International Journal of Hybrid Information Technology
Vol.7, No.3 (2014), pp.93-104
http://dx.doi.org/10.14257/ijhit.2014.7.3.11

Online Service Quality of the B2C e-commerce Companies in China

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Abstract

The measurement of online service quality has become increasing important as the e-commerce companies deliver an expanding array of service through the websites. There are few quantitative studies on the online service quality assessment focused on the market in China, which is one of the developing countries with the highest online population growth. This paper is an attempt to identify the measurement of the online service quality in China, and grey approach is applied to identify the criteria of online service quality assessment. The results could be the guideline for the e-commerce companies in terms of improving their service.

Keywords: *Leading industries, Environmental factor, Grey approach, Sustainable development.*

1. Introduction

As the development of the internet, there are increasingly users in the world engaging in e-commerce activities. As is known to all, China is one of the developing countries with the highest online population growth rates. With the development of the e-commerce, an increasing number of customers have used the e-commerce websites to obtain the related information about products and services, with possible follow-up purchase (Korner and Zimmerman, 2000; Geissler, 2001).The measurement and evaluation of the online service quality is becoming increasing important as the e-commerce companies deliver an expanding array of services through the internet, in which the websites clearly emerge as a critical channel for e-commerce companies.

It is necessary for the e-commerce companies to identify customers' needs, wants, and preferences in order to deliver high quality service performance (Howard and Worboys, 2003). Effective measurements are indispensable; several measurement scales and their extensions prevail, though most originally stemmed from conventional, face-to-face service contexts (Kassim and Bojeib, 2002; Kettinger et al., 1995; Pitt *et al.*, 1995). However, the service environment differs a lot between the physical stores and online storefronts, so it is necessary to study the online service quality.

This paper is an attempt to identify the main factors affecting online service quality for the e-commerce companies in China, which could be the guideline for the development of the companies. The remainder of this study is organized as follows. Section 2 introduces the related literature about the online service quality. Following is a brief introduction about the

ISSN: 1738-9968 IJHIT

Grey approach which is employed in this research. Section 4 discusses the main factors that have an impact on the online service, and illustrate an empirical analysis of 18 B2C e-commerce websites in China. In the last section, the related managerial implications of this research are discussed.

2. Literature Review

Consumers usually evaluate e-commerce companies based on the perceived online service quality and satisfaction (Peterson and Wilson, 1992).Service quality remains of focal interest to researchers and practitioners. Many researchers consider service quality a measure of how well the delivered service level meets the customer's expectation. Compared with the abundant research examining the quality of face-to-face services, investigations of online service quality remain in their infancy (Serkan et al., 2010).

A handful of scales measure web site quality (Loiacono *et al.*, 2002; Yoo and Donthu, 2001), online service quality (Bauer *et al.*, 2006; Parasuraman *et al.*, 2005; Zeithaml *et al.*, 2000), or e-retailing quality (Wolfinbarger and Gilly, 2003). In general, these scales derive from rigorous development efforts and focus on important characteristics pertaining to information or the system; few consider the service dimension of online services comprehensively (Nelson *et al.*, 2005; Wixom and Todd, 2005). Table 1 summarizes the related research results:

Table 1. Online service quality scales in prior related research

Article	System related	Service related
Zeithaml *et al.* (2000)	Access, ease of navigation, flexibility, reliability, price knowledge, aesthetics, efficiency, personalization, privacy.	Responsiveness, assurance
Francis and White (2002)	Product attribute, functionality, ownership conditions, security	Delivery, customer service
Loiacono *et al.* (2002)	Appeal, response time, flow, image, operations, better than alternatives, innovativeness, interactivity, trust	
Barnes and Vidgen (2002)	Usability, design	Empathy, trust
Wolfinbarger and Gilly (2003)	Website design, privacy	Fulfillment/reliability, customer service
Parasuraman *et al*. (2005)	Efficiency, availability, privacy	Fulfillment
Parasuraman *et al.* (2005)		Compensation, responsiveness contract
Bauer *et al.* (2006)	Reliability, process, functionality/design	Responsiveness, enjoyment
Yoo and Donthu (2001)	Ease of use, aesthetic design, reliability, tangibles	Responsiveness
Aldwani and Palvia (2002)	Technical adequacy, specific content, content quality, web appearance	
Janda *et al.* (2002)	Access, security, information	Sensation
Li *et al*. (2002)	Competence, quality of information, web assistance, empathy	Responsiveness, call-back systems
Ranganathan and Ganapathy (2002)	Information content, design, security, privacy	
Yang and Jun (2002)	Reliability, access, ease of use, personalization, security	Responsiveness
Cai and Jun (2003)	Website design/content	Trustworthiness, prompt/reliable service, communication
Gounaris and Dimitriadis (2003)		Customer care and risk reduction benefit, information benefit,

		interaction facilitation
Jun *et al.* (2004)	Ease of use, attentiveness, access, security, credibility	Reliable/prompt responses
Kim and Stoel (2004)	Web appearance, entertainment, information fit-to-task, transaction capacity	Response time, trust
Lee and Lin (2005)	Website design, reliability, personalization	Responsiveness, trust
Parasuraman *et al.* (2005)	Efficiency, system availability, privacy	Fulfillment
Yang *et al.* (2005)	Usability, usefulness of content, adequacy of information, accessibility	Interaction
Bauer *et al.* (2005)	Functionality/design, process, reliability	Enjoyment, responsiveness
Collier and Bienstock (2006)	Functionality, information accuracy, design, privacy, ease of use, order condition, order accuracy , procedural fairness, outcome fairness	Timeliness, interactive fairness
Ibrahim *et al.* (2006)	Convenience/accuracy, accessibility/reliability, good queue management, personalization	Friendly/responsive customer service, targeted customer service
Cristobal *et al.* (2007)	Web design, assurance, order management	Customer service
Ho and Lee (2007)	Information quality, security, website functionality	Customer relationships, responsiveness
Sohn and Tadisina (2008)	Trust, ease of use, website content and functionality, reliability	Customized communication, speed of delivery
Wang *et al.* (2010)	Reliability, competence, ease of use, product portfolio, security	Responsiveness, satisfaction
Ding *et al.* (2011)	Perceived control	Service convenience, customer service, fulfillment

3. Methodology

3.1. Grey system theory

Grey system theory which can help evaluate outcomes under the situation with incomplete and indeterminate information is first proposed in 1982 (Deng, 1982). To introduce some fundamental aspects of grey system theory, some basic definitions and notation are shown as follows:

x is denoted as a closed and bounded set of real numbers. A grey number, $\otimes x$, is defined as an interval with known upper and lower bounds but unknown distribution information for x (Deng, 1989), which is,

$$\otimes x = [\underline{\otimes} x, \overline{\otimes} x] = [x' \in x \mid \underline{\otimes} x \le x' \le \overline{\otimes} x] \quad (1)$$

where $\underline{\otimes} x$ and $\overline{\otimes} x$ are the lower and upper bounds of $\otimes x$ respectively.

Expression (2)－(5) demonstrate some basic grey number mathematical operations:

$$\otimes x_1 + \otimes x_2 = [\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2] \quad (2)$$

$$\otimes x_1 - \otimes x_2 = [\underline{x}_1 - \overline{x}_2, \overline{x}_1 - \underline{x}_2] \quad (3)$$

$$\otimes x_1 \times \otimes x_2 = [\min(\underline{x}_1 \underline{x}_2, \underline{x}_1 \overline{x}_2, \overline{x}_1 \underline{x}_2, \overline{x}_1 \overline{x}_2), \max(\underline{x}_1 \underline{x}_2, \underline{x}_1 \overline{x}_2, \overline{x}_1 \underline{x}_2, \overline{x}_1 \overline{x}_2)] \quad (4)$$

$$\otimes x_1 \div \otimes x_2 = [\underline{x}_1, \overline{x}_1] \times [\frac{1}{\underline{x}_2}, \frac{1}{\overline{x}_2}] \quad (5)$$

3.2. GRA (Grey Relational Analysis)

Below is a briefly review of relevant definitions and the calculation procedure for the GRA approach.

GRA uses several small sub-problems to present the decision problem, and the problem is decomposed into a hierarchy with a goal at the top, criteria and sub-criteria at levels and sub-levels and decision alternatives at the bottom of the hierarchy.

The comparison matrix involves the comparison in pairs of the elements of constructed hierarchy. The aim is to set their relative priorities with respect to each of the elements at the next higher level.

$$D = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_m \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ \vdots & & & & \\ x_{m1} & x_{m2} & x_{m3} & \cdots & x_{mn} \end{bmatrix} \end{array}$$

Where x_{ij} is the degree preference of i^{th} year over j^{th} criterion. Before the calculation of vector of priorities, the comparison matrix has to be normalized into the range of [0, 1] by the equation below:

The larger, the better type (Yang and Hung, 2007):

$$y_{ij} = \frac{\left[x_{ij} - \min\left\{ x_{ij} \right\} \right]}{\left[\max\left\{ x_{ij} \right\} - \min\left\{ x_{ij} \right\} \right]}$$

The smaller, the better type:

$$y_{ij} = \frac{\left[\max\left\{ x_{ij} \right\} - x_{ij} \right]}{\left[\max\left\{ x_{ij} \right\} - \min\left\{ x_{ij} \right\} \right]}$$

The normalized decision matrix is denoted by $Y = [y_{ij}]_{m \times n}$.

Assume Y is a factor set of grey correlation. Let $y_0(k)$ and $y_i(k)$ denote the initial criteria values of y_0 and y_i on company k respectively.

As average correlation value $r(y_0, y_i)$ of $\{ r(y_0(k), y_i(k)) | k = 1, 2, \ldots, m \}$ is a real number, the value can be defined by grey correlation.

Let $r(y_0, y_i) = \frac{1}{m} \sum_{k=1}^{m} r(y_0(k), y_i(k)) = r_{0i}$,where

$$r(y_0(k), y_i(k)) = \frac{\min_i \min_k |y_0(k) - y_i(k)| + \rho \max_i \max_k |y_0(k) - y_i(k)|}{|y_0(k) - y_i(k)| + \rho \max_i \max_k |y_0(k) - y_i(k)|}$$

, where ρ is the distinguished coefficient ($\rho \in$ [0,1]).

Grey correlation matrix $R = (r_{ij})$ is derived by grey correlation analysis, where $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$. The definition of clustering financial ratios based on the entries of the grey correlation matrix is presented as follows.

Definition 1: If $r_{ij} \geq r$ and $r_{ji} \geq r$, Y_i and Y_j belong to the same cluster, where r is a threshold value of clustering.

Definition 2: If $r_{ij} \geq r$, $r_{ji} \geq r$, $r_{ik} \geq r$ and $r_{ki} \geq r$, but $r_{jk} < r$ or $r_{kj} < r$, if $min\{ r_{ij}, r_{ij} \} \geq min\{ r_{ki}, r_{ik} \}$, then Y_i , Y_j and Y_k belong to the same cluster.

As those indices can be partitioned into several clusters, the finding of representative indices of clusters is stated as follows.

Definition 3: If Y_i and Y_j belong to the one cluster, the representative index of the cluster is determined according to the maximum value of r_{ij} and r_{ji}. If $r_{ij} \geq r_{ji}$, the representative index of the cluster is financial ratio *i*.

Definition 4: If Y_i, Y_j and Y_k are in the one cluster, the representati88888888888ve index of the cluster is decided according to the maximum value of $r_{ij} + r_{ik}$, $r_{ji} + r_{jk}$ and $r_{ki} + r_{kj}$. If $r_{ij} + r_{jk}$ is the maximum value, then the representative index of the cluster is financial ratio *i*.

3.3. The grey approach

The grey approach is appropriate for solving the group decision-making problem in an uncertain environment. Let $A = \{A_1, A_2, \cdots A_m\}$ is a discrete set of m leading industry alternatives. $\otimes w = \{\otimes w_1, \otimes w_2, \cdots \otimes w_n\}$ is the vector of criteria weights. Linguistic variables (Li et al., 2007) are adopted in this research, as shown in Table 1:

Table 1. Scale of Attribute Weights

Rank	Sub-criteria grade	Membership function
Very Low (VL)	1	[0.00,0.10]
Low (L)	2	[0.10,0.30]
Medium Low (ML)	3	[0.30,0.40]
Medium (M)	4	[0.40,0.50]
Medium High (MH)	5	[0.50,0.60]
High (H)	6	[0.60,0.90]
Very High (VH)	7	[0.90,1.00]

The criteria rating value is shown in table 2:

Table 2. Scale of Attribute Weights

Rank	Sub-criteria grade	Membership function
Very Poor (VP)	1	[0.00,1.00]
Poor (P)	2	[0.10,0.30]
Medium Low (ML)	3	[0.30,0.40]
Medium (M)	4	[0.40,0.50]
Medium High (MH)	5	[0.50,0.60]
High (H)	6	[0.60,0.90]
Very High (VH)	7	[0.90,1.00]

The detailed procedure is summarized as follows:

Step 1: Criteria weight identification

If the decision maker group has K raters, then the criteria weight is calculated using:

$$\otimes w_j = \frac{1}{K}[\otimes w_j^1 + \otimes w_j^2 + \cdots \otimes w_j^K]$$

Where $\otimes w_j^K \ (j = 1, 2, \cdots, n)$ is the criteria weight of K^{th} rater and can be described by Grey number $\otimes w_j^K = [\underline{w}_j^K, \overline{w}_j^K]$.

Step 2: Criteria rating value in linguistic variables

Criteria rating value in linguistic variables are calculated using

$$\otimes Y_{ij} = \frac{1}{K}[\otimes Y_{ij}^{1} + \otimes Y_{ij}^{2} + \cdots \otimes Y_{ij}^{K}]$$

Where $\otimes Y_{ij}^{K}\ (i = 1, 2, \cdots, m;\ j = 1, 2, \cdots, n)$ is the criteria weight of K^{th} rater and can be described by Grey number $\otimes Y_{ij}^{K} = [\underline{Y}_{ij}^{K}, \overline{Y}_{ij}^{K}]$.

Step 3: Establish the normalized grey decision matrix:

Since we had already normalized the decision matrix in the GRA process, then we should transfer the normalized numbers in the decision matrix into Grey numbers.

$$D = \begin{bmatrix} \otimes Y_{11} & \otimes Y_{12} & \otimes Y_{13} & \cdots & \otimes Y_{1n} \\ \otimes Y_{21} & \otimes Y_{22} & \otimes Y_{23} & \cdots & \otimes Y_{2n} \\ \otimes Y_{31} & \otimes Y_{32} & \otimes Y_{33} & \cdots & \otimes Y_{3n} \\ \vdots & & & & \\ \otimes Y_{m1} & \otimes Y_{m2} & \otimes Y_{m3} & \cdots & \otimes Y_{mn} \end{bmatrix}$$

Step 4: Establish the weighted normalized Grey decision matrix

The weighted normalized Grey decision matrix can be derived by the normalized Grey decision matrix and criteria weights by the equation as follows:

$$\otimes V_{ij} = \otimes Y_{\mathrm{ij}} \times \otimes W_{j}$$

Then the weighted normalized Grey decision matrix can be established as follows:

$$D = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \otimes V_{13} & \cdots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & \otimes V_{23} & \cdots & \otimes V_{2n} \\ \otimes V_{31} & \otimes V_{32} & \otimes V_{33} & \cdots & \otimes V_{3n} \\ \vdots & & & & \\ \otimes V_{m1} & \otimes V_{m2} & \otimes V_{m3} & \cdots & \otimes V_{mn} \end{bmatrix}$$

Step 5: Set ideal solution for the alternatives

$$S^{\max} = \{[\max_{1\le i\le m} \underline{V}_{i1}, \max_{1\le i\le m} \overline{V}_{i1}], [\max_{1\le i\le m} \underline{V}_{i2}, \max_{1\le i\le m} \overline{V}_{i2}], \cdots, [\max_{1\le i\le m} \underline{V}_{in}, \max_{1\le i\le m} \overline{V}_{in}]\}$$

Step 6: Calculate the Grey possibility

Compare the alternatives set $A = \{A_1, A_2, \cdots A_m\}$ with the ideal solution $A^{\max}$:

$$P\{A_i \le A^{\max}\} = \frac{1}{n}\sum_{j=1}^{n}\{\otimes V_{ij} \le \otimes Y_{j}^{\max}\}$$

Step 7: Prioritize the industries

Sort the alternative industries based on $P\{A_i \le A^{\max}\}$ comparison. If A_i value is smaller, the ranking order of A_i is better. Otherwise, the ranking order is worse.

4. Data Collection and Results Analysis

Considering the differences among B2C, C2C and B2B e-commerce, and our research is focus on B2C e-commerce in China, the 18 B2C e-commerce websites in retail market shown in table 3 are selected based on the user coverage.

Table 3. 18 B2C e-commerce websites in retail market in China

No.	E-Commerce Website	No. of users (per million)
1	Tmall	9010
2	Jingdong Mall	6940
3	Tencent	3930
4	Amazon	3450
5	Handle group buying	2580
6	Dangdang	2160
7	Vancl	2160
8	Full King	1290
9	No.1	1050
10	F group buying	770
11	Yixun	760
12	Moonbasa	700
13	Letao	640
14	Newegg	600
15	M18	570
16	Okbuy	560
17	VIPshop	490
18	Mbaobao	450

The specific original measures are listed in Table 3. The decision problem consists of three levels: the objective of the problem is the highest level, while in the second level, the criteria are listed, and the sub-criteria are listed in the third level.

Table 3. The original measures of online service quality assessment

Goal	Aspects	Criteria
Assessment of online service quality	A_1 *System related*	OC_1 Access OC_2 Ease of navigation OC_3 Flexibility OC_4 Reliability OC_5 Price knowledge OC_6 Aesthetics OC_7 Efficiency OC_8 Personalization OC_9 Privacy OC_{10} Ease of use OC_{11} Design OC_{12} Speed OC_{13} Security OC_{14} Ownership conditions
	A_2 *Service related*	OC_{15} Responsiveness OC_{16} Assurance OC_{17} Delivery OC_{18} Customer service

As shown in Table 3, there are thirteen original measures, so GRA is employed for the representative selection. Grey Correlation matrix is derived from the DPS 9.0 (software which can determine the grey correlation matrix) as below (He and Zhai, 2009):

$$
R_{A1} = \begin{bmatrix}
1.00 & 0.46 & 0.40 & 0.31 & 0.28 & 0.36 & 0.57 & 0.33 & 0.34 & 0.34 & 0.45 & 0.37 & 0.36 & 0.40 \\
0.40 & 1.00 & 0.39 & 0.25 & 0.34 & 0.38 & 0.53 & 0.36 & 0.41 & 0.40 & 0.50 & 0.45 & 0.40 & 0.48 \\
0.37 & 0.44 & 1.00 & 0.25 & 0.36 & 0.32 & 0.41 & 0.37 & 0.31 & 0.36 & 0.56 & 0.28 & 0.37 & 0.37 \\
0.31 & 0.29 & 0.26 & 1.00 & 0.44 & 0.36 & 0.32 & 0.32 & 0.41 & 0.35 & 0.34 & 0.29 & 0.35 & 0.35 \\
0.23 & 0.31 & 0.29 & 0.37 & 1.00 & 0.35 & 0.34 & 0.28 & 0.44 & 0.35 & 0.33 & 0.27 & 0.53 & 0.40 \\
0.33 & 0.40 & 0.30 & 0.33 & 0.38 & 1.00 & 0.41 & 0.41 & 0.35 & 0.50 & 0.34 & 0.33 & 0.39 & 0.37 \\
0.59 & 0.54 & 0.37 & 0.28 & 0.33 & 0.39 & 1.00 & 0.32 & 0.40 & 0.37 & 0.47 & 0.43 & 0.45 & 0.37 \\
0.29 & 0.35 & 0.35 & 0.27 & 0.27 & 0.38 & 0.34 & 1.00 & 0.45 & 0.28 & 0.36 & 0.28 & 0.46 & 0.38 \\
0.28 & 0.39 & 0.27 & 0.35 & 0.44 & 0.34 & 0.37 & 0.44 & 1.00 & 0.32 & 0.43 & 0.31 & 0.83 & 0.53 \\
0.30 & 0.39 & 0.31 & 0.27 & 0.36 & 0.49 & 0.37 & 0.28 & 0.33 & 1.00 & 0.32 & 0.33 & 0.35 & 0.36 \\
0.40 & 0.52 & 0.53 & 0.29 & 0.34 & 0.34 & 0.45 & 0.38 & 0.43 & 0.32 & 1.00 & 0.37 & 0.42 & 0.41 \\
0.37 & 0.46 & 0.31 & 0.29 & 0.34 & 0.37 & 0.50 & 0.34 & 0.40 & 0.38 & 0.43 & 1.00 & 0.42 & 0.43 \\
0.29 & 0.38 & 0.32 & 0.27 & 0.49 & 0.38 & 0.42 & 0.44 & 0.78 & 0.36 & 0.39 & 0.34 & 1.00 & 0.47 \\
0.38 & 0.49 & 0.38 & 0.31 & 0.48 & 0.40 & 0.42 & 0.41 & 0.60 & 0.39 & 0.44 & 0.42 & 0.48 & 1.00
\end{bmatrix}
$$

$$
R_{A2} = \begin{bmatrix}
1.00 & 0.44 & 0.44 & 0.32 \\
0.38 & 1.00 & 0.27 & 0.37 \\
0.34 & 0.28 & 1.00 & 0.31 \\
0.32 & 0.43 & 0.39 & 1.00
\end{bmatrix}
$$

According to the above matrices and the definitions described earlier, the measures can be grouped into several clusters by threshold value r = 0.55. The classification result is shown in Table 4, and the final measures of selection of the leading industries are identified as shown in Table 5.

Table 4. The classification of the representative measures

Aspects	**Measures with each cluster**	**Representative measures**
A_1 System related	OC_1 , OC_7 OC_2 OC_3 , OC_{11} OC_4 OC_5 OC_6 OC_8 OC_9,OC_{13},OC_{14} OC_{10} OC_{12}	OC_7 OC_2 OC_3 OC_4 OC_5 OC_6 OC_8 OC_{14} OC_{10} OC_{12}
A_2 Service related	OC_{15}, OC_{16}, OC_{17}, OC_{18}	OC_{15} OC_{16}, OC_{17}, OC_{18}

Table 5. The final measures of online service quality

Goal	Aspects	Criteria
Assessment of online service quality	*A_1 System related*	C_1 Efficiency C_2 Ease of navigation C_3 Flexibility C_4 Reliability C_5 Price knowledge C_6 Aesthetics C_7 Personalization C_8 Ownership conditions C_9 Ease of use C_{10} Speed
	A_2 Service related	C_{11} Responsiveness C_{12} Assurance C_{13} Delivery

		C_{14} Customer service

The important degrees of the above sub-criteria weights are given with linguistic terms, i.e. VL, L, M, H, and VH, employed by four experts E_1, E_2, E_3 and E_4, as shown in Table 6.

Table 6. The Grey weights given by four decision makers

Criteria	DM_1	DM_2	DM_3	DM_4	$\otimes w_j$
C_1	H[0.60,0.90]	H[0.60,0.90]	M[0.40,0.50]	H[0.60,0.90]	[0.55,0.80]
C_2	H[0.60,0.90]	MH[0.50,0.60]	H[0.60,0.90]	M [0.40,0.50]	[0.53,0.73]
C_3	H[0.60,0.90]	H[0.60,0.90]	MH[0.50,0.60]	H[0.60,0.90]	[0.58,0.83]
C_4	MH[0.50,0.60]	VH[0.90,1.00]	VH[0.90,1.00]	H[0.60,0.90]	[0.73,0.88]
C_5	H[0.60,0.90]	H[0.60,0.90]	MH[0.50,0.60]	H[0.60,0.90]	[0.58,0.83]
C_6	H[0.60,0.90]	M[0.40,0.50]	M[0.40,0.50]	H[0.60,0.90]	[0.50,0.70]
C_7	H[0.60,0.90]	H[0.60,0.90]	MH[0.50,0.60]	MH[0.50,0.60]	[0.55,0.75]
C_8	H[0.60,0.90]	VH[0.90,1.00]	MH[0.50,0.60]	M[0.40,0.50]	[0.60,0.75]
C_9	H[0.60,0.90]	VH[0.90,1.00]	VH[0.90,1.00]	H[0.60,0.90]	[0.75,0.95]
C_{10}	H[0.60,0.90]	H[0.60,0.90]	MH[0.50,0.60]	H[0.60,0.90]	[0.58,0.83]
C_{11}	H[0.60,0.90]	VH[0.90,1.00]	VH[0.90,1.00]	H[0.60,0.90]	[0.75,0.95]
C_{12}	MH[0.50,0.60]	H[0.60,0.90]	H[0.60,0.90]	H[0.60,0.90]	[0.58,0.83]
C_{13}	H[0.60,0.90]	VH[0.90,1.00]	MH[0.50,0.60]	H[0.60,0.90]	[0.65,0.85]
C_{14}	H[0.60,0.90]	VH[0.90,1.00]	VH[0.90,1.00]	VH[0.90,1.00]	[0.83,0.98]

The normalized decision matrix is shown in Table 7.

Table 7. Normalized decision matrix

No.	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
S_1	0.23	0.42	0.88	0.98	0.36	0.33	0.99	1.00	0.86
S_2	0.98	0.23	0.99	0.45	0.20	1.00	0.12	0.89	0.81
S_3	0.44	0.33	0.43	0.33	0.08	0.28	0.98	0.67	1.00
S_4	0.44	0.21	1.00	1.00	0.21	0.03	0.99	1.00	0.88
S_5	0.13	0.42	0.39	0.09	0.39	0.01	0.79	0.87	0.91
S_6	0.46	0.03	0.94	0.00	1.00	0.04	0.84	0.88	0.92
S_7	0.17	0.46	1.00	0.07	0.01	0.06	1.00	1.00	0.74
S_8	0.07	1.00	0.00	0.54	0.10	0.35	0.77	0.99	0.73
S_9	1.00	0.18	0.74	0.00	0.94	0.26	0.00	0.98	0.81
S_{10}	0.00	0.66	0.98	0.05	0.03	0.06	0.94	0.11	0.72
S_{11}	0.05	0.70	0.93	0.03	0.00	0.02	0.96	0.44	0.47
S_{12}	0.24	0.43	1.00	0.04	0.06	0.00	1.00	1.00	0.98
S_{13}	0.26	0.51	0.98	0.02	1.00	0.08	0.91	0.99	0.00
S_{14}	0.62	0.23	0.98	0.03	0.31	0.03	0.98	1.00	0.79
S_{15}	0.31	0.35	1.00	0.00	0.00	0.00	0.98	0.95	0.74
S_{16}	0.33	0.26	1.00	0.00	0.12	0.00	0.99	0.97	0.98
S_{17}	0.98	0.00	1.00	0.03	0.01	0.00	0.62	0.86	0.90
S_{18}	0.98	0.00	1.00	0.03	0.01	0.00	0.62	0.86	0.90

In the next step, the Grey variables discussed in Section 3.3 is applied to transform Table 6 into Table 7 as explained by the following example. If the numeric rating is 0.05, then its Grey variable is "VL". Therefore, the new pairwise comparison matrix is shown in Table 8:

Table 8. Normalized decision matrix using Grey variables

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	L	M	H	VH	ML	ML	VH
A_2	VH	L	VH	M	L	VH	L
A_3	M	ML	M	ML	VL	L	VH
A_4	M	L	VH	VH	L	VL	VH
A_5	L	M	ML	VL	ML	VL	H
A_6	M	VL	VH	VL	VH	VL	H
A_7	L	M	VH	VL	VL	VL	VH
A_8	VL	VH	VL	MH	L	ML	H
A_9	VH	L	H	VL	VH	L	VL
A_{10}	VL	H	VH	VL	VL	VL	VH
A_{11}	VL	H	VH	VL	VL	VL	VH
A_{12}	L	M	VH	VL	VL	VL	VH
A_{13}	L	MH	VH	VL	VH	VL	VH
A_{14}	H	L	VH	VL	ML	VL	VH
A_{15}	ML	ML	VH	VL	VL	VL	VH
A_{16}	ML	L	VH	VL	L	VL	VH
A_{17}	VH	VL	VH	VL	VL	VL	H
S_{18}	0.98	0.00	1.00	0.03	0.01	0.00	0.62

The Grey variables of the above matrix are then transformed into a Grey decision marix, as shown in Table 9:

Table 9. Part of the Grey decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	[0.10,0.30]	[0.40,0.50]	[0.60,0.90]	[0.90,1.00]	[0.30,0.40]	[0.30,0.40]	[0.90,1.00]
A_2	[0.90,1.00]	[0.10,0.30]	[0.90,1.00]	[0.40,0.50]	[0.10,0.30]	[0.90,1.00]	[0.10,0.30]
A_3	[0.40,0.50]	[0.30,0.40]	[0.40,0.50]	[0.30,0.40]	[0.00,0.10]	[0.10,0.30]	[0.90,1.00]
A_4	[0.40,0.50]	[0.10,0.30]	[0.90,1.00]	[0.90,1.00]	[0.10,0.30]	[0.00,0.10]	[0.90,1.00]
A_5	[0.10,0.30]	[0.40,0.50]	[0.30,0.40]	[0.00,0.10]	[0.30,0.40]	[0.00,0.10]	[0.60,0.90]
A_6	[0.40,0.50]	[0.00,0.10]	[0.90,1.00]	[0.00,0.10]	[0.90,1.00]	[0.00,0.10]	[0.60,0.90]
A_7	[0.10,0.30]	[0.40,0.50]	[0.90,1.00]	[0.00,0.10]	[0.00,0.10]	[0.00,0.10]	[0.90,1.00]
A_8	[0.00,0.10]	[0.90,1.00]	[0.00,0.10]	[0.50,0.60]	[0.10,0.30]	[0.30,0.40]	[0.60,0.90]
A_9	[0.90,1.00]	[0.10,0.30]	[0.60,0.90]	[0.00,0.10]	[0.90,1.00]	[0.10,0.30]	[0.00,0.10]
A_{10}	[0.00,0.10]	[0.60,0.90]	[0.90,1.00]	[0.00,0.10]	[0.00,0.10]	[0.00,0.10]	[0.90,1.00]
A_{11}	[0.00,0.10]	[0.60,0.90]	[0.90,1.00]	[0.00,0.10]	[0.00,0.10]	[0.00,0.10]	[0.90,1.00]
A_{12}	[0.10,0.30]	[0.40,0.50]	[0.90,1.00]	[0.00,0.10]	[0.00,0.10]	[0.00,0.10]	[0.90,1.00]
A_{13}	[0.10,0.30]	[0.50,0.60]	[0.90,1.00]	[0.00,0.10]	[0.90,1.00]	[0.00,0.10]	[0.90,1.00]
A_{14}	[0.60,0.90]	[0.10,0.30]	[0.90,1.00]	[0.00,0.10]	[0.30,0.40]	[0.00,0.10]	[0.90,1.00]
A_{15}	[0.30,0.40]	[0.30,0.40]	[0.90,1.00]	[0.00,0.10]	[0.00,0.10]	[0.00,0.10]	[0.90,1.00]
A_{16}	[0.30,0.40]	[0.10,0.30]	[0.90,1.00]	[0.00,0.10]	[0.10,0.30]	[0.00,0.10]	[0.90,1.00]
A_{17}	[0.90,1.00]	[0.00,0.10]	[0.90,1.00]	[0.00,0.10]	[0.00,0.10]	[0.00,0.10]	[0.60,0.90]
$\otimes w_j$	[0.58,0.83]	[0.65,0.85]	[0.48,0.63]	[0.53,0.73]	[0.53,0.73]	[0.63,0.84]	[0.58,0.83]

Following the resulting Grey weighted decision matrix can be derived based on Table 9 and the weights identified before, and the values of ideal leading industry A^{max} are shown below for our illustration.

$$A^{max} = \{[0.52,0.83],[0.59,0.85],[0.43,0.63],[0.48,0.73],[0.48,0.73],[0.57,0.84],[0.52,0.83],$$
$$[0.63,0.85],[0.52,0.83]\}$$

Then the Grey possibility value for each industry is given below:

$P(A_1 \le A^{max}) = 0.1401; P(A_2 \le A^{max}) = 0.1536; P(A_3 \le A^{max}) = 0.1732; P(A_4 \le A^{max}) = 0.1667;$
$P(A_5 \le A^{max}) = 0.1924; P(A_6 \le A^{max}) = 0.1867; P(A_7 \le A^{max}) = 0.1952; P(A_8 \le A^{max}) = 0.1714;$
$P(A_9 \le A^{max}) = 0.1851; P(A_{10} \le A^{max}) = 0.2164; P(A_{11} \le A^{max}) = 0.2122; P(A_{12} \le A^{max}) = 0.1941;$
$P(A_{13} \le A^{max}) = 0.1962; P(A_{14} \le A^{max}) = 0.1772; P(A_{15} \le A^{max}) = 0.1934; P(A_{16} \le A^{max}) = 0.1920;$
$P(A_{17} \le A^{max}) = 0.1996$

The industries are prioritized based on the Grey possibility values:

$A_1 > A_2 > A_4 > A_8 > A_3 > A_{14} > A_9 > A_6 > A_{16} > A_5 > A_{15} > A_{12} > A_7 > A_{13} > A_{17} > A_{11} > A_{10}$

5. Conclusions

This research is focused on identify the selection standards of leading industries in China, which could be the guideline for the harmonious development of regional economy and environment. Grey approach is employed to identify the selection standards of leading industries.

According to the criteria weights derived from this section earlier, the relative top three important measures to select the leading industries in China are (1) dust emissions per enterprise; (2) product sales ratio and (3) employment absorption rate. As such, the Chinese government shall pay more attention to these measures when make the decision of the selection of the regional leading industries.

Based on the results of this research, the processing of foods, coal mining and dressing, manufacture of foods, production and supply of electricity, gas and water, manufacture of non-metallic mineral products, manufacture of beverages and mining and processing of non-ferrous metal ores should be the priorities of the regional leading industries for the city selected for the empirical study.

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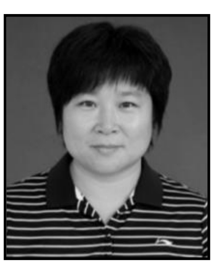

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