An Integrated Model for the Institutionalisation of Tacit Knowledge in Safety-Critical Environments

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Abstract: This study examines how knowledge management, particularly tacit knowledge, is conceptualised and institutionalised within safety-critical environments. Despite advances in technology and decision-support systems, organisations continue to struggle to capture and integrate experiential knowledge into formal structures. Using a qualitative, theory-informed approach, the study combines a scoping review with document analysis to explore knowledge management practices across aviation, healthcare, and nuclear sectors. The findings reveal consistent patterns across these environments. Tacit knowledge is critical for decision-making but remains embedded in individuals and informal practices. Knowledge transfer is largely social and experience-based, while formal systems prioritise explicit knowledge. Organisational structures, governance, and culture further shape how knowledge is shared and institutionalised, highlighting a systemic misalignment between knowledge characteristics and management mechanisms. Based on these findings, the study proposes an integrated model for the institutionalisation of tacit knowledge in safety-critical environments, linking formal systems, tacit processes, and organisational factors. The model offers transferable insights across safety-critical environments.

Keywords: Knowledge management, Tacit knowledge, Safety-critical environments, Knowledge Institutionalisation, Conceptual model, High-reliability organisations

1. Introduction

Organisations operating in safety-critical environments depend on effective knowledge management to support decision-making (Davenport & Prusak, 1998; Miao *et al*., 2022; Weiland, 2020; Mitchell, 2023). These environments are characterised by complexity, uncertainty, and time pressure, where even minor errors can have significant consequences (Karsika *et al*., 2022; Rinaldi & Utomo, 2024). Decision-making therefore relies not only on structured data but also on human expertise, experience, and contextual understanding. In air traffic management, for example, coordinating airspace, aircraft, and operational constraints requires continuous interpretation of large volumes of information to ensure efficiency and safety (Tubigi & Alshwai, 2015). Increasing demand for air transport, alongside congestion and capacity limitations, has intensified this complexity, requiring systems to optimise traffic flow while maintaining safety (Tubigi & Alshawi, 2015). In response, organisations have adopted advanced technological solutions, including knowledge-based systems and artificial intelligence, to support decision-making and improve performance (Taherdoost & Madanchin, 2023). Recent developments highlight AI's growing role in analysing performance, supporting training, and enhancing decision-making in complex, multitasking environments (He & Burger-Helmchen, 2024). However, despite these advancements, decision-support approaches in safety-critical environments remain focused on computational efficiency, optimisation models, and system performance (Rinald & Utomo, 2024).

While AI and knowledge-based systems aim to enhance or replicate human reasoning, they often fail to capture the full spectrum of organisational knowledge required for effective decision-making (Taherdoost & Madanchian, 2023). In particular, knowledge management remains underdeveloped, with limited attention to how knowledge is embedded within organisational processes and decision-support systems (Olan *et al*., 2022). Although the importance of knowledge in safety-critical environments is widely recognised, processes for capturing, formalising, and integrating tacit knowledge remain insufficient. Existing research has prioritised technological solutions and system optimisation, with less focus on how experiential and context-dependent knowledge is incorporated into decision-making (Adeniran & Oluwaseyi, 2020; Taherdoost *et al*., 2023; Nakash *et al*., 2025). This is particularly significant in high-reliability environments such as aviation, where effectiveness depends on both data-driven systems and human judgement. Shamsiev (2022) notes that, despite longstanding recognition of tacit knowledge, its integration into modern systems remains fragmented and inconsistent (He & Burger-Helmchen, 2024). As a result, a gap persists between the conceptual understanding of tacit knowledge and its practical application in safety-critical systems, suggesting that the key challenge lies in its

institutionalisation. This study addresses this gap through a qualitative, theory-informed approach combining a scoping review with document analysis of organisational practices across safety-critical environments. The scoping review maps how tacit knowledge is conceptualised, while document analysis examines its implementation in practice, enabling a comparative analysis of theory and application. The study is guided by the research question:

How is knowledge management, particularly tacit knowledge, conceptualised in theory, and how is it institutionalised in practice within safety-critical environments?

Given limited research on tacit knowledge in aviation, the study adopts a cross-industry perspective. By examining healthcare and nuclear sectors, it develops an integrated model and derives transferable insights for safety-critical environments.

2. Research Design

This study focuses on aviation, healthcare, and nuclear sectors as representative safety-critical environments based on defined selection criteria. These sectors are well-established high-reliability domains characterised by time-critical decision-making, low tolerance for error, and severe consequences of failure. They also depend strongly on both formalised procedures and experiential (tacit) knowledge in practice. Selection was further guided by the availability of both academic literature and organisational documentation, enabling comparison between theory and practice. While other sectors (e.g., energy, finance, telecommunications) may share safety-critical features, they were excluded due to differences in risk immediacy and the centrality of human-in-the-loop decision-making. Based on these criteria, a scoping review was conducted across the selected sectors.

2.1 Scoping Review

A scoping review was conducted to examine how knowledge management, particularly tacit knowledge, is conceptualised in safety-critical environments. This approach maps key concepts and research gaps in complex areas. The review followed PRISMA guidelines to ensure a systematic study selection process. Searches were conducted in Scopus, Web of Science, and Google Scholar using targeted terms such as ("knowledge management" AND "tacit knowledge" AND aviation), ("tacit knowledge" AND "safety-critical environments"), ("knowledge sharing" AND healthcare AND "high-risk"), and ("knowledge management" AND nuclear AND safety). Results are presented in Figure 1.

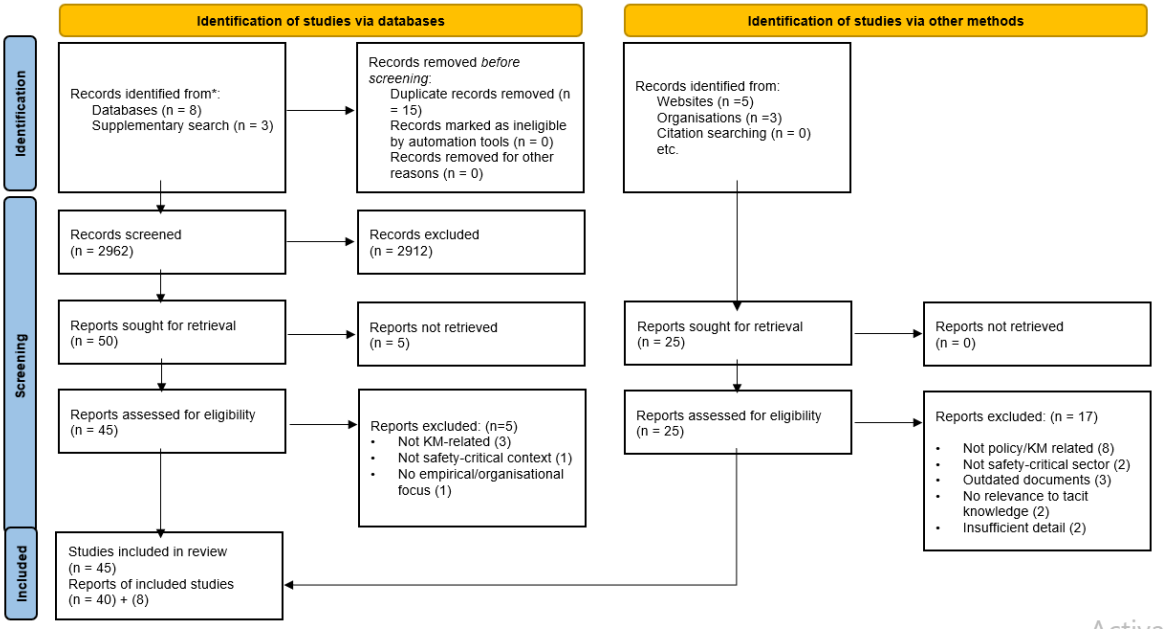

Figure 1: PRISMA data collection process

Initial searches using the term "knowledge management" yielded limited results within safety-critical contexts across various databases. As a result, additional search terms were incorporated to broaden the scope, including

"knowledge retention", "knowledge loss", "knowledge transfer", and "organisational learning", which are conceptually related to knowledge management.

Studies were included if they addressed knowledge-related processes (e.g., knowledge sharing, retention, decision-making, or organisational learning) within safety-critical or high-risk contexts. Articles that were not directly related to knowledge management or lacked relevance to organisational practices were excluded. The analysis followed an iterative process, allowing for refinement of search terms and inclusion criteria as patterns emerged. Data were synthesised thematically to identify dominant concepts, recurring challenges, and gaps in the literature, with particular attention given to the institutionalisation of tacit knowledge.

2.2 Document Analysis

Document analysis was employed to complement the scoping review and provide an organisational perspective on knowledge management practices within safety-critical environments. While the scoping review identified key theoretical insights, it highlighted that empirical academic literature; particularly in aviation and nuclear contexts, remains fragmented. In contrast, these sectors produce extensive organisational and policy-level documentation addressing knowledge management, safety, training, and operational practices.

Given the regulatory nature of safety-critical industries, knowledge management is often embedded within formal documents rather than academic publications. Document analysis was therefore incorporated to examine how knowledge management is articulated and operationalised in practice. This enabled the inclusion of authoritative sources such as international aviation and nuclear bodies, regulatory frameworks, and organisational reports. Documents were identified through targeted searches using combinations of keywords such as: ("knowledge management" AND aviation AND ICAO), ("knowledge retention" OR "knowledge transfer" AND nuclear AND IAEA), ("air traffic management" AND EUROCONTROL AND reports), ("knowledge sharing" AND healthcare AND policy), and ("safety management" AND aviation OR nuclear reports).To enhance transparency, Table 1 summarises the key documents included in the analysis.

Table 1: Summary of Documents Included in the Analysis

Document Type	Source Organisation	Focus Area	Relevance to Study
Safety Management Manual	ICAO	Safety management, procedures	Illustrates formal systems and procedural knowledge in aviation
knowledge management Guidelines	IAEA	Retention, transfer, workforce planning	Demonstrates structured knowledge management practices in nuclear environments
ATM Reports	EUROCONTROL	Human factors, decision-making	Shows tacit knowledge use in aviation contexts
Organisational Reports	ANSPs (e.g., ATNS, NATS)	Training, safety, operations	Reflects real-world application of knowledge in aviation
Healthcare Policy Documents	WHO / National Health Departments	Knowledge sharing, clinical practice	Shows knowledge management practices in healthcare environments
Safety Reports	Aviation & Nuclear Organisations	Risk management, operations	Evidence of knowledge use in safety-critical decision-making

These documents were selected based on their relevance to knowledge-related processes and their availability through official and publicly accessible organisational sources.

3. Findings

The findings are presented through a comparative analysis of knowledge management practices across aviation, healthcare, and nuclear environments. Drawing on the scoping review and document analysis, Table 2 synthesises key dimensions, including knowledge characteristics, transfer processes, and organisational factors. This comparison highlights recurring patterns and differences in how knowledge is conceptualised and implemented in safety-critical environments, forming the basis for the key findings that follow.

Table 2: Summary of Key Findings Across Safety-Critical Industries

Dimension	Aviation (Air Traffic Management)	Healthcare	Nuclear	Key References
Role of Tacit Knowledge	Critical for real-time decision-making and situational awareness; embedded in controllers	Central to clinical judgement; developed through experience	Critical for safety, troubleshooting, and system understanding; embedded in experts	Lozano-Ramirez (2022); Knuuti *et al*. (2022);
Nature of Knowledge	Hybrid: explicit procedures and tacit experience; time-sensitive	Mix of explicit records and tacit knowledge; tacit often dominant	Dual: explicit systems and tacit expertise ("know-how" vs "know-why")	Beattie *et al*. (2022); English et al. (2022)
Knowledge Transfer & Informal Practices	Formal (training, simulation, OJT) and informal (mentoring); experiential and not fully institutionalised	Primarily informal and social: teamwork, peer interaction, shared practice	Structured and informal: training, mentoring, storytelling, communities of practice	ICAO (2018); Stoumpos *et al*. (2024)
Formal Knowledge Systems	Strong for explicit knowledge (procedures, databases); weak for tacit capture	Increasing reliance on digital tools and decision-support systems	Advanced systems: repositories, policies, KM frameworks	Pentland (2011); ATNS (2023)
Knowledge Retention & Loss Risk	Weak and reactive; high risk due to retirements and workforce shifts	Ongoing challenge due to staff turnover; Knowledge loss	Strategic retention through succession planning; high risk if unmanaged	Van Burg *et al*. (2014); El Asri (2025)
Organisational Structures	Strong procedural and training structures; limited tacit integration	Fragmented and decentralised; uneven knowledge flow	Highly integrated across policy, HR, IT, and governance	IAEA (2012); ICAO (2018); dos Santos Grecco (2022)
Governance & KM Strategy	Strong regulatory and safety focus; KM not fully strategic	Increasingly formalised but inconsistent	KM embedded in national and international frameworks	IAEA (2012); ICAO (2018)
Knowledge Sharing Culture & Leadership	Compliance-driven culture; leadership focused on operations	Trust- and collaboration-driven; leadership enables sharing	Regulation-driven culture; leadership drives KM and safety	IAEA (2015); Alboliteeh (2022); Jankelová (2025)
Barriers & Emerging Practices	Barriers: generational gaps, tech resistance; Practices: simulation, mentoring, blended learning	Barriers: workload, trust; Practices: culture, mentoring, continuous learning	Barriers: ageing workforce, skill gaps; Practices: KM frameworks, succession planning	Imroz & Sadique (2022); Karsikas (2022); Gupta & Gupta (2024)

The comparative analysis in Table 2 reveals consistent patterns across aviation, healthcare, and nuclear environments, particularly regarding tacit knowledge, knowledge transfer, and organisational context. Common challenges include limited institutionalisation of tacit knowledge, reliance on informal sharing, and the dominance of formal systems focused on explicit knowledge. These patterns indicate a broader misalignment between knowledge characteristics and organisational practices. The following section synthesises these findings and their implications for aviation.

4. Discussion of Key Findings

4.1 Tacit Knowledge as a Critical yet Under-institutionalised Resource

Tacit knowledge is a central component of knowledge management across aviation, healthcare, and nuclear environments, underpinning decision-making in high-risk, time-pressured, and uncertain contexts. In aviation, air traffic controllers rely on experience-based judgement and situational awareness (Tubigi & Alshwai, 2015; Imroz & Sadique, 2022); in healthcare, clinical decisions depend on knowledge developed through practice and interaction (Sheng *et al*., 2013; English *et al*., 2022); and in nuclear settings, tacit knowledge supports system understanding, troubleshooting, and safety assurance (Beattie, 2022). Despite its importance, tacit knowledge remains embedded in individuals and is not systematically captured or integrated into organisational systems. This reflects its experiential, context-dependent nature, which resists codification. Across all three industries, formal mechanisms, such as procedures, documentation, and digital systems, primarily support explicit knowledge, leaving tacit knowledge within human experience and informal interactions. Even in structured environments like the nuclear sector, tacit knowledge transfer remains a persistent challenge (IAEA, 2015; ICAO, 2018; ATNS, 2023). Similarly, healthcare relies heavily on interpersonal knowledge sharing (Santhose & Lawrence, 2023), while aviation continues to depend on experiential learning that is not fully institutionalised (Moghimi Esfandabadi *et al*., 2023).

These limitations have direct implications across safety-critical environments, including aviation, where performance depends on experience-based decision-making. The evidence suggests that existing procedural and training systems are insufficient to institutionalise tacit knowledge. Insights from healthcare and nuclear contexts highlight the need for mechanisms such as structured mentoring, knowledge elicitation, and experiential knowledge capture to better integrate tacit knowledge into organisational systems.

4.2 Knowledge Transfer Remains Predominantly Informal Despite the Presence of Formal Systems

Knowledge transfer across aviation, healthcare, and nuclear environments continues to rely heavily on informal, socially embedded processes, despite the presence of advanced formal systems. In aviation, transfer is supported through simulation, classroom instruction, and on-the-job training; however, the effective sharing of operational knowledge remains dependent on mentoring and experiential learning (El Asri & Anakkar, 2025; ATNS, 2023). Similarly, in healthcare, knowledge sharing occurs primarily through interpersonal interactions such as teamwork, peer discussions, and collaborative practice rather than formal systems (Santhose & Lawrence, 2023). In nuclear environments, although supported by structured programmes, documentation, and regulatory frameworks, knowledge transfer still depends on informal mechanisms such as mentoring, communities of practice, and expert interaction (Zakaria, 2014; Baxter & Stulberg, 2025).

This pattern reflects theoretical perspectives that view knowledge transfer as inherently social and relational. Tacit knowledge is context-dependent, experiential, and difficult to articulate, making it resistant to formalisation. Consequently, organisations across all three industries continue to depend on informal mechanisms, even within highly structured environments. The coexistence of formal systems and informal practices indicates a misalignment between knowledge management approaches and the nature of knowledge itself. Across safety-critical environments, this highlights a critical gap in the institutionalisation of knowledge transfer. While formal training systems are well developed, they do not fully capture the depth of experiential knowledge required for effective decision-making in complex operational contexts. Insights from healthcare and nuclear contexts suggest the need to integrate structured informal mechanisms, such as formalised mentoring, communities of practice, and knowledge-sharing platforms, into existing systems.

4.3 Formal Knowledge Management Systems Prioritise Explicit Knowledge at the Expense of Tacit Knowledge

Across aviation, healthcare, and nuclear environments, formal knowledge management systems are primarily designed to capture, store, and disseminate explicit knowledge, often at the expense of tacit knowledge (Alboliteeh *et al*., 2022; Knuuti *et al*., 2022; Beattie *et al*., 2022). In aviation, knowledge management is embedded in procedural documentation, training manuals, and operational systems that emphasise standardisation and compliance. While these ensure consistency and safety, they are limited in capturing experiential knowledge and context-specific decision-making (Cizelj *et al*., 2024). Similarly, in healthcare, digital systems, electronic records, and decision-support tools focus on codified information, while experiential knowledge is shared through informal interaction (Ghabban, 2024; Stoumpos *et al*., 2024). In nuclear environments, highly advanced systems, such as repositories, policies, and assessment frameworks, remain more effective in managing explicit knowledge than in capturing nuanced, experience-based expertise (IAEA,

2015; Cizelj, 2024). This emphasis reflects a broader theoretical bias towards codification and standardisation, assuming knowledge can be fully articulated and controlled. However, such approaches overlook the contextual and interpretive nature of tacit knowledge. Consequently, organisations may achieve procedural standardisation while still relying on informal processes to support effective decision-making.

Across safety-critical environments, this imbalance is particularly critical**,** as effective performance depends on integrating procedural knowledge with real-time judgement and situational awareness**.** The findings suggest that existing knowledge management systems are overly focused on documentation and compliance, with limited attention to tacit knowledge integration. Insights from healthcare and nuclear sectors highlight the need for a more balanced approach, where formal systems are complemented by mechanisms such as knowledge elicitation, reflective practices, and structured experiential learning.

4.4 Organisational Structures and Governance Shape Knowledge Management Outcomes

Knowledge management practices across aviation, healthcare, and nuclear environments are shaped by organisational structures and governance mechanisms. The comparative analysis shows that differences in knowledge management are influenced not only by knowledge characteristics but also by how organisations are structured, regulated, and governed. In aviation, knowledge management is embedded in highly regulated systems that prioritise standardisation, compliance, and procedural consistency. While these support safety and reliability, they emphasise formal processes with limited focus on institutionalising tacit knowledge (Tubigi, 2015; Imroz & Sadique, 2022). In contrast, healthcare is characterised by more decentralised and fragmented structures, where knowledge flows are shaped by professional roles, team dynamics, and organisational culture, resulting in more informal, interaction-based practices (Alboliteeh *et al*., 2022; Karsikas *et al*., 2022; Gupta & Gupta, 2024). In nuclear environments, knowledge management is strongly embedded in formal governance frameworks, supported by policies, regulation, and structured systems that integrate knowledge management into operational and strategic processes (IAEA, 2012: 2015). These differences highlight the role of organisational context in shaping knowledge management. Highly structured environments support standardisation and retention but may limit flexibility, while less structured environments enable knowledge exchange but lack consistency. Across safety-critical environments, this suggests that improving knowledge management requires not only better knowledge capture but also rethinking how knowledge is embedded within organisational structures and governance systems. Insights from nuclear contexts emphasise formal integration, while healthcare highlights the value of flexible, interaction-driven knowledge sharing.

4.5 Knowledge Management Reflects a Systemic Imbalance Between Formalisation and Practice

The comparative analysis reveals that knowledge management across aviation, healthcare, and nuclear environments is characterised by a persistent systemic imbalance between formalised systems and knowledge-in-practice. While organisations invest significantly in formal structures, such as procedures, documentation, training programmes, and digital systems, these mechanisms primarily support explicit knowledge and standardisation (Lazano-Ramirez, 2022; Miao *et al*., 2022; Nakash & Bolisani, 2025). In aviation, knowledge management is strongly embedded within procedural systems designed to ensure safety and compliance, yet these systems do not fully capture the experiential knowledge required for real-time decision-making (Weiland & Sunjka, 2020; Shamsiev, 2022; ATNS, 2023). In healthcare, although formal systems are widely implemented, effective knowledge use remains heavily dependent on informal interaction and clinical experience (Karsikas, 2022; Beattie *et al*., 2022). Similarly, in nuclear environments, despite highly structured knowledge management frameworks, tacit knowledge continues to rely on expert interaction and experiential learning (IAEA, 2015).

This reflects a broader theoretical misalignment between the nature of knowledge and the mechanisms used to manage it. Formal systems prioritise standardisation and control, while tacit knowledge is dynamic, contextual, and socially constructed. As a result, organisations operate with parallel formal and informal knowledge systems that are not fully integrated. Across safety-critical environments, addressing this imbalance requires integrating formal systems with tacit knowledge processes**.** Insights from healthcare and nuclear environments suggest that this can be achieved through structured mentoring, knowledge elicitation, communities of practice, and experiential learning. Aligning formal systems with knowledge-in-practice would enable a more integrated and effective knowledge management approach.

5. Conceptual Model for the Institutionalisation of Tacit Knowledge in Safety-Critical Environments

To synthesise the findings and illustrate the relationships between formal systems, tacit knowledge processes, and organisational factors, this study proposes the conceptual model presented in Figure 1.

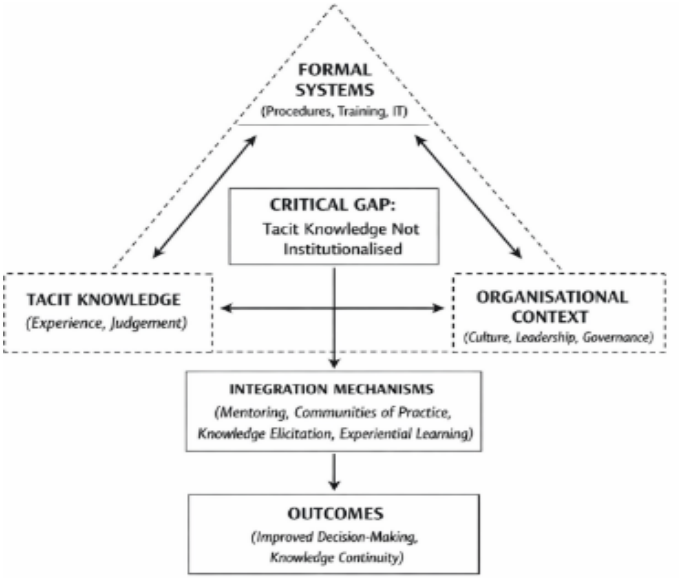

Figure 1: An Integrated Model of Tacit Knowledge Institutionalisation in Safety-Critical Environments

The model illustrates a systemic imbalance between formal knowledge management systems and tacit knowledge processes across aviation, healthcare, and nuclear environments. Formal systems, such as procedures, training, and information systems, primarily support explicit knowledge through standardisation and compliance, while tacit knowledge remains embedded in experience, judgement, and social interaction. This reflects the findings that tacit knowledge is critical yet under-institutionalised, knowledge transfer remains largely informal, and formal systems prioritise codified knowledge. The model conceptualises this as a structural disconnect between knowledge-in-practice and organisational knowledge management mechanisms.

To address this gap, the model introduces integration mechanisms, such as mentoring, communities of practice, knowledge elicitation, and experiential learning, that embed informal knowledge processes within formal systems. Their effectiveness is shaped by organisational conditions, including culture, leadership, and governance. This integration supports the institutionalisation of tacit knowledge, leading to improved decision-making, knowledge continuity, and performance in safety-critical environments. In aviation, particularly air traffic management, the model provides a framework for aligning procedural systems with experiential knowledge processes, enabling more adaptive and resilient knowledge management practices.

6. Conclusion

This study examines knowledge management across aviation, healthcare, and nuclear environments, focusing on the institutionalisation of tacit knowledge. The findings show that while tacit knowledge is critical for decision-making in safety-critical contexts, it remains insufficiently embedded within formal organisational systems. Across all three industries, knowledge management approaches are largely oriented towards explicit knowledge, creating a persistent gap between formal systems and knowledge-in-practice. Using insights across sectors, including aviation as an analytical lens, the study demonstrates that this challenge is systemic rather than industry specific. The reliance on procedural systems without adequately integrating experiential knowledge limits knowledge management effectiveness in dynamic environments. The study highlights the need for more integrated approaches that combine formal structures with mechanisms supporting tacit knowledge capture and transfer. Addressing this imbalance is essential for improving decision-making, ensuring knowledge continuity, and enhancing organisational performance in safety-critical environments. The primary contribution of this study is the development of an integrated model that explains the institutionalisation of tacit knowledge across safety-critical environments.

Ethics Declaration: For this research, ethical clearance was not required.

AI Declaration: For this research, the writing assistant software tool Grammarly was used.

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