Evaluating Airport Services Using Fuzzy Approximate Reasoning

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Abstract : This paper presents a model that incorporates fuzzy sets and approximate reasoning to determine the ranking of fourteen airports based on their services. Airport services were represented by six attributes namely comfort, processing time, convenience, courtesy of staff, information visibility and security. Data for the attributes given by travel experts are in the triangular fuzzy number form. This study enables the inclusion of requirements which are incomplete and imprecise and making of decisions in a subjective environment. The use of fuzzy rules which are extracted directly from the input data in making evaluation, contributes to a better choice of a decision and is less dependent on experts. Experimental results show that the proposed model is comparable to previous study. The model has been implemented using C++ programming language and is suitable for various fuzzy environments.

1. Introduction

A reliable evaluation method which is of quality is a necessary process in decision making environments. In practice, the evaluation of performance usually uses subjective criteria. In doing so, one has to depend on one's wisdom, experience, professional knowledge and information, which is difficult to define and/or describe accurately. When making an analysis using incomplete data, a lot of uncertainties will arise and this will confuse decision-makers and will complicate decision making as it is made under uncertain situations. The application of fuzzy sets theory in evaluation systems can improve the evaluation results (see [15]). Several researchers have tried to solve this problem through analytical hierarchy process (AHP) where evaluation was done by aggregating all the fuzzy sets, for example in personnel selection (see [6] and [11]) and shipping performance (see [2]). However, the presence of imprecision, vagueness and subjectivity at each level further accumulates greatly the undesired elements in aggregating the marks.

Various concepts have been proposed focusing on the combination of fuzzy logic model with multi objective decision that can assist in reducing errors in making a judgment (see [6] and 10]). The research provides approaches to judgment procedure on personnel selection through the development of AHP fuzzy multi criteria. It is cited as being able to minimize subjectivity. Some studies in fuzzy evaluation methods are discussed in [7], [8] and [9]. The authors have proposed algorithms based either on fuzzy similarity function or fuzzy synthetic decision and ranking procedure through satisfaction function. Fuzzy membership sets enable the interpretations of linguistic variables in a very natural and plausible way to formulate and solve various problems.

However, expressing the linguistic variable using the singleton fuzzy sets could result in the loss of much important information and would additionally complicate the course of action. Although many evaluation methods for selecting or ranking have been suggested in the literature, there is so far no method which can give a satisfactory solution to every situation.

In this paper, a model that incorporates fuzzy sets and approximate reasoning is used to determine the ranking of the airports based on their services.

2. Case Background

This study has adopted the data used in a study done by [14] on fourteen Asia-Pacific international airports. Airport services were represented by six attributes namely the comfort, processing time, convenience, courtesy of staff, information visibility and security as depicted in Table 1.

Table 1: Service Attributes

Service Attribute	**Performance Measure**
Comfort (C_1)	Cleanliness, lighting and congestion level of waiting areas/lounges, and ambience of the airport as a whole
Processing time (C_2)	Total time required for immigration processing, customs inspection, and luggage claiming
Convenience (C_3)	Availability/accessibility of washrooms, shops, restaurants, money exchange, cash machines, luggage carts, and rental facilities
Courtesy of staff (C_4)	Helpfulness, friendliness and courtesy of airport staff
Information visibility (C_5)	Clearness and/or frequency of information display for flights, airport facilities, and signposting
Security (C_6)	Sense of security about airport safety measures and security facilities

The fourteen airports indicate by their codes are listed in Table 2 together with the average fuzzy performance ratings, in fuzzy triangular form, given by travel experts. The data are the average performance rating and the values are in the range 0 to 100, represented as a triangular fuzzy number that can be defined as a triplet (a_1, a_2, a_3), individually.

Table 2: Performance Ratings Assessed by Travel Experts

Airport	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**
BKK	(50, 60, 68)	(51, 60, 68)	(59, 68, 76)	(33, 48, 65)	(45, 55, 64)	(50, 62, 70)
CGK	(42, 56, 67)	(41, 55, 71)	(56, 65, 74)	(48, 56, 64)	(61, 68, 78)	(30, 40, 53)
HKG	(48, 65, 74)	(65, 74, 82)	(63, 74, 82)	(55, 65, 75)	(48, 57, 66)	(71, 82, 88)
KIX	(54, 63, 72)	(58, 71, 78)	(62, 73, 78)	(71, 81, 87)	(62, 77, 85)	(61, 69, 77)
KUL	(52, 65, 80)	(59, 64, 72)	(62, 71, 81)	(65, 74, 85)	(49, 58, 67)	(63, 73, 85)
MEL	(47, 55, 68)	(60, 70, 73)	(60, 69, 78)	(68, 78, 88)	(50, 65, 78)	(61, 82, 86)
MNL	(32, 40, 51)	(40, 51, 61)	(41, 52, 61)	(30, 40, 53)	(34, 44, 58)	(32, 45, 54)
. .						
TPE	(52, 62, 70)	(53, 64, 73)	(56, 66, 76)	(51, 59, 67)	(64, 75, 91)	(60, 70, 80)

3. Proposed Fuzzy Evaluation Model

There are 9 steps in the proposed model for evaluating the service performance of the airports. The first step is to transform the input data into membership set score. The grade mid-point & mid-interval marks are then identified followed by the determination of the fuzzy membership set and fuzzy set grade. Calculation of the similarity value is taken in the fifth step and this is followed by the calculation of the normalized synthetic score value. The last three steps in this proposed model deal with the evaluation of attribute rule value and appraisal product value followed by the calculation of the satisfaction value. The ranking of the airport services is based on the obtained satisfaction value where the biggest value would indicate the best service airport.

In this section, data from previous study by [14] is used to illustrate how the ranking of the airport services is obtained by the proposed model. Results of the transformation of the input into membership set score for service attribute C_1 of each airport are shown in Table 3.

Table 3: Membership Set Score for C_1

	C_1										
Airport	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
BKK	0	0	0	0	0	0	1.00	0	0	0	0
CGK	0	0	0	0	0	0.57	0.64	0	0	0	0
HKG	0	0	0	0	0	0.12	0.71	0.44	0	0	0
KIX	0	0	0	0	0	0	0.67	0.22	0	0	0
KUL	0	0	0	0	0	0	0.62	0.62	0	0	0
MEL	0	0	0	0	0	0.38	0.62	0	0	0	0
MNL	0	0	0	0	1.00	0.10	0	0	0	0	0
. .											
TPE	0	0	0	0	0	0	0.80	0	0	0	0

Grade was used to feed the model with knowledge. In this study, grades are represented by the letters “A”, “B”, “C”, “D” and “E”. The mid-point and mid-intervals for each grade are determined as illustrated in Table 4. This notion of mid-point for the range is introduced by [12]. The construction of the fuzzy membership set is undertaken in the third step as shown in Table 5 where each row represents a fuzzy membership set. The standard grade fuzzy set is then defined, as practiced by [1] as shown in Table 6.

Table 4: Grade Mid-Point and Mid-Interval Mark

Grade	Range	Mid-Point	Mid-Interval
A	90.0 – 100.0	95.0	92.5, 97.5
B	70.0 – 90.0	80.0	75.0, 85.0
C	50.0 – 70.0	60.0	55.0, 65.0
D	30.0 – 50.0	40.0	35.0, 45.0
E	00.0 – 30.0	15.0	7.5, 22.5

Table 5: Fuzzy Membership Set of C1

Airport	C_1										
BKK	0.00/0	0.00/10	0.00/20	0.00/30	0.00/40	0.00/50	1.00/60	0.00/70	0.00/80	0.00/90	0.00/100
CGK	0.00/0	0.00/10	0.00/20	0.00/30	0.00/40	0.57/50	0.64/60	0.00/70	0.00/80	0.00/90	0.00/100
HKG	0.00/0	0.00/10	0.00/20	0.00/30	0.00/40	0.12/50	0.71/60	0.44/70	0.00/80	0.00/90	0.00/100
KIX	0.00/0	0.00/10	0.00/20	0.00/30	0.00/40	0.00/50	0.67/60	0.22/70	0.00/80	0.00/90	0.00/100
KUL	0.00/0	0.00/10	0.00/20	0.00/30	0.00/40	0.00/50	0.62/60	0.62/70	0.00/80	0.00/90	0.00/100
MEL	0.00/0	0.00/10	0.00/20	0.00/30	0.00/40	0.38/50	0.62/60	0.00/70	0.00/80	0.00/90	0.00/100
MNL	0.00/0	0.00/10	0.00/20	0.00/30	1.00/40	0.10/50	0.00/60	0.00/70	0.00/80	0.00/90	0.00/100
. .											
TPE	0.00/0	0.00/10	0.00/20	0.00/30	0.00/40	0.00/50	0.80/60	0.00/70	0.00/80	0.00/90	0.00/100

Table 6: Grade Fuzzy Set

Grade	Linguistic Variable	Fuzzy Set
A	Excellent	{0, 0, 0, 0, 0, 0, 0.33, 0.67, 1}
B	Very Good	{0, 0, 0, 0, 0, 0, 0.5, 1, 0.5, 0}
C	Good	{0, 0, 0, 0, 0, 0.5, 1, 0.5, 0, 0}
D	Satisfactory	{0, 0, 0.5, 1, 0.5, 0, 0, 0, 0}
E	Unsatisfactory	{1, 0.67, 0.33, 0, 0, 0, 0, 0, 0, 0}

Normalization of the input data which is undertaken in the fifth step involves calculation of the similarity value and determining the grade for each criterion. Similarity value, *S(F,M),* is calculated as follows.

$$S(F,M) = \frac{\hat{F} \bullet \hat{M}}{\max(\hat{F} \bullet \hat{F}, \hat{M} \bullet \hat{M})},$$

where $\hat{F}$ = $(\mu_F(x_1), (\mu_F(x_2), \ldots)$, $\hat{M}$ = $(\mu_M(x_1), (\mu_M(x_2), \ldots)$ are the vectors and $\hat{M}$ denotes the transpose vectors grade fuzzy set A^T, B^T, C^T, D^T and E^T. $\hat{F}$ represents the transpose vector of fuzzy set f_{ij} . Set $X = (x_1, x_2, \ldots, x_n)$ represents the set of universe of discourse and '•' is the dot product. The similarity values for airport BKK is presented in Table 7.

Table 7: Similarity Value

Airport	Grade	C_1	C_2	C_3	C_4	C_5	C_6
BKK	A	0	0	0	0	0	0
	B	0.33	0.33	0.54	0.1	0.15	0.28
	C	0.67	0.67	0.32	0.49	0.46	0.55
	D	0	0	0	0.16	0	0
	E	0	0	0	0	0	0

The maximum similarity value is determined by identifying the maximum of the similarity values in Table 7. Table 8 displayed the maximum similarity value, grade and fuzzy mark for airport BKK. Maximum similarity values of Table 8 are used as input to developed normalized synthetic score value as shown in Table 9.

Table 8: Maximum Similarity Value

Airport	Attribute	Max Similarity Value	Grade	Fuzzy Mark
BKK	C_1	0.67	C	60
	C_2	0.67	C	60
	C_3	0.54	B	80
	C_4	0.49	C	60
	C_5	0.46	C	65
	C_6	0.55	C	65

Table 9: Normalized Synthetic Score Value

Airport	C_1	C_2	C_3	C_4	C_5	C_6
BKK	0.60	0.60	0.80	0.60	0.65	0.65
CGK	0.60	0.60	0.70	0.60	0.70	0.40
HKG	0.65	0.75	0.75	0.65	0.65	0.85
KIX	0.65	0.75	0.75	0.8	0.80	0.70
KUL	0.65	0.70	0.75	0.80	0.60	0.75
MEL	0.55	0.75	0.75	0.85	0.65	0.80
MNL	0.40	0.50	0.55	0.40	0.45	0.45
. .						
TPE	0.60	0.55	0.70	0.60	0.75	0.70

The decision criteria, DC_i, $i = 1, 2, 3, \ldots, 5$, is the intersection or combination of fuzzy rules which is the antecedent of the rule (refer to Table 10). The combination multi criteria rules described in Table 10 can be generalized as follows:

$$\text{If } (DC_i = \bigcap_{j=1}^{6} \bigcup C_j) \text{ then } A_k$$

where C_j is the attribute rule, A_k is the linguistic variable and k represents the grade. For example, the decision criteria C_1 rule can be written as

$$\text{If } C_1 = C_1 \cap C_4 \text{ then } A_1 \text{ satisfactory } A_1(v) = v,$$

The appraisal set, v, is defined as, $v = \{0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1\}$ where V is unit appraisal space in [0,1].

Table 10: Multi Criteria Rules Combination

Decision Criteria	Attribute Rule	Linguistic Variable	Description	Appraisal Set
DC_1	$C_1 \cup C_4$	A_1	Satisfactory	v
DC_2	$C_1 \cap C_2 \cap C_6$	A_1	Satisfactory	v
DC_3	$C_1 \cap C_2 \cap C_4$	A_1	Satisfactory	v
DC_4	C_6	A_1	Satisfactory	v
DC_5	$C_1 \cup C_4$	A_1	Satisfactory	v

The rule value in Table 11 is obtained by processing the normalized synthetic score value according to the multi criteria decision of Table 10.

Table 11: Attribute Rule Value

	Attribute				
Airport	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
BKK	0.6000	0.6000	0.6000	0.6500	0.6000
CGK	0.6500	0.6000	0.6000	0.4000	0.6500
HKG	0.6500	0.7000	0.7000	0.8500	0.7000
KIX	0.8500	0.6000	0.6000	0.8000	0.8500
KUL	0.6000	0.7000	0.7000	0.8000	0.7500
MEL	0.6000	0.6000	0.6000	0.8000	0.8500
MNL	0.4500	0.4500	0.4500	0.4500	0.4500
. .					
TPE	0.6000	0.6000	0.6000	0.7000	0.6000

The appraisal fuzzy value of Table 12 for the decision criteria is computed as follows [4]:

$$d_j(m,l) = 1 \wedge (1 - \tilde{c}(u_m) + A_k(v_l))$$

where j = 1, 2, 3, …,5, m = 1, 2, 3, …, 5, l is the number of appraisal in V and is given by l = 1, 2, ..., 11 and $\tilde{c}(u_m)$ is the different of attribute rule value from one unit. This is followed by the computation of the appraisal product value, D, using the formulae D $=\prod_{j=1}^{5} d_j(m,l)$. The appraisal product values for the airports are shown in Table 13.

Table 12: Appraisal Fuzzy Value for Decision Criteria DC1

Airport	**Appraisal Set**										
BKK	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000	1.0000	1.0000	1.0000	1.0000
CGK	0.3500	0.4500	0.5500	0.6500	0.7500	0.8500	0.9500	1.0000	1.0000	1.0000	1.0000
HKG	0.3500	0.4500	0.5500	0.6500	0.7500	0.8500	0.9500	1.0000	1.0000	1.0000	1.0000
KIX	0.1500	0.2500	0.3500	0.4500	0.5500	0.6500	0.7500	0.8500	0.9500	1.0000	1.0000
KUL	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000	1.0000	1.0000	1.0000	1.0000
MEL	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000	1.0000	1.0000	1.0000	1.0000
MNL	0.5500	0.6500	0.7500	0.8500	0.9500	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
. .											
TPE	0.4000	0.5000	0.6000	0.7000	0.8000	0.9000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 13: Appraisal Product Value

Airport	**Appraisal Set**						
BKK	0.0090	0.0281	0.0713	…	1.0000	1.0000	1.0000
CGK	0.0118	0.0354	0.0871	…	1.0000	1.0000	1.0000
HKG	0.3000	0.4000	0.5000	…	1.0000	1.0000	1.0000
KIX	0.1500	0.2500	0.3500	…	0.9500	1.0000	1.0000
KUL	0.2500	0.3500	0.4500	…	1.0000	1.0000	1.0000
MEL	0.1500	0.2500	0.3500	…	0.9500	1.0000	1.0000
MNL	0.5500	0.6500	0.7500	…	1.0000	1.0000	1.0000
. .							
TPE	0.4000	0.5000	0.6000	…	1.0000	1.0000	1.0000

Performance can be ranked using the satisfaction value, *SV(m)*, given below:

$$SV(m) = \frac{1}{\alpha_{\max}} \sum_{l=1}^{11} H_l(E_{m\alpha})\Delta\alpha_l$$

where α = degree of appraisal product value, $\Delta\alpha_l = \alpha_l - \alpha_{l-1}$, $\alpha_0 = 0$, $H_l(E_{m\alpha})$ = mid-point V_l (l = 1,2,3…,11) and $\alpha_{\max}$ = maximum degree of appraisal product value. The calculated values of the range of α , $\Delta\alpha_l$, and $H_l(E_{m\alpha})$ are tabulated in Table 14.

Table 14: Calculated range of α , $\Delta\alpha_l$, and $H_l(E_{m\alpha})$

l	Range α	$E_{m\alpha}$	$H_l(E_{m\alpha})$	$\Delta\alpha_l$
1.	0.0000 < α ≤ 0.0090	{0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1}	0.50	0.0090
2.	0.0090 < α ≤ 0.0281	{0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1}	0.55	0.0192
3.	0.0281 < α ≤ 0.0713	{0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1}	0.60	0.0432
4.	0.0713 < α ≤ 0.1561	{0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1}	0.65	0.0848
5.	0.1561 < α ≤ 0.3072	{0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1}	0.70	0.1511
6.	0.3072 < α ≤ 0.5577	{0.5, 0.6, 0.7, 0.8, 0.9, 1}	0.75	0.2505
7.	0.5577 < α ≤ 0.9500	{0.6, 0.7, 0.8, 0.9, 1}	0.80	0.3923
8.	0.9500 < α ≤ 1.0000	{0.7, 0.8, 0.9, 1}	0.85	0.0500
9.	1.0000< α ≤ 1.0000	{0.8, 0.9, 1}	0.90	0.0000
10.	1.0000< α ≤ 1.0000	{ 0.8, 1}	0.95	0.0000
11.	1.0000< α ≤ 1.0000	{1}	1	0.0000

The highest satisfaction value is considered as the best performance which implies that the experts are much more satisfied with the airport service as discussed in [5].

4. Numerical Results

Comparison of results between [14] and the proposed model are depicted in Table 15. The airport services are ranked based on the satisfaction values. The experimental results show that the proposed method is comparable to [14]. The proposed method is in fact better because of the use of fuzzy rules in making a good ranking in accordance to human decision making (see [3]). The proposed method has shown good consistency in accuracy in ranking with shorter rule properties where there is only five (5) rules with a minimum length of one (1) and the maximum length of three (3). In addition, the most important feature is that the developed rules have extracted the knowledge from the data input and hence it is more understandable to human (see [13]).

In all cases, the satisfaction values calculated by the proposed method are higher as compared to values obtained in [14]. The higher value of satisfaction means the quality performance or alternatives were more satisfactory to the decision-maker. Therefore the quality evaluation done by the proposed model is reliable (see [5]).

The experiment on data normalization in the proposed method was seen significant to stabilize the input data since there are extreme values in the input data. Noise or bias in the data distribution can be diminished through data normalization which is one of the objectives of the proposed method. The use of rules in the proposed method has demonstrated to be reliable as it works like human thinking and meets the goals of the assessment. The quality of a method depends on the properties of the method and the functions for which the method is designed (see [16]). The proposed model had exhibited a good method where it had fulfilled three major properties: 1) formal consistency; 2) usefulness; 3) efficiency in the desired function at a minimum effort, time and cost.

Table 15: Comparison of Results

Method	**Yeh & Kuo**		**Proposed Model**	
Airport	Performance	Rank	Performance	Rank
BKK	0.4890	9	0.7520	9
CGK	0.4740	10	0.7420	10
HKG	0.5760	4	0.8071	4
KIX	0.5930	3	0.8074	3
KUL	0.5740	6	0.7979	6
MEL	0.5830	5	0.8030	5
MNL	0.3660	14	0.6536	14
NRT	0.5610	7	0.7881	7
PEK	0.4020	13	0.6676	13
SEL	0.4580	11	0.7079	11
SHA	0.4400	12	0.7024	12
SIN	0.6410	1	0.8656	1
SYD	0.6060	2	0.8397	2
TPE	0.5440	8	0.7630	8

5. Conclusion

A new fuzzy evaluation model has been proposed for the evaluation of the airport services. The model has been implemented using C++ programming language and is suitable for various fuzzy environments that involve uncertainty. The main advantage of this model is that the membership set score are not predetermined by the expert. This is important to ensure the consistency of the decision. This is not so in the original study, whereby the fuzzy set data are constructed by the travel experts. The formulation of similarity function and approximate reasoning of the fuzzy set theory were used to attain the set of degree of membership and ranking so that the evaluation process can be conducted consistently. The approximate reasoning of the method allows the decision maker to make the best choice in accordance with human thinking and reasoning processes.

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