Journal of Business Economics and Management
ISSN 1611-1699 print / ISSN 2029-4433 online
2013 Volume 14(Supplement 1): S227–S256
doi:10.3846/16111699.2012.721391

CHINESE AIRLINE COMPETITIVENESS EVALUATION BASED ON EXTENDED BINARY RELATIVE EVALUATION (BRE) MODEL

Chong Wu[1], Xin Wang[2], Xinying Zhang[3], Yongli Li[4], Brad O'Brien[5]

[1, 2, 3, 4]School of Economics and Management, Harbin Institute of Technology (HIT), Harbin, China
[5]Department of Foreign Language, University of Utah, Salt Lake City, United States
E-mails: [1]wuchong@hit.edu.cn (corresponding author); [2]lulixinmeimei@163.com; [3]alpha3068@sina.com; [4]0440004@fudan.edu.cn; [5]brad.obrien@utah.edu

Received 06 September 2011; accepted 13 August 2012

Abstract. In order to eliminate the impact of the sample's objective merits on the evaluation results, this research built a two-stage model of Chinese airline competitiveness evaluation to reflect the subjective management and performance. In the first stage, Analytic Hierarchy Process (AHP) and Factor Analysis (FA) models were used to analyze the data from 2008 to 2009. In the second stage, two kinds of comprehensive evaluation indexes in 2008 were taken as the reference index set, and two kinds of comprehensive evaluation indexes in 2009 as the current index set. The four sets of data were calculated with the Group Decision-making Model Based on Data Envelopment Analysis (DEA) with Restraint Cone. This paper has (1) enriched the theory of airline competitiveness,(2) built a more scientific and comprehensive evaluation index system of airlines' competitiveness, (3) constructed a competitiveness evaluation model based on BRE, and (4) conducted an empirical study of the improved model based on the 2008 and 2009 data from 15 Chinese airlines. The ranking results of the proposed method, theory and model coincide with the real conditions of the airline market demonstrating that our evaluation of airline competitiveness based on BRE is accurate, reliable and objective.

Keywords: airline; competitiveness evaluation, data envelopment analysis, binary relative evaluation.

Reference to this paper should be made as follows: Wu, C.;Wang, X.; Zhang, X. Li, Y.; O'Brien, B. 2013. Chinese airline competitiveness evaluation based on extended binary relative evaluation(BRE) model, *Journal of Business Economics and Management* 14(Supplement 1): S227–S256.

JEL Classification: C67, L21.

Introduction

With the economic globalization and the in-depth development of regional economic integration, the Chinese aviation market is gradually opening up, and the liberalization of international air transportation will be more rapid and profound. According to the World Trade Organization (WTO) rules and the basic commitments of WTO, foreign

http://www.tandfonline.com/TBEM

airlines will enter China, and therefore airlines from different countries will enter a new era of competition in China. Facing tough challenges and fierce competition, an imperative task for every airline that will take part in the Chinese aviation market will be to understand the comprehensive competitiveness of Chinese airlines.

1. Literature review

1.1. Review of competitiveness research

In the aviation industry, quite a few theoretical and empirical studies have been conducted on the evaluation of aviation competitiveness in terms of some key factors, such as cost (Button *et al.* 2011), operational performance (Barrosa, Peypochb 2009.), cost and productivity, price and productivity, price and service quality (Bureau of Transport and Communications Economics, 1993), productivity and efficiency, probability, safety (Chena, Chena 2012.), service quality (Liou *et al.* 2011) and service quality and productivity. New theories and methods continue to make more prominent progress in the study of scientific and efficient evaluation of airlines' competitiveness (Liou *et al.* 2007), but there are still some points to be improved. Few researchers have studied airline competitiveness from a microscopic point of view, and they have focused only on a particular aspect of the competitiveness of airlines.

Even though some researches that did so only focused on a particular aspect of the competitiveness of airlines, especially, in the following evaluations of airline competitiveness. Moreover, in previous studies of airline competitiveness the impact of the sample's objective merits on the evaluation results cannot be eliminated, leading to the fact that these evaluations cannot truly reflect the quality of management. These studies can be categorized into the following groups.

1. *Evaluation in terms of service quality*

Service quality i.e. a safe, timely and accurately passenger or cargo transport from one place to another, has a direct impact on the customer's choice of airlines. In assessing the airlines' competitiveness, Park *et al.* (2009) analyzed the relationship between various factors and their relative importance for evaluating the operation of air express delivery service in the Korean market. Through AHP, the analysis showed that the most competitive airlines were the ones that were most accurate and timely. Further study of these two factors found that price impact was also a major factor in airlines' competitiveness. Therefore, accuracy, timeliness, and price were the main competitiveness factors for cargo airlines. Using the panel data model and focusing on European and American airlines, Santana (2009) takes a different approach to studying the evaluation of service quality. His analysis showed that the Public Service Obligations in Europe do affect the economic performance of carriers, but this is not the case for the US's Essential Air Service Program.

2. *Evaluation in terms of financial security*

The main indicators reflecting financial security are the operating costs, current ratio, operating profit, main business income, interest coverage ratio, return on capital, etc.

Lin (2012) investigated the financial performance of a set of large international airlines from North America, Europe, Latin America, Asia, and the Middle East. Efficiency measures were related to their strategically focused expenditures on operations and on customer services. The results, based on data envelopment analysis, indicated that operation management, including that of customer service attribute evaluation, could be improved through the adoption of activity-based costing analysis. Jang *et al* (2011) investigated the cross-sectional efficiency of the US airline industry and its changes using the data envelopment analysis technique. The primary findings suggest that 9/11 affected the network carriers (NCs) more severely than the low-cost carriers (LCCs), while fuel costs more seriously influenced the LCCs than the NCs.

3. *Evaluation in terms of market choice*

Airlines' market can be divided into short- and long-distance markets. Lu *et al* (2012) explored the relationship between operating performance and corporate governance in 30 airline companies operating in the US. First, this study applied a two-stage Data Envelopment Analysis (DEA) to evaluate the production efficiency and marketing efficiency of the airlines. Their findings indicated that, in general, there was not as much dispersion in the relative productive efficiencies of the airlines as there was in their marketing efficiencies. The low-cost airlines, on average, were more efficient carriers than the full-service ones, but less efficient marketers. Secondly, truncated regression was used to explore whether the characteristics of corporate governance would affect the airline performance. The results demonstrated that corporate governance influenced firm performance significantly. Finally, they addressed the managerial decision-making matrix and made suggestions to help airline managers improve performance.

4. *Evaluation in terms of technical efficiency*

Many researchers evaluate the airlines' operational competitiveness in the aspects of technical efficiencies and the ratio of the input and the output (Qi *et al.* 2008) used the Stochastic Frontier Function to estimate the technical efficiency of airlines worldwide. The results showed that Chinese airlines' inadequate operation and management mechanism and the institutional environment of development were the cause of their technical inefficiency and poor resource allocation. Therefore, the improvement of the airlines' competitiveness demanded improvements in both the institutional environment and the management mechanism.

Overall, previous studies of airline competitiveness have two obvious disadvantages. On one hand, this research takes into account the industry and international competitiveness separately, not simultaneously. This has resulted in an ambiguous evaluation index system that fails to provide a comprehensive analysis of competitiveness. There is no specific comparative study of evaluation index systems, which results in the lack of the related theories and practices. On the other hand, single indicators (instead of all the efficiencies) were used in the evaluation of airlines' competitiveness. Single evaluation efficiency cannot fully reflect the competitiveness of airlines. Therefore, various evaluation efficiencies should be taken in into consideration when evaluating airlines' competitiveness.

These single efficiencies cannot reflect overall aviation competitiveness. Specifically, airlines' competitiveness should be addressed by considering all critical competitiveness measures of both efficiency and effectiveness from the viewpoint of both the airlines and the customers. A study on a competitiveness index developed by Aviation Week and Space Technology defines a set of competitiveness dimensions identified for assessing the relative competitiveness of publicly traded aerospace and airline companies in an attempt to provide insight into the impact of management decisions on overall organizational competitiveness. The competitiveness dimensions identified are operating efficiency, financial stability, asset utilization, earning protection, liquidity, and market valuation. Despite its practical advantages as a benchmarking tool for objective assessment of competitiveness, this index cannot be applied to a specific environment, such as the Chinese airline market, where customer-oriented competitiveness measures contribute significantly to overall competitiveness (Velocci 1998). Therefore, this research proposes evaluating the competitiveness of Chinese airlines in terms of their competitiveness both internationally and within the aviation industry.

1.2. Review of competitiveness evaluation methods

At present, the 7 popular competitiveness evaluation methods are DEA, the AHP, fuzzy comprehensive evaluation, multilevel gray evaluation, multivariate statistical evaluation (MSE), evaluation of neural networks, and binary relative evaluation (BRE).

1. *DEA*

This approach is a nonparametric method in operations research and economics for the estimation of production frontiers. It is used to empirically measure productive efficiency of decision making units (DMUs). Cao *et al.* (2008) introduced DEA in the evaluation of enterprise competitiveness and conducted the empirical analysis of 25 small and medium Chinese insurance enterprises. This method only evaluated the competitiveness results and could not find or evaluate the internal factors affecting competitiveness. Without priori information, the traditional DEA model can not rationally allocate the weights of various input and output indicators. Meanwhile, the traditional DEA model provides insufficient decision-making information because it optimizes the input or output indicators based on the same standard.

2. *AHP*

This approach is a structured technique for dealing with complex decisions. Rather than prescribing a "correct" decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem—it is a process of organizing decisions that people are contemplating. Cheng and Lu (2010) evaluated tourism resources exploration potential of Zhangdu Lake wetland using the evaluation index system of tourism resources exploration potential. The key factors of important influence on tourism resources were analyzed and then evaluation index system of tourism resource exploration potential was established with theoretical analysis, frequency statistical method and Analytic Hierarchy Process (AHP). In order to get a relatively correct index weight, this paper used the combination of AHP method and entropy technology. First the weighs of each index were obtained through "AHP" method, and then they were modified by "entropy" technology. The tourism resources exploration of Zhangdu Lake Wetland Nature Reserves were evaluated and sorted based on the multi-level grey approach and evaluation index system of tourism resource exploration potential. The results showed that Mayi Lake Wetland Forest Park Nanshan Wetland Ecological Demonstration Area was preferential development areas with great exploration potentiality.

3. *Fuzzy comprehensive evaluation*

In enterprise competitiveness evaluation, the fuzziness of some factors makes them difficult to evaluate, but a comprehensive evaluation method based on fuzzy mathematics can quantitatively evaluate the competitiveness of enterprises to make up for the disadvantage of AHP. This method first establishes the factor sets and their weight sets, the evaluation grade sets and fuzzy evaluation matrixes, and then conducts the fuzzy comprehensive evaluation. Song and Liu (2009) constructed a model of fuzzy comprehensive evaluation based on membership transformation with the entropy-based data mining method. Through mining the data information of objective classification hidden in the membership of parameters and introducing the distinguishable weight, it better solved the interference problem of the redundant data. An example of the evaluation model for competitiveness of a university was presented, which indicated that the model was convenient and feasible and that the result of assessment was objective and reliable. Wang *et al.* (2011) built a set of environmental evaluation index system of developing the circular economy for the iron and steel industry based on the ideas and theories of circular economy. Using fuzzy comprehensive evaluation, they evaluated the steel industry in Hebei Province of circular economy development environment. Their research aims at combining characteristics of the iron and steel industry and requirements of the development of circular economy, finding support on the external environmental factors to development of circular economy in the iron and steel industry and providing the reference in order to promote development of circular economy in the iron and steel industry.

4. *Multilevel gray evaluation*

In an incomplete and inaccurate competitiveness system, due to many complex factors or inadequate data, multilevel gray evaluation expands the information sources and improves the reliability of evaluation and analysis. In addition, gray correlation analysis between these two factors can quantitatively analyze the correlation degree, which is more reasonable and more accurate. In the basic theory and method of the grey correlation analysis, Wang and Wang (2009) used multilevel gray evaluation method to evaluate the innovation capability of hub-and-spoke enterprises clusters which combined the advantages of the analytic hierarchy process and a grey clustering method. Firstly, this paper set up a multi-hierarchy index system based on the structure and character of hub-and-spoke cluster innovation systems. Secondly, it confirmed the weight of every index with AHP and gave a general assessment by means of a grey clustering method. Finally, a case study was conducted to validate the evaluation model and the evaluation process. The result showed that their methodology was especially useful when there was partial information and/or qualitative variables were used.

5. *Multivariate statistical evaluation (MSE)*

This approach is a form of statistics encompassing the simultaneous observation and analysis of more than one statistical variable. The application of multivariate statistics is called multivariate analysis. Multivariate analysis concerns understanding the different aims and backgrounds of each of the different forms of multivariate analysis, and how they relate to each other. The practical implementation of multivariate statistics to a particular problem may involve several types of univariate and multivariate analysis in order to understand the relations between variables and their relevance to the actual problem being studied (Multivariate … 2011). Gerab and Ching (2012) identified the factors and correlated indicators that impact corporate financial performance and determined the indicators that most affect profitability of Brazilian cyclical consumer goods industry. Sixteen companies with current asset greater than 50% of total asset, for the period 2005-2009, were selected. Principal Component Analysis PCA was used to extract, from 20 variables and ratios, five factors that impact financial performance. The variable with the biggest component loading in each one of the five factors was selected to be its representative in the multiple regression analysis MRA. Finally, MRA was used to assert which indicators affect corporate profitability the most as measured by ROS return on sales, ROA return on assets and ROE return on equity. The results showed that five factors impact corporate financial performance with 18 correlated variables and ratios. The contributions of their study were to combine both techniques: the use of PCA to identify the most relevant indicator in each factor followed by a MRA to assert which indicators affect the corporate profitability the most.

6. N*eural network evaluation method*

The research showed that the neural network was usually better than traditional statistical methods. But too much emphasis on the output of competitive scores made the evaluation poor. In response to the index system of competitiveness comprehensive evaluation, Chi and Zhao (2012) established the prediction system of e–business performance for Chinese service industry based on Back Propagation (BP) neural network algorithms. In their BP neural network model, the inputs were the data of e–business performance measured by a five–point scale, and the expected outputs of training neural network came from cluster analysis. Then, they took 14 indicators of e–business performance as inputs, and the level of e–business performance as outputs. The results showed that the evaluation system was reliable and accurate; it could be used for evaluating enterprise performance effectively.

7. *BRE*

In the real world, different peer companies have different objective bases, i.e. the same input does not mean the same output. Therefore, an absolute evaluation index system often overlooks the impact caused by different objective conditions and cannot really evaluate benefits from the management of the finances. Therefore, Li (2007) evaluated the China provincial government websites with the binary relative evaluation method. The evaluation result showed that the binary relative performance had incentive to all the governments and made the evaluation fairer. Li and Le (2008) proposed the binary relative performance of e-government with the binary relative evaluation method in order to remove the influence of the objective indicators on the e-government evaluation and measured the binary relative performances of 28 Chinese provincial e-governments. The result showed the binary relative performance had incentive to all the governments and made the evaluation fairer. Zhang *et al* (2009) proposed a binary relative evaluation method to assess the government websites performances. In the above empirical research, the evaluation index system often contains only a few (usually only 4-7) indicators, most of which are the financial indicators, leading to unconvincing competitiveness evaluation results. The unscientific evaluation index system for airlines causes a gap between theory and practice and provides only a partial analysis of the competitiveness of the aviation industry. The traditional BRE model has no limitation of the relative importance of various indicators. When the model is applied to the system of multi-inputs or outputs, the evaluation method is not effective due to the excessive units.

In summary, both the theory and methods to evaluate the competitiveness of the airlines need to be developed and improved. Therefore, the core issue is to study the competitiveness of airlines, discuss the mechanism of airline competitiveness, the evaluation system and the method used to enhance competitiveness.In order to evaluate airline management and performance, this paper presents a new approach. We utilize the decision-making method, the multi-objective optimization and the fuzzy set theory. It combines AHP, FA and DEA to establish a second, more relevant and subjective model for evaluating airline competitiveness. This model can determine how much the management of individual airlines contributes to competitiveness. The financial statistical data and the production operations data of Chinese airlines in 2008 and 2009 were adopted for the empirical study in this paper. What's more important, we use the group decision-making DEA model which can face each component of the inputs and outputs for the analysis and evaluation. The results of the extended BRE model are comparatively suitable to reflect the contribution of the airline subjective efforts and the capability to the development of the company. The evaluation results can inspire the airlines and encourage them to find the gap and explore the potential to improve their business. This extended BRE model can produce a significant incentive effect to the airlines.

2. Methodology

2.1. Components and their contributions in BRE

2.1.1. Contributions of AHP in BRE

The biggest advantage of the AHP method is to provide a consistency test, to ensure that the logic consistency of the experts' thinking. The so-called consistency of the critical thinking refers to the occasion that when experts judge the importance and more than three indicators need to be compared, each judgment can coordinate each other without internal conflicting results. It solves the problems that we can hardly use quantitative figures to describe the potential factors or sub-factors in the combination of the subjective and objective conclusions in the airlines competitiveness analysis. With the experts' judgment, we used the quantitative principles to test the correctness of this judgment, and finally integrated the overall airline competitiveness. The combination of the deductive and inductive method to solve the complex problems includes both qualitative analysis and the quantitative results, providing a flexible, easily operative and effective means to comprehend the profound knowledge of airlines competitiveness.

2.1.2. Contributions of FA in BRE

The subjectivity of the index in the traditional BRE model will affect the evaluation results. The weight distribution of the comprehensive competitiveness evaluation of AHP is subjective. Therefore, factor analysis, a more objective method, should be taken in the evaluation to analyze the raw data and to correct the subjectivity in the evaluation process. (1) Factor analysis can reduce the number of the original indicators, reflecting a few main factors in the original data, which is conducive to the further data processing. (2) In the process of factor score calculation, FA does not artificially distribute the index weights, thus avoiding the influence of the subjective factors on the evaluation results. The so-calculated weights can objectively reflect the real relations between the sample data, improving the results of the comprehensive evaluation. (3) In the statistical analysis on the raw data, factor analysis, with data standardization and transformation, can eliminate the impact caused by the different dimensions of the indicators and the data difference. (4) When ranking the evaluation units, the results of FA are highly accurate with few errors. What's more, FA has a certain ability to control the accuracy and error. FA can easily recognize the main factors to achieve a more objective evaluation and an in-depth understanding of the research, improving the evaluation results.

2.1.3. Contributions of DEA in BRE

The combination of DEA method and characteristics of the airline competitiveness is feasible in the airline competitiveness evaluation, reflecting the strong advantages in the following four aspects: (1) DEA especially adapts to the complex-structured system with multi-inputs and multiple outputs. Meanwhile, the airline competitiveness evaluation model is a complex system with more than one goal, which includes the complex relationship between the multiple inputs and the outputs. Therefore, DEA method can be more effective in the airline competitiveness evaluation and the airline overall efficiency. (2) There is an obvious "benefit correlation" between the airline operating costs and the passenger service. The airline competitiveness analysis can help increase both the number of passengers and the riding rates of the aircraft, and reduce the operating costs of airlines as well. The airlines evaluation with DEA method will be able to help us see more clearly the characteristics of the scale income brought by the stable cooperative relations between airlines and customers. (3) The airline competitiveness evaluation requires different aspects to be described with multiple indicators, including qualitative and quantitative indicators, although the dimensions of these indicators are not the same. DEA method does not need to consider the different dimensions; we can input data and then obtain the evaluation results.

2.2. Modeling methodology of BRE

The evaluation model based on BRE includes the following steps:

Step One. In order to describe the differences of the objective basis of the evaluation objects, calculate the airline conditions in 2008 and 2009 respectively using AHP, obtain the evaluation results and rankings of the airline companies, and then analyze the evaluation results.

Step two. Calculate the airline conditions in 2008 and 2009 respectively using FA, obtain the evaluation results and rankings of the airline companies, and then analyze the evaluation results.

Step Three. If there are negative figures in the four sets of data obtained by AHP and FA, we will use the maximum difference dormalization method to process the reference and the current competitiveness evaluation figures to ensure that the data are positive and to meet the premise that DEA model requires all the input and output data to be positive.

Step Four. Choose the two sets of the processed comprehensive evaluation data in 2008 as the reference index, denoted as the input, and the two sets of the processed comprehensive evaluation data in 2009 as the current index, denoted as the output. Use DEA to calculate the airline competitiveness evaluations based on BRE.

Step Five. Rank airlines based on the results obtained with BRE and make the analysis of the ranking result.

2.3. Comparison of the proposed model with other existing models

Other evaluation methods can only assess the airline rankings in a certain year, which is conducted on the first stage of the proposed extended BRE model in this research. The characteristic of this BRE model is to reflect the subjective effectiveness and the capability by exploring the dynamic changes of the reference and current indicators of the airline performances. This model has the following unique characteristics in the evaluation of airline competitiveness.

1. The reference index and the current index in this BRE evaluation model can effectively portray the relative characteristics and trends of the dynamic changes in the airline competitiveness to further measure the validity of the airlines' competitive behaviors.
2. Comprehensively considering the different basic conditions of each unit, the extended BRE model eliminates the impacts of the objective basic conditions and truly reflects the priorities of the different economic benefits caused by the different airline competitiveness indicators. Therefore, it is relatively fair to use the results of the extended BRE model, which have strong comparability, as the indicators to measure the airline management levels.
3. The extended BRE model can truly reflect the contribution of the airline subjective efforts and the capability to the development of the company. This model, as a measure of the airline competitiveness evaluation, can make all the evaluated airlines in the state of going forward otherwise falling behind. Therefore, the airlines with good basic conditions can not sit back and relax, and the airlines with poor conditions will not feel it hopeless to catch up because as long as an airline makes a great progress, it would also have a better BRE competitiveness evaluation result.

3. Model and data

3.1. Modeling

This evaluation model contains the following competitiveness indexes: financial performance, development capacity, service quality, operation capacity, strength and scale, and human resources. See Table 1.

Table 1. Index of airlines' competitiveness evaluation

Layer of Standard	Layer of Index	Unit	Code	Type
Financial Performance	ROE	%	X_1	Forward
	OPE	%	X_2	Forward
	Asset-liability Ratio	%	X_3	Moderate
Development Capacity	ROA	%	X_4	Forward
	Total Asset Turnover	%	X_5	Forward
	Total Assets Growth Rate	%	X_6	Forward
Service Quality	Baggage Error(1/10000)	%	X_7	Backward
	Cargo Error(1/10000)	%	X_8	Backward
	Flight Punctuality	%	X_9	Forward
	Rate of Passenger Complaints	%	X_{10}	Backward
	Incident Symptom (1/10000 hours)	%	X_{11}	Backward
Operation Capacity	Passenger Loading Rate	Day	X_{12}	Forward
	Passenger Operational Efficiency	%	X_{13}	Forward
	Cargo Operational Efficiency	%	X_{14}	Forward
	Total Loading Rate	%	X_{15}	Forward
Strength and Scale	Total Assets	10,000 yuan	X_{16}	Forward
	Passenger Turnover	Time	X_{17}	Forward
	Freight Ton Turnover	10,000 tons	X_{18}	Forward
	Flights	Time	X_{19}	Forward
	Passenger Traffic	10,000 trips	X_{20}	Forward
Human Resources	Faculty	Person	X_{21}	Forward
	Per Capita Main Business Profits	10,000 yuan	X_{22}	Forward
	Per Capita Main Business Income	10,000 yuan	X_{23}	Forward
	Per Capita Training	Hour	X_{24}	Forward

3.2. Samples and data

3.2.1. Samples

As of January, 2010, China had set up 26 airlines. Taking data availability and adequacy of the sample statistics into account, this research took the data from 15 airlines as empirical samples in order to effectively calculate the competitiveness of Chinese airlines and analyze their problems. 11 airlines were not selected due to their bankruptcy, reorganization, late establishment, resulting in insufficient data for 2008 and 2009, and other factors affecting the availability of data.. For categories of selected Chinese airlines, see Table 2.

Table 2. Categories of the selected Chinese airlines

Type	Airlines
State-owned Airlines	China Eastern Airlines
	Air China
	Hainan Airlines
	China Southern Airlines
Private Airlines	Okay Airways
	Spring Airlines
	Juneyao Airlines
	Shenzhen Airlines
	United Eagle Airlines
State-owned Holding Airlines	Deer Air
	United Airlines
	Shandong Airlines
	Sichuan Airlines
	Xiamen Airlines
	Lucky Air

3.2.2. Data

Original data about the above airlines came mainly from the major Chinese airline websites and various databases. Among them there were multiple financial data sources: (1) RESSET financial research database; (2)Sohu Securities; (3) financial reports of airlines. The production data sources included were: (1) Chinese transportation industry database in CSMAR; (2) Civil Aviation Statistics in China Civil Aviation; (3) CAAC; (4) Aviation News at Eflye. The original data has been omitted due to paper length restrictions.

3.2.3. Preprocess of the sample data

In order to compare the indicators in different dimensions, the following formulae were used to normalize the raw data, including a total of 24 indicators from 15 airlines.

$$X'_{ij} = \frac{X_{ij} - \overline{X}_j}{S_j}, \tag{1}$$

where $\overline{X}_j$ is the mean of the samples, and S_j the standard deviation.

$$\overline{X_j} = \frac{1}{15}\sum_{i=1}^{15} x_{ij} , \tag{2}$$

$$S_j{}^2 = \frac{1}{15-1}\sum_{i=1}^{15}\left(x_{ij} - \overline{X}_j\right). \tag{3}$$

4. Evaluation based on binary relative analysis

4.1. Stage one: AHP–FA

In order to avoid human bias in the subjective evaluation method, and to overcome the fact that the single objective evaluation method can not reflect the experts' and decision-makers' preferences, integrated evaluation, both subjective and objective, was established through the AHP-FA model. Specific steps were as follows:

1. Constructed the judgment matrix of the evaluation indexes through AHP and determined the index weight vectors after conducting a consistency test of the matrix.
2. Standardized the decision matrix of raw data and determined the index weight vectors using FA.
3. Evaluated respectively through AHP and FA.

4.2. Stage two: Group Decision-making model based on DEA with the Restraint Cone

4.2.1. Basic steps

1. Selected two comprehensive evaluation indexes in 2008 as the reference indexes, i.e. the Input, respectively denoted as IAHP and IFA.
2. Selected two comprehensive evaluation indexes in 2009 as the current indexes, i.e. the Output, respectively denoted as OAHP and OFA.
3. Processed the data of reference indexes and current indexes of the competitiveness evaluation through Differential Standardization.
4. Put the four groups of data in the Group Decision-making Model Based on DEA with Restraint Cone to obtain the binary relative evaluation of the competitiveness of Chinese airlines.

Since many researchers have covered the basic principles of the first 3 steps above, this paper only describes the calculation in the empirical study and mainly introduces the calculation of the restraint cone for group decision-making and the principles of the Group Decision-making model Based on DEA with Restraint Cone.

4.2.2. Calculation of Restraint Cone for Group Decision-making

Step 1. Let $u_1, u_2, v_1, v_2 \geq 0$, calculate the corresponding efficiency and weight vector u and v of each decision making unit (DMU) through the C^2R model:

$$u = \begin{vmatrix} u_{11} & u_{12} & u_{13} & \cdots & u_{1j} \\ u_{21} & u_{22} & u_{23} & \cdots & u_{2j} \end{vmatrix}_{2\times 15} \quad j = 15 \;\; \text{and} \tag{4}$$

$$v = \begin{vmatrix} v_{11} & v_{12} & v_{13} & \cdots & v_{1j} \\ v_{21} & v_{22} & v_{23} & \cdots & v_{2j} \end{vmatrix}_{2\times 15} \quad j = 15. \tag{5}$$

Step 2. Calculated u and μ, each component's weight vectors in the input and output, and obtained the pairwise comparison results of each component's weight coefficient. The comparison matrix of weight coefficients is:

$$U_k = \begin{vmatrix} 1 & u_{1k}/u_{2k} \\ u_{2k}/u_{1k} & 1 \end{vmatrix} \qquad \text{k} = 1,2,3,\ldots..,15, \;\text{and} \tag{6}$$

$$V_k = \begin{vmatrix} 1 & v_{1k}/v_{2k} \\ v_{2k}/v_{1k} & 1 \end{vmatrix} \qquad \text{k} = 1,2,3,\ldots..,15, \tag{7}$$

where u_{1j}/u_{2j} denotes the relevant importance ratio of the *1st* and the *2nd* input indexes of the j^{th} airline. v_{1j}/v_{2j} denotes the relevant importance ratio of the 1st and the 2nd output indexes of the j^{th} airline.

Step 3. Using Geometric Mean Judgment (GMJ) matrix, classified the 30 judgment matrixes according to the input or output indexes, and integrated them into group judgment matrixes. Assuming that the judgment matrixes of the 15 airlines are $A_k = U_k = a_{ij_k}, B_k = V_k = b_{ij_k}, k = 1,2,\cdots,15$ respectively, the group comprehensive judgment matrix is:

$$A = a_{ij} = \prod_{k=1}^{15} a^{1/15}{}_{ijk} \quad \text{and} \tag{8}$$

$$B = b_{ij} = \prod_{k=1}^{15} b^{1/15}{}_{ijk}\,. \tag{9}$$

Step 4. Assuming that $a_{ijk}(k = 1,2,\cdots,k-1) \ge a_{ij}$, and $a_{ijk}\ (k = k+1,\cdots,15) \le a_{ij}$, $a_{ijk}\ , k = 1,2,\cdots,15$, the interval of u_1 and u_2 is:

$$\text{U} = \left[a_{ij} - \rho\cdot\frac{\sum\limits_{k=k+1}^{15}(a_{ij} - a_{ijk})}{15-1} J - a_{ij} + \rho\cdot\frac{\sum\limits_{k=1}^{k-1}(a_{ijk} - a_{ij})}{15-1} \right]. \tag{10}$$

Assuming that $b_{ijk}\ (k = 1,2,\cdots,k-1) \ge b_{ij}$,and $b_{ijk}\ (k = k+1,\cdots,15) \le b_{ij}$, $b_{ijk}, k = 1,2,\cdots,15$, the interval of v_1 and v_2 is:

$$\mathrm{V}=\left[b_{ij}-\rho\cdot\frac{\sum_{k=k+1}^{15}(b_{ij}-b_{ijk})}{15-1} \quad \cdot b_{ij}+\rho\cdot\frac{\sum_{k=1}^{k-1}(b_{ijk}-b_{ij})}{15-1} \right], \tag{11}$$

where $0<\rho\leq 1$. Therefore, the interval can be controlled by adjusting Coefficient ρ. Through the above steps, the Group Decision-making Model Based on DEA with Restraint Cone can be obtained.

4.2.3. The Group Decision-making model based on DEA with the Restraint Cone

In the calculation of the restraint cone of DEA for group decision-making, there may be multiple optimal solutions, i.e. more than one $u_1,u_2,v_1,v_2\geq 0$, resulting in more than one weight coefficient comparison matrix U_k or V_k. Thus, we can assume that the standard of weight coefficient selection of an airline is to maximize its own relative comprehensive evaluation value, and to take into account that of the other airlines,and reach $\max\sum_{k=1}^{15}\theta_k$,where θ_k denotes the relevant comprehensive evaluation value of the K^{th} airline.

On the assumption of the restraint cone of DEA for group decision-making and the optimization of group efficiency, we can create a group decision-making model based on DEA:

$$\max=\frac{u_{10}y_{10}+u_{20}y_{20}}{v_{10}x_{10}+v_{20}x_{20}};$$

$$s.t.\begin{cases}\dfrac{u_{1j}y_{1j}+u_{2j}y_{2j}}{v_{1j}x_{1j}+v_{2j}x_{2j}}\leq 1\\ u_1\in\mathrm{U},u_2\in\mathrm{U},v_1\in\mathrm{V},v_2\in\mathrm{V}\\ j=1,\cdots,n\end{cases}, \tag{12}$$

where U and V are as shown respectively in Formula (11) and (12).

According to the above formulas, the comprehensive evaluation value of the 15 airlines $\theta_1^*,\theta_2^*,\theta_3^*,\cdots,\theta_{15}^*$ can be obtained. The value and the index weight ratio of each index weight are shown as:

$$\left|\begin{matrix} u_{11}/u_{21} & u_{12}/u_{22} & u_{13}/u_{23} & \cdots & u_{1j}/u_{2j}\\ v_{11}/v_{21} & v_{12}/v_{22} & v_{13}/v_{23} & \cdots & v_{1j}/v_{2j}\\ \theta_1^* & \theta_2^* & \theta_3^* & \cdots & \theta_{15}^*\end{matrix}\right|_{3\times 15} \quad j=15. \tag{13}$$

The extended BRE model for the competiveness evaluation of the Chinese airlines is shown in Figure 1.

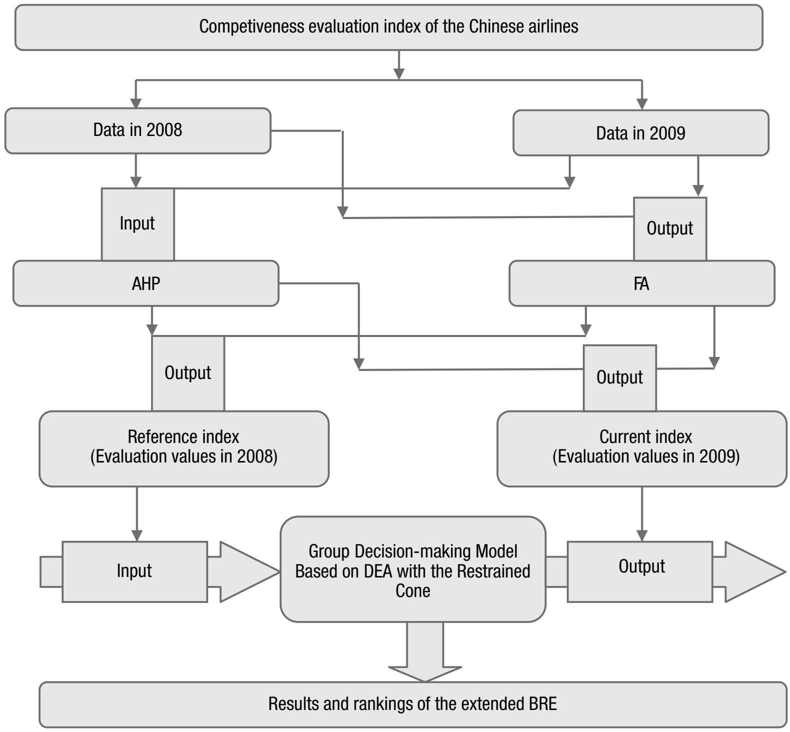

Fig. 1. Extended BRE model for the competiveness evaluation of Chinese airlines

5. The empirical study

5.1. The primary empirical study

5.1.1. AHP

In order to establish a pairwise comparison matrix and determine the index weight, we surveyed the experts in e aviation industry using questionnaire e-mails and assessed the index system of airline competitiveness evaluation. Among the 50 questionnaires sent, 43 were actually recovered, of which 39 were valid.

1. *Hierarchical structure of the evaluation system*

The established airlines competitiveness evaluation includes three structural layers.

1.1. The top layer. There is only one element in this layer. Generally it is the desired result of the intended target or the expected achievement of the analyzed issue, and the highest standards of the systematic evaluation. In this research, it refers to the airline competitiveness.

1.2. The middle layer. This layer includes the intermediate links involved to achieve the target. In this research, this layer includes six standards.

1.3. The bottom layer. This layer includes the optional programs and measures to achieve the goal, i.e. the evaluated objects. In this research, they mainly refer to the 24 evaluation indicators.

2. *Single-layer ranking and the consistency test*

2.1. Establish the pairwise judgment matrix for the middle (standard) layer and judge the indicators on the standard layer of the airline competitiveness evaluation system, as shown in Table 3. U_1, U_2, U_3, U_4, U_5, and U_6 respectively denote the financial performance, the development capacity, the service quality, the operation capacity, the strength and scale, and the human resources.

Table 3. U-Um comparison matrixes and relevant data

U(Airline Competitiveness)	U_1	U_2	U_3	U_4	U_5	U_6	W_i^0
U_1	1	2	1/2	2	3	5	0.2558
U_2	1/2	1	1/3	1	2	3	0.1427
U_3	2	3	1	2	4	2	0.3109
U_4	1/2	1	1/2	1	1	3	0.1386
U_5	1/3	1/2	1/4	1	1	1	0.0856
U_6	1/5	1/3	1/2	1/3	1	1	0.0664
Consistency test	CI=0.053, RI=1.26, and CR=CI/RI=0.042<0.1. The matrix passed the consistency test.						

2.2. Establish the pairwise judgment matrix for the indicator layer and judge the indicators of on the indicator layer of the airline competitiveness evaluation system, as shown in Tables 4–9.

Table 4. Judgment matrix and relative data of U_1–U_{1n}

Financial Performance (U_1)	ROE (U_{11})	OPE (U_{12})	Asset-liability Ratio (U_{13})	W_i^0
ROE (U_{11})	1	3	1/2	0.3487
OPE (U_{12})	1/3	1	1/2	0.1677
Asset-liability Ratio (U_{13})	2	2	1	0.4836
Consistency test	CI = 0.020, RI = 0.52, and CR = CI/RI = 0.039 < 0.1. The matrix passed the consistency test.			

Table 5. Judgment matrix and relative data of U_2–U_{2n}

Development Capacity(U_2)	ROA(U_{21})	Total Asset Turnover(U_{22})	Total Assets Growth Rate(U_{23})	W_i^0
ROA(U_{21})	1	3	1/3	0.2583
Total Asset Turnover(U_{22})	1/3	1	1/5	0.1047
Total Assets Growth Rate(U_{23})	3	5	1	0.6370
Consistency test	CI = 0.019, RI = 0.52, and CR = CI/RI = 0.037 < 0.1. The matrix passed the consistency test.			

Table 6. Judgment matrix and relative data of U_3–U_{3n}

Service Quality (U_3)	Baggage Error (U_{31})	Cargo Error (U_{32})	Flight Punctuality (U_{33})	Rate of Passenger Complaints (U_{34})	Incident Symptom (U_{35})	W_i^0
Baggage Error (U_{31})	1	2	1	1	2	0.25
Cargo Error (U_{32})	1/2	1	1/2	1/2	1	0.125
Flight Punctuality (U_{33})	1	2	1	1	2	0.25
Rate of Passenger Complaints (U_{34})	1	2	1	1	2	0.25
Incident Symptom (U_{35})	1/2	1	1/2	1/2	1	0.125
Consistency test	CI = 0, RI = 1.12, and CR = CI/RI = 0<0.1. The matrix passed the consistency test.					

Table 7. Judgment matrix and relative data of U_4–U_{4n}

Operation Capacity (U_4)	Passenger Loading Rate (U_{41})	Passenger Operational Efficiency (U_{42})	Cargo Operational Efficiency (U_{43})	Total Loading Rate (U_{44})	W_i^0
Passenger Loading Rate (U_{41})	1	2	3	1	0.3601
Passenger Operational Efficiency (U_{42})	1/2	1	3	1	0.2546
Cargo Operational Efficiency (U_{43})	1/3	1/3	1	1/2	0.1117
Total Loading Rate (U_{44})	1	1	2	1	0.2736
Consistency test	CI = 0.027, RI = 0.89, and CR = CI/RI = 0.03 < 0.1. The matrix passed the consistency test.				

Table 8. Judgment matrix and relative data of U_5–U_{5n}

Strength and Scale (U_5)	Total Assets (U_{51})	Passenger Turnover (U_{52})	Freight Ton Turnover (U_{53})	Flights (U_{54})	Passenger Traffic (U_{55})	W_i^0
Total Assets (U_{51})	1	2	4	3	1	0.3156
Passenger Turnover (U_{52})	1/2	1	3	5	2	0.2873
Freight Ton Turnover (U_{53})	1/4	1/3	1	2	1/3	0.0938
Flights (U_{54})	1/3	1/5	1/2	1	1/4	0.0642
Passenger Traffic (U_{55})	1	1/2	3	4	1	0.2392
Consistency test	CI = 0.056, RI = 1.12, CR = CI/RI = 0.05 < 0.1. The matrix passed the consistency test.					

Table 9. Judgment matrix and relative data of U_6–U_{6n}

Human Resources (U_6)	Faculty (U_{61})	Per Capita Main Business Profits (U_{62})	Per Capita Main Business Income (U_{63})	Per Capita Training (U_{64})	W_i^0
Faculty (U_{61})	1	1/3	1/2	1	0.1411
Per Capita Main Business Profits (U_{62})	3	1	2	3	0.4550
Per Capita Main Business Income (U_{63})	2	1/2	1	2	0.2627
Per Capita Training (U_{64})	1	1/3	1/2	1	0.1411
Consistency test		CI = 0.0034, RI = 0.89, CR = CI/RI = 0.0039 < 0.1. The matrix passed the consistency test.			

3. *Total ranking and consistency test*

Totally rank the results as shown in Table 10:
According to the formula

$$CR = \frac{\sum_{j=1}^{m} CI(j)a_j}{\sum_{j=1}^{m} RI(j)a_j}, \tag{14}$$

we calculated that the consistency testing results of the total hierarchical ranking is CR = 0.0313 < 0.1, passing the consistency test.

Table 10. Index and its weight distribution of the airline competitiveness evaluation

	Financial Performance	Development Capacity	Service Quality	Operation Capacity	Strength and Scale	Human Resources	Ranking of weights
1	2	3	4	5	6	7	8
Weight	0.2561	0.1428	0.3109	0.1385	0.0855	0.0663	---
ROE	0.3487	0	0	0	0	0	0.0893
OPE	0.1677	0	0	0	0	0	0.0429
Asset-liability Ratio	0.4836	0	0	0	0	0	0.1238
ROA	0	0.2583	0	0	0	0	0.0369
Total Asset Turnover	0	0.1047	0	0	0	0	0.0150

End of Table 10

1	2	3	4	5	6	7	8
Total Assets Growth Rate	0	0.637	0	0	0	0	0.0910
Baggage Error(1/10000)	0	0	0.25	0	0	0	0.0777
Cargo Error(1/10000)	0	0	0.125	0	0	0	0.0389
Flight Punctuality	0	0	0.25	0	0	0	0.0777
Rate of Passenger Complaints	0	0	0.25	0	0	0	0.0777
Incident Symptom (1/10000 hours)	0	0	0.125	0	0	0	0.0389
Passenger Load Factor	0	0	0	0.3601	0	0	0.0499
Passenger Operational Efficiency	0	0	0	0.2546	0	0	0.0353
Cargo Operational Efficiency	0	0	0	0.1117	0	0	0.0155
Total Load Factor	0	0	0	0.2736	0	0	0.0379
Total Assets	0	0	0		0.3156	0	0.0270
Passenger Turnover	0	0	0	0	0.2873	0	0.0246
Freight Ton Turnover	0	0	0	0	0.0938	0	0.0080
Flights	0	0	0	0	0.0642	0	0.0055
Passenger Traffic	0	0	0	0	0.2392	0	0.0205
Faculty	0	0	0	0	0	0.1411	0.0094
Per Capita Main Business Profits	0	0	0	0	0	0.455	0.0302
Per Capita Main Business Income	0	0	0	0	0	0.2627	0.0174
Per Capita Training	0	0	0	0	0	0.1411	0.0094

4. *Airline competitiveness evaluation results*

We got the two-year raw data of the 15 airlines in the annual financial and statistical reports, and multiplied the weights and the scores of the indicators. For the scores and the ranking, see Tables 11–13.

Table 11. Score & Ranking of Airline Competitiveness in 2008 based on AHP

Indicator	Financial Performance		Development Capacity		Service Quality		Operation Capacity		Strength and Scale		Human Resources		Composite score in 2008 based on AHP	
Airlines	Score	#	Score	#	Score	#	Score	#	Score	#	Score	#	Score	#
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Deer Air	0.5387	2	–0.1558	10	0.7446	1	0.179	9	–0.6379	13	2.2429	1	0.5206	1
Shandong Airlines	1.4297	1	–0.4799	12	0.1126	5	0.1184	10	–0.2603	6	–0.2605	8	0.3318	2

End of Table 11

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
China Eastern Airlines	0.5275	3	0.0837	6	–0.0148	8	0.6382	2	–0.6155	12	–0.4664	15	0.1999	3
Air China	0.208	7	0.8245	2	–0.1678	10	0.5471	3	–0.5022	11	–0.2982	10	0.1748	4
United Eagle Airlines	–0.0405	10	0.1395	5	0.4939	2	0.2031	8	–0.3116	8	–0.4134	14	0.1638	5
Xiamen Airlines	–0.1488	11	1.7345	1	–0.415	14	0.2875	6	–0.0719	4	0.2332	3	0.1357	6
China Southern Airlines	0.356	5	–0.7301	13	0.2341	4	0.3125	5	–0.7363	15	–0.3979	13	0.0766	7
Hainan Airlines	–0.0236	9	0.5275	3	–0.4316	15	0.257	7	–0.3869	10	0.0689	5	–0.0248	8
Juneyao Airlines	0.4655	4	–0.065	9	0.0356	7	–1.002	14	–0.3116	7	–0.3911	12	–0.0436	9
Shenzhen Airlines	0.0801	8	–1.0351	14	0.055	6	0.4284	4	–0.0932	5	–0.3518	11	–0.0741	10
Spring Airlines	–0.4885	12	–1.22	15	–0.0373	9	1.4102	1	–0.3135	9	–0.1448	7	–0.1252	11
Sichuan Airlines	–0.5784	13	0.5051	4	–0.3536	13	0.0745	11	2.0831	1	0.3159	2	–0.1547	12
Okay Airways	0.2232	6	0.017	8	–0.2157	11	–0.963	13	–0.7061	14	–0.2616	9	–0.1582	13
United Airlines	–1.1594	14	0.0738	7	0.3123	3	–1.672	15	1.67	2	–0.0353	6	–0.4232	14
Lucky Air	–1.3893	15	–0.2199	11	–0.3521	12	–0.819	12	1.1936	3	0.1602	4	–0.5994	15

Table 12. Score & Ranking of Airline Competitiveness in 2009 based on AHP

Indicator	Financial Performance		Development Capacity		Service Quality		Operation Capacity		Strength and Scale		Human Resources		Composite score in 2009 based on AHP	
Airlines	Score	#	Score	#	Score	#	Score	#	Score	#	Score	#	Score	#
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
United Eagle Airlines	1.8845	1	–0.1394	9	–0.1243	11	0.8396	1	–0.2491	6	–0.5779	12	0.502	1
Air China	0.2697	5	0.3115	4	0.3117	3	0.5769	4	–0.625	12	1.5158	1	0.3908	2

End of Table 12

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shandong Airlines	0.2786	4	1.6087	1	–0.0114	7	0.0574	7	–0.7365	15	–0.2283	9	0.2902	3
Hainan Airlines	0.3943	3	–0.7271	13	0.1272	5	0.7868	2	–0.3285	9	1.27	2	0.2299	4
Spring Airlines	–0.225	10	0.2536	7	0.7521	1	0.2453	5	–0.0099	4	–0.6731	14	0.2018	5
China Southern Airlines	0.0131	8	0.3461	3	0.3336	2	–0.011	8	–0.3211	8	–0.4826	10	0.123	6
United Airlines	0.7624	2	–0.2338	10	–0.5953	15	0.6112	3	2.0403	1	0.4031	4	0.0882	7
China Eastern Airlines	–0.6099	13	0.1467	8	0.1406	4	–0.115	10	–0.6275	13	–0.6353	13	–0.1496	8
Shenzhen Airlines	0.1383	6	–0.5163	11	0.0272	6	–0.687	13	–0.4461	11	–0.6815	15	–0.1701	9
Xiamen Airlines	–0.7083	14	0.273	6	–0.147	12	0.0807	6	–0.0517	5	0.0396	5	–0.1743	10
Juneyao Airlines	0.0217	7	–0.7936	14	–0.0344	8	–0.262	12	–0.7307	14	–0.5587	11	–0.1918	11
Deer Air	–0.5938	12	–0.5272	12	–0.0368	9	–0.068	9	–0.3169	7	0.6548	3	–0.2049	12
Lucky Air	–0.9611	15	0.675	2	–0.2003	13	–0.211	11	1.2053	3	0.0224	7	–0.2397	13
Okay Airways	–0.2123	9	0.2736	5	–0.4371	14	–0.898	14	–0.3931	10	–0.1073	8	–0.2827	14
Sichuan Airlines	–0.4522	11	–0.9507	15	–0.1058	10	–0.946	15	1.5905	2	0.039	6	–0.4128	15

5.1.2. FA

1. Standardized the raw data, adjusted the mean and variance of the indexes to 0 and 1, eliminated differences between variable dimensions, extracted factors using Principal Component Analysis with SPSS13.0, and obtained the eigenvalues and the variance contribution rate of each factor. According to the principle that the cumulative contribution rate is more than 85%, we selected six factors, $F_1 \sim F_6$, whose cumulative variance contribution rate is 85.91%.
2. Obtained the component matrix through varimax and estimated the factor scores through the regression method. Determined that the weight of each factor is the ratio of its variance contribution to the 6 factors' total variance contributions. Aggregated all the weights and obtained the composite scores of all the airlines F:

$$F = (F_1 * 0.36 + F_2 * 0.17 + F_3 * 0.11 + F_4 * 0.08 + F_5 * 0.07 + F_6 * 0.07) / 0.86. \quad (15)$$

3. Put the values of the above factor scores in Formula (14), and obtained the composite scores of the evaluated alternatives. The results are shown in Table 14. The detailed calculations are omitted due to the paper length restrictions.

5.2. Binary relative analysis

Because the comprehensive evaluation based on AHP and FA is subjective and objective, we conducted the evaluation based on binary relative analysis.

5.2.1. Evaluation process based on binary relative analysis model

1. *Raw data of reference index and current index*

Two kinds of comprehensive evaluation values are shown in Tables 13 and 14.

Table 13. Scores and rankings of Chinese airlines based on AHP

Airlines	AHP2008		AHP2009	
	Score	Ranking	Score	Ranking
Okay Airways	–0.1582	13	–0.2827	14
Spring Airlines	–0.1252	11	0.2018	5
China Eastern Airlines	0.1999	3	–0.1496	8
Air China	0.1748	4	0.3908	2
Hainan Airlines	–0.0248	8	0.2299	4
Juneyao Airlines	–0.0436	9	–0.1918	11
Deer Air	0.5206	1	–0.2049	12
United Airlines	–0.4232	14	0.0882	7
China Southern Airlines	0.0766	7	0.123	6
Shandong Airlines	0.3318	2	0.2902	3
Shenzhen Airlines	–0.0741	10	–0.1701	9
Sichuan Airlines	–0.1547	12	–0.4128	15
Xiamen Airlines	0.1357	6	–0.1743	10
Lucky Air	–0.5994	15	–0.2397	13
United Eagle Airlines	0.1638	5	0.502	1

2. *Differential standardization of data*

Standardized the negative numbers into positive ones through Maximum Differential Standardization:

$$B_i = (b_i - b_{\min})/(b_{\max} - b_{\min}), \tag{16}$$

where b_i denotes a certain evaluation value of the i^{th} airline, $b_{\min}$ the minimum value of all the airlines in this evaluation, and $b_{\max}$ the maximum one. All the values can be converted to [0–1] through Maximum Differential Standardization. The values can be seen in Table 15.

Table 14. Scores and the rankings of Chinese airlines based on FA

Airlines	FA2008		FAP2009	
	F Score	Ranking	F Score	Ranking
Okay Airways	–0.1803	11	–0.2266	12
Spring Airlines	–0.9111	15	0.0589	8
China Eastern Airlines	0.1286	5	0.1686	5
Air China	–0.0512	8	1.0271	1
Hainan Airlines	0.5034	3	0.2641	2
Juneyao Airlines	0.0115	7	0.1231	7
Deer Air	0.7728	1	0.2593	3
United Airlines	–0.2403	13	–0.0359	10
China Southern Airlines	0.1017	6	0.1395	6
Shandong Airlines	–0.1007	10	0.0246	9
Shenzhen Airlines	0.4648	4	–0.862	15
Sichuan Airlines	0.5158	2	–0.5923	14
Xiamen Airlines	–0.7152	14	–0.2021	11
Lucky Air	–0.2238	12	–0.3975	13
United Eagle Airlines	–0.0762	9	0.2512	4

Table 15. Input and output data through Maximum Differential Standardization

Airlines	IAHP	IFA	OAHP	OFA
Okay Airways	0.3940	0.4340	0.1422	0.3363
Spring Airlines	0.4234	0.0001	0.6718	0.4875
China Eastern Airlines	0.7137	0.6175	0.2877	0.5455
Air China	0.6913	0.5107	0.8784	1
Hainan Airlines	0.5131	0.8400	0.7025	0.5961
Juneyao Airlines	0.4962	0.5479	0.2416	0.5215
Deer Air	1	1	0.2273	0.5935
United Airlines	0.1573	0.3984	0.5476	0.4373
China Southern Airlines	0.6036	0.6015	0.5856	0.5301
Shandong Airlines	0.8314	0.4813	0.7685	0.4693
Shenzhen Airlines	0.4690	0.8171	0.2653	0.0001
Sichuan Airlines	0.3970	0.8474	0.0001	0.1427
Xiamen Airlines	0.6564	0.1163	0.2607	0.3493
Lucky Air	0.0001	0.4082	0.1892	0.2459
United Eagle Airlines	0.6815	0.4958	1	0.5893

3. *Comparison between traditional C^2R model and Group Decision-making Model based on DEA with the Restrained Cone in airline competitiveness evaluation*

Calculate all the data in Table 13 and Table 14 using the traditional C^2R model. The results are shown in Table 16.

As can be seen from Table 16, the evaluation results are defined as the evaluation of the relative efficiency of the airlines, i.e. the efforts of the airlines from 2008 to 2009. When the relative efficiency values are calculated, the traditional DEA model has too many effective units. For example, Spring Airlines, China Eastern Airlines, Air China, and United Airlines all become the benchmark airlines, which is not conducive to the rankings of the airline competitiveness or the measurement of the gap between the various airlines. As a result, the traditional DEA model is incapable of accurately determining airline competitiveness, and with this model, the gap between the various airlines cannot be effectively measured. In this paper, as can be seen from the calculation results the group decision-making DEA model with cone ratios, the effective units, i.e. the number of the benchmark airlines reduces significantly, which can solve the problem of the excessive effective units, leaving one benchmarking aviation – international airlines. Thus, we can effectively rank the relative efficiency scores of the airlines and can clearly see the gap between the subjective efforts of the various airlines from 2008 to 2009.

After obtaining the calculation results using the C^2R model, we then used the Group Decision-making Model based on DEA with the Restrained Cone to calculate the data shown in Tables 15 and 16 and obtain the evaluation values and weight ratios shown in Table 17.

Table 16. Results and weight ratios of Chinese airlines' relative efficiency through C^2R model

Airlines	u_1	u_2	v_1	v_2	q
Okay Airways	0.436	0.336	0.181	0.199	0.962
Spring Airlines	0.672	0.488	0.423	0.220	1.000
China Eastern Airlines	0.714	0.545	0.319	0.276	1.000
Air China	1.315	1.000	0.615	0.454	1.000
Hainan Airlines	0.760	0.596	0.270	0.443	0.662
Juneyao Airlines	0.676	0.521	0.280	0.389	0.522
Deer Air	0.772	0.594	0.331	0.331	0.519
United Airlines	0.548	0.437	0.157	0.389	1.000
China Southern Airlines	0.690	0.530	0.296	0.295	0.865
Shandong Airlines	0.768	0.580	0.381	0.220	0.751
Shenzhen Airlines	0.265	0.209	0.092	0.160	0.622
Sichuan Airlines	0.100	0.143	0.057	0.121	0.461
Xiamen Airlines	0.475	0.349	0.276	0.049	0.543
Lucky Air	0.189	0.246	0.103	0.408	0.642
United Eagle Airlines	1.000	0.760	0.469	0.341	0.813

θ denotes the efficiency value from the C^2R model,θ* the efficiency value from the the Group-making Model Based on DEA with the Restrained Cone,u_1/u_2 the weight ratios of the two output indexes, and v_1/v_2 the weight ratios of the two input indexes.

In Table 17, the calculation results are defined as the evaluation values of the airlines' relative efficiencies, i.e. the airlines' competitiveness in 2008 and 2009. The results of the Decision-making Model Based on DEA with the Restrained Cone show that the effective units (the benchmarking airlines) are reduced significantly. There is only one benchmarking airline, Air China. By reducing the number of effective units, we can effectively rank the airlines' relative efficiencies. Therefore, the gap between the airlines' competitiveness in 2008 and 2009 can be seen clearly.

Table 17. Results and weight ratios of Chinese airlines' relative efficiency from Group-making Model based on DEA with Restrained Cone

Airlines	q	u_1/u_2	v_1/v_2	θ*
Okay Airways	0.962	1.298	0.910	0.944
Spring Airlines	1.000	1.377	1.923	0.987
China Eastern Airlines	1.000	1.310	1.156	0.897
Air China	1.000	1.315	1.355	1.000
Hainan Airlines	0.662	1.275	0.609	0.657
Juneyao Airlines	0.522	1.298	0.720	0.521
Deer Air	0.519	1.300	1.000	0.512
United Airlines	1.000	1.254	0.404	0.884
China Southern Airlines	0.865	1.302	1.003	0.826
Shandong Airlines	0.751	1.324	1.732	0.666
Shenzhen Airlines	0.622	1.268	0.575	0.611
Sichuan Airlines	0.461	0.699	0.471	0.439
Xiamen Airlines	0.543	1.361	5.633	0.537
Lucky Air	0.642	0.768	0.252	0.616
United Eagle Airlines	0.813	1.316	1.375	0.784

4. *Evaluation results and rankings based on BRE*

According to the previous results, the competitiveness of the 15 airlines in 2008 and 2009 was ranked using the Group Decision-making Model Based on DEA with the Restrained Cone as shown in Table 18.

Table 18. Evaluation results and rankings based on BRE

Airlines	Ranking
Okay Airways	3
Spring Airlines	2
China Eastern Airlines	4
Air China	1
Hainan Airlines	9
Juneyao Airlines	13
Deer Air	14
United Airlines	5
China Southern Airlines	6
Shandong Airlines	8
Shenzhen Airlines	11
Sichuan Airlines	15
Xiamen Airlines	12
Lucky Air	10
United Eagle Airlines	7

6. Analysis of the comprehensive competitiveness evaluation results

6.1. State-owned airlines

Air China, China Eastern Airlines, China Southern Airlines and Hainan Airlines are recognized as the four major Chinese airlines. They provide Chinese and international passengers and cargo transportations due to their large scales and comparatively wide route networks. Due to their large scales and comparatively wide route networks, they can transport Chinese and international passengers as well as cargo. As can be seen from the AHP and FA evaluation values in Table 19, the four state-owned airlines in 2008 and 2009 had some of the highest rankings, illustrating their high competitiveness. Their rankings in BRE were also in the top ten, with an average score of 0.845. They had strong growth productivity even though the influence of their large scales was excluded.

6.2. State-owned holding airlines

State-owned holding airlines, in the medium scales, mainly focus on the Chinese routes. They build route networks based on large and medium cities and core cities of different regions in China, like Beijing, Guangzhou, Shanghai, Xi'an, and Chengdu. In addition, these airlines have few international routes except the routes in the countries and regions around China.

As can be seen from the AHP and FA rankings of the six state-owned holding airlines in Table 19, in 2008 and 2009 these airlines were not ranked in the top ten, which indicated that their average competitiveness was significantly lower than that of the four major state-owned airlines and the private airlines. In the BRE results, four of them were ranked lower than 10. United Airlines and Shandong Airlines were respectively the fifth and the eighth. Their average ranking was 10. These data indicate that in 2008 and 2009, the relative competitiveness of the six state-owned holding airlines was not high. They even ranked behind the private airlines.

Table 19. Comprehensive competitiveness evaluation results of Chinese airlines

Airline information			AHP2008		AHP2009		FA2008		FA2009		BRE	
Type	Airlines	Start Date	Ranking	Average Score	Ranking	Average Score	Ranking	Average Score	Ranking	Average Score	Ranking	Average Score
State-owned Airlines	Air China	1987	4	0.107	2	0.149	8	0.171	1	0.4	1	0.845
	China Eastern Airlines	1988	3		8		5		5		4	
	China Southern Airlines	1989	7		6		6		6		6	
	Hainan Airlines	1989	8		4		3		2		9	
State-owned Holding Airlines	Deer Air	2006	1	–0.032	12	–0.109	1	0.002	3	–0.157	14	0.609
	United Airlines	2004	14		7		13		10		5	
	Shandong Airlines	1994	2		3		10		9		8	
	Sichuan Airlines	1988	12		15		2		14		15	
	Xiamen Airlines	1984	6		10		14		11		12	
	Lucky Air	2006	15		13		12		13		10	
Private Airlines	Okay Airways	2005	13	–0.048	14	0.012	11	–0.138	12	–0.131	3	0.78
	Spring Airlines	2005	11		5		15		8		2	
	Juneyao Airlines	2006	9		11		7		7		13	
	Shenzhen Airlines	1993	10		9		4		15		11	
	United Eagle Airlines	2005	5		1		9		4		7	

6.3. Private airlines

Private airlines were generally established in China's Tenth Five-year Project and began to operate between 2005 and 2006. They are mainly engaged in Chinese routes, covering cities of all sizes with their passenger and cargo flights. They take large cities as the center, and the capital cities as a transit to form the route network.

As can be seen from Table 19, the AHP and FA rankings of the five private airlines in 2008 and 2009 were around 10, which indicated that their average competitiveness was significantly lower than that of the four major state-owned airlines but higher than that of the six state-owned holding airlines. In the BRE results, only Juneyao Airlines ranked among the bottom few airlines. Spring Airlines and Okay Airways were respectively the second and the third. Their average ranking was 7. These data indicated that in 2008 and 2009, the relative competitiveness of the five private airlines was high. The mainly reason was that they were newly established with flexible systems and had a strong development potential.

Conclusions

This paper has analyzed airline competitiveness based on BRE. The Group Decision-making Model Based on DEA with the Restrained Cone can reflect not only actual airline competitiveness but also the competitiveness of the airlines' management. We hope the work in this paper has (1) enriched the theory of airline competitiveness, (2) built a more scientific and comprehensive evaluation index system of airlines' competitiveness, (3) constructed a competitiveness evaluation model based on BRE, and (4) conducted an empirical study of the improved model based on the 2008 and 2009 data from 15 Chinese airlines. The ranking results of the proposed method, theory and model coincide with the real conditions of the airline market demonstrating that our evaluation of airline competitiveness based on BRE is accurate, reliable and objective.

Based on the related literature and our own empirical study, further avenues for research and discussion may include studying (1) the competitiveness evaluations of Chinese and international airlines, (2) the enrichment and the improvement of the evaluation theory and methodology, (3) the selection of non-financial indicators in the competitiveness evaluation, and (4) the detailed recommendations and suggestions for the airlines' management.

Acknowledgements

This paper was funded by the National Natural Science Foundation of China(71271070), the Doctoral Research Foundation of Education Department of China (20092302110060), and the Foundation of New Century Educational Talents Plan of Chinese Education Ministry, China (NCET-08-0171).

References

Bureau of Transport and Communications Economics. 1993. *The Progress of Aviation Reform,* Rep. No. 81. Canberra: Australian Government Publishing Service: 34.

Barrosa, C. P.; Peypochb, N. 2009.An evaluation of European airlines' operational performance, *International Journal of Production Economics* 122(2):525–533. http://dx.doi.org/10.1016/j.ijpe.2009.04.016

Button, K.; Costa, A; Costa, F; Cruz, C. 2011. Problems of cost recovery by European airlines since market liberalization, *Transportation Planning and Technology* 34(2): 125–138. http://dx.doi.org/10.1080/03081060.2011.554703

Cao, M.; Zhang, B.; Luo, J. 2008. Core competence of small and medium-sized insurance enterprises based on DEA model, *Journal of Xi'an University (Social Sciences Edition)* 18(3): 54–60.

Chena, C. F.; Chena, S. C. 2012. Scale development of safety management system evaluation for the airline industry, *Accident Analysis & Prevention* 47: 177–181. http://dx.doi.org/10.1016/j.aap.2012.01.012.

Cheng, G. Z.; Lu, S. P. 2010. The multilevel gray evaluation of tourism resources in the Zhangdu Lake wetland, *Journal of Xiangfan Vocational and Technical College* 9(6): 48–51.

Chi, M. M.; Zhao, J. 2012. Application of BP neural network in evaluating e–business performance for service industry, *International Journal of Networking and Virtual Organizations* 10(3–4): 374–385. http://dx.doi.org/10.1504/IJNVO.2012.046458

Gerab, F.; Ching, H. Y. 2012. Determinants of financial performance in Brazilian companies: a multi-ratio model using multivariate statistical method, *Journal of Global Business and Economics* 5(1): 83–106.

Jang, S. C.; Choi, K.; Lee K. 2011. External shocks and efficiency changes in the US airline industry, *Service Industries Journal* 31(14): 2411–2435. http://dx.doi.org/10.1080/02642069.2010.504819

Li, H. L.; Le Z. J. 2008. E-government evaluation based on binary relative performance, in J. Y. Chung, C. X. Wan, G. Q. Liao (Eds.). *2nd International Conference on Management of e-Commerce and e-Government, Jiangxi, P.R.China* 2008: 115–119.

Li, H. L.2007.Binary relative evaluation on performance of government websites, in *International Conference on Public Administration (ICPA 3rd), Chengdu, P.R.China* 1: 509–514.

Liou, J. J. H.; Hsu, C. C.; Yeh, W. C.; Lin, R. H. 2011. Using a modified grey relation method for improving airline service quality, *Tourism Management* 32(6):1381–1388. http://dx.doi.org/10.1016/j.tourman.2011.01.013

Liou, J. J.; Tzeng, G.; Chang, H. 2007. Airline safety measurement using a hybrid model, *The International Journal of Management Science* 13(4): 243–249. http://dx.doi.org/10.1016/j.jairtraman.2007.04.008

Lin, W. C. 2012. Financial performance and customer service: an examination using activity-based costing of 38 international airlines, *Journal of Air Transport Management* 2012(19): 13–15. http://dx.doi.org/10.1016/j.jairtraman.2011.12.002

Lu, W. M.; Wang, W. K.; Hung, S.W. 2012. The effects of corporate governance on airline performance: production and marketing efficiency perspectives, *Transportation Research Part E-Logistic and Transportation Review* 48(2): 529–544. http://dx.doi.org/10.1016/j.tre.2011.09.003

Multivariate Statistics: an Introduction [online], [cited 2 February 2011]. Available from Internet: http://www.socialresearchmethods.net/tutorial/Flynn/multivar.htm

Park, Y.; Choi, J. K.; Zhang, A. M. 2009. Evaluating competitiveness of air cargo express services, *Transportation Research Part E* 45(2):321–334. http://dx.doi.org/10.1016/j.tre.2008.09.004

Qi, J. S.; Jiang, Z. H.; Wu, C. 2008. An international comparative research of the technical efficiency in China corporations – taken the China air transport corporations as example, *Studies in Science of Science* 26(5): 1006–1013.

Santana, I. 2009. Do public service obligations hamper the cost competitiveness of regional airlines, *Journal of Air Transport Management* 15(6): 344–349. http://dx.doi.org/10.1016/j.jairtraman.2008.12.001

Song, Y. F.; Liu, F. M. 2009. Fuzzy comprehensive evaluation model of core competitiveness of universities based on information fusion, in L. Qi (Ed.). *Asia-Pacific Conference on Information Processing (APCIP 2009)*, *Shenzhen, P.R.China* 1(14–19): 35–37. http://dx.doi.org/10.1109/APCIP.2009.17

Velocci, A. L. 1998. More rigorous methodology applied to gauge competitiveness, *Aviation Week and Space Technology* 149: 67–68.

Wang, L.; Wang, K. 2009. The multilevel gray evaluation of innovation capability of Hub-and-Spoke enterprise clusters, *International Conference on Information Management, Xi'an, P.R.,China* 4: 254–257.

Wang, J. L.; Zhao, R. F.; Wang, X. 2011. Fuzzy comprehensive evaluation on Hebei steel industry environment for the development of circular economy, *Ecological Economy* 10: 343–349.

Zhang, G. J.; Tian, J. H.; Zeng, W. 2009. Binary relative evaluation for government websites performance: a case study from China, in Q. H. Zhou (Ed.). *Proc. of 2009 International Forum on International Technology and Applications Chengdu, P.R.China* (3): 664–667.

Chong WU. Dr, is Professor at the School of Economics and Management, Harbin Institute of Technology (HIT), Harbin, China. He is Vice President of Department of Management Science and Engineering at the School of Economics and Management, Harbin Institute of Technology. He holds a PhD in Mathematics from the Science School, HIT and a Postdoctoral degree in Management Science and Engineering from the School of Business and Economics, HIT. He is author and reviewer of several articles in scientific journals indexed by SCI, SSCI and EI and international conferences. His research interests are in the areas of financial econometrics, quantitative finance, computational statistics, time series analysis, multivariate data analysis and forecasting.

Xin WANG. Dr Candidate Xin Wang is working for the PhD in Management Science and Engineering at the School of Economics and Management, Harbin Institute of Technology (HIT), Harbin, China. He is author and reviewer of several papers in international conferences. His research interests are in the areas of financial econometrics, quantitative finance, computational statistics, time series analysis, multivariate data analysis and forecasting.

Xinying ZHANG. Dr Candidate Xinying Zhang is working for the PhD in Management Science and Engineering at the School of Economics and Management, Harbin Institute of Technology (HIT) , Harbin, China. She is author and reviewer of several papers in international conferences and journals indexed by SCI, SSCI and EI. Her current research interests are in the areas of Modern Financial Engineering, ANN (Artificial Neural Network) in Management, EPNN (Elliptical Probabilistic Neural Network), Credit Risk Management, and Management and Decision Analysis.

Yongli LI. Dr Candidate Yongli Li is working for the PhD in Management Science and Engineering at the School of Economics and Management, Harbin Institute of Technology (HIT), Harbin, China. He is author and reviewer of several papers in international conferences and journals indexed by SCI, SSCI and EI. His current research interests are in the areas of Management and Decision Analysis, Operations Research and Modern Financial Engineering.

Brad O'BRIEN is tutor at the University of Utah, Salt Lake City, United States. He is author and reviewer of several scientific papers in international conferences.