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An Integrated Framework for Implementing Safety-I and Safety-II Principles in Aviation Safety Management

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Abstract: Despite advanced aviation safety systems, recurring operational failures demonstrate that current safety management system (SMS) implementation practices remain predominantly reactive, with organizations adopting SMS frameworks theoretically embracing Safety-II philosophy while continuing Safety-I-oriented reactive management. This study develops an integrated framework for implementing both Safety-I and Safety-II principles in aviation safety management, addressing the gap between SMS theoretical requirements and actual implementation. Using the HEAR (human error analysis and reduction) framework, we analyzed three representative aviation cases involving FMS operation, turbulence response, and aircraft energy management through a qualitative multiple-case study design. Data collection utilized internal safety reports, official investigation reports, and reconstructed operational scenarios. The analysis employed a four-phase approach integrating predetermined categorization with inductive pattern recognition. Results revealed that 87% of all causes were organizational factors—6.7 times higher than individual/task factors (13%)—yet safety management responses primarily target individual behaviors. We defined "flight crew's resilient behavior" and developed implementation guidelines by integrating the HEAR framework with the LPAC (learn, plan, adapt, coordinate) model and PAM (pressures, adaptations, and manifestations) framework. Effectiveness evaluation demonstrated a transition from 54 discrete contributing factors to 19 systematically related factors with clearer implementation pathways. Our integrated framework enables organizations to systematically implement both Safety-I analytical capabilities and Safety-II adaptive responses, transforming safety management from reactive "failure prevention" to proactive "success expansion".

Keywords: safety-I; safety-II; integrated framework; aviation safety management; resilient behavior

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1. Introduction

1.1. Research Background

The aviation industry maintains exceptionally high safety standards through continuous technological development and systematic implementation of safety management systems (SMSs) [1,2]. While advanced technology and data-driven safety approaches have significantly reduced catastrophic accidents [2,3], recurring operational failures in routine operations reveal fundamental implementation gaps between safety theory and actual practice.

Analysis of aviation safety management reveals critical implementation challenges despite mature SMS frameworks. First, our preliminary investigation reveals that 87% of failure causes stem from organizational factors. Yet safety departments focus predominantly on individual behavior modification and procedural compliance. Second, similar operational errors, such as FMS (flight management system)-related deviations, recur within short timeframes despite SMS continuous improvement requirements, as evidenced by incidents occurring at 2-month intervals [4,5]. Third, adverse events such as turbulence-related crew injuries persist despite repeated conventional safety responses [4,6], indicating ineffective implementation of Safety-II learning mechanisms [7]. Fourth, safety managers operate with limited analytical tools and time constraints, preventing systematic implementation of Safety-I root cause analysis to address fundamental organizational factors [8]. These challenges create an implementation paradox. Organizations adopt SMS frameworks that theoretically embrace Safety-II philosophy, yet they continue Safety-I reactive practices in actual operations.

This research addresses these implementation challenges by developing an integrated framework that bridges the gap between SMS theoretical requirements and operational implementation. Our approach combines systematic Safety-I analysis through the HEAR (human error analysis and reduction) framework [9] with Safety-II adaptive capabilities through the LPAC (learn, plan, adapt, coordinate) model [10,11] and PAM (pressures, adaptations, and manifestations) framework [12]. Our research develops such an integrated implementation framework specifically tailored for aviation safety contexts, providing concrete tools for systematic organizational change rather than competing paradigm discussions.

1.2. Research Objectives

This research develops a practical framework for implementing both Safety-I and Safety-II principles in aviation safety management. The fundamental goal is to transform the theory–practice gap in SMS implementation into systematic organizational change that addresses underlying organizational factors.

Our integrated implementation framework addresses three interconnected objectives. First, we systematically identify and analyze organizational factors underlying aviation failures through the HEAR framework. This demonstrates the predominance of system-level issues over individual errors in aviation safety incidents. Second, we define and operationalize "flight crew's resilient behavior" based on Safety-II methodology to enhance adaptive operational capabilities that complement systematic organizational improvements. This creates specific implementation guidelines for transforming failure cases into resilient success cases. Third, we transform the safety management paradigm from "failure prevention" to "success expansion" through the integrated application of both methodologies, thereby enhancing organizational safety culture through systematic coordination of Safety-I analytical capabilities and Safety-II adaptive responses rather than treating them as competing approaches.

The research methodology employs three representative aviation cases—FMS operation errors, turbulence response failures, and energy management issues—as proof-of-concept demonstrations for the integrated framework rather than statistical generalization. These cases are strategically selected to represent technical, environmental, and managerial aspects of aviation operations, providing comprehensive validation of the framework's applicability across different operational contexts.

This research contributes to aviation safety management by providing concrete tools for implementing Safety-I and Safety-II principles that bridge the gap between SMS theoretical requirements and actual operational practice. The integrated framework offers safety managers, aviation organizations, and training institutions specific methodologies for addressing organizational factors currently overlooked in implementation, transforming reactive safety management into proactive organizational capability building.

1.3. Research Process

This study employs a systematic research approach to develop and validate an integrated framework for implementing Safety-I and Safety-II principles in aviation safety management. The research methodology combines theoretical analysis, case study investigation, and framework development. This approach bridges the implementation gap between theoretical SMS requirements and actual operational practice.

The study is structured across six sections that build systematically toward comprehensive safety management improvement. Section 2 establishes theoretical foundations through an examination of the evolution of safety management systems.

Section 3 presents the theoretical framework and research methodology, demonstrating the systematic integration of three complementary frameworks (HEAR-LPAC-PAM) and establishing methodological approaches for empirical investigation.

Section 4 conducts a systematic failure case analysis using the Safety-I methodology to identify organizational factors underlying aviation safety incidents. Three representative cases covering FMS operation errors, turbulence response failures, and energy management issues are analyzed, demonstrating the predominance of organizational over individual factors in aviation failures.

Section 5 develops a flight crew's resilient behavior framework based on the Safety-II methodology, building upon the organizational factors identified in the failure analysis.

Section 6 presents the integrated application of the Safety-I and Safety-II methodologies, demonstrating how systematic organizational analysis and adaptive capability building can be implemented simultaneously. The integrated framework is validated through comparative effectiveness evaluation, examining improvements in organizational issues and identifying requirements for systematic enhancement of education and training systems.

2. Literature Review

This literature review examines the evolution of aviation safety management paradigms, organizational factors in aviation safety, and implementation challenges to lay the theoretical foundation for integrated Safety-I and Safety-II implementation.

2.1. Safety Management Paradigm Evolution and Integration Challenges

Recent publications in *Safety* demonstrate the ongoing evolution of aviation safety management paradigms and persistent implementation challenges. Ham (2021) [13] published a comprehensive review explaining that traditional Safety-I concepts have contributed significantly to enhancing industrial system safety. However, they prove insufficient for complex socio-technical systems.

Stroeve et al. (2022) [14] developed the SMS Maturity Assessment and Refinement Tool (SMART). This tool assesses SMS maturity while integrating Safety-II and resilience engineering insights. Their Safety journal publication revealed that organizations face significant challenges in developing informal and human-related factors while maintaining resilience to changing demands. Stroeve et al.'s research confirms that Safety-II has not provided immediately usable practical solutions that fit well with SMS and operational processes. This directly supports the implementation gap addressed in this study.

Despite the widespread SMS adoption that includes Safety-II capabilities such as proactive risk management and organizational learning [4], organizations continue to rely on reactive management in actual operations [8].

2.2. Organizational Factors in Aviation Safety

Aviation safety research consistently shows that human factors are involved in 70–80% of all civil and military aviation accidents, with organizational factors accounting for a much larger proportion than individual factors [15,16]. The Human Factors Analysis and Classification System (HFACS) has been extensively applied in aviation contexts, showing consistent patterns where organizational factors predominate over individual causation [17–19].

Kharoufah et al.'s (2018) comprehensive review of commercial aviation accidents from 2000 to 2016 provides quantitative evidence that organizational factors consistently outweigh individual factors [20]. Kontogiannis and Malakis (2012) identified recurring organizational breakdown patterns, demonstrating that root causes lie in complex organizational factors including systemic decision-making weaknesses and gaps between safety management systems and operational practices [21].

Resilience engineering has emerged as the theoretical foundation for Safety-II implementation, emphasizing socio-technical systems' ability to adjust function despite changes and disturbances [13]. However, Pillay et al. (2020) documented fundamental measurement gaps in resilience engineering, revealing wide conceptual diversity, theoretical fragmentation, and an absence of shared analytical frameworks that confuse organizations about implementation focus [22].

2.3. Implementation Gaps and Research Needs

Current literature shows significant gaps between the theoretical development of integrated Safety-I and Safety-II approaches and practical implementation in aviation contexts. Research consistently documents implementation challenges but provides limited comprehensive frameworks that systematically combine Safety-I analytical capabilities with Safety-II adaptive responses.

Safety-I methodologies like HFACS provide systematic frameworks for accident analysis. However, they focus primarily on post-accident reactive investigation rather than proactive organizational improvement. Conversely, Safety-II frameworks like LPAC and PAM provide adaptive capability development. However, they have limited integration with systematic organizational analysis tools [10–12].

Where previous studies such as Stroeve et al. (2022) or Pillay et al. (2020) identify these implementation barriers [14,22], they provide limited practical guidance for operational integration in complex aviation environments. While these studies have established theoretical foundations, they offer few actionable tools that aviation organizations can immediately implement.

This study addresses these gaps by developing an integrated framework that systematically combines Safety-I analytical capabilities with Safety-II adaptive responses. The research integrates the HEAR framework for systematic organizational analysis with the LPAC and PAM models for adaptive capability development, providing practical implementation tools that bridge the identified theory–practice gap [9,11,12].

This research contributes to the literature by providing the first comprehensive integrated framework validated through systematic case study analysis, addressing the critical implementation gaps, and advancing both theoretical understanding and practical application of integrated safety management approaches in aviation contexts.

3. Theoretical Framework and Research Methodology

This section presents the study's theoretical foundation through the systematic integration of three complementary frameworks and establishes the methodological approach for empirical investigation. The integration addresses implementation gaps through coordinated tool application rather than sequential paradigm adoption, providing comprehensive analytical capability for aviation safety management implementation.

3.1. Theoretical Framework

3.1.1. Integration Logic of HEAR-LPAC-PAM Frameworks

The HEAR-LPAC-PAM integration addresses implementation gaps through coordinated tool application, recognizing that effective safety management requires systematic organizational analysis capabilities (Safety-I) combined with adaptive operational responses (Safety-II).

The integration builds on complementary theoretical strengths: Safety-I provides systematic causation analysis through established frameworks like HFACS, while Safety-II offers adaptive capability development through resilience engineering principles [7,16]. However, existing research demonstrates that neither approach alone addresses the implementation paradox. Organizations adopt advanced SMS frameworks yet continue reactive practices [14].

The HEAR framework enables systematic Safety-I implementation by providing structured organizational factor identification, addressing the limitation identified by Pillay et al. (2020) regarding fragmented analytical approaches [22]. The LPAC model transforms abstract Safety-II concepts into concrete behavioral capabilities, addressing the practical implementation gap documented by the MITRE Corporation (2024) [23]. The PAM framework coordinates both paradigms based on operational context, preventing the default to reactive patterns that characterize current SMS implementation challenges.

Table 1 summarizes the key elements and expected effects of the integrated approach.

Table 1. Integration framework for the Safety-I and Safety-II methodologies (based on paradigms defined in Section 2.1) (the authors' synthesis based on Hollnagel, 2015 [2]; American Airlines, 2020 [10]; Flight Safety Foundation, 2022 [12]).

Key Elements	Safety-I Application	Safety-II Application	Integration Effects
Analysis Method	HEAR framework	LPAC model, PAM framework	Systematic failure analysis and resilience enhancement
Primary Focus	Root cause identification	Adaptation strategy development	Comprehensive safety management approach
Implementation Tools	Why–Because Tree	Resilient behavior definition	Practical application guidelines
Expected Effects	Failure prevention	Success expansion	Sustainable safety improvement

3.1.2. HEAR Framework: Safety-I Organizational Analysis

The HEAR framework enables systematic Safety-I implementation by progressing through three analytical levels that address the organizational factor predominance identified in aviation safety research. Level 1 analyzes direct errors, Level 2 examines personnel/task factors, and Level 3 investigates organizational factors including regulations, education, management, and culture [9].

In this research, the HEAR framework analysis categorizes all contributing factors using predetermined organizational categories to identify systematic patterns across the three cases, following methodological approaches validated in safety literature. Table 2 presents the detailed structure of the HEAR framework analytical levels.

Table 2. HEAR framework analytical structure (based on the HEAR Framework).

Level	Category	Subcategories	Focus Areas
Level 1	Direct errors	Information recognition errors, decision-making errors, execution errors	Immediate manifestation of system failures
Level 2	Personnel/task factors	Worker knowledge/experience/abilities, task characteristics	Individual and task-related contributing factors
Level 3	Organizational factors	Regulations and procedures, human resource management, management and supervision, organizational culture	Systematic organizational deficiencies

3.1.3. LPAC Model: Safety-II Behavioral Implementation

The LPAC model transforms theoretical Safety-II principles into operational behaviors through four systematic components, addressing implementation challenges identified in resilience engineering research [10,11].

The four components work systematically to address different aspects of resilience building. "Learn" encompasses knowledge acquisition and experience sharing bridging individual and organizational learning gaps. "Plan" involves proactive scenario development addressing reactive versus anticipatory response gaps. "Adapt" focuses on real-time response capabilities resolving rigid procedural versus flexible operational requirement gaps. "Coordinate" emphasizes effective communication bridging individual actions and team-based safety management [10,11]. Table 3 details the LPAC model components and their specific applications.

Table 3. LPAC model components and applications (based on American Airlines, 2020, 2021) [10,11].

Component	Definition	Key Activities	Implementation Focus
Learn	Knowledge acquisition and experience sharing	Apply previous learning, debrief experiences, seek knowledge, share knowledge	Individual and organizational learning integration
Plan	Proactive scenario development	Develop "what if" scenarios, discuss expected actions, establish countermeasures	Reactive to anticipatory response transformation
Adapt	Real-time response capabilities	Address unanticipated pressures, adjust communication, change systems, manage workload	Rigid to flexible operational requirement resolution
Coordinate	Effective communication and teamwork	Affirm information, ask for assistance, cross-check actions, monitor status	Individual to team-based safety management

3.1.4. PAM Framework: Integration Coordination

The PAM framework coordinates Safety-I and Safety-II implementation through systematic operational dynamics analysis across three elements, addressing integration challenges identified in resilience engineering research [12].

The three elements work together to address integration challenges. "Pressures" identify external demands and internal efficiency requirements that create implementation challenges [24]. "Adaptations" analyze system response mechanisms [24], connecting HEAR organizational analysis with LPAC adaptive capabilities. "Manifestations" examine actual system responses, demonstrating [24] integrated implementation effectiveness across operational contexts.

The "manifestations" element examines five distinct patterns of operational resilience that demonstrate how integrated implementation effectiveness materializes in actual aviation operations: (1) remaining within the prevention space through proactive risk management, (2) recovering from critical states when approaching safety margins, (3) recovering from hazardous states through coordinated interventions, (4) rebounding back within the safety control envelope after temporary deviations, and (5) enveloping expansion through enhanced operational capabilities developed from experience integration [12,25].

Table 4 summarizes the PAM framework elements and their coordination functions.

Table 4. PAM framework elements and coordination functions (based on Flight Safety Foundation, 2022) [12].

Element	Definition	Analysis Focus	Coordination Function
Pressure	External demands and internal efficiency requirements	Demand pressure, efficiency pressure, conflicting pressure	Implementation challenge identification
Adaptations	System response mechanisms	HEAR organizational improvements, LPAC adaptive capabilities	Safety-I and Safety-II coordination
Manifestations	Actual system responses	Prevention maintenance, crisis recovery, range expansion	Implementation effectiveness evaluation

3.1.5. Framework Integration Effectiveness and Validation

Integrated framework application enables systematic effectiveness evaluation through comparative before–after analysis using standardized HEAR categorization schemes. The evaluation methodology employs Why–Because Tree analysis for visual confirmation of causal relationship changes and comparative contributing factor analysis for systematic assessment of organizational improvement patterns.

3.2. Research Methodology

3.2.1. Philosophical Position and Research Paradigm

This study adopts a pragmatic philosophical approach to address the implementation gap between Safety-I and Safety-II theoretical integration and actual organizational practice [26]. A pragmatic approach is adopted, consistent with Creswell (2022), [27] who emphasizes that pragmatism is problem-centered, pluralistic, and real-world practice-oriented. This philosophical position is particularly relevant for aviation safety research, where theoretical frameworks must translate into operational improvements and practical risk mitigation strategies.

3.2.2. Qualitative Research Design

This study employs a qualitative multiple case study design, following established approaches in aviation safety research, particularly suitable for investigating complex organizational factors underlying safety management implementation challenges [16,20,21]. The research design emphasizes maximum variation sampling, selecting cases representing technical (FMS operations), environmental (turbulence response), and managerial (energy management) aspects of aviation operations.

The case selection strategy ensures comprehensive representation across different operational domains (Table 5): Case 1 focuses on technical aspects through FMS operation-related failure cases, Case 2 addresses environmental factors through turbulence response incidents, and Case 3 examines managerial elements through energy management failure cases. Each case type addresses specific organizational issues, including inadequate education systems, limited analytical capabilities, and persistent traditional approaches.

Table 5. Case selection criteria and characteristics.

Case	Type	Operational Aspect	Specific Phenomenon	Main Organizational Issues
Case 1	FMS operation related	Technical	Path/altitude deviation	Inadequate FMS function education, limited safety manager analytical capabilities
Case 2	Turbulence related	Environmental	Crew injury	Insufficient adverse weather response education, traditional safety management persistence
Case 3	Energy management related	Managerial	Approach abort	Inappropriate energy management education, traditional approach persistence

3.2.3. Sampling Strategy and Case Selection

This study employs purposive convenience sampling, appropriate for qualitative research aimed at theoretical development rather than statistical generalization.

3.2.4. Data Collection and Sources

This study utilizes multiple data sources to ensure comprehensive case analysis and enable triangulation for enhanced credibility. Internal safety communications were accessed through the researcher's legitimate operational role via established organizational safety reporting systems, with complete anonymization of personnel, timing, and identifying details.

Primary data sources include internal safety reports from Cases 1-1 and 1-2, derived from airline internal safety notices. Official investigation reports serve as secondary data sources, with Case 2 utilizing publicly available ARAIB accident investigation reports [6]. Case 3 represents reconstructed operational scenarios to prevent association with specific incidents.

3.2.5. Data Analysis Procedures

The analytical approach integrates predetermined categorization (HEAR framework) with inductive pattern recognition (LPAC and PAM frameworks) to enable both systematic organizational factor identification and emergent behavioral guideline development. Analysis progressed through four systematic phases designed to maximize analytical rigor while maintaining practical relevance (Table 6).

Each safety case was systematically reviewed using a structured HEAR coding template, with codes recorded in Excel across three HEAR framework levels. Recurring patterns were grouped into emergent themes, which directly informed resilient behavior guidelines using the LPAC model based on the American Airlines Learning and Improvement Team's Master CodeBook [11]. Flight crew resilient behaviors in each case were systematically analyzed through iterative review across LPAC (learn, plan, adapt, coordinate) categories and incorporated into the research findings.

PAM coordination mechanisms were mapped deductively by analyzing operational pressures, resource constraints, and decision-making processes evident within each case, establishing linkages between organizational factors and adaptive responses. The PAM framework systematically bridges LPAC-developed behaviors with operational contexts through three coordinated elements: identifying specific operational pressures that create implementation demands, mapping how LPAC components provide structured responses to these pressures, and evaluating manifestations of integrated implementation effectiveness in actual aviation environments.

Table 6. Data analysis procedures and applications (the authors' methodological framework synthesis based on aviation safety case study research approaches).

Phase	Method	Framework Applied	Analytical Focus	Expected Outcomes
Phase 1	HEAR coding analysis	HEAR framework	Systematic coding using a structured template across three levels (direct errors, personnel/task factors, and organizational factors)	Individual case factor identification and Excel-based categorization
Phase 2	Cross-case pattern recognition	HEAR framework	Comparative analysis of recurring categorical patterns across all three cases	Common organizational deficiency patterns and implementation challenges
Phase 3	Resilient behavior development	LPAC model (AA LIT CodeBook)	Iterative review across LPAC categories (learn, plan, adapt, coordinate) for each case	Case-specific resilient behavior guidelines and behavioral frameworks
Phase 4	Integration coordination	PAM framework	Deductive mapping of operational pressures, resource constraints, and decision-making processes	Linkages between organizational factors and adaptive responses with effectiveness validation

3.2.6. Trustworthiness and Rigor

This study ensures trustworthiness through multiple strategies addressing credibility, transferability, dependability, and confirmability. Credibility is ensured through comprehensive data triangulation using multiple sources, including internal safety reports, official accident investigations, operational scenarios, and regulatory documentation. Transferability is enhanced through detailed case descriptions and systematic documentation of analytical procedures, enabling other researchers to apply similar approaches in comparable aviation safety contexts. Extended domain engagement leverages the researcher's 23 years of aviation industry experience, providing deep contextual understanding and the ability to recognize significant patterns that might be overlooked by researchers without domain expertise.

3.2.7. Researcher Reflexivity

The researcher's position as an aviation professional with 23 years of flight operations experience provides both analytical advantages and potential limitations requiring systematic reflexive consideration. Analytical advantages include a deep contextual understanding of aviation safety management practices, enabling accurate interpretation of complex operational scenarios and organizational dynamics. Potential limitations include an industry insider perspective potentially limiting external viewpoints and possible unconscious bias toward current industry practices. Bias mitigation strategies include systematic framework application to minimize subjective interpretation, with predetermined HEAR categorization providing structured analytical procedures.

4. Analysis of Failure Cases and Safety Management Behavior Through Safety-I Methodology

Building upon the integrated theoretical framework established in Section 3, this section demonstrates its practical application through systematic analysis of three representative aviation failure cases using the HEAR framework to identify organizational factors underlying safety incidents. The analysis demonstrates how current safety management practices fail to implement effective Safety-I systematic analysis, revealing predominant organizational causation that current SMS implementation overlooks.

4.1. Case Analysis and Reconstruction

The three cases are analyzed through systematic application of the HEAR framework methodology detailed in Section 3.1.2, enabling comprehensive identification of organizational factors underlying each failure pattern. Cases utilize inherently anonymized data sources without personal identification information, following ethical research practices established in Section 3.2.7. Cases 1-1 and 1-2 derive from airline internal safety notices focusing on operational procedures and organizational factors. Case 2 utilizes publicly available ARAIB accident investigation reports following standard anonymization practices. Case 3 represents reconstructed operational scenarios generalized to prevent association with specific incidents while maintaining analytical relevance for comprehensive framework application. The case selection strategy ensures representation of different operational domains and organizational challenges, providing a comprehensive foundation for developing integrated Safety-I and Safety-II implementation approaches. Table 7 presents a comprehensive overview of all three cases, showing their operational contexts and primary characteristics.

Table 7. Case detail summary.

Category	Case 1	Case 2	Case 3
Case Type	FMS operation related	Turbulence related	Energy management related
Occurrence Phase	Instrument approach phase	Climb phase	Instrument phase
Specific Phenomenon	Path/altitude deviation	Crew injury	Approach abort
Detailed Situation	Case 1-1: safety altitude violation Case 1-2: approach path deviation	Altitude 16,700 feet during climb, encountered turbulence resulting in cabin crew left ankle fracture	High energy state [1] continuation resulting in unstable approach and landing abort
Main Cause	Inadequate FMS function education, inappropriate manual input procedures	Inadequate turbulence avoidance strategy formulation/execution	Inappropriate energy management strategy
Education/Training Related Elements	Inadequate FMS operation principle education system	Insufficient adverse weather response education	Inappropriate energy management education system
Organizational Related Elements	Limited systematic analysis capabilities	Habitually repeating conventional safety education	Adherence to traditional navigation methods Traditional approach persistence

Note: [1] High energy state refers to "too high or too fast or both" conditions during the approach phase [28].

4.1.1. Path and Altitude Deviation Due to Inappropriate Use of FMS Functions

Two related failure cases occurring at two-month intervals are analyzed as integrated incidents demonstrating systematic organizational deficiencies in FMS operation management. The first case involved the New York airport instrument landing system (ILS) 13L approach where path discontinuity occurred due to a mismatch between the STAR (Standard Arrival Procedure) endpoint and the IAP (Instrument Approach Procedure) starting point. During the manual input process to resolve the discontinuity, altitude restriction (2900 FT) input was omitted, resulting in a safety altitude violation that was resolved through Air Traffic Control altitude correction instruction. Table 8 provides a detailed reconstruction of this failure case.

Table 8. Case reconstruction 1-1: altitude deviation during the ILS RWY (instrument landing system runway) 13L approach at New York Airport.

Flight Phase	Event Status (Change in System Status)	Captain (CAPT)	First Officer (FO)	Air Traffic Controller (ATC)
FMS Set up	Refer to information from D-ATIS and enter landing runway and instrument approach procedure type into FMS.	Ordered FO to set up FMS for STAR (LENDY 8 ARR) & IAP (ILS13L)	Due to mismatch between endpoint of STAR and start point of IAP, it was not automatically entered into FMS. FO attempted to insert KMCHI and BUZON waypoints manually, and KMCHI altitude constraint value of 2,900 FT was additionally entered. However, BUZON altitude constraint of 2,900 FT input was missed.	
Approach Briefing	Conduct approach briefings based on checklists.	Checked and briefed information entered in FMS, including altitude constraint of manually entered point, but did not identify that altitude constraint was not entered.		
Descent	Controller instructed to head to KMCHI, one of IAFs, and to proceed with instrument approach clearance issued by KMCHI.			Direct to KMCHI, Descant to 2900 FT. Cleared ILS 13L
	Use FMS's Direct function to enter route to KMCHI	Ordered to FO "Direct to KMCHI"	Using FMS function key DCT, set course towards KMCHI.	
Initial Approach Segment	Leaving at KMCHI and commence instrument approach	Maintained altitude of 2900 FT and reached KMCHI, referring to altitude displayed on the ND (Navigation Display). Start descent from KMCHI to BUZON from 2900 FT to 1900 FT.		
	ATC alerts aircraft that it has descended below safe altitude			Climb and Maintain 2900 FT until BUZON. Follow Published Procedure
	Climb above safe altitude	Climbed above safe altitude per ATC's instruction. (Pilots did not recognize aircraft had descended below safe altitude before ATC corrected situation.)	Read-back of ATC instruction	
Final Approach Segment	Landing	Landed after entering published approach path.		

The second case involved the Haneda Airport ILS Z RWY 23 approach, where a similar path deviation occurred. This resulted from a STAR endpoint and ILS starting point mismatch. Inappropriate waypoints were entered during the manual input process to resolve the discontinuity. Path deviation occurred due to delayed FMS settings when changing instrument approach procedures. A normal approach path entry was achieved through Air Traffic Control guidance. Table 9 details the specific sequence of events and contributing factors.

Table 9. Case reconstruction 1-2: path deviation during the ILS Z RWY 23 approach at Haneda Airport.

Flight Phase	Event Status (Change in System Status)	Captain (CAPT)	First Officer (FO)	Air Traffic Controller (ATC)
FMS Set up	Refer to information from D-ATIS and enter landing runway and instrument approach procedure type into FMS.	Instructed FO to input STAR (XAC 1K ARR) IAP (ILS Y 34L) into FMS.	Input STAR and IAP into FMS.	
Approach Briefing	Conduct approach briefings based on checklists.	Conducted briefing based on approach procedure type set in FMS and relevant information confirmed.		
Descent	Delays in assigning runway and approach procedure type due to changes in weather conditions and increased traffic.	Instructed FO to confirm runway and approach procedure type with air traffic control.	Reconfirmed runway and approach procedure with air traffic control.	Conveyed that runway and approach procedure type have not been determined.
	Following air traffic control instructions for path adjustment and altitude descent for landing and for traffic separation.	Adjust aircraft's trajectory according to air traffic control's instructions.		
	Runway and approach procedure type set in FMS have been changed.	Instructed FO to change FMS settings.	Due to mismatch between endpoint of STAR at KAHIO and starting point of IAP which were not automatically entered into FMS, three omitted waypoints (STEAM, SWEET, SNAKE) were manually inputted. Additionally, waypoint SMILE, which was automatically selected by FMS, was determined to be incorrect and replaced with NYLON.	Direct to STEAM, Descend to 3000 FT, Speed ILS RWY 34L
Initial Approach Segment	Confirm FMS setting changes.	While confirming changes made to FMS settings, discrepancy with approach chart was discovered. Attempts were made to manually adjust it, but it remained unresolved as aircraft passed SNAKE point.		
	Air traffic control recognized that aircraft has deviated from its course.	Recovered to final approach course according to air traffic control instructions.		Air traffic controller, noticing deviation from course, guided aircraft back to final approach path.
Final Approach Segment	Landing	Entered normal approach path and landed.		

HEAR framework analysis reveals systematic organizational deficiencies underlying both incidents rather than individual errors. The Why–Because Tree analysis (Figure 1) demonstrates hierarchical progression from surface errors to organizational root causes, including inadequate training systems, conventional safety education approaches, and limited systematic analysis capabilities.

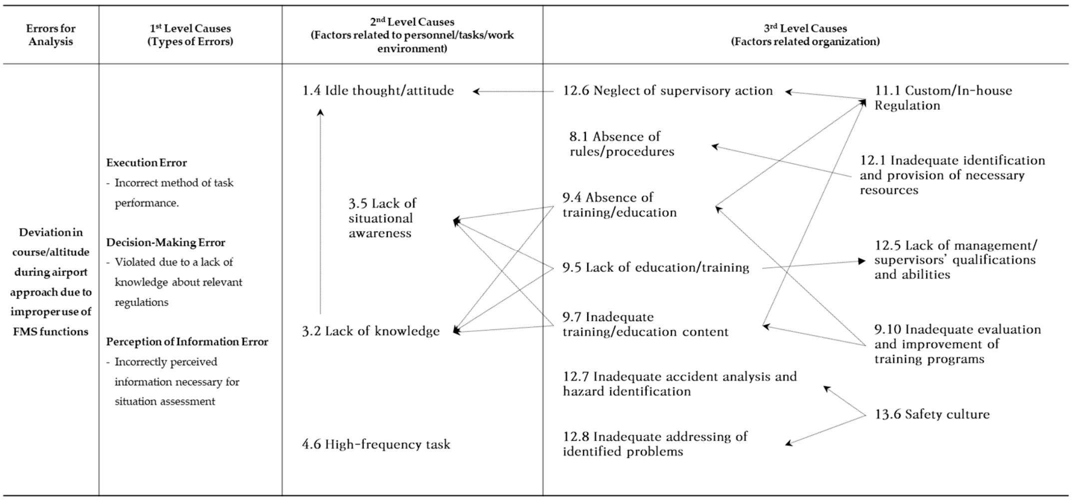

Figure 1. Why–Because Tree analysis (Case 1).

Organizational factor analysis reveals that workers demonstrated insufficient knowledge of STAR-IAP relationships and PANS-OPS standards in situations where ATC guides aircraft from STAR endpoints to intermediate segments [29]. Training programs provided insufficient theoretical and practical education content to prevent FMS-related failures, despite internal documentation specifying the necessity of waypoint input verification in similar situations.

Current safety management responses emphasize thorough approach procedure confirmation, enhanced briefing requirements, and strict procedural compliance. These interventions focus on individual behavior modification rather than addressing systematic organizational deficiencies identified through HEAR analysis. Figure 2 shows the distribution across organizational categories, with the management of an organization's human resources representing the predominant factor (53%), followed by management and supervision issues (20%), organizational processes and culture (13%), regulations and procedures characteristics (7%), and worker knowledge and abilities (7%).

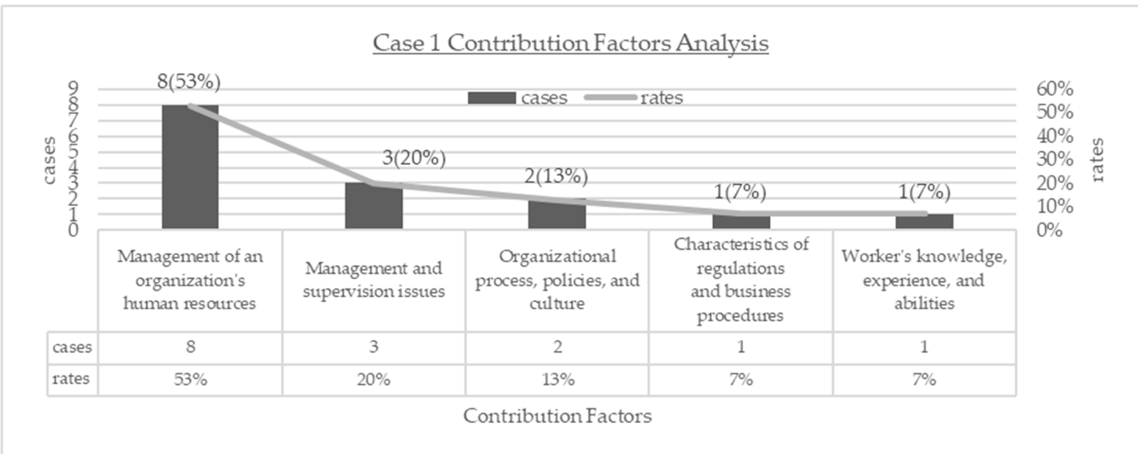

Figure 2. Contributing factor analysis (Case 1).

4.1.2. Crew Injury Due to In-Flight Turbulence

The turbulence encounter case is based on official accident investigation reports from Korea's Ministry of Land, Infrastructure and Transport's Aviation and Railway Accident Investigation Board (ARAIB). The aircraft was climbing at approximately 16,700 feet in an area where turbulence potential had been forecasted. While the cabin crew was moving to check passenger safety with the seat belt sign illuminated, body movement due to the turbulence encounter caused a loss of balance resulting in a fractured left ankle [6]. Table 10 provides a comprehensive reconstruction of this incident.

HEAR framework analysis reveals systematic deficiencies in turbulence response strategy formulation rather than individual weather assessment errors. The Why–Because Tree analysis (Figure 3) demonstrates the progression from the injury event to underlying organizational factors including deficient weather education systems and persistent conventional safety management approaches.

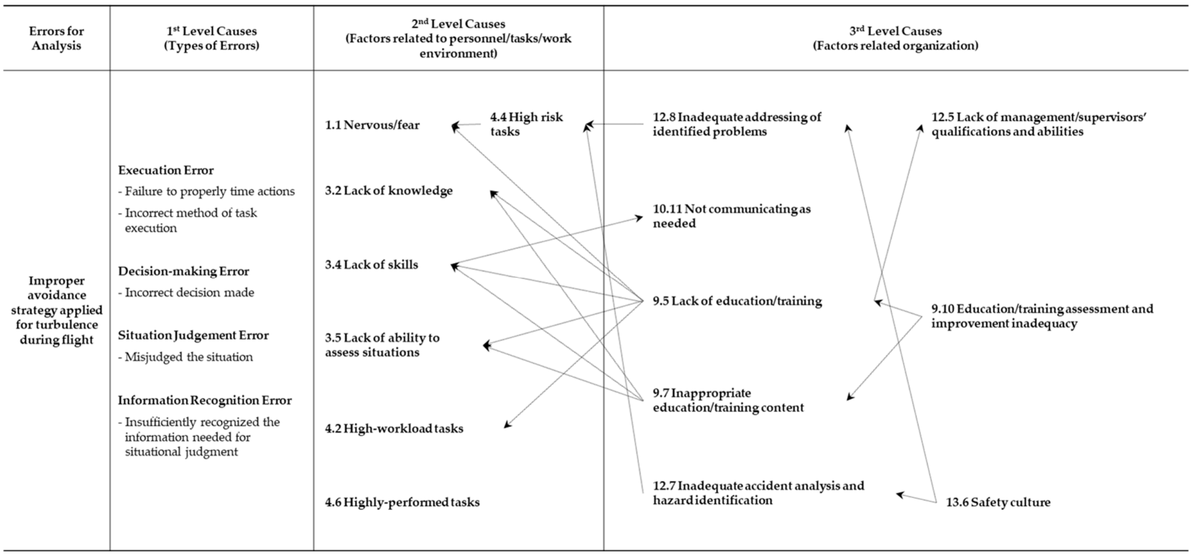

Figure 3. Why–Because Tree analysis (Case 2).

Analysis reveals that weather-related incidents stem from organizational failures in developing effective weather response capabilities. Training programs provided insufficient practical weather analysis education and failed to develop systematic turbulence avoidance capabilities, despite meteorological forecasting systems indicating potential turbulence areas along the flight route.

Current safety management responses demonstrate repetitive conventional safety emphasis items, addressing only surface measures while failing to properly address identified organizational issues. These interventions focus on crew procedural compliance and weather information utilization rather than addressing systematic organizational deficiencies identified through HEAR analysis.

Figure 4 displays the specific distribution of contributing factors for this case, with management of an organization's human resources representing the overwhelming majority (69%), followed by organizational processes and culture (13%), management and supervision issues (6%), worker knowledge and abilities (6%), and task characteristics (6%).

Table 10. Case reconstruction 2: cabin crew injury due to in-flight turbulence.

Time	Event Status (Change in System Status)	Captain (CAPT)	Purser	(Injured) Flight Attendant	Passenger Wanting to Use Lavatory
(Est 07:00:00)	Joint Briefing	Shared departure/arrival airport weather and turbulence-related information with crew.			
07:55:11		Depart from origin airport.			
(Est 08:00:00)	Around 10,000 FT during climb	Kept the seatbelt sign on due to observed precipitation and turbulence, communicated to the purser via intercom.			
(Est 08:02:00)	Passenger attempts to use the lavatory.			Advised passenger to remain seated due to turbulence while moving around aircraft.	Inquired with cabin crew about lavatory availability.
08:07:43	Cockpit weather radar identifies cloud formations.	Decided to climb to avoid cloud formation. While maintaining FL160, requested ACC for climb to FL260.		While attempting to unfasten seatbelt to check on passenger using lavatory, seatbelt sign chimed twice. During turbulence, lost balance, attempted to follow turbulence procedures, but twisted ankle. Subsequent turbulence caused body to jerk upward, placing weight on ankle and resulting in fall to floor.	
(Est 08:07:50)	Flight Attendant moves to lavatory area to check on passenger.				
08:07:57	Seatbelt sign chimed twice	Anticipated turbulence and activated seatbelt sign twice.	Made passenger announcement to prepare for turbulence.		
08:08:21	Turbulence occurs.				
08:15:00	Crew member's injury acknowledged and reported to relevant departments.		After turbulence subsided, reported to Captain about crew member's injury caused by turbulence and provided update on injured crew member's condition.		Passenger returned to seat.
		Condition of injured crew member and her position reported to sub-center using company communication network, and request for follow-up action made.			

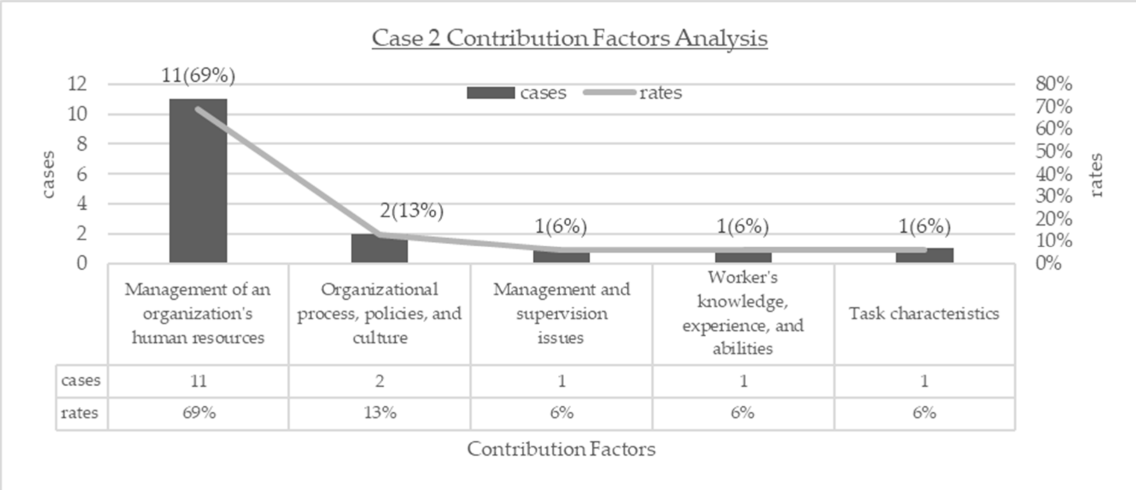

Figure 4. Contributing factor analysis (Case 2).

4.1.3. Approach Abort Due to Aircraft High Energy During Instrument Approach

The energy management case analysis is based on operational experience and flight crew expertise, focusing on systematic organizational factors rather than specific incident details. The initial problem was identified as pilot arbitrary speed reduction regardless of traffic flow management requirements. This led to a high energy state occurring during the control instruction process for airspace altitude restrictions and aircraft separation, ultimately resulting in an approach abort as landing standard altitude and speed criteria were exceeded. Table 11 details the operational sequence and contributing factors.

Although aborting an approach from an unstable approach condition is not generally considered a failure, attempting a landing without proper energy management exposes operations to serious risks including late landing gear completion, speed limit exceedance, runway excursion, and CFIT (Controlled Flight Into Terrain).

HEAR framework analysis reveals systematic organizational deficiencies in energy management education and persistent cultural preferences for traditional navigation methods. Figure 5 illustrates the causal progression identified through Why–Because Tree analysis.

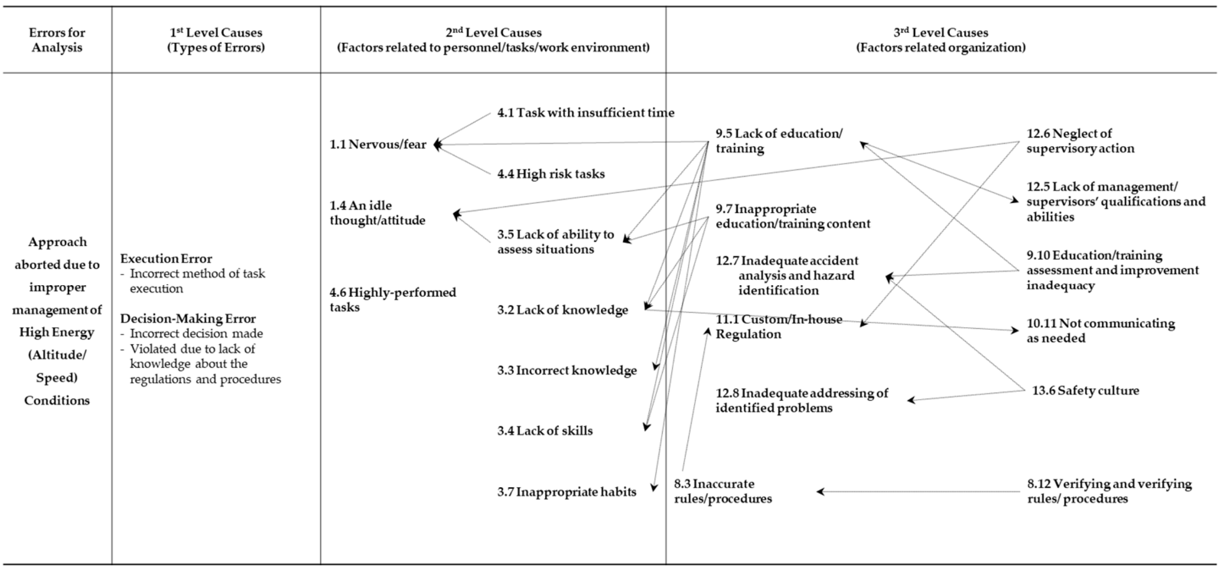

Figure 5. Why–Because Tree analysis (Case 3).

Analysis reveals that energy management failures stem from organizational inadequacies in systematic FMS-based education and cultural resistance to technology integration. Training programs provided insufficient FMS energy management education and failed to develop a systematic understanding of aircraft energy prediction capabilities, despite advanced FMS technology being available for optimal approach profile management.

Table 11. Case reconstruction 3: approach abort due to a high energy condition during the instrument approach.

Flight Phase	Event Status (Change in System Status)	Air Traffic Controller (ATC)	Captain (CAPT)	First Officer (FO)
Cruise	Pilot requests ATC for altitude descent from calculated Top of Descent (TOD).	Descent FL160 reach by OLMEN.	Request Descent	ICN CTL, XXX, REQUEST DESCENT
Descent (Idle Segment)			Complete altitude descent to FL160 before reaching OLMEN by 5 NM, and reduce speed to 250 KIAS.	
	ATC instructs the pilot to short cut the route.	OLMEN direct ENFIL	OLMEN direct ENPIL	FMS set OLMEN-ENPIL
Descent (Geometric Segment	Due to route short cut, aircraft's energy (altitude) increases.	Descent 13,000 FT	Begin descent to 13,000 FT, mentally calculated distance to ENFIL considering headwind/tailwind conditions.	
	Pilot requests further descent after reaching assigned altitude, but denied due to airspace restrictions.	Unable. Maintain 13,000 FT due to Airspace restriction.	Request further descent.	SEL APP, XXX, Request further descent
	Pilot initiates speed reduction to decrease aircraft's energy.	Descent 10,000 FT	DES 10,000 FT/Reduce speed to 210 KIAS during the descent.	
	ATC instructs pilot to maintain high speed, considering spacing between aircraft ahead and behind.	Speed Maintain 280 KIAS until 10,000 FT, and Reduce 250 KIAS until ENPIL. You are #1 traffic.		
	Pilot requested speed reduction, but ATC instructed to maintain highspeed considering separation.	Maintain Speed 250 KIAS below 10,000 FT	Request Normal Speed	Request Normal Speed
	Pilot received instructions to descend to 7000 FT at initial approach fix (IAF) and maintain a speed higher than normal approach speed.	Descend 7000 FT Cleared ILS 33R approach, Maintain 230 KIAS until ENPIL	Descend 7000 FT, Speed Maintain 230 KIAS	Descend 7000 FT. Cleared ILS 33R approach. Maintain 230 KIAS until ENPIL

Table 11. *Cont.*

Flight Phase	Event Status (Change in System Status)	Air Traffic Controller (ATC)	Captain (CAPT)	First Officer (FO)
Approach Segment	Pilot maintained 7000 FT and 230 KIAS until reaching the initial approach to (IAP) at which point deceleration and descent began for instrument approach.		Used speed brakes to reduce aircraft energy, but deceleration and descent were not sufficient.	
	Aircraft did not configure for landing prior to reaching final approach point (FAP), necessitating a go-around.			

Current safety management responses emphasize proactive requests for aircraft guidance from control agencies and compliance with standard operating procedures. These interventions focus on traditional approach reinforcement and standard procedure adherence rather than addressing systematic organizational deficiencies identified through HEAR analysis.

Figure 6 presents the comprehensive distribution of contributing factors. The distribution shows that the management of an organization's human resources represents the largest proportion (57%), followed by relatively equal distributions among management and supervision issues (9%), organizational processes and culture (9%), regulations and procedures characteristics (9%), worker knowledge and abilities (9%), and task characteristics (9%).

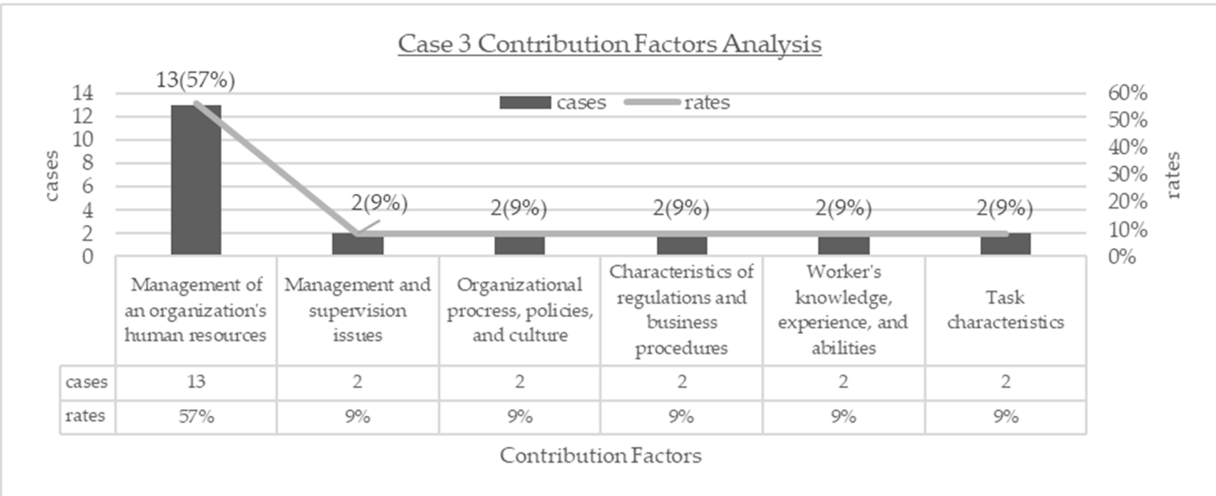

Figure 6. Contributing factor analysis (Case 3).

4.2. Comprehensive Analysis Results

4.2.1. Contributing Factor Analysis

The HEAR framework analysis across all three cases reveals systematic patterns demonstrating the predominant organizational nature of aviation safety challenges. Comprehensive statistical analysis of contributing factors provides quantitative evidence supporting the need for systematic organizational improvements rather than continued individual-focused interventions. Forty-seven out of fifty-four contributing factors (87%) are organization-related, representing a 6.7:1 ratio compared to individual and task factors (seven factors, 13%). This finding provides quantitative evidence that the root causes of aviation failures lie predominantly at organizational rather than individual levels. Human resource management represents the most significant organizational deficiency category, accounting for 32 out of 54 total factors (59.3%). Specific breakdowns include inadequate education and training (14 cases, 25.9%), inadequate educational content (10 cases, 18.5%), inadequate evaluation (5 cases, 9.3%), and absence of training (3 cases, 5.6%). Management and supervision factors account for six cases (11.1%), with supervisory neglect representing four cases (7.4%). Organizational processes, policies, and culture represent six cases (11.1%), indicating systematic cultural barriers to effective safety implementation. Personnel knowledge, experience, and abilities represent only four cases (7.4%), while task characteristics account for three cases (5.6%). The minimal proportion of individual factors confirms that safety improvement efforts should focus on organizational rather than individual capability enhancement, challenging conventional safety management approaches that emphasize individual behavior modification. Table 12 presents the complete statistical breakdown of contributing factors across all cases.

Table 12. Statistical analysis of related causes from failure cases.

Causes and Contributing Factors		Cases				Rates (%)			
		C1	**C2**	**C3**	**Total**	**C1**	**C2**	**C3**	**Total**
2nd Level: Personnel and Task Related	Personnel Knowledge and Experience					6.7	6.3	8.6	7.4
	- Insufficient knowledge	0	1	1	2				
	- Limited assessment ability	1	0	1	2				
	Task Characteristics					0.0	6.3	8.6	5.6
	- Insufficient time	0	0	1	1				
	- High-risk tasks	0	1	1	2				
3rd Level: Organization Related	Regulations and Procedures					6.7	0.0	8.6	5.6
	- Absence/inaccurate procedures	1	0	2	3				
	Human Resources Management					53.4	68.8	56.5	59.3
	- Absence of training	3	0	0	3				
	- Inadequate education	1	6	7	14				
	- Inadequate content	3	3	4	10				
	- Inadequate evaluation	1	2	2	5				
	Management and Supervision					20.0	6.3	8.7	11.1
	- Resource provision issues	1	0	0	1				
	- Supervisory neglect	2	0	2	4				
	- Inadequate analysis	0	1	0	1				
	Organizational Culture					13.3	12.5	8.7	11.0
	- Safety culture issues	2	2	2	6				
Total		15	16	23	54	100	100	100	100

Notes: C1: Case 1 (FMS operation); C2: Case 2 (turbulence); C3: Case 3 (energy management).

4.2.2. Safety Management Behavior Evaluation

Current safety management responses to the three failure cases reveal consistent patterns that demonstrate fundamental gaps in implementing Safety-I systematic analysis principles. Safety departments consistently focus on surface-level solutions targeting procedural compliance rather than conducting systematic organizational analysis to address the identified 87% organizational factors.

The FMS case response emphasized thorough approach procedure confirmation and briefing. The turbulence case response stressed enhanced weather confirmation and crew briefing. The energy management case response emphasized strict adherence to standard procedures. These interventions target the 13% individual factors while neglecting the 87% organizational factors identified through systematic analysis.

The persistent occurrence of similar failure cases despite safety interventions indicates fundamental failures in applying Safety-I systematic analysis principles. FMS-related deviations recurred at two-month intervals, turbulence-related injuries persisted across multiple incidents, and energy management issues continued despite conventional safety responses. This pattern confirms that current safety management approaches fail to address the predominant organizational causation revealed through systematic analysis.

This comparison reveals an implementation gap where organizations adopt SMS frameworks containing Safety-I systematic analysis elements while continuing reactive, individual-focused responses in practice.

4.3. Cross-Case Pattern Analysis

Cross-case analysis reveals consistent implementation challenges across all three cases, demonstrating systematic patterns that transcend individual incident characteristics. The analysis identifies recurring organizational deficiencies that create conditions enabling failure across different operational contexts, providing evidence for the need for comprehensive organizational transformation rather than case-specific interventions.

All three cases demonstrate fundamental inadequacies in education and training systems, representing 59.3% of total organizational factors. FMS operation cases reveal inadequate system principle education, turbulence cases show insufficient practical weather analysis training, and energy management cases indicate a preference for traditional methods over systematic approaches.

Consistent patterns of supervisory neglect and inadequate analysis capabilities appear across all cases, representing 11.1% of total factors. Safety managers demonstrate limited analytical capabilities, inadequate root cause identification skills, and a tendency toward reactive rather than systematic responses.

All cases demonstrate organizational cultural barriers to implementing systematic improvements, representing 11.1% of total factors. Organizations show a preference for traditional approaches, resistance to systematic analysis methodologies, and a tendency to repeat conventional safety responses despite their demonstrated ineffectiveness.

4.4. Implementation Gap Assessment

This comparison reveals an implementation gap where organizations adopt SMS frameworks containing Safety-I systematic analysis elements while continuing reactive, individual-focused responses in practice. Table 13 summarizes the comparison between safety management department responses and Safety-I methodology analysis results across all three cases.

The analysis demonstrates that existing safety management approaches consistently focus on individual behavior modification and procedural compliance, addressing surface-level symptoms rather than underlying organizational causes.

The quantitative evidence demonstrates that organizational factors represent 87% of contributing causes, yet current safety responses predominantly target the 13% individual factors, creating a fundamental misalignment between causal reality and intervention focus.

Table 13. Comparison of safety management department response and Safety-I methodology analysis results by case.

Case	Safety Management Department Response	Safety-I Methodology Analysis Results
Case 1: FMS Operation	Surface-level solutions emphasizing procedural compliance and individual behavior modification	Systematic organizational deficiencies in training systems and safety manager analytical capabilities
Case 2: Turbulence	Conventional safety emphasis focusing on crew procedures and weather information utilization	Educational inadequacies in practical weather analysis and persistent ineffective safety management approaches
Case 3: Energy Management	Traditional approach reinforcement with emphasis on standard procedure adherence	Organizational resistance to systematic FMS utilization and inadequate principle-based education
Cross-Case Pattern	Reactive individual-focused interventions targeting 13% of contributing factors	Systematic organizational improvements required for 87% of contributing factors

5. Development of Flight Crew's Resilient Behavior Framework

Building upon the organizational factors identified through Safety-I analysis in Section 4, this section develops a Safety-II implementation framework by defining and operationalizing the flight crew's resilient behavior. The systematic identification of predominant organizational factors (87%) underlying aviation failures necessitates coordinated development of adaptive capabilities that enable flight crews to successfully manage adverse events while organizations implement the structural improvements identified through HEAR analysis.

5.1. Definition of Resilient Behavior

This study defines "flight crew's resilient behavior" as "the capability of flight crews to successfully manage adverse events by effectively utilizing aircraft systems, predicting and planning for adverse events based on effective learning". This definition reflects Safety-II characteristics by emphasizing the successful management of operational challenges rather than merely preventing failures. The definition directly addresses the implementation gap between SMS theoretical requirements and actual operational practice identified in Section 4.

The definition incorporates four core elements that systematically implement Safety-II principles in aviation operations while addressing the organizational deficiencies revealed through HEAR analysis. First, high-level effective learning includes professional knowledge acquisition about aircraft operation, skill enhancement through actual operational experience, and learning from various situations' success and failure cases [3,30,31].

Second, the ability to predict and plan for adverse events involves identifying potential risk factors in advance, establishing response plans for situation changes, and preparing contingencies for various scenarios [2,7,32]. This element implements the Safety-II anticipate capability by developing proactive rather than reactive operational approaches, directly addressing the reactive management patterns identified in current safety management behavior evaluation.

Third, effective utilization of aircraft systems means optimal operation based on a comprehensive understanding of systems in both normal and abnormal situations and an understanding of system limitations and alternatives [13,32,33]. This element implements systematic integration of technological capabilities with human adaptive responses, addressing the organizational tendency toward traditional methods and inadequate system understanding identified across all three failure cases.

Fourth, successful management of adverse events involves real-time situation awareness and response, flexible and timely decision-making, and effective problem-solving capability in abnormal situations [2,3,7,13,32]. This element implements the Safety-II "respond" and "monitor" capabilities by developing adaptive operational responses that complement the systematic organizational improvements identified through Safety-I analysis.

5.2. Theoretical Basis of Resilient Behavior

The theoretical foundation for implementing resilient behavior combines Rasmussen's SRK (Skills, Rules, Knowledge) framework [30,31] and metacognition-motivation theory [34] to provide a systematic basis for transforming the education and training approaches identified as deficient in the organizational analysis. This theoretical approach directly addresses the implementation gaps revealed through HEAR analysis while providing a structured foundation for Safety-II capability development.

Rasmussen's SRK framework provides essential understanding for implementing effective resilient behavior in aviation operations. According to this framework, skill-based behavior occurs as automated patterns without conscious control, rule-based behavior follows established procedures or regulations, and knowledge-based behavior requires high-level cognitive effort for problem-solving in novel situations [30,31]. The failure case analysis in Section 4 revealed that current education approaches focus predominantly on providing rule-based knowledge, which proves inadequate for the complex operational situations identified in the three cases.

The organizational deficiencies identified through HEAR analysis demonstrate that rule-centered training approaches fail to develop the adaptive capabilities required for effective operational performance. FMS operation failures resulted from an inadequate understanding of system principles, turbulence response failures occurred due to an inability to adapt procedures to dynamic conditions, and energy management failures stemmed from rigid adherence to traditional approaches rather than systematic technology utilization.

Metacognition and motivation theories provide additional foundations for implementing effective learning approaches. Metacognition represents the ability to understand one's cognitive state and apply learning strategies effectively, while motivation serves as the driving force that enhances learning behavior and achievement [25]. These theoretical elements support the development of education approaches that build adaptive capabilities rather than merely transferring procedural knowledge.

5.3. Case-Specific Resilient Behavior Enhancement Methods

This section develops specific implementation guidelines for resilient behavior based on the three failure cases analyzed in Section 4, demonstrating how Safety-II principles can be systematically implemented to address organizational deficiencies. The enhancement methods apply the LPAC model to transform failure patterns into resilient success capabilities. Table 14 presents the comprehensive framework for each case, while Table 15 provides detailed implementation guidelines for the FMS operation case as a representative demonstration of the integrated HEAR-LPAC-PAM methodology.

Table 14. Resilient behavior framework for each case.

Category	FMS Operation	Turbulence Response	Energy Management
Resilient Behavior Definition	FMS principle understanding-based quick/accurate response during instrument approach procedure changes	Weather information analysis and system utilization-based turbulence avoidance response	FMS-based energy state monitoring and appropriate management
Key Systems	FMS database Instrument approach procedures	Weather radar Weather information systems	FMS-based energy management Air traffic flow management
Pressure Factors	STAR/IAP mismatch Late runway change Time constraints	Forecasted turbulence Passenger safety requirements Schedule adherence pressure	ATC instructions Airspace restrictions Traffic flow
Learn	FMS principle and function understanding Approach procedure change experience sharing	Weather phenomenon understanding Weather data analysis capability enhancement	Energy management principle knowledge FMS-based energy management
Plan	Runway/approach procedure change preparation Alternative procedure discussion	Avoidance strategy pre-establishment Cabin safety measure planning	Energy management strategy establishment FMS profile optimization
Adapt	Quick FMS reconfiguration ATC cooperation request	Real-time weather assessment Vertical/horizontal avoidance	FMS-based energy adjustment Aircraft configuration optimization
Coordinate	Flight crew intention sharing ATC communication	Cabin crew safety measure coordination ATC information sharing	Energy state continuous sharing Additional distance/altitude request if needed

Table 15. Integrated HEAR-LPAC-PAM framework application: FMS operation resilient behavior implementation.

Flight Crew's Resilient Behavior Definition	
The repetitive capability to accurately and quickly reconfigure FMS in adverse situations such as setting/changing instrument approach procedures or late runway changes, based on effective learning and high-level understanding of FMS principles	
Operational System to be studied	System Boundaries: • Sharp End System: Flight crew FMS operations during the approach phase • Blunt End System: FMS training procedures, approach procedure design, ICAO certification standards Key System Components: • FMS database and navigation functions • Instrument approach procedures (STAR/IAP relationships–ICAO DOC 8168 PANS-OPS [29]) • Air Traffic Management procedures (ICAO DOC 4444 PANS-ATM [35]) • Performance-Based Navigation Manual (ICAO DOC 9613 PBN) • Chart interpretation standards (Jeppesen Airway Manual)

Table 15. *Cont.*

Flight Crew's Resilient Behavior Definition	
System Demand and Efficiency Pressure	Demand Pressures: • STAR/IAP endpoint mismatch—procedural discontinuity requiring immediate manual intervention • Late runway change—real-time approach procedure reconfiguration under time pressure • ATC instruction compliance–maintaining approach accuracy while adapting to control changes Efficiency Pressures: • Time constraints during the approach phase limiting verification procedures • Traffic flow management requirements constraining approach modification options Conflicting Pressures: • Safety vs. Efficiency: Manual waypoint verification vs. rapid approach execution • Procedure vs. Adaptation: Standard FMS procedures vs. real-time modifications
LPAC Framework Implementation	
LEARN (Knowledge Accumulation): • Systematic analysis of past STAR/IAP mismatch experiences • Share successful FMS reconfiguration techniques • Develop airport-specific approach procedure expertise	PLAN (Proactive Preparation): • Pre-program FMS "Secondary Flight Plan" for alternative approaches • Brief potential runway change scenarios during the cruise phase • Plan verification procedures for approach modifications
ADAPT (Real-time Flexibility): • Prioritize FMS database procedures over manual entry • Real-time risk evaluation of approach path deviations • Flexible response to unexpected ATC instructions	COORDINATE (Collaborative Actions): • Clear communication of FMS reconfiguration intentions between PF/PM • Proactive coordination with ATC regarding approach modifications • Shared situation awareness maintenance throughout approach changes
Manifestations of Operational Resilience	Five Patterns of Resilience Manifestations: • Remaining within Prevention Space: Successful FMS reconfiguration without path/altitude deviations • Recovering from Critical State: Correction of approach path deviations through coordinated crew actions • Recovering from Hazardous State: Prevention of Pilot Operational Deviation through timely ATC coordination • Rebounding within Safety Control: Restoration of standard approach procedures after runway changes • Envelope Expansion: Development of enhanced FMS operational capabilities through experience integration

Note: This table demonstrates the systematic transformation of organizational deficiencies into resilient operational capabilities through the integrated HEAR-LPAC-PAM framework. The FMS operation case illustrates how HEAR-identified training inadequacies are addressed through structured LPAC implementation, providing flight crews with specific behavioral guidelines that enhance adaptive capacity while maintaining compliance with international aviation standards.

5.3.1. FMS Operation Resilient Behavior

FMS operation resilient behavior is defined as "the repetitive capability to accurately and quickly reconfigure FMS in adverse situations such as setting/changing instrument approach procedures or late runway changes, based on effective learning and high-level understanding of FMS principles". This definition directly addresses the organizational deficiencies identified in Section 4.1.1, particularly inadequate FMS function education (53% human resource management factors) and inappropriate emphasis on manual input procedures rather than systematic understanding.

The LPAC model application for FMS operation resilient behavior development proceeds through the systematic implementation of four interconnected components. The "learn" component involves flight crews accumulating and sharing knowledge based on approach procedure experiences at specific airports. This particularly enhances an in-depth understanding of STAR and IAP relationships through systematic analysis of past experiences. The "plan" component involves a thorough review of all possible approach scenarios and FMS setting methods during pre-flight briefing, particularly utilizing "Secondary Flight Plan" functions to pre-program alternative approach methods. The "adapt" component involves flexible response in actual situations, including requesting guidance to final approach paths from control agencies when needed and quickly reconfiguring approach procedures using the FMS database capabilities. The "coordinate" component involves sharing and confirming procedure changes through clear and effective communication between flight crew members, immediately informing control agencies, and requesting cooperation when path or altitude deviations are detected.

While the integrated framework was applied across all three cases (FMS operation, turbulence response, and energy management), Table 15 presents the FMS operation case as a representative demonstration of the HEAR-LPAC-PAM integration methodology. This case exemplifies how organizational deficiencies identified through HEAR analysis are systematically transformed into actionable resilient behavior guidelines through LPAC implementation, providing a comprehensive template applicable to diverse aviation safety challenges.

5.3.2. Turbulence Response Resilient Behavior

Turbulence response resilient behavior is defined as "the repetitive capability to analyze weather-related situations and establish and execute strategies for mitigation, based on effective learning and high-level understanding of adverse weather and aircraft weather radar systems". This definition addresses the organizational deficiencies identified in Section 4.1.2, particularly deficient weather education systems (69% human resource management factors) and conventional safety management approaches that proved ineffective in preventing recurring turbulence-related incidents.

The LPAC model application for turbulence response resilient behavior development proceeds through the systematic implementation of four coordinated components. The "learn" component involves developing in-depth knowledge of weather phenomena and weather radar interpretation through systematic analysis and sharing of past turbulence encounter experiences and successful response cases. The "plan" component involves a thorough analysis of weather conditions along flight routes before a flight, identifying potential turbulence sections, and establishing response strategies. The "adapt" component involves real-time weather condition assessment during flight and flexible response, accurately determining turbulence location and intensity using radar data and preceding aircraft information. The "coordinate" component involves maintaining smooth communication between flight crews, cabin crews, and control agencies, sharing information about anticipated turbulence locations and intensities with cabin crew in advance.

5.3.3. Energy Management Resilient Behavior

Energy management resilient behavior is defined as "the repetitive capability to effectively utilize FMS to manage aircraft energy at appropriate levels in adverse situations such as High Energy approach conditions, based on effective learning and high-level understanding of FMS energy management principles". This definition addresses the organizational cultural preferences for traditional navigation methods (57% human resource management factors) and inadequate FMS-based energy management education identified through failure analysis in Section 4.1.3.

The LPAC model application proceeds through the systematic implementation of four integrated components. The "learn" component involves developing a comprehensive understanding of aircraft energy management principles and FMS energy prediction and management functions. The "plan" component involves establishing energy management strategies before entering approach phases, considering airspace restrictions and expected traffic flow while optimizing approach profiles using FMS. The "adapt" component involves continuous monitoring of aircraft energy states during actual approaches and strategy adjustment as needed, quickly updating FMS routes when control instructions change. The "coordinate" component involves maintaining clear communication between flight crew members regarding energy states and management strategies, particularly in situations deviating from standard operating procedures.

5.4. Integration with Organizational Improvements

The resilient behavior framework developed in this section provides a systematic Safety-II implementation that complements the Safety-I organizational improvements identified through HEAR analysis in Section 4. While organizational factors account for 87% of contributing causes and require systematic structural improvements, resilient behavior development enables flight crews to effectively manage operational challenges during the implementation period of organizational changes.

6. Integrated Application of Safety-I and Safety-II

This section demonstrates the practical application and effectiveness of the integrated HEAR-LPAC-PAM framework, synthesizing the theoretical foundation established in Section 3, the organizational deficiencies identified in Section 4, and the resilient behavior guidelines developed in Section 5. The integration transforms the implementation paradox—where organizations adopt SMS frameworks that theoretically embrace Safety-II philosophy while continuing Safety-I reactive practices—into a systematic organizational capability that addresses both analytical and adaptive requirements simultaneously.

6.1. Integrated Application Framework

This section demonstrates the practical application of the integrated framework established in Section 3.1.1, focusing on case-specific implementation and effectiveness evaluation. The systematic methodology for transforming failure cases into resilient success cases follows the integrated process illustrated in Figure 7, which demonstrates the progression through three distinct phases of coordinated Safety-I and Safety-II implementation.

The process begins with Safety-I analysis through HEAR framework implementation, moves through Safety-II development via resilient behavior creation, and culminates in integrated coordination through the PAM framework application.

Table 16 summarizes the key elements and expected effects of the integrated approach, showing how Safety-I and Safety-II applications complement each other through systematic coordination.

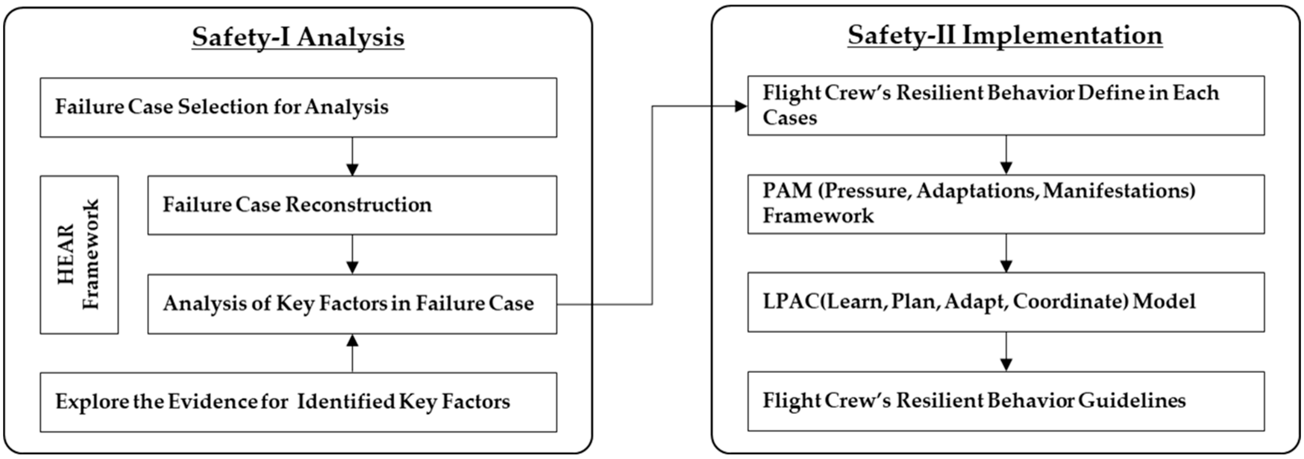

Figure 7. Integrated application process of Safety-I and Safety-II.

Table 16. Integrated application results (the authors' synthesis based on empirical analysis).

Key Elements	Safety-I Application	Safety-II Application	Integration Effects
Analysis Method	HEAR Framework systematic organizational analysis	LPAC/PAM behavioral and coordination frameworks	Comprehensive failure analysis and resilience enhancement
Primary Focus	Root cause identification and organizational improvements	Adaptation strategy development and behavioral capabilities	Holistic safety management approach
Implementation Tools	Why–Because Tree analysis and organizational categorization	Resilient behavior definition and coordination mapping	Practical application guidelines with measurable outcomes
Expected Effects	Systematic organizational improvements addressing predominant factors	Adaptive capability development for operational excellence	Sustainable safety transformation

6.1.1. Case-Specific Integrated Implementation

The FMS operation case demonstrates coordinated analytical and behavioral improvements. Systematic organizational improvements address inadequate FMS education while resilient behavior guidelines enable principle-based operation capabilities.

The PAM framework coordination maps operational pressures (STAR/IAP mismatches, late runway changes, time constraints) to appropriate implementation responses. When pressures involve systematic training deficiencies, HEAR-identified organizational improvements take precedence through educational system enhancement. When pressures involve real-time operational challenges, the LPAC-developed adaptive capabilities provide an immediate response.

The turbulence response case addresses deficient weather education through systematic improvements and proactive response capabilities, preventing the reactive repetition of conventional approaches.

The energy management case addresses cultural preferences for traditional methods through systematic FMS-based capability development and organizational cultural enhancement.

6.1.2. Coordinated Paradigm Application

The integrated framework enables appropriate Safety-I or Safety-II application based on operational context rather than paradigmatic preferences.

The integrated approach enables efficient resource allocation by focusing organizational attention on systematic patterns rather than fragmented individual issues. The 65% reduction in contributing factors (from 54 to 19) while maintaining comprehensive improvement coverage demonstrates that the integrated implementation creates manageable improvement pathways.

6.2. Effectiveness Evaluation

The effectiveness evaluation demonstrates quantifiable implementation gap reduction through systematic comparative analysis of contributing factors before and after integrated framework application. The evaluation employs Why–Because Tree analysis for visual confirmation of causal relationship changes and quantitative contributing factor analysis for systematic assessment of organizational improvement patterns, providing comprehensive evidence of integrated implementation effectiveness.

6.2.1. Quantitative Analysis Results

Comprehensive effectiveness evaluation reveals significant improvements in organizational implementation through integrated HEAR-LPAC-PAM application. The analysis compares contributing factor distributions before framework application (using conventional Safety-I reactive approaches) with after framework application (using integrated Safety-I and Safety-II implementation).

Contributing factors decreased from 54 to 19 (65% reduction) while maintaining comprehensive improvement coverage. This substantial reduction demonstrates that integrated implementation enables organizations to address systematic patterns rather than disconnected individual issues, creating manageable improvement pathways that focus organizational resources on essential enhancement areas.

The quantitative analysis reveals systematic improvements across all organizational categories through integrated implementation. Regulations and business procedures-related issues decreased from three cases (5.6%) to zero cases (0%), demonstrating complete resolution of systematic procedural deficiencies. Management and supervision issues decreased from six cases (11.1%) to zero cases (0%), confirming that the integrated approach addresses systematic oversight failures.

Organizational processes, policies, and culture-related issues decreased from six cases (11.1%) to zero cases (0%), indicating that integrated implementation successfully transforms organizational cultural barriers.

Human resource management factors show meaningful transformation through integrated implementation. While absolute numbers decreased from 32 cases to 13 cases, their proportional representation increased from 59.3% to 68.4%.

Personnel knowledge, experience, and ability factors increased proportionally from 7.4% to 15.8%, while task characteristic factors increased from 5.6% to 15.8%. Table 17 presents the comprehensive comparison of causal factors between conventional and integrated approaches, illustrating the systematic transformation achieved through coordinated implementation.

Figure 8 provides a visual representation of the effectiveness evaluation results, clearly illustrating the systematic transformation achieved through an integrated safety management approach.

The effectiveness evaluation demonstrates that the integrated HEAR-LPAC-PAM framework provides aviation organizations with practical tools for transforming SMS theoretical requirements into operational capabilities.

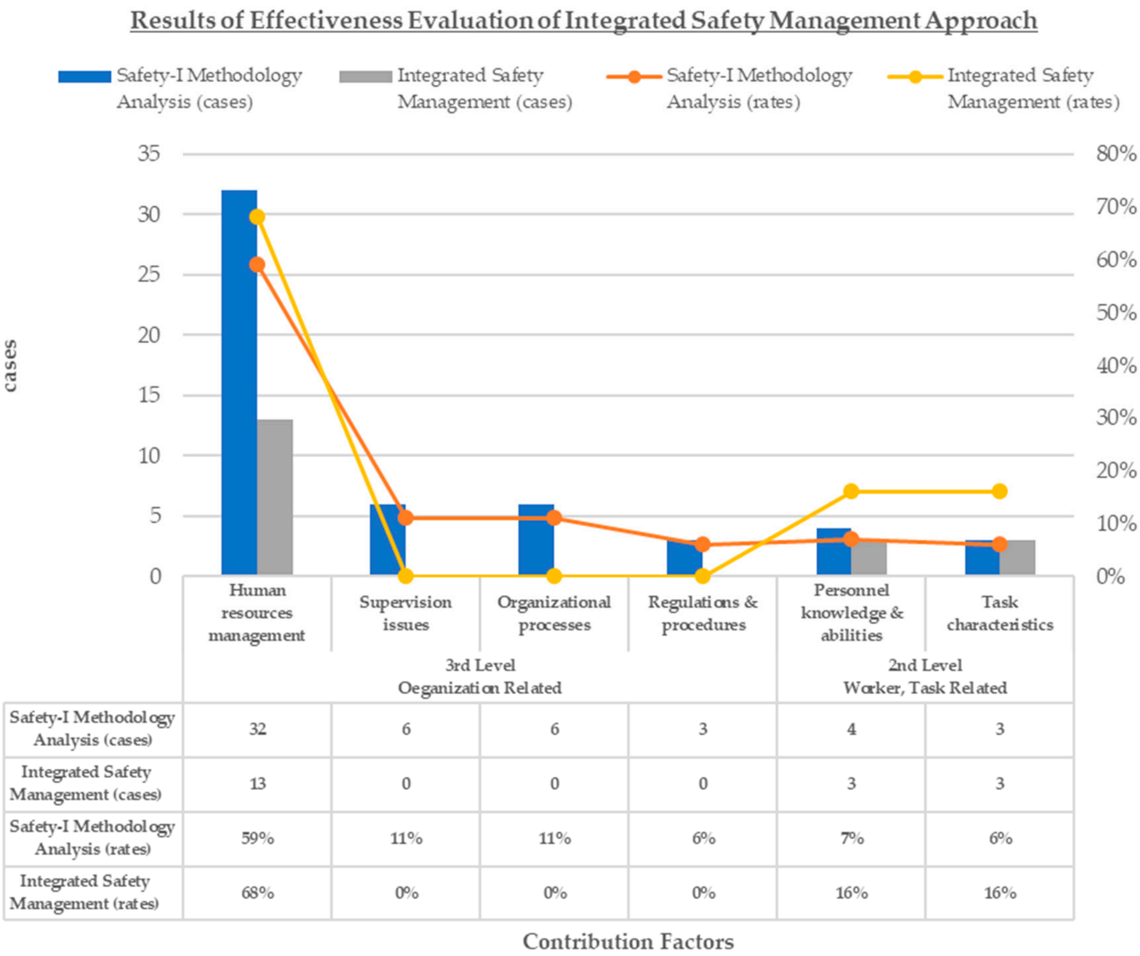

Figure 8. Results of effectiveness evaluation of integrated safety management approach.

Table 17. Comparison of causal factors between Safety-I methodology analysis and integrated safety management approach.

Causes	Contribution Factors	Existing (Safety-I Methodology Analysis)				Improved (Integrated Safety Management)			
		Count (n)				Count (n)			
		C1	C2	C3	Total	C1	C2	C3	Total
2nd Level Personnel, Task Related	Personnel's knowledge, experience, abilities	1	1	2	4	1	0	2	3
	Task characteristics	0	1	2	3	0	1	2	3
3rd Level Organization Related	Characteristics of regulations and business procedures	1	0	2	3	0	0	0	0
	Management of an organization's human resources	8	11	13	32	4	5	4	13
	Management and supervision issues	3	1	2	6	0	0	0	0
	Organizational processes, policies, and culture	2	2	2	6	0	0	0	0
	Total	15	16	23	54	5	6	8	19

Table 17. *Cont.*

Causes	Contribution Factors	Existing (Safety-I Methodology Analysis)				Improved (Integrated Safety Management)			
		Rates (%)				Rates (%)			
		C1	C2	C3	Total	C1	C2	C3	Total
2nd Level Personnel, Task Related	Personnel's knowledge, experience, abilities	6.7	6.3	8.7	7.4	20.0	0.0	25.0	15.8
	Task characteristics	0.0	6.3	8.7	5.6	0.0	16.7	25.0	15.8
3rd Level Organization Related	Characteristics of regulations and business procedures	6.7	0.0	8.7	5.6	0.0	0.0	0.0	0.0
	Management of an organization's human resources	53.3	68.8	56.5	59.3	80.0	83.3	50.0	68.4
	Management and supervision issues	20.0	6.3	8.7	11.1	0.0	0.0	0.0	0.0
	Organizational processes, policies, and culture	13.3	12.5	8.7	11.1	0.0	0.0	0.0	0.0
Total		100	100	100	100	100	100	100	100

Notes: C1: Case 1 (FMS Operation). C2: Case 2 (Turbulence). C3: Case 3 (Energy Management).

6.2.2. Visual Analysis Through Why–Because Tree Comparison

Why–Because Tree comparative analysis provides visual confirmation of systematic improvements achieved through integrated framework application.

The FMS operation case transformation (Figure 9) shows a substantial reduction in organizational culture and management supervision-related factors, with the focus shifting to qualitative improvement of education and training systems through integrated analytical and behavioral approaches.

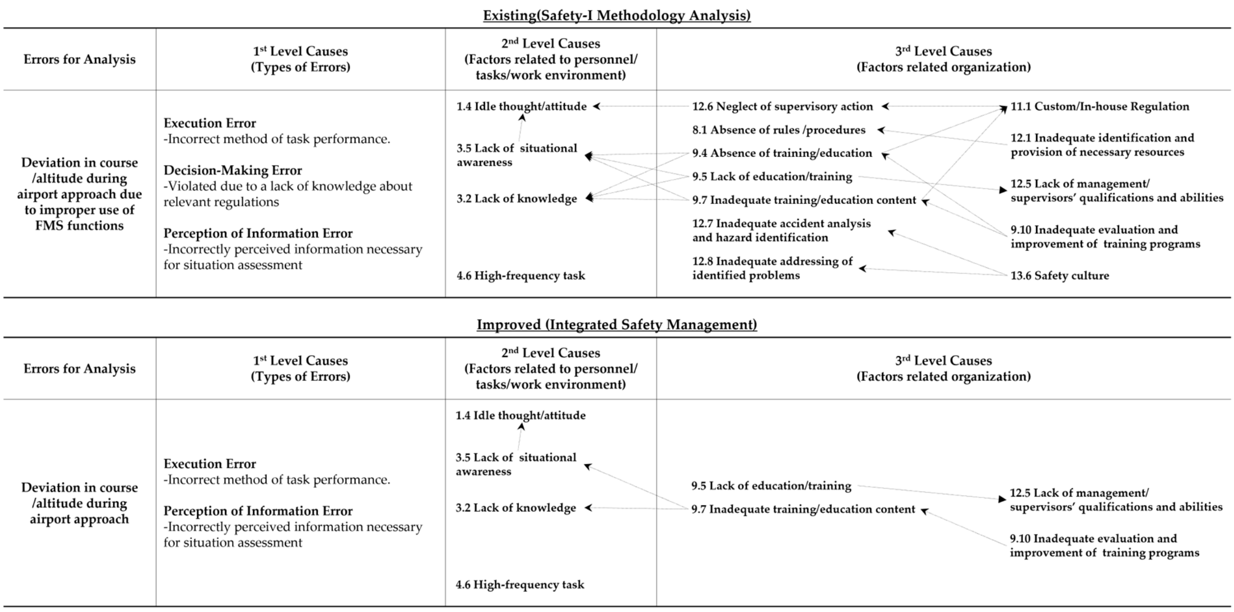

Figure 9. Case 1 Why–Because Tree comparison: existing (Safety-I methodology analysis) vs. improved (integrated safety management).

The turbulence response case improvements (Figure 10) emphasize the importance of practical weather information utilization education while reducing the complexity of organizational factors requiring attention.

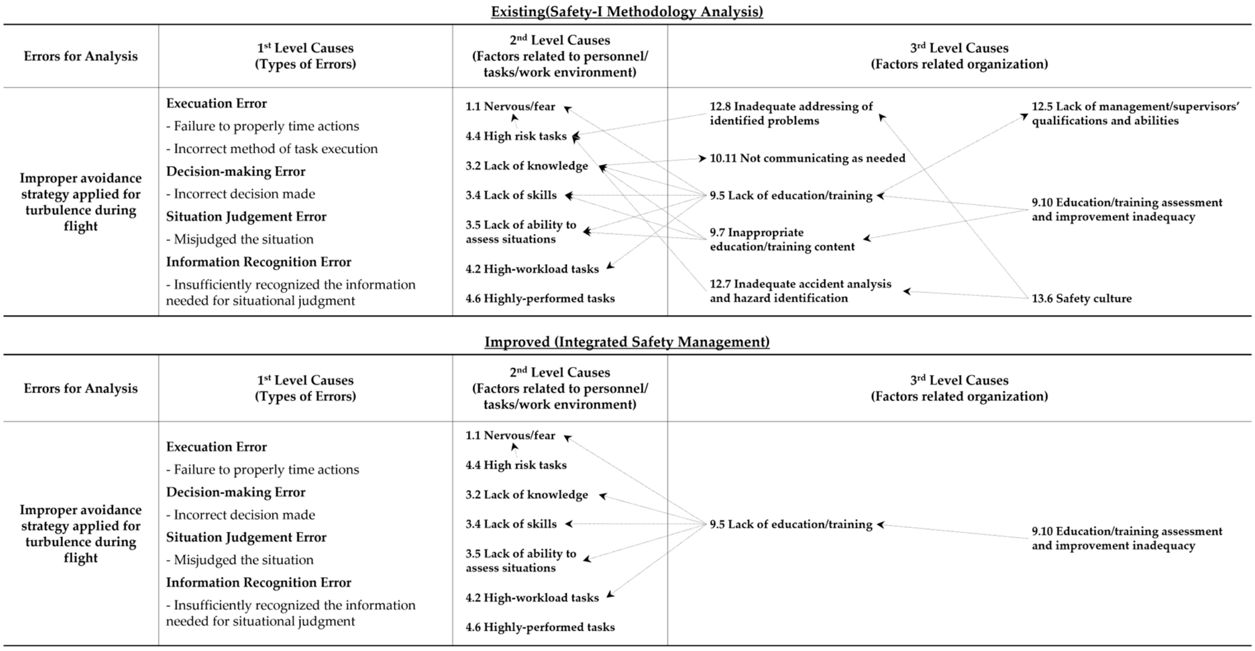

Figure 10. Case 2 Why–Because Tree comparison: existing (Safety-I methodology analysis) vs. improved (integrated safety management).

The energy management case transformation (Figure 11) clearly reveals the need for systematic approaches to improve FMS utilization capabilities while addressing cultural preferences for traditional methods.

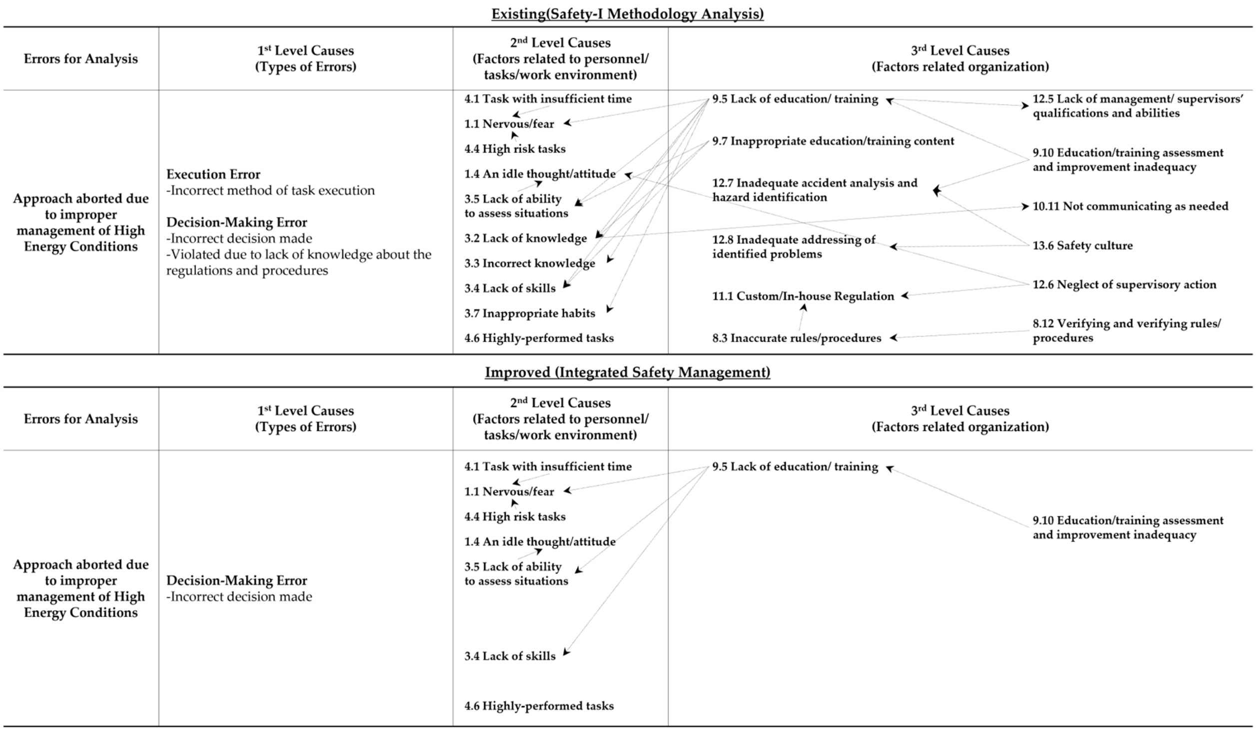

Figure 11. Case 3 Why–Because Tree comparison: existing (Safety-I methodology analysis) vs. improved (integrated safety management).

The most notable change across all three cases involves clarification and simplification of relationships between causal factors. Previously complex and multi-layered organization-related factors show a significant reduction, demonstrating that systematic integration of analytical and adaptive approaches enables effective implementation of coordinated improvements rather than fragmented interventions addressing individual factors separately.

6.2.3. Implementation Gap Reduction Evidence

The effectiveness evaluation confirms systematic implementation gap reduction through integrated HEAR-LPAC-PAM application. The quantitative improvements demonstrate that the integrated framework enables simultaneous implementation of Safety-I analytical capabilities and Safety-II adaptive responses, creating practical organizational change rather than theoretical paradigm competition.

The complete elimination of systematic organizational deficiencies (regulations, management supervision, organizational culture) combined with an enhanced focus on human resource development confirms that integrated implementation enables coordinated rather than competing paradigm application. The shift from 54 disconnected factors to 19 systematically related factors with clear implementation pathways provides a foundation for sustainable organizational improvement.

6.3. Implementation Guidelines

This section presents practical implementation guidelines derived from the integrated framework application, providing systematic pathways for aviation organizations to transform theoretical safety management requirements into operational capabilities. The guidelines address three primary stakeholder groups: safety managers implementing integrated principles, aviation organizations implementing systematic change, and training organizations implementing principle-based education.

6.3.1. For Safety Managers Implementing Integrated Principles

Safety managers can implement the integrated framework to systematically address organizational factors currently overlooked in conventional safety management approaches. The HEAR methodology provides structured tools for implementing Safety-I systematic analysis beyond reactive incident response.

The LPAC model enables safety managers to implement concrete Safety-II adaptive capabilities in daily operations through structured development of learning, planning, adaptation, and coordination behaviors. Rather than treating resilience as an abstract concept, safety managers can use LPAC to develop specific behavioral guidelines that transform failure patterns into resilient success capabilities.

6.3.2. For Aviation Organizations Implementing Systematic Change

Aviation organizations can implement the integrated framework to address the implementation paradox between SMS theoretical adoption and Safety-I reactive practice. Organizations should systematically implement both paradigms by using the HEAR framework to identify organizational factors requiring Safety-I interventions, developing LPAC-based adaptive capabilities for Safety-II implementation, and applying the PAM framework to ensure appropriate principle application based on operational demands.

Organizations should implement systematic changes in human resource management approaches, recognizing that qualitative improvement in education and training becomes more prominent after addressing fundamental organizational deficiencies. The framework enables organizations to transform from reactive safety management focused on failure prevention to proactive organizational development focused on success expansion, building sustainable safety culture through systematic implementation of both analytical and adaptive capabilities.

6.3.3. For Training Organizations Implementing Principle-Based Education

Training organizations should implement principle-based education approaches that address the educational deficiencies identified as predominant organizational factors. Rather than continuing rule-centered training that proves inadequate for complex operational situations, training organizations should develop implementation curricula emphasizing system understanding and principle-based decision-making using the integrated framework approaches.

Training organizations should create concrete assessment methods evaluating the implementation of both Safety-I systematic analysis and Safety-II adaptive capabilities, moving beyond procedural compliance evaluation to comprehensive capability assessment.

6.4. Framework Enhancement and Future Development Directions

6.4.1. Current Implementation Scope

This integrated framework application focused on commercial airline operations as a proof-of-concept demonstration. Three strategically selected cases representing technical, environmental, and managerial aspects provided comprehensive validation of implementation principles within specific operational contexts. The evaluation timeframe emphasized immediate implementation effectiveness, demonstrating systematic change potential through before–after comparative analysis rather than long-term sustainability assessment.

6.4.2. Methodological Development Directions

Future methodological improvements should focus on enhancing analytical rigor and validation approaches. Quantitative measurement tools for Safety-II resilient behavior implementation could strengthen the current qualitative assessment framework. Standardized metrics for evaluating organizational transformation effectiveness would enable more systematic comparison across different implementation contexts. Advanced statistical validation methods, including regression analysis and structural equation modeling, could provide stronger empirical evidence for the relationships between organizational factors and safety outcomes identified through HEAR analysis. Integration of real-time data collection methods and digital monitoring systems could enhance the accuracy and timeliness of implementation effectiveness evaluation, moving beyond retrospective case study analysis.

6.4.3. Framework Development Directions

Future framework development should expand the integration capabilities of HEAR-LPAC-PAM methodologies. Automated decision support tools could assist safety managers in selecting appropriate Safety-I or Safety-II interventions based on real-time operational context analysis. The development of industry-specific adaptation protocols would enable consistent framework application across different organizational environments while maintaining core integration principles. Digital implementation platforms could streamline the complex coordination requirements identified in the PAM framework application.

7. Conclusions

7.1. Key Research Findings

This research developed a practical framework for implementing both Safety-I and Safety-II principles in aviation safety management, addressing the critical implementation gap between SMS theoretical requirements and actual operational practice. The study demonstrates that organizations adopt SMS frameworks theoretically embracing Safety-II philosophy while continuing Safety-I reactive paradigms, creating fundamental contradictions that undermine safety effectiveness.

The systematic analysis using the HEAR framework revealed that organizational factors account for 87% of all contributing causes, representing a 6.7:1 ratio compared to individual and task factors. This finding provides quantitative evidence contradicting current safety management approaches that focus primarily on individual behavior modification and procedural compliance. Human resource management issues constitute 59.3% of all factors, with inadequate education and training representing the most significant organizational deficiencies.

The research successfully operationalized "flight crew's resilient behavior" through systematic LPAC model application, transforming abstract Safety-II concepts into concrete operational behaviors that address organizational deficiencies identified through Safety-I analysis. The integrated framework implementation demonstrated a transition from 54 discrete contributing factors to 19 systematically related factors with clearer implementation pathways, indicating a potential for 65% reduction in implementation complexity while maintaining comprehensive improvement coverage.

7.2. Theoretical and Practical Contributions

7.2.1. Theoretical Contributions

This research advances aviation safety management theory by providing empirical validation of Safety-I and Safety-II integration through systematic quantitative analysis. The study contributes quantitative evidence of organizational factor predominance over individual factors in aviation failures, supporting organizational-centered safety management theories and challenging traditional human error approaches.

The research extends resilience engineering theory by operationalizing abstract Safety-II concepts through concrete behavioral frameworks. The LPAC model adaptation provides validated mechanisms for implementing Safety-II principles in aviation contexts, addressing measurement and implementation challenges identified in resilience engineering literature.

7.2.2. Practical Implications

For safety managers, the integrated framework provides systematic methodologies for addressing organizational factors currently overlooked in conventional approaches. The HEAR framework enables structured Safety-I systematic analysis beyond reactive incident response, while the LPAC model provides concrete Safety-II adaptive capabilities for daily operations.

For aviation organizations, the framework enables systematic resolution of the implementation paradox between SMS theoretical adoption and Safety-I reactive practice. Organizations can achieve a systematic reduction in causal complexity while maintaining focus on essential improvement areas through simultaneous Safety-I and Safety-II implementation. The framework enables a transition from reactive safety management to proactive organizational development, building a sustainable safety culture through coordinated analytical and adaptive capabilities.

For training organizations, the research demonstrates the need for principle-based education approaches addressing educational deficiencies identified as predominant organizational factors. Rather than rule-centered training inadequate for complex operational situations, training organizations should develop curricula emphasizing system understanding and principle-based decision-making through integrated Safety-I and Safety-II methodologies.

7.3. Research Limitations and Future Directions

7.3.1. Current Limitations

This study establishes proof-of-concept for integrated Safety-I and Safety-II implementation with specific scope limitations. The framework development employed three strategically selected cases representing technical, environmental, and managerial aspects of aviation operations, providing a comprehensive demonstration of implementation principles rather than statistical generalization across aviation populations.

The organizational focus was limited to commercial airline operations implementing SMS frameworks, providing depth of analysis within specific operational contexts rather than breadth across diverse aviation sectors. The research timeframe focused on immediate implementation effectiveness rather than longitudinal organizational development.

7.3.2. Application Expansion Directions

Future research should prioritize three critical directions: (1) quantitative validation studies across cargo operations, low-cost carriers, business aviation, and general aviation sectors; (2) longitudinal studies measuring sustained organizational implementation effectiveness and factors supporting sustainable organizational change; (3) development of standardized implementation protocols enabling consistent application across different organizational contexts and operational environments. Cross-industry application research should investigate framework effectiveness in maritime, rail, and automotive safety management contexts to verify the transferability of integrated Safety-I and Safety-II principles beyond aviation contexts. The framework provides a systematic foundation for implementing Safety-I and Safety-II principles in aviation safety management, demonstrating a practical approach for addressing implementation gaps between SMS theoretical requirements and actual operational practice.

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