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Applying the decision trial and evaluation laboratory method as a decision tool for an effective safety management system in aviation transport

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Abstract

In recent years, weak engineering controls and lapses in the aviation industry associated with safety management systems (SMSs) have been responsible for seemingly unprecedented disasters. A previous study confirmed the difficulties experienced by safety managers with SMSs and the need to direct research to this area of investigation for more insights and progress in the evaluation and maintenance of SMSs. The purpose of this work is to examine the application of the Decision Trial and Evaluation Laboratory (DEMATEL) method to the aviation industry in developing countries, illustrating the Nigerian aviation survey data for the validation of the method. The advantage of this procedure over other decision making methods is in its ability to apply feedback in decision making. It also affords us the opportunity of breaking down complex aviation SMS components and elements that are multi-variate in nature through analysis of their contributions from the perspective of cause and effects. This in turn yields easier and more effective aviation transportation accident pre-corrective actions. In this work, six revised components of an SMS were identified and DEMATEL was applied to obtain their direct and indirect impacts and influences on the overall SMS performance. Data collection was by a survey questionnaire, which served as the initial direct-relationship matrix, coded in Matlab software for establishing an impact relation map (IRM). The IRM was then plotted in an Excel spreadsheet. From our results, the safety structure and regulations had the highest positive impact on an SMS. The results agree with those of previous researchers who used grey relational analysis. Thus, DEMATEL serves as a valid tool and resource for safety managers.

Keywords: DEMATEL, Safety manager, Relationship matrix, Safety management system

1. Introduction

Globally and in recent years, the aviation industry in developing countries of the world more frequently experience accidents, which are disasters that account for financial and property wreckages and great loss of lives. The corresponding causes of these disasters are the weak engineering controls and lapses associated with safety management systems (SMSs) in the aviation industry [1]. The implication of these safety loopholes is that the frequent accident occurrences globally, high fatalities and injury rates linked to aviation transportation make this means of transportation very dangerous to both aviation service customers and the employees. This threat must stop. Urgent corrective actions must be implemented to stop this unwarranted situation. As a starting point in achieving the above stated pursuit, the complex safety management system (SMS) is analysed and made more attractive and useful in the safety managers decision making by the application of Decision Making Trail and Evaluation Laboratory (DEMATEL) [2-5].

The historical development of DEMATEL could be traced to the 1970s when the Science and Human Affairs (SHA) programme located in the Battle Memorial Institute (BMI), Geneva evolved this decision making tool that easily allows scientists to disintegrate the complex multi-variate set of components through systematic analysis that permits the diverse system criteria from the perspectives of their causes and effects. The result is that decision making is made easier and increasingly effective. An advantage of DEMATEL is that it helps in the clarification of the interrelationships among the complex factor of a system from the perspective of influences that each factor has on every other factor [6-7].

DEMATEL is one of the most promising research tools in decision sciences, which has garnered scholarly attention over the past several years. The use of DEMATEL has increased greatly from earlier years, with studies documenting theoretical and practical examinations of a wide array of systems, including cost of quality selection [8], human resources management [9], auto spare-parts industry [10], information technology [11-12], educational institutions [13], park and recreation activities [14] and EDA industry [15]. Prior studies have focused largely on integrating concepts with DEMATEL as a good and effective approach of deriving the most benefits of DEMATEL, bringing out novel concepts under different nomenclature.

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Examples are the integration of DEMATEL with AHP [10], and ANP or ANP and fuzzy cognitive map [8, 13, 16], added to MMDE [17], with fuzzy [18-19], combined with fuzzy C means [20], added to fuzzy, AHP and ANP [21].

From a review of literature on SMSs in the aviation industry, the main observations made are as follows: (a) A significant amount of studies have been reported in the literature, with a few applications of DEMATEL to the aviation industry; (b) DEMATEL is a useful tool with wide applications in sciences and technology; (c) there is a very scanty research on the aviation in industry in developing countries and further, very few investigations have considered the SMSs in the industry; (d) there is no research in Nigeria that has considered SMS and applied DEMATEL to the aviation industry system effectiveness in any form (e) there are great potentials for the enhancement of the safety managers decision making task in the Nigerian aviation industry if DEMATEL is systematically applied and implemented in the Nigeria aviation environment. (f) There is need to complement and compare the performance of DEMATEL and grey relational analysis in the Nigerian aviation environment.

To complement these observations and knowledge gaps, a previous study by authors has affirmed the frustrating situation and difficulties experienced by safety managers in the developing countries. Drawing data from a developing country, Nigeria, the study established the feasibility of applying the grey relational analysis on the SMS in the Nigeria aviation industry and called for more investigations. In response to this important call, the current investigation provides some insights and made some progress in the evaluation and maintenance of SMSs in the aviation industry in developing country, illustrating with data from the Nigerian aviation industry. The purpose of this work is to examine the application of DEMATEL for SMS effectiveness for the Nigerian aviation industry.

2. Methodology

Data collection was conducted by the survey using questionnaire. It was distributed to safety experts with experience of above 15 years in aviation safety. DEMATEL was applied to the six revised components of an SMS to obtain their direct and indirect impacts and influences on overall SMS performance. Table 1 reflects these components.

Table 1 Components of SMS in aviation industry

SMS Component	Notation
Safety Structure and Regulation	C1
Safety Documentation	C2
Safety Risk Management	C3
Safety Monitoring and Quality Assurance	C4
Communication of Safety	C5
Promotion of Safety	C6

The salient information on their questionnaire is seen in the appendix section showing and displaying pair-wise comparisons. According to Hsu et al. [1] and Falatoonitoosi et al. [2], the DEMATEL process is outlined in the following steps:

1. Determine the first average matrix by scores.

In the first instance, the values of the relationships existing between diverse factors according to the experts' opinion should be decided based on four scales. Respondents are requested to point out the express effect they consider that each element i exerts on each element j of others, as suggested by a_{ij}, by means of an integer scale ranging from 0, 1, 2, 3, and 4 where,

0 – No influence
1 – Low influence
2 – Medium influence
3 – High influence
4 – Very high influence

Given that there are H experts and n criteria to be taken into account, the scores are provided by every expert and X^1, X^2,….., X^H are the answers each of them gave that make the n x n non-negative matrix $X^k = \lfloor x_{ij}^k \rfloor_{nxn}$ with $1<k<H$. A high score indicates a belief that greater improvement in i is required to improve j.

2. Calculate the first direct-relation matrix A

Calculate the n x n average matrix **A** using all the opinions of all the experts by finding the average of all experts' scores in the following manner:

$$[a_{ij}]_{n \times n} = \frac{1}{H}\sum_{k=1}^{H}[x_{ij}^k]_{n \times n} \quad (1)$$

The matrix **A** is called the initial direct-relation matrix and is a n x n matrix found by pair-wise comparisons with respect to influences as well as directions among the criteria, in which a_{ij} is indicated as the degree to which the criterion i affects the criterion j, that is, $\mathbf{A} = [a_{ij}]_{n \times n}$.

3. Normalized direct-relation matrix **B** is obtained

Normalize the initial direct-relation matrix **A.** This is achieved by applying the following equations given below

$$\mathbf{B} = \mathbf{A}/s \quad (2)$$

and

$$s = \max\left(\max\sum_{j=1}^{n}[a_{ij}], \max\sum_{i=1}^{n}[a_{ij}]\right) \quad (3)$$

Consequently, this means that the total direct effects that criterion i gives to the other criteria is obtained by sum of each row i of matrix **A** while the sum of each column j represents direct effects of the other criterion or simply the total direct effects received to other criteria by criterion i. Since the sum of each column j of matrix **A** represents the total direct effects received to other criteria by criterion i, $\sum_{i=1}^{n}[a_{ij}]$ represents the total direct effects that the criterion j receives from other criteria. Each element b_{ij} of the matrix **B** is between zero and one, that is $0 \leq b_{ij} \leq 1$ and $\mathbf{B} = [b_{ij}]_{n \times n}$.

4. Calculate the total-relation matrix **T**

The total-relation matrix $\mathbf{T}_{n \times n}$ is obtained using Equation (4),

$$\mathbf{T} = \mathbf{B}(\mathbf{I} - \mathbf{B})^{-1} \quad (4)$$

where,

I = identity matrix
T = total-relation matrix
B = normalized direct-relation matrix

5. Add up the rows as well as columns in a separate manner, represented as **R** as well as **C**, respectively, within the total-relation matrix **T**

The addition of the rows and that of columns of the total relation matrix **T** (*n* x *n*) are calculated as **R** (*n* x 1) and **C** (1 x *n*) vectors using Equations (5) to (7):

$$\boldsymbol{T} = t_{ij} \qquad i, j = 1,2, \ldots, n \tag{5}$$

$$R = [r_i]_{n \times 1} = \sum_{j=1}^{n} [t_{ij}]_{nx1} \tag{6}$$

$$C = \left[c_j\right]_{1xn} = \sum_{i=1}^{n} \left[t_{ij}\right]_{1xn} \tag{7}$$

6. Provide a drawing of the Impact Relation Map (IRM)

The impact relation map is obtainable through mapping of the dataset of (**R** + **C** , **R** - **C**), in which the horizontal axis (**R** + **C**) is obtained through the addition of **R** to **C**. The vertical axis (**R** - **C**) is made through the subtraction of **C** from **R**.

3. Results and discussions

DEMATEL was applied to the six revised components of an SMS to obtain their direct and indirect impacts and influences on overall SMS performance. After obtaining the results from the survey, we calculated the initial direct-relation matrix **A** according to Equation (1). The methods employed as shown in our methodology were all coded in Matlab to obtain the required matrices **R** and **C** that will enable us to draw the impact relation map (IRM). The IRM was then plotted using Excel.

From the survey, the matrix will be a 6 by 6 matrix. The initial direct-relation matrix **A** is obtained as

$$\mathbf{A} = \begin{bmatrix} 0 & 3.667 & 3.000 & 2.667 & 2.667 & 2.333 \\ 3.000 & 0 & 2.667 & 3.000 & 3.000 & 2.667 \\ 3.000 & 2.667 & 0 & 3.333 & 2.667 & 2.000 \\ 2.667 & 3.000 & 3.000 & 0 & 2.333 & 2.000 \\ 3.000 & 2.667 & 3.000 & 2.333 & 0 & 3.000 \\ 3.000 & 2.333 & 2.000 & 2.333 & 3.000 & 0 \end{bmatrix}$$

The normalized direct-relation matrix **B** is then obtained using Equation (2) as

$$\mathbf{B} = \begin{bmatrix} 0 & 0.256 & 0.209 & 0.186 & 0.186 & 0.163 \\ 0.209 & 0 & 0.186 & 0.209 & 0.209 & 0.186 \\ 0.209 & 0.186 & 0 & 0.233 & 0.186 & 0.140 \\ 0.186 & 0.209 & 0.209 & 0 & 0.163 & 0.140 \\ 0.209 & 0.186 & 0.209 & 0.163 & 0 & 0.209 \\ 0.209 & 0.163 & 0.140 & 0.163 & 0.209 & 0 \end{bmatrix}$$

The total-relation matrix **T** is then obtained using Equation (4) as

$$\mathbf{T} = \begin{bmatrix} 3.793 & 3.949 & 3.769 & 3.746 & 3.729 & 3.344 \\ 3.954 & 3.733 & 3.742 & 3.749 & 3.734 & 3.351 \\ 3.809 & 3.748 & 3.449 & 3.630 & 3.580 & 3.194 \\ 3.648 & 3.620 & 3.484 & 3.304 & 3.428 & 3.072 \\ 3.880 & 3.815 & 3.686 & 3.646 & 3.491 & 3.304 \\ 3.584 & 3.508 & 3.357 & 3.365 & 3.386 & 2.882 \end{bmatrix}$$

The addition of rows as well as the columns, individually represented by **R** as well as **C** respectively within the total-relation matrix **T** are then obtained as

$$\mathbf{R} = \begin{bmatrix} 14.667 \\ 14.334 \\ 13.667 \\ 13.666 \\ 13.667 \\ 12.000 \end{bmatrix}, \text{ and } \mathbf{J} = \begin{bmatrix} 14.334 \\ 14.334 \\ 13.667 \\ 13.000 \\ 14.000 \\ 12.666 \end{bmatrix}$$

Defining a matrix **J** = **R**+ **C**, **J** = $\begin{bmatrix} 29.001 \\ 28.668 \\ 27.334 \\ 26.666 \\ 27.667 \\ 24.666 \end{bmatrix}$ and a matrix **K**= **R** - **C**, **K** = $\begin{bmatrix} 0.333 \\ 0 \\ 0 \\ 0.666 \\ -0.333 \\ -0.666 \end{bmatrix}$

To better represent these results, we make use of Table 2,

Using this, we can draw the IRM with J on the horizontal axis and K on the vertical axis. The IRM was drawn on the Excel spreadsheet and is shown in Figure 1.

Note:

SSR – Safety Structure and Regulation

SD – Safety Documentation

SRM – Safety Risk Management

SMQA – Safety Monitoring and Quality Assurance

CS – Communication of Safety

PS – Promotion of Safety

The J-axis represents the effect that a particular component contributes to the system while the K-axis shows the net effect that a particular component has on the system.

DEMATEL differ from the grey system in the following way. DEMATEL recognises that there are causes-and-effects, and interrelationships among the components of the safety management system in the airline company. However, the grey relational analysis collapses the obtained information on the importance of the various components. The results that DEMATEL gives are very important since if a component is found to be affected more by others than it is being affected, it means that that component is very important. This implies the need to focus on the independent components since if in reality affects the dependent components. Thus, in the current paper, there are 6 components being considered in the Nigerian aviation safety management system for analysis based on the DEMATEL tool. From the results, the most important components can then be obtained in terms of the degree of relationships among the components. It was realised that in applying DEMATEL to the aviation industry's SMS, there is need for data. This data was obtained from the experienced staff of airlines that have spent at least 15 years in the aviation industry.

It is interesting to know how the results obtained from the respondents were merged. Now, considering the format of presentation of the results, as six components are considered, a 6 x 6 matrix surfaces in which there are six components on both the horizontal and vertical sides of the matrix. Across the diagonal are zeros, indicating that each component does not affect itself. Then, merging of the results was done by taking the average of all the responses, for each part of the matrix.

Table 2 SMS component analytical results

Notation	SMS Component	R	C	J = R+C	K = R – C
C1	Safety Structure and Regulation	14.667	14.334	29.001	0.333
C2	Safety Documentation	14.334	14.334	28.668	0
C3	Safety Risk Management	13.667	13.667	27.334	0
C4	Safety Monitoring and Quality Assurance	13.666	13.000	26.666	0.666
C5	Communication of Safety	13.667	14.000	27.667	-0.333
C6	Promotion of Safety	12.000	12.666	24.666	-0.666

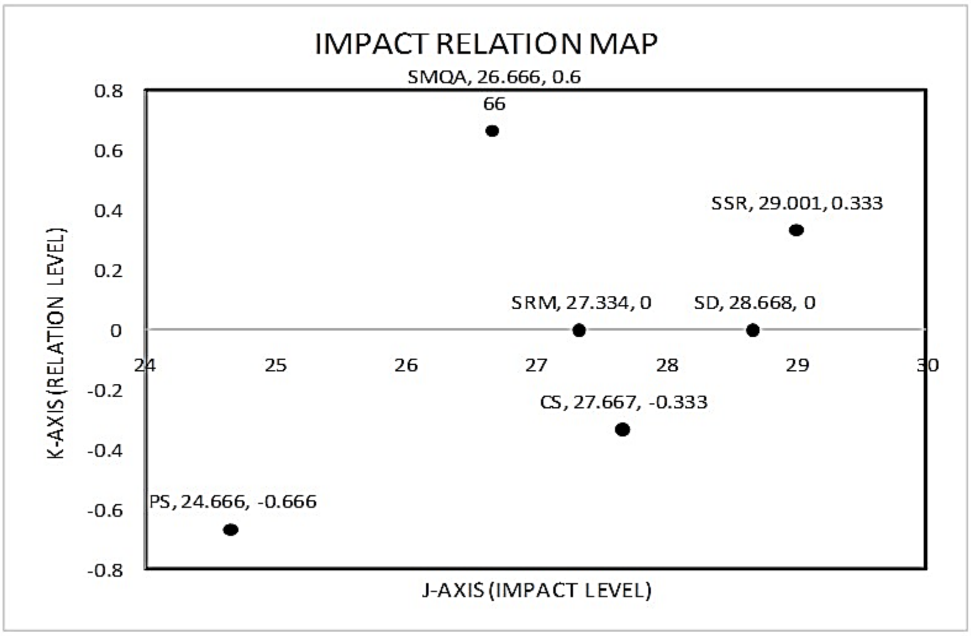

Figure 1 Impact relationship map (IRM) of six components of SMS

To illustrate the procedure, say, for "safety risk management" and "safety documentation" it is desired to know the degree of relationship of these components, the respondents are allowed to put numbers, based on likert scale norm in the questionnaire boxes. Suppose four respondents puts values 3 (high influence), 4, 2 and 4, then the average is calculated from 3+4+2+4 = 13, and 13/4 = 3.25. This value of 3.25 is an entry in direct initial relational matrix and other entries are obtained in a similar manner. The rest procedure is from the methodology in which the calculations of summations of all the rows and columns are made while the highest number is designated as "s". This number is used to divide the first initial matrix obtained. From this, the normalized direct relation matrix is obtained. The total direct impact relation matrix would have been obtained. After obtaining **C**, which is the total impact matrix, the sum of all the rows and columns are taken (i.e. matrices **R** and **C**). What these matrices help to achieve is that the addition of matrices R and C generates the impact that a certain component has on the whole system which the **R**-**C** reveals the relation level to the whole system.

Thus, for a positive **R**+**C**, the component that has the highest **R**+**C** level has the highest impact on the SMS. However, if that component has a negative **R**-**C** level, it means that though it has the highest impact on the system, it depends a lot on others more than they depend on it. This helps to sieve out some components in the analysis. That is any component that has a negative **R**-**C** shows that it needs others to be in place before it will be stable since it is very dependent on others. However, if a component has a high positive **R**+**C** and a positive **R**-**C** value, it means that this component affects other components more than they affect it. Definitely, it can even be viewed as a very independent component in a sense. Notice that they all affect the component, but it affects others more than they affect it. This means that it should be given priority. The result obtained agrees with that of grey relational analysis by earlier researchers. Since when the analysis was done, it was noted that "safety structure and regulation" has the highest **R**+**C** level and it also has a positive **R**-**C** level, which is the second highest position **R**-**C** level. This shows us that "safety structure and regulation" actually has the most impact on an SMS. It also affects the other components more than they affect it. This means that if an SMS is to be established, there need to give it a lot of consideration. This is because, if it is not in place, the SMS in itself will not be stable because it affects other systems.

Due to its positive relation value, this means that it affects all other components more than they do it except for "safety monitoring and quality assurance" which has a more positive relation level value. The next most important component is "safety documentation" with the next highest impact level and a relation level of zero. This shows that this component affects all other components equally and vice versa. "Communication of safety" has the next highest impact level, but it has a negative relation level meaning that other components affect it more than it does them. This would mean that in having a clear model for SMS implementation, we will have to skip this component because it will not be stable till all others are relatively stable. This would mean that the next most important component is safety risk management with the next highest impact level and a zero relation level. The zero relation level shows that this component exerts the same impact on other components as they do on it.

The next in line is "safety monitoring and quality assurance" which has the highest positive relation level, meaning that it affects all the five other components more than they affect it. This means that it is important in SMS implementation. The last two components will then be "communication of safety" and "promotion of safety" with both having negative relation levels. These ones therefore will come after all the others have stabilized or been attended to first. "Communication of safety" ranks as the fifth most important component while promotion of safety comes in as the sixth. The DEMATEL method gives us more insight into the interrelationships between components, something that grey relational analysis does not consider. GRA gives us the impact level solely, while DEMATEL gives the impacts and the relationships between components.

Decision Making Trial and Evaluation Laboratory was employed to determine the impact and relation levels between the six SMS components. Grey relational analysis, however, was used to ascertain the importance of each element to the stability of the entire SMS. We, however, were able to obtain the aggregate impact effects of each component by taking the mean sum of its respective elements. On this note, then, we would be able to compare results from both approaches. Note, however, that one pitfall of the grey relational analysis is that it does not, directly, measure the degree of interrelations between elements and components of a system. It deals more with an element/component singular impact on the entire system. On this note, we will compare results according to the impact levels of the six components obtained with DEMATEL and the grey relational grades of the six components obtained using GRA. Relation levels will be neglected. According to our results from grey relational analysis, the ranking of the components are as follows (Table 3) [22]:

Table 3 SMS components and their respective overall grey grades

SMS Component	Overall grey relational grade	Ranking
Safety Structure and Regulation	0.753	1
Promotion of Safety	0.683	2
Safety Risk Management	0.666	3
Safety Documentation	0.658	4
Communication of Safety	0.651	5
Safety Monitoring and Quality Assurance	0.590	6

According to our impact level values solely, obtained using Decision Making Trial and Evaluation Laboratory, the ranking of components are as follows (Table 4):

Table 4 SMS components and their respective Impact values

SMS Component	Impact Level	Ranking
Safety Structure and Regulation	29.001	1
Safety Documentation	28.668	2
Communication of Safety	27.667	3
Safety Risk Management	27.334	4
Safety Monitoring and Quality Assurance	26.666	5
Promotion of Safety	24.666	6

Results show that, three components are consistent in the top four of both result tables. These are "safety structure and regulation", "safety risk management" and "safety documentation". This shows that these components are crucial in the establishment of an effective SMS. "Safety structure and regulation", by both approaches, occupies the first place and is clearly the most important component of an effective SMS. Note, however, that due to the fact that GRA does not measure directly relation levels, there will be a slight inconsistency in results.

4. Conclusions

SMSs, although complex in structure and multi-components in nature, are strong pillars of the aviation industry that promote the industry's effective functioning in passenger and cargo transportation [23-24]. SMSs are important in the aviation industry due to the increased fatalities in aviation disasters as well as the resulting huge compensations paid by the affected aviation organisations due to liabilities incurred on accident victims. Consequently, substantial knowledge of SMSs worldwide are gained from agitations of past aviation industrial accidents. It then becomes necessary for developing countries' aviation industries, especially Nigeria, despite the disparities in their management structures, incomes, sizes, policies and other organisational characteristics, to improve their SMSs. This is to demonstrate their commitment to safety practice improvements. Commitment is necessary as a result of the legal requirements by a number of world-class organizations. Such organisations sometimes make policies of dealing only with suppliers that comply with safety practices in their own organisations. With this in mind, it is apparent that safer aviation industry and practices may result in considerable reduction of accidents.

In this study, DEMATEL was applied to the six revised components of an SMS for the aviation industry, to obtain their direct and indirect impacts and influences on the overall SMS performance. Survey questionnaire was used for the collection of data among experts in safety. These experts must have spent a minimum of 15 years in aviation safety. From the results, it could be observed that "safety structure and regulation" is the most important component in the SMS and should be the primary focus in terms of SMS implementation and development. This agrees with the results of grey relational analysis of a set of researchers in a previous work. This work serves as a great tool and resource for the safety manager. There is scope for future research in the application of analytical hierarchy process (AHP) to the SMS in the Nigerian aviation industry. Till date, no documentation exists on this in literature. Investigations in future work could also consider uncertainty and the application of fuzzy logic will be relevant in this case. This is necessary as no literature report has been given till date on the subject as it relates to SMS in the Nigerian aviation industry.

5. Appendix

On a scale of 0-4 where, 0 – No influence 1 – Low influence 2 – Medium influence 3 – High influence 4 – Very high influence

Respondents were asked to indicate the direct effect they believe each element exerts on each and every other element using the scale above. The element to the left is compared with each element to the top starting from the first to the last.

Zero is seen on the diagonal because each element has zero influence on itself.
Note:
SSR – Safety Structure and Regulation
SD – Safety Documentation
SRM – Safety Risk Management
SMQA – Safety Monitoring and Quality Assurance
CS – Communication of Safety
PS – Promotion of Safety

S/N	SSR	SD	SRM	SMQA	CS	PS
SSR						
SD						
SRM						
SMQA						
CS						
PS						

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