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Challenges in the Implementation of Resilience in Flight Operations: The Role of Safety Management Systems

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ABSTRACT

Resilience has become a central concept in contemporary aviation safety, reflecting the industry's need to manage complexity, uncertainty, and unexpected disturbances across increasingly automated and dynamic operational environments. While flight operations depend on the capacity of individuals, teams, and organisations to anticipate, adapt, and recover from disruptions, the practical implementation of resilience remains challenging. Safety Management Systems (SMS), as mandated frameworks across global aviation, play a critical role in shaping how resilience is operationalised, monitored, and sustained. This paper examines the challenges associated with implementing resilience in flight operations and analyses how SMS can support or hinder this integration. The analysis begins by defining resilience as a multi-dimensional capability, encompassing anticipation of potential threats, monitoring of system variability, adaptation to changing conditions, and recovery from disruptions. Within flight operations, resilience extends beyond pilot decision-making to include coordination between dispatchers, maintenance personnel, air traffic controllers, and organisational structures that guide operational decisions. Despite its conceptual prominence, resilience is often poorly translated into training programmes, procedural design, and operational policies, leading to fragmented or superficial implementation. The paper identifies several systemic challenges that hinder resilience adoption. First, traditional safety approaches remain predominantly reactive, focusing on compliance and incident investigation rather than proactive monitoring of system variability and weak signals. This reactive orientation limits the ability of SMS to identify early indicators of fragility or organisational drift. Second, existing performance metrics often prioritise efficiency and procedural adherence, inadvertently discouraging the adaptive behaviours that resilience requires. Third, high automation in modern flight decks can lead to reduced pilot engagement, erosion of manual flying skills, and over-reliance on automated systems—conditions that undermine adaptive capacity during system surprises or degraded modes. Human factors challenges are also examined. Pilots and operational personnel must maintain cognitive flexibility, situational awareness,

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and collaborative communication under dynamic conditions, yet training programmes frequently emphasise standardisation over adaptability. Additionally, organisational cultures that struggle with Just Culture principles may inhibit the open reporting and learning necessary for resilience development. The role of Safety Management Systems is critically analysed as both an enabler and a constraint. SMS offers structured processes for hazard identification, risk assessment, safety assurance, and safety promotion—all of which can support resilience if applied through a proactive, systems-oriented lens. The paper concludes by proposing a resilience-enhanced SMS model tailored for flight operations. This model incorporates continuous monitoring of operational variability, systemic learning loops, transparent reporting structures, and training designed to cultivate adaptive cognitive and teamwork skills.

Keywords: Resilience, Flight operations, Safety management systems (SMS), Adaptive capacity, Human factors, Automation, Just culture, Organisational learning

INTRODUCTION

Flight operations are conducted within increasingly complex socio-technical systems characterised by high levels of automation, operational tempo, and continuous exposure to uncertainty. Airlines and flight crews must manage variability arising from weather, air traffic constraints, technical reliability, organisational pressures, and dynamically changing operational environments. Within this context, resilience has emerged as a defining capability for sustaining safe and effective flight operations, reflecting the need to cope with disturbances that cannot be fully anticipated or eliminated through procedural control alone (Hollnagel, 2014; Woods, 2015).

Resilience in flight operations is no longer understood solely as individual pilot skill or the ability to recover following failure, but as a system-level property that enables organisations to anticipate threats, adapt dynamically, and sustain reliable performance under stress and uncertainty. This shift aligns with contemporary developments in human factors and safety science, which recognise that operational success in complex systems depends on adaptive human performance and effective coordination across organisational boundaries, rather than strict adherence to prescriptive rules alone (Reason, 1997; Hollnagel, 2014).

Modern aviation organisations increasingly operate within environments shaped by **hybrid operational pressures**, including technological acceleration, high automation dependency, economic constraints, and evolving regulatory and airspace demands. These pressures place significant cognitive, emotional, and ethical demands on flight crews, dispatchers, maintenance personnel, and operational leadership. As a result, resilience has become central not only to flight safety and operational reliability, but also to organisational sustainability and long-term safety performance (Woods, 2015; Dekker, 2014).

Safety Management Systems (SMS) represent the primary regulatory and organisational mechanism through which aviation organisations manage safety risks and assure compliance with international standards. SMS frameworks provide structured processes for hazard identification, risk assessment, safety assurance, and safety promotion. In principle, these elements align closely with resilience functions such as anticipation, monitoring, response, and learning. Aviation failure analyses reveal organizational factors account for

87.1% of causes compared to individual/task factors (12.9%), demonstrating that resilience depends primarily on systemic SMS design rather than crew behavior alone (No & Chang, 2024). However, research has shown that SMS is frequently implemented in a compliance-driven and reactive manner, limiting its ability to support proactive monitoring of system variability and adaptive capacity in everyday operations (Reason, 1997; Hollnagel, 2014).

This paper examines the challenges associated with implementing resilience in flight operations and critically analyses the role of Safety Management Systems as both an enabler and a constraint in this process. By integrating resilience engineering principles with contemporary SMS practice, the paper explores how flight operations can move beyond compliance-oriented safety management toward a more adaptive, learning-centred approach. In doing so, the study contributes to the broader human factors and resilience engineering literature by highlighting the conditions under which SMS can support sustained safety performance in complex, safety-critical aviation systems (Woods, 2015; Ziakkas, 2023).

CONCEPTUAL FOUNDATIONS: RESILIENCE AND SAFETY MANAGEMENT SYSTEMS IN FLIGHT OPERATIONS

Resilience in flight operations is increasingly understood as a multi-level, socio-technical capability that enables aviation systems to function safely under conditions of uncertainty, variability, and operational pressure. Rather than equating safety solely with the absence of accidents or deviations, contemporary resilience engineering frameworks define resilience as the ability of a system to anticipate potential threats, monitor ongoing performance, adapt to changing conditions, and recover effectively from disturbances (Hollnagel, 2014; Woods, 2015). This perspective reflects a fundamental shift in aviation safety thinking—from controlling failure to supporting success in everyday operations.

Within flight operations, resilience manifests across interconnected levels of the system. At the individual level, it involves pilots' cognitive flexibility, situational awareness, and capacity to manage workload and ambiguity. At the team level, resilience is expressed through coordination, communication, and shared mental models among flight crew, dispatchers, air traffic controllers, and maintenance personnel. At the organisational level, resilience depends on leadership practices, training philosophies, and safety cultures that enable learning and adaptation rather than rigid compliance. Finally, at the system level, resilience emerges from the interaction between humans, automation, procedures, and regulatory frameworks that shape operational behaviour.

Safety Management Systems (SMS) represent the primary institutional mechanism through which aviation organisations attempt to manage these interactions. SMS frameworks—mandated by ICAO and adopted globally—are designed to provide structured processes for hazard identification, risk assessment, safety assurance, and safety promotion. In principle, these elements align closely with resilience functions, as both aim to support anticipation, monitoring, response, and learning. However, in practice, SMS implementation often remains compliance-driven and reactive, focusing on documentation, audits, and post-incident investigation rather

than proactive engagement with operational variability (Reason, 1997; Hollnagel, 2014).

A central conceptual challenge lies in the tension between standardisation and adaptability. Flight operations require a high degree of procedural standardisation to ensure coordination and predictability across complex systems. At the same time, real-world operations routinely deviate from nominal assumptions due to weather, traffic constraints, technical anomalies, and organisational pressures. Resilience depends on the ability of individuals and teams to adapt safely within procedural boundaries, yet many SMS implementations implicitly discourage such adaptation by framing deviations primarily as risks to be controlled rather than as sources of insight into system functioning (Dekker, 2014).

Automation further complicates the relationship between resilience and SMS. Highly automated flight decks can reduce workload and enhance efficiency during nominal operations, but they may also reduce pilot engagement, erode manual flying skills, and obscure system state during abnormal or degraded modes. From a resilience perspective, over-reliance on automation can diminish adaptive capacity precisely when it is most needed. SMS frameworks that focus narrowly on compliance with automation procedures may therefore fail to address deeper vulnerabilities related to skill degradation, mode confusion, and loss of situational awareness (Woods, 2015).

Conceptually, integrating resilience into SMS requires a shift from viewing safety as rule compliance toward understanding safety as the management of performance variability. This implies that SMS should not only capture failures and hazards but also systematically examine how everyday operations succeed despite constraints and disturbances. Such an approach aligns with Safety-II thinking, which emphasises learning from normal work and supporting adaptive performance rather than attempting to eliminate variability altogether (Hollnagel, 2014).

Table 1 synthesises the conceptual relationship between resilience functions and core SMS elements in flight operations, highlighting both areas of alignment and common implementation gaps.

Table 1: Conceptual relationship overview.

Resilience Function	Condensed Description	SMS Element	Typical Gap
Anticipation	Detecting emerging threats and operational drift	Hazard identification	Reactive, past-event focus
Monitoring	Tracking performance and workload in normal ops	Safety assurance	Limited visibility of everyday operations
Adaptation	Adjusting actions under changing conditions	Procedures & training	Compliance over adaptability
Recovery & Learning	Managing degraded states and organisational learning	Emergency response & safety promotion	Limited surprise training and weak feedback loops

The conceptual foundations of resilience and SMS in flight operations reveal both strong theoretical alignment and persistent practical disconnects. While SMS provides the structural framework through which resilience could be operationalised, its effectiveness depends on whether it is implemented as a living system that supports adaptation and learning, or as a static compliance instrument. Addressing this disconnect is essential for advancing resilience from an aspirational concept to an operational reality within contemporary flight operations.

METHODOLOGY

This study employs a qualitative, conceptual–analytical methodology to examine challenges in implementing resilience in flight operations and the role of Safety Management Systems (SMS) in shaping adaptive capacity. A qualitative approach is appropriate given the socio-technical nature of flight operations, where safety performance emerges from interactions between human, organisational, and technological elements rather than isolated variables (Reason, 1997; Hollnagel, 2014).

The analysis is grounded in resilience engineering and contemporary human factors theory, conceptualising resilience as a multi-dimensional capability encompassing anticipation, monitoring, adaptation, and recovery within complex systems (Hollnagel, 2014; Woods, 2015). This framework is applied across individual, team, organisational, and system levels, with SMS examined as the primary organisational mechanism through which these resilience functions are operationalised.

Data sources include peer-reviewed resilience and SMS literature, Safety-II research, and established aviation safety frameworks, supplemented by the authors' professional experience in flight operations, safety management, and aviation training. The analytical process followed a theoretically informed thematic synthesis, identifying recurring tensions between compliance-driven SMS practices and the adaptive behaviours required for resilient performance (Dekker, 2014).

Table 2: Research methodology overview.

Element	**Description**
Design	Qualitative conceptual–analytical
Framework	Resilience engineering (anticipate–monitor–adapt–recover)
Focus	SMS as enabler and constraint of resilience
Sources	Safety science literature, SMS frameworks, practitioner expertise
Analysis	Theoretically informed thematic synthesis

FINDINGS

The qualitative conceptual analysis reveals a set of recurring and interrelated challenges that constrain the effective implementation of resilience within flight operations when mediated through existing Safety Management System

(SMS) frameworks. These findings highlight systemic patterns rather than isolated deficiencies, underscoring that resilience limitations emerge from the interaction between organisational structures, human performance demands, and technological design.

A central finding concerns the dominance of compliance-oriented SMS implementation. Although SMS frameworks formally incorporate hazard identification, safety assurance, and safety promotion, their operationalisation is frequently anchored in retrospective analysis of adverse events rather than proactive engagement with everyday operational variability. Current "if–then" procedural approaches prove insufficient for unanticipated operational uncertainties, requiring adaptive response strategies beyond rigid compliance frameworks (Hancock & Cruit, 2024). As a result, early indicators of system fragility—such as workload saturation, procedural workarounds, or subtle coordination breakdowns—often remain invisible to formal safety processes (Reason, 1997; Hollnagel, 2014).

A second key finding relates to the misalignment between performance metrics and resilience objectives. Operational performance indicators in flight operations tend to prioritise efficiency, punctuality, and procedural conformity. While these metrics support standardisation and predictability, they inadvertently suppress adaptive behaviours by framing deviations primarily as non-compliance rather than as adaptive responses to contextual demands. This dynamic limits the capacity of SMS to capture how safety is actively created in real-world operations (Dekker, 2014; Woods, 2015).

The analysis also identifies automation-induced erosion of adaptive capacity as a significant resilience challenge. High levels of automation in modern flight decks, while beneficial under nominal conditions, contribute to reduced manual skill retention, diminished system transparency, and delayed recognition of degraded modes. SMS processes often fail to address these vulnerabilities adequately, focusing instead on adherence to automated procedures rather than on sustaining human engagement and adaptability (Parasuraman et al., 2008; Woods, 2015).

Human factors findings further indicate that training and organisational culture frequently lag behind resilience requirements. Flight crew resilient behavior depends on 22 hierarchically-related factors spanning individual, cockpit, organizational, and social dimensions, necessitating integrated SMS interventions across all system levels (He et al., 2025). Training programmes tend to emphasise procedural correctness and error avoidance, offering limited exposure to ambiguity, surprise, and conflicting operational goals. At the organisational level, incomplete implementation of Just Culture principles constrains open reporting and reflective learning, weakening the feedback loops necessary for resilience development (Dekker, 2014; Reason, 1997).

Finally, the findings suggest that SMS holds latent potential as a resilience enabler, but this potential is inconsistently realised. Where SMS processes are applied through a systems-oriented, learning-focused lens, they can support anticipation, monitoring, and adaptation. However, where SMS is treated primarily as a regulatory compliance mechanism, it risks reinforcing brittleness rather than resilience.

Table 3: Key findings overview.

Finding Area	Observed Pattern	Operational Consequence	Resilience Implication
SMS orientation	Predominantly reactive and compliance-driven	Limited visibility of weak signals and operational drift	Reduced anticipatory capacity
Performance metrics	Emphasis on efficiency and procedural adherence	Suppression of adaptive behaviours	Constrained adaptation
Automation reliance	Reduced human engagement and skill erosion	Delayed response to system surprises	Weakened recovery capability
Training focus	Standardisation over adaptability	Limited exposure to uncertainty	Reduced cognitive flexibility
Organisational culture	Incomplete Just Culture implementation	Under-reporting and weak learning loops	Impaired organisational learning

DISCUSSION

The findings underscore a fundamental tension between traditional safety management paradigms and the requirements of resilience in contemporary flight operations. While SMS frameworks are structurally aligned with resilience functions, their prevailing implementation reflects a Safety-I orientation that prioritises control, compliance, and failure prevention over adaptive performance and learning from normal work (Hollnagel, 2014).

One of the most significant implications concerns the conceptualisation of **safety within SMS**. The findings suggest that safety is often treated as a static property to be assured through procedures and audits, rather than as a dynamic capability that must be continuously enacted by humans operating within complex, variable environments. This framing limits the ability of SMS to engage meaningfully with performance variability—the very phenomenon that resilience engineering identifies as central to both success and failure (Woods, 2015).

The discussion also highlights the **paradox of standardisation**. Standard operating procedures are indispensable for coordination and predictability in flight operations; however, excessive procedural rigidity can undermine resilience by constraining adaptive responses to unanticipated conditions. SMS implementations that implicitly discourage deviation risk conflating safe adaptation with unsafe non-compliance, thereby eroding trust and discouraging reflective learning (Dekker, 2014).

Automation emerges as a critical moderating factor in the resilience–SMS relationship. The findings align with prior research demonstrating that adaptive capacity degrades when automation reduces human involvement without compensatory strategies for maintaining engagement, situational awareness, and skill proficiency (Parasuraman et al., 2008). From a

resilience perspective, SMS must therefore extend beyond procedural oversight of automated systems to include explicit strategies for sustaining human–automation coordination under degraded and non-nominal conditions.

Human factors considerations further reinforce the need for **resilience-informed training and culture**. Training that privileges rule adherence over sensemaking and adaptability leaves crews ill-prepared for ambiguity and surprise—conditions that define real-world flight operations. Similarly, organisational cultures that fall short of genuine Just Culture principles inhibit the open dialogue and learning necessary to transform operational experience into systemic improvement (Reason, 1997; Dekker, 2014). Aviation organizations must evolve SMS from compliance-focused frameworks toward proactive safety cultures that incorporate management of change methodologies and continuous learning mechanisms (Cabral & Dutta, 2025).

Critically, the discussion suggests that **SMS is not inherently incompatible with resilience**, but that its effectiveness depends on how it is interpreted and enacted. When SMS processes are used to explore how work is actually performed, to monitor variability during normal operations, and to support adaptive learning loops, they can serve as powerful resilience enablers. Conversely, when SMS is reduced to a compliance checklist, it risks institutionalising brittleness within an already complex socio-technical system.

Table 4 presents a resilience-informed reinterpretation of core SMS functions, illustrating how SMS can be reframed to actively support adaptive capacity in flight operations. Fatigue Risk Management Systems exemplify resilience-oriented SMS evolution by replacing rigid duty-hour regulations with human-managed, context-adaptive safety controls that maintain operational flexibility (Cabon et al., 2017).

Table 4: SMS functions - operations overview.

SMS Function	Traditional Focus	Resilience-Oriented Reframing
Hazard identification	Past incidents and deviations	Weak signals, operational drift, emerging pressures
Safety assurance	Audits and compliance checks	Monitoring variability in normal operations
Safety promotion	Information dissemination	Learning-oriented dialogue and sensemaking
Training integration	Procedural correctness	Adaptive decision-making under uncertainty
Reporting systems	Error and violation capture	Insight into successful adaptations and trade-offs

CONCLUSION

This paper has examined the challenges associated with implementing resilience in flight operations and critically analysed the role of Safety Management Systems (SMS) as both an enabler and a constraint in this process. The analysis demonstrates that, while resilience is widely recognised as essential for managing complexity, uncertainty, and automation in modern aviation, its operationalisation remains limited by compliance-driven safety paradigms. SMS frameworks, although structurally aligned with resilience functions such as anticipation, monitoring, response, and learning, are frequently implemented in ways that privilege procedural adherence and retrospective investigation over proactive engagement with everyday operational variability.

The findings highlight that resilience in flight operations cannot be reduced to individual pilot skill or post-event recovery, but must be understood as a system-level property emerging from interactions between humans, technology, organisational practices, and regulatory structures. High levels of automation, efficiency-oriented performance metrics, and standardisation-focused training models can inadvertently erode adaptive capacity, particularly when SMS does not explicitly address human–automation coordination, cognitive flexibility, and sensemaking under uncertainty. Moreover, organisational cultures that struggle to fully embed Just Culture principles constrain the learning processes required to transform operational experience into sustained safety improvement.

The paper concludes that advancing resilience in flight operations requires a deliberate reframing of SMS from a static compliance mechanism to a dynamic, learning-centred system that supports adaptive performance. A resilience-enhanced SMS should prioritise the monitoring of normal work, the identification of weak signals and operational drift, and the cultivation of adaptive cognitive and teamwork skills through training and organisational learning loops. By integrating resilience engineering principles into SMS practice, aviation organisations can strengthen their capacity to manage complexity proactively, sustain human performance under stress, and enhance long-term safety in increasingly automated and uncertain operational environments.

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REFERENCES

Cabon, P., Deharvengt, S., Berechet, I., Grau, J. Y., Maille, N., & Mollard, R. (2017). From flight time limitations to fatigue risk management systems: A way toward resilience. In Resilience Engineering in Practice, Volume 2 (pp. 73–86). CRC Press.

Cabral, M., & Dutta, P. C. (2025). How organisations can adapt and evolve their safety management systems to foster a culture that prioritises safety at every level. Safety Science, 171, 106392. https://doi.org/10.1016/j.ssci.2024.106392

Dekker, S. (2014). *Just culture: Balancing safety and accountability* (2nd ed.). Ashgate.

Hancock, P. A., & Cruit, J. (2024). Resilience in operators, technologies, and systems. Applied Ergonomics, 115, 104172. https://doi.org/10.1016/j.apergo.2023.104172

He, P., Lu, F., Sun, R., & Zhang, Z. (2025). Examining influencing factors and their hierarchical relationships in flight crew resilient behavior through a hybrid ISM-DEMATEL approach. Safety Science, 172, 106418. https://doi.org/10.1016/j.ssci.2024.106418

Hollnagel, E. (2014*). Safety-I and Safety-II: The past and future of safety management*. Ashgate.

International Civil Aviation Organization. (2018). *Safety management manual (SMM)* (4th ed.; Doc 9859). ICAO.

No, H. W., & Chang, W. (2024). A study on practical guidelines for resilient flight operation behavior through case analysis based on integrated safety management system. Applied Sciences, 14(3), 1183. https://doi.org/10.3390/app14031183

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2008). Situation awareness, mental workload, and trust in automation: Viable, empirically supported cognitive engineering constructs. *Journal of Cognitive Engineering and Decision Making, 2(2),* 140–160. https://doi.org/10.1518/155534308X284417

Reason, J. (1997). *Managing the risks of organizational accidents*. Ashgate.

Woods, D. D. (2015). Four concepts for resilience and the implications for the future of resilience engineering. *Reliability Engineering & System Safety, 141, 5–9*. https://doi.org/10.1016/j.ress.2015.03.018

Ziakkas, D. (2023). Human-centric safety management in complex socio-technical systems: Implications for resilience and adaptive performance. In *Proceedings of the AHFE International Conference on Human Factors in Transportation*. Springer.