

Introducing a Collaborative Aviation Safety Model: from SMS to C-SMS

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Aviation safety operates within a complex environment involving multiple independent stakeholders such as airports, airlines, regulators, and service providers. Traditional safety models and Safety Management Systems (SMS) mainly focus on risks within individual organizations and often fail to address the interdependencies across the aviation ecosystem. This study introduces the Collaborative Safety Management System (C-SMS) model, which conceptualizes aviation safety as a systemic and inter-organizational process and proposes a holistic framework for collaborative safety management. A conceptual research approach was adopted. Existing traditional and systemic aviation safety models were reviewed to identify their strengths and limitations in addressing complex, multi-stakeholder operational environments. Based on this analysis, a multidimensional conceptual framework the C-SMS model was developed to integrate operational stakeholders, organizational hierarchy, and contextual influencing factors such as procedures, technology, time constraints, and personal characteristics.

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Volume 5, Editorials Page 46



The proposed C-SMS model presents aviation safety as a three-dimensional system consisting of: (1) operational stakeholders, (2) organizational hierarchy levels, and (3) cross-cutting influencing factors. The intersections of these dimensions illustrate how safety emerges from coordinated communication, decision-making, and shared responsibilities across organizations and operational levels. The framework emphasizes proactive risk management, horizontal and vertical alignment of safety practices, and the integration of technological tools to enhance collaboration and situational awareness. The C-SMS model shifts aviation safety management from an organization-centric perspective toward a systemic and collaborative approach. By highlighting interactions among stakeholders and organizational levels, it provides a framework for proactive safety management across complex aviation systems. The model contributes to aviation safety research by offering a practical conceptual tool for improving collaboration, risk identification, and safety culture across the broader aviation ecosystem.

Keywords: Aviation Safety Management, Collaborative Safety Management (C-SMS), Safety Management Systems (SMS), Socio-technical Systems, Inter-organizational Safety Collaboration.

Safety is a critical priority in many high-risk sectors, including healthcare, oil/gas and construction (Cornelissen et al., 2017). In these industries, however, operational control is typically centralized within a primary organization (e.g., a hospital), while other stakeholders, such as suppliers or contractors, play secondary and largely supportive roles (Grote, 2012). Aviation differs fundamentally from this structure. The aviation system involves a large number of independent stakeholders including airports, airlines, ground handling companies, regulators, security providers, police authorities, migration services, fuel suppliers, and air traffic control (ATC) whose roles are all essential to the execution of air operations rather than peripheral (Paraschi et al., 2019). The wide range of aviation stakeholders requires not only robust internal Safety Management Systems (SMS) but also mechanisms that enable collaborative identification of hazards, systematic exchange of safety information, and coordinated mitigation strategies across organizational boundaries (Murphy & Efthymiou, 2017; Kurt & Gerede, 2017). This broad scope of aviation safety is a distinguishing feature compared to other sectors, where safety may be more localized or less systemically integrated (Rodrigues, 2021).

Despite the growing recognition of the systemic nature of aviation safety, the existing body of research remains largely centered on safety management within individual organizations. Most Safety Management System (SMS) frameworks, regulatory guidance, and maturity models are designed to assess safety performance at the organizational level, with limited attention given to the dynamics that emerge across organizational boundaries. While several studies acknowledge the importance of collaboration and information sharing among aviation stakeholders (Murphy & Efthymiou, 2017; Paraschi et al., 2019), the conceptualization of safety management as a truly inter-organizational process remains underdeveloped. In particular, there is a lack of integrated models capable of capturing the complex network of operational, organizational, and technological interactions that characterize modern aviation systems.

Existing approaches tend to focus either on operational teamwork (e.g., crew–ATC coordination) or on internal organizational processes, without adequately addressing how safety is collectively produced across multiple independent actors operating within the same operational ecosystem (Liou et al., 2007; Vismari & Junior, 2011; Chang & Yeh, 2004). This gap is particularly significant given the increasing operational interdependencies among aviation stakeholders and the growing reliance on digital and intelligent systems that further shape safety-related decision-making processes (Oster et al., 2013). Consequently, there is a need for conceptual frameworks that move beyond organization-centric safety models and explicitly address the collaborative and systemic nature of aviation safety management.

Within such an environment, safety management cannot be confined to individual organizational boundaries. Instead, it must operate effectively both within organizations and across them, ensuring alignment among multiple operational actors whose activities are tightly interconnected (Netjasov, 2012). This structural characteristic of aviation challenges traditional safety models, such as the Swiss Cheese Model (Reason et al., 2006), the Dupont's Dirty Dozen (Mellema, 2018) or the SHEL model (Sun & Shi, 2011), which primarily conceptualize safety failures within single organizational systems. As aviation operations increasingly reflect the properties of complex socio-technical systems, there is a growing need for systemic and holistic approaches capable of capturing the multidimensional interactions among system components (Mogles et al., 2018; Paraschi et al., 2022). Systemic methods, such as Systems Theoretic Accident Modelling and Processes (STAMP) (Leveson, 2004), and Functional Resonance Analysis Method (FRAM) (Hollnagel, 2017) are increasingly used to investigate aviation incidents, as they can better account for the multifaceted and dynamic nature of aviation safety. However, existing systemic methods do not allow for full consideration of the dynamic complexity inherent in socio-technical aviation systems.

As the complexity of these systems increases, existing systemic approaches, struggle to simultaneously and effectively describe both inadequate human–aircraft–environment interactions and organizational deficiencies (Gong et al., 2014; Tian et al., 2016). The limitations of current systemic methods highlight the need for new, holistic hazard modeling and analysis techniques that encompass all facets of aviation socio-technical system. Such approaches would better support qualitative safety design information and collaborative safety management, moving beyond the constraints of probabilistic and component-focused methods (Malakis et al., 2023).

Despite the substantial safety improvements associated with SMS implementation, several limitations remain. In practice, many SMS frameworks continue to operate in a predominantly reactive manner, despite the theoretical shift toward proactive and predictive risk management (No & Cha, 2025). Furthermore, as aircraft systems became increasingly reliable, attention shifted toward human performance, organizational processes, and safety culture as key determinants of operational risk (Velazquez et al., 2015; Murphy & Efthymiou, 2017). So far, the less formal dimensions of safety management including informal inter-organizational relationships, trust, and shared safety culture are often insufficiently captured in conventional SMS maturity assessments (Díaz & Cabrera, 1997).

In this context, collaborative safety emerges as a critical function of the interaction between individual competence, organizational capabilities, and effective inter-organizational coordination. Collaborative safety in aviation can be understood as the coordinated sharing of information and the synchronization of decision-making processes among multiple operators, organizations, and technological systems in order to manage safety risks across operational and organizational boundaries. This concept encompasses both operational collaboration such as coordination between flight crews and air traffic controllers and broader inter-organizational mechanisms involving airlines, airports, regulators, and ground service providers.

Increasingly, such collaboration is also supported by artificial or hybrid intelligence systems that assist human operators in complex risk environments (Murphy & Efthymiou, 2017; Leib & Lu, 2013).

In response to these challenges, this paper develops and discusses a Collaborative Safety Management (C-SMS) Model, designed to reflect the complex, interdependent, and multi-organizational nature of the aviation system. The model aims to provide a holistic framework capable of capturing interactions among organizational actors, operational processes, and technological systems that collectively shape aviation safety.

Theoretical background:

1. Traditional Safety models

1.1. The Swiss Cheese Model

The Swiss Cheese Model (SCM), developed by James Reason (Reason et al., 2006), is a conceptual framework used to understand accident causation and risk management across various fields, including healthcare, engineering, and transportation (Zhan, Zheng & Zhao, 2017). The model emphasizes that safety is maintained by having several layers of protection (represented as slices of Swiss cheese), such as regulations, operational controls, training, technology, and public awareness. Each layer is imperfect, but together they significantly reduce the likelihood of a catastrophic event. The holes in each slice represent active failures (unsafe acts by individuals) or latent conditions (systemic flaws such as poor design, inadequate policies, or organizational deficiencies). These holes are not static; they can change over time and may vary in size and position. A system failure or accident only occurs when the holes in all layers momentarily align, allowing a hazard to pass through every defense. This alignment is referred to as the "trajectory of accident opportunity" (Haghani et al., 2023). This illustrates that no single failure is sufficient to cause an accident; rather, it is the combination of multiple failures across different layers that leads to adverse outcomes.

While the SCM has been adopted as the dominant paradigm for accident investigation, focusing on the interplay between unsafe acts and latent organizational conditions, some critics argue that it may oversimplify the multifaceted nature of risk and accident causation, especially in complex systems, potentially overlooking critical interactions between different system components (Larouzee & Le Coze, 2020).

1.2. Dupon's Dirty Dozen

DuPont's Dirty Dozen was developed by Gordon Dupont at Transport Canada (Çoban, 2025). The term "Dirty Dozen" refers to a list of twelve human error elements identified as common precursors to accidents, particularly in aviation maintenance (Table 1). This model is widely used in human factors training for maintenance technicians and aviation personnel (Kelly & Efthymiou, 2019; Reiman & Pietikäinen, 2012; Patankar, 2019).

While the DuPont Dirty Dozen model is widely recognized and used for identifying and mitigating human error in aviation, its limitations include a lack of comprehensiveness (Muecklich et al., 2023), a primary focus on maintenance and individual factors (Kelly & Efthymiou, 2019, Mengtao et al., 2023; Muecklich et al., 2023), insufficient attention to organizational and systemic contributors (Reiman & Pietikäinen, 2012), challenges in real-time application (Mengtao et al., 2023), and an overreliance on awareness-raising rather than systemic change (Atak & Kingma, 2011).

Table 1. The DuPont's Dirty Dozen

Factor	Brief Description	Impact on Aviation Safety
Lack of communication	Failures in verbal or written information transfer between personnel	Increases likelihood of task misinterpretation and undesired outcomes; communication problems were especially prominent in incident reports.
Complacency	Overconfidence or reduced vigilance from routine or familiarity	Degrades attention to procedures and increases chances of missed defects or checks.
Lack of knowledge	Insufficient technical skill or procedural understanding	Reduces correct task execution and raises probability of maintenance errors.
Distraction	Interruptions or competing tasks during critical work	Causes task omissions and incorrect actions that can produce safety-critical faults.
Lack of teamwork	Poor coordination, unclear roles, or ineffective cooperation	Impairs complex task coordination and can allow errors to propagate uncorrected.
Fatigue / Exhaustion	Physical or mental tiredness affecting alertness	Lowers attention and decision quality, increasing error rates during maintenance.
Lack of resources	Missing tools, parts, time, or access to information	Forces workarounds or delays that can compromise procedure compliance and safety.
Pressure	Time, production, or schedule pressure to complete tasks	Encourages shortcuts and reduced procedural compliance, elevating error risk.
Norms	Unsafe informal practices accepted as normal behavior	Normalized unsafe practices persist and increase systemic error likelihood.
Lack of assertiveness / authority	Inability or reluctance to question unsafe conditions or orders	Prevents intervention when errors or unsafe conditions are observed, allowing errors to continue.
Lack of attention / focus	Poor concentration on the task at hand	Leads to slips and lapses during maintenance activities that can create latent faults.
Stress	Acute or chronic psychological strain affecting performance	Impairs cognitive function and decision making, contributing to maintenance mistakes.

1.3. The SHEL Model

The SHEL model conceptualizes safety as the set of interfaces among Software, Hardware, Environment, and Liveware (Table 2) and it is used to locate mismatches that lead to human error (Perboli et al., 2021). Each cell in the SHEL analysis focuses on the interface between Liveware and the other element (e.g., Liveware–Software or Liveware–Hardware) because human performance is shaped by both the human attributes and the interacting artifact or context (Sun & Shi, 2011). Investigators map those interfaces to classify human-factor contributions and guide corrective actions (Zhu & Gu, 2023).

Table 2. The SHEL Model

Component	Core Meaning	Typical Mismatch Examples
Software	Procedures, checklists, documentation, training, and non-physical information flows	Outdated procedures, ambiguous checklists, inadequate training that leads to incorrect decisions
Hardware	Physical equipment, tools, cockpits, displays, and mechanical interfaces	Poorly designed controls, ergonomics that produce slips or reachability problems, unreadable displays
Environment	Operational setting including weather, lighting, workspace layout, and organizational conditions	Adverse weather, high noise, crowded apron, time pressure from scheduling or organizational constraints
Liveware	Humans as individuals and as interacting team members (skills, health, cognition, culture)	Fatigue, poor situational awareness, cultural communication barriers, inadequate crew coordination

While the SHEL model provides a foundational framework for analyzing human factors in aviation safety, its limitations include insufficient coverage of organizational and management issues (Gong et al., 2017), reliance on subjective expert analysis (Marciacq et al., 2010), potential for missing key contributing factors (Fukuoka & Furusho, 2022), the need for adaptation to different contexts, and the risk of fragmented safety analysis due to the evolution of human factors into separate disciplines (Davies & Delaney, 2017).

2. Systemic Models

2.1. Systems Theoretic Accident Modelling and Processes (STAMP)

Systems Theoretic Accident Model and Processes (STAMP) is a systemic accident analysis and simulation method grounded in control theory and systems theory (Leveson, 2004). It conceptualizes safety as a control problem, where accidents result from inadequate control or enforcement of safety-related constraints during the design, development, and operation of complex systems, rather than from simple component failures or linear chains of events. STAMP models the system as a hierarchy of control structures, representing the control-feedback relationships between different organizational and technical levels (Leveson, 2004).

This approach allows for the identification of flaws in control mechanisms, including managerial, organizational, operational, manufacturing-based, and social controls, and provides a taxonomy of control flaws such as inadequate control of actions, inadequate execution of control actions, and missing or inadequate feedback (Ceylan et al., 2021).

The model is effective in modelling and analyzing the control structure of aviation systems, identifying unsafe control actions and the main causes of accidents by examining the relationships and feedback loops between different system levels (e.g., pilots, air traffic controllers, management, regulatory bodies) (Chen et al., 2024; Mogles et al., 2018). It also supports comprehensive accident investigations by identifying ineffective safety barriers and analyzing the roles of technical, organizational, and human factors in accident causation (Bauranov & Rakas, 2024). STAMP addresses the limitations of linear models by focusing on the control and enforcement of safety constraints, rather than attributing accidents solely to component failures or human error.

Despite its strengths, STAMP has several limitations, such as difficulty in identifying single causal factors, which can make it less suitable for investigations where a clear, direct cause is sought (Rajapakse & Emad, 2021). In addition, while STAMP is effective for technical system analysis, it may be less suited for analyzing purely organizational processes (Zhao, Tang & Ning, 2017). Finally, there is evidence of a gap between research and practice, with systemic accident analysis methods like STAMP not always meeting practitioners' needs or being widely adopted in operational settings (Underwood & Waterson, 2013).

2.2 Functional Resonance Analysis Method (FRAM)

The Functional Resonance Analysis Method (FRAM) is a systems-based approach developed to analyze accident causation and risk in complex socio-technical systems (Hollnagel, 2017).

It is grounded in the principles of Resilience Engineering and Safety-II thinking, which focus on understanding how systems succeed under varying conditions, rather than solely on preventing failures.

In FRAM, the Functional Resonance Analysis is performed in four steps (Hollnagel, 2017):

1. Identify essential system functions through the six basic parameters (Input, Output, Precondition, Resources, Control, and Time);
2. Characterize the potential variability (positive or negative) of each function as a function of the context;
3. Define functional resonance based on possible dependencies or couplings between these functions;
4. Identify barriers or damping factors to absorb the variability and specify required performance monitoring.

FRAM is used to model the adaptive dynamics of aviation systems, capturing how variability in human actions and technological functions interact and propagate through the system (Wang & Yan, 2025). FRAM has been combined with fuzzy logic to provide dynamic monitoring and risk management in aviation ground operations, allowing for the identification and analysis of potential failure modes (Dang et al., 2025). It has also been used in Maintenance Operations Optimization by integrating with optimization algorithms (Patriarca, Lovaglio & Simone, 2025). FRAM has also been extended with formal verification tools to model and analyze emergent hazards in ATM systems, such as the Minimum Safe Altitude Warning (MSAW) system, by identifying how small variabilities in functions can combine to create significant safety risks (Yang, Tian & Zhao, 2017).

Despite its advantages, FRAM has several notable limitations including its high complexity which can become difficult to manage and analyze due to the large number of interacting functions and dependencies (Dang et al., 2025).

In FRAM-based models, physical process variables are often used only to calculate state transition probabilities, rather than being treated as independent modeling objects, which may limit the depth of analysis (Dang et al., 2025). Moreover, some FRAM applications focus on modeling functional interactions but may overlook the internal and external variabilities within individual functions, or vice versa, failing to fully capture the dynamic interplay between functions (Mohsendokht et al., 2026).

Overall, both traditional and systemic safety models focus on ex-post explanation of risk factors. Traditional models are too simplistic to capture the complex interdependencies between aviation system components. Existing systemic models capture this complexity using sophisticated methodologies and tools that, while appropriate for research purposes, are difficult for aviation practitioners to apply in everyday operations. Drawing on the author's extensive professional experience in aviation management, a more practical and holistic approach the Collaborative Safety Management (C-SMS) model has been developed and presented in the following sections.

The Collaborative Safety Management (C-SMS) Model

The Collaborative Safety Management (C-SMS) model is a conceptual framework that captures the organizational, operational, and human factors influencing aviation operations within the airport context (Figure 1). This model illustrates the dynamic interactions between the management hierarchy, operational stakeholders, and contextual factors that collectively impact aviation system safety. The airport environment was chosen as the focus because it encompasses all major aviation stakeholders. The following sections provide a detailed description of the model, highlighting its key components and the interactions among them.

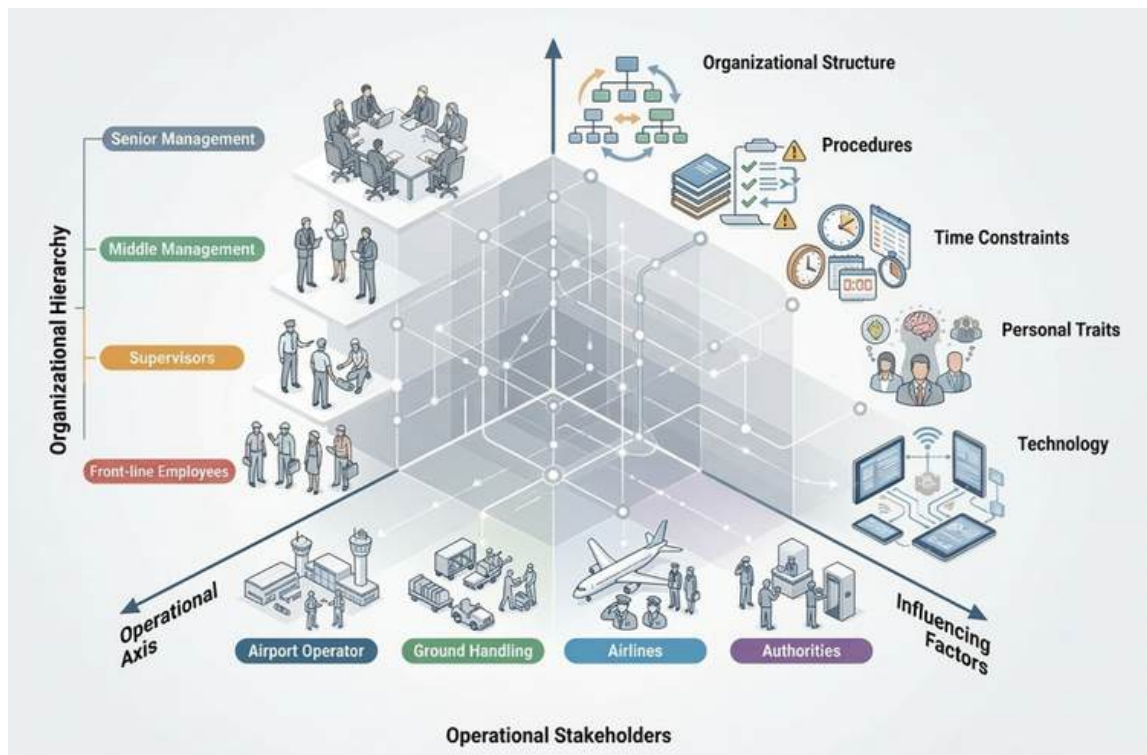


Figure 1. The Collaborative Safety Management (C-SMS) conceptual model

1. x-axis /horizontal: Operational Stakeholders

Airport Operator – Manages airport infrastructure, safety, and coordination among stakeholders.

Ground Handling – Responsible for baggage, aircraft servicing, and passenger assistance.

Airlines – Oversee flight operations, crew management, and passenger experience.

Authorities – Include customs, immigration, and aviation regulators ensuring compliance and security.

2. y-axis/vertical: Organizational hierarchy

Senior Management – Strategic decision-makers responsible for policy, resource allocation, and long-term planning.

Middle Management – Translators of strategy into operational plans; coordinate between senior management and supervisors.

Supervisors – Oversee daily operations, ensure compliance with procedures, and manage front-line staff.

Front-line Employees – Execute operational tasks directly impacting service delivery and safety.

3. z-axis/diagonal: Influencing factors

Organizational Structure – Defines communication flow, authority, and decision-making efficiency.

Procedures – Standard operating processes that ensure consistency and safety.

Time Constraints – Operational deadlines and turnaround times influencing performance and coordination.

Personal Traits – Individual behaviors, leadership styles, and interpersonal skills affecting teamwork and decision-making.

Technology – Digital systems, automation, and data analytics that enhance efficiency, communication, and real-time decision-making across all operational levels.

The C-SMS framework visualizes how different organizational levels and operational stakeholders interact within the airport ecosystem, with a focus on safety-critical processes. It accounts for structural, procedural, temporal, and personal factors that influence operational safety. The framework supports identification of communication pathways, decision-making bottlenecks, and areas where safety and process improvements are needed.

4. Intersection of Axes

The intersections of these axes create a multidimensional framework that illustrates how each element affects operational safety and efficiency. Understanding these intersections is crucial for optimizing both airport operations and safety performance. Example intersections include:

1. Senior Management & Airport Operator: Senior management sets strategic safety and operational goals that the airport operator must implement to maintain compliance and reduce risk.
2. Middle Management & Ground Handling: Middle management develops safety procedures that ground handling teams must follow to ensure safe aircraft turnaround and minimize operational hazards.
3. Supervisors & Airlines: Supervisors coordinate with airlines to manage schedules safely, monitor compliance with safety protocols, and ensure timely service delivery without compromising safety.
4. Front-line Employees & Catering: Front-line employees interact with catering services to ensure that food and beverage operations meet hygiene and safety standards for passengers and crew.
5. Influencing Factors & All Levels: Structural, procedural, temporal, and personal factors can impact all levels of the hierarchy and stakeholder interactions. For example, technology can enhance safety reporting and communication between front-line employees and supervisors, while time pressures may increase the risk of procedural shortcuts if not properly managed. Table 3 interprets some example intersections within the C-SMS model.

Table 3. Sample Intersections within C-SMS model

Organizational Level	Stakeholder Interaction	Safety Focus Example
Senior Management & Airport Operator	Align strategic goals	Implement safety management systems (SMS) and emergency preparedness plans
Middle Management & Ground Handling	Develop procedures	Standardize safe aircraft turnaround processes and hazard reporting
Supervisors & Airlines	Coordination	Ensure safe boarding, luggage handling, and timely communication on incidents
Front-line Employees & Catering	Day-to-day operations	Maintain hygiene standards, safe food handling, and passenger safety
Influencing Factors & All Levels	Cross-cutting impact	Structural: clear signage and secure equipment Procedural: checklists Temporal: avoid rushed decisions Personal: fatigue management

C-SMS characteristics

1. Systemic Nature

Airports are inherently multi-stakeholder environments, where the actions of one entity (e.g., an airline, ground handler, or service provider) can directly impact the safety of others (Paraschi et al., 2019). Effective safety management in these settings requires robust inter-organizational cooperation. The C-SMS model extends beyond single organizational boundaries to take account of all major actors of the aviation system.

2. Proactive Approach

The C-SMS model emphasizes proactive safety management, rather than merely investigating accidents after they occur. While incident analysis can provide insight into organizational, operational, and individual factors contributing to events, the primary focus of C-SMS is to anticipate risks and prevent accidents. Being proactive means that information flows are bidirectional: organizational policies and procedures do not just cascade downward; they actively seek input from those directly involved in operations. This feedback is integrated into rules and processes, enabling organizational learning and continuous improvement.

3. Holistic Scope

Collaborative risk management takes a holistic approach, considering the interconnectedness of risks and their impact on organizational goals. It avoids narrow or reactive focus on isolated incidents, instead emphasizing systemic understanding and long-term safety outcomes. In contrast, traditional risk management often concentrates on discrete risks, such as accidents or property damage, without accounting for systemic interactions.

4. 3D Alignment

The collaborative safety model fosters an organization-wide safety culture by aligning values, processes, and behaviors across three dimensions:

- Horizontal Alignment: Shared values and safety priorities among all stakeholders.
- Vertical Alignment: Consistent safety principles across all hierarchical levels, from executives to front-line staff.
- Transversal Alignment: Integration of processes from root causes to operational outcomes.

5. Integration into Everyday Operations

5.1. Effective Communication Among Stakeholders

Open and timely communication is essential for collaborative safety. All parties from contractors to regulatory bodies must maintain clear communication channels. Regular meetings, digital tools, and structured reporting mechanisms ensure that safety concerns are shared in real time, enabling proactive hazard mitigation and accident prevention.

5.2. Shared Responsibility

Unlike traditional risk management, which often centralizes responsibility within a single department, collaborative safety distributes accountability across all stakeholders. This shared responsibility fosters a sense of ownership and engagement in risk management, enhancing vigilance and compliance at every level.

5.3. Systemic Critical Incident Review

A core component of the C-SMS model is the Systemic Critical Incident Review. Unlike conventional incident reviews that often focus on front-line error, this approach analyzes how organizational decisions, resource allocation, and inter-organizational interactions contribute to outcomes. It emphasizes systemic understanding to prevent recurrence and improve safety processes.

5.4. Embedding Safety into Daily Operations

Beyond training and orientations, C-SMS provides advanced, role-specific education that integrates safety science principles into routine operations. By embedding these principles into existing workflows, the organization creates artifacts and processes that reflect and reinforce a culture of safety.

5.5. Sustainability and Evaluation

For culture change to be effective, safety initiatives must be sustainable. The C-SMS model is designed to withstand organizational changes and evolving operational demands. Ongoing evaluation, conducted collaboratively with stakeholders, measures both the impact of culture change and the effectiveness of the model, ensuring continuous improvement in safety performance.

Steps for Effective C-SMS implementation

Figure 2 presents a roadmap for implementing the Collaborative Safety Management System (C-SMS) within the airport operational context.



Figure 2. Steps for effective C-SMS implementation

1. Form Cross-Functional Teams

Establish multidisciplinary teams to ensure the full scope of operational and safety risks is considered. Risks in airport operations often span departments airlines, ground handling, maintenance, and security so including representatives from each area provides diverse perspectives and facilitates comprehensive mitigation strategies.

2. Encourage Open Communication

Foster an environment where team members feel comfortable identifying risks, discussing potential safety issues, and proposing mitigation strategies. Open dialogue during meetings, workshops, and digital forums ensures all stakeholders' insights are captured and considered.

3. Hold Regular Meetings

Schedule frequent meetings to review emerging risks, track mitigation progress, and adjust strategies as needed. Regular discussions reinforce the importance of proactive risk management and support continuous monitoring of safety initiatives. Use risk registers or safety management documents to track hazards, actions, and outcomes systematically.

4. Provide Training and Education

Ensure all team members are familiar with risk management principles and any specific tools or procedures used in your organization. Regular, role-specific training sessions build competence and confidence, enabling staff to contribute effectively to a safety-focused culture.

5. Leverage Technology to Facilitate Collaboration

Use digital tools to streamline risk identification, reporting, and collaboration. Real-time dashboards, incident reporting apps, project management platforms, and virtual meeting software enhance information sharing, reduce administrative burden, and support timely decision-making.

6. Recognize and Reward Contributions

Positive reinforcement motivates active participation in risk management. Acknowledge team members who identify significant risks or propose effective mitigation strategies, and celebrate milestones to reinforce the value of their contributions.

Recognition fosters ownership, accountability, and sustained engagement.

7. Continuous Improvement

Regularly review and refine the risk management framework based on insights from monitoring, incident analysis, and stakeholder feedback. Update risk assessments, revise mitigation strategies, and enhance communication or collaboration processes to maintain a proactive, resilient safety culture.

Benefits and Challenges of Collaborative Safety Management

Collaborative risk management in complex operational environments, such as airports or construction sites, offers several advantages but also presents challenges that must be systematically addressed. The following section summarizes the key benefits and associated challenges, along with strategies to enhance effectiveness.

Table 4. Summary of Benefits and Challenges of Collaborative Safety Management

Aspect	Benefits	Associated Challenges & Strategies
Diverse Perspectives	Inclusion of employees from multiple roles and departments broadens the identification of potential risks and informs comprehensive mitigation strategies.	Coordinating stakeholders with different priorities can be difficult. Strategy: Establish clear, standardized safety guidelines and structured communication channels.
Proactive Risk Detection	Early identification of risks through multiple viewpoints allows timely interventions, reducing the likelihood and impact of incidents.	Risks may still be overlooked if reporting is inconsistent. Strategy: Implement regular meetings, structured reporting systems, and real-time digital tools to ensure continuous monitoring.
Improved Employee Morale	Engaging staff in safety initiatives increases sense of ownership, motivation, and participation, fostering a culture of safety.	Resistance to change and reluctance to adopt new practices may occur. Strategy: Conduct comprehensive training, highlight benefits of collaboration, and involve leadership in modeling safety behaviors.
Efficient Resource Utilization	Collaborative approaches leverage collective knowledge and resources, prevent duplication, and promote cost-effective mitigation.	Misalignment of roles and responsibilities can reduce efficiency. Strategy: Clearly define roles, assign accountability, and conduct regular audits to ensure alignment.
Sustained Safety Culture	Shared responsibility encourages consistent adherence to safety protocols and continuous improvement.	Maintaining long-term engagement requires ongoing evaluation. Strategy: Use systematic audits, feedback mechanisms, and iterative improvements to sustain culture change.

The implementation of collaborative safety management allows organizations to integrate diverse perspectives into operational decision-making, enhancing both proactive safety measures and employee engagement. Challenges, such as stakeholder coordination and resistance to change, can be mitigated through structured communication, training, and leadership involvement. Regular audits and clearly defined roles further strengthen the system by ensuring accountability and continuous improvement. Together, these strategies enable organizations to create a resilient and safety-focused environment that optimizes both human and material resources.

C-SMS case study: Collaborative Safety Programs – National Air Traffic Controllers Association (USA)

The National Air Traffic Controllers Association (NATCA) has implemented multiple collaborative safety programs in partnership with the Federal Aviation Administration (FAA) to enhance operational safety within the National Airspace System (NAS). These programs illustrate the application of collaborative safety management principles, emphasizing proactive risk mitigation, employee engagement, and systemic improvement (NATCA, 2018).

Professional Standards Program

This program, embedded within the NATCA/FAA collective bargaining agreement, promotes professional conduct among employees. It enables peers to address performance or conduct concerns before they escalate to formal corrective actions, thereby fostering a culture of accountability and early intervention.

Turn Off Tune In

Launched in 2013, this initiative targets distractions in operational workplaces, particularly electronic distractions. A collaborative workgroup of NATCA and FAA representatives developed a communications campaign to raise awareness of safety risks, targeting air traffic controllers, supervisors, managers, and operational staff.

Fully Charged

Initiated in 2014 by the Collaborative Steering Committee (CSC) with NATCA, FAA, and the Professional Aviation Safety Specialists (PASS), Fully Charged addresses workforce fatigue. The program educates personnel on fatigue risks, promotes alertness, and provides tools for self-mitigation, thereby changing organizational culture around fatigue management.

Air Traffic Safety Action Program (ATSAP)

Implemented fully in 2010, ATSAP allows voluntary, non-punitive reporting of safety and operational concerns by controllers. The data collected is shared via the Confidential Information Share Program (CISP) and Aviation Safety Information Analysis and Sharing (ASIAS), enabling stakeholders to identify hazards and develop mitigation strategies. An extension, ATSAP-X, includes additional FAA personnel reporting system-level issues, such as airspace design, equipment conflicts, and regulatory waivers.

RESPECT and Partnership for Safety (PFS)

RESPECT fosters workplace dignity, professionalism, and mutual support, while PFS empowers local facility teams to identify and address hazards using localized data. Both initiatives emphasize employee engagement and the development of safety solutions before incidents occur.

Targeted Safety Campaigns

Several campaigns, such as All Points Safety and Take a Stand for Safety, raise awareness of emerging safety issues and operational trends, including weather-related conflicts and IFR/VFR coordination, promoting proactive mitigation and real-time risk management.

Technological and Operational Integration

Programs such as ADS-B, Command Center Space Operations, and Low Altitude Authorization and Notification Capability (LAANC) demonstrate collaborative integration of advanced technology into NAS operations. These initiatives enhance situational awareness, enable near-real-time airspace authorization, and improve safety and efficiency across airports and airspace operations.

Operational Risk Management and Runway Safety

NATCA and the FAA employ Operational Risk Management (ORM) to identify, assess, and mitigate risks before activities occur, while Runway Safety programs address surface hazards using proactive, risk-based approaches. Tools such as Runway Safety Action Teams (RSATs) and Runway Status Lights (RWSL) illustrate data-driven hazard mitigation efforts that improve both the number and severity of safety incidents.

Collectively, these initiatives highlight the effectiveness of collaborative safety management in air traffic operations. They demonstrate the benefits of proactive risk identification, employee engagement, systemic hazard mitigation, and integration of technology to enhance operational safety across the NAS. The NATCA/FAA partnership serves as a model for collaborative safety programs in complex, high-risk environments.

Conclusions and Discussion

Collaborative safety in aviation is a multi-dimensional endeavor that requires the alignment of individual skills, organizational systems, and inter-agency cooperation. The future of aviation safety lies in strengthening the links between these components and expanding collaborative efforts across the entire industry. This paper deploys the Collaborative Safety Management (C-SMS) model as a holistic framework to capture the complexity that shapes aviation system safety.

The Collaborative Safety Management (C-SMS) model expands into three dimensions, enrapturing major stakeholders (x-axis), organizational hierarchy (y-axis) and influencing factors (z-axis). Their intersection shapes safety levels at any given moment so that safety is an emergent quality of the entire system. Any disruption in any of these components results in safety weaknesses.

The Collaborative Safety Management (C-SMS) is a managerial framework with main aim to proactively align all critical safety components. Its effective implementation requires open communication, close collaboration, fostering safety culture, leverage of technology, and continuous improvement. The Collaborative Safety Management (C-SMS) model moves safety beyond compliance and isolated incident response toward a proactive, systemic, and culturally embedded approach. More specifically, it can add value to aviation safety in the following manners:

1. Enhanced Risk Identification: By engaging multiple stakeholders air traffic controllers, pilots, ground staff, management, and regulators C-SMS captures diverse perspectives on potential hazards. Risks that might be overlooked in siloed systems, such as operational, procedural, or human factors, are more likely to be identified early.
2. Proactive Safety Culture: C-SMS emphasizes prevention rather than reaction, allowing organizations to address hazards before they lead to incidents. Encourages reporting of near-misses and unsafe conditions without fear of reprisal, fostering transparency and trust.

3. Improved Decision-Making: Shared information among departments and agencies provides a more complete picture of operational risks, enabling evidence-based decision-making. Collaboration ensures that mitigation strategies are coordinated, practical, and consider interdependencies within complex aviation systems.
4. Operational Efficiency: By coordinating efforts across teams and levels, C-SMS reduces duplication, ensures optimal resource allocation, and aligns organizational priorities with safety objectives. Integrates safety into routine operations, making it a core operational value rather than an additional task.
5. Workforce Engagement and Ownership: Employees at all levels become active participants in safety management, increasing morale, accountability, and engagement. Encourages shared responsibility, making frontline staff partners in both risk identification and mitigation.
6. Continuous Learning and Improvement: C-SMS creates feedback loops through systemic reviews, reporting programs, and post-incident analyses, allowing lessons to be integrated into procedures and training. Supports organizational learning by adapting policies and practices based on real operational experience.
7. Integration of Technology and Innovation: Collaborative models facilitate the use of modern tools, such as digital reporting systems, predictive analytics, and real-time monitoring technologies (e.g., ADS-B, LAANC), enhancing situational awareness and response.

Despite its demonstrated advantages, the C-SMS model in its current form presents several notable limitations:

1. Lack of Quantitative Analysis: C-SMS is primarily qualitative, and its outcomes often depend on the experience and judgment of analysts. This reliance can reduce objectivity and reproducibility, limiting the robustness of findings. Integrating quantitative methods, such as probabilistic risk assessment, statistical modeling, or data-driven analytics, alongside qualitative insights and combining qualitative and quantitative approaches can enhance the rigor, objectivity, and comparability of C-SMS results.

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Volume 5, Editorials Page 70

2. Complexity Management: In highly complex aviation systems, the C-SMS model can become challenging to manage and analyze due to numerous interacting functions, dependencies, and stakeholders. Employing modular or hierarchical modeling techniques to break down complex systems into manageable sub-systems and leveraging visualization tools and software platforms can help organize and track interactions, making analysis more tractable.

3. Dependence on Expert Judgment: The model relies heavily on expert evaluation, which introduces subjectivity and potential variability in outcomes. Differences in expertise, perspective, or bias can influence results. To address this limitation, standardize evaluation protocols, incorporate structured decision-making frameworks (e.g., Delphi method, multi-criteria decision analysis), and triangulate assessments with empirical data can be used to reduce bias and improve consistency.

4. Lack of Empirical Validation: The current study focuses on the theoretical development of C-SMS. Its practical effectiveness in real-world aviation operations remains underexplored. Future research can conduct pilot studies and field applications in operational settings, such as air traffic control facilities or airport operations and collect empirical data to evaluate the model's predictive accuracy, usability, and impact on safety outcomes, and iteratively refine the framework based on observed results.

In conclusion, while C-SMS offers substantial benefits for proactive and systemic safety management, addressing these limitations through integration of quantitative methods, complexity reduction techniques, structured expert evaluation, and empirical validation will enhance its reliability, applicability, and impact in aviation organizations.

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