Advances in Consumer Research
https://acr-journal.com/
Volume-3 | Issue-1 | Jan 2026
Original Researcher Article

Human Factors in Aviation Safety: A Bibliometric–Systematic Review of Evolving Paradigms and Emerging Challenges

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ABSTRACT
The study integrates bibliometric mapping and systematic literature review (SLR) methods to examine seven decades of scholarship on human factors in aviation safety. The analysis of 1,397 publications (1956 - 2023) reveals the field's evolution across four thematic domains: Human error and accident models, Crew resource management (CRM) and non-technical skills, Risk, safety, and fatigue management, and Emerging technologies and associated challenges. Results demonstrate a paradigmatic shift from reactive error analysis to predictive, resilience-based, and socio-technical approaches, highlighting increased interdisciplinary and a growing emphasis on automation. Persistent geographical skewness in publication trends is identified, emphasising the need for broader global representation. This review synthesises the conceptual trajectory and emerging directions of aviation safety research, offering a framework for advancing adaptive, data-driven, and globally inclusive safety science.
Keywords: Human factors, Aviation safety, HFACS, Crew Resource Management (CRM), Automation and human–AI collaboration, Bibliometric–systematic review...

1. INTRODUCTION:

Aviation safety has been a primary focus for researchers, practitioners, and regulators for more than seven decades, primarily due to the complex interplay among human, organisational, and technological factors in flight operations. While mechanical failures and environmental conditions contribute to accidents, extensive evidence indicates that human factors are responsible for 70% to 80% of aviation accidents (Chan & Li, 2023; J. Reason, 1990b; Wilson, 2022). These human factors encompass a broad spectrum of cognitive, psychological, and social dimensions, including situational awareness, decision-making, fatigue, communication, and the interaction between humans and increasingly automated technologies (Flin et al., 2013; Shappell & Wiegmann, 2017).

The significance of human factors is evident in both academic research and regulatory frameworks. The Human Factors Analysis and Classification System (HFACS), for instance, offers a structured method for investigating accidents by linking unsafe acts to underlying organisational conditions (Wiegmann & Shappell, 2012). Similarly, Crew Resource Management (CRM) emphasises teamwork, communication, and error management, evolving from corrective training programs to comprehensive approaches embedded within airline safety cultures (Glish, 2023; Helmreich et al., 1999). These developments have shifted the focus of aviation safety discourse from attributing blame to fostering systemic resilience and organisational learning.

Despite significant progress, several challenges persist. A primary concern is that research on human factors in aviation safety is distributed across diverse topics, including error modelling, crew resource management (CRM), safety management systems (SMS), fatigue, automation, and unmanned aerial vehicles (UAVs). This fragmentation complicates the development of a comprehensive and unified understanding of the field's evolution. Second, regional disparities persist. Bibliometric studies and safety reports on human factors in aviation indicate that North America, Europe, and parts of Asia dominate scholarly output, whereas Africa and the Middle East, which continue to experience higher occurrence rates, are underrepresented (ICAO, 2024; Okine et al., 2024). Third, although bibliometric mapping offers quantitative insights into publication trends and influential works, it often lacks the qualitative depth required to synthesise findings into thematic narratives that inform theory, practice, and policy (Donthu et al., 2021; Moher et al., 2009; Öztürk et al., 2024).

This study addresses these gaps through a systematic and bibliometric review of human factors in aviation safety from 1956 to 2023. By integrating bibliometric techniques with systematic review procedures, the paper provides both a macro-level mapping of research activity and a micro-level synthesis of intellectual contributions.

Specifically, the study maps the historical development of human factors in aviation safety research using bibliometric indicators, including annual publication counts, citation trends, and keyword co-occurrence networks. It identifies the most influential works, their evolution and sources, and their impact on the field's intellectual structure, highlighting regional disparities in research contributions and implications for global aviation safety. It proposes a future research agenda that incorporates research findings and addresses emerging risks.

To enhance clarity and focus, the study synthesises highly cited works into four thematic domains that illustrate the evolution of human factors research in aviation:

Theme 1: Human error and accident models,

Theme 2: Crew resource management (CRM) and non-technical skills (NTS),

Theme 3: Risk, safety, and fatigue management,

Theme 4: Emerging technology and associated challenges.

By integrating quantitative bibliometric mapping with qualitative synthesis from systematic literature review (SLR), this study advances beyond descriptive analysis to deliver a comprehensive review of human factors in aviation safety. It presents a roadmap of the field's intellectual development, practical implications for training and regulation, and recommendations for future research in an era increasingly influenced by automation, system integration, and globalised air traffic systems.

2. METHODS

A hybrid review approach was employed, combining bibliometric analysis with elements of a systematic literature review (SLR). Bibliometric methods offer strong tools for mapping the structure and dynamics of scientific domains, while SLR procedures ensure transparency and reproducibility in synthesising intellectual contributions (Donthu et al., 2021). Integrating bibliometric analysis with SLR procedures enables a comprehensive examination of human factor safety science, linking quantitative structural mapping with qualitative conceptual synthesis. This approach provides both the breadth and depth required to inform evidence-based policy and research directions.

2.1 Data Source and Search Strategy

Scopus was selected as the primary data source for its comprehensive coverage of peer-reviewed journals and conference proceedings, as well as its extensive citation indexing (Burnham, 2006). A structured search strategy was implemented to identify publications on human factors and aviation safety. Keywords were iteratively developed to capture concepts of human factors in aviation safety, using Boolean operators and truncations, as detailed in Table 1, to maximise coverage while maintaining relevance.

Table 1: Search Keywords and Boolean Operators Used

Search Method	**Keywords**
Article Title, Abstract, Keywords	(("Human factors") AND (aviation OR "air transport*" OR aircraft) AND (safety OR accident)) AND PUBYEAR > 1955 AND PUBYEAR < 2024 AND (LIMITTO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ar") OR LIMITTO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "ch") OR LIMIT-TO (DOCTYPE , "cr") OR LIMIT-TO (DOCTYPE , "bk")) AND (EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "DENT") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "MEDI"))

The search yielded 2,107 records spanning 1956 to 2023. Inclusion criteria limited the results to English-language publications in journals, conference proceedings, books, and book chapters. Exclusion criteria removed unrelated works in fields such as medicine, marine navigation, and road transport.

All records retrieved from Scopus were exported to CSV and subsequently processed for deduplication and quality screening. This yielded a final dataset of 1,397 documents. The methodology followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines by Moher et al. (2009) to ensure transparency throughout the identification, screening, and inclusion phases (see Figure 1)

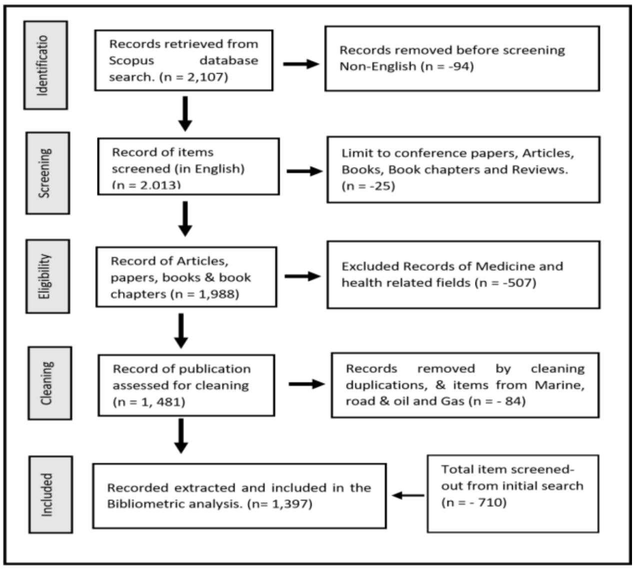

Figure 1: PRISMA Flow Diagram of Search Strategy

2.2 Bibliometric Procedure

Bibliometric analysis was conducted using the Bibliometrix R package (Version 4.4.0) for performance analysis and descriptive statistics, and VOSviewer (Version 1.6.20) for visual mapping of intellectual structures and thematic clusters (Aria & Cuccurullo, 2017; van Eck & Waltman, 2010). The bibliometric procedure comprised citation and co-citation analyses to identify the most influential publications, authors, and country contributions; keyword cooccurrence analyses to detect dominant themes and emerging research fronts; and thematic mapping and science visualisation to trace the intellectual evolution of human factors in aviation safety.

Collectively, these procedures provided a quantitative, macro-level overview of the field, identifying publication trends, citation patterns, and thematic clusters. The findings of this analysis informed the subsequent qualitative synthesis.

2.3 Systematic Review Procedure

A systematic qualitative synthesis was conducted to interpret and contextualise the most influential works identified through citation and co-citation analyses, thereby complementing the bibliometric mapping. This approach ensured that bibliometric findings were grounded in conceptual understanding and consistent with the field's intellectual evolution.

The systematic review followed three stages:

Selection of core works: The 50 most-cited publications and those belonging to major co-citation clusters were extracted as the analytical corpus.

Screening for relevance: Each document was reviewed to ensure substantive focus on human factors and aviation safety, with peripheral works excluded.

Thematic synthesis: Publications were grouped into four main themes that reflect the field’s historical and conceptual evolution. These themes include Human error and accident models; Crew Resource Management (CRM) and non-technical skills; Risk, safety, and fatigue management; and Emerging Technologies and Associated Challenges.

This process adhered to the guidelines proposed by Tranfield et al. (2003) for evidence-informed systematic reviews, enabling the integration of quantitative bibliometric evidence with qualitative theoretical interpretation.

3. RESULTS AND THEMATIC SYNTHESIS

This section reports the results of the bibliometric and systematic analyses. Quantitative bibliometric findings are presented first to illustrate publication trends, authorship patterns, and thematic evolution. These quantitative results were integrated with a qualitative thematic synthesis of the most influential works, providing a comprehensive interpretation of the intellectual development in human factors within aviation safety research.

3.1 Descriptive Bibliometric Overview

Research trends in human factors in aviation safety were examined by analysing the annual scientific production and average annual citations of the 1,397 extracted documents (1956 – 2023). Figure 2 shows that publication volume remained modest until the late 1980s. A steady increase followed, corresponding with the introduction of Crew Resource Management (CRM) programs in the early 1990s and the institutionalisation of Safety Management Systems (SMS) in civil aviation. A marked surge in scholarly output was observed around 2010, coinciding with increased research on automation, fatigue, and unmanned aerial vehicles (UAVs).

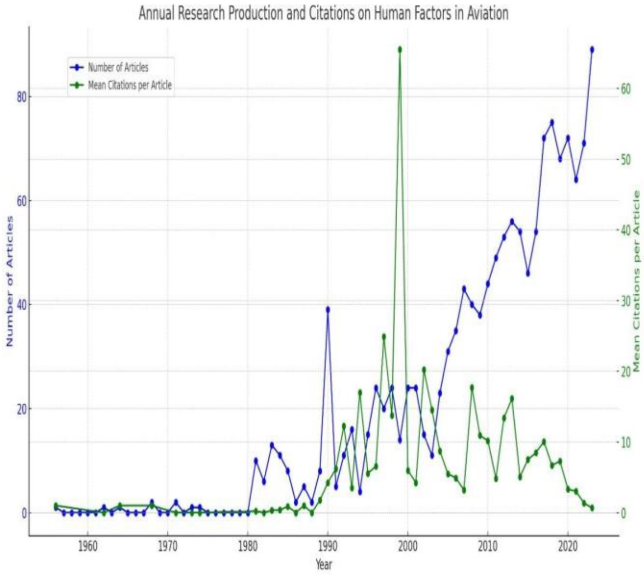

Figure 2: Annual Scientific Production on Human Factors in Aviation Safety (1956–2023).

The bibliometric results shown in Table 2 list the ten most-cited works in the dataset. These include foundational publications such as Helmreich (1997) and J. Reason (1990a) on human error, Helmreich et al. (1999) on CRM, and Wiegmann and Shappell’s (2012, 2001) development of the Human Factors Analysis and Classification System (HFACS). Collectively, these works establish the intellectual foundations of human factors in aviation safety and demonstrate a shift from individual-error paradigms to systemic safety models.

Table 2: Ten Most-Cited Works in Human Factors and Aviation Safety Research

S/No	Author	Document Title	Total Citations (TC)	TC per Year	Normalized TC
1.	Helmreich R. L. et.al, (1999).	"The evolution of crew resource management training in commercial aviation"	768	29.54	11.73
2.	Flin R. et.al, (2013).	"Safety at The Sharp End: A Guide to Non-Technical Skills"	510	42.50	31.63
3.	Wiegmann & Shappell (2012).	" A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System"	496	38.15	37.03
4	Shappell S.A. & Wiegmann D. A., (2017)	"Applying Reason: The human factors analysis and classification system (HFACS)"	256	32.00	25.46
5	Liou James J. H, (2008)	Building an effective safety management system for airlines"	243	14.29	13.71
6	Helmreich R.L, (1997)	"Managing human error in aviation."	164	5.86	6.59
7	Wiegmann D.A, (1997)	"Human factors analysis of postaccident data: Applying theoretical taxonomies of human error"	140	5.00	5.62
8	Goode J.H. (2003).	"Are pilots at risk of accidents due to fatigue?"	136	6.18	9.35
9	Netjasov F, 2008	"A review of research on risk and safety modelling in civil aviation"	134	7.88	7.56
10	Wild G. (2016)	"Exploring Civil Drone accidents and incidents to help prevent potential air disasters"	118	13.11	13.91

3.2 Thematic Clustering and Evolution

To ensure a comprehensive, objective, and comparable analysis of the evolution of human factors in aviation safety, the study examined all keywords in the dataset. As Okine et al. (2024) noted, bibliometric keyword analysis provides valuable insights into overarching trends and the field's knowledge structures.

Analysis of keyword co-occurrence and co-citation networks (Figure 3) identified four principal thematic clusters, representing interacting paradigms rather than discrete topics. Cluster 1, identified as Human Error and Accident Models, characterised by keywords such as accident investigation, human error, error analysis, HFACS. Cluster 2, designated Crew Resource Management (CRM) and Non-Technical Skills, with dominant terms including communication, teamwork, and situational awareness.

Cluster 3, identified as Risk, Safety and Fatigue Management, with keywords including risk assessment, safety management systems, and fatigue. Cluster 4, which we have labelled Emerging Technologies and Associated Challenges, includes human–machine interaction, unmanned aerial vehicles (UAV), autonomy, and artificial intelligence as major keywords.

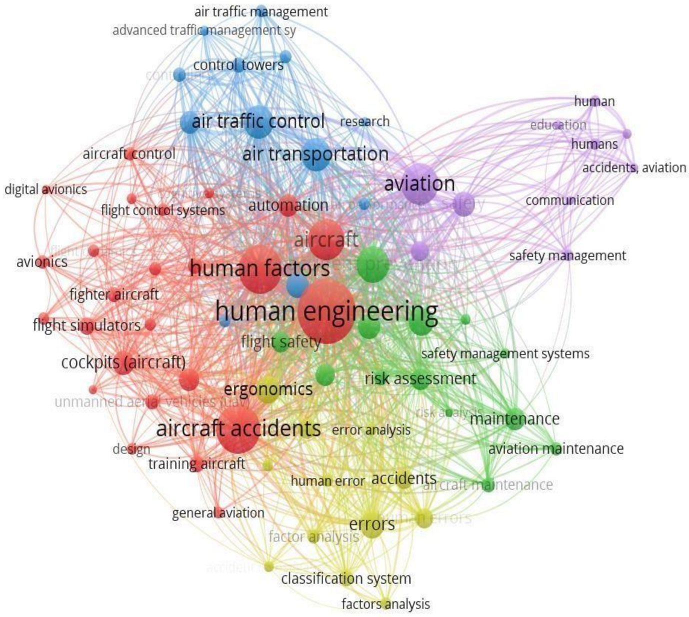

Figure 3: Keyword Co-occurrence and Co-citation Networks Visualisation

Similarly, the temporal evolution mapping (Figure 4) illustrates a progression from humancentric failure analysis to systemic adaptation and human–autonomy integration, reflecting historical paradigms in contemporary aviation safety scholarship.

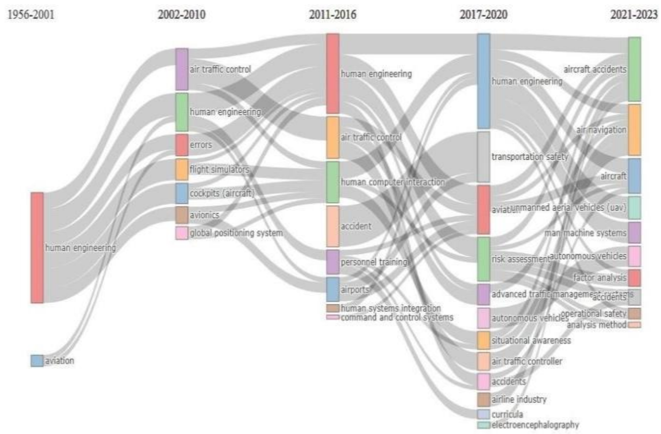

Figure 4: Thematic Evolution Mapping

3.3 Country Contributions

The global distribution of publications reveals a markedly uneven research landscape (see Figure 5). The United States accounts for 513 approximately 36% of total publications. It has the highest citation impact (total citations: 5538), underscoring its central role in developing foundational frameworks such as Crew Resource Management (CRM), the Human Factors Analysis and Classification System (HFACS), and Safety Management Systems (SMS). China accounts for approximately 9% of total publications, with significant growth in the number of contributors since 2010, particularly in research on automation, resilience, and unmanned aerial systems (UAS). The United Kingdom, France, Australia, and Germany each contribute between 8% and 3% of global output, with a primary focus on human error modelling and safety culture.

In contrast, total contributions from Africa, Latin America, and the Middle East remain below 5%. This underscores significant regional disparities in human factors and aviation safety research capacity. These imbalances exemplify broader patterns of knowledge asymmetry within safety science. Dominant theoretical and regulatory frameworks, primarily developed in the Global North, are frequently disseminated worldwide with minimal adaptation to local contexts. Consequently, safety management models may achieve global standardisation but often with limited adaptation to local settings (Reader et al., 2022).

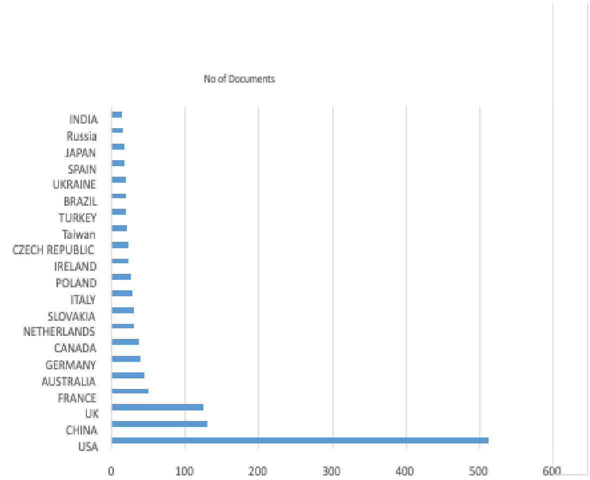

Figure 5: Top Twenty-Country Contributors to Human Factors in Aviation Safety Research (1956–2023).

In summary, bibliometric evidence indicates that aviation safety research has transitioned from nationally focused programmes to a globally networked knowledge system, reflecting the complex adaptive behaviour characteristic of contemporary aviation operations. However, persistent regional disparities underscore the need for deliberate decentralisation of safety knowledge production, enabling emerging aviation markets to serve as both data sources and co-creators of theory and policy.

3.4 Thematic Synthesis

The qualitative synthesis evaluates bibliometric results across four principal research domains. The identified themes are: Human Error and Accident Models; Crew Resource Management (CRM) and Non-Technical Skills; Risk, Safety, and Fatigue Management; and Emerging Technology and New Challenges. Each theme forms a distinct yet interconnected phase in the conceptual evolution of aviation human factors. They represent overlapping and interacting paradigms rather than discrete eras.

Theme 1- Human Error and Accident Models

Bibliometric analysis indicates that research on human error underpins aviation safety studies. Network visualisation of influential publications (Figure 6) and the list of Top 10 publications on human factors (Table 2) show that early aviation safety literature conceptualised accidents as linear sequences of human failures. Reason's Swiss Cheese Model reframed these failures as systemic vulnerabilities distributed across organisational layers. The multi-layered framework provided the basis for subsequent error taxonomies, although its primarily descriptive nature limits its predictive utility.

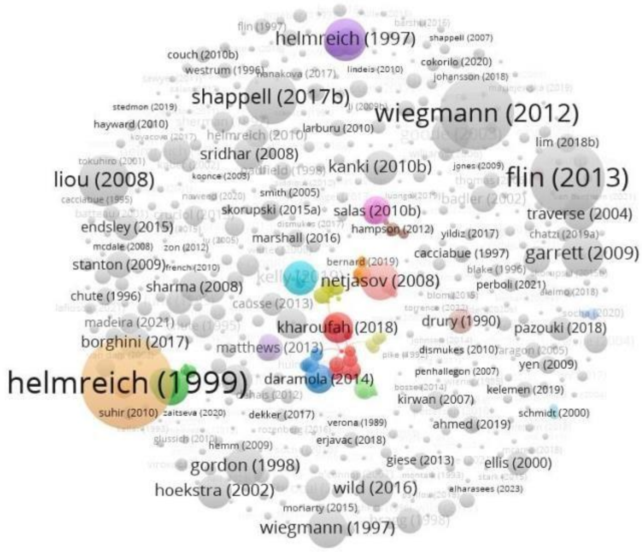

Figure 6: Network Visualisation of Influential Publications

Helmreich (1997) perspectives on managing human error at both the individual and organisational levels encourage a shift in safety culture from blaming individuals to addressing systemic vulnerabilities. Wiegmann and Shappell (2012; 2001b) translated this approach into the Human Factors Analysis and Classification System (HFACS), which remains central to contemporary investigation protocols. Shappell and Wiegmann (2017) further refined applications of HFACS across various contexts, reinforcing its status as a standard tool for accident investigation. However, critics have noted its reliance on investigator judgment, raising concerns about consistency and interrater reliability.

Together, Bibliometric-SLR analysis indicates that publications on this theme accounted for approximately 34% of outputs before 2000, highlighting the establishment of the cognitivepsychological foundation of human-factors research during this period. The continued citation influence of these works demonstrates that error models serve as the intellectual backbone of aviation safety research. Nonetheless, the limitations of the Swiss Cheese Model, HFACS and similar frameworks have prompted recent calls to integrate machine learning and natural language processing to automate error classification and enhance predictive validity (Madeira et al., 2021).

Theme 2- Crew Resource Management (CRM) and Non-Technical Skills (NTS)

Following the initial focus on human error, aviation safety research shifted toward examining teamwork, leadership, situational awareness, and communication. These dimensions are addressed through Crew Resource Management (CRM) and non-technical skills (NTS) as preventive strategies. Notably, Robert Helmreich and Rhona Flin are among the most frequently cited scholars in this domain (Figure 5 and Table 3).

Helmreich et al. (1999) influential article documented this evolution, arguing that social and organisational interventions are most effective in mitigating human error. The authors provide evidence that CRM redirected attention from individual competencies to collective crew performance, thereby reducing crew-related accidents. The article's enduring citation count (over 700 citations) underscores its academic and practical significance.

The publication of "Safety at the Sharp End" by Flin et al. (2013) expanded this perspective by offering a systematic framework for identifying, training, and assessing NTS, including leadership, decision-making, workload management, and communication. In addition to its theoretical contributions, the book introduced practical tools such as behavioural markers and assessment guides, which have been widely implemented in airline training and regulatory audits. Its high annual citation rate (42.5 per year) demonstrates its continued relevance in both academic and professional contexts.

Collectively, these works illustrate a significant paradigm shift from retrospective error classification to proactive prevention through training and organizational learning. CRM and NTS are now integral to global aviation safety practices, serving as the foundation for training curricula required by the International Civil Aviation Organization (ICAO) and national regulatory bodies. However, bibliometric analyses suggest that the field is maturing, as fewer foundational CRM publications have appeared in the past decade. The current challenge involves adapting CRM principles to new contexts, such as automation, unmanned aerial vehicle (UAV) operations, and human–AI collaboration, which are reshaping teamwork and communication dynamics (Hollnagel et al., 2012)

Theme 3: Risk, Safety, and Fatigue Management

Following the institutionalisation of Safety Management Systems (SMS), researchers, including Liou et al. (2008), Netjasov & Janic (2008) and Goode (2003) advanced quantitative risk-assessment methods and fatigue-management systems. These studies conceptualised safety as a measurable, feedback-driven process by integrating behavioural and engineering data streams. Bibliometric analysis reveals that keywords such as SMS, risk analysis, and fatigue are closely associated, indicating a convergence toward systemic oversight. This phase aligns with the principles of Resilience Engineering, which prioritise anticipation, monitoring, and adaptation rather than mere rule compliance.

Liou et al. (2008) formalised the concept of Safety Management Systems (SMS) as a structured framework for proactive hazard identification, risk assessment, and continuous improvement within aviation. Liou contended that SMS should extend beyond regulatory compliance to foster a dynamic, organisation-wide safety culture. The influence of this work is reflected in the International Civil Aviation Organisation's (ICAO) subsequent global mandate for the implementation of SMS.

Goode (2003) examined pilot fatigue as a significant contributor to aviation accidents. The study reframed fatigue from an individual shortcoming to a systemic occupational hazard, advocating for regulatory oversight and duty-hour reforms. This work contributed to establishing Fatigue Risk Management Systems (FRMS) as essential components of SMS frameworks.

Netjasov & Janic (2008) synthesised various approaches to risk and safety modelling in civil aviation, including probabilistic safety assessments and stochastic rare-event modelling. The study demonstrated the potential for quantitative risk analysis to complement qualitative human factors methodologies. Its primary contribution was to bridge engineering methods with organisational safety, though it did not fully address the complexity of human behaviour

(Kıvanç et al., 2025).

Collectively, these contributions signalled a paradigm shift from reactive accident investigation to proactive organisational safety frameworks. SMS and FRMS institutionalised systemic approaches to risk, embedding human factors into both regulatory and organisational practices. Nevertheless, bibliometric evidence indicates that fatigue research remains underrepresented relative to error and Crew Resource Management (CRM) studies, despite its ongoing relevance. Future research should incorporate biometric monitoring, circadian rhythm modelling, and predictive fatigue analytics within SMS frameworks to enable more dynamic risk management.

Theme 4: Emerging Technologies and Associated Challenges

The digital transformation of aviation has introduced automation, artificial intelligence, and unmanned systems, serving as both enablers and disruptors. Bibliometric trend analysis (Figure 4) demonstrates strong associations among automation, trust, resilience, and human–machine interaction, indicating the rise of a Socio-Technical Resilience Paradigm in aviation safety discourse. Since 2011, the exponential growth in publications (Figure 2) reflects the sector's response to increasing technological complexity. Recent research reconceptualises the human operator as a collaborative partner within hybrid socio-technical teams (Cummings et al., 2022; Wild et al., 2016).

Wild et al. (2016) conducted one of the earliest analyses of civil UAV incidents, reviewing accident data and concluding that inadequate operator training, regulatory gaps, and insufficient integration of human factors were recurrent causes of UAV operational failures. The study identified strong parallels with the early years of manned aviation safety and remains a foundational reference on UAV human factors. It also recommended that regulators examine technologies rather than focus solely on operators.

Collectively, these studies indicate a shift toward a socio-technical era in aviation safety. Unlike traditional aviation, unmanned aerial vehicle (UAV) operations and human–artificial intelligence (AI) collaboration are redefining the safety paradigm through supervisory control, distributed cognition, and advanced interface design. These developments present both technical and regulatory challenges. While the ICAO and national authorities have established Safety Management System (SMS) requirements for manned aviation, comprehensive frameworks for UAVs are still lacking. Current evidence from the study indicates that adapting human factors approaches, such as Crew Resource Management (CRM), Human Factors Analysis and Classification System (HFACS), and SMS, to autonomy and human–machine teaming represents the next significant challenge.

4. DISCUSSION

The evolution of human factors in aviation safety constitutes a paradigm shift shaped by technological advancements, regulatory philosophies, and global influences, rather than a straightforward accumulation of knowledge. By integrating bibliometric mapping with systematic synthesis, this review clarifies the field's structural development. It underscores a conceptual transition from error prevention to systemic resilience and, more recently, to sociotechnical adaptation.

The findings indicate that aviation safety functions as a complex adaptive system (CAS), with outcomes resulting from the dynamic interactions among human, technological, and organisational elements (Hollnagel et al., 2012). Over the past seven decades, research on human factors has advanced in parallel with technological progress in aviation, moving from mechanical systems and analog cockpits to data-driven, partially autonomous environments. Each technological innovation has prompted corresponding theoretical developments, redefining the relationships among human operators, machines, and the broader system. This trajectory reflects broader trends in safety science, which have shifted from reactive investigations to proactive and predictive resilience strategies (Hollnagel et al., 2012; Reason et al., 2006).

Transition from error prevention to systemic resilience

Early models, such as Reason's Swiss Cheese and HFACS, provided foundational frameworks for accident analysis and for identifying organisational contributors to error. However, these models are primarily retrospective. The emergence of Crew Resource Management (CRM) and Non-Technical Skills (NTS) research shifted the emphasis toward proactive training interventions aimed at enhancing communication, leadership, and situational awareness. Collectively, these developments have redirected the discourse from assigning blame to fostering resilience through team and organisational learning.

Transition from training interventions to organisational integration

The introduction of Safety Management Systems (SMS) and fatigue risk management broadened the scope of human factors beyond cockpit dynamics to include organisational and regulatory domains (Liou, 2008; Goode, 2003). SMS institutionalised proactive hazard identification and continuous improvement, embedding human factors principles within safety culture at multiple organisational levels (ICAO, 2018). Although fatigue management remains underdeveloped, it is increasingly recognised as a systemic risk that requires the integration of physiological and predictive monitoring technologies (Morais et al., 2023).

Transition from traditional to emerging operational contexts

Recent advancements highlight the growing importance of unmanned aerial vehicles (UAVs), automation, and human–machine collaboration. Analyses of UAV incidents consistently reveal persistent deficiencies in operator training and inadequate regulatory oversight (Wild et al., 2016). Research on human–autonomy teaming demonstrates that supervisory control necessitates distinct cognitive and organisational strategies compared to direct piloting (Cummings et al., 2022; Li et al., 2022). These findings indicate that, while established frameworks such as CRM and HFACS remain robust, they must adapt to address the complexities of hybrid human–artificial intelligence ecosystems.

5. IMPLICATIONS FOR FUTURE RESEARCH AND PRACTICE

The integration of bibliometric and thematic findings illustrates how aviation safety has evolved over seven decades of human-factors research, yielding significant implications for both practice and theory. This synthesis underscores the urgent need for adaptive models and globally representative safety research.

Traditional models such as HFACS and Reason's Swiss Cheese Model require revision to address the challenges posed by automation and data-driven operations. Future frameworks should integrate real-time data analytics to identify algorithmic and human–automation interaction errors. Furthermore, the concept of "human error" should be broadened to encompass systemic and algorithmic vulnerabilities, consistent with resilience engineering and complex adaptive systems perspectives.

Crew Resource Management (CRM) and Non-Technical Skills (NTS) training remain essential, but must be adapted for hybrid human–machine teams and remote operations. Effective digital communication and shared situational awareness across automated interfaces require simulator-based, AI-supported training. From a theoretical perspective, CRM should integrate principles from distributed cognition and human–autonomy teaming

(HAT) to model authority, workload, and trust in human–AI coordination.

Safety Management Systems (SMS) and Fatigue Risk Management Systems (FRMS) should incorporate predictive analytics and biometric monitoring to address fatigue and workload proactively. Advancements in safety theory should move beyond compliance, emphasising resilience-based prediction and conceptualising safety as a dynamic equilibrium sustained by human, organisational, and technological feedback loops.

Artificial Intelligence (AI), automation, and Unmanned Aircraft Systems (UAS) require renewed attention to trust calibration, algorithmic transparency, and ethical human oversight. Human-organisation safety theory should evolve toward digital humanism by integrating ethics, resilience, and socio-technical systems theory to preserve human relevance in autonomous operations.

Finally, bibliometric evidence of geographical skewness, indicated by limited research output from Africa, Latin America, and the Middle East, highlights persistent epistemic asymmetry. Enhancing global collaboration, research capacity, and knowledge accessibility is essential to ensure that aviation safety frameworks reflect diverse operational realities. Policymakers and funding agencies should prioritise capacity building, regional research partnerships, and openaccess knowledge sharing to democratise safety science and ensure that standards and interventions are responsive to varied operational contexts.

6. LIMITATIONS

Although the Bibliometric-SLR approach provides a comprehensive understanding of human factors in aviation safety, it is not without limitations. Relying solely on Scopus may exclude pertinent publications available in other databases, including Web of Science and IEEE Xplore. Limiting the analysis to English-language publications may introduce linguistic bias. Furthermore, while bibliometric methods ensure objectivity in data retrieval, thematic synthesis requires interpretive judgment, which may affect classification. These limitations, however, align with those identified in previous bibliometric–systematic studies (Donthu et al., 2021).

7. CONCLUSION

This review employed bibliometric mapping and systematic synthesis to analyze the intellectual evolution of human factors in aviation safety over nearly seven decades. Covering the period from 1956 to 2023 and encompassing 1,397 publications, the findings reveal a progression from early human-error and cognitive-reliability models, through the institutionalization of Crew Resource Management (CRM) and Safety Management Systems (SMS), to a contemporary era defined by automation, artificial intelligence (AI), and sociotechnical integration. The integration of quantitative and qualitative analyses provides both a macro-level overview of disciplinary development and a micro-level understanding of conceptual change. Future research should update legacy frameworks for hybrid human– autonomy environments, adapt SMS and Fatigue Risk Management Systems (FRMS) for datadriven applications, and address global disparities in knowledge production. Sustained progress in aviation safety relies on integrating predictive analytics, ethical AI, and inclusive collaboration to ensure safety and resilience in increasingly complex airspace

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