicators were derived from China Statistical Yearbook, China Urban Statistical Yearbook, Environmental Statistical Yearbook and China Motor Vehicle Pollution Prevention and Control(2017). The actual values are processed by relevant formulas. The weight of each index can be calculated. According to the weights and model, the early-warning indexes of the compound system and subsystems are judged. The results are shown in Tables 4 and Figure 1.

Table 4. Early warning of carrying capacity in Yangtze River Economic Belt.

	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
Comprehensive sign	3.68	2.92	4.38	4.30	4.22	5.35	4.49	4.16	5.71
Social economy sign	2.86	2.61	2.95	3.40	2.91	3.44	2.75	2.90	3.48
Traffic resource sign	3.73	2.52	4.50	4.89	4.67	5.76	6.44	4.37	6.53
Environmental sign	4.06	3.43	4.31	4.30	4.42	5.50	4.21	4.17	5.69

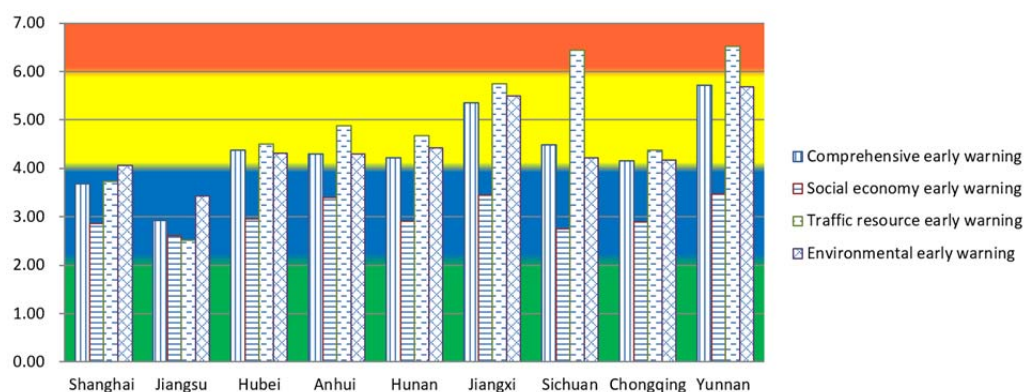


Figure 1. Early warning of carrying capacity in Yangtze River Economic Belt.

As can be seen in Table 4 and Figure 1, the comprehensive early warning level of carrying capacity of Shanghai and Jiangsu is light, and the other regions is middle. About the carrying capacity of social economic subsystem, all regions are light, indicating that social and economic development in the Yangtze River Economic Belt is healthy. In terms of carrying capacity of traffic resources subsystem, status of Shanghai and Jiangsu is light, because they have formed relatively mature transportation networks with relatively large investment in traffic construction; status of Sichuan and Yunnan is heavy for the serious shortage of traffic infrastructure construction; and other regions are middle policemen, and should continue making efforts to increase transport infrastructures. As for the carrying capacity of environment subsystem, status of Jiangsu is light; the other regions are all middle, traffic pollutions in these areas are serious or the pollution control measurements are insufficient, so corresponding policies and measures should be taken.

5. Conclusions

Drawing on DPSIR, PSR model and other research results, this paper chose indexes of social economy, traffic resources and environment, and construct an early warning index system of carrying capacity of

the compound system. The index weights were calculated by correlation entropy, and the matter-element model of carrying capacity early warning was established. Taking the Yangtze River Economic Belt for example, this paper evaluated the early warning status of the carrying capacity of the compound system and its subsystems in various regions. The evaluation results have a clear practical significance, can better reflect the actual situation of the carrying capacity of the socioeconomic-traffic resources-environment compound system, and can also provide a direction for the formulation of policies and measures to deal with the various problems of insufficient carrying capacity. The index system and model have strong practicability and operability, and have guiding significance for realizing the coordination and sustainable development of social economy, traffic resources and environment.

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