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THE PERSPECTIVE OF THE AVIATION ORGANIZATIONS ON THE ICAO'S SMS FRAMEWORK: A SPHERICAL FUZZY AHP STUDY

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Abstract. The International Civil Aviation Organization (ICAO) has developed a Safety Management System (SMS) to ensure safety in aviation organizations. SMS components are essential to overall safety performance in aviation organizations. However, the importance of these components may be perceived differently among different aviation organizations. This study aims to evaluate the perception of the importance of ICAO SMS components in aviation organizations in Turkey using the Global Fuzzy Analytical Hierarchical Process (SFAHP). The sample of the research consists of managers and employees of different aviation organizations. Data were collected using a survey questionnaire and analyzed via the SFAHP method. The results of this study indicate that all ICAO SMS components were considered important by the participants. In this context, hazard identification, training, and education and safety risk assessment and mitigation are the most important components. The study also revealed that the perception of the importance of SMS components differs between different types of aviation organizations. The SMS components with the highest deviation are listed as the appointment of key safety personnel, safety risk assessment and mitigation and management commitment. Therefore, the study provides valuable information regarding the perception of the importance of ICAO SMS components in aviation organizations.

Keywords: aviation organizations, analytical hierarchical method, ICAO, SMS framework, spherical fuzzy sets, aviation safety.

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1. Introduction

The aviation industry is a complex and high-risk sector, and safety is its top priority. A Safety Management System is a holistic approach that enables aviation organizations to continuously improve their safety performance (Muecklich et al., 2023). SMS provides a framework for ensuring aviation safety and is supported by International Civil Aviation Organization [ICAO] standards and guidance (ICAO, 2013, 2019). The system enables aviation organizations to review their operations, management structure, and culture. The implementation of SMS ensures that organizations comply with legal and ethical requirements. The implementation of SMS in aviation applies to a wide range of aviation businesses, from airlines to airports, with each organization customizing and implementing its SMS according to its own requirements. As a result, SMS enables aviation organizations to continuously monitor, evaluate, and improve safety performance, ensuring safe and efficient air transport across the industry (Murphy & Efthymiou, 2017; Malakis et al., 2023).

The aviation industry, like other high-risk industries that have adopted SMS earlier, is seeking to transform safety management into a business function, employing a more proactive and performance-based approach to safety. Historically, safety has been achieved through compliance with rules, processes and procedures, but the fact that accidents continue to occur in the aviation industry has created the need for a new approach. Although traces of SMS can be witnessed in many aviation organizations in the past, the widespread adoption of SMS for all aviation organizations has come as a result of regulatory overriding (Malakis et al., 2023; ICAO, 2013; 2018). Historically, aviation authorities favored a reactive, punitive approach to preventing accidents and incidents. Authorities exerted some pressure on organizations to identify and correct non-compliance. SMS, which emerged at the end of this punitive process, placed the emphasis on compliance rather than punishment.

SMS is a structured approach to overseeing safety within an organization. It encompasses the establishment of organizational frameworks, delineation of responsibilities, formulation of policies, and development of procedures. SMS integrates principles derived from system safety, quality management systems, and related fields. Its implementation and upkeep are motivated by the imperative to conform to safety standards or adhere to recognized best practices. SMS finds extensive application in aviation, especially in sectors characterized by heightened safety hazards or intricate operations. ICAO has established standardized SMS requirements for the aviation sector, mandating compliance from Member States. SMS serves as a tool to facilitate organizations in comprehending safety principles and devising and modifying suitable management systems. The evolution of safety management has transitioned from a primary focus on occupational health and safety to a more comprehensive systems-oriented approach. ICAO's latest perspective adopts a holistic systems approach, regarding the aviation industry as a system and individual organizations as subsystems (ICAO, 2013; 2018).

Many aircraft accidents have occurred from the past to the present. To prevent the recurrence of accidents, the causes were examined in detail, and the rules and procedures were updated to meet contemporary needs. Thus, the aviation field has become a highly regulated and specialized industry. Organizations in the field now operate within boundaries drawn by regulators. Particularly concerning safety, these boundaries have become more defined, with regulators demanding that organizations prioritize safety. The coercive, normative, and mimetic mechanisms of the field (Meyer & Rowan, 1977; DiMaggio & Powell, 1991, p. 64) can standardize aviation organizations seeking legitimacy and survival based on safety. There are many national and international rule-makers and regulators who monitor, audit, and guide activities in aviation (such as ICAO, EASA, IATA, FAA, and CAAs). These organizations determine the legal framework within which aviation organizations operate, based on national and international law, and they monitor compliance with current regulations. Regulators' activities create a coercive legitimacy zone for organizations (DiMaggio & Powell, 1983). Organizations that prefer certainty to uncertainty may adopt legitimacy as an important need (Deephouse & Suchman, 2008), leading them to align with their environment and stay within the legitimacy zone (Daft et al., 2010). In the aviation field, many stakeholders (such as associations, unions, and interest groups) contribute to the development of safety, alongside rule-makers and regulators. An organization's alignment with institutional pressures and social norms provides legitimacy and ensures survival (Hatch & Cunliffe, 2006). Therefore, stakeholders' social norms and institutional pressures, such as regulatory enforcement, can lead organizations to adopt safety-based cohesion. Governments, stakeholders, and social expectations shape socially acceptable and expected organizational behaviors, forcing organizations to behave similarly and adopt the same structures (Miles, 2012, p. 146).

Regulatory organizations in the field of aviation have put into effect many regulations, procedures, and rules for the implementation of aviation organizations of member countries with motivations such as ensuring the order of activities, reducing uncertainty, and preventing accidents. Individuals and organizations that do not implement these regulations may face penalties and sanctions. External pressures (such as regulators and governments) and the attitudes of organizational stakeholders (such as customers, suppliers, and professional associations) to safety can induce the emergence of significant safety norms within the organization (Deephouse, 1996). In addition, developments and changes in the organizational environment regarding safety can push the organization to take some decisions unintentionally and to adopt practices in other organizations. In addition, developments and changes in the organizational environment regarding safety may unintentionally push the organization to make decisions and act on the practices of other organizations (Hasle et al., 2014).

According to Rational Organization Theory, organizations tend to prefer structures that enhance productivity and organizational outcomes. However, the extent of these outcomes and productivity may not always sufficiently explain the survival of an organization. Environmental cohesion can impact the survival of an organization as significantly as other factors (Tosi, 2009). Organizations are both influenced by and exert influence on their environment in terms of structure, functioning, and survival. Therefore, aviation organizations bear the responsibility of ensuring safety while striving to increase efficiency and outcomes. They should allocate some of their resources to safety rather than solely focusing on production.

The responsibility to allocate resources for safety can create a management dilemma for organizations. Misallocation of resources may confront organizations with the risk of bankruptcy or accidents. A decline in safety levels or the occurrence of accidents can increase the possibility of losing legitimacy and facing sanctions. This exemplifies the pressure on regulators to standardize organizations, particularly concerning safety issues. Notably, ICAO's policies aim to establish common safety standards worldwide through the concept of safety management. This creates regulatory pressures on both states and aviation organizations. The current study is focused on finding answers to the following question.

Do aviation organizations have a similar perception about SMS?

Organizations with different organizational structures and management understanding cooperate in the aviation industry. Although their operational systems are different, these organizations operate together. In order to ensure safety at aviation organizations and not to disrupt its operations, it is necessary to cooperate with many organizations. Aviation organizations are based on ICAO SMS documents. But do all aviation organizations perceive ICAO SMS components in the same way? In other words, is the level of importance given to SMS components by aviation organizations different? Therefore, the main motivation of this study is to determine the importance of perceptions of aviation organizations to the ICAO SMS components. There are studies in the literature examining ICAO SMS components (Chang et al., 2015; Chen & Chen, 2012; Gerede, 2014; Maragakis et al., 2009; Mbaye et al., 2022; Remawi et al., 2011; Stolzer et al., 2018; Yang et al., 2022). However, a limited number of studies have been conducted in the context of aviation organizations.

The rest of the study is designed as follows. In the second section, there is a literature review. The methodology of the study is in the third section. In the fourth section, there is the application of the study. The fifth section is results and discussion. The last section is about the conclusion, limitations, and future research of the study.

2. Literature review

The concept of safety varies depending on context and industry. In aviation, it refers to minimizing and controlling risks related to aircraft operations and supporting activities to an acceptable level (ICAO, 2013). Safety itself refers to a state of being free from unacceptable consequences, while safety management involves the processes and activities to achieve this state. The goal of safety management is to protect people, the environment, equipment, and property from unacceptable risks (Li & Guldenmund, 2018). An effective safety management system (SMS) is crucial for organizations to meet their moral, legal, and financial responsibilities (Stolzer et al., 2016).

The International Civil Aviation Organization (ICAO) guides governments and service providers in establishing, planning, and operating SMS. ICAO also sets safety requirements and standards. According to ICAO, SMS provides a systematic approach to safety, which is necessary for continuous improvement. This involves proactively identifying hazards, collecting safety data, and assessing risks to prevent accidents and incidents. ICAO Annex 19 outlines the SMS framework, which includes four key components and twelve elements: Safety policy and objectives, safety risk management, safety assurance, and safety promotion (ICAO, 2013).

A safety policy represents a publicly declared commitment to safety, outlining the safety objectives of an aviation organization, the fundamental responsibilities of safety-related employees, and the supervisory controls related to these responsibilities. The corporate safety policy asserts the organization's dedication to safety, prioritizing it above all other operational concerns. Safety objectives are defined both qualitatively and quantitatively, reflecting the desired level of safety that the aviation organization aims to achieve (ICAO, 2013, 2018, 2019). Safety risk management encompasses the entire process of identifying hazards that pose a threat to the activities of an aviation organization, assessing the associated risks, and subsequently eliminating or reducing these risks to an acceptable level (ICAO, 2013, 2018, 2019). The SRM process systematically identifies hazards linked to products or services. Safety assurance includes all SMS processes, such as collecting information, analyzing and evaluating this data to determine safety performance, comparing it with the organization's safety targets, and assessing the extent to which risk control performance and effectiveness can be (ICAO, 2013, 2018, 2019). Safety promotion involves all tools, processes, and procedures designed to ensure that aviation employees are adequately trained and competent to perform their safety management duties. Additionally, it aims to establish effective two-way communication between management and employees on safety issues (ICAO, 2013, 2019).

Numerous studies have examined the ICAO's SMS framework. However, the majority of these studies have utilized the SMS framework to measure safety performance. It is crucial to note that this framework is not a safety performance measurement tool but rather a guideline to assist states and service providers in managing safety (ICAO, 2019). In evaluating safety performance, the measurement of quantitative values for different safety indicators, as defined in Annexes 6, 8, 11, 13, and 14, is employed according to the field of activity. Multi-Criteria Decision-Making (MCDM) methods are frequently used in studies where the SMS framework is applied as a performance measurement tool. For instance, Chang et al. (2015) compared the SMS performance of airports using the ICAO SMS framework. Airport performances were evaluated using the Analytic Network Process (ANP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods, with airports ranked according to their performance. The research findings indicated that safety risk management has the greatest weight among SMS components. Following SRM, the most important component is safety policy and objectives, succeeded by safety promotion, and finally, safety assurance. In another study, Rolita et al. (2018) evaluated the safety performance of airports under the ICAO SMS framework using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and ANP methods. Stolzer et al. (2018) utilized SMS components to measure and test SMS effectiveness. Unlike other studies, this research compared the SMS performance of different types of organizations operating in the aviation sector. Data collected from carriers, manufacturers, airports, and freight hauler organizations from various countries were evaluated using Structural Equation Modeling (SEM) and Data Envelopment Analysis (DEA) methods to assess the safety levels of the organizations. In addition to these studies, several others have employed the ICAO SMS framework. For example, Chen and Chen (2012) conducted a scale development study to identify key components of SMS and measure SMS performance. They utilized components, elements, implementation plans, and steps created by ICAO, FAA, CASA, Transport Canada, UK CAA, and Taiwan CAA. The research yielded a component structure distinct from the ICAO SMS framework, incorporating documentation and commands, safety promotion and training, executive management commitment, emergency preparedness and response plans, and safety management policy. Leib and Lu (2013) conducted a case study involving air traffic controllers, airport management, and ground handling companies, examining the compliance of safety strategies implemented at Taiwan airports with the ICAO framework.

Recent studies on SMS components are limited. Yang et al. (2022) proposed a new unified approach to select drone management strategies. examined how the safety culture strategy has been accepted by regulators and

Table 1. ICAO safety framework

Components	Elements		Definitions
Safety policy and objectives	C_1	Management commitment	It states the commitment of top management, who has the primary responsibility for the implementation of SMS, decision making and resource allocation to declared safety policy and safety objectives of the organization (ICAO, 2013, 2018, 2019).
	C_2	Safety accountability and responsibilities	It states to accountabilities and responsibilities of all management and staff involved in safety-related duties, defined in the SMS documents (ICAO, 2013, 2018, 2019).
	C_3	Appointment of key safety personnel	It defines the person(s) responsible for the management of safety activities, appointed by the top management for the realization of the organization's safety policy and objectives (ICAO, 2013, 2018, 2019).
	C_4	Coordination of emergency response planning	It is the planning and coordination of actions, processes and controls to effectively manage and mitigate an operational emergency that may arise (ICAO, 2013, 2018, 2019).
	C_5	SMS documentation	It is the system where routine operational records are collected and maintained, which includes the definition and details of processes and procedures such as hazard identification, safety risk assessment, performance monitoring, and investigation together with safety policy and (ICAO, 2013, 2018, 2019).
Safety risk management	C_6	Hazard identification	It is the determination of all situations, events and circumstances that affect aviation safety, which may cause injury, illness, disaster or death, damage or loss of equipment and property, and damage to the environment (Čokorilo & Dell'Acqua, 2013; ICAO, 2013)
	C_7	Safety risk assessment and mitigation	It is the process of collecting and analyzing qualitative and quantitative safety data within the organization and determining acceptable/ unacceptable, assessing, controlling and mitigating of risks (ICAO, 2013, 2018, 2019).
Safety assurance	C_8	Safety performance monitoring and measurement	It is the activities carried out to verify the validity and effectiveness of the safety performance by using the safety performance indicators defined by the internal audit and monitoring (ICAO, 2013, 2018, 2019).
	C_9	The management of change	Organizational, environmental and technological changes may have the potential to affect organizations' safety management and existing risk mitigations. Change management includes identifying hazards that emerge due to change, assessing risks, and controlling risks (ICAO, 2013, 2018, 2019; Stolzer et al., 2016)
	C_{10}	Continuous improvement of the SMS	It is continuous monitoring and assessing of processes to maintain the effectiveness of SMS (Stolzer et al., 2016; ICAO, 2013).
Safety promotion	C_{11}	Training and education	It refers to the formal, repetitive and customized training and education processes created for employees to fulfill their safety-related duties competently (ICAO, 2013, 2018, 2019).
	C_{12}	Safety communication	It refers to the process of communicating the objectives and procedures of the organization regarding SMS to all employees and transferring information and data that employees have regarding safety to the organization, using appropriate communication methods (ICAO, 2013, 2018, 2019).

companies in the transportation industry and the principles for implementing safety management systems (SMS). Nævestad et al. (2023) examined how the safety culture strategy has been accepted by regulators and companies in the transportation industry and the principles for implementing safety management systems (SMS). Teske and Adjekum (2022) investigated the relationship between Mindful Organizing (MO) factors and Safety Management Systems (SMS) in the aviation industry. Mbaye et al. (2022) analyzed the process flow modeling for the Aviation Safety Management System (SMS) on a case-by-case basis using bowtie diagrams. Kurzweil (2022) examined Prague Airport's safety management system (SMS) in the context of Covid-19. However, there is a limited number of studies in literature examining the SMS perceptions of aviation organizations. Therefore, this study is important in terms of filling the gap in the literature and examining the perceptions of the importance of ICAO SMS components.

3. Methodology

In the section, spherical fuzzy sets and spherical fuzzy analytical hierarchy method were briefly described.

3.1. Spherical fuzzy sets

Spherical fuzzy sets (STS) are based on the idea that a decision maker's hesitancy can naturally be defined independently from his/her membership and non-membership degrees. Basically, it is constructed as the synthesis of Pythagorean and Neutrosophic Fuzzy Sets, however, it lets the decision-makers use membership functions on a spherical surface, and independently define all the parameters, including hesitancy, in a larger domain. Thus, in SFS, all of the membership, non-membership, and hesitancy parameters can be chosen independently as long as they are between 0 and 1 individually, and their squared sum is at most equal to 1 (Gündoğdu & Kahraman, 2019).

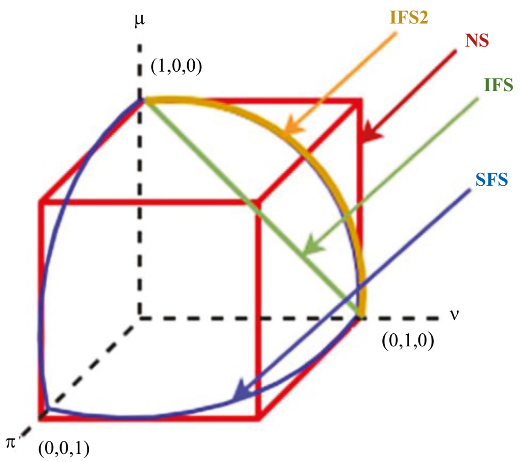

Figure 1. Geometric representations

3.2. Spherical fuzzy analytic hierarchy process

The proposed spherical fuzzy AHP method is composed of several steps as given in this section (Kutlu Gündoğdu & Kahraman, 2020a, 2020b). Information on all the steps of the method is provided in the Appendix.

4. Application

In this section, in the light of research questions, it concerns that the defined safety criteria in accordance with ICAO have been evaluated with respect to the institutionalization of safety in the organizations of aviation. The organization as *TCAA* (S_1), *Ground Handling Operators* (S_2), *Airlines Companies* (S_3), and *Airport Authorities* (S_4) participated in this study. Furthermore, in Figure 1, the proposed methodology of this study is given. The criteria were evaluated by (*i*) *TCAA*, (*ii*) *Ground Handling Operators*, (*ii*) *Airlines Companies*, (*iv*) *Airport Authorities*. Also, (*v*) the criteria were *Aggregated* by these organizations' decisions.

In our research methodology shown in Figure 2, the levels of institutionalization of safety in organizations are addressed from the ICAO perspective. The term "service provider" refers to all organizations providing aviation services within the framework of the State Safety Program (SSP). This includes approved training organizations, aircraft operators, approved maintenance organizations, organizations responsible for aircraft type design and/or production, air navigation service providers, and approved airports that are exposed to safety risks in the provision of their services. In current study TCAA represents the SSP. Additionally, airlines, ground handlers, and airports were

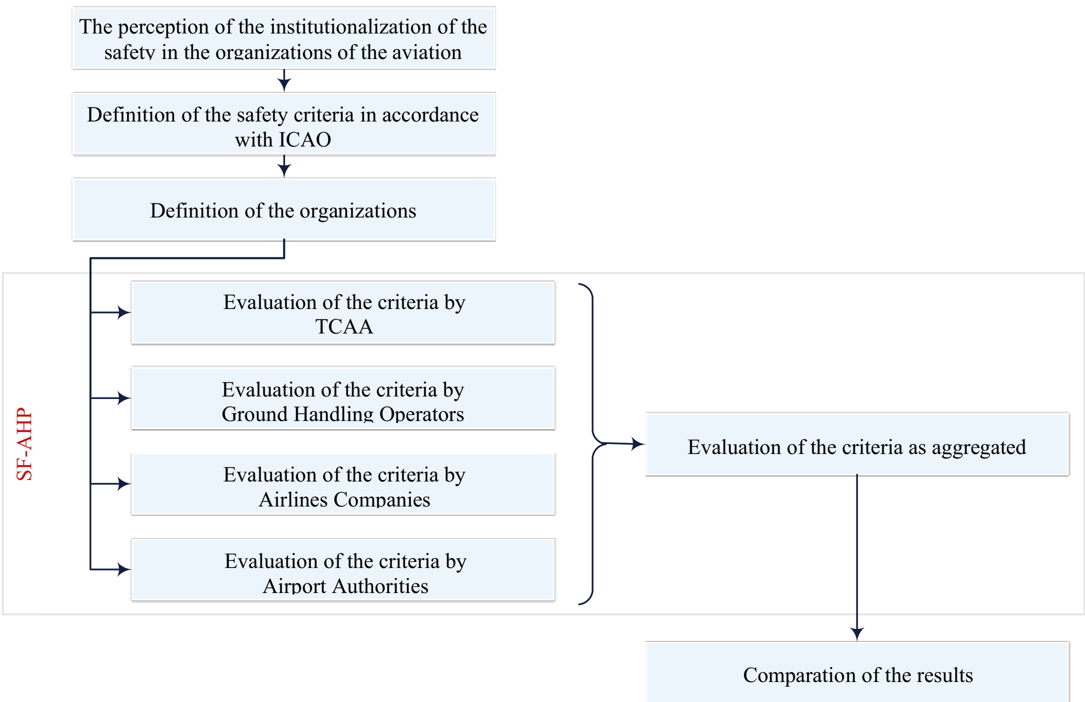

Figure 2. Proposed methodology

incorporated to represent the service providers. Maintenance and repair organizations (MROs) were excluded due to the lack of a sufficient number of expert opinions available from them. In Turkey, DHMI (State Airport Authority), a governmental organization, provides air navigation services both at airports and within the airspace. Since this organization is responsible for airport operations, air navigation service providers were categorized under "Airports" in the study.

The evaluation by decision makers was performed based on the criteria, and the weighted ranking process was performed using the SF-AHP method for all. In this study, decision makers working in these organizations were conducted with surveys and obtained their opinions. Decision-makers having between 5 and 15 years of experience in the aviation industry, in various departments of the organizations but especially those interested in safety have participated as experts in Turkey.

4.1. Evaluating the criteria by SF-AHP

In this section, following the presentation of the safety criteria provided by the ICAO in Table 1, the criteria were evaluated by decision makers also, the weighting and ranking of the criteria in terms of the institutionalization of safety in the organizations of aviation were performed by using the SF-AHP method. The results are presented in Table 2 and Figure 3. All data and solution tables such as the linguistic variables, the pairwise comparison decision matrices, and the decision matrix are presented in supplementary data in Appendix.

With respect to the results of *TCAA*, as indicated by the computed results of the criteria weights in Table 2, the most weighted criterion among the safety criteria is C_6 *Hazard identification*, the second is C_{11} *Training and education* and the third is C_7 *Safety risk assessment and mitigation*. The standard deviation among the weights of the criteria is 0.0106 for *TCAA* in Table 2. The criteria were ranked in the order of $C_6 \succ C_{11} \succ C_7 \succ C_8 \succ C_{10} \succ C_{12} \succ C_9 \succ C_2 \succ C_4 \succ C_1 \succ C_5 \succ C_3$ as the result.

With respect to the results of *Ground Handling Operators*, as indicated by the computed results of the criteria weights in Table 2, the most weighted criterion among the safety criteria is C_6 *Hazard identification*, the second is C_{11} *Training and education* and the third is C_8 *Safety performance monitoring and measurement*. The standard deviation among the weights of the criteria is 0.0068 for *Ground Handling Operators* in Table 2. The criteria were ranked in the order of $C_6 \succ C_{11} \succ C_8 \succ C_5 \succ C_{10} \succ C_9 \succ C_4 \succ C_{12} \succ C_7 \succ C_2 \succ C_1 \succ C_3$ as the result.

With respect to the results of *Airlines Companies*, as indicated by the computed results of the criteria weights in Table 2, the most weighted criterion among the safety criteria is C_7 *Safety risk assessment and mitigation*, the second is C_6 *Hazard identification* and the third is C_8 *Safety performance monitoring and measurement*. The criteria were ranked in the order of $C_7 \succ C_6 \succ C_8 \succ C_{11} \succ C_{12} \succ C_3 \succ C_{10} \succ C_2 \succ C_9 \succ C_5 \succ C_4 \succ C_1$ as the result. The standard deviation among the weights of the criteria is 0.0100 for *Airlines Companies* in Table 2.

With respect to the results of *Airport Authorities*, as indicated by the computed results of the criteria weights in Table 2, the most weighted criterion among the safety criteria is C_{11} *Training and education*, the second is C_6 *Hazard identification* and the third is C_{12} *Safety communication*. The criteria were ranked in the order of $C_{11} \succ C_6 \succ C_{12} \succ C_7 \succ C_8 \succ C_4 \succ C_{10} \succ C_5 \succ C_2 \succ C_3 \succ C_9 \succ C_1$ as the result. The standard deviation among the weights of the criteria is 0.0089 for *Airport Authorities* in Table 2.

With respect to the results of the *Aggregated*, as indicated by the computed results of the criteria weights in Table 2, the most weighted criterion among the safety criteria is C_6 *Hazard identification*, the second is C_{11} *Training and education* and the third is C_7 *Safety risk assessment and mitigation*. The criteria were ranked in the order of $C_6 \succ C_{11} \succ C_7 \succ C_8 \succ C_{12} \succ C_{10} \succ C_9 \succ C_2 \succ C_5 \succ C_4 \succ C_3 \succ C_1$ as the result. The standard deviation among the weights of the criteria is 0.0081 for the *Aggregated* in Table 2.

The highest standard deviation among the organizations is for *TCAA*.

Table 2. Results

Codes	Elements	TCAA		ground handling		airline		airport		aggregated	
		Weights	Rank	Weights	Rank	Weights	Rank	Weights	Rank	Weights	Rank
C_1	Management commitment	0.072	10	0.077	11	0.060	12	0.066	12	0.069	12
C_2	Safety accountability and responsibilities	0.081	8	0.078	10	0.081	8	0.079	9	0.080	8
C_3	Appointment of key safety personnel	0.065	12	0.073	12	0.087	6	0.078	10	0.075	11
C_4	Coordination of emergency response planning	0.077	9	0.081	7	0.070	11	0.083	6	0.077	10
C_5	SMS documentation	0.070	11	0.085	4	0.078	10	0.079	8	0.078	9
C_6	Hazard identification	0.101	1	0.097	1	0.092	2	0.095	2	0.097	1
C_7	Safety risk assessment and mitigation	0.094	3	0.079	9	0.097	1	0.090	4	0.091	3
C_8	Safety performance monitoring and measurement	0.092	4	0.087	3	0.092	3	0.086	5	0.089	4
C_9	The management of change	0.083	7	0.084	6	0.081	9	0.074	11	0.081	7
C_{10}	Continuous improvement of the SMS	0.087	5	0.085	5	0.084	7	0.080	7	0.084	6
C_{11}	Training and education	0.095	2	0.095	2	0.091	4	0.097	1	0.095	2
C_{12}	Safety communication	0.083	6	0.080	8	0.088	5	0.094	3	0.086	5

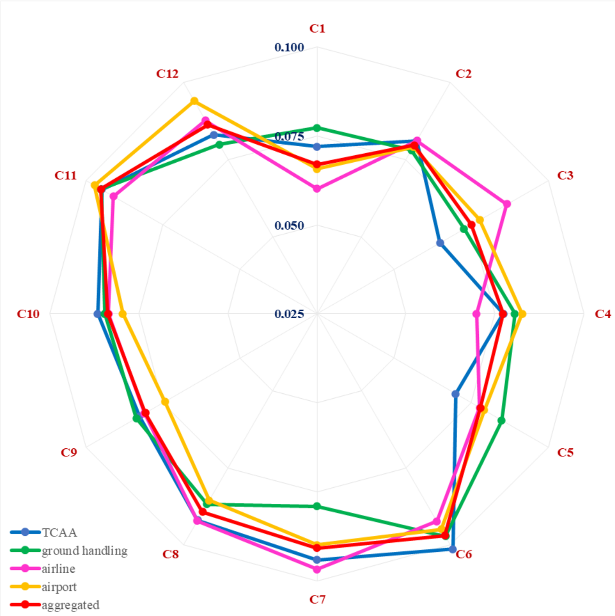

Figure 3. Results

According to Figure 3, Figure 4, and Figure 5, the maximum divergence is the criteria for C_3 *Appointment of key safety personnel* whereas the minimum divergence is the criteria for C_2 *Safety accountability and responsibilities*. The criteria were ranked in the order of $C_3 \succ C_7 \succ C_1 \succ C_5 \succ C_{12} \succ C_4 \succ C_9 \succ C_6 \succ C_8 \succ C_{10} \succ C_{11} \succ C_2$ as the result of the divergence amount.

Figure 4 shows the organization-based deviation results in the perception of SMS components among aviation organizations in Turkey. The results indicate that TCAA, the legal aviation authority in Turkey, had the least deviation among the aviation organizations. On the other hand, grand handling organizations had the biggest deviation in their perception of SMS components.

Figure 5 displays the criteria-based deviation results in the perception of SMS components among aviation organizations in Turkey. The results reveal that the criteria with the least deviation are safety accountability and responsibilities and training and education. In contrast, the criteria with the highest deviation are the appointment of key safety personnel, safety risk assessment and mitigation, and management commitment.

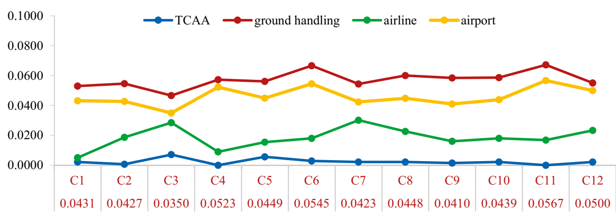

Figure 4. Deviation from Mean (Standard deviation)

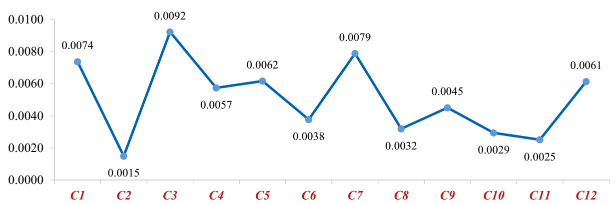

Figure 5. Divergence basis of criterion

5. Results and discussion

Safety management in aviation entails the identification of hazards, data analysis, and the continuous improvement of safety through effective risk management (International Civil Aviation Organization, 2018). The Safety Management System (SMS) serves as a framework designed to assist organizations in managing safety risks, tailored to accommodate the organization's size and complexity. This study explores how various aviation entities perceive and prioritize SMS components, seeking to understand whether there is alignment or divergence in these priorities. For SMS implementation to be effective, a shared understanding of the significance of its components across different organizations is crucial. Although all SMS elements are fundamental for ensuring aviation safety, recognizing the variations in priorities among different entities – such as airports, airlines, ground handling operators, maintenance organizations, and regulatory bodies – provides valuable insights. Prior research has consistently emphasized hazard identification as a key SMS component (Chang et al., 2015; Chen & Chen, 2012; Georgiev, 2021; Yang et al., 2022). The findings of this study affirm that hazard identification is widely regarded as the most critical component, particularly by organizations like the TCAA and ground handling operators. Airlines, however, assign the highest priority to safety risk assessment and mitigation. In contrast, airport authorities place the greatest emphasis on training and education, ranking hazard identification as the second most important element. Training and education play a vital role in fostering safety awareness and cultivating a positive safety culture. The study indicates that this component is especially significant for airport authorities and ground handling operators, whereas airlines view it as comparatively less critical (International Civil Aviation Organization, 2018). The component of safety risk assessment and mitigation, which involves evaluating and managing safety risks, also holds substantial importance. Airlines consider it the top priority, while the TCAA places it third in importance. For ground handling operators, hazard identification is prioritized above safety risk assessment and mitigation. There is a consensus among all stakeholders regarding the importance of safety performance monitoring and measurement, which is essential for evaluating safety performance and the effectiveness of risk controls (International Civil Aviation Organization, 2018; Chen & Li, 2016).

In conclusion, the study highlights distinct differences in how various aviation organizations perceive and prioritize SMS components, underscoring the need for a unified approach to enhance safety practices across the aviation sector.

5.1. Managerial implications

The study examined the importance of the information given to SMS criteria by aviation organizations. The results of the study demonstrate that there are differences of opinion among the organizations operating in the aviation field in Turkey regarding the importance levels of some of the SMS components. The purpose of this discussion is not to determine which organization's perspective on SMS is more correct. However, there is a lack of consensus on the importance of SMS components among aviation organizations, which is considered to be a critical issue. It is out of the scope of this study whether the organizations have the same point of view about the SMS components and whether it creates a problem related to safety risk. Therefore, our main purpose in this study is to determine the importance given to each of the SMS components by aviation organizations and to reveal the components with deviations. The results of the study indicate that aviation industry in Turkey have different perceptions regarding the importance levels of SMS components. The study suggests that the authority (TCAA) and organizations prioritize assessing whether having a different point of view poses a safety risk. Additionally, the difference in perspective on the importance of SMS components can be examined based on incident or accident cases. Therefore, it can be determined whether the root causes of incidents and accidents that aviation organizations with the philosophy of "safety first" are due to the difference in perspective on SMS components.

6. Conclusions

Service providers operating in Turkey – including approved training organizations, operators of airplanes or helicopters conducting international commercial air transport, approved maintenance organizations servicing these operators, organizations responsible for aircraft type design or manufacturing, air traffic services, and certified aerodrome operators – were mandated by the TCAA to establish and implement a SMS. The adoption of SMS began in 2012, marking a significant shift in aviation safety practices across the sector. However, the initial transition presented notable challenges, as service providers faced uncertainties stemming from several factors: a limited comprehension of ICAO regulations, a shortage of adequately qualified personnel in SMS units, an absence of safety measurement indicators tailored to their specific operational areas, and the excessive workload burdening SMS staff. This study, which examines the extent of similarity in SMS implementation across aviation organizations, reveals that after a decade of SMS adoption, convergence has been achieved for certain criteria, while others remain divergent. A strong alignment is evident in several key elements, particularly hazard identification, training and education, continuous SMS enhancement, and safety performance monitoring and measurement. The findings indicate a shared understanding among aviation organizations regarding the identification of potential hazards, the effectiveness of safety performance monitoring, and the pursuit of safety performance improvements through targeted training and educational initiatives. The TCAA's regulations reveal that ground handling and airline organizations exhibit similar approaches toward safety communication and change management, while airport operators diverge in their practices. This suggests that safety communication holds a higher priority across aviation organizations, whereas change management is comparatively less emphasized. Given that airports serve as hubs for various aviation activities involving diverse organizations, airport operators may place a greater emphasis on communication to ensure an effective Safety Management System (SMS). For airport organizations, robust safety communication between the airport authority and the numerous entities operating within the airport environment is deemed essential. Although minor differences exist among organizations in terms of safety accountability, responsibilities, and coordination of emergency response planning, there is a general alignment concerning these aspects. Within the scope of ICAO's 12-element SMS framework, significant disparities arise only with respect to management commitment, the appointment of key safety personnel, and SMS documentation. The research findings indicate a pronounced trend toward convergence among aviation organizations in Turkey based on the ICAO SMS framework. While institutional pressures initially drove this alignment with safety practices, it is likely that as safety becomes more ingrained within the industry, SMS is regarded by organizations not only as a means of achieving legitimacy but also as an essential requirement for continued operation and survival.

Limitations

This study has several limitations. The first is that the data were collected from only one country where SMS is implemented. Additionally, the data are limited to the experience, knowledge, expectations, and tendencies of the experts participating in the study. Another limitation is that the experts represent only four types of organizations, excluding other service providers such as MROs, aircraft manufacturers, and training organizations. This exclusion is primarily due to the lack of civil aircraft production in Turkey and the insufficient data available from MROs and training organizations. Consequently, further research is needed to generalize the findings to the entire aviation sector. Including all organizations defined as service providers by ICAO in future studies is expected to enhance the generalizability of the results.

Future research

SMS components created by ICAO are the basic criteria of this study. The importance perceptions of four aviation organizations (ground handling, airport operator, airline, and Turkish Civil Aviation Authority) in Turkey regarding SMS components were analyzed. The proposal is for the researchers to develop a new model by adding new criteria to the ICAO SMS components. In addition, new research can be done with a different multi-criteria decision-making method using the same ICAO SMS components. Finally, this study included ground handlings, airport operators, airlines, and the Turkish Civil Aviation Authority. However, the scope of the study can be expanded by adding new stakeholders that are assumed to be of critical importance for SMS.

Author contributions

Cemal Durmuşçelebi spearheaded the study's design, conceptual framework, and literature review, while also ensuring the cohesive execution of the research. Ercan Akan was entrusted with developing the methodological framework and conducting the subsequent data analysis. Kasım Kiracı undertook the primary data collection and contributed to the interpretation of the analytical findings.

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Appendix

All information about the A SPHERICAL FUZZY AHP method used in this study is given step by step below.

1. Spherical fuzzy sets

Step 1. The initial step in the process of utilizing the spherical fuzzy AHP method is to establish a hierarchical framework. This framework consists of a minimum of three levels, with the first level representing the ultimate objective based on a score index. The Score Index (SI) is calculated based on a defined set of criteria presented at the second level of the hierarchy. A multitude of sub-criteria is established within criterion C in the established hierarchical structure. As a result, at the third level of the hierarchical structure, a collection of m potential alternatives, denoted as A_m, is established.

Definition 1. Assuming that $\tilde{A}_S$ and $\tilde{B}_S$ are two spherical numbers, and x and y are defined in two universes, U_1 and U_2 respectively as follows in Equations (1–4).

$$\tilde{A}_S = \left\{ x, \left(\mu_{\tilde{A}_S}(x), \nu_{\tilde{A}_S}(x), \pi_{\tilde{A}_S}(x) \right) \middle| x \in U_1 \right\}, \ \forall x \in X, \quad (1)$$

where $\mu_{\tilde{A}_S}(x): U_1 \to [0,1]$, $\nu_{\tilde{A}_S}(x): U_1 \to [0,1]$, $\pi_{\tilde{A}_S}(x): U_1 \to [0,1]$, and

$$0 \le \mu^2_{\tilde{A}_S}(x) + \nu^2_{\tilde{A}_S}(x) + \pi^2_{\tilde{A}_S}(x) \le 1, \ \forall x \in X. \quad (2)$$

For each x, the $\mu_{\tilde{B}_S}(x)$, $\nu_{\tilde{A}_S}(x)$ and $\pi_{\tilde{A}_S}(x)$ represent the membership, non-membership, and hesitancy degrees, respectively, of each x to $\tilde{A}_S$.

$$\tilde{B}_S = \left\{ y, \left(\mu_{\tilde{A}_S}(x), \nu_{\tilde{A}_S}(x), \pi_{\tilde{A}_S}(x) \right) \middle| y \in U_1 \right\}, \ \forall y \in X, \quad (3)$$

where $\mu_{\tilde{B}_S}(x): U_1 \to [0,1]$, $\nu_{\tilde{B}_S}(x): U_1 \to [0,1]$, $\pi_{\tilde{B}_S}(x): U_1 \to [0,1]$, and

$$0 \le \mu^2_{\tilde{B}_S}(x) + \nu^2_{\tilde{B}_S}(x) + \pi^2_{\tilde{B}_S}(x) \le 1, \ \forall y \in X. \quad (4)$$

For each x, the $\mu_{\tilde{B}_S}(x)$, $\nu_{\tilde{B}_S}(x)$ and $\pi_{\tilde{B}_S}(x)$ represent the membership, non-membership, and hesitancy degrees, respectively, of each x to $\tilde{B}_S$.

Definition 2. In the following, primarily spherical fuzzy sets operators are defined as in Equations (5–16).

Union

$$\tilde{A}_S \cup \tilde{B}_S = \left\{ \max\left\{ \mu_{\tilde{A}_S}, \mu_{\tilde{B}_S} \right\}, \min\left\{ \nu_{\tilde{A}_S}, \nu_{\tilde{B}_S} \right\}, \left(\min\left\{ 1 - \left(\left(\max\left\{ \mu_{\tilde{A}_S}, \mu_{\tilde{B}_S} \right\} \right)^2 + \left(\min\left\{ \nu_{\tilde{A}_S}, \nu_{\tilde{B}_S} \right\} \right)^2 \right), \max\left\{ \pi_{\tilde{A}_S}, \pi_{\tilde{B}_S} \right\} \right\} \right) \right\}. \quad (5)$$

Intersection

$$\tilde{A}_S \cap \tilde{B}_S = \left\{ \min\left\{ \mu_{\tilde{A}_S}, \mu_{\tilde{B}_S} \right\}, \max\left\{ \nu_{\tilde{A}_S}, \nu_{\tilde{B}_S} \right\}, \left(\min\left\{ 1 - \left(\left(\min\left\{ \mu_{\tilde{A}_S}, \mu_{\tilde{B}_S} \right\} \right)^2 + \left(\max\left\{ \nu_{\tilde{A}_S}, \nu_{\tilde{B}_S} \right\} \right)^2 \right), \min\left\{ \pi_{\tilde{A}_S}, \pi_{\tilde{B}_S} \right\} \right\} \right) \right\}. \quad (6)$$

Addiction

$$\tilde{A}_S \oplus \tilde{B}_S = \left\{ \begin{array}{l} \left(\mu^2_{\tilde{A}_S} + \mu^2_{\tilde{B}_S} - \mu^2_{\tilde{A}_S}\mu^2_{\tilde{B}_S} \right)^{1/2}, \ \nu_{\tilde{A}_S}\nu_{\tilde{B}_S}, \\ \left(\left(1-\mu^2_{\tilde{B}_S}\right)\pi^2_{\tilde{A}_S} + \left(1-\mu^2_{\tilde{A}_S}\right)\pi^2_{\tilde{B}_S} - \pi^2_{\tilde{A}_S}\pi^2_{\tilde{B}_S} \right)^{1/2} \end{array} \right\}. \quad (7)$$

Multiplication

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{ \begin{array}{l} \mu_{\tilde{A}_S}\mu_{\tilde{B}_S}, \ \left(\nu^2_{\tilde{A}_S} + \nu^2_{\tilde{B}_S} - \nu^2_{\tilde{A}_S}\nu^2_{\tilde{B}_S} \right)^{1/2}, \\ \left(\left(1-\nu^2_{\tilde{B}_S}\right)\pi^2_{\tilde{A}_S} + \left(1-\nu^2_{\tilde{A}_S}\right)\pi^2_{\tilde{B}_S} - \pi^2_{\tilde{A}_S}\pi^2_{\tilde{B}_S} \right)^{1/2} \end{array} \right\}. \quad (8)$$

Multiplication by a scalar λ (for λ)

$$\lambda \tilde{A}_S = \left\{ \begin{array}{l} \left(1-\left(1-\mu^2_{\tilde{A}_S}\right)^{\lambda} \right)^{1/2}, \ \nu^{\lambda}_{\tilde{A}_S}, \\ \left(\left(1-\mu^2_{\tilde{A}_S}\right)^{\lambda} - \left(1-\mu^2_{\tilde{A}_S} - \pi^2_{\tilde{A}_S}\right)^{\lambda} \right)^{1/2} \end{array} \right\}. \quad (9)$$

$\tilde{A}_S$ to the power of λ (for λ)

$$\tilde{A}^{\lambda}_S = \left\{ \begin{array}{l} \mu^{\lambda}_{\tilde{A}_S}, \ \left(1-\left(1-\nu^2_{\tilde{A}_S}\right)^{\lambda} \right)^{1/2}, \\ \left(\left(1-\nu^2_{\tilde{A}_S}\right)^{\lambda} - \left(1-\mu^2_{\tilde{A}_S} - \pi^2_{\tilde{A}_S}\right)^{\lambda} \right)^{1/2} \end{array} \right\}. \quad (10)$$

Definition 3. For these SFS $\tilde{A}_S$ and $\tilde{B}_S$ the following are valid under the condition $\lambda, \lambda_1, \lambda_2 > 0$.

$$\tilde{A}_S \oplus \tilde{B}_S = \tilde{B}_S \oplus \tilde{A}_S; \quad (11)$$

$$\tilde{A}_S \otimes \tilde{B}_S = \tilde{B}_S \otimes \tilde{A}_S; \quad (12)$$

$$\lambda\left(\tilde{A}_S \oplus \tilde{B}_S\right) = \lambda \tilde{B}_S \oplus \lambda \tilde{A}_S; \quad (13)$$

$$\lambda_1 \tilde{A}_S \oplus \lambda_2 \tilde{A}_S = \left(\lambda_1 + \lambda_2\right)\tilde{A}_S; \quad (14)$$

$$\left(\tilde{A}_S \otimes \tilde{B}_S\right)^{\lambda} = \tilde{A}^{\lambda}_S \otimes \tilde{B}^{\lambda}_S; \quad (15)$$

$$\tilde{A}^{\lambda_1}_S \otimes \tilde{B}^{\lambda_1}_S = \tilde{A}^{\lambda_1+\lambda_{12}}_S. \quad (16)$$

Definition 4. Spherical weighted arithmetic mean (SWAM) with respect to, $w = (w_1, w_2, \ldots, w_n)$; $w_i \in [0,1]$; $\sum_{i=1}^{n} w_i = 1$; SWAM is defined as in Eq. (17).

$$SWAM_w\left(\tilde{A}_{S_1}, \ldots, \tilde{A}_{S_n}\right) = w_1\tilde{A}_{S_1} + w_2\tilde{A}_{S_2} + \cdots + w_n\tilde{A}_{S_n}$$
$$= \left\{ \begin{array}{l} \left[1-\prod_{i=1}^{n}\left(1-\mu^2_{\tilde{A}_{S_1}}\right)^{w_i}\right]^{1/2}, \ \prod_{i=1}^{n}\nu^{w_i}_{\tilde{A}_{S_1}}, \\ \left[\prod_{i=1}^{n}\left(1-\mu^2_{\tilde{A}_{S_1}}\right)^{w_i} - \prod_{i=1}^{n}\left(1-\mu^2_{\tilde{A}_{S_1}} - \pi^2_{\tilde{A}_{S_1}}\right)^{w_i}\right]^{1/2} \end{array} \right\}. \quad (17)$$

Definition 5. Spherical weighted geometric mean (SWGM) with respect to, $w = (w_1, w_2, \ldots, w_n)$; $w_i \in [0,1]$; $\sum_{i=1}^{n} w_i = 1$; SWGM is defined as in Equation (18).

$$SWGM_w\left(\tilde{A}_{S_1}, \ldots, \tilde{A}_{S_n}\right) = \tilde{A}^{w_1}_{S_1} + \tilde{A}^{w_2}_{S_2} + \cdots + \tilde{A}^{w_n}_{S_n}$$
$$= \left\{ \begin{array}{l} \prod_{i=1}^{n}\mu^{w_i}_{\tilde{A}_{S_1}}, \ \left[1-\prod_{i=1}^{n}\left(1-\nu^2_{\tilde{A}_{S_1}}\right)^{w_i}\right]^{1/2}, \\ \left[\prod_{i=1}^{n}\left(1-\nu^2_{\tilde{A}_{S_1}}\right)^{w_i} - \prod_{i=1}^{n}\left(1-\nu^2_{\tilde{A}_{S_1}} - \pi^2_{\tilde{A}_{S_1}}\right)^{w_i}\right]^{1/2} \end{array} \right\}. \quad (18)$$

Definition 6. The score function and Accuracy function of sorting SFS are defined as in Equations (19–20).

$$Score\left(\tilde{A}_S\right) = \left(\mu_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2 - \left(\nu_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2; \quad (19)$$

$$Accuracy\left(\tilde{A}_S\right) = \mu^2_{\tilde{A}_S} + \nu^2_{\tilde{A}_S} + \pi^2_{\tilde{A}_S}. \quad (20)$$

Note that: $\tilde{A}_S < \tilde{B}_S$ if and only if

$Score\left(\tilde{A}_S\right) < Score\left(\tilde{B}_S\right)$ or

$Score\left(\tilde{A}_S\right) = Score\left(\tilde{B}_S\right)$ and

$Accuracy\left(\tilde{A}_S\right) < Accuracy\left(\tilde{B}_S\right)$.

2. Spherical fuzzy analytic hierarchy process

Step 2. Pair-wise comparisons are established through the use of SF judgment matrices, utilizing the linguistic terms presented in Table A1. The SI is determined through the application of Equations (21–22).

Table A1. Linguistic measures of importance

Linguistic Variables	(μ, ν, π)	Score Index (SI)
Absolutely More Importance (AMI)	(0.9, 0.1, 0.0)	9
Very High Importance (VHI)	(0.8, 0.2, 0.1)	7
High Importance (HI)	(0.7, 0.3, 0.2)	5
Slightly More Importance (SMI)	(0.6, 0.4, 0.3)	3
Equally Importance (EI)	(0.5, 0.4, 0.4)	1
Slightly Lower Importance (SLI)	(0.4, 0.6, 0.3)	1/3
Low Importance (LI)	(0.3, 0.7, 0.2)	1/5
Very Low Importance (VLI)	(0.2, 0.8, 0.1)	1/7
Absolutely Low Importance (ALI)	(0.1, 0.9, 0.0)	1/9

$$SI=\sqrt{\left|100x\left[\left(\mu_{\tilde{A}_S}-\pi_{\tilde{A}_S}\right)^2-\left(\nu_{\tilde{A}_S}-\pi_{\tilde{A}_S}\right)^2\right]\right|}\ \text{for AMI, VHI, HI, SMI, EI;} \tag{21}$$

$$\frac{1}{SI}=\frac{1}{\sqrt{\left|100x\left[\left(\mu_{\tilde{A}_S}-\pi_{\tilde{A}_S}\right)^2-\left(\nu_{\tilde{A}_S}-\pi_{\tilde{A}_S}\right)^2\right]\right|}}\ \text{for EI, SLI, LI, VLI, ALI.} \tag{22}$$

Step 3. Evaluate the consistency of the pairwise comparison matrices by converting the linguistic terms to numerical values and comparing them to established consistency standards. The consistency ratio (CR) should not exceed 10%.

Step 4. Determine the relative importance of criteria and alternatives by calculating their spherical fuzzy local weights. The SWAM operator outlined in Equations (23) is utilized to calculate the weight of each alternative in relation to each criterion. The weighted arithmetic mean method is applied to calculate the SF weights.

$$SWAM_w\left(\tilde{A}_{S_1},\ \ldots,\ \tilde{A}_{S_n}\right)=w_1\tilde{A}_{S_1}+w_2\tilde{A}_{S_2}+\cdots+w_n\tilde{A}_{S_n}$$
$$=\left\langle \begin{array}{l}\left[1-\prod_{i=1}^{n}\left(1-\mu^2_{\tilde{A}_{S_1}}\right)^{w_i}\right]^{1/2},\ \prod_{i=1}^{n}\nu^{w_i}_{\tilde{A}_{S_1}},\\ \left[\prod_{i=1}^{n}\left(1-\mu^2_{\tilde{A}_{S_1}}\right)^{w_i}-\prod_{i=1}^{n}\left(1-\mu^2_{\tilde{A}_{S_1}}-\pi^2_{\tilde{A}_{S_1}}\right)^{w_i}\right]^{1/2}\end{array}\right\rangle, \tag{23}$$

where $w=1/n$.

Step 5. The hierarchical structure of the spherical fuzzy AHP method is utilized to determine the global weights of the criteria and alternatives, which are then used to establish the final ranking order of the feasible alternatives.

The second option is to use the defuzzification method provided in Equation (27) to convert the criteria weights from a fuzzy format to a crisp value and then normalize them with Equation (25) before applying the spherical fuzzy multiplication as outlined in Equation (26).

$$S\left(\tilde{w}_j^S\right)=\sqrt{\left|100x\left[\left(3\mu_{\tilde{A}_S}-\frac{\pi_{\tilde{A}_S}}{2}\right)^2-\left(\frac{\nu_{\tilde{A}_S}}{2}-\pi_{\tilde{A}_S}\right)^2\right]\right|}. \tag{24}$$

The criteria weighted by the Equation (24) are normalized.

$$\tilde{w}_j^S=\frac{S\left(\tilde{w}_j^S\right)}{\sum_{j=1}^{n}S\left(\tilde{w}_j^S\right)}; \tag{25}$$

$$\tilde{A}_S=\tilde{w}_j^S\tilde{A}_S=\left\langle\begin{array}{l}\left(1-\left(1-\mu^2_{\tilde{A}_S}\right)^{\tilde{w}_j^S}\right)^{1/2},\ \nu^{\tilde{w}_j^S}_{\tilde{A}_S},\\ \left(\left(1-\mu^2_{\tilde{A}_S}\right)^{\tilde{w}_j^S}-\left(1-\mu^2_{\tilde{A}_S}-\pi^2_{\tilde{A}_S}\right)^{\tilde{w}_j^S}\right)^{1/2}\end{array}\right\rangle,\ \forall i. \tag{26}$$

The SF-AHP score $\left(\tilde{F}\right)$ for each alternative A_i is determined by conducting SF arithmetic addition on the global preference weights as outlined in Equation (27).

$$\tilde{F}=\sum_{j=1}^{n}\tilde{A}_{S_{ij}}=\tilde{A}_{S_{i1}}\oplus\tilde{A}_{S_{i2}}\cdots\oplus\tilde{A}_{S_{in}},\ \forall i$$

$$i.e.\ \tilde{A}_{S_{11}}\oplus\tilde{A}_{S_{12}}=\left\langle\begin{array}{l}\left(\mu^2_{\tilde{A}_{S_{11}}}+\mu^2_{\tilde{A}_{S_{12}}}-\mu^2_{\tilde{A}_{S_{11}}}\mu^2_{\tilde{A}_{S_{12}}}\right)^{1/2},\ \nu_{\tilde{A}_{S_{11}}}\nu_{\tilde{A}_{S_{12}}},\\ \left(\left(1-\mu^2_{\tilde{A}_{S_{12}}}\right)\pi^2_{\tilde{A}_{S_{11}}}+\left(1-\mu^2_{\tilde{A}_{S_{11}}}\right)\pi^2_{\tilde{A}_{S_{12}}}-\pi^2_{\tilde{A}_{S_{11}}}\pi^2_{\tilde{A}_{S_{12}}}\right)^{1/2}\end{array}\right\rangle. \tag{27}$$

The second approach is to proceed without converting the fuzzy values to crisp values so, the SF global preference weights are calculated utilizing the equation specified in Equation (28).

$$\prod_{j=1}^{n}\tilde{A}_{S_{ij}}=\tilde{A}_{S_{i1}}\otimes\tilde{A}_{S_{i2}}\cdots\otimes\tilde{A}_{S_{in}},\ \forall i$$

$$i.e.\ \tilde{A}_{S_{11}}\otimes\tilde{A}_{S_{12}}=\left\langle\begin{array}{l}\mu_{\tilde{A}_{S_{11}}}\mu_{\tilde{A}_{S_{12}}},\ \left(\nu^2_{\tilde{A}_{S_{11}}}+\nu^2_{\tilde{A}_{S_{12}}}-\nu^2_{\tilde{A}_{S_{11}}}\nu^2_{\tilde{A}_{S_{12}}}\right)^{1/2},\\ \left(\left(1-\nu^2_{\tilde{A}_{S_{12}}}\right)\pi^2_{\tilde{A}_{S_{11}}}+\left(1-\nu^2_{\tilde{A}_{S_{11}}}\right)\pi^2_{\tilde{A}_{S_{12}}}-\pi^2_{\tilde{A}_{S_{11}}}\pi^2_{\tilde{A}_{S_{12}}}\right)^{1/2}\end{array}\right\rangle. \tag{28}$$

The computation of the final score $\left(\tilde{F}\right)$ is performed utilizing the equation Equation (27).

Step 6. Defuzzify the final score of each alternative from a fuzzy value to a crisp value by applying the score function specified in Equation (24).

Step 7. The alternatives are ranked based on the defuzzified final scores, with the alternative having the highest value being considered the most favorable option.