Journal of Air Transport Management 13 (2007) 243–249

Journal of
AIR TRANSPORT
MANAGEMENT

www.elsevier.com/locate/jairtraman

Airline safety measurement using a hybrid model

James J.H. Liou[a], Gwo-Hshiung Tzeng[b,c,*], Han-Chun Chang[a]

[a]*Department of Air Transportation, Kainan University, Taiwan*
[b]*Department of Business Administration, Kainan University, No. 1, Kainan Road, Luchu, Taoyuan 338, Taiwan*
[c]*Institute of Management of Technology, National Chiao Tung University, 1001, Ta-Hsueh Road, Hsinchu 300, Taiwan*

Abstract

Although air transport has a good safety record, public perception often focuses excessively on accidents. Safety is affected by many factors such as management, operations, maintenance, environment, aircraft design, and air traffic control. Quantitative measurement of the airline safety index is the goal of this paper. Some previous efforts to measure aviation safety have assumed the criteria to be independent, but this is not the case in the real world. Here a hybrid multiple criteria decision-making model to address dependent relationships among criteria, using a decision-making trial and evaluation laboratory along with an analytical network process, to decide the relative weights of criteria, showing inter-dependence and feedback.

Keywords: Analytical network process; Multiple criteria decision-making; Airline safety

1. Introduction

Meeting safety requirements is particularly difficult in a dynamic sector such as air transportation. The demands for air transportation are forecast to grow by 5% per annum over the next 20 years (Graaff, 2001) placing increasing pressure on airline safety programs. Despite this, and the fact that aviation safety is affected by management, operations, maintenance, environment, aircraft design, and air traffic control (ATC) decisions, safety has received little attention in the operations literature (McFadden and Hosmane, 2001).

The commonly used measurement in safety performance is accident rate (Bureau of Transport and Communications Economics, 1992). However, these are only the tip of the iceberg and over 90% of "latent" events are not reflected by in them. Another way of looking at safety is within multiple criteria decision-making (MCDM) characterized by multiple conflicting criteria (Hwang and Yoon, 1981). Keeney and Raiffa (1993) suggest that five principles be considered when criteria are being formulated: completeness, operations, decomposition, redundancy, and minimum size. In the aviation safety field, Chang and Yeh (2004) developed an MCDM safety index, using 13 criteria, divided into four dimensions. They assume these criteria to be independent and use an analytic hierarchical process (AHP) to construct the index. In reality such criteria are, however, seldom independent.

Here, a decision-making trial and evaluation laboratory (DEMATEL) method is used to detect complex relationships and build relation structure among criteria for airline safety measurement. An analytic network process (ANP) was used by Saaty (1996) to overcome the problem of dependence and feedback among criteria or alternatives. This is a general form of the AHP that releases hierarchical structural restrictions. Here DEMATEL is used in conjunction with an ANP to construct a new safety measurement model.

2. Airline safety measurements

The quality management movement, technological changes, cost saving objectives, regulatory pressures, and social responsibility are motivations for making safety an operating priority (Brown, 1996). Airline safety measurements involve a number of complex factors, however, including management techniques, and training and human

---

[*] Corresponding author. Department of Business Administration, Kainan University, No. 1, Kainan Road, Luchu, Taoyuan 338, Taiwan.
E-mail address: ghtzeng@cc.nctu.edu.tw (G.-H. Tzeng).

0969-6997/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jairtraman.2007.04.008

resource issues. A safety index could be based, simply, on the aggregate accident rate for a period of time or landing cycles but this may be incomplete.

While many studies provide useful insights into aircraft accident and incident data, accidents are infrequent making it difficult to quickly detect and isolate problems. Rose (1992) and Gellman Research Associates (1997) suggested that airline accident rates may not be useful in predicting future accidents, indicating the need for an alternative index to identify airlines' relative safety levels and to monitor trends. Apart from pilot error, which still accounts for approximately 70% of aviation accidents, maintenance, design flaws, and operational deficiencies are typically cited as causes of accidents (McFadden and Towell, 1999). It has been suggested that "proactive" safety measures be instituted, especially when monitoring human-error-related accidents. Here a hybrid model, combining DEMATEL and ANP, considers more complex relationships using them in creating an improved safety index.

3. A hybrid model

It can be difficult to quantify precise values in complex evaluation systems. A complex evaluation environment can, however, be divided into subsystems to more easily judge differences and measure scores. A DEMATEL is used to construct interrelations between criteria; then, the criteria weights are obtained through ANP, measuring dependence and feedback.

3.1. Clarifying interrelations between criteria

In a complex system, all criteria are related, either directly or indirectly making it difficult to define a specific objective/aspect in isolation. While the vision of an interdependent system can lead to passive positioning, a clearer hierarchical structure can lead to linear activity, with no dependence or feedback, which may create new problems (Tzeng et al., 2007).

DEMATEL has been successfully applied in many situations, such as marketing strategies, e-learning evaluation, control systems and safety problems (Chiu et al., 2006; Hori and Shimizu, 1999). The methodology can confirm interdependence among variables/criteria and restrict the relations that reflect characteristics within an essential systemic and developmental trend. The end product of the DEMATEL process is a visual representation by which the respondent organizes his or her action in the world (Tzeng et al., 2007).

The method can be summarized as:

Step 1: *Calculate the initial average matrix by scores.* Respondents are asked to indicate the direct effect they believe each element i exerts on each element j of others, as indicated by a_{ij}, using an integer scale ranging from 0, 1, 2, 3, and 4 (going from "No influence (0)," to "Very high influence (4)"). From any group of direct matrices of respondents, it is possible to derive an average matrix $\boldsymbol{A}$, each element being the mean of the same elements in the various direct matrices of the respondents.

Step 2: *Calculate the initial influence matrix*. The initial influence matrix $\boldsymbol{D}$ ($\boldsymbol{D}=[d_{ij}]_{n\times n}$) is obtained by normalizing the average matrix $\boldsymbol{A}$ (shown by degree, i.e. shown by membership and $0 \leqslant d_{ij} < 1$, called the "fuzzy cognitive matrix"), in which all principal diagonal elements equal zero. Based on $\boldsymbol{D}$, the initial effect that an element exerts and receives from another is shown. The map portrays a contextual relationship among the elements of a system, in which a numeral represents the strength of influence (affected degree). For example, in Fig. 1, an arrow from c to d represents the fact that c affects d, and its influence score is 4. The DEMATEL method can convert the relationship between the causes and effects of criteria into an intelligible structural model of the system by influence degree.

Step 3: *Derive the full direct/indirect influence matrix.* A continuous decrease of the indirect effects of problems along the powers of $\boldsymbol{D}$, e.g. $\boldsymbol{D}^2,\boldsymbol{D}^3,\ldots,\boldsymbol{D}^\infty$, guarantees convergent solutions to the matrix inversion. As shown in Fig. 1, the effect of c on g is greater than that of c on f. Thus, the infinite series of direct and indirect effects can be illustrated. Let the (i,j) element of matrix $\boldsymbol{A}$ be denoted by a_{ij}, the matrix can be gained following Eqs. (1)–(4).

$$\boldsymbol{D} = s\cdot \boldsymbol{A}, \quad s>0 \tag{1}$$

or

$$[d_{ij}]_{n\times n} = s[a_{ij}]_{n\times n}, \quad s>0, \quad i,j\in\{1,2,\ldots,n\}, \tag{2}$$

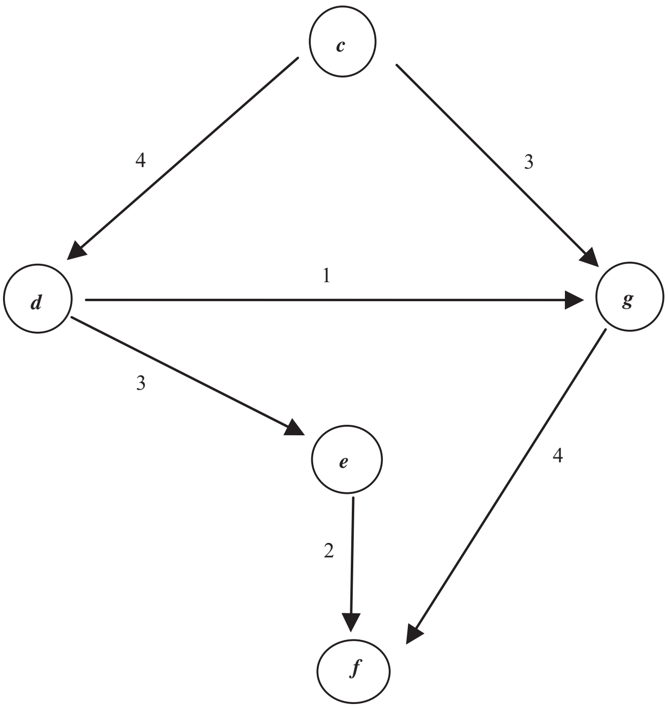

Fig. 1. Illustration of influential map.

where

$$s = \mathrm{Min}\left[\frac{1}{\max_{1\leqslant i\leqslant n}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max_{1\leqslant i\leqslant n}\sum_{i=1}^{n}|a_{ij}|}\right] \tag{3}$$

and

$$\lim_{m\to\infty} \boldsymbol{D}^m = [0]_{n\times n} \quad \text{where } \boldsymbol{D} = [d_{ij}]_{n\times n},\ 0\leqslant d_{ij} < 1. \tag{4}$$

The total-influence matrix $\boldsymbol{T}$ can be obtained by using Eq. (5) where $\boldsymbol{I}$ is denoted as the identity matrix.

$$\boldsymbol{T} = \boldsymbol{D} + \boldsymbol{D}^2 + \cdots + \boldsymbol{D}^m = \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{D})^{-1} \quad \text{when } m \to \infty. \tag{5}$$

If we define the sum of rows and the sum of columns separately denoted as vector $\boldsymbol{r}$ and $\boldsymbol{c}$ within the total-influence matrix $\boldsymbol{T}$ through Eqs. (6)–(8) then

$$\boldsymbol{T} = [t_{ij}], \quad i,j = 1,2,\ldots,n, \tag{6}$$

$$\boldsymbol{r} = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1}, \tag{7}$$

$$\boldsymbol{c} = [c_j]'_{1\times n} = \left(\sum_{i=1}^{n} t_{ij}\right)'_{1\times n}, \tag{8}$$

where superscript $'$ denotes transposition.

Suppose r_i denotes the row sum of the ith row matrix $\boldsymbol{T}$, then r_i shows the sum of direct and indirect effects of factor i on the other factors/criteria. If c_j denotes the column sum of the jth column of matrix $\boldsymbol{T}$, then c_j shows the sum of direct and indirect effects that factor j has received from the other factors. Furthermore, when $j = i$ (i.e. the sum of the row and column aggregates) $(r_i + c_i)$ provides an index of the strength of influences given and received, that is, $(r_i + c_i)$ shows the degree that the factor i plays in the problem. If $(r_i - c_i)$ is positive, then factor i is affecting other factors, and if $(r_i - c_i)$ is negative, then factor i is being influenced by other factors (Tzeng et al., 2007).

Step 4: *Set threshold value and obtain the impact-relations-map* (*IRM*). Setting a threshold value, p, to filter the minor effects denoted by the elements of matrix $\boldsymbol{T}$, is necessary to isolate the relation structure of the elements. Based on the matrix $\boldsymbol{T}$, each element t_{ij} of matrix $\boldsymbol{T}$ provides information about how element i affects element j. To reduce the complexity of the IRM, the decision maker sets a threshold value for the influence level. Only elements whose influence level in matrix $\boldsymbol{T}$ is higher than the threshold value are chosen and converted into the IRM.

The threshold value can be decided through the brainstorming of experts. As long as the threshold value and relative IRM have been decided, the final results can be shown in an IRM.

3.2. The ANP

The ANP is an extension of AHP by Saaty (1996) to overcome the problem of interdependence and feedback between criteria or alternatives. Although the AHP and the ANP derive ratio scale priorities by making paired comparisons of elements of a criterion, there are differences between them. The first is that the AHP is a special version of the ANP; the ANP handles dependence within a cluster (inner dependence) and among different clusters (outer dependence). Secondly, the ANP is a nonlinear structure, while the AHP is hierarchical and linear, with the goal at the top and the alternatives in the lower levels (Saaty, 1999).

The initial step of the ANP is to compare the criteria in the entire system to form a supermatrix through pairwise comparisons by asking "How much importance does one criterion have compared to another criterion, with respect to our interests or preferences?" The relative importance is determined using a scale of 1–9 representing equal importance to extreme importance (Huang et al., 2005). The general form of the supermatrix is

$$\boldsymbol{W} = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_{11}\cdots e_{1n_1} & e_{21}\cdots e_{2n_2} & \cdots & e_{m1}\cdots e_{mn_m} \end{array} \\ \begin{array}{cc} & e_{11} \\ & e_{12} \\ C_1 & \vdots \\ & e_{1n_1} \\ & e_{21} \\ & e_{22} \\ C_2 & \vdots \\ & e_{2n_2} \\ \vdots & \vdots \\ & e_{m1} \\ C_m & e_{m2} \\ & \vdots \\ & e_{mn_m} \end{array} & \begin{bmatrix} \boldsymbol{W}_{11} & \boldsymbol{W}_{12} & \cdots & \boldsymbol{W}_{1m} \\ \boldsymbol{W}_{21} & \boldsymbol{W}_{22} & \cdots & \boldsymbol{W}_{2m} \\ \vdots & \vdots & & \vdots \\ \boldsymbol{W}_{m1} & \boldsymbol{W}_{m2} & \cdots & \boldsymbol{W}_{mm} \end{bmatrix} \end{array}, \tag{9}$$

where C_m denotes the mth cluster, e_{mn} denotes the nth element in the mth cluster, and matrix $\boldsymbol{W}_{ij}$ is the principal eigenvector of the influence of the elements compared in the jth cluster to the ith cluster. The form of the supermatrix depends on the variety of the structure. For example, if the structure of the system is as in Fig. 2, the unweighted supermatrix $\boldsymbol{W}$, containing the local priorities derived from the pairwise comparisons throughout the network, is

$$\boldsymbol{W} = \begin{array}{cc} & \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{array}{c} C_1 \\ C_2 \\ C_3 \end{array} & \begin{bmatrix} 0 & 0 & \boldsymbol{W}_{13} \\ \boldsymbol{W}_{21} & 0 & 0 \\ 0 & \boldsymbol{W}_{32} & \boldsymbol{W}_{33} \end{bmatrix} \end{array} \tag{10}$$

where $\boldsymbol{W}_{21}$ is a matrix that represents the weights of cluster 2 in respect to cluster 1, matrix $\boldsymbol{W}_{32}$ is the weights of cluster 3 with respect to cluster 2, and matrix $\boldsymbol{W}_{13}$ shows the

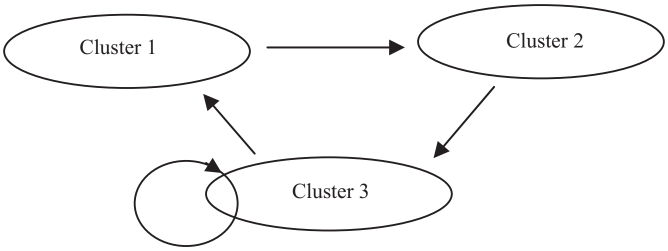

Fig. 2. Illustration of system structure.

weights of cluster 1 in respect to cluster 3. In addition, matrix $\boldsymbol{W}_{33}$ is denoted as the inner dependence and feedback within cluster 3. The weighted supermatrix is derived by setting the ‘‘all columns sum’’ to unity. This step is very similar to the concept of the Markov chain for ensuring the sum of the probabilities of all states equals 1 (Huang et al., 2005). Then the weighted supermatrix can be raised to limiting powers such as in Eq. (11) to calculate the overall priorities.

$$\lim_{k\to\infty} \boldsymbol{W}^k. \tag{11}$$

Finally, the safety index of each airline can be obtained from Eq. (12) where x_{ij} is the performance value of airline i on criterion j and w_j is the weight of criterion j, which is obtained using the ANP method.

$$\text{Safety index of airline} \quad A_i = \sum w_j x_{ij}. \tag{12}$$

4. Empirical study of airline safety systems

Taiwan’s flight-safety record has forced the government to impose many safety regulations upon airlines in an effort to reduce the accident rate. Airlines’ flight-safety records are also considered when new routes or increased flight quotas are applied for. Proper measuring of safety records has proved a challenge, however, as insufficient data makes objective assessment difficult. Previous work (McFadden and Hosmane, 2001; Gill and Shergill, 2004) has indicated that human error is a factor in any safety system. Chang and Yeh (2004) used an MCDM model, and considered other factors, such as operations, maintenance, and management, in addition to the accident rate, to evaluate the safety of airlines. Their approach neglects that in any real life situation some degree of dependence between factors. To reflect these conditions we consider the interrelationship between criteria and a variety of influential factors in the Taiwan context.

4.1. Constructing safety systems

Safety systems are complex organisms, composing of environmental, software, hardware, and human factors and it is clear that airline safety measures must be context-dependent and based on real operations. Three senior aviation experts were consulted, and the *Operation Inspection Handbook* and the *Airworthiness Inspection Handbook* of the Civil Aviation Administration (CAA) were consulted to develop a three-dimensional safety system (management, operations, and maintenance) with each dimension having six to eight criteria. A questionnaire was used to find out from three groups comprising 12 experts—five from the CAA, three from the Aviation Safety Council (ASC), and four from industry—their ranking of each criterion with respect to flight safety using a 5-point scale ranging from 5 (extremely important) to 1 (no effect). The highest scoring three criteria from each dimension were extracted to construct the system for measuring airline safety. Since accident rates are important factors in safety measurements, they are used as a further criterion (Table 1).

4.2. Measuring relationships among dimensions

The aim is not only to determine the most important safety criteria but also to measure relationships among

Table 1
Dimensions and criteria for airline safety systems

Dimensions	Criteria for measurement
Management (D_1)	Safety policy and strategy of airlines (C_1) Managers’ attitude/commitment (C_2) Employee attitude/commitment (C_3)
Operations (D_2)	Competence status of flight crew (C_4) Compliance with aviation task procedures (C_5) Training status of pilots (C_6)
Maintenance (D_3)	Compliance with maintenance task procedures (C_7) Training status of maintenance personnel (C_8) Number of certificated technicians/number of maintenance crew (C_9)
Accident rate (D_4)	Number of accidents per 100,000 departures (C_{10})

Table 2
The initial influence matrix $\boldsymbol{A}$

	Management	Operations	Maintenance	Accident rate
Management	0	3.82	3.61	1.15
Operations	1.23	0	2.25	3.92
Maintenance	0.62	2.94	0	2.66
Accident rate	3.60	1.22	1.08	0

Table 3
The total-influence matrix $\boldsymbol{T}$

	Management	Operations	Maintenance	Accident rate
Management	0.72	1.34	1.21	1.20
Operations	0.81	0.86	0.97	1.24
Maintenance	0.63	0.95	0.62	1.10
Accident rate	0.90	0.93	0.84	0.80

criteria. The aviation experts were thus asked to determine the importance of the relationships among the dimensions. The average initial direct-relation 4 × 4 matrix $\boldsymbol{A}$, obtained by pairwise comparisons in terms of influences and directions between dimensions is seen in Table 2.

Table 4
The sum of influences given and received on dimensions

Dimensions	$r_i + c_i$	$r_i - c_i$
Management	7.53	1.41
Operations	7.96	−0.20
Maintenance	6.94	−0.34
Accident rate	7.90	−0.87

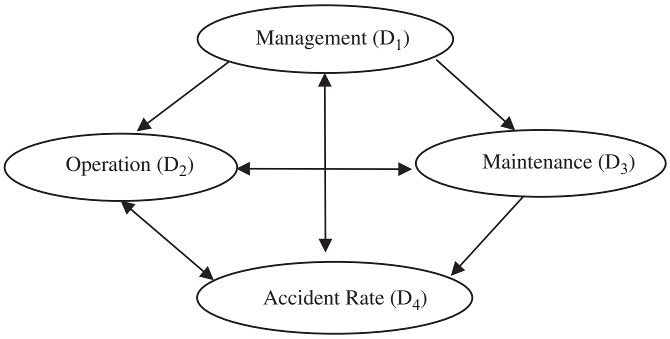

Fig. 3. The impact-relations-map of relations within safety systems.

As matrix $\boldsymbol{A}$ shows, the normalized direct-relation $\boldsymbol{D}$ is calculated from Eqs. (1)–(3). Then, using Eq. (5), total-influence $\boldsymbol{T}$ is derived (Table 3) and by using Eqs. (7) and (8), the sum of influence given and received by each dimension (Table 4).

A threshold value of 0.9 was chosen in consultation with the experts. A value under 0.9 resulted in too complex a relationship for the whole system, the relationship not being obvious above 0.9. Based on this, the IRM of the DEMATEL method is shown in Fig. 3.

4.3. Weighting of criteria in safety systems

After determining the relationship structure between safety system factors, the ANP method is applied to obtain criteria weights. Initially, the importance of relationships between each criterion are compared based on the IRM. For example, the experts were asked to respond to a series of questions, such as "For the safety policy and strategy of airlines, how much more important is one operation criteria over another." These pairwise comparisons are based on Saaty's 9-point scale with a score of 1 indicating equal importance and 9 the extreme importance of one element over another. As the local weights of these criteria are obtained through the principal eigenvector of comparison, an unweighted supermatrix can be generated (Table 5).

Table 5
The unweighted supermatrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	0	0	0	0	0	0	0	0	0	0.15
C_2	0	0	0	0	0	0	0	0	0	0.26
C_3	0	0	0	0	0	0	0	0	0	0.09
C_4	0.15	0.13	0.19	0	0	0	0.16	0.22	0.16	0.14
C_5	0.18	0.11	0.12	0	0	0	0.18	0.20	0.20	0.14
C_6	0.21	0.15	0.18	0	0	0	0.19	0.21	0.19	0.22
C_7	0.06	0.16	0.08	0.19	0.15	0.18	0	0	0	0
C_8	0.06	0.12	0.06	0.11	0.17	0.13	0	0	0	0
C_9	0.05	0.10	0.05	0.12	0.11	0.12	0	0	0	0
C_{10}	0.29	0.23	0.32	0.58	0.57	0.57	0.47	0.37	0.45	0

Table 6
The weighted supermatrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
C_2	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
C_3	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
C_4	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101
C_5	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101
C_6	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134
C_7	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
C_8	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
C_9	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
C_{10}	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317	0.317

By calculating the limiting power of the weighted supermatrix, Eq. (11) is applied until a steady-state condition is reached (Table 6). Each row represents the weight of each criterion. As seen in the table, the highest priority is accident rate (31.7%), while the lowest priority is employee attitude/commitment (2.9%). For operations, priorities such as flight crew competence, compliance with aviation task procedures, and the training status of pilots are assessed at 10.1%, 10.1%, and 13.4%. For maintenance criteria, priorities are compliance with maintenance task procedures; training status of maintenance personnel; and number of certified technicians/number of maintenance crew. The managers' attitude/commitment was determined to be the most important criterion within management (see Fig. 4).

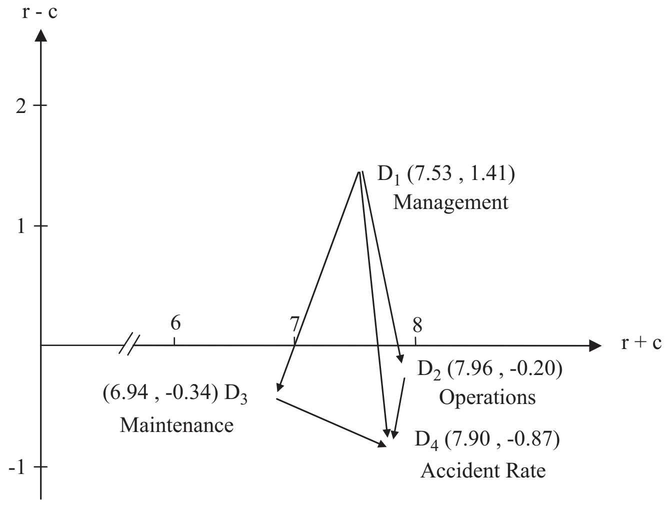

Fig. 4. The impact-direction map.

4.4. Using the method to measure airline safety levels

Thirteen senior aviation safety inspectors, employed by Taiwan's CAA, conduct safety assessments and participate in the annual safety evaluation program for the six major airlines in Taiwan. For each airline, these inspectors are asked to evaluate the level of satisfactions for each criterion, excluding accident rates and ratios of certified technicians; these were directly obtained from the Taiwan CAA annual statistics report. The normalized performance score [0, 1] for the airlines is shown in Table 7. Since lower accident rate is desirable a high score indicates preferable.

Using the performance data of each airline (Table 7) and the weight of each criterion (Table 6), the safety index of each airline was calculated, using Eq. (12). The results are shown in Table 8.

Table 7 shows that when using traditional accident rate as a safety index, the safety levels of airlines A_2, A_3, A_4, and A_6 are identical. This is because there were very few air accidents overall. This may cause some airlines to cut back

Table 7
Performance matrix of airlines for each criterion

Airlines	Weights	A_1	A_2	A_3	A_4	A_5	A_6
Management (D_1)							
Safety policy and strategy of airlines (C_1)	0.047	0.724	0.873	0.679	0.736	0.708	0.648
Managers' attitude/commitment (C_2)	0.082	0.758	0.864	0.723	0.826	0.695	0.684
Employee attitude/commitment (C_3)	0.029	0.612	0.772	0.638	0.708	0.674	0.574
Operations (D_2)							
Competence status of flight crew (C_4)	0.080	0.521	0.834	0.668	0.774	0.679	0.624
Compliance with aviation task procedures (C_5)	0.076	0.628	0.882	0.648	0.722	0.657	0.613
Training status of pilots (C_6)	0.110	0.537	0.862	0.702	0.776	0.674	0.625
Maintenance (D_3)							
Compliance with maintenance task procedures (C_7)	0.077	0.731	0.781	0.568	0.685	0.591	0.576
Training status of maintenance personnel (C_8)	0.060	0.663	0.768	0.682	0.753	0.621	0.609
Number of certificated technicians/number of maintenance crew (C_9)	0.052	0.479	0.384	0.641	0.254	0.497	0.492
Accidental rate (D_4)							
Number of accidents per 100,000 departures[a] (C_{10})	0.317	0.544	1.000	1.000	1.000	0.000	1.000

[a] Data are for 2001–2005 and normalized by formula: $(f_{\max}-f_j)/(f_{\max}-f_{\min})$, where j denotes criteria j.

Table 8
Airline safety index

Airline	A_1	A_2	A_3	A_4	A_5	A_6
Integrating safety index	0.556 (5)	0.807 (1)	0.724 (3)	0.753 (2)	0.397 (6)	0.699 (4)

Parentheses denotes rankings in integrating safety index.

on safety expenditures to reduce their costs. If an airline uses accident rate as a safety measurement when applying for new routes, flight quotas, or safety rankings, it may not be easily differentiated from other companies. Using our method that combines accident rate with three other dimensions, individual airline safety indexes may be more easily distinguished. If $A \succ B$ means that A outranks B in Table 8 then the airline safety ranking is $A_2 \succ A_4 \succ A_3 \succ A_6 \succ A_1 \succ A_5$ indicates that A_2 has the best safety record, because it has the highest managers' attitude/commitment and this influences its performances on other criteria.

5. Conclusions

Over the past decade its poor airline safety record has led to Taiwan's CAA conducting annual safety evaluations of six major airlines. Traditionally, the safety is assessed on the number of accidents, and possibly "findings" during audits. These statistics are not always helpful when accident or incident rates are very low and give little indication of possible future trends. Based on several aspects of aviation safety systems we have combined the DEMATEL and ANP methods to form a hybrid MCDM approach that considers interdependence between a range of criteria and their weighting. An empirical testing of the approach using a Taiwanese case study illustrates its usefulness.

Acknowledgement

This paper was supported by National Science Committee of Taiwan under Grant no. NSC 95-3114-E-424-002.

References

Brown, K.A., 1996. Workplace safety: a call for research. Journal of Operations Management 14, 157–171.

Bureau of Transport and Communications Economics, 1992. Quality of service in Australian passenger aviation. Research Report 80, Australian Government Publishing Service, Canberra.

Chang, Y.H., Yeh, C.H., 2004. A new airline safety index. Transportation Research B 38, 369–383.

Chiu, Y.J., Chen, H.C., Tzeng, G.H., 2006. Marketing strategy based on customer behavior for the LCD-TV. International Journal of Management and Decision Making 7, 143–165.

Gellman Research Associates, 1997. Safety reports: aviation safety data accessibility study index. Office of System Safety, Federal Aviation Administration, Washington, DC.

Gill, G.K., Shergill, G.S., 2004. Perceptions of safety management and safety culture in the aviation industry in New Zealand. Journal of Air Transport Management 10, 133–239.

Graaff, A., 2001. Aviation safety, an introduction. Air and Space Europe 3, 203–205.

Hori, S., Shimizu, Y., 1999. Designing methods of human interface for supervisory control systems. Control Engineering Practice 7, 1413–1419.

Huang, J.J., Tzeng, G.H., Ong, C.S., 2005. Multidimensional data in multidimensional scaling using the analytic network process. Pattern Recognition Letters 26, 755–767.

Hwang, C.L., Yoon, K.S., 1981. Multiple Attribute Decision Making: Method and Applications. Springer, New York.

Keeney, R., Raiffa, H., 1993. Decision with Multiple Objectives, Preferences and Value Tradeoffs. Cambridge University Press, New York.

McFadden, K.L., Hosmane, B.S., 2001. Operations safety: an assessment of a commercial aviation safety program. Journal of Operations Management 19, 579–591.

McFadden, K.L., Towell, E.R., 1999. Aviation human factors: a framework for the new millennium. Journal of Air Transport Management 5, 177–184.

Rose, N.L., 1992. Fear of flying: economic analyses of airline safety. Journal of Economic Perspectives 6, 75–94.

Saaty, T.L., 1996. Decision Making with Dependence and Feedback: Analytic Network Process. RWS Publications, Pittsburgh.

Saaty, T.L., 1999. Fundamentals of the analytic network process. International Symposium on the Analytic Hierarchy Process, Kobe.

Tzeng, G.H., Chiang, C.H., Li, C.W., 2007. Evaluating intertwined effects in e-learning programs: a novel hybrid MCDM model based on factor analysis and DEMATEL. Expert Systems with Applications 32, 1028–1044.