Building an effective safety management system for airlines

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Abstract

To understand the role that human factors play in major aviation accidents, it is important to look at the organization that people work in and the management that they work under. A method for building an effective safety management system for airlines is developed that incorporates organization and management factors. It combines both fuzzy logic and Decision Making Trial and Evaluation Laboratory (DEMATEL). This method can map out the structural relations among diverse factors in a complex system and identify the key factors. Data from the Taiwanese civil aviation industry is used for demonstration purposes.
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1. Introduction

Improving air safety has always been the top priority for the airline industry, and having an acceptable air safety record is important to an airline's success. While there has been a dramatic increase in the reliability of machines and computers over the years, the reliability of human beings and safety systems has not improved at the same pace. As a result, human error and systemic defects have become the major cause of most aviation accidents.

To address the human factors issue, aviation safety management has changed from being reactive to being proactive using safety management systems (SMS). Furthermore, Brown et al. (2000) suggests that behind every accident is a failed organization suggesting that airlines should include organization and management factors in their SMS to address air safety in a comprehensive way (McDonald et al., 2000). However, the root causes of accidents are usually composed of many complex, interrelated factors within an organization.

The management of these organization and management factors, ''latent factors'', has become increasingly impor-

tant but little emphasis has been given to defining what constitutes an effective SMS and the relations among the factors in a SMS (Santos-Reyes and Beard, 2002).

To address these issues, we use a combination of fuzzy logic and Decision Making Trial and Evaluation Laboratory (DEMATEL) to map out complex relationships among factors and to identify key factors in an effective SMS for airlines. The DEMATEL method uses the knowledge of experts to layout the structural model of a system. Compared to structural equation modeling (SEM), the DEMATEL method not only helps visualization of causal relationships among sub-systems through an impact-relations map (IRM) but also indicates the degree of influence among factors. However, the original crisp version of DEMATEL has shortcomings. When people fill out questionnaires, their judgments and preferences are hard to quantify in exact numerical values due to the inherent vagueness of human language. We use fuzzy logic to handle human language by designing a survey questionnaire with triangular fuzzy numbers (TFNs) scales. The result is a hybrid that is called the fuzzy DEMATEL method (Wu and Lee, 2007).

2. Air safety and safety management systems

There are many reasons why air safety is an operating priority for airlines and is embraced in total quality

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management (TQM) movement, technological change, costing, regulations, and customer expectation (Brown, 1996). While air safety involves many complex factors, air safety analysis has tended to be based on aggregate statistics of accident and incident rates over a period of time or landing cycles. These rates can provide useful insights but there are problems associated with their use. First, modern aircraft are very reliable and accidents are infrequent making it hard to detect problem quickly using accident rates. Second, Gellman Research Associates (1997) suggest that airline accident rates may not be useful in predicting the occurrence of future accidents. Third, a safety system based on accident rates is one that has to wait for an accident to happen before it can react; this is not acceptable by today's safety standards.

McFadden and Towell (1999), Chang and Yeh (2004), and others suggest that some 'proactive' safety measurements should be developed to identify airline safety issues, especially in monitoring human-related safety factors. As a result, organizations have been shifting from reactive to proactive approaches to safety (Santos-Reyes and Beard, 2002). In this context, McDonald et al. (2000) studied four aircraft maintenance organizations from the point of view of organizational functions including analysis of documentation and qualitative interviews, surveys of safety climate and attitudes, expected response to incidents, and compliance with task procedures. But their study mainly focuses on the safety culture within maintenance organizations and not the safety of airlines. Gill and Shergill (2004) use an industry-wide survey to assess employees' perceptions of safety management and safety culture in the aviation industry. Relationship between safety records and organizational components has been analyzed by Liou et al. (2007). But none of these studies clearly identify the structural relations among the safety factors.

As a result of the switch in focus and regulatory pressure, SMS have been institutionalized by most airlines but there is no comprehensive SMS model for the aviation industry, and the structural relations among the safety factors of a SMS still remain unknown. Here we try to address these issues by using a hybrid model combining fuzzy logic and DEMATEL.

3. Fuzzy DEMATEL method

In a complex system, all systemic factors are directly or indirectly mutually related. As a result, it is difficult for a decision maker to measure a single effect from a single factor while avoiding interference from the rest of the system. The DEMATEL method was developed to study the structural relations in complex systems. The crisp version of it can be done as follows (Liou et al., 2007).

Step 1: Find the average matrix. Suppose H is the number of experts consulted, and n is the number of factors that each expert considers. Each expert is asked to indicate the degree to which he/she believes factor i affects factor j by giving an integer score system; 'No influence (0),' 'Low influence (1),' 'Medium influence (2),' 'High influence (3),' and 'Very high influence (4)'. The integer score that the kth expert gives to indicate the degree that factor i has on factor j is x_{ij}^k. The $n \times n$ average matrix A if found by averaging all the experts' scores:

$$a_{ij} = \frac{1}{H} \sum_{k=1}^{H} x_{ij}^k. \tag{1}$$

Step 2: Calculate the normalized initial direct-relation matrix. The normalized initial direct-relation matrix D is obtained by normalizing the average matrix A:

$$\text{Let} \quad s = \max\left(\max_{1 \leqslant i \leqslant n} \sum_{j=1}^{n} a_{ij}, \ \max_{1 \leqslant j \leqslant n} \sum_{i=1}^{n} a_{ij} \right) \tag{2}$$

$$\text{then} \quad D = \frac{A}{s}. \tag{3}$$

Since the sum of each row j of matrix A represents the direct effects that factor and i gives to the other factors, $\max\left(\max_{1 \leqslant i \leqslant n} \sum_{j=1}^{n} a_{ij}, \ \max_{1 \leqslant j \leqslant n} \sum_{i=1}^{n} a_{ij} \right)$ represents the direct effects of the factor with the most direct effects on others.

Step 3: Compute the relation matrix. A continuous decrease of the indirect effects of problems along the powers of matrix D, e.g. D^2, D^3, ..., D^∞, guarantees convergent solutions to the matrix inversion similar to an absorbing Markov chain matrix. The total relation matrix, T, is defined as an $n \times n$ matrix $T = [t_{ij}]$, $i, j = 1, 2, ..., n$, and

$$T = D(I - D)^{-1}, \quad \text{when} \quad \lim_{m \to \infty} D^m = [0]_{n \times n}, \tag{4}$$

where I is the $n \times n$ identity matrix. We also define r and c as $n \times 1$ vectors as the sum of rows and the sum of columns, respectively, of the total relation matrix T:

$$r = [r_i]_{n \times 1} = \left(\sum_{j=1}^{n} t_{ij} \right)_{n \times 1} \tag{5}$$

$$c = [c_j]'_{1 \times n} = \left(\sum_{i=1}^{n} t_{ij} \right)'_{1 \times n}, \tag{6}$$

where superscript $'$ denotes transpose.

Let r_i be the sum of the ith row in matrix T. The sum r_i shows the total given effects, both directly and indirectly, that factor i has on the other factors. Let c_j denotes the sum of the jth column in matrix T. The sum c_j shows the total received effects, both directly and indirectly, that all the other factors have on factor j. Thus when $j = i$, the sum $(r_i + c_i)$ gives us an index representing the total effects both given and received by factor i. In addition, the difference $(r_i - c_i)$ shows the net effects or the net contribution by factor i on the system.

Step 4: Set a threshold value to obtain the IRM. To explain the structural relation among factors while keeping the complexity of the whole system to a manageable level,

it is necessary to set a threshold value p to filter out negligible effects in matrix T. Only the factors whose effect in matrix T is greater than the threshold value will be shown in an IRM. Here the threshold value p has been chosen by the experts.

Fuzzy set theory can be helpful in dealing with the vagueness of human thought and expression in decision making. In particular, linguistic ambiguities can be represented through the conversion of linguistic variables into fuzzy numbers (Wu and Lee, 2007). Fuzzy numbers expand on the idea of the confidence interval and are defined over a fuzzy subset of real numbers. A TFN is a type of fuzzy number and, according to Laarhoven and Pedrycz (1983), should possess the some basic properties. A fuzzy number $\tilde{A}$ defined on $\Re$ is a TFN if its membership function $\mu_{\tilde{A}}(x) : \Re \rightarrow [0, 1]$ is equal to

$$\mu_{\tilde{A}}(x) = \begin{cases} (x - a_1)/(a_2 - a_1), & a_1 \leqslant x \leqslant a_2 \\ (a_3 - x)/(a_3 - a_2), & a_2 \leqslant x \leqslant a_3, \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

where a_1 and a_3 are the lower and upper bounds of the fuzzy number $\tilde{A}$, and a_2 is the modal value.

A linguistic variable is a one whose values are words or sentences in natural or artificial language. Its use is a convenient way for decision makers to express their assessments (Malaviya and Peters, 1997). Pedrycz (1994) states that TFNs are an effective fuzzy membership function to use with linguistic variables. The linguistic variable scale and the corresponding TFNs used here are shown in Table 1.

Fuzzy theory is incorporated with DEMATEL through an evaluation form that uses linguistic variables like those in Table 1. The value of the linguistic variables that an expert has assigned to the pairwise comparison between each two factors is converted into TFN scores.

Let $\tilde{x}_{ij}^k = (l_{ij}^k, m_{ij}^k, r_{ij}^k)$ indicate the fuzzy assessments of evaluator k about the degree to which the factor i affects factor j. We then calculate the fuzzy average matrix $\tilde{A}$, where each element $\tilde{a}_{ij}$ is computed by averaging all the experts' TFN scores as:

$$\tilde{a}_{ij} = (L_{ij}, M_{ij}, R_{ij}) = \frac{1}{H} \sum_{k=1}^{H} \tilde{x}_{ij}^k = \frac{1}{H} \sum_{k=1}^{H} (l_{ij}^k, m_{ij}^k, r_{ij}^k). \quad (8)$$

Next, there is defuzzifying of the fuzzy average matrix $\tilde{A}$. A center of area (COA) defuzzification method is used to determine the best non-fuzzy performance (BNP) value of the fuzzy numbers mainly because it is practical (Opricovic and Tzeng, 2003). The BNP value of a fuzzy number can be calculated as:

$$BNP_{ij} = \frac{L_{ij} + [(R_{ij} - L_{ij}) + (M_{ij} - L_{ij})]}{3}. \quad (9)$$

After we have defuzzified the fuzzy average matrix $\tilde{A}$, we are left with a $n \times n$ average matrix A. We can then carry the average matrix A into the rest of the DEMATEL computation by computing the normalized initial direct-relation matrix D and the total relation matrix T.

4. SMS for Taiwanese airlines using fuzzy DEMATEL

Aviation authorities in many countries have already mandated the institution of SMS for all their airlines. Taiwan Civil Aviation Administration (CAA) is no exception. Since 2004, Taiwan CAA has required all Taiwanese airlines to adopt SMS as a formal safety system, but the complexities in developing a SMS have led to difficulties in implementation. The fuzzy DEMATEL method can help analyze the structural relations among the safety factors of a SMS by measuring the causal impact of each factor on the system.

Since safety systems are complex entities, there are still no well-defined and accepted criteria among researchers and practitioners on how to establish a definitive SMS in the aviation industry. Nevertheless, using the Delphi method, senior officials from Taiwan CAA and managers in the Taiwanese airline industry were consulted as were Taiwan Civil Aviation Administration (2006), UK Civil Aviation Administration (2002), and US Federal Aviation Administration (2006), to construct a generic airline SMS based on 11 major safety factors (Table 2).

The impact relation for these factors is assessed using questionnaires. Those with the capabilities to do this, however, are limited because an airline SMS should comply with government policies and relative regulations, implying a respondent person not only has experience working for the airlines but also be familiar with government regulations. As a result three groups of experts were selected—12 from the Taiwan CAA, 3 from the Aviation Safety Council (ASC), and 5 from the industry. All have more than 20 years of experience in the aviation industry and those from the Taiwan CAA and ASC have all worked for the airline industry previously but had retired and become government regulators. In particular, their primary duty is to audit the airlines' SMS to see if they comply with government regulations. The 20 individuals filled the questionnaire indicating the degree of influence that they believe each factor has on every other factor, for all the 11 factors according to the linguistic variable scale in Table 1. An example of the assessments received from an evaluator is seen in Table 3. This individual is from the Taiwan CAA and the TFN number (2,3,4) corresponding to row 1

Table 1
Linguistic variable scale and the corresponding TFNs

Value of linguistic variable	TFN
Very high influence (VH)	(3,4,4)
High influence (H)	(2,3,4)
Low influence (L)	(1,2,3)
Very low influence (VL)	(0,1,2)
No influence (No)	(0,0,1)

Table 2
Factors of a SMS and their functions

Factors	Functions
Communication (F_1)	Language barrier, crew coordination, crew resource management (CRM), maintenance resource management (MRM)
Documentation (F_2)	SOPs, procedures, standards, audit reports, assessment findings, regulatory requirements, incident investigations, etc.
Equipments (F_3)	Tools, plants, and other required equipment maintenance and calibration
Incident investigation and analysis (F_4)	Contributing factors, human error risk, event and remedy cost, rating alternative remedies, corrective actions, etc.
Safety policy (F_5)	Setting organizational structure, roles and responsibilities, plans and managers' commitment to safety
Rules and regulations (F_6)	In-house safety rules and regulations enforced by administrations
Safety committee (F_7)	Developing strategies for safety, supervising safety plans, corrective actions, sub-contractors, and allocating resources for safety improvement
Safety culture (F_8)	Organizational values, beliefs, legends, rituals, mission goals, performance measures, and responsibility to its employees, customers, and community
Safety risk management (F_9)	Internal audits, hazard/risk identification, analysis/assessment and control, compliance with legal and other requirements
Training and competency (F_{10})	Initial and recurrent training, individuals in the positions meet competency requirements
Work practice (F_{11})	Flight operations, maintenance, ground handling servicing, compliance with procedures, standards, SOPs, emergency preparedness and other activities

Table 3
Sample assessment data from a CAA evaluator

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
F_1	(0,0,0)	(1,2,3)	(0,1,2)	(2,3,4)	(0,0,1)	(0,0,1)	(0,0,1)	(2,3,4)	(3,4,4)	(0,1,2)	(3,4,4)
F_2	(1,2,3)	(0,0,0)	(2,3,4)	(3,4,4)	(0,1,2)	(1,2,3)	(1,2,3)	(0,0,1)	(2,3,4)	(1,2,3)	(3,4,4)
F_3	(2,3,4)	(2,3,4)	(0,0,0)	(3,4,4)	(0,0,1)	(0,0,1)	(0,0,1)	(1,2,3)	(2,3,4)	(0,1,2)	(3,4,4)
F_4	(1,2,3)	(0,1,2)	(1,2,3)	(0,0,0)	(3,4,4)	(3,4,4)	(3,4,4)	(2,3,4)	(1,2,3)	(2,3,4)	(2,3,4)
F_5	(2,3,4)	(2,3,4)	(2,3,4)	(1,2,3)	(0,0,0)	(3,4,4)	(1,2,3)	(2,3,4)	(1,2,3)	(1,2,3)	(3,4,4)
F_6	(3,4,4)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(0,0,0)	(2,3,4)	(3,4,4)	(1,2,3)	(2,3,4)	(2,3,4)
F_7	(2,3,4)	(3,4,4)	(2,3,4)	(1,2,3)	(2,3,4)	(2,3,4)	(0,0,0)	(3,4,4)	(3,4,4)	(2,3,4)	(3,4,4)
F_8	(3,4,4)	(2,3,4)	(1,2,3)	(2,3,4)	(0,1,2)	(0,1,2)	(0,1,2)	(0,0,0)	(3,4,4)	(2,3,4)	(3,4,4)
F_9	(1,2,3)	(1,2,3)	(1,2,3)	(2,3,4)	(3,4,4)	(2,3,4)	(2,3,4)	(2,3,4)	(0,0,0)	(1,2,3)	(2,3,4)
F_{10}	(2,3,4)	(2,3,4)	(1,2,3)	(2,3,4)	(0,1,2)	(0,01)	(0,0,1)	(2,3,4)	(2,3,4)	(0,0,0)	(3,4,4)
F_{11}	(0,0,1)	(0,0,1)	(0,0,1)	(3,4,4)	(0,1,2)	(0,0,1)	(0,0,1)	(0,1,2)	(3,4,4)	(0,1,2)	(0,0,0)

Table 4
The initial direct-relation matrix A

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
F_1	0.000	1.250	0.861	2.889	0.333	0.917	0.333	2.917	3.111	3.278	3.279
F_2	2.083	0.000	3.111	3.111	1.139	0.472	0.972	2.444	3.500	2.972	3.111
F_3	2.111	3.112	0.000	3.167	0.333	0.389	0.389	1.333	3.167	1.111	3.556
F_4	2.750	1.917	0.750	0.000	3.472	3.167	3.583	1.444	3.250	2.250	1.500
F_5	2.806	2.917	2.917	1.250	0.000	3.556	2.806	2.917	1.333	2.861	3.528
F_6	3.583	2.833	3.325	2.250	3.222	0.000	3.444	3.611	1.417	2.944	3.333
F_7	3.361	3.222	3.389	1.250	2.917	2.972	0.000	3.250	2.333	2.833	3.189
F_8	3.417	3.056	2.083	2.333	1.167	1.528	0.972	0.000	3.500	2.333	3.389
F_9	1.250	2.250	2.083	3.444	2.472	3.001	3.000	1.417	0.000	1.250	2.250
F_{10}	2.333	0.944	2.333	3.333	0.500	0.639	0.667	3.472	3.444	0.000	3.167
F_{11}	1.583	0.444	0.333	3.306	1.083	1.583	0.389	0.500	3.250	1.556	0.000

column 8 indicates that this person believes that communication has a 'high influence (H)' on safety culture.

After averaging all the experts' TFN scores and defuzzifying the TFNs, the initial direct-relation matrix A can be obtained as seen in Table 4. From matrix A, the normalized direct-relation matrix D is calculated by using

Eqs. (2) and (3). The total-influence matrix T is computed using Eq. (4). Matrix T is shown in Table 5.

The IRM can be drawn based on the total-influence matrix T, but first there is a need to simplify the web of causal relationships in T by setting different threshold values to filter insignificant ones. As an example, if the

Table 5
Total-influence matrix T

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
F_1	0.168	0.182	0.162	0.281	0.131	0.159	0.130	0.240	0.298	0.255	0.298
F_2	0.261	0.171	0.254	0.321	0.174	0.168	0.168	0.252	0.346	0.273	0.332
F_3	0.224	0.231	0.128	0.283	0.127	0.139	0.128	0.185	0.293	0.187	0.299
F_4	0.315	0.261	0.220	0.249	0.269	0.275	0.271	0.262	0.361	0.288	0.324
F_5	0.330	0.299	0.299	0.310	0.165	0.286	0.247	0.313	0.329	0.316	0.401
F_6	0.376	0.318	0.318	0.364	0.279	0.200	0.282	0.354	0.361	0.342	0.424
F_7	0.359	0.321	0.314	0.328	0.262	0.280	0.173	0.334	0.376	0.328	0.414
F_8	0.308	0.269	0.232	0.309	0.180	0.205	0.174	0.188	0.355	0.267	0.351
F_9	0.255	0.256	0.241	0.334	0.229	0.256	0.242	0.239	0.246	0.240	0.323
F_{10}	0.254	0.188	0.216	0.308	0.145	0.163	0.150	0.266	0.324	0.169	0.313
F_{11}	0.182	0.131	0.120	0.248	0.134	0.157	0.115	0.139	0.254	0.174	0.157
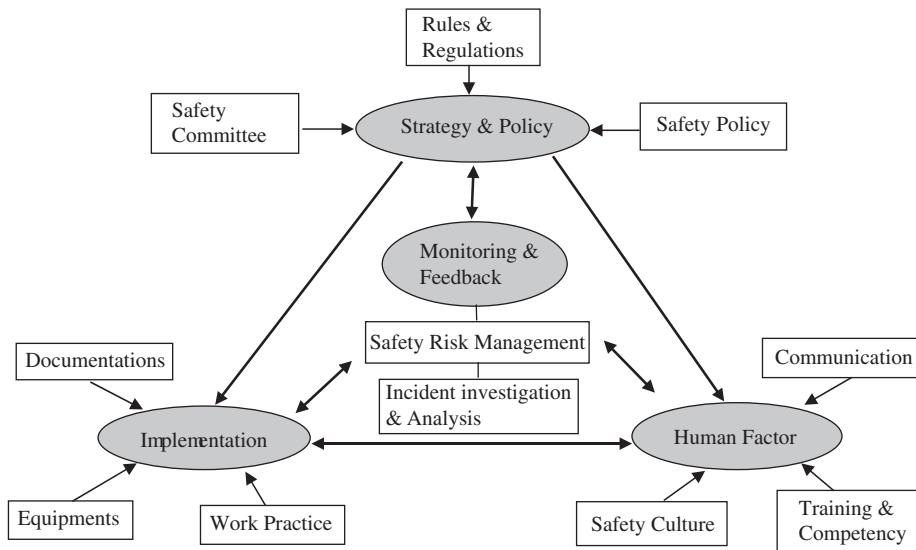
Fig. 1. IRM for an effective SMS.

threshold value is 0.3, factor F_5 will affect F_1, F_4, F_8, F_9, F_{10}, and F_{11} producing arrows from F_5, to F_1, F_4, F_8, F_9, F_{10}, and F_{11} to represent their influences in the IRM. For this a threshold value of 0.25 is used; a value below 0.25 gives us an IRM that is too complex in its web of relationships, and one above 0.25 gives us an IRM that is too sparse in details.

We can now draw the resulting IRM that corresponds to this matrix but if one were to draw a cursory diagram of this web of tangled relationships it could become impossible to decipher. So the IRM is simplified by grouping related factors that have the greatest relations between them. Here we grouped F_1, F_8, and F_{10} together as *Human Factor*; F_2, F_3, and F_{11} together as *Implementation*; F_4 and F_9 together as *Monitoring and Feedback*; and factors F_5, F_6, and F_7 as *Strategy and Policy*. The resultant IRM for an effective SMS is illustrated in Fig. 1, and using Eqs. (5) and (6), the sum of influences given and received for each factor are shown in Table 6 with $(r_i + c_i)$ representing the effect that factor i contributes to the system and

Table 6
Total effects and net effects for each factor

Factors	$r_i + c_i$	$r_i - c_i$
Communication (F_1)	5.335 (9)	−0.727 (10)
Documentation (F_2)	5.345 (8)	0.093 (4)
Equipments (F_3)	4.726 (11)	−0.279 (7)
Incident investigation and analysis (F_4)	6.431 (1)	−0.240 (6)
Safety policy (F_5)	5.388 (7)	1.199 (3)
Rules and regulations (F_6)	5.906 (3)	1.330 (2)
Safety committee (F_7)	5.567 (6)	1.408 (1)
Safety culture (F_8)	5.609 (4)	0.069 (5)
Safety risk management (F_9)	6.403 (2)	−0.684 (9)
Training and competency (F_{10})	5.334 (10)	−0.344 (8)
Work practice (F_{11})	5.446 (5)	−1.825 (11)

$(r_i - c_i)$ shows the net effect that factor i has on the system. When the $(r_i + c_i)$ value is graphed on the horizontal axis and the $(r_i - c_i)$ value on the vertical axis, we get the IDM in Fig. 2.
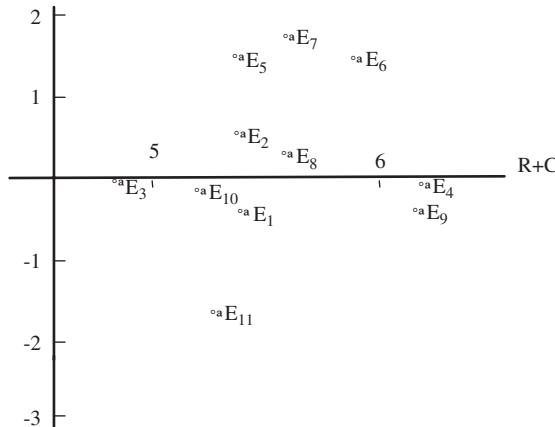
Fig. 2. Impact-direction map.

5. Results

An IRM of an effective SMS for airlines is drawn in the shape of a "safety triangle" (Fig. 1). It is largely self explanatory. At the top of the safety triangle is strategy and policy that includes a safety committee, safety policy, and safety rules and government regulations. The rules set out by an airline's safety committee must comply with government regulations. The left corner of the triangle is implementation that is affected by policy and human factors and embraces documentation, tools, plants, flight operations, maintenance, ground handling servicing, emergency preparedness, and other activities that directly influence the safety level of the organization. The right corner of the safety triangle is human factors including language barriers, crew resource management (CRM), maintenance resource management (MRM), safety culture, initial and recurrent training, and individuals' competency requirements. At the center is monitoring and feedback that embraces safety risk management and incident investigation and analysis.

In addition, individual factors within the safety triangle can be examined using Table 6 and the IDM in Fig. 2. In Table 7, the factors are groups for easier viewing. First, the strategy and policy group have the highest positive $r_i + c_i$'s suggesting it is the largest net generator of effects and plays the most important role in the SMS. These net initiators affect other factors much more than the other factors will affect them implying they should be a priority for improvement.

Second, the factors in the monitoring and feedback group have the highest $r_i + c_i$'s. Unlike factors in strategy and policy that can be viewed as the net initiators for higher safety, factors in the monitoring and feedback are the net multipliers that both tie the system together and propagate the improvements from one factor to the rest of the system implying that airlines should make sure that incident investigation, safety monitoring, and feedback within the system function are effective and efficient to tie the various factors together within the safety triangle.

Table 7
Group/factors with their total effects and net effects

Group/factors	$r_i + c_i$	$r_i - c_i$
Strategy and policy group		
Safety policy (F_5)	5.388 (7)	1.199 (3)
Safety rules and regulations (F_6)	5.906 (3)	1.330 (2)
Safety committee (F_7)	5.567 (6)	1.408 (1)
Implementation group		
Documentation (F_2)	5.345 (8)	0.093 (4)
Equipments (F_3)	4.726 (11)	−0.279 (7)
Work practice (F_{11})	5.446 (5)	−1.825 (11)
Human factor group		
Communication (F_1)	5.335 (9)	−0.727 (10)
Safety culture (F_8)	5.609 (4)	0.069 (5)
Training and competency (F_{10})	5.334 (10)	−0.344 (8)
Monitoring and feedback group		
Incident investigation and analysis (F_4)	6.431 (1)	−0.240 (6)
Safety risk management (F_9)	6.403 (2)	−0.684 (9)

Third, the factors in the implementation group have high $r_i + c_i$'s, but their $i - c_i$ values range from close to zero to strongly negative meaning these factors have a large effect on the system, but are also affected by the other factors. They are the net receivers and should be ranked lower in management priority; a result different from the usual knee-jerk reaction every time an accident occurs whereby attention is mainly focused on whether there has been some kind of failure in equipment, work practice, or documentation of safety records.

6. Conclusions

We have shown that fuzzy DEMATEL can be useful in visualizing the structural relations and identifying key factors in a complex system such as a SMS for airlines. In addition, it has been shown that fuzzy DEMATEL can be used to identify the net initiating factors and the net multiplier factors of a SMS to prioritize the management of such a system.

One on hand, the IRM shows that we can visualize the SMS for airlines as a safety triangle. While strategy and policy are at the top of safety triangle, implementation and human factor form the other two corners of this triangle, with monitoring and feedback playing a central role in this triangle. On the other hand, the IDM shows that strategy and policy play the most important role in an effective SMS; they have the highest net influence on all the other factors.

References

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

Brown, K.A., Willis, P.G., Prussia, G.E., 2000. Predicting safe employee behavior in the steel industry: development and test of a sociotechnical model. Journal of Operations Management 18, 445–465.

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

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, 231–237.

Laarhoven, P.J.M., Pedrycz, W.A., 1983. Fuzzy extension of Saaty's priority theory. Fuzzy Sets and Systems 11, 229–241.

Liou, J.H., Tzeng, G.H., Chang, H.C., 2007. Airline safety measurement using a hybrid model. Journal of Air Transport Management 13, 243–249.

Malaviya, A., Peters, L., 1997. Fuzzy feature description of handwriting patterns. Pattern Recognition 30, 1591–1604.

McDonald, N., Corrigan, S., Daly, C., Cromie, S., 2000. Safety management systems and safety culture in aircraft maintenance organizations. Safety Science 34, 151–176.

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

Opricovic, S., Tzeng, G.H., 2003. Defuzzification within a fuzzy multi-criteria decision model. International Journal of Uncertainty, Fuzziness and Knowledge-based Systems 11, 635–652.

Pedrycz, W., 1994. Why triangular membership function? Fuzzy Set and System 64, 21–30.

Santos-Reyes, J., Beard, A., 2002. Assessing safety management systems. Journal of Loss Prevention in the Process Industries 15, 77–95.

Taiwan Civil Aviation Administration, 2006. Safety Management System, AC120-32A. Taiwan Civil Aviation Administration, Taipai.

UK Civil Aviation Administration, 2002. Safety Management System for Commercial Air Transport Operations, second ed. CAP 712UKCAA, London.

US Federal Aviation Administration, 2006. Introduction to Safety Management Systems for Air Operators, AC 120-92. FAA, Washington, DC.

Wu, W.W., Lee, Y.T., 2007. Developing global managers' competencies using the fuzzy DEMATEL method. Expert Systems with Applications 32, 499–507.