Erzincan Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
2016, 9(3), 147-163
Araştırma Makalesi

Erzincan University
Journal of Science and Technology
2016, 9(3), 147-163
Research Article

An Analytic Hierarchical Approach to Building Airline Safety Management Systems

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(Geliş Tarihi/Received: 25.05.2016, Kabul Tarihi/Accepted: 24.08.2016)

ABSTRACT

The airline literature has attracted considerable attention of scholars and significant modelling and empirical reports have been contributed. However, despite being significantly agitated in the recent past in view of unprecedented airline failures, the Nigerian airline industry is least studied. The safety management system (SMS) meant to be a constant measuring tool has been downplayed in research concerning this country's airline system. To correct this anomaly, this study takes a frontline empirical initiative to prioritise the safety management system components and elements which hitherto has been very challenging and currently being approached by intuition. In this paper, the collective wisdom of experts is integrated into a framework of the analytical hierarchy process (AHP) wherein experienced professionals' ideas are obtained through questionnaire administration and interviews. The AHP methodology is a classical, merit-driven and validated approach in decision making and applied in this instance to the Nigerian aviation industry. The results indicated an effective prioritisation of SMS elements and further validate the efficacy of the AHP model developed originally by Thomas Saaty.

Keywords: Safety management system, analytical hierarch process, airline, decision making

Havayolu Emniyet Yönetim Sistemleri Oluşturmak İçin Analitik Bir Hiyerarşik Yaklaşım

ÖZET

Havayolu literatürü akademisyenlerin dikkatini önemli oranda çekmiş ve önemli modelleme ve deneysel raporlara katkıda bulunmuştur. Bununla birlikte yakın geçmişte yaşanan benzeri görülmemiş havayolu hataları nedeniyle büyük bir tedirginlik duyulmasına rağmen, Nijerya hava yolu endüstrisi en az incelenmiştir. Sabit bir ölçme aracı olarak tanımlanan emniyet yönetim sistemi, bu ülkenin havayolu sistemi ile ilgili araştırmalarda önemsenmemiştir. Bu çalışma, bu durumu düzeltmek için emniyet yönetim sistemi bileşenlerinin ve unsurlarının önceliğinin belirlenmesi amacıyla deneysel bir girişim başlatmıştır. Bu çalışmada, uzmanların toplu bilgeliği, deneyimli profesyonellerin fikirlerine ve anket yönetimi ve görüşmeler yoluyla elde edinilen analitik hiyerarşi süreci (AHP) verilerine entegre edilmiştir. Belirtilen AHP metodolojisi, karar alma sürecinde klasik, iyi yönlendirilmiş ve onaylanmış bir yaklaşım olup Nijeryalı havacılık endüstrisine uygulanmaktadır. Sonuçlar, emniyet yönetim sisteminin (SMS) öğelerinin etkili bir önceliklendirilmesine ve daha önce Thomas Saaty tarafından geliştirilen AHP modelinin etkililiğinin doğruluğuna işaret etmiştir.

Anahtar kelimeler: Emniyet yönetim sistemi, analitik hiyerarşi süreci, havayolu, karar verme

ISSN: 1307-9085
e-ISSN: 2149-4584
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DOI: 10.18185/eufbed.47498

1. Introduction

Decision making, considered as a constant and major activity in airline industries, has been employed in diverse airline real-life problems. With the ever-expanding demands of customers in the airline industry and the increasing complexity of aircraft decision problems in developing countries, it is challenging for individual worker in safety management systems (SMSs) (Hsu et al., 2010, Chen and Chen, 2012) to make elemental and component prioritisation decisions while precisely assessing the total necessary items of decisions. Consequently, reliable as well as reasonable decisions in the aviation industry could only be made through the participatory efforts of the trained and experienced safety officers and managers with the adoption of scientific approaches to decision making. In this study, extensive reliance is made on the knowledge, training and experience of safety managers operating in the Nigerian aviation industry, in the development of a safe, reliable and reasonable safety management system by engaging those who have spent at least fifteen years in the safety area on aviation safety, to fill questionnaires and through interviews. Their inputs are fed into a structured format for the application of analytical hierarchy process, which is a robust and reliable scientific tool for decision making that the current SMSs need to have competitive edge in business.

The safety management systems, which are central to making real and long-lasting airline industrial decisions, have been investigated with huge vigour, particularly in terms of the effectiveness of making safety decisions. The SMSs therefore need continuous investigations and enhancements to make them deliver the best benefits to the airline industry (Zaim et al., 2013; Wang et al., 2015). In a previous report, Onyegiri and Oke (2016a) developed an effective SMS focusing on grey relational analysis. The SMS problem was overcome by evolving a methodology that functioned effectively in situations where incomplete information abounds. The case study focused on the Nigerian aviation industry. Similarly, in another article (Onyegiri and Oke, 2016b), the same authors recognised the need for further study of the aviation industry in Nigeria and applied DEMATEL, a decision making tool to prioritise the components and elements of a safety management system and successfully created an order. The analysis of SMS components and elements on the basis of prioritisation is sparsely focused on the analytical hierarchy process (AHP) technique application and no record has been found for the Nigerian airline industry. However, investigations with a focus on AHP have potential advantages i.e. building effective and stable systems.

Although previous investigators mentioned the strong need for more studies on SMSs, there is complete omission of such studies in literature on the Nigerian environment. Safety analysis in other areas, apart from the SMS, showed that AHP has been successfully applied to attain effective and stable structures in diverse applications of manufacturing safety, mining safety, and agricultural safety, among others. Based on these success stories, the current researchers concluded that AHP could be applied to safety management systems. Thus, in this investigation, a distinguished approach to prioritisation of SMSs in the Nigerian aviation industry is sought with a focus on building an effective and stable structure. This nature of investigation has not been reported anywhere in literature. Although scanty studies describe works on AHP or integrated AHP and other tools, the main concern of such studies had been model developments, and at best applications in the advanced countries, which are different in nature, culture and operations of safety practices. In this study, the focus is on the perception of the workers in the Nigerian aviation industry based on their significant working experience in the industry. This report will expose the readers to some basic knowledge and understanding of the Nigerian environment.

The AHP is a multi-attribute decision making approach that was built-up by Thomas Saaty in the late 1970s based on mathematics and psychology. Its purpose is to give the decision maker a tool whereby s/he can synthesise his entire world experience, her/his feelings, intuition, logic, experience and knowledge to obtain the most desirable result from a set of alternatives. The analytic network process (ANP) is a basic tool that aids the mind in organising its thoughts as well as experiences and also to implement judgements stored in memory as well as value them with respect to priority scales, enabling the user to make a solid decision (Saaty and Vargas, 2006). The AHP measurement theory is implemented through pairwise comparisons. It depends on the judgements of experts to obtain scales of priority that measures intangible items in relation to one another. Items are compared with the use of scales of absolute judgements that shows the quality by which one element is greater than the other, relevant to a defined attribute (Saaty, 2008).

As a multi-criteria decision making (MCDM) technique, AHP, has been applied extensively in numerous fields. These fields include planning (Saaty and Kearns, 1985), in the evaluation of technology investment decisions (Boucher and McStravic, 1991), resource allocation (Saaty, 2001), layout design (Cambron and Evans, 1991), prediction and forecasting of chess tournaments (Saaty and Vargas, 1991), in structuring airline safety management systems (Hsu et al., 2010) and also in flexible manufacturing systems (Wabalickis, 1988). Our interest in AHP is due to its ability to measure intangibles by use of its absolute scales. Intangibles such as safety require tools that can synthesise data and the knowledge of experts to make better and more solid safety management systems.

The analytic hierarchal process is a very effective MCDM technique as well as is specifically special because it can measure intangibles. This is the reason it is been employed in this study. Safety management systems are relatively complex systems. They are affected by a number of factors. This is reflected in the Safety Manual of the ICAO (Doc 9859-AN/460) which states that safety is the condition that risks associated with aviation tasks are minimised and regulated to a permissible threshold. It then labelled a safety management system as an organised method to maintaining safety, such as the important organisational frameworks, accountabilities, policies and steps. This means that achieving effective and stable safety management systems is a function of being able to grow a solid structure of necessary safety elements and components.

2. Methodology

According to Saaty (2008) and Tzeng and Huang (2011), in solving a multivariate problem using AHP, the following procedures must be undergone:

1. Define the kind of problem. This means that the goal of the problem must be described; the elements that affect that goal must be identified and clearly laid out.

2. Create and structure the problem into a hierarchy by breaking the problem down into various elements from top to bottom. At the top will be the goal of the problem, then the criteria that immediately and directly affect the goal follow next at the next lower level, and then sub-criteria (that is, criteria that affect the above criteria) follow below on the lower hierarchal level and this goes on till the lowest level. Assuming that an SMS has N elements affecting it and the n^{th} sub-element indicates the last sub-element under each element, a sample hierarchical structure of AHP in SMS systems is shown in Figure 1. This information was motivated by the classical study of Tzeng and Huang (2011).

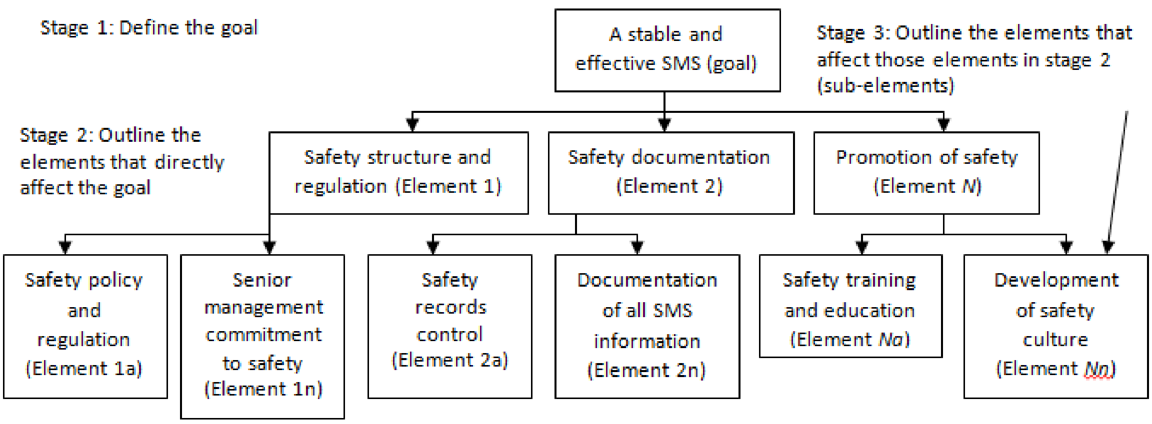

Figure 1: The AHP hierarchal structure of an SMS

3. Make use of a set of pairwise comparison matrices to compare elements. First, the elements in the top-level are compared using the goal as the yardstick. That is to say, the question to be asked will be, "How much more importance is criterion 1 over criteria 2, 3, 4 to criterion n with respect to the goal at hand?" The

responses are then quantified using the Saaty's 9-point scale. According to Saaty (2008), in comparing, there is need for a number scale, which shows the number of times more necessary or dominant element is above other elements in terms of the comparison element/criterion. Table 1 shows the basic scale of absolute numbers employed in AHP. This is also known as Saaty's 9-point scale. The first pairwise comparison matrix is used to aggregate the comparisons with reference to the aim. Each element occupying the apex position in the hierarchy is then employed for comparison with the one at the immediate lower position. The comparison element is also known as the parent element. This same process is repeated all the way down the hierarchal structure.

4. Synthesise the data from the pairwise comparison matrices to obtain individual relative weights at the top-level. In this paper, we obtain the priority values using the eigenvalue method. After this, proceed in the hierarchal position immediately following it. This must be carried out for each element in the immediate lower position. After this is done, the overall or global priorities of every element in the immediate lower level are obtained by multiplying their priority values with those of their parent element.

Table 1: Saaty's 9-point scale (Saaty, 2008)

Importance intensity	How is it defined?	Details
1	Matching significance	The two issues add in the same way to the objective
2	Faint or minor significance	
3	Ordinary significance	Experience and review weakly esteem one task above the other
4	Ordinary plus significance	
5	Robust significance	Experience and review robustly esteem one task above the other
6	Robust plus significance	
7	Very robust or established significance	A task is esteemed very robustly above another; its supremacy established in practice
8	Very, very robust significance	
9	Tremendous significance	The evidence esteeming one task above the other has the highest classification of confirmation
Reciprocals relating to the above	If task *i* contains a non-zero number allotted to it when related to task *j*, consequently j contains the reciprocal value in comparison to *i*	A sound supposition
1.1-1.9	If the tasks are extremely near	Could be challenging to allot the most excellent value but when related to other different tasks, the magnitude of the small numbers may not be significantly noticed, yet they can still show the relative importance of the tasks

In comparing a set of elements using the AHP, we make use of pairwise comparison matrices. Consider a set of n elements, represented as e_1, e_2, ..., e_n. The pairwise comparison matrix would contain appropriated scale numbers (or weights, that is, of the judgments) from quantifying the results of the comparison survey, interview, or questionnaire that was administered or conducted using Saaty's 9-point scale. Let us say these scale numbers/weights are represented as w_1, w_2, ..., w_n, the respective matrices will be of the form;

$$E = \begin{bmatrix} e_{11} & & e_{1j} & e_{1n} \\ e_{i1} & \cdots & e_{ij} & e_{in} \\ \cdots & \cdots & \cdots & \cdots \\ e_{n1} & \cdots & e_{nj} & e_{nn} \end{bmatrix}$$

The matrix containing elements in the pairwise comparison is represented by matrix **E**. Note that $e_{ij} = 1/e_{ij}$ and is a positive reciprocal of it and also that, $e_{ij} = e_{ik}/e_{jk}$.

$$W = \begin{bmatrix} w_1 & w_j & \cdots\ w_n \\ w_1/w_1 & w_1/w_j & \cdots w_1/w_n \\ w_n/w_1 & w_n/w_j & \cdots w_n/w_n \end{bmatrix}$$

The matrix **W** is the weight matrix of the matrix **E**. If we multiply the matrix **W** by the matrix ***w*** where ***w*** $= \begin{bmatrix} w_1 \\ w_j \\ w_n \end{bmatrix}$, we obtain $n \begin{bmatrix} w_1 \\ w_j \\ w_n \end{bmatrix}$.

This can also be written as,

$(\boldsymbol{W}-n\boldsymbol{I})\boldsymbol{w}=\mathbf{0}$ **(1)**

Equation **(1)** is an eigenvalue problem, and must be solved in order for us to obtain our priority values. To obtain our priority values, we have to obtain the eigenvector ***w*** with the associated $\lambda_{\max w}$ that satisfies the equation,

Ew= $\lambda_{\max w}$ **(2)**

where $\lambda_{\max w}$ is the largest eigenvalue of the matrix **E**.

According to Saaty (1980), so as to make sure that there is consistency of judgments, the consistency ratio, or C.R. is to be at most 0.1. The consistency ratio is obtained using the equation below,

Consistency ratio (C.R.) = Consistency index (C.I.)/Random consistency index (R.I.) **(3)**

where, consistency index =

$(\lambda_{\max w} - n)/(n-1)$ **(4)**

and the random consistency index can be obtained from the Table 2.

Table 2: R.I. Values for different matrix sizes (Tzeng and Huang, 2011)

Matrix size (*n*n*)	3	4	5	6	7	8	9
R.I. Values	0.52	0.89	1.11	1.25	1.35	1.40	1.45

5. Interprete the results and use the priorities to get a clearer representation for easy resource allocation.

Table 3: Components and elements of an SMS (Onyegiri and Oke, 2016a)

S/N	Component	Element	Definition
1	Safety structure and regulation	Safety policy and regulation	A formal, written statement containing the company's safety policy
		Safety objectives and goals	Safety objectives and goals are properly defined, time-oriented and realistic.
		Safety responsibilities, accountabilities and authorities	There is proper designation of safety roles and responsibilities
		Senior management commitment to safety	Senior management is actively involved and dedicated to the SMS.
2	Safety documentation	Documentation, implementation and continuous review of standard regulations	Regulations, standards and exemptions are periodically reviewed to ensure that information is available.
		Safety records control	There is proper archiving of safety data for later use.
		Documentation of all SMS information	All SMS information are clearly documented and available to all.
3	Safety risk management	Emergency response plan	There is reactive plan in place in the event of accident occurrence
		Hazard identification capability	There is a system in place for accurate and timely reporting of relevant information related to hazards, incidents or accidents.
		Safety data collection capability	There is a system in place for collection of safety information for processing
		Assessment of safety risks and hazards	There is a system in place for proper assessment of safety risks and hazards
		Investigation of incidents and accidents	Ability to investigate incidents and accidents
		Safety data analysis	Ability to properly analyse safety information and proffer preventive solutions
		Implementation of risk assessment and analysis results in hazard control	Whether and the degree to which safety recommendations are implemented
4	Safety monitoring and quality assurance	Ability to verify and monitor SMS effectiveness and performance	The degree to which SMS progress can be tracked
		Establishment of performance indicators	Establishment of performance standards
		Internal safety audits	Regular internal inspections of safety compliance within all units in the company
		Change management capability	A process to evaluate the effectiveness of corrective actions.
5	Promotion of safety	Communication of SMS roles and duties to staff	Proper sensitisation of staff about their SMS duties
		Effective safety information dissemination systems	Effective platforms that gender proper safety information dissemination
		Safety training and education	Equipping of staff with necessary skills to perform their SMS roles
		Development of safety culture	Platforms that gender safety reporting and experience sharing

3. Structuring the problem

According to Onyegiri and Oke (2016a), the framework for SMS implementation was defined and revised from other research work and standard safety documents to have six components and 22 elements. After classical study of the paper, we obtain five major components and 22 elements of an SMS system. These are shown in Table 3.

Table 3 gives us a clear view of what a safety management system should look like and what it should contain. We know that all elements do not affect the safety system equally as some are more important than others. This guide however, does not give us the amount of resources to focus on each element. This therefore proves a daunting task for the safety manager. He will need a tool to enable him simplify this complex system. He will need a tool that can help him appropriate his scarce resources so as to make his SMS grow well and be stable and functional.

In this research work, we must first seek to factor out the most influential components of an SMS. We will construct the hierarchal level from our revised SMS structure. The hierarchy will be of the form (Figure 2);

The required data was obtained by the use of interviews. The entire duration of all the interviews was about 16 hours. The interviews were conducted with aviation safety experts with experience of above 15 years in aviation safety. A total number of 30 safety experts were contacted. We had a response rate of 80% as 24 out of 30 experts provided statistically-relevant information and were available to be interviewed. The demographics of the respondents with respect to age range, number, and years of experience are given in Table 4.

It was noted that the major statistical meaning to the various respondents' age range differences hinge in the fact that more experienced respondents were able to give more accurate and precise statements to the relative importance of one element over another and they did so in quicker times. They were able to distinguish more holistically one element from another without losing sense of the contribution of all elements to the system. The less experienced ones found it a bit more difficult to clearly distinguish some elements and did so at longer time periods.

Their judgements were quantified using Saaty's fundamental scale as shown in Figure 2. Pairwise comparison matrices were first applied to the five revised components of an SMS to derive their priorities. The same process was carried for each of the five components associated with the elements under them as stated in Step 3. There are six pairwise comparison matrices in total, one for the six components with respect to the goal (which is a stable and effective safety management system), and five more for the SMS elements with respect to their five respective components.

The global weights of all the components and elements are then obtained as stated in Step 4.

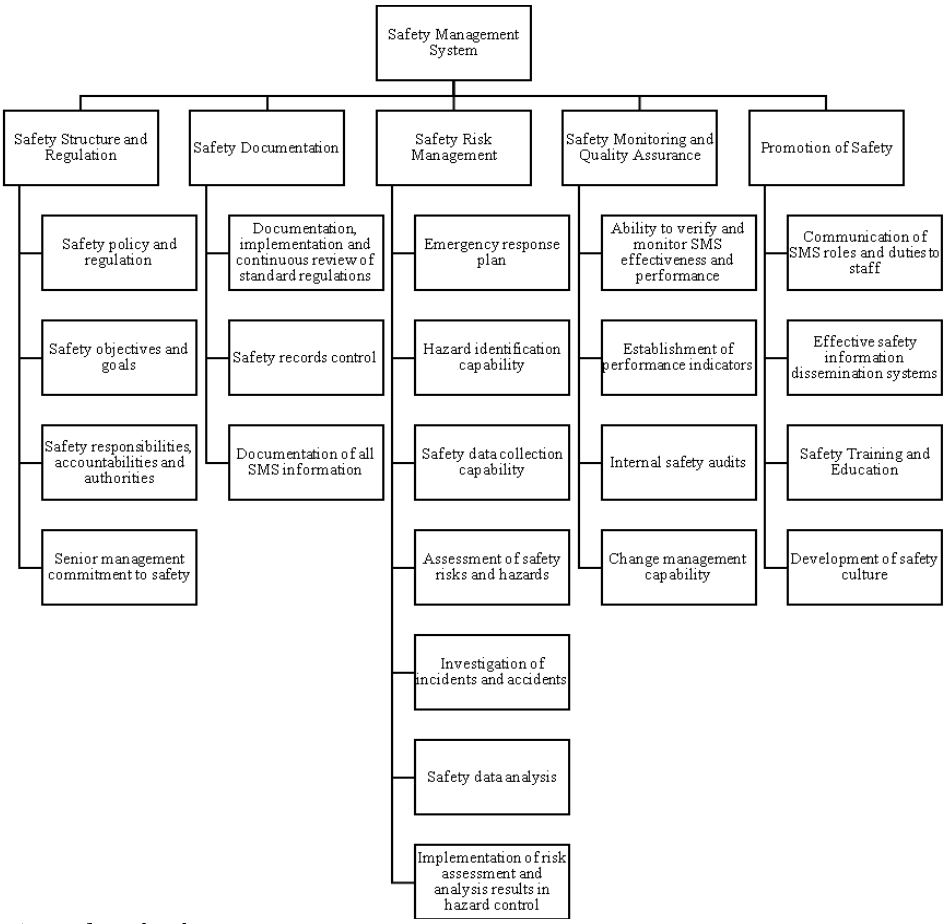

Figure 2: Hierarchy of safety management system

Table 4: Relationship between age and mean years of experience

S/N	Age range	Number of persons in age range	Mean years of experience of persons in age range
	40 - 45	5	16.5
	45 - 49	5	18.7
	50 - 54	7	22
	55 - 59	6	26.7
	60 - 64	1	30

Table 5: SMS components and their notations

SMS component	Notation
Safety structure and regulation	C1
Safety documentation	C2
Safety risk management	C3
Safety monitoring and quality assurance	C4
Promotion of safety	C5

The pairwise comparison matrices are all shown in the appendix section of this paper. Table 5 shows the five revised SMS components and their notations.

We first deal with the first level hierarchy to obtain the priorities of the five SMS components. After this, we obtain weights of the elements per component and aggregate them to obtain the global priorities of the SMS elements.

5. Results and Discussions

After applying AHP to the five components of a safety management system, we obtain the following priority values or weights (Table 6).

This has a consistency ratio of 0.0464. Next, we move unto the elements under safety structure and regulation. Applying AHP to them, we obtain their respective weights as given in Table 7.

With a consistency ratio of 0.0590. The results for the elements under safety documentation are given in Table 8.

Table 6: Priority values/weights of the SMS components

Notation	SMS component	Normalised weights	Idealised weights
C1	Safety structure and regulation	0.3563	1.0000
C2	Safety documentation	0.2556	0.7174
C3	Safety risk management	0.1543	0.4331
C4	Safety monitoring and quality assurance	0.0302	0.0848
C5	Promotion of safety	0.2035	0.5711

Table 7: Weights and global weights of SMS elements under safety structure and regulation

Notation	SMS element	Weights	Global weights
C1E1	Safety policy and regulation	0.5305	0.1890
C1E2	Safety objectives and goals	0.1567	0.0558
C1E3	Safety responsibilities, accountabilities and authorities	0.0664	0.0237
C1E4	Senior management commitment to safety	0.2464	0.0878

Table 8: Weights and global weights of SMS elements under safety documentation

Notation	SMS element	Weights	Global weights
C2E1	Documentation, implementation and continuous review of standard regulations	0.1634	0.0418
C2E2	Safety records control	0.2970	0.0759
C2E3	Documentation of all SMS information	0.5396	0.1379

Table 9: Weights and global weights of SMS elements under safety risk management

Notation	Element	Weights	Global weights
C3E1	Emergency response plan	0.0473	0.0073
C3E2	Hazard identification capability	0.3228	0.0498
C3E3	Safety data collection capability	0.1084	0.0167
C3E4	Assessment of safety risks and hazards	0.1837	0.0283
C3E5	Investigation of incidents and accidents	0.1106	0.0171
C3E6	Safety data analysis	0.1381	0.0213
C3E7	Implementation of risk assessment and analysis results in hazard control	0.0897	0.0138

Table 10: Weights and global weights of SMS elements under safety monitoring and quality assurance

Notation	SMS element	Weights	Global weights
C4E1	Ability to verify and monitor SMS effectiveness and performance	0.4633	0.0140
C4E2	Establishment of performance indicators	0.3132	0.0095
C4E3	Internal safety audits	0.1522	0.0046
C4E4	Change management capability	0.0713	0.0022

Table 11: Weights and global weights of SMS elements under promotion of safety

Notation	SMS element	Weights	Global weights
C5E1	Communication of SMS roles and duties to staff	0.0544	0.0111
C5E2	Effective safety information dissemination systems	0.1798	0.0366
C5E3	Safety training and education	0.5418	0.1103
C5E4	Development of safety culture	0.2240	0.0456

This has a consistency ratio of 0.0088. The results for the elements under Safety Risk Management are given in Table 9.

This has a consistency ratio of 0.0725. The results for the elements under safety monitoring and quality assurance are given in Table 10.

This has a consistency ratio of 0.0403. The results for the elements under promotion of safety are given in Table 11.

This has a consistency ratio of 0.0524. Ranking the elements based on their global priorities, we have Table 12.

Managing safety management systems is a complex task that requires training, experience and solid decision making and resource allocation skills. As these systems have become a legal requirement in the airline industry, the safety manager is faced with the task of understanding how best to build an effective and stable safety management system. It is in this bid that AHP was applied to provide the safety manager with a clearer picture of how to set up a good SMS. From our results in Table 6, we can see that as touching safety components, safety structure and regulation has the highest priority value coming in at 35.63%, followed by safety documentation in second place with 25.56%, promotion of safety in third place with 20.35%, and safety risk management and safety monitoring and quality assurance come in fourth and fifth place, respectively, with 15.43 and 3.02%. These results already show that in setting up a solid SMS, one must have a solid safety structure and regulation, which involves a documented policy conveying the organisation's commitment to safety in all its operations, from its senior staff and in attaining its goals and objectives and its mission and vision. This component deals with the organisation's core values. It is also concerned with what the organisation deems as most important.

This is the engine of the SMS. This is what will show and affirm the organisation's dedication to allocate resources to ensure safety in all that it does. Safety documentation then shows that the organisation must dedicate resources to proper documentation of all SMS information so that it can be accessible to those that may need it. Promotion of safety comes in close third place and shows that to attain a good SMS, an organisation must train, educate and culture its staff to be able to perform their SMS duties. This would involve SMS training and communication of SMS information to all staff. Also, safety culture must be developed.

Safety risk management will then be attainable since staff will be aware of safety risks and hazards, how to identify them, avoid them, report them and investigate incidents and accidents. This will ensure that the SMS is more proactive than reactive which will go a long way in mitigating risks and hazards. Safety monitoring comes in the last place with about 3%. This shows that it depends a lot on the success of the implementation of the first four components. This makes sense since if a stable system is not in place yet, then safety cannot be monitored and assured effectively and mediocre safety standards will be set.

Despite our observations from the first results of AHP on the SMS components, we must delve deeper into specifics as these components themselves have elements that affect them in diverse manners and to different degrees. These results are seen in Tables 7 to 11. Our focus will be on Table 11, which contains the global weights of all 22 elements ranked in descending order. This is done because our overall goal is concerned with the SMS as a whole, not its components. The global weights give us the direct effects of SMS elements on overall safety performance. For the sake of analysis, all elements above 1.5% are considered critical to SMS success. This percentage was obtained by consensus of our experts. Doing this, we are left with 15 critical elements. Also, for better representation, three categories where made under the critical elements. Elements having above 5% priority percentages are referred to as major critical elements. Elements between 3-5% priority percentages are average critical elements while those between 1.5-3% are minor critical elements.

According to our results, there are six major critical elements; Safety policy and regulation is the most critical element with 18.9% priority percentage, second is documentation of all SMS information with 13.8%, third is safety training and education with 11.03%, fourth senior management commitment to safety with 8.78%, fifth is safety records control with 7.59% and safety objectives and goals comes sixth with 5.58% priority percentage. These results show that the foundation of a solid SMS is in having a solid, well-documented safety policy, which will drive the allocation of resources to safety, gender the proper safety training and education of staff, ensure that senior management is accountable and committed to safety and ensure that both short-term and long-term safety goals and objectives have a platform upon which to stand and be achieved. This will also ensure that all safety information are properly documented and archived for use in building proactive and preventive SMSs. There are four average critical elements, which follow after from the major ones, these are hazard identification capability with 4.98%, second is development of safety culture with 4.56%, the third is documentation, implementation and continuous review of standard regulations with 4.18% and lastly is effective safety information dissemination systems with 3.66% priority percentage.

These four shows that staff must be properly trained in order for them to be able identify safety hazards and risks. This is a crucial element necessary for building proactive and preventive safety management systems. Everyone must be involved to some degree and this is seen next in the need for the development of a safety culture. A safety culture is a necessary step in building long-lasting SMSs as this element deals with encouraging everyone to be acquainted with safety and all that it entails. This element promotes safety in forms like non-punitive reporting systems, safety talks and workshops and safety bonuses amongst others. After this are documentation, implementation and continuous review of standard regulations which are released by safety governing bodies. It entails that the organisation must be up-to-date with information as touching standard regulations and must comply and adapt to accommodate changes. Lastly, the organisation then must set up effective safety information sharing systems to keep the staff up-to-date with the latest safety news and information. Platforms like safety billboards, safety meetings, bulletins and memos are some examples of these systems.

The minor critical elements are five in number. They are assessment of safety risks and hazards; safety responsibilities; accountabilities and authorities; safety data analysis; investigation of incidents and accidents; and safety data collection capability with 2.83, 2.37, 2.13, 1.71 and 1.67 priority percentages, respectively. Four out of five of them have to deal with safety risk management and deal with the ability of the organisation to assess, investigate, collect and analyse safety data that has been identified and obtained in order to mitigate risks and hazards. Due to this, and their close priority values, we can assume that, due to the overlapping definitions of these elements, that been able to assess safety risks and hazards that have been identified, investigate safety hazards, incidents and accidents, collect safety data and analyse it to procure solutions are somewhat together and can all be viewed together as average critical elements. Safety responsibilities, accountabilities and authorities deal with the allocation of safety duties and oversight figures of safety and are also necessary in proper SMS execution.

5. Conclusion

From our results and discussion, we can attest to the fact that the AHP is an effective tool for handling and simplifying complex multivariate systems like SMSs. Our results show that for a stable, continuous and effective SMS to be attained and sustained, focus must be placed firstly on safety structure and regulation and chiefly on having a well laid out, solid documented safety policy. This is the back-bone of an SMS. This will drive all other elements. Effective safety documentation, training and education will then follow next in making sure there is sufficient safety information, training and culture for staff to perform their various SMS duties at and in their various capacities effectively and efficiently thus creating a continuous reactive and proactive safety management system.

Table 12: Ranking of SMS elements based on their global weights

Notation	SMS element	Global weights	Ranking
C1E1	Safety policy and regulation	0.1890	1
C2E3	Documentation of all safety information	0.1379	2
C5E3	Safety training and education	0.1103	3
C1E4	Senior management commitment to safety	0.0878	4
C2E2	Safety records control	0.0759	5
C1E2	Safety objectives and goals	0.0558	6
C3E2	Hazard identification capability	0.0498	7
C5E4	Development of safety culture	0.0456	8
C2E1	Documentation, implementation and continuous review of standard regulations	0.0418	9
C5E2	Effective safety information dissemination systems	0.0366	10
C3E4	Assessment of safety risks and hazards	0.0283	11
C1E3	Safety responsibilities, accountabilities and authorities	0.0237	12
C3E6	Safety data analysis	0.0213	13
C3E5	Investigation of incidents and accidents	0.0171	14
C3E3	Safety data collection capability	0.0167	15
C4E1	Ability to verify and monitor SMS effectiveness and performance	0.0140	16
C3E7	Implementation of risk assessment and analysis results in hazard control	0.0138	17
C5E1	Communication of SMS roles and duties to staff	0.0111	18
C4E2	Establishment of performance indicators	0.0095	19
C3E1	Emergency response plan	0.0073	20
C4E3	Internal safety audits	0.0046	21
C4E4	Change management capability	0.0022	22

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