A Fuzzy Multi-criteria Decision Model for International Tourist Hotels Location Selection

Abstract

The main purpose of this paper is to present a fuzzy multi-criteria decision making (FMCDM) model for international tourist hotel location selection. First, 21 criteria for selecting the international tourist hotel location acquired from literatures review and practical investigations are constructed. The concepts of fuzzy set theory, hierarchical structure analysis and analytic hierarchy process (AHP) are used to consolidate decision-makers' assessments about criteria weightings and the weighted suitability of different alternatives versus various criteria above the alternative level. Then the distance of different alternatives versus the positive ideal solution and the negative ideal solution can be obtained by using the proposed ranking method. Further, the relative approximation values of various alternatives versus the positive ideal solution are ranked to determine the best international tourist hotel location. Finally, an empirical study for identifying the international tourist hotel location selection in Taiwan is conducted to demonstrate the computational process and effectiveness of FMCDM proposed by this paper.

Keywords: International tourist hotel, Location choice, Linguistic value, Fuzzy multi-criteria decision

1 INTRIDUCTION

In order to reduce passengers' cost of seeking accommodations, enforce the return ratio efficiency of guest rooms and enhance total operating performance, evaluating and selecting a suitable hotel location has become one of the most critical issues for hotel industries. Location decision has drawn increasing attention from academic and business communities in the past two decades. It has been well recognized that selection of a facility location has important strategic implications because a location decision will normally involve a long-term commitment of resources. From the practical operating situation of a hotel, we can gather that the influential factors for hotels to achieve success are reputation, building style, financial structure, marketing, staffs' quality, and initial location selection. But location is the significant factor influencing operation performance in the future (Yang & Lee, 1997). So, good hotel location can not only help increase market share and profitability, but also enhance the convenience of customer lodging because establishing a fine location will shorten the payoff period for fixed capital investments. Moreover, in the age of customer-based service, satisfying customer requirements or enhancing the convenience of customer lodging will directly raise customer loyalty.

Many methods for location selection have been developed. Aikens (1985) utilized mathematical programming to develop the facility location models for distribution planning. Cheng & Li (2004) also used mathematical programming to identify the location selection of factory and retail store. Chen (1996) applied mathematical programming to build a location choice model for distribution centers. In exploring the choice location of factory or retail store, Chen (1999) presented a fuzzy group decision model for the allocation of a distribution center. Chen, Tzeng & Lou (1997) adopted fuzzy multi-objectives facility location programming to search for an airport fire station. Nicolau (2002) used regression analysis method to assess new hotel opening through an event study. Teng (2000) applied multi-criteria decision making method to deal with the site selection of restaurants. Tzeng *et al*. (2002) developed the multi-criteria selection for a restaurant location in Taipei. Other scholars applied the same method in the aviation industry (Chang, Hsu & Chen, 1997), retail business (Kuo, Chi & Kao, 2002), distribution center (Chen, 2001), and sales-delivery facility location (Aberbakh & Berman, 1995).

Almost every evaluation method has its strong points or defects and issues about the suitability for different situations. Some methods apply to the evaluation of qualitative criteria evaluation while others are suitable for quantitative criteria. But in reality, sometimes both qualitative and quantitative criteria exist simultaneously. In order to confront this situation, we can adopt the AHP method to build a systemic evaluation structure integrating all of the criteria and allowing easier operation based on consistence test approving. Moreover, due to the availability and uncertainty of information in our decision process as well as the vagueness of human feeling and recognition, it is difficult to make an exact evaluation and convey the feeling and recognition of objects for decision makers. Fuzzy set theory (Zadeh, 1965) can play a significant role in this kind of decision situation.

Generally, multi-criteria problems are fuzzy. It is difficult to express the character and significance of criteria exactly or clearly through traditional methods. Using the concept of fuzzy sets theory and natural language to evaluate the site selection criteria is more convenient, allowing decision makers to express their ideas freely and adequately. Therefore, we combine fuzzy sets theory and linguistic value concept to establish a model that can provide decision makers with the tool to deal with complex issues in a fuzzy environment. Thus, a fuzzy-based decision model for tourist hotel location selection is more appropriate and effective than traditional precision-based models. In addition, by establishing an ideal to stimulate the creativity and invention of a new alternative, the direction to the process of generating alternatives becomes clear and definite. Based on the reasons stated above, by combining the concepts of fuzzy set theory, hierarchical structure analysis, ideal and anti-ideal, and analytic hierarchy process, a fuzzy multi-criteria decision making model is developed to tackle international tourist hotel location selection in a fuzzy decision environment.

2 TOURIST HOTEL

2.1 The criteria of international tourist hotel location selection

Location selection involves the provision of an overall distribution blueprint for the region, and traffic and transportation conditions are also very important (Coltman, 1989). During the decision-making process of selecting the tourist hotel location, the objective of synergy can be accomplished if facilities such as commercial areas, conventional centers and airports can be taken into consideration. Gray & Liguori (1998), in a feasibility study of hotel establishment, suggested several considerations for location selection; local economic environment, regional or zone regulations, height limit of buildings, car park facilities, public facilities, traffic convenience and accessibility, geographic factors, natural resources, and the size of the location. Also, Pan (2002) categorized tourist hotel location selection factors according to base station suitability, traffic convenience and fine visual perception, public facilities and other services, application of certain regulations, and flexible space. The basis of these discussions is focused on the overall facilities surrounding the hotel, traffic conditions, and future considerations for expandability.

On the other hand, some scholars have also utilized the location theory's central place theory, principle of minimum differentiation, and bid rent theory as the basis for making decisions on tourist hotel locations (Wey & Liao, 2004, Hsieh & Huang, 1998, Lee, Lee & Hsu, 2000). From the standpoint of the central place theory's two primary concepts of "service scope" and "demand threshold," the service scope has to exceed demand threshold in order for the hotel operator to survive. Given these two concepts, we can theorize that the consumer characteristics and scope covered under the overall market conditions include factors such as consumption standard and number of consumers. It noted that the considerations of consumer "quality" and "quantity" in the service sphere.

Factors attributed to the principle of minimum differentiation mainly emphasized on the concept of cluster effect, which is a result of the consumer behavior of asking for quotations. In order to minimize the cost of transportation during the process in which consumers are seeking price information, companies will engage in cluster activities. According to Lee, Lee & Hsu (2000) and Hsieh & Huang (1998), the number of competitive store locations is an important factor for location selection, where competitiveness is demonstrated by market share in commercial circles. The degree of proximity to competitor locations is also an indicator of competitiveness. Therefore, when businesses are making location selection decisions, future development potential is an important consideration in addition to projecting the competitiveness of the new location. From the perspective of surrounding environment, public order issues such as the outbreak of theft, fire, and robbery are also major concerns in location selection. Through the viewpoints of cluster economy effect, this paper discusses the competitive situation, developmental potential and surrounding environment given certain market and geographic conditions.

Factors attributed to the bid rent theory involve an important location concept: the nature of land use is determined by the ability to pay the rent; the higher the rent-paying ability, the closer the location is to the city center. We can use this view to discuss the aspects of base station characteristics, surrounding environment, accessibility, traffic volume, and financial conditions associated with geographic, traffic, and management considerations. Lee, Lee & Hsu (2000) has indicated that the base station area is a major factor of location selection; operating area is positively related to sales. Teng (2000) and Tzeng *et al*. (2002) noted that car parking conditions should also be included into location selection factors, as additional numbers of parking space will attract more customers. Meanwhile, other base station traffic accessibility or convenience is one of consumers' primary concerns in selecting a tourist hotel location.

Hotels' unique core ability is also one of customers' main consideration in selecting a tourist hotel. Such as entertainment facilities, food and beverage services, and environmental conditions are major attributes in hotel selection. Also, developing hotel genre, amalgamating with local culture, and using decorative styles to create competitive advantage are all prime components influencing customers' choice of hotels. Furthermore, the quantity and quality of local human resources is also a focal point for enterprises when making decisions on the establishment of international tourist hotels.

Combining the criteria of selecting the hotel location reported in the above literature review and considering the characteristics of Taiwan's hotel industry and comments from expert academics as well as known hotel managers in Taiwan, 21 criteria were selected to assess the superiority of an international tourist hotel location. The results are shown in Table 3.

3 RESEARCH METHOD

3.1 Analytic Hierarchy Process

Herein, the Analytic Hierarchy Process (AHP) (Saaty, 1980) is used to solve multiple criteria decision problems. By means of a systematic hierarchy structure, complex estimation criteria can be clearly and distinctly presented. Ratio scales are utilized to make reciprocal comparisons for each element and layer. After completing the reciprocal matrix, the comparative weights for each element can be obtained.

Let us consider the criteria $C_1,\ldots, C_i,\ldots, C_j,\ldots,C_n$ of the first level in a hierarchy. We wish to find their weights of importance, $w_1,\ldots, w_i,\ldots, w_j,\ldots,w_n$, of some elements in the next level and allow a_{ij}, i,j=1, 2,…, n, to be the importance strength of C_i when compared to C_j.

Obtaining an exact priority vector, $w = (w_1, w_2, \ldots w_n)$, is complex (Saaty, 1980), so this paper adopts the Normalization of Row Average (NRA) method (Saaty & Luis, 1982) to replace the more complex operation. This method sums up and standardizes each row element it by totaling all elements of the matrix. The equation is:

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}} \qquad , i = 1,2,\ldots,n \tag{1}$$

Generally, we can represent the comparative importance scale of criteria, as shown in Table 1.

Consistency test is an important issue (Saaty, 1980) and contains two layers. One is to check whether the pairwise comparative matrix of decision makers' answers is a consistent one. Another is to check the consistency of hierarchy structure. The ratio to estimate the consistency is the Consistency Ratio (C.R.).

$$\text{C.R.} = \frac{\text{C.I.}}{\text{R.I.}} \tag{2}$$

and

$$\text{C.I.} = \frac{\lambda_{\max} - n}{n-1}$$, where n is the number of criteria being compared.

C.I. is consistency index and R.I. is random index, and both are obtainable from Table 2. When the value of C.R. is less than or equal to 0.1, consistency is guaranteed.

3.2 Fuzzy Set Theory

The Fuzzy set theory introduced by Zadeh (1965) is suitable for handling problems involving the absence of sharply defined criteria. In a universe of discourse X, a fuzzy subset A of X is defined by a membership function $f_A(x)$ which maps each element x in A to a real number in the interval [0, 1]. The function value $f_A(x)$ represents the grade of membership of x in A. The larger the $f_A(x)$, the stronger is the grade of membership for x in A.

3.2.1 Triangular Fuzzy Number

A fuzzy number A in $\Re$ (real line) is a triangular fuzzy number if its membership function $f_A : \Re \rightarrow [0,1]$ is

$$f_A(x)=\begin{cases}(x-c)/(a-c), c\le x\le a\\(x-b)/(a-b),\ a\le x\le b\\0,\ otherwise\end{cases}$$

with $-\infty < c \le a \le b < \infty$. The triangular fuzzy number *A* can be denoted by (*c*, *a*, *b*).

The parameter *a* gives the maximal grade of $f_A(x)$, i.e. $f_A(a)=1$ and it is the most possible value of the evaluated data. *c* and *b* are the lower and upper bounds of the available area for the evaluated data. They are used to reflect the fuzziness of the evaluation data. The narrower the interval [*c*, *b*], the lower is the fuzziness of the evaluated data.

By the extension principle (Zadeh, 1965) the fuzzy addition, $\oplus$, of any two triangular fuzzy numbers is also triangular fuzzy numbers. But the fuzzy multiplication, $\otimes$, of any two triangular fuzzy numbers is only approximate triangular fuzzy numbers. That is, if $A_1=(c_1, a_1, b_1)$ and $A_2=(c_2, a_2, b_2)$ then

$$A_1 \oplus A_2 = (c_1+c_2, a_1+a_2, b_1+b_2); \tag{3}$$

$$k \otimes A_1 = (kc_1, ka_1, kb_1)\ , k \ge 0, \quad k \in \Re . \tag{4}$$

3.2.2 Linguistic value

The concept of linguistic values (Zadeh, 1975/ 1976) is very useful in handling situations that are too complex or ill-defined to be reasonably described in conventional quantitative expressions. In this paper, the triangular fuzzy numbers defined on [0,1] and/or the linguistic values characterized by triangular fuzzy numbers defined on [0,1] are utilized to convey the suitability evaluation of alternatives versus criteria. For example, S= {VG, G, M, B, VB}. The membership functions of those linguistic values are VB (Very Bad) = (0, 0, 0.2), B (Bad) = (0, 0.2, 0.4), M(Medium)= (0.3, 0.5,0.7), G(Good) = (0.6, 0.8, 1), VG(Very Good) = (0.8, 1, 1).

3.2.3 Ranking of triangular fuzzy numbers

Obtaining the ideal and anti-ideal values is important and essential, and the ranking method plays a key role. Many fuzzy ranking methods have been developed (Chen, 1985, Chen & Hsieh, 2000, Cheng, 1998, Kim & Park, 1991). Because of the graded mean integration representation method (Chen & Hsieh, 2000) not only improves existing ranking methods, but also possess the advantage of easy implementation and powerfulness of problem solving, it is adopted by this study to find the ideal and anti-ideal solutions.

Based on the graded mean integration representation method, we can obtain the presented and ranking value of triangular fuzzy number $A_i=(c_i, a_i, b_i)$, as

$$P(A_i)=R(A_i)=\frac{c_i+4a_i+b_i}{6}. \tag{5}$$

Using $R(A_i)$, i =1,2, …, n, we can rank the n triangular fuzzy numbers, A_1, A_2,…, A_n. Let A_i and A_j be two fuzzy numbers and define $A_i > A_j \Leftrightarrow Rk(A_i) > Rk(A_j)$; $A_i = A_j \Leftrightarrow Rk(A_i) = Rk(A_j)$; $A_i < A_j \Leftrightarrow Rk(A_i) < Rk(A_j)$.

3.2.4 Distance between two triangular fuzzy numbers

There are three distance formulae constructed on trapezoidal fuzzy numbers (Chen, 1985, Chen & Hsieh, 2000, Kaufmann & Gupta, 1991, Kim & Park, 1991). We utilized Chen's (1985) modified geometrical distance with parameter p=2 that can meet the concept of the classical distance in order to solve the distance between two triangular fuzzy numbers mentioned in this paper. Based on the Chen's (1985) modified geometrical distance formula for trapezoidal fuzzy numbers, the distance between two triangular fuzzy numbers $A_i = (c_i, a_i, b_i)$ and $A_k = (c_k, a_k, b_k)$ with distance parameter p=2 can be denoted as $D(A_i, A_k)$,

$$D(A_i, A_k) = \{\frac{1}{4}[(c_i - c_k)^2 + 2(a_i - a_k)^2 + (b_i - b_k)^2]\}^{1/2}$$

3.3 <u>Ideal and anti-ideal concepts</u>

The ideal point represents a point at which all criteria would be optimized. It provides an anchor for human adaptivity, intransitivity, and dynamic adjustment of preferences, and can also be as close as possible to the perceived ideal that is rational of human choice (Zaleny, 1982). The operation method of ideal and anti-ideal concepts can be summarized as follows.

Assume that there are m alternatives versus n evaluation criteria. Let x_i^k, $i = 1,2,\Lambda, n$; $k = 1,2,\Lambda, m$, be the linguistic rating assigned to alternative k for criteria i.

Let x_i^* and $x_i^\sim$ be the ideal value and anti-ideal value, respectively of criterion i. Then, (1) For the positive criterion i, $x_i^* = \max_k\{x_i^k\}$, $x_i^\sim = \min_k\{x_i^k\}$; (2) For negative criterion i $x_i^* = \min_k\{x_i^k\}$, $x_i^\sim = \max_k\{x_i^k\}$.

Let $\lambda_i, i = 1,2,\Lambda, n$, be the integrated weight of criterion i. And let $x^* = (x_1^*, x_2^*, \Lambda\ x_i^*, \Lambda, x_n^*)$ and $x^\sim = (x_1^\sim, x_2^\sim, \Lambda\ x_i^\sim, \Lambda, x_n^\sim)$ be the ideal and anti-ideal solutions, respectively. Define

$$D_k^* = \sqrt{\sum_{i=1}^{n} \lambda_i^2 D(x_i^*, x_i^k)^2} \quad (6)$$

and $$D_k^\sim = \sqrt{\sum_{i=1}^{n} \lambda_i^2 D(x_i^\sim, x_i^k)^2}\ . \quad (7)$$

Then, D_k^* and $D_k^\sim$ can be utilized to denote the distance of alternative *k* versus ideal and anti-ideal solutions, respectively.

Allow C_k^*, $k = 1,2,\Lambda,m$, to denote the relative approximation value of alternative *k* versus the ideal solution. Define

$$C_k^* = \frac{D_k^\sim}{D_k^* + D_k^\sim} \quad (8)$$

where $0 \le C_k^* \le 1$. Then the value of C_k^* close to 1 implies a closer alternative *k* approach to the positive ideal solution.

4 EMPIRICAL STUDY

Three alternatives are available to this empirical study and the details of these alternatives are described as follows:

1. Alternative 1: This case concerns Taichung's business district, which is next to the National Museum of Natural Science, National Taiwan Museum of Fine Arts, and the Botanical Garden. It is located about 50 minutes away from the airport, 25 minutes away from the train station and freeway. The surrounding land has almost been fully developed and there are 5 competitors within close proximity of this location.
2. Alternative 2: The site is located on the north of Taichung's business district, which is close to the Da-Ken scenic area. Tourists can go to the famous night market, which is within walking distance, but public security is not ideal. It is located just 30 minutes away from the airport and 25 minutes away from the train station and freeway. The surrounding land has almost been fully developed. No competitor is within close proximity to this location.
3. Alternative 3: This location is on the border of the Da-Du scenic area, which is considered a remote district. However, the landscape and scenic view are very good, although the public security is of medium quality. It is located just 20 minutes away from the airport and 10 minutes away from the freeway. The surrounding land has not been fully developed. No competitor is within close proximity of this location.

4.1 Criteria Hierarchical Structure

The systemic hierarchical structure of criteria is adopted to select the international tourist hotel location. The first level reveals the objective of this study and the second level describes four perspectives taken into consideration for selecting the location. The third and fourth levels illustrate the factors and criteria determined for each perspective. The last level, the alternatives of decision-making, demonstrates three locations for consideration. The details are presented in Table 3.

4.2 Criteria Fuzzy Weight for Each Level

After applying the test of consistency by using Equation (2), the consistency ratio of the pairwise comparative matrix of AHP questionnaires and the hierarchy structure were less than 0.1. Thus, we could guarantee that the pairwise comparative matrix and the hierarchy structure were consistent.

To consolidate evaluation group members' opinions, the geometric average method suggested by Saaty (1980) was used. For instance, let $a_{jk}, k = 1,2,...,n$ be the numerical value weightings given to criteria *j* by group member *k*. Then, the fuzzy weight of the criterion *j* is defined as

$$B_j = (c_j, a_j, b_j). \tag{9}$$

where $c_j = \min\{a_{j1}, a_{j2},..., a_{jn}\}$,

$$a_j = \left(\prod_{k=1}^{n} a_{jk} \right)^{1/n},$$

$$b_j = \max\{a_{j1}, a_{j2},..., a_{jn}\}.$$

Combining the methods of NRA and Equation (1), the precise weights of each adjuster were obtained. Then, using Equation (9) to transform these weights into fuzzy numbers, the weights of all factors and criteria were obtained, as illustrated in Table 4. And the integrated weight of criterion *i* will be obtained by Equation (5).

4.3 <u>Tabulate the evaluation ratings of alternatives versus criteria and transfer the values into triangular fuzzy numbers.</u>

The preponderances of alternatives versus criteria could be obtained by using the linguistic values and these values could be transferred into triangular fuzzy numbers as defined in Section 3.2.2 (shown in Table 5). After obtaining all the triangular fuzzy numbers by committee, we can get the average method to get the average evaluation rating of each criterion (by Equation (3) and (4)) .

4.4 <u>Calculate the ideal value x_i^* and anti-ideal value $x_i^{\sim}$ of alternatives versus evaluation criteria.</u>

To utilize the ranking of triangular fuzzy numbers method (presented in section 3.2.3) and the concept of ideal and anti-ideal solution, we could obtain the idea solution and anti-ideal solution of alternatives versus criteria.

At this point, we could determine whether or not the performance of each criterion is excellent, meaning that managers will be able to know the gap between the location criteria rating and the ideal target as well as the strength or weakness of the location.

4.5 <u>To solve the distance between alternatives and the ideal and anti-ideal solution.</u>

The Equations (6) and (7) shown in Section 3.3 were used to obtain the distance between two triangular fuzzy numbers and to get the distance of alternatives versus the ideal and anti-ideal solutions (D_k^* and $D_k^{\sim}$, shown in Table 6).

4.6 To obtain the close index of alternative k versus the ideal solution and select the best alternative

Using Equation (8) (Section 3.3), the close index (C_k^*) of three alternatives was obtained (shown in Table 7), which expressed the final results clearly. Moreover, managers will be able to know the criteria gap between location characteristics and the ideal target and devise the operation strategies for the location they selected.

Using the equation (8) in Section 3.3, the relative approximation value of each alternative *k* versus ideal solution (C_k^*) could be obtained. As Table 5 demonstrated, alternative 1 was the best location.

5 CONCLUSION

Because hotel location is directly related to the level of hotel business activity, the hotel budget plan, when settled, will affect future hotel customer quantity as well as access of foreign independent tourists. Therefore, developing a set of integrated tourist hotel location selection system and comparing its suitability to major alternatives are needed for managers to sharpen their competitive edge. This article presents a fuzzy multi-criteria decision model for selecting a location for tourist hotel. The process of deriving the solution is illustrated through an easy-to-understand empirical study. Results demonstrate that the model can provide a framework to assist decision makers in analyzing location factors and making a dispassionate and objective location selection.

In real life, due to the uncertainty of information as well as the vagueness of human feeling and recognition, it is difficult to exactly evaluate and convey the feeling and recognition of objects. Hence, the authors, base on the AHP method, combine fuzzy sets theory with linguistic value concept in setting up a model that can help decision makers deal with complex issues under the fuzzy environment. Thus, this paper proposes a simple and practical decision model that will provide significant managerial insights to evaluation committees when making location selection decisions. Also, the committee members can understand the organizational goal and decision process. The model will further enhance organizational communication ability. Meanwhile, tourist hotel managers and investors should decide on the strength of each location in an effort to enhance their understanding of the new hotel's competitiveness. The paper also demonstrates how comparison could be made through this selecting model, which gives a clear direction for hotel managers and investors when devising operating strategies and activities.

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Table 1

Comparative Importance Scale of Criteria

Scales	Definition	Scales	Definition
1	Equally important	7	Demonstrably important
3	Weakly important	9	Absolutely important
5	Strongly important	2, 4, 6, 8	Intermediate scales between adjacent judgments

Table 2

Random Index

n	1	2	3	4	5	6	7
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32

Table 3

The hierarchical structure of location selection model

Perspective	Factors	Criteria
C_1 Geographical conditions	C_{11} Surrounding environment	C_{111} Proximity to public facilities
		C_{112} The distance to existing competitors
		C_{113} Public security
	C_{12} Rest resources	C_{121} Natural resources characteristic
		C_{122} Nearby rest facilities
C_2 Traffic conditions	C_{21} Access	C_{211} The distance to airport or freeway
		C_{212} The distance to downtown area
		C_{213} The distance to tourism scenic spots
		C_{214} Parking area
	C_{22} Convenience	C_{221} Convenience of airport or freeway communication
		C_{222} Extensiveness of traffic routes
		C_{223} Convenience of traffic to tourism scenic spots
C_3 Hotel characteristic	C_{31} Internal development	C_{311} Indoor leisure facilities
		C_{312} The diversity of restaurants in the hotel
	C_{32} External development	C_{321} Amalgamation with local culture
		C_{322} Outside leisure facilities area
		C_{323} Convenience of obtaining nearby land
C_4 Operation management	C_{41} Human resource	C_{411} Sufficient human resources
		C_{412} Quality of manpower
	C_{42} Operating Conditions	C_{421} Land cost
		C_{422} Regulation restrictions

Table 4

The fuzzy weight and integrated weight of criteria in each level

Criteria	Fuzzy weight	Integrated weight
C_{111}	(0.1976, 0.4090, 0.6378)	0.41190
C_{112}	(0.1698, 0.3150, 0.6070)	0.33948
C_{113}	(0.0891, 0.1959, 0.4905)	0.22722
C_{121}	(0.2500, 0.5466, 0.8333)	0.54496
C_{122}	(0.1667, 0.3685, 0.7500)	0.39845
C_{211}	(0.0832, 0.2322, 0.5119)	0.25398
C_{212}	(0.0736, 0.2165, 0.3530)	0.21545
C_{213}	(0.0701, 0.2223, 0.3944)	0.22564
C_{214}	(0.0624, 0.2498, 0.4708)	0.25538
C_{221}	(0.0994, 0.2319, 0.5131)	0.25667
C_{222}	(0.0945, 0.2494, 0.3833)	0.24588
C_{223}	(0.1025, 0.1962, 0.3452)	0.20544
C_{311}	(0.2000, 0.4711, 0.8333)	0.48626
C_{312}	(0.1667, 0.4092, 0.8000)	0.43394
C_{321}	(0.1103, 0.3212, 0.6327)	0.33795
C_{322}	(0.0897, 0.2699, 0.5889)	0.29306
C_{323}	(0.1085, 0.2879, 0.6714)	0.32189
C_{411}	(0.2000, 0.5128, 0.8000)	0.50854
C_{412}	(0.2000, 0.3943, 0.8000)	0.42951
C_{421}	(0.1667, 0.4223, 0.8333)	0.44821
C_{422}	(0.1667, 0.5466, 0.8333)	0.53107

Table 5

The average evaluation ratings of each criterion

	Alternative1	Alternative2	Alternative3	Ideal solution	Anti-ideal solution
C_{111}	(0.7, 0.7, 0.7)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)
C_{112}	(0.6, 0.8, 1.0)	(0.7, 0.9, 1.0)	(0.4, 0.6, 0.8)	(0.7, 0.9, 1.0)	(0.4, 0.6, 0.8)
C_{113}	(0.6, 0.8, 1.0)	(0.6, 0.8, 1.0)	(0.4, 0.6, 0.8)	(0.6, 0.8, 1.0)	(0.4, 0.6, 0.8)
C_{121}	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.4, 0.6, 0.8)	(0.5, 0.7, 0.9)	(0.4, 0.6, 0.8)
C_{122}	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)	(0.5, 0.7, 0.8)	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)
C_{211}	(0.5, 0.7, 0.9)	(0.6, 0.8, 0.8)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)
C_{212}	(0.6, 0.8, 1.0)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)
C_{213}	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.4, 0.6, 0.8)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)
C_{214}	(0.5, 0.7, 0.9)	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)
C_{221}	(0.6, 0.8, 1.0)	(0.5, 0.7, 0.9)	(0.4, 0.6, 0.8)	(0.6, 0.8, 1.0)	(0.4, 0.6, 0.8)
C_{222}	(0.4, 0.6, 0.8)	(0.6, 0.8, 0.9)	(0.5, 0.7, 0.9)	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)
C_{223}	(0.4, 0.6, 0.8)	(0.5, 0.7, 0.9)	(0.4, 0.6, 0.8)	(0.5, 0.7, 0.9)	(0.4, 0.6, 0.8)
C_{311}	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)	(0.4, 0.6, 0.8)	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)
C_{312}	(0.7, 0.9, 1.0)	(0.6, 0.8, 1)	(0.4, 0.6, 0.8)	(0.7, 0.9, 1.0)	(0.4, 0.6, 0.8)
C_{321}	(0.5, 0.7, 0.9)	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)	(0.6, 0.8, 0.9)	(0.4, 0.6, 0.8)
C_{322}	(0.7, 0.9, 1.0)	(0.6, 0.8, 1)	(0.5, 0.7, 0.9)	(0.7, 0.9, 1.0)	(0.5, 0.7, 0.9)
C_{323}	(0.5, 0.7, 0.9)	(0.6, 0.8, 0.9)	(0.3, 0.5, 0.7)	(0.6, 0.8, 0.9)	(0.3, 0.5, 0.7)
C_{411}	(0.5, 0.7, 0.7)	(0.6, 0.8, 0.9)	(0.5, 0.7, 0.8)	(0.6, 0.8, 0.9)	(0.5, 0.7, 0.8)
C_{412}	(0.5, 0.7, 0.7)	(0.3, 0.5, 0.7)	(0.4, 0.6, 0.8)	(0.5, 0.7, 0.7)	(0.3, 0.5, 0.7)
C_{421}	(0.5, 0.7, 0.9)	(0.4, 0.6, 0.8)	(0.4, 0.6, 0.8)	(0.5, 0.7, 0.9)	(0.4, 0.6, 0.8)
C_{422}	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)

Table 6

The distance between alternatives and the ideal and anti-ideal solution

	Alternative 1	Alternative 2	Alternative 3
D_k^*	0.300	0.322	0.461
$D_k^{\sim}$	0.543	0.353	0.211

Table 7

The close index of alternatives versus the ideal solution

	Alternative 1	Alternative 2	Alternative 3
C_k^*	0.644	0.523	0.314