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Study of Fuzzy Evaluation Method on Ecological civilization construction Based on Grey Interval Number

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Abstract

Ecological civilization evaluation is an important part of the sustainable development strategy. However, because of subjective and objective reasons, it is becoming increasing clear that much data or information is of poor quality, which has serious effects on the research results. With the analysis on the cause and process of the low quality data, this article presents a fuzzy evaluation method based on gray interval number, which would assess the ecological civilization performance. The application of data-gray-correction model could change the original statistics into gray interval number to reduce the influence of statistical error. A modified FAHP is used to capture and convert experts' subjective judgment. A modified TOPSIS on three parameters interval-valued sets is applied to rank the objects. The research show that: corrected gray interval number could contain much more information than original crisp data; compared to traditional assessment algorithms, results by fuzzy evaluation method based on interval number would match more reality.

Keywords: *information quality; gray interval number; ecological civilization evaluation.*

1. Introduction

At the age of industry civilization, although human society have obtained enormous economic achievements, conflicts between economic development and the environmental protection becomes increasingly severe. How to realize sustainable development has become the most urgent problem needed to solve. The Chinese government sized up the situation and proposed a new development strategy which takes the ecological civilization construction as nucleus. Hu[1] said in the 18th National Congress report that promoting ecological progress is a long-term task of vital importance to the people's wellbeing and China's future. The "five in one" strategy layout raised in Third Plenary Session of the eighteen reveals that the ecological civilization construction has already become the key point during new period of China Social development.

Scholars have conducted widespread researches in view of the ecological civilization construction. S.Orfanidis[2] designed evaluation index system of coastal waters ecology condition; L.T.Phong[3] compared sustainability of agriculture aquaculture eco-system under different forms and intensity; Joanna Burger[4] discussed the relationship among ecological evaluation, ecological restoration and natural resource harm assessment; Zhang & Lei [5] assessed the development of leisure agriculture with SWOT-AHP model; Guan[6] carried on accessibility analysis about ecological civilization evaluation system with taking Xiamen as example. Gao & Huang[7] conducted assessment research about ecological civilization performance of Jiangsu with equal index weights. Existing

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researches have provided theoretical basis for ecological civilization evaluation based on fuzzy system. However, above researches pay little attention to data quality. As we known, the limitation of investigation techniques, the complexity of study objects and the people's decision-making preference, all of them make it become increasing clear that much information is of poor quality, whether at home or abroad, no industry, company within any industry or any department is immune to the effects of poor quality data. While most effects are barely observable, the cumulative impact of poor data quality is enormous[8]. In order to keep assessment results accurate, it's essential to provide a model to revise the data and reduce the impacts of data distortion[9]. Many researches on data quality control, assessment technologies and management system have been done. Beverly[10] determined the essential dimensions of data for delivering high quality information; Kuchler[11] summarized that the concept of accuracy is often used to describe the quality of a data. Lukasz & Belinda[12] based on the 2-page CRF completed at the 6 week follow-up to assess the recruitment rates, timeliness and completeness of data. So Young Sohn[13] used PLS estimation to determine how the factors might influence customer satisfaction and provided feedback to the responsible statistics agency to improve the quality of statistics. Liu & Huang[14]made use of classical econometric model to simulate the change of time series and evaluate the quality of statistical data. Deng[15] proposed the grey system theory which can solve the problems about "small sample, less information", it focus on objects whose boundary is clear and connotation is vague, deducing unknown useful information from the known incomplete data. Liu[16, 17] further expanded the grey theory application scope, and provided the technical support for the theory realization of ecological civilization gray evaluation. Wang & Zhu[18] found that in fuzzy environment fuzzy assessment results would be more accurate than others.

The main goal of this paper is to propose a new evaluation methodology based on gray interval number for estimating the validity of ecological civilization of 7 administrative regions in East China. This paper includes four parts. Section 2 introduces a new ecological validity assessment index system, combining the "five in one" strategy layout and ecology civilization construction core elements. Section 3 presents the evaluation method, which contains modified FAHP model dynamically calculating index weights, application of data-gray-correction model could change the original data into gray interval number to reduce the influence on final results; A TOPSIS evaluation method on three parameters interval-valued fuzzy sets is applied to rank the units. Section 4, an illustrative example on seven administrative regions in East China is used to demonstrate the ecology civilization evaluation process in above method. Section 5gives the conclusion and suggestions.

2. Ecology Civilization Construction Evaluation System

Ecological civilization is a new stage of the development of human civilization, which takes harmonious between human and nature as the core principle and the coordinated development of economic, political, cultural, social and ecological civilization as the goal.

2.1 The Principle of Index Selection

Index selection is the basis for evaluation problem. The scholars have put forward a series of the principles for selection, which can be roughly divided into three categories: ① **universality**. Wang[19] proposed three principles of simplicity, dynamics and operational; ② **pertinence**. Guan[20] considers that index should be satisfied with systemic and regional, comprehensive and representative, scientific and practical, pertinence and characteristic, orientation and creativity. ③ **comprehensiveness**. Wang[21] points out that index system should meet the integrity, independence, operability, guidance and purposiveness. However, the existing researches lack principles of index selection for ecological civilization construction.

Based on current literatures and combined with the goal of provincial ecological construction in China, this paper provides six principles as follow:

(1) **Purposiveness**: index selected must be consistent with the overall target of ecological civilization evaluation in China;
(2) **Systemic**: index system could describe characteristic of ecological civilization in system, comprehensive and science;
(3) **Independence**: index should be set up without content cross;
(4) **Regional**: index selection must take fully into account geographical characteristics in China;
(5) **Operability**: take the acquisition of data as the first essential factor and index selected should be convenient for application;
(6) **Guidance**: the index system should be able to provide guidance for future ecological civilization construction.

2.2 The Selection of Index for Evaluation

According to the principle of index system selection for ecological civilization construction evaluation, combined with the general design of "five in one" development layout and connotation of ecological civilization, this paper constructs index system applied for China provincial ecological civilization evaluation, as shown in table 1.

As we can see in Table 1, the overall goal of ecological civilization construction can be divided into four parts: ecological- baseline, ecological-efficiency, ecological-humanity, ecological-investment, containing 23 indicators. Ecological-baseline is foundation of evaluation for ecological civilization construction, reflecting the basic situation to the human life; with this basis, can we reflect the core concept of ecological civilization construction, which is the harmonious and sustainable development of politics, economy, culture, society and ecology. Then, through studying on ecological efficiencies, ecological humanities, ecological investment, we could reflect the performance of ecological civilization construction, as shown in fig.1. In addition, there is a significant positive correlation between ecological baseline as foundation and ecological efficiency, ecological humanity, ecological investment as effect. Basic index can directly restrain effect index, meanwhile, the effect index can affect the change of basic index in the future, which is called bi-directional dynamic characteristic of evaluation index system for ecological civilization construction. The characteristic also reflect two spiral evolution of ecological civilization, which is reciprocal causation bidirectional response mechanism of development foundation and development achievements in the construction of ecological civilization. Besides, this is the key difference between the construction of ecological civilization evaluation and other general affairs evaluation.

According to the selection of index hierarchy system, we design the indicators section based on the selection principles of evaluation index system for ecological civilization construction. Specifically:

(1) **Ecological-baseline**: It is the foundation of ecological civilization construction, also the final result. Ecological civilization construction reflects the living environment which is comfortable, healthy and safe. This paper describe the basic situation of ecological by forest, green, water, air, solids waste, environment clean and water and soil erosion.
(2) **Ecological-efficiencies**: It is the guarantee of ecological civilization construction. Ecological civilization should make resource utilization improving and

environment pollution reducing, keep economic growth and environmental protection developing. In order to reflect this requirement, this paper chooses GDP per capita, the rate in GDP of tertiary industry, water consumption, energy consumption and solids waste emissions for per unit of GDP, chemical oxygen demand in waste water, sulfur dioxide in exhaust gas and so on.

(3) **Ecological-humanity**: It is the background of ecological civilization construction, containing political, cultural and social three aspects. Considering that: ① the political achievements are difficult to quantify and access, meanwhile, the consequent of the political construction can be reflected by social and cultural construction achievements; ② cultural development results can be internalized into the achievements of social construction; ③ There are logical relationship among index system capacity, availability of data and indexes themselves, this paper measure the performance of socialist spiritual civilization in science, education, culture and health four aspects, mainly containing patent number, proportion of investment in education, proportion of higher education, the number of medical technical personnel and so on.

Table 1. Evaluation Index System for Ecological Civilization Construction

Object	Criteria	Indicator		unit
ecological civilization construction C	Ecological baseline C1	C11	Forest coverage	%
		C12	Per capita public green area	%
		C13	Rate of Sweeping cleaning area	%
		C14	Surface water quality	%
		C15	Rate of days of air quality equal to or above Ⅱ	%
		C16	Rate of solid waste utilization	%
		C17	Rate of soil erosion	%
	Ecological efficiency C2	C21	GDP per capita	ten thousand
		C22	Rate in GDP of tertiary industry	%
		C23	Unit GDP water consumption	cubic meters per million
		C24	Unit GDP energy consumption	million tons of coal/ million
		C25	In units of GDP emissions of solid waste	ton/million
		C26	In units of GDP emissions of chemical oxygen demand	ton/million
		C27	In units of GDP emissions of sulfur dioxide	ton/million
	Ecological humanity C3	C31	Total of three kinds patent licenses	part piece /person
		C32	Rate in GDP of education investment	%
		C33	Percentage of equal to or above college educated	%
		C34	Per thousand of population health	person

		technician	
Ecological investment C4	C41	Rate in GDP of forestry construction investment	%
	C42	Rate in GDP of industrial pollution control investment	%
	C43	Rate of living garbage harmless disposal	%
	C44	Ecological water use rate	%
	C45	Rate of cleaning energy usage	%

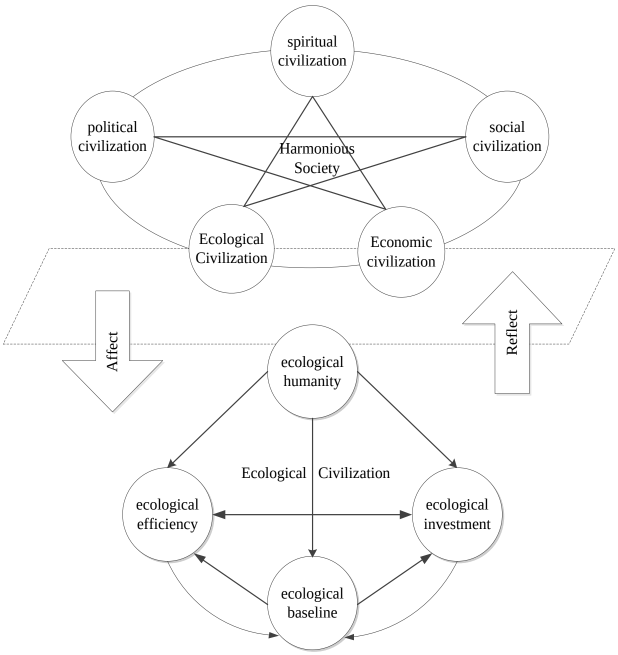

Figure 1. Structure of Evaluation Index System based on "five in one" Development Layout

(4) **Ecological-environment**: It is the motion of ecological civilization construction, which decides the future evolution of the ecological civilization. Matching with the ecological-baseline indications, this paper chooses forestry investment, industrial pollution abatement investment, rate of life waste treatment, rate of ecological water usage, rate of clean energy usage to reflect. The former two indexes reflect the ecological investment in pollution abatement, and the latter three indexes reflect the ecological investment in ecological protection.

3. Evaluation Method Based On Gray Interval Number

3.1 Gray-Interval Data Fitting Theory

Formally, the types of data deviation includes system error, accidental error and personal error[22]. Traditional data correction method mostly test abnormal values or distribution, then chose appropriate model to exclude, ignoring the distortion of other normal data, which are not exactly equal to the real value. Gray–interval data fitting theory, by carrying time series analysis of objects' statistical data sets, data simulation, data assessment and data forecast, can transform the original statistics into gray interval number, whose boundary is clear but connotation is not explicit. Compared with unchanged crisp data, interval number contains much more information and has less negative impacts on the results.

Definition 3.1.1 Let $\otimes$ be gray interval number, which just know about the scope and do not know the exact value. Where $\otimes \in \left[\underline{a}, \overline{a}\right]$, $\underline{a}$ and $\overline{a}$ are range limits. The real value $x*$ is also within this range.

Definition 3.1.2 Let g° be gray degree of $\otimes$,which tends for the uncertainty level on the gray system, and its range is [0, 1]; when use the gray number to estimate the crisp number, $\mu(\otimes)$ is measurement of $\otimes$,the smaller it is, the more correct the result is; $\mu(\Omega)$ is domain where $\otimes$ comes from. Liu[23] proposed the calculation method as:

$$g^{\circ} = \mu(\otimes) / \mu(\Omega) \qquad (1)$$

Definition 3.1.3 Let $\hat{\otimes}$ be nucleus of $\otimes$, where the continuous gray number's nucleus is calculated as:

$$\hat{\otimes} = \frac{1}{2}\left(\underline{a}, \overline{a}\right) \qquad (2)$$

Where $(\tilde{a} \in \hat{\otimes})$,and $\tilde{a} = \left[\underline{a}, a, \overline{a}\right]$. $\underline{a}$ and $\overline{a}$ are the range of the interval , a is real number most likely to be.

The steps of data-gray-correction algorithm can be expressed as follows:

Step1: List the data graphs and observe the time series of indicator for the object. Determine the data series' regression function type—linear or curve estimation. Normally, we do stationary test and unit root test on the time sequence.

Step2: According to the method of trend simulation, establish relationship between variable and independent under the given confidence interval, which is expressed in exponential regression model as:

$$y_t = f(x) + \varepsilon_t \qquad (3)$$

Where $f(x)$ represents the average of y_t changes over time, ε_t is random deviation.

Step 3: According to Liu & Huang[14], we does stationary test on residuals until ε_t come to be stationary. Then model the sequence ε_t and determine the best fitting relationship:

$$\varepsilon_t = m\varepsilon_{t-1} + n\varepsilon_{t-2} \qquad (4)$$

Where *m* and *n* are constant.

Step4: Introduce the best model random deviation's lags in to meta-model, use Eviews to re-estimate the overall relationship and get the final regression equation:

$$\hat{y} = f(x) + m\varepsilon_{t-1} + n\varepsilon_{t-2} \qquad (5)$$

Step5: Based on above functions, calculate the indicator predicted value, the deviation rates over the years P_t and average deviation $\overline{P}$. With the y_t, $\hat{Y}_t$, P_t and $\overline{P}$, we can determine range limits y^-, y^+ and y^*, then make the indicator's interval number expression $\tilde{x}_{ij}$. P_t and $\bar{P}$ are calculated as:

$$P_t = \frac{Y_t - \hat{Y}_t}{Y_t} \times 100\% \ (t = 1, 2, \cdots, l)$$

$$\bar{P} = \frac{1}{l}\sum_{i=1}^{t}|P_i|$$

(6)

Through the above process, we can replace the statistical data with the gray interval data to act as assessment foundation, minding hidden information from the incomplete original crisp number, and improve the description precision of the data system. Yue[24] compared tow results respectively calculated by gray number model and crisp number model in the same situation of incomplete information and inaccurate statistics, and found that the former one is much more accurate.

3.2 Modified FAHP

In a typical AHP method, experts have to give a definite number within a 1-9 scale to the pair-wise comparison so that the priority vector can be computed. However, factor comparisons often involve certain amount of uncertainty and subjectivity. The expert cannot give a definite scale to the comparison because the expert is not sure about the degree of importance of two factors. Sometimes, experts cannot compare two factors due to the lack of adequate information. In this case, a typical AHP method has to be discarded due to the existence of fuzzy or incomplete comparisons. A fuzzy AHP approach may therefore be expected. A Fuzzy AHP is an important extension of the typical AHP method which was first introduced by Laarhoven & Pedrycz[25]. Zeng[26] and Cengiz[27] solved the problems of complicated fuzzy operation and lack of proven techniques to address fuzzy consistency and fuzzy priority vector. In order to fully express the expert's decision preference, this paper proposed a modified pair-wise comparison rule, which let experts give fuzzy judgment not around a scale, but across several ones. For example, scale [1, 9] means the expert cannot compare the two factors at all. FAHP here use standardized trapezoidal fuzzy number (STFN) to capture and convert experts' fuzzy information and subjective judgment. Fuzzy aggregation is used to create group decisions, then defuzzication is employed to transform the STFN scales into crisp scales for the computation of priority weights. The group preference of each factor then calculated by applying fuzzy aggregation operators. The steps to calculate index weights are as below.

Step 1: Measure in the evaluation index system.

Members in the ecological civilization evaluation group are required to provide their judgments on the basis of their knowledge and expertise for each index in the system. The experts can provide a precise numerical value, a range of numerical values, a linguistic term or a fuzzy number. For example, "C11 is equal to C13", "about 6", "(3, 5, 7, 8)".

Step2: Convert preferences into the STFN.

As described in steps1, because the values of index comparisons provided by members in the ecological civilization assessment in various kinds, e.g. a numerical value, a range of numerical value, a linguistic term or a fuzzy number. The STFN is employed to convert these experts' judgments into a universal format for the composition of group preferences. Let $\tilde{A}$ be the universe of discourse, $\tilde{A} = (a, b, c, d)$, where $0 \le a \le b \le c \le d$. The MF is:

$$\mu_{\tilde{A}}(x)=\begin{cases}\dfrac{(x-a)}{(b-a)}, & a\le x\le b\\ 1, & b\le x\le c\\ \dfrac{(d-x)}{(d-c)}, & c\le x\le d\\ 0, & \text{for others}\end{cases}$$

(7)

The aggregation of STFN scales is defined as:

$$\tilde{a}_{ij}=c_1\otimes a_{ij}^{1}\oplus c_2\otimes a_{ij}^{2}\oplus\cdots\oplus c_k\otimes a_{ij}^{k}$$

(8)

Where $\tilde{a}_{ij}$ is the aggregated fuzzy scale of comparing Ci to Cj; $a_{ij}^1, a_{ij}^2, \ldots, a_{ij}^k$ are the corresponding STFN scales of Ci comparing Cj by experts $E_1, E_2, \ldots, E_k$ respectively; $c_1, c_2, \ldots, c_k$ are CFs allocated to experts and $c_1+c_2+\ldots c_k=1, c_k\in[0, 1]$.

Step3: Defuzzify the STFN scales

In order to convert the aggregated STFN scales into matching crisp values that can adequately represent the group preferences, a proper defuzzification is needed. Assume an aggregated STFN scale $\tilde{a}_{ij}=\left(a_{ij}^l, a_{ij}^m, a_{ij}^n, a_{ij}^u\right)$, the matching crisp value a_{ij} can be obtained by

$$a_{ij}=\frac{a_{ij}^l+2(a_{ij}^m+a_{ij}^n)+a_{ij}^u}{6}$$

(9)

Where $a_{ii}=1$, $a_{ji}=1/a_{ij}$.

Step4: Calculate the priority weights of evaluation indicators.

Through above steps, change the fuzzy judgment matrix into crisp one represented by *A*. Priority weights of indicators in the matrix *A* can be calculated by using the arithmetic averaging method[26].

$$A=a_{ij}=\begin{array}{c} \\ F_1\\ F_2\\ F_3\\ F_4\end{array}\begin{array}{c}\begin{array}{cccc}F_1 & F_2 & \cdots & F_n\end{array}\\ \begin{bmatrix}1 & a_{12} & \cdots & a_{1n}\\ 1/a_{12} & 1 & \cdots & a_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 1/a_{1n} & 1/a_{2n} & \cdots & 1\end{bmatrix}\end{array}$$

(10)

Where *i*, *j* = 1, 2, … , *n*.

$$w_i=\frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{kj}}$$

(11)

Where w_i is the section weight of Ci. Assume Ci has x upper section at different level in the index system, and $w_{section}^{(i)}$ is the section weight of ith upper section which contains Ci in the system, the final weight w_i^x can be divided by:

$$w_i^x = \prod_{x=1}^{x} w_i^{\sec tionx}; x = 1, 2, \cdots, y$$

(12)

With this modified FAHP, we can fully obtain the experts decision information and preference, but reduce the expression deviation caused by lack of adequate information, uncertainty or subjectivity.

3.3 Method of Interval Triangular Fuzzy TOPSIS

Yoon and Hwang[28] introduced the TOPSIS method based on the idea that the best alternative should have the shortest distance from an ideal solution. Chen[29] extends the TOPSIS method to fuzzy group decision making situations by considering triangular fuzzy numbers and defining crisp Euclidean distance between two fuzzy numbers. Lan[30] proposed new fuzzy TOPSIS method based on triangular interval number. However, the complicated fuzzy calculation and strict criteria structure have undermined their implementation in practice. This paper propose a new method to calculate the “and” and “or” among the father-criteria and son-criteria: for the same section, the relationship between different criteria is OR; belong to the same criteria, the relationship between different index is AND. An algorithm of the fuzzy decision-making method for ranking as follows:

Step1: Construct a decision matrix.

Suppose an evaluation problem having N objects, expressed by $D_1, D_2, \ldots, D_n$; and M criteria, which are $C_1, C_2, \ldots, C_m$. Each object has an original data set for every indicator, convert these statistics sets into interval number set with method described in 3.1 and construct fuzzy matrix *B*. Normalize and weight the matrix B [31], we get the final decision matrix $\overline{B}$.

$$\overline{B} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}$$

(13)

Where $\overline{B} = \left(\tilde{B}_1, \tilde{B}_2, \cdots, \tilde{B}_m\right)^{\mathrm{T}}$, fuzzy vector $\tilde{B}_i = (\tilde{x}_{i1}, \tilde{x}_{i2}, \ldots, \tilde{x}_{in})$, $\tilde{x}_{in} = \left(a^-, a, a^+\right)$ is interval value of D_i respects to all the indicators.

Step2: Apply the evaluation function E[32] to calculate value $\tilde{b}_i$ of every object assessed. Belong to the same criteria Ci, evaluation unit D_i satisfies that indicators $Ci1$ and $Ci2$ and … and Cil ; for different criteria, D_i obey the regulation $C1$ or $C2$ or … or Ch . There are h criteria in up section and a criteria has l indicators in low section.

This process can be defined as:

$$\tilde{C} = (C_{11} \wedge C_{12} \wedge \cdots \wedge C_{1n_1}) \vee \cdots \vee (C_{l1} \wedge C_{l2} \wedge \cdots \wedge C_{\ln_l}) \vee \cdots \vee (C_{k1} \wedge C_{k2} \wedge \cdots \wedge C_{kn_k})$$

(14)

$$\tilde{b}_i = E(\tilde{B}_i) = (b_i^-, b_i, b_i^+)$$

(15)

$$\tilde{b}_i = \{\left(\tilde{b}_{i11} \wedge \tilde{b}_{i12} \wedge \cdots \wedge \tilde{b}_{i1n_1}\right) \vee \cdots \vee \left(\tilde{b}_{il1} \wedge \tilde{b}_{il2} \wedge \cdots \wedge \tilde{b}_{i\ln_l}\right) \vee \cdots \vee \left(\tilde{b}_{ik1} \wedge \tilde{b}_{ik2} \wedge \cdots \wedge \tilde{b}_{ikn_k}\right)$$

(16)

Step3: Determine positive ideal solution (maximum value on each criterion) and negative ideal solution (minimum value on each criterion) from the weighted normalized decision matrix.

$$V^{+} = \left(\tilde{v}_1^{+}, \tilde{v}_2^{+}, \cdots, \tilde{v}_k^{+}\right)$$

$$V^{-} = \left(\tilde{v}_1^{-}, \tilde{v}_2^{-}, \cdots, \tilde{v}_k^{-}\right)$$

(17)

Step4: Calculate the distance from the positive ideal solution $d(\tilde{b}_i, \tilde{b}^{\Delta})$ to the negative ideal solution $d(\tilde{b}_i, \tilde{b}^{\nabla})$ for each object. The distance between two triangular interval numbers $\tilde{a} = \left(a^{-}, a, a^{+}\right)$ and $\tilde{b} = \left(b^{-}, b, b^{+}\right)$ is showed as

$$d\left(\tilde{a}, \tilde{b}\right) = \frac{\left|a^{-} - b^{-}\right| + \left|a^{+} - b^{+}\right| + \left|a + b\right| + \left|\pi_{\tilde{a}} - \pi_{\tilde{b}}\right|}{3}$$

(18)

Where $\pi_{\tilde{a}} = a^{+} - a^{-}$ is called the unknown degree.

Step5: Work out the closeness coefficient of each object . According to the closeness coefficient to understand the assessment status of each object and determine the ranking order of all them.

$$s_i = \frac{d(\tilde{a}_i, \tilde{a}^{\nabla})}{d(\tilde{a}_i, \tilde{a}^{\Delta}) + d(\tilde{a}_i, \tilde{a}^{\nabla})}, 1 \le i \le m$$

(19)

4. Application and Discussion

In this section, a case example of ecological civilization evaluation on seven administration regions in East China is presented to demonstrated the application of the proposed ecological civilization construction evaluation methodology. Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi and Shandong have struggled for many years to construct the ecological civilization, it's necessary to evaluate their achievement and propose suggestions.

4.1 case calculation

Step1 : gray interval number

There are seven provinces in East China: Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi and Shandong, which are named D_1, D_2, D_3, D_4, D_5, D_6, D_7. According to 3.1 data gray correction model, change the original crisp value into three parameters interval number, and obtains the fuzzy number judgment matrix. e.g. the normalized statistical data related to indicator $C41$ of Shanghai during 2003 and 2010 is [0.22, 0.14, 0.09 0.09, 0.03, 0.03, 0.04, 0.03, 0.04], the transmitted interval number in 2010 is [0.02, 0.06, 0.10].

Step 2: calculate the factors' weights

Ten experts with high qualification regarding this subject are selected to form a ecological civilization construction assessment group for undertaking ecology evaluation by using the proposed FAHP methodology. CF of every experts in this case is equal and be 0.2. Via pair wise comparison, the original evaluation matrix, which is relevant to these areas, is established. By using formula (7) and (8), we obtain matrix in standardized trapezoidal fuzzy number; according to formula (9), we defuzzify the STFN scales and get crisp number judgment matrix. Such as matrix *A* of criteria section shown

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} 1 & 3.250 & 5.625 & 8.167 \\ 0.308 & 1 & 4 & 6.250 \\ 0.178 & 0.250 & 1 & 5.471 \\ 0.122 & 0.160 & 0.185 & 1 \end{bmatrix} \end{array}$$

Then by applying formula (11) and (12), the final weights of the four criteria and 23 indicators are obtained as shown in Table 2.

Table 2. Weights of Index System

criteria	weight	indicator	weight	Aggregation weight	criteria	weight	indicator	weight	Aggregation weight
C1	0.46	C11	0.23	0.105	C2	0.27	C21	0.216	0.058
		C12	0.181	0.083			C22	0.183	0.049
		C13	0.14	0.064			C23	0.098	0.026
		C14	0.113	0.052			C24	0.125	0.034
		C15	0.149	0.068			C25	0.232	0.062
		C16	0.087	0.040			C26	0.100	0.027
		C17	0.1	0.046			C27	0.046	0.0123
C3	0.13	C31	0.25	0.032	C4	0.14	C41	0.325	0.047
		C32	0.20	0.026			C42	0.195	0.028
		C33	0.20	0.013			C43	0.182	0.027
		C34	0.45	0.058			C44	0.213	0.031
							C45	0.085	0.013

Step3: ranking order of objects

Based on interval number matrix *B*, through normalizing and weighting, we get the final decision matrix $\overline{B}$; with the application of formula (14), (15) and (16), we get evaluation function $\tilde{b}_i$, which is relevant to the administrative region D_i; using formula (18) and (19), work out the closeness coefficient of each object and get the final ranking order, the larger S_i is, the better evaluation results is. The ranking orders respectively calculated by three method-Traditional TOPSIS, Gray correlation TOPSIS, and method introduced this paper are shown in Table 3.

Table 3. Ranking Orders of Ecological Civilization Evaluation

Object	Interval number score	$d(\tilde{a}_i,\tilde{a}^{\Delta})$	$d(\tilde{a}_i,\tilde{a}^{\nabla})$	s_i
D1	（1.200,1.200,1.200）	1.020	0.099	0.089
D2	（1.240,1.248,1.261）	0.963	0.142	0.128
D3	（1.400,1.468,1.494）	0.735	0.347	0.320
D4	（1.092,1.120,1.148）	1.081	0	0
D5	（2.147,2.179,2.240）	0	1.081	1
D6	（1.136,1.159,1.232）	1.013	0.069	0.064

D7	（1.233,1.242,1.249）	0.974	0.135	0.122

As we can see from Table 3, the final evaluation result is $s_5 > s_3 > s_2 > s_7 > s_1 > s_6 > s_4$. Therefore, the final ranking order of ecological civilization construction on administrative regions in East China with application of evaluation method based on gray interval number is Fujian > Zhejiang > Jiangsu > Shandong > Shanghai > Jiangxi > Anhui. The evaluation of ecology in Fujian is the best.

4.2 Results and Discussion

(1) Comparison between Different Evaluation Methods

In order to check the rationality and correctness of the proposed algorithm, with the same index system and priority weights, this paper also evaluate these seven administrative regions through traditional TOPSIS and Gray Correlation TOPSIS. The comparison among three evaluation results can be seen in Table 4.

Table 4. Comparison among Different Method

Rank	Traditional TOPSIS	Gray correlation TOPSIS	Interval number TOPSIS
1	Shanghai	Shanghai	Fujian
2	Fujian	Zhejiang	Zhejiang
3	Zhejiang	Fujian	Jiangsu
4	Jiangxi	Jiangsu	Shandong
5	Jiangsu	Shandong	Shanghai
6	Shandong	Jiangxi	Jiangxi
7	Anhui	Anhui	Anhui

Comparing columns in table 4, the outcomes produced by above ways are significantly different. The seven units are sorted into three groups: no.1 belongs to group A; the second one and third one compose group B; group C contains No.4, No5 and No.6; the last region is in group D. Separately compare results of TOPSIS 1 and TOPSIS2, TOPSIS2 and TOPSIS 3, we found that ranking results change significantly: Shanghai falls from group A to group C, Fujian rises from group B to group A, Jiangsu goes up from group C to group B. There are mainly two reasons for this phenomenon: on the one hand, different evaluation algorithm pay different degrees of attention to the index of economic development and environment protection during calculate the overall score of ecological civilization construction; on the other hand, the fuzzy data evaluation method proposed by this paper can increase the information content of statistics through changing the original crisp data into gray interval number and improve the assessment process of original fuzzy TOPSIS method, which makes full use of implicit information and reflects the real situation.

(2) Rationality Analysis of Index Weights

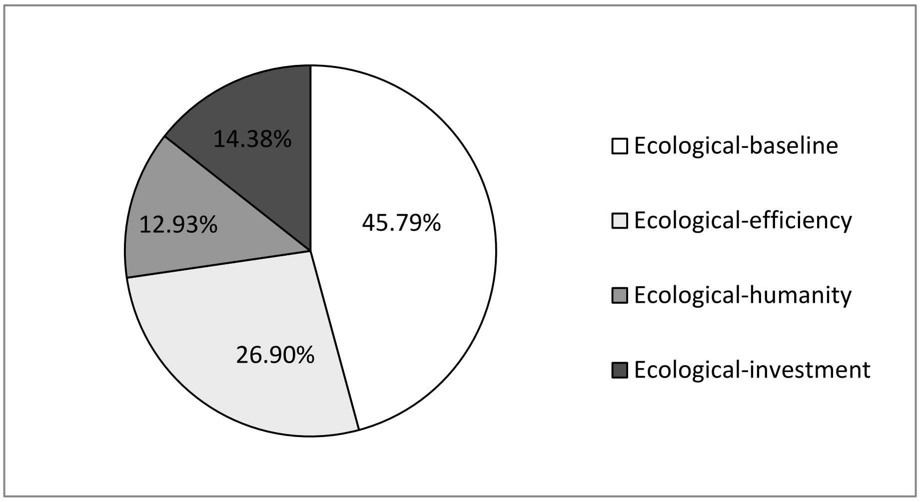

Figure 2. Proportion of Criteria Weights

Fig.2 shows the fuzzy AHP weights of four criteria, Basic-condition, Material-efficiency, Spiritual-civilization, and Ecological-investment, what reflect experts' pair-comparison preference and the final weighting results changing with the experts. As described in the above, we can deduce something as fellow. Firstly, , the weight on Basic-condition is near 50%, what reveal people's attention to issues such as environmental pollution, resource shortages are on the rise. The grate importance of environment and natural resources has become main preference when a person is making decisions. This distribution is also consistent with social development status-conflicts between economic develop and environmental protection- in China, whose characteristic are "conflicts among human" and "conflicts between human and nature". Weight of Material-efficiency comes in second, which tells us most people have the same awareness of the concept that the essence of ecological civilization construction is to liberate and develop the productive forces. Therefore we must construct ecological civilization in a way to enhance the efficiency. Weights of Spiritual-civilization and Ecological-investment are close and far below the other two, what demonstrate that superstructure of ecological civilization construction has not drawn enough attention. On the other hand, not only promoting positive role of propaganda and law in the aspects of science, education, cultural and health, but also Active exploration and effective practice in the area of environmental protection investment and financing, all of them could improve construction efficiency and ensure the development sustainability.

(3) Regional Analysis of Index Weights

Criteria weights of seven administrative regions in East-China are shown in Fig.3. As we can see from this column, we found that: ① Development gap between different regions is very obvious. The scores of the same criteria in different areas are obviously different. Because the natural environment, resource conditions and development strategy are different, the efforts and results of ecological construction in these provinces exhibit different characteristics. Compared among seven districts, every data set has a wide range and large variance, the former is over 0.8 and the latter is greater than 0.08, what demonstrate large achievement gaps exist , especially in the construction of spiritual civilization. ② Each area has distinct development weak point.

As we can see in above chart, for one place, its four types of construction achievement rankings change greatly. For example, Shanghai ranked first in basic-condition but last in spiritual-civilization, case in Anhui and Jiangxi Similarly. However, ecological civilization construction in Zhejiang is more reasonable. On the one hand, the industrial structure is reasonable, dominated by light industry, processing industry and the collective industry, coordinated development of agriculture, fisheries, and so on. On the other hand, comparatively good quality of population and development environment is also powerful ecological civilization construction support.

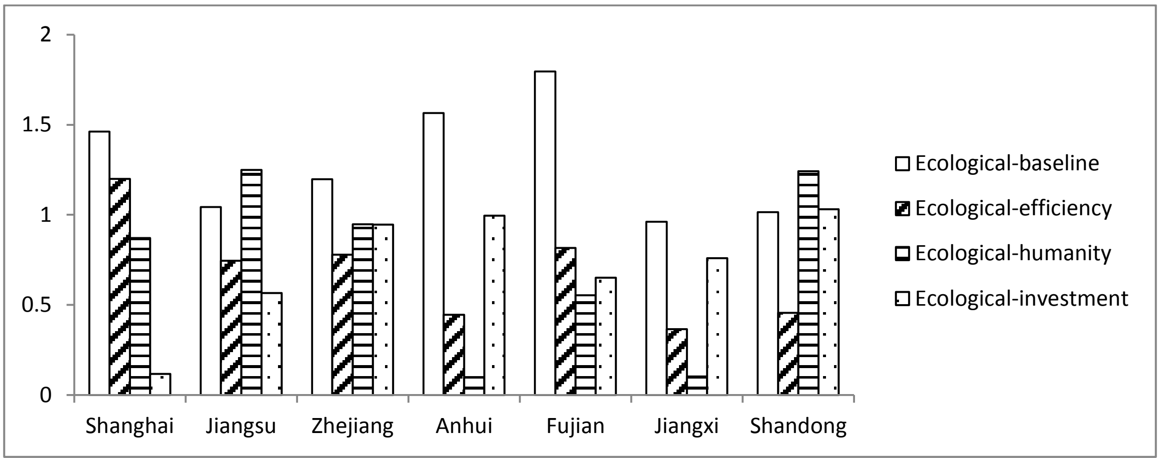

Figure 3. Distribution of Criteria Scores

(4)Regional Analysis of Ecological Construction Achievement

As demonstrated in Fig.4, ecological civilization not only affected by regional economic development and natural conditions, but also significantly associated with geographical location. ① The ranking order of seven provinces is generally declining from south to north and coastal area to inland area. From the point of geographical features, south areas are famous for rainy and forestry, which contribute to good natural environment and developed agriculture; large proportion of territory are plains and hills, which lead to convenient transportation and prosperous trading. Furthermore, comfortable social and natural environment could attract more excellent people. Consequently, modern economic, education, science and technology all rise and flourish, society form into a benign development model. Consider that the essence of ecological civilization construction is liberation and expansion of the productive forces, productivity promotion has a signification influence to enhance ecological civilization construction, therefore, southern areas with above features-Fujian, Zhejiang and Jiangsu could have good ecological civilization performance. ② The basis for ecological civilization construction has decisive effects on the final evaluation results. Through the compartment between ranking fluctuations of Fujian and Shanghai, we find that ecological civilization is different from industrial civilization, and does not take GDP as the sole criterion. Ecological civilization is a comprehensive concept with economic, natural, social, cultural and so on, which emphasizes sustainability and harmony. Shanghai is good at economic performance, but is weak at ecological baseline and ecological investment, so its final assessment result is behind other four regions. Society and government must pay more attention to the ecological basis and resource protection during ecological construction.

Fig.4 Spatial Differences in Ecological Civilization Construction in East-China

5. Discussion and Conclusion

From the point of data recovery and with application of gray theory, this paper propose a fuzzy comprehensive evaluation method system, which is used for the problem that the deviation of the official statistics data during ecological civilization evaluation would affects the assessment results. The application of data-gray-correction model could change the original data into gray interval number to reduce the influence on final results. A modified fuzzy analytical hierarchy process is used to capture and convert experts' fuzzy information and subjective judgment. A TOPSIS evaluation method on three parameters interval-valued fuzzy sets is applied to rank the units.

(1) Compared with the traditional TOPSIS algorithm and gray correlation TOPSIS ranking algorithm, the fuzzy comprehensive evaluation method can improve the amount of information acquired from original statistics by data-gray-correction model. What's more, it will improve the ability of information processing of fuzzy data by the modified FAHP weighting and modified TOPSIS ranking on interval numbers of three parameters. After all, the evaluation method proposed by this paper could make fuzzy data reflect truth more effective in practice.

(2) By the weights of the four criteria, it can be seen that improved FAHP algorithm can describe the decision preferences of experts more accurately, which make the weighting results satisfy the restriction of objective environment and subjective preference. On the other hand, ecological civilization development in China is not balanced, construction of ecological humanity and ecological investment are insufficient. Under the traditional development concept, most policies are made to promote economic achievement, plans as ecological humanity and ecological investment, which are "long-term investment" , have little effect and couldn't be transformed into economic growth soon, often are ignored by government and people. However, with the quick development, the limited resources and the backward humanity atmosphere would finally constrain social progress. Therefore, "five in one" strategy what means containing economic, political, social, cultural and ecological develops harmoniously is the only way to solve the current predicament.

(3) Compared the for criteria weights of seven regions, it can be shown that: ① the differences of development emphasis among regions are significant; ② the weakness of the ecological civilization construction is obvious, especially in Shanghai, Anhui and Jiangxi, relatively, ecological civilization construction in Zhejiang province is reasonable. Different social and natural background leads to different policy targets and focus in different areas. Ecological baseline is the foundation of ecological civilization. Because of the interaction between four criteria, the other three aspects perform not obviously bad in the region where ecological baseline performs well. The fundamental law of political economy shows superstructure is up to economic level, and Maslow's Hierarchy of Needs also reveal that people will go to the higher hierarchy after satisfied with the lower hierarchy. Therefore, during regional ecological civilization construction, the regions undeveloped invest less in ecological humanity and ecological investment, but more pay emphasis on how to obtain economic achievement with existing resources, as results, ecological civilization construction is unbalanced. The provinces relatively developed have enough resource on science education, culture, and social benefits, environment protection and ecological restoration. Therefore, the construction of a harmonious society means comprehensive development, neither promotion natural protection without the foundation of region development, nor pursuit economic performance without environmental protection; need to establish a long-term development mechanism by the idea of "five in one".

(4) By analyzing the ranking order of the seven administrative regions in ecological civilization assessment, we find that: ① final ranking order of seven objects from the first to the last one is consistent with the pattern that reduces from south to north and from the coastal to inland areas; ② ecological basic situation has decisive role in assessment of ecological civilization construction. Ecological civilization is a win-win development with both social civilization and nature protection, whose consequent is not only related to modernization level, but also based on natural resource. In the perspective of social developmental model, these seven regions, from south to north and from the coastal to inland areas, their major industries gradually change from tertiary industry to agriculture and secondary industry, change from intensive to extensive pattern; in the perspective of natural environment, their topographies vary from plain, stream and vegetation to mountainous and less drier. The more mineral resources the region has, the worse performance ecological civilization has, just like Shandong, Anhui, Jiangxi; the more developed the transportation is, the higher ecological civilization efficiency is. Therefore, in order to overcome the crisis of industrial civilization development, we must reconsider the relationship between social development and resource utilization, and orientate the relationship between the development of ecological civilization era and environment.

As the limitations of article space and the data availability, the evaluation index system for ecological civilization construction raised by this paper is still need to modify. Meanwhile, the data-gray-correction model remains to be tested by strict mathematical logic. Our next step will focus mainly on these two aspects.

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