Regional tourism competitiveness evaluation method based on fuzzy analytic hierarchy process

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Abstract

To promote the regional tourism competitiveness capability, regional tourism competitiveness should be evaluated objectively and accurately, and then provide useful suggestions to support government decision making. Therefore, in this paper, we focus on the problem of regional tourism competitiveness evaluation using fuzzy analytic hierarchy process. In order to enhance the performance of standard AHP, we exploit the fuzzy theory and then make the comparative judgments through trapezoid fuzzy numbers. Seven types of quantitative factors are used in our evaluation model, such as "Essential factors of tourism competitiveness", "Tourism enterprises competitiveness", "Tourism market competitiveness", "Tourism basic industry competitiveness", "Tourism Supporting industry competitiveness", "Government competitiveness", and "Others". Furthermore, trapezoid membership functions are defined for each quantitative factor, and then the level of the regional tourism competitiveness evaluation can be obtained by computing the highest membership utilizing the membership matrix. To demonstrate the effectiveness of our proposed, we collect related data from ten different regions of China using the Statistical yearbook to make dataset. Then, experiments are conducted to make performance evaluation compared with AHP and Fuzzy DEA. Experimental results testify that our proposed fuzzy AHP based method performs better than others.

Keywords: Regional tourism competitiveness, Fuzzy theory, Fuzzy analytic hierarchy process, Membership function, Judgment matrix

1 Introduction

Research of competitiveness ability is belonged to the economic theory, which was originated from the western countries in 1980s. This research can satisfy the trend of economic systematization [1] [2]. Particularly, competitiveness ability study develops rapidly, due to it has attracted by more and more researchers [3]. In China, tourism industry is a new industry with large potentiality, and the investment in tourism increases rapidly. Since 1980, the regional tourism competitive ability has been the hot topic in the domestic and foreign tourism academia [4]. However, the current theoretical research in this area is not satisfied by us, and there are several defects in it.

Under this background, in this paper, we aim to utilize regional competition strategy theories to the development of regional tourism through integrating modern regional competitive capability theory and the regional tourism theory. In order to enhance the regional tourism compe--titive capability, we will try to construct a new elementary theory and evaluation system for regional tourism competitive ability. Afterwards, we will exploit the research findings to support government decision making.

To implement the regional tourism competitiveness evaluation, the fuzzy analytic hierarchy process technology is utilized. Analytic hierarchy process (denoted as AHP) is proposed by Saaty[5], which has been extensively exploited in many application fields, such as performance evaluation, decision making, and state prediction[6][7]. Furthermore, analytic hierarchy process is suitable to solve the problems in complex systems, and then it can make a choice from several alternatives and then gives a comparison of the several options [8]. The standard analytic hierarchy process needs accurate judgments from decision makers. To enhance the accuracy of judgments, fuzzy judgments have been suggested and then fuzzy analytic hierarchy process has been widely utilized in different applications.

Combining the fuzzy theory and the analytic hierarchy process technology, fuzzy analytic hierarchy process is obtained. Fuzzy theory can solve the ambiguous information, which contains the concepts of fuzzy set, membership function, fuzzy numbers and so on[9]. Particularly, fuzzy set theory exploits groups of data with boundaries of different levels. Fuzzy analytic hierarchy process has been proved to be a powerful technology for the field of multiple criteria decision-making[10][11].

The purpose of this paper is to develop a fuzzy analytic hierarchy process based method to evaluate regional tourism competitiveness. The rest of the paper is organized as follows. Section 2 presents literature review of fuzzy analytic hierarchy process application. Section 3 gives preliminaries of the fuzzy analytic hierarchy process. In section 4, fuzzy analytic hierarchy process evaluation model for regional tourism competitiveness evaluation is proposed. Section 5 gives experimental results to demonstrate the effectiveness of the proposed method. Finally, section 6 concludes the whole paper.

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2 Literature review

As the fuzzy analytic hierarchy process is of great importance in this paper, this section will provide related works about the application of analytic hierarchy process and fuzzy analytic hierarchy process.

The key problem of utilizing fuzzy AHP for decision making is how to compute priority vectors from fuzzy pairwise comparison matrices. Some typical works about fuzzy AHP have been done.

Van et al. utilized triangular fuzzy judgments instead of precise judgments and then proposed a logarithmic least squares approach for fuzzy analytic hierarchy process [12]. Boender et al. illustrated that there is a defect in of the algorithm in paper [12] in normalizing fuzzy weights and then proposed an improved normalization approach [13]. Afterwards, the improved normalization approach for logarithmic least squares method can be found in paper [14] by Wang et al. In this paper, the authors proposed a modified fuzzy logarithmic least squares method for fuzzy AHP. Xu et al. presented a logarithmic least squares method for fuzzy judgment matrices, however, logarithmic least squares method is based on a different Euclidean distance metric which is defined as the integral of the distance of every t-level set[15]. Similarly, Xu et al. exploited the same distance metric to design a fuzzy least-square priority approach for fuzzy judgment matrices [16].

Recently, there are more and more researches about applications of fuzzy analytic hierarchy process, and in the following parts we will show them in detail.

Gim et al. utilized fuzzy analytic hierarchy process to evaluate hydrogen storage systems for automobiles in Korea. Particularly, five hydrogen storage systems for automobiles are evaluated using the analytic hierarchy process with eight criteria [17].

Yu et al. applied fuzzy analytic hierarchy process compute the weights of the classification performance indices to evaluate the classification performance. Particularly, the dimensionless transformation restrains the influence of the different dimensions. Afterwards, the comprehensive evaluation value of the classification performance is conducted via a linear weighted approach [18].

Lin et al. proposed a novel method to determinate the criteria weight in a fashion design framework evaluation system. In this work, the authors utilize the fuzzy Delphi method by fashion design experts of academia and Industries for fashion design evaluation criteria. Next, the fuzzy analytic hierarchy process is used to pursue the criteria weight. Then, case study is designed to explain the process of obtaining the criteria weights for the evaluation of a fashion design scheme [19].

Wan et al. proposed an evaluation approach to solve the learning content management systems using a modified fuzzy analytic hierarchy process. In this paper, the authors utilized the fuzzy analytic hierarchy process to choose the best learning content management system, and both qualitative and quantitative criteria are considered. Particularly, all selected teach content management systems were ranked via a defined Trapezoidal Fuzzy Number [20].

To compute the watermark embedding strength in the block-based discrete cosine transform, Jin et al. presented a novel image watermark method based fuzzy comprehendsive evaluation and analytic hierarchy process. Experimental results demonstrate that the proposed algorithm has not only the good robustness to commonly image processing but also the very strong resistant ability to translation and rotation attacks [21].

On the other hand, technique for order preference by similarity to ideal solution (TOPSIS) can be combined with fuzzy analytic hierarchy process to solve many problems. Lin et al. proposed a fuzzy analytic hierarchy process to compute the criteria weight for evaluating fashion design methods. In this paper, technique for order preference by similarity to ideal solution is also designed to compute the index value of each scheme for the best selection of the fashion design [22].

In the field of intelligent hospital information management system construction, fuzzy analytic hierarchy process can be utilized as well. Ho et al. utilizes fuzzy analytic hierarchy process for customers to make weight assessment on evaluation indexes of Health Management Centre [23]. Ho et al. proposed a method to use fuzzy analytic hierarchy process in optimal evaluation of infectious medical waste disposal companies. The authors utilized the fuzzy analytic hierarchy process to set the objective weights of the evaluation criteria and then choose the optimal infectious medical waste disposal firm through calculation and sorting [24].

However, in the former studies, there are no researches on evaluating regional tourism competitiveness using fuzzy analytic hierarchy process. Therefore, in this paper, we will try to use fuzzy AHP technology in the problem of regional tourism competitiveness.

3 Preliminaries

In this section, preliminaries are given to introduce the fuzzy analytic hierarchy process. As our proposed regional tourism competitiveness evaluation method is based on fuzzy analytic hierarchy process, the standard analytic hierarchy process should be illustrated in advance.

Analytic hierarchy process can obtain a priority of the importance of each alternative. That is, an overall object is located at the top level, and the criteria in the middle level represents to the overall object. The elements at a given level are represented as $X_1, X_2, \cdots, X_n$. Utilizing the relative evaluations calculated by a decision maker, a pairwise comparison matrix is defined in Eq.1.

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \quad (1)$$

Where Eq.1 satisfy the reciprocal property $a_{ij} \cdot a_{ji} = 1$. The derivation of priorities at some levels is executed by the pairwise matrix in Eq.1. Next, the perfectly consistent case where the pairwise comparisons matrix is based on the vector $w = (w_1, \cdots, w_n)$.

$$A=\begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} \quad (2)$$

Thus, utilizing matrix A, a priority vector is obtained as follows.

$$Aw = nw \quad (3)$$

$$Aw = \lambda_{\max} w \quad (4)$$

Where $\lambda_{\max}$ refers to the largest eigenvalue of matrix A and w is the weight vector which is the eigenvector solution of Eq.4. Exploiting the parameter $\lambda_{\max}$, the consistency index can be obtained by Eq.5.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (5)$$

To obtain the priority vector, we utilize the EV approach to solve the eigenvector problem, and the framework of analytic hierarchy process is described in Fig.1 as follows

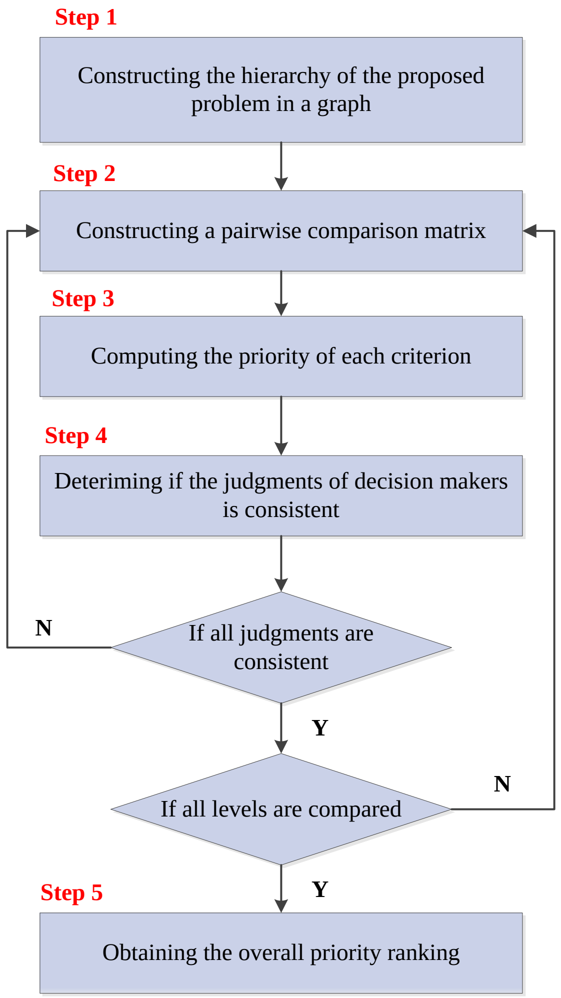

FIGURE1. Framework of analytic hierarchy process

Considering AHP needs to exact judgments, it may be unrealistic or even impossible to get precise judgments. Therefore, we utilize fuzzy judgments to replace the precise values. The definition of triangular fuzzy number is proposed as follows.

$$\mu(x|M)=\begin{cases} 0, & x<a_1 \\ \frac{x-a_1}{a_2-a_1}, & x\in[a_1,a_2] \\ \frac{a_3-x}{a_3-a_2}, & a_2\in[x,a_3] \\ 0, & x>a_3 \end{cases} \quad (6)$$

In the above equation, M represents a fuzzy set, and (a_1,a_2,a_3) means a triangular fuzzy number, where a_1,a_2,a_3 denote the smallest possible value, the most optimal value and the highest value respectively, and this process is illustrated in Fig.2.

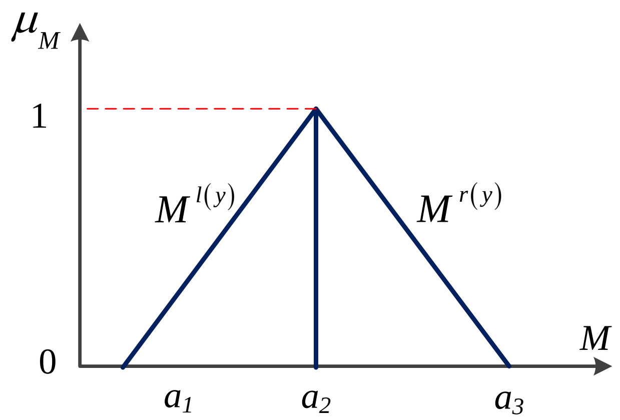

FIGURE2. Illustration of the triangular fuzzy number M

In our regional tourism competitiveness evaluation method, two triangular fuzzy numbers $M_1(m_1^-,m_1,m_1^+)$ and $M_2(m_2^-,m_2,m_2^+)$ are defined in advance, where $m_1^- \ge m_2^-$, $m_1 \ge m_2$ and $m_1^+ \ge m_2^+$ are satisfied.

Fuzzy pairwise comparison matrix R is obtained based on index system, which is defined as follows..

$$R=\begin{bmatrix} 1 & \tilde{r}_{12} & \cdots & \tilde{r}_{1n} \\ \tilde{r}_{21} & 1 & \cdots & \tilde{r}_{2n} \\ \cdots & \cdots & 1 & \cdots \\ \tilde{r}_{n1} & \tilde{r}_{n2} & \cdots & 1 \end{bmatrix} \quad (7)$$

Where conditions $\tilde{r}_{ij}=(x^-,x,x^+)$ and $r_{ij}\cdot r_{ji}=1$, $i,j\in[1,n]$ are satisfied, and the $n\times n$ pairwise comparison fuzzy matrix is given as follows.

$$T = \begin{bmatrix} 1 & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & 1 & \cdots & \tilde{t}_{2n} \\ \cdots & \cdots & 1 & \cdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & 1 \end{bmatrix} \quad (8)$$

In Eq.8, $t_{ij} \cdot t_{ji}$ is equal to one and i, j is belonged to the range $[1, n]$, triangular fuzzy number $\tilde{t}_{ij}$ is computed utilizing the following equation.

$$\tilde{t}_{ij} = (m_{ij}^{-}, m_{ij}, m_{ij}^{+}) \quad (9)$$

Based on the above analysis, the proposed regional tourism competitiveness evaluation problem can be converted to the following minimizing problem.

$$\min R_i = \sum_{v=1}^{m} T_{ij} \otimes \left(\sum_{u=1}^{n} \sum_{v=1}^{m} T_{ij} \right)^{-1}, i \in \{1, 2, \cdots, n\} \quad (10)$$

4 Fuzzy analytic hierarchy process evaluation model for regional tourism competitiveness evaluation

To enhance the performance of standard AHP, we introduce the fuzzy theory and then present the comparative judgments using trapezoid fuzzy numbers. Particularly, seven influencing factors are defined as follows.

$$U = (u_1, u_2, u_3, u_4, u_5, u_6, u_7), \quad (11)$$

where quantitative factors $u_1, u_2, u_3, u_4, u_5, u_6, u_7$ mean "Essential factors of tourism competitiveness", "Tourism enterprises competitiveness", "Tourism market competitiveness", "Tourism basic industry competitiveness", "Tourism Supporting industry competitiveness", "Government competitiveness", and "Others" respectively. The Index system for regional tourism competitiveness evaluation is provided in Fig.3.

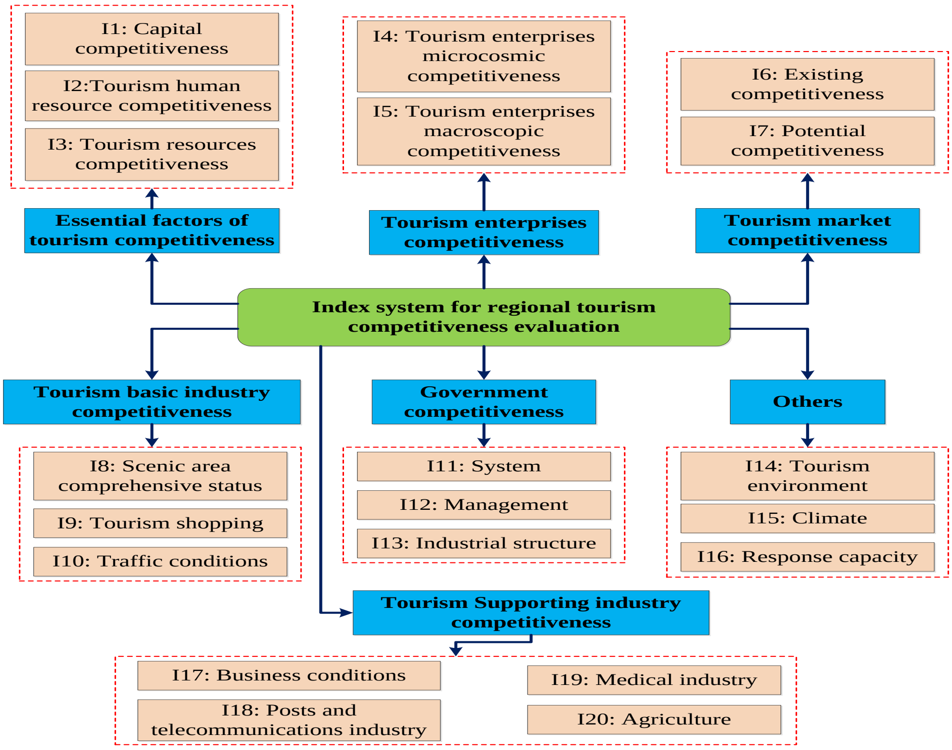

FIGURE 3Index system for regional tourism competitiveness evaluation

Afterwards, the evaluation sets are defined as:

$$V = (v_1, v_2, v_3, v_4, v_5), \quad (12)$$

where refers to the grade of regional tourism competitiveness. Afterwards, the trapezoid membership functions are defined for quantitative factors $u_1, u_2, u_3, u_4, u_5, u_6, u_7$ as follows.

$$u_1 = \begin{cases} 0, (x < y_1 \ or \ x > y_2) \\ \dfrac{x - y_1}{y_4 - y_1}, (y_1 < x < y_4) \\ 1, (y_4 < x < y_2) \end{cases} \quad (13)$$

$$u_2 = \begin{cases} 0, (x < y_1) \\ \dfrac{x - y_1}{y_2 - y_1}, (y_1 < x < y_2) \\ 1, (x > y_2) \end{cases} \quad (14)$$

$$u_3 = \begin{cases} 0, (x > x_2) \\ \dfrac{y_2 - x}{y_2 - y_1}, (y_1 < x < y_2) \\ 1, (x < y_1) \end{cases} \quad (15)$$

$$u_4=\begin{cases}0,(x<y_1 \ or \ x>y_2)\\ \dfrac{y_2-x}{y_2-y_3},(y_3<x<y_2)\\ 1,(y_1<x<y_3)\end{cases} \tag{16}$$

$$u_5=\begin{cases}0,(x<y_1 \ or \ x>y_2)\\ x-y_1,(y_1<x<y_3)\\ y_2-x,(y_4<x<y_2)\\ 1,(y_3<x<y_4)\end{cases} \tag{17}$$

$$u_6=\begin{cases}0,(x<y_1)\\ \dfrac{x-y_1}{y_5-y_1},(y_1<x<y_5)\\ 1,(x>y_5)\end{cases} \tag{18}$$

$$u_7=\begin{cases}0,(x<y_1 \ or \ x>y_5)\\ \dfrac{y_5-x}{y_5-y_3},(y_3<x<y_5)\\ 1,(y_1<x<y_3)\end{cases} \tag{19}$$

Where in Eq.13-Eq.19, the values of parameters y_1, y_2, y_3, y_4, y_5 are set to 1, 4, 2.5, 3, 5.5 respectively.

Assuming that k refers to number of levels of each factor, and each level is related to the index of the evaluation set. Evaluation matrix M is defined as follows.

$$M=\begin{bmatrix}M_1\\ \cdots\\ M_n\end{bmatrix}=\begin{bmatrix}m_{11} & \cdots & m_{1k}\\ \cdots & \cdots & \cdots\\ m_{n1} & \cdots & m_{nk}\end{bmatrix} \tag{20}$$

Where m_{nk} denotes the k^{th} membership degree corresponding to the n^{th} factor.

Next, the important task we should solve is to obtain the index weight. In this work, we compute the weight vector by integrating two parts as follows.

$$w=\lambda_1\cdot w^o+\lambda_2\cdot w^s \tag{21}$$

Where w^o and w^s refer to the objective weight vector and subjective weight vector, λ_1 and λ_2 means the influencing factors of w^o and w^s respectively. w^o Refers to the objective weight vector, which is calculated as follows.

$$w^o=\frac{N_i/N}{\sum_{i=1}^{n}N_i/N} \tag{22}$$

Where N and n mean the number of statistical cases and number of evaluation index, and N_i denotes the frequency of the i^{th} evaluation index. w^s is the subjective weight vector, and it is computed by the following equation.

$$w^s=\frac{\left(\prod_{k=1}^{n}M_{ij}\right)^{\frac{1}{n}}}{\sum_{k=1}^{n}\left(\prod_{k=1}^{n}M_{ij}\right)^{\frac{1}{n}}} \tag{23}$$

Where M_{ij} means an element in the judgment matrix at the position row i and column j

Based on the above definitions, the relevant factors can be evaluated by fuzzy transform principle to construct the evaluation sets as follows.

$$H=w\cdot M=(w_1,w_2,\cdots,w_n)\cdot\begin{bmatrix}m_{11} & \cdots & m_{1k}\\ \cdots & \cdots & \cdots\\ m_{n1} & \cdots & m_{nk}\end{bmatrix} \tag{24}$$

Using the membership matrix computed by Eq.24, the highest membership is obtained, and then the corresponding level of the regional tourism competitiveness evaluation is obtained as well.

5 Experiments

In this section, a series of experiments are conducted based on the dataset which is collected from ten different regions of China using the Statistical yearbook. For each region, the data we collected can cover the above 20 indexes. To make the problem be easier to be solved, all the values are normalized, and the experiment data after normalizing are listed in Table.1 as follows.

TABLE1 The index value for regional tourism competitiveness evaluation of ten regions.

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18	I19	I20
Region1	.53	.42	.48	.47	.44	.45	.46	.54	.46	.46	.51	.51	.42	.41	.51	.43	.40	.53	.54	.50
Region2	.26	.46	.48	.46	.52	.45	.52	.37	.31	.36	.25	.43	.34	.26	.53	.53	.25	.29	.51	.49
Region3	.76	.83	.72	.77	.77	.75	.81	.68	.81	.81	.81	.73	.80	.73	.83	.77	.75	.66	.83	.73
Region4	.53	.57	.43	.34	.55	.38	.49	.53	.38	.40	.48	.43	.37	.53	.45	.44	.52	.60	.37	.52
Region5	.32	.81	.47	.63	.83	.88	.81	.73	.67	.82	.62	.38	.75	.61	.58	.82	.36	.50	.80	.47
Region6	.78	.79	.80	.78	.75	.85	.81	.82	.84	.89	.73	.75	.80	.87	.71	.87	.86	.74	.73	.86
Region7	.26	.39	.25	.35	.42	.70	.35	.57	.75	.64	.29	.68	.46	.22	.52	.43	.56	.30	.38	.73
Region8	.51	.52	.56	.62	.64	.45	.69	.57	.48	.60	.70	.72	.77	.63	.51	.60	.64	.48	.68	.53
Region9	.58	.34	.23	.40	.33	.63	.52	.39	.68	.14	.16	.60	.56	.21	.30	.51	.48	.16	.27	.39
Region10	.68	.72	.47	.59	.72	.57	.66	.57	.59	.80	.79	.71	.58	.61	.83	.68	.61	.82	.52	.64

Based on the data in Table.1, index weight of the proposed index system can be computed by the fuzzy AHP approach, and the results are shown in Fig.4.

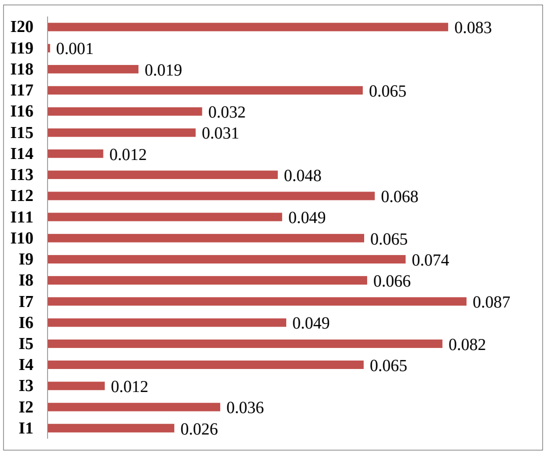

FIGURE 4 Weight of each index in the index system.

Afterwards, integrating the index value and the index weight for the given regional tourism competitiveness evaluation problem, values of the regional tourism competitiveness for all then ten regions are shown in Table.2 in a descending order.

TABLE 2 Ranking list according to regional tourism competitiveness for the ten regions.

Region ID	Value of the regional tourism competitiveness
Region 6	0.6354
Region 3	0.5736
Region 5	0.4418
Region 10	0.4334
Region 8	0.3575
Region 7	0.2822
Region 1	0.2138
Region 4	0.2132
Region 9	0.2018
Region 2	0.1711

To illustrate the performance of our method more clearly, we compare the performance of our method with other approaches. AHP [7] [25], and Fuzzy DEA [26] [27]. Analytic hierarchy process aims to decompose the decision-making process into a hierarchical structure, under the conditions that the relationships of criteria in different levels have no relationships with others. Data envelopment analysis (DEA) is exploited to measuring the relative efficiencies of decision making units with more than one input elements and multiple elements. But, undesirable outputs may be present in the production process which required to be optimized. Hence, the DEA model with undesirable outputs is integrate with the fuzzy environment, that is, fuzzy DEA model. Particularly, the ground truth is obtained by expert evaluation, and we invite ten experts to given regional tourism competitiveness scores for each region. Then, the scores are averaged to construct the ground truth. Next, values of regional tourism competitiveness for different methods are shown in Fig.5.

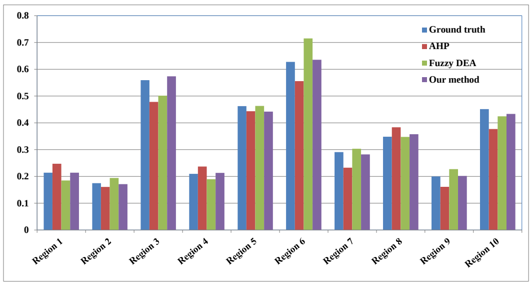

FIGURE5. Values of regional tourism competitiveness for different methods

In Table.3, error rate for different methods shown in Fig.4 is proposed in Table.3. Particularly, we compare error rate for AHP, Fuzzy DEA and our method based on the ground truth respectively.

TABLE.3 Error rate for different methods

Region ID	**AHP**	**Fuzzy DEA**	**Our method**
Region 1	0.1566	0.1363	0.0000
Region 2	0.0803	0.1118	0.0204
Region 3	0.1451	0.1031	0.0257
Region 4	0.1298	0.0959	0.0174
Region 5	0.0409	0.0016	0.0441
Region 6	0.1146	0.1396	0.0123
Region 7	0.2010	0.0431	0.0294
Region 8	0.1010	0.0015	0.0273
Region 9	0.1950	0.1372	0.0094
Region 10	0.1649	0.0595	0.0394
Average	0.1329	0.0830	0.0226

Integrating all the experiments above, it can be seen that our method performs better than AHP and Fuzzy DEA, and the average error rate for AHP, Fuzzy DEA and our method are 0.1329, 0.083 and 0.0226 respectively. The reasons lie in that:

1) Standard AHP only utilizes crisp pair-wise judgments to derive weights without considering the uncertainty of person's intentions.
2) On the other hand, when applying the standard AHP for interval judgments, the measurement of inconsistencies, while generating weights, becomes hard to implement.
3) A defect of fuzzy DEA lies in that there are several optimum weights which on the one hand maximizes the efficiency value of the targeted decision making unit.
4) For the fuzzy DEA, to obtain the complete ranking of the efficient decision making units, the average cross efficiency related to only the efficient decision making units are evaluated and are utilized as a ranking criterion for the ranking of decision making units in the fuzzy DEA model.
5) Using the fuzzy theory, the proposed method can solve the ambiguous information, and then can effectively tackle the multiple criteria decision-making problem.
6) The index system of this paper can cover most influencing factors about the regional tourism competitiveness evaluation problem.
7) Our proposed method combine the objective weight vector and subjective weight vector together, and then relevant factors can be evaluated by fuzzy transform principle to construct the evaluation sets.

6 Conclusions

This paper concentrates on how to evaluate regional tourism competitiveness using fuzzy AHP. Particularly, we apply the fuzzy theory and then make the comparative judgments through trapezoid fuzzy numbers. Afterwards, trapezoid membership functions are defined for each quantitative factor, and then the regional tourism competitiveness can be evaluated through calculating the highest membership via the membership matrix.

In the future, we will study on regional tourism competitiveness evaluating in foreign countries, and design a new index system to match it. Moreover, we will extend the experiment dataset to evaluate the proposed algorithm more accurately.

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