

Safety Management System Implementation and Barriers in Iranian Aviation: A Structured Review and Roadmap

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Abstract

The aviation industry depends on robust Safety Management Systems (SMS) to manage complex operational risks and prevent accidents. This review synthesizes the historical evolution of aviation safety, core SMS concepts, and practical implementation mechanisms, with emphasis on the four pillars of SMS: Safety Policy, Safety Risk Management, Safety Assurance, and Safety Promotion. It links accident causation theory (Swiss Cheese model) to SMS mechanisms that address latent conditions, clarifies distinctions between proactive and predictive safety approaches, and provides practical examples of each. Focusing on the Islamic Republic of Iran, it examines regulatory developments, implementation barriers, and presents a pragmatic roadmap for integrating SMS into national aviation operations. Key recommendations include structured gap analysis, capacity building, improved safety data systems, and alignment with ICAO Annex 19. Limitations and avenues for future research are discussed.

Keywords: Safety Management System (SMS); Aviation Safety; Air Transportation; Risk Management; Safety Culture.

1. Introduction

1.1 Background of Aviation Safety

The aviation industry has historically faced numerous accidents and incidents with significant political, economic, cultural, and social consequences. Given its high level of complexity and sensitivity, the implementation of a robust Safety Management System (SMS) is essential for sustaining operations and ensuring the survival of aviation organizations. Beyond humanitarian concerns and regulatory requirements mandated by ICAO and national authorities, many airlines have developed internal tools and procedures to monitor, control, and mitigate risks before, during, and after flight operations[1], [2], [3].

Safety is not absolute but relative, and its objective is to reduce risks to an Acceptable Level of Safety (ALoS) rather than to eliminate them [4], [5]. Since risk is an

inherent byproduct of service delivery, complete elimination of hazards is unattainable. Therefore, effective safety and risk management, supported by proactive hazard identification and mitigation strategies, remain among the most critical challenges for all aviation organizations[6].

In recognition of this, Annex 19 of the Chicago Convention was introduced in 2013 to consolidate and unify safety regulations under a global framework. This Annex, together with ICAO Document 9859, defines safety as “a state in which the possibility of harm to people or property damage is reduced to, and maintained at, an acceptable level through a continuous process of hazard identification and risk management.” [7], [8].

Consequently, a strong safety culture has become a fundamental requirement for aviation organizations[3]. Such a culture emphasizes leadership commitment, organizational learning, and the systematic management of hazards and risks[1].

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While numerous international studies and reviews have examined Safety Management Systems (SMS) in aviation[1], [9], [10], [11], very few have contextualized these frameworks within the operational and cultural realities of sanctioned or resource-constrained aviation industries such as Iran's. This review specifically addresses that gap by synthesizing global SMS principles (as defined in ICAO Annex 19 and related literature) with the distinct implementation challenges, regulatory limitations, and organizational cultures in the Iranian aviation sector. Hence, the study contributes to both the theoretical understanding of SMS adaptability and the practical roadmap for enhancing aviation safety in developing contexts.

This background provides the foundation for analyzing the historical evolution of aviation safety, which is addressed in the following section.

1.2 Historical Evolution of Aviation Safety

The development of aviation safety can be broadly categorized into three historical eras (**Figure 1**). Each era reflects a gradual shift in understanding—from technical causes, to human factors, and finally to organizational dynamics—and each has provided essential lessons for the current framework of Safety Management Systems (SMS)[12].

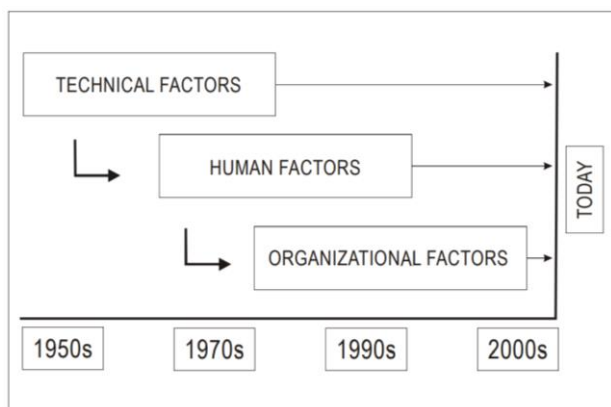


Figure 1. The evolution of safety [12]

1.2.1 The Technical Era (Early 1900s – Late 1960s)

During this period, aviation transformed into a mode of mass transportation. Safety deficiencies were primarily attributed to mechanical or technical failures, and solutions were sought mainly through engineering improvements and regulatory compliance[13]. Technological advancements in the 1950s significantly reduced accident rates[12]. This era demonstrated that compliance with technical standards is necessary but not sufficient; technical solutions alone cannot eliminate risk[12].

1.2.2 The Human Factors Era (Early 1970s – Mid-1990s)

With continuing improvements in technology, accidents were no longer dominated by mechanical failures. Instead, human error, decision-making limitations, and human-machine interaction became central to aviation safety. This led to the introduction of Crew Resource Management (CRM) and the recognition of training and communication as vital elements of safe operations[14], [15]. This era highlighted that human performance must be systematically managed, forming the basis for safety promotion and training, which later became one of the four SMS pillars[12].

1.2.3 The Organizational Era (Mid-1990s – Present)

By the mid-1990s, it became clear that both technical failures and human errors often reflected deeper systemic issues within organizations. The focus shifted toward organizational culture, leadership, policies, and resource allocation as determinants of safety performance[16]. This era directly led to the development of SMS as a holistic framework emphasizing proactive hazard identification, risk assessment, and continuous improvement. International bodies such as ICAO codified SMS requirements in Annex 19, making them a global standard for aviation safety[17].

Taken together, the three eras illustrate the progressive broadening of safety management—from machines, to people, to organizations. Modern SMS integrates all these lessons within a single, proactive, and data-driven framework that addresses technical reliability, human performance, and organizational processes[12].

1.3 Safety Concepts

Aviation organizations generally adopt three complementary approaches to safety: reactive, proactive, and predictive. Together, these approaches reflect the maturity of an organization's safety culture and form the operational basis of Safety Management Systems (SMS)[12], [18], [19].

1.3.1 Reactive Approach

The reactive approach addresses safety after an adverse event has occurred. Accidents or incidents are investigated, causes are identified, and corrective measures are implemented to prevent recurrence. For instance, the investigation of the 1977 Tenerife airport disaster led to the introduction of Crew Resource Management (CRM) training worldwide[20], [21].

While reactive methods are unavoidable, SMS frameworks integrate them as a foundation for safety assurance (by monitoring performance after events)[12].

1.3.2 Proactive Approach

In the proactive approach, organizations actively monitor operations to identify hazards before they result in incidents. This involves implementing systematic reporting systems, conducting safety audits, and performing risk assessments. For instance, Airlines requiring pilots and maintenance staff to submit confidential hazard reports allow risks (e.g., runway incursions) to be addressed before they cause accidents[22], [23], [24]. Proactive methods align with the Safety Risk Management pillar of SMS, emphasizing anticipation and early intervention[12].

1.3.3 Predictive Approach

The predictive (or preventive) approach represents the most advanced stage of safety management. It involves analyzing trends and big data to forecast potential risks even before hazards emerge. Predictive tools use flight data monitoring (FDM), machine learning, and trend analysis. For instance, using real-time Flight Data Monitoring systems, airlines can predict abnormal descent patterns before they cause Controlled Flight Into Terrain (CFIT) accidents[25], [26]. Predictive safety management embodies continuous improvement by anticipating risks and embedding data-driven decision-making into daily operations[27]. It is important to note that these approaches are not mutually exclusive. A mature SMS integrates all three: reactive learning from past events, proactive identification of present risks, and predictive anticipation of future hazards. Together, they represent a comprehensive safety philosophy that enables aviation organizations to maintain an Acceptable Level of Safety (ALoS)[12], [28].

2. Methodology of the Review

This study was conducted as a structured and systematic literature review designed to provide a comprehensive understanding of Safety Management Systems (SMS) in aviation, with particular focus on their implementation in Iran.

2.1 Search Strategy and Databases

To ensure methodological transparency, the literature search was conducted across several major academic databases: Scopus, Web of Science, and Google Scholar, as well as relevant regulatory documents published by ICAO and CAO.IRI.

The following search string and keyword combinations were applied:

- ("Safety Management System" OR "SMS") AND ("aviation" OR "air transport" OR "airline") AND ("risk management" OR "safety culture") AND ("Iran" OR "Middle East").

The search covered the period 2000–2025, reflecting the evolution of SMS from its introduction in ICAO Annex 19 (2013) to recent academic and regulatory developments.

2.2 Inclusion and Exclusion Criteria

Publications were included if they:

- Explicitly addressed the structure, implementation, or evaluation of SMS in aviation.
- Discussed safety culture, regulatory frameworks, or accident causation models related to aviation.
- They were peer-reviewed journal articles, official reports, or regulatory documents.

Exclusion criteria were:

- Studies unrelated to aviation.
- Publications lacking methodological transparency or empirical grounding.
- Non-English or duplicate records.

2.3 Screening and Selection Process

The review process followed a three-stage procedure:

1. **Identification:** The initial database search yielded approximately 85 publications and official documents.
2. **Eligibility:** Abstracts and full texts were screened for relevance to SMS concepts and frameworks.
3. **Inclusion:** After applying the inclusion and exclusion criteria, 43 core sources were selected for detailed synthesis.

2.4 Quality Assessment

Each selected publication was evaluated based on clarity of methodology, relevance to SMS, and citation credibility. Priority was given to sources published in indexed journals (Scopus or WoS) and official regulatory materials from ICAO or CAO.IRI.

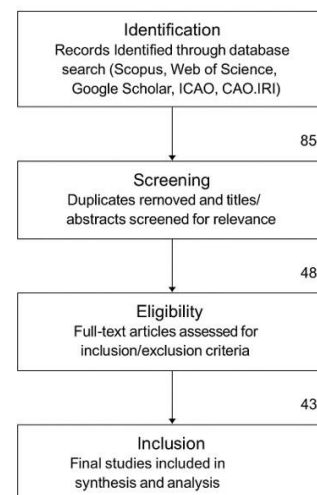


Figure 2. Flow of the literature selection process for the structured review

2.5 Synthesis and Flow Description

A conceptual flow diagram (Figure 2) illustrates the selection process from identification to inclusion. The

final set of sources was thematically categorized into five domains:

1. Evolution of aviation safety
2. Core SMS pillars and components
3. Accident Causation and the Swiss-Cheese Model
4. SMS implementation practices in airlines

5. Regional and Iranian applications

This structured process ensures transparency, replicability, and analytical rigor, consistent with the principles of systematic review methodology.

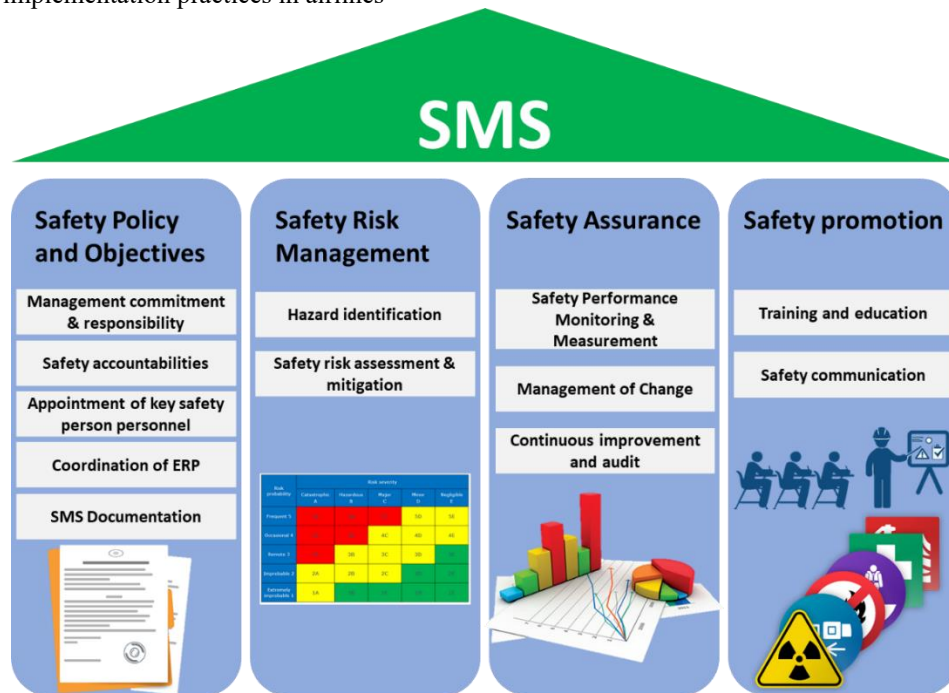


Figure 3. The safety management system pillars, developed based on the ICAO guidelines [7]

3. Safety Management System in Airlines

A Safety Management System (SMS) provides a comprehensive and proactive framework for identifying and mitigating safety risks in airline operations. According to ICAO Document 9859, an SMS is composed of structured processes organized under four pillars: Safety Policy, Safety Risk Management, Safety Assurance, and Safety Promotion. Together, these pillars transform safety from a compliance activity into a strategic organizational priority (Figure 3) [8], [29].

3.1 Objectives of SMS

The SMS framework helps organizations achieve four main objectives:

- Identify operational hazards through systematic data collection.
- Implement corrective and preventive actions to maintain an Acceptable Level of Safety (ALoS).
- Continuously monitor and evaluate safety performance using key performance indicators (KPIs).

- Promote ongoing improvement and learning within the organization.

These objectives emphasize that safety is a dynamic process, requiring constant adaptation to new technologies, operational challenges, and organizational changes [7].

3.2 SMS Components – The Four Pillars

3.2.1 Safety Policy and Objectives

This pillar ensures that senior management demonstrates commitment and accountability for safety. It requires clear safety responsibilities, the appointment of key safety personnel, effective emergency response planning, and proper documentation. For instance, many airlines designate a Chief Safety Officer who reports directly to the CEO, ensuring independence and authority in safety decision-making [19].

3.2.2 Safety Risk Management

This component involves systematic hazard identification, risk assessment, and mitigation strategies. Tools such as risk matrices, bow-tie diagrams, and hazard

reporting systems are widely used. In practice, airlines may introduce fatigue risk management systems (FRMS) to identify risks from pilot work schedules and mitigate them through duty-hour regulations [30].

3.2.3 Safety Assurance

Safety assurance ensures that safety performance is monitored, evaluated, and improved continuously. This includes safety audits, change management, and analysis of safety indicators. For example, flight data monitoring (FDM) allows airlines to detect unsafe trends—such as unstable approaches—and take corrective measures [31].

3.2.4 Safety Promotion

This pillar emphasizes the cultural and educational dimension of SMS. It includes training, workshops, safety bulletins, and internal communication to build a shared safety mindset among all employees [7], [32]. A “just culture” training program is often adopted, encouraging employees to report hazards without fear of punishment [32].

3.3 National Regulations and Implementation

At the national level, many aviation authorities—including CAO.IRI in Iran has mandated SMS implementation across flight service providers. Regulations emphasize:

- Integration of SMS into all operational processes.
- Use of data-driven monitoring systems.
- A phased implementation: starting with reactive processes, progressing to proactive, and ultimately achieving predictive capabilities [1], [17].

This stepwise adoption ensures that organizations mature gradually while maintaining regulatory compliance [33].

3.4 Accident Causation and the Swiss-Cheese Model

The Swiss-Cheese Model, developed by James Reason, illustrates how accidents occur when multiple layers of defense fail simultaneously (Figure 4). Each layer has potential “holes,” created by either active failures (human error) or latent conditions (management decisions, system design flaws) [34], [35], [36].

The relevance of the Swiss-Cheese Model to SMS lies in its clear demonstration that both organizational and human factors must be managed proactively to prevent accidents. Within the SMS framework, these potential “holes” in the layers of defense are addressed through redundant and systematic mechanisms. Hazard reporting systems help detect latent issues before they combine with other vulnerabilities, while structured risk assessment and mitigation strategies reduce the likelihood of threats escalating into accidents. Safety training programs further minimize the probability of

human error, and continuous monitoring ensures that weaknesses in organizational processes are identified and corrected in time. In this way, SMS can be regarded as the practical embodiment of the Swiss-Cheese Model, transforming a theoretical understanding of accident causation into structured, operational processes that enhance safety at every level of aviation organizations [37], [38], [39].

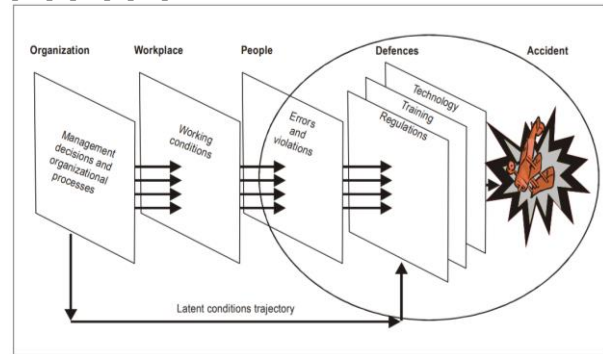


Figure 4. The concept of accident causation [7]

4. SMS in the Aviation Industry of Iran

4.1 Historical Context of Iranian Aviation

The aviation industry in Iran has experienced significant transformations since the Islamic Revolution. Despite facing political and economic sanctions that limited access to new aircraft and spare parts, the sector has continued to operate through resourceful management and reliance on domestic expertise. However, the aging fleet, combined with high demand for air travel, has often placed additional pressure on safety standards. In recent years, the gradual introduction of modern aircraft has marked the beginning of a new phase, creating opportunities for stronger integration of international safety practices [33], [40].

4.2 Regulatory Framework (CAO.IRI & ICAO)

Iran’s Civil Aviation Organization (CAO.IRI), aligned with ICAO requirements, has mandated the implementation of SMS across all aviation service providers, according to Article 33 of the Aviation Accident Investigation Regulations (2013). CAO.IRI is responsible for developing and monitoring the State Safety Program (SSP). In addition, ICAO Annex 19 provides the global framework for SMS, ensuring that Iranian carriers adopt internationally recognized standards. While these regulatory measures demonstrate strong alignment with international practices, gaps remain in enforcement mechanisms and oversight capacity, particularly in smaller domestic airlines [10], [11], [29], [41].

4.3 Challenges and Barriers

Despite notable regulatory progress under CAO.IRI oversight, the implementation of Safety Management Systems (SMS) across Iranian airlines, remains uneven. The degree of SMS maturity varies significantly among carriers due to differences in financial resources, managerial commitment, and organizational culture.

National flag carrier Iran Air, supported by a long-established operational structure and relatively stable management, has implemented a partially mature SMS that includes structured safety audits, internal reporting programs, and crew resource management (CRM) training. Similarly, Mahan Air has invested in data-driven safety monitoring, including limited flight data monitoring (FDM) and fatigue risk management systems (FRMS), aligning more closely with the proactive and predictive stages of SMS.

In contrast, smaller regional and charter airlines—such as Aseman Airlines, Kish Air, and Qeshm Air—often operate with constrained budgets and limited access to modern analytical tools. Their SMS programs are typically reactive in nature, focusing primarily on post-incident investigations and basic compliance reporting rather than continuous hazard monitoring. High turnover among safety managers and limited English proficiency in technical documentation create additional barriers to consistent SMS application.

Cultural factors also play a major role. In several organizations, the absence of a robust “just culture” discourages frontline employees from reporting hazards due to fear of punitive action. This restricts the flow of safety information and inhibits the transition from reactive to proactive safety management. Additionally, while CAO.IRI mandates SMS implementation; its oversight capacity is stretched thin, leading to inconsistent monitoring and enforcement, especially among smaller carriers.

Collectively, these disparities demonstrate that SMS maturity in Iran’s aviation sector is stratified: large carriers show moderate to high implementation levels, while smaller airlines remain in the early stages of SMS adoption. This heterogeneity highlights the need for differentiated regulatory support and targeted capacity-building strategies.

4.4 Opportunities and Policy Recommendations

To promote uniform SMS development across the Iranian aviation sector, several targeted measures are recommended.

First, CAO.IRI should implement a tiered regulatory oversight model that differentiates between large and small carriers. Such an approach would allow resource-limited airlines to adopt a phased SMS roadmap—beginning with safety policy formation and hazard

reporting, and gradually integrating data analytics and predictive tools.

Second, a national SMS benchmarking program could be introduced to evaluate and compare the maturity levels of each airline using standardized ICAO criteria. Publishing anonymized benchmarking results would encourage healthy competition among carriers while highlighting best practices. For example, the mature SMS components of Iran Air and Mahan Air could serve as reference models for smaller airlines.

Third, capacity building through specialized training programs is essential—collaborative initiatives between CAO.IRI, universities, and international aviation organizations (such as ICAO and IATA) can strengthen human capital and promote a shared safety culture across all airlines.

Fourth, fostering a “just culture” is crucial to enhancing voluntary hazard reporting. Establishing clear non-punitive reporting policies, coupled with digital reporting platforms accessible to flight and ground crews, would improve the transparency and timeliness of safety data.

Finally, the integration of national safety databases—linking flight data, maintenance records, and incident reports—would create a unified foundation for predictive safety analytics. This would not only support proactive risk management but also enable evidence-based policy decisions at both the organizational and national levels.

Through these targeted strategies, Iran’s aviation industry can bridge the maturity gap among airlines, strengthen regulatory compliance, and align more closely with the global standards defined in ICAO Annex 19[1], [3], [9], [29], [42].

5. Discussion

5.1 Lessons from Global SMS Practices

Global experience shows that successful SMS implementation depends on both regulatory enforcement and a strong safety culture. Studies such as Stroeve et al.[28] and Malakis et al. [42] confirm that proactive and predictive tools enhance hazard anticipation and organizational learning [28], [37]. However, other researchers (e.g., Piric et al. [18]) note that inconsistent performance indicators and limited data integration constrain SMS effectiveness. These contrasting views indicate that SMS success is context-dependent and linked to organizational maturity and cultural readiness for change.

5.2 Practical Implications for Iran

For Iran, adopting these global lessons requires careful adaptation to local conditions. Stronger regulatory enforcement must be balanced with financial support for carriers, especially smaller ones, to avoid safety gaps

between larger and smaller operators. Training programs for pilots, maintenance staff, and safety managers should be expanded to improve hazard identification and risk management capacity. Additionally, creating a “just culture” within Iranian airlines would encourage employees to report hazards without fear of punishment, improving proactive safety management.

This divergence in global findings underscores the importance of contextualized implementation in Iran. At the same time, Iranian airlines have formally adopted SMS under CAO.IRI regulations, the lack of standardized safety performance indicators, and limited digital data systems hinder consistent evaluation. Therefore, rather than assuming uniform effectiveness, the Iranian context demands a tailored approach—one that aligns SMS processes with local organizational cultures, language capacities, and resource availability to achieve meaningful safety outcomes [43].

5.3 Limitations and Challenges

This study is limited by the scarcity of publicly available safety data from Iranian airlines, which restricts the ability to conduct detailed quantitative analysis. Moreover, cultural and organizational issues, such as reluctance to share incident information, pose ongoing challenges. These limitations highlight the importance of future research that incorporates empirical data, case studies, and surveys of aviation professionals to provide deeper insights into SMS effectiveness in Iran.

6. Conclusion

6.1 Summary of Key Findings

This study reviewed the evolution of aviation safety management and the structure of SMS, with particular attention to its implementation in Iran. Findings show that while regulatory alignment with ICAO standards exists, operational and cultural barriers continue to hinder effective application. The Swiss-Cheese Model illustrates that safety requires managing both human and organizational factors, which SMS addresses through its four pillars.

This study fills an important gap in existing literature by linking global SMS frameworks with the unique socioeconomic and cultural conditions of Iran’s aviation industry, offering a contextualized understanding of safety management that has been largely overlooked in prior research.

6.2 Policy Recommendations

To enhance SMS implementation, Iranian policymakers and aviation authorities should strengthen regulatory oversight, provide incentives for safety investments, expand training and awareness programs, and promote a just culture across the industry. Collaboration with

international organizations can accelerate knowledge transfer and improve compliance with global standards.

6.3 Future Research Directions

Future studies should focus on collecting empirical data from Iranian carriers, including safety performance indicators and organizational safety culture surveys. Comparative case studies with other countries in the region could provide valuable insights into shared challenges and effective solutions. Furthermore, research into the integration of predictive analytics and digital safety tools in Iranian aviation could contribute to the development of a more mature and data-driven SMS.

Conflict of Interests

No conflict of interest has been expressed by the authors.

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