İŞLETME ARAŞTIRMALARI DERGİSİ
JOURNAL OF BUSINESS RESEARCH-TURK
2025, 17(4), 2778-2798
https://doi.org/10.20491/isarder.2025.2124

Adapting HR Strategies to Enhance CRM in Aviation: A Qualitative Study on Emerging Technologies Grounded in Socio-Technical Systems Theory

Kağan Cenk MIZRAK [a]

[a] İstanbul Nişantaşı University, İstanbul, Türkiye. kagancenk.mizrak@nisantasi.edu.tr

ARTICLE INFO

Keywords:
Human Resource Management
Aviation Management
CRM
Socio-Technical Systems Theory

Received 9 January 2025
Revised 24 October 2025
Accepted 30 October 2025

Article Classification:
Research Article

ABSTRACT

Purpose – This study aims to explore how Human Resource Management (HRM) strategies can enhance Crew Resource Management (CRM) effectiveness in the context of emerging technologies such as artificial intelligence (AI) and augmented reality (AR) in aviation. While these technologies improve operational efficiency, they also highlight the critical need for maintaining human oversight and decision-making processes.

Design/methodology/approach – The research employs a qualitative methodology grounded in Socio-Technical Systems (STS) theory. Data were collected through interviews with 15 aviation experts, including pilots, HR professionals, and operations managers, and analyzed using thematic analysis with NVivo software.

Results – The findings indicate that while automation significantly enhances operational efficiency, maintaining manual skills and human decision-making remains essential for sustainable operations. The study also identifies the need for HR strategies to adapt to technological change through enhanced training programs, continuous learning initiatives, and revised recruitment practices.

Discussion – This study contributes to STS theory by emphasizing the importance of balancing technological and social systems to ensure effective CRM in aviation. Practical recommendations for HR strategies are provided, including improving training programs, fostering a culture of continuous learning, and modernizing recruitment processes to support the successful integration of emerging technologies in aviation.

1. Introduction

In aviation, Crew Resource Management (CRM) has played a critical role in enhancing safety and teamwork through improved communication, decision-making, and leadership. As a systematic approach developed to mitigate human error, CRM emphasizes the importance of collaboration among crew members and has been widely adopted across the aviation industry. However, the evolution of CRM relies not only on the skills and behaviors of the crew but also on the organizational support provided through Human Resource Management (HRM). HRM is integral to CRM's success, particularly in areas such as recruitment, training, and development, where the focus is on fostering effective teamwork, communication, and leadership skills within aviation crews.

Emerging technologies such as artificial intelligence (AI), augmented reality (AR), and biometric systems are rapidly transforming aviation operations, presenting both opportunities and challenges. AI is playing a crucial role in optimizing predictive maintenance, as seen with Boeing using AI-powered robots on its assembly lines to enhance precision and efficiency. Predictive maintenance systems now monitor aircraft in real-time, enabling early detection of potential issues, thus minimizing downtime and improving safety (Aeologic, 2023). Additionally, AR is being used in pilot training simulations to create immersive, real-world scenarios for emergency preparedness, offering airlines like Lufthansa a cost-effective and safe alternative to traditional training methods (Future Travel Experience, 2024).

In terms of enhancing CRM practices, biometric systems are being deployed at major airports like Dubai International, where facial and iris recognition streamlines passenger flow and security, reducing human interaction and error. The implementation of AI in air traffic management is also progressing, with projects

ETHICAL APPROVAL: The ethical approval for this study was obtained from the Ethics Committee of Istanbul Nişantaşı University with the decision dated November 21, 2024, and numbered 20241221-055.

Suggested Citation
Mızrak, K.C. (2025). Adapting HR Strategies to Enhance CRM in Aviation: A Qualitative Study on Emerging Technologies Grounded in Socio-Technical Systems Theory, İşletme Araştırmaları Dergisi, 17 (4), 2778-2798.

like the UK's Project Bluebird, which explores how AI can assist human controllers to improve airspace management efficiency (Xie et al., 2021). These advancements demonstrate how the integration of AI, AR, and biometrics can both enhance and complicate human-machine interaction within aviation. In this scope, this study seeks to explore how HR strategies can be adapted to enhance CRM effectiveness, particularly in the context of emerging technologies.

To ground this research theoretically, Socio-Technical Systems (STS) Theory provides a robust framework. STS theory examines the interaction between social systems (people, roles, and communication) and technical systems (tools, technologies, and processes). In the context of aviation, this theory highlights the interdependence of human and technological factors in achieving operational effectiveness. As emerging technologies increasingly become part of aviation operations, the balance between these social and technical systems must be maintained to ensure the continued success of CRM practices. This study applies STS theory to investigate how HR strategies can support the socio-technical dynamics of CRM, ensuring that human and technological elements work cohesively in aviation environments.

The research problem focuses on how HR strategies can evolve to better support CRM in an increasingly technology-driven aviation sector, considering both social and technical elements. Specifically, this study aims to explore how HR strategies can enhance CRM effectiveness in the face of technological advancements and to investigate the impact of emerging technologies on the socio-technical systems of aviation, particularly CRM and HRM.

The research is guided by the following questions:

- How are emerging technologies reshaping CRM practices within the framework of STS theory?
- What HR strategies are required to maintain the balance between the social and technical aspects of CRM in this changing environment?
- How do aviation experts perceive the challenges and opportunities at the intersection of CRM, HR, and technological advancement?

Through these questions, this study provides insights into how HR strategies can be adapted to support both the social and technical dimensions of CRM, ensuring that aviation crews are prepared to operate effectively in a technologically advanced environment. The qualitative approach of this research involves interviewing pilots, HR professionals, and other experts to gather in-depth perspectives on these evolving dynamics.

2. Literature Review

2.1. Socio-Technical Systems (STS) Theory

Socio-Technical Systems (STS) Theory emerged in the mid-twentieth century to explain how organizational performance depends on the joint optimization of social and technical subsystems rather than on technology or human factors alone. In its contemporary form, STS frames organizations as ensembles where roles, norms, communication, and governance mechanisms interact with tools, data, and processes to produce outcomes—especially salient in safety-critical settings such as aviation (Bayramova et al., 2023; Ciriello et al., 2024; Thomas, 2024). Recent scholarship extends this lens beyond generic "fit" to emphasize explicit design of socio-technical barriers and interfaces that prevent incidents while enabling learning, showing how safety mechanisms themselves are socio-technical artifacts (Subedi, Bucelli, & Paltrinieri, 2025). Parallel advances in Industry 4.0 demonstrate that value creation arises when digital technologies are braided with work design, incentives, and collaboration routines—not when automation is layered onto unchanged social systems (Alonso et al., 2025). In aviation, this means cockpit and cabin teamwork, procedures, and governance must continually co-evolve with flight management systems, decision-support tools, and AI-enabled analytics, preserving human authority while leveraging machine strengths (Govers & van Amelsvoort, 2023). This theoretical vantage underpins the present study's focus on CRM and HR strategy as levers for balancing socio-technical change in flight operations.

Building on this foundation, contemporary STS work highlights that digital transformation introduces ambidexterity requirements: systems must amplify human judgment and coordination while guarding against new failure modes like automation bias and data myopia. Evidence from manufacturing and auditing indicates that performance gains materialize only when human-technology complementarities are

intentionally cultivated—via redesigned workflows, feedback channels, and accountability structures—rather than assumed (Zhang et al., 2023; Dahabiyeh & Mowafi, 2023). For aviation CRM, this translates into coupling technical upgrades (e.g., automated flight controls, predictive maintenance dashboards, and AI-based decision aids) with social capabilities such as briefing discipline, mutual monitoring, graded assertiveness, and leadership that sustains shared situational awareness (Bayramova et al., 2023). At the same time, big-data infrastructures can be both savior or saboteur of innovative behavior depending on how visibility, trust, and autonomy are structured—an STS contingency that cautions airlines to align data governance with crew learning and psychological safety (Yuan et al., 2025). Platform-style ecosystems intensify these demands: as avionics, airports, and service providers interconnect, governance design—roles, rules, and escalation paths—becomes a first-order technical requirement (Hanafizadeh & Mehrasa, 2025). Integrating knowledge-management practices into socio-technical design (e.g., codified lessons learned feeding back into procedure updates and simulator scenarios) further stabilizes the human–machine balance under continual change (Azmi & Ismail, 2025).

Recent STS applications in aviation environments reinforce a user-centered, context-sensitive approach to system design and decision-making. Airport case studies show that service quality and resilience improve when technology rollouts are co-designed with frontline work practices, role definitions, and communication protocols—a principle that maps directly onto CRM objectives for coordination and error management (Gambo, Ogundare, & Oluyide, 2023). Decision-making analyses in socio-technical systems likewise demonstrate that reliability hinges on coupling algorithmic aids with robust human cross-checks, especially under uncertainty or anomaly conditions typical of flight operations (Shmelova & Sikirda, 2021). Beyond transport, integrated socio-technical frameworks proposed in digital-heritage domains illustrate transferable blueprinting methods—joint modeling of actors, artifacts, workflows, and rules—that aviation can adopt to govern AI and automation in training, line operations, and post-event learning (Lu, García-Badell, & Rodriguez, 2025). Accordingly, this study operationalizes STS by examining how HR strategies (recruitment for tech-savvy teamwork, competency-based training that blends manual and automated modes, and governance that aligns incentives with vigilance) can sustain a productive equilibrium between social and technical elements in CRM as emerging technologies diffuse across flight decks and airports (Ciriello et al., 2024; Thomas, 2024; Govers & van Amelsvoort, 2023; Muehlberger et al., 2024).

2.2. Crew Resource Management (CRM)

Crew Resource Management (CRM) emerged in the late 1970s as a structured response to a cluster of accident investigations that traced proximate causes to "human error," but whose deeper roots were embedded in cockpit culture, role dynamics, and information flow across the team. Drawing on early NASA workshops, the nascent CRM movement reframed pilot error as a systemic breakdown of leadership, communication, and decision-making under time pressure and uncertainty, thereby targeting steep authority gradients, muted dissent, and poorly managed workload transitions (Alexander, 2025; Helmreich et al., 2001). First-generation courses emphasized communication discipline, standard briefings, callouts, and cross-checks that surface weak signals before they cascade into incidents, while also normalizing graded assertiveness and advocacy–inquiry dialogue to counteract deference traps (Helmreich et al., 2001). Over subsequent decades, the scope widened as evidence accumulated that safety is a team property rather than a pilot-only competence, which motivated the integration of CRM behaviors into cabin, maintenance, dispatch, and air traffic control interfaces so that shared mental models span organizational seams (Helmreich & Merritt, 2017). This expansion aligned CRM with emerging Safety Management Systems (SMS), positioning non-technical skills (NTS) as auditable elements linked to standard operating procedures and line-oriented flight training (LOFT), rather than as optional "soft skills" (Helmreich & Merritt, 2017; Salas et al., 2006). A robust empirical base—including controlled evaluations and field studies—now shows CRM's association with improved checklist discipline, error interception, and event recovery, thereby validating its original thesis that teamwork processes are co-determinants of safety alongside technical proficiency (O'Connor et al., 2008; Aframchuk, 2025). The theoretical and practical maturation of CRM thus institutionalized system-level routines—brief, execute, monitor, adapt—that make safe outcomes more probable across diverse operating conditions, while preserving individual accountability within clearly articulated team roles (Salas et al., 2006; Helmreich & Merritt, 2017). In this way, CRM's historical arc transitions from cockpit-centric remediation to enterprise-level

capability building, sustaining vigilance against cognitive biases such as authority bias and confirmation bias that are known to degrade performance under stress (Helmreich et al., 2001; Helmreich & Merritt, 2017).

The core principles of CRM emphasize teamwork, communication, leadership, situational awareness, and decision-making as interdependent competencies that must be practiced deliberately and evaluated continuously to ensure operational effectiveness (Salas et al., 2006). Training packages therefore cultivate skills such as shared attention management, explicit plan–contingency articulation, closed-loop communication, and mutual performance monitoring, so that critical information is communicated clearly, timely, and at the appropriate level of assertiveness regardless of seniority (Salas et al., 2006; Helmreich & Merritt, 2017). Meta-analytic results demonstrate that well-designed CRM interventions can reduce error rates and enhance safety outcomes, with effects mediated by improvements in NTS and the reliability of team coordination mechanisms under volatility and surprise (O'Connor et al., 2008). Field studies complement this picture: for example, research on flight attendants shows that CRM training improves attitudes toward safety, strengthens communication norms, and supports more effective management of passenger and inter-crew contingencies, underscoring CRM's relevance beyond the flight deck (Ford et al., 2014). Contemporary practice also recognizes that CRM must explicitly counter recurrent cognitive pitfalls—plan continuation bias, attentional tunneling, and automation complacency—through techniques such as time-outs, red-team questioning, and pre-briefed "balk" criteria that empower junior members to halt hazardous trajectories (Helmreich et al., 2001; Helmreich & Merritt, 2017). In parallel, organizations increasingly embed CRM indicators into debrief templates and recurrent checks, making behaviors observable and coachable with feedback loops that connect training, line operations, and safety reporting (Salas et al., 2006; O'Connor et al., 2008). The cumulative implication is that CRM functions both as a knowledge domain and as a governance mechanism that orchestrates people, procedures, and tools in real time to contain complexity and risk (Helmreich & Merritt, 2017; Aframchuk, 2025). This orchestration is especially critical during high-workload phases—approach, landing, abnormal checklists—when the interplay of leadership and followership calibrates team cognition and error resilience (Salas et al., 2006).

In recent years, CRM has diffused beyond aviation to other high-risk sectors—healthcare, trauma teams, emergency response—where the same underlying coordination challenges and error mechanisms recur, thereby providing external validation of CRM's generalizability and boundary conditions (Alhawsawi & Macedo, 2024; Jakonen et al., 2023). Cross-domain adoptions commonly retain the aviation core (briefings, closed-loop communication, role clarity, shared situational awareness) while tailoring to local constraints such as shifting team composition, asynchronous information, and heterogeneous expertise under time pressure (Curcio, 2023). The historical narrative of CRM's genesis at NASA and its subsequent codification in aviation offers a blueprint for these sectors: recognize that human error is often the symptom of latent organizational and team design issues, then train and measure the behaviors that reveal and resolve those issues before they escalate (Alexander, 2025; Helmreich et al., 2001). Evidence from healthcare meta-reviews shows improvements in handoff quality, protocol adherence, and adverse event reduction when CRM-like programs are integrated with simulation and structured debriefs, which mirrors aviation's LOFT tradition (Alhawsawi & Macedo, 2024; O'Connor et al., 2008). Such translations also highlight a recurring theme: the benefits of CRM materialize when leadership legitimizes speaking up, operationalizes psychological safety, and aligns incentives so that reporting and learning are rewarded rather than penalized (Curcio, 2023; Helmreich & Merritt, 2017). Conversely, partial implementations that treat CRM as a one-off classroom event without embedding measurement, coaching, and reinforcement into the operations system tend to fade, offering a cautionary note for any domain contemplating adoption (Salas et al., 2006; O'Connor et al., 2008). Taken together, these cross-industry trajectories strengthen the argument that CRM is a robust framework for managing human error and optimizing team performance in dynamic, high-stakes environments (Alhawsawi & Macedo, 2024; Jakonen et al., 2023; Curcio, 2023).

Finally, CRM continues to evolve to accommodate external factors and technological change, extending its toolkit to integrate meteorological intelligence, data-driven decision aids, and digital collaboration platforms while preserving human oversight and judgment. Studies that embed structured weather data into briefings and threat-and-error management have shown gains in preparedness and response to rapidly changing conditions, reinforcing the principle that information must be transformed into shared situational awareness to be effective (Bayazıtoğlu & Güngör, 2023). Digital transformation similarly invites both opportunity and

risk: decision-support apps, electronic flight bags, and collaborative planning platforms can enhance cue discovery and coordination, but only when they are selected, configured, and trained in ways that sustain CRM behaviors rather than displace them (Helmreich & Merritt, 2017; Salas et al., 2006). Recent decision-analysis work demonstrates how multi-criteria methods can help organizations prioritize and integrate digital solutions that strengthen, rather than dilute, CRM's behavioral core—by weighting criteria such as usability, transparency, workload impact, and training burden in addition to technical performance (Öz & Kütahya, 2025). Concurrent syntheses of accident prevention continue to affirm CRM's central place in safety strategies, emphasizing its role in error interception, escalation management, and post-event learning across the full life cycle of operations (Aframchuk, 2025). The enduring lesson from the NASA-era origins to today's digital ecosystems is that CRM's value lies in coupling technical capability with social processes—leadership, communication, and mutual monitoring—so that human and technical systems reinforce each other rather than compete for control (Alexander, 2025; Helmreich et al., 2001). Accordingly, in the context of this study, CRM is treated not as a static training module but as an evolving organizational capability that must be continually tuned to new threats, tools, and workflows to maintain safety, communication, and operational efficiency (Helmreich & Merritt, 2017; Salas et al., 2006; O'Connor et al., 2008).

2.3. Human Resource Management in Aviation

Human Resource Management (HRM) is the organizational lever that converts Crew Resource Management (CRM) from a training program into a durable capability by shaping who enters, how they are socialized, and which behaviors are reinforced in everyday operations. In tightly coupled, time-pressured aviation settings, selection must privilege interpersonal and team-cognition competencies—communication, teamwork, leadership, and followership—alongside technical proficiency because these map directly to CRM's error-management routines and threat-and-error mitigation strategies (Mızrak, 2023). In practice, this requires validated behavioral interviews, scenario-based assessments, and psychometric tools that elicit graded assertiveness, advocacy–inquiry dialogue, and situational awareness under uncertainty, rather than relying solely on hours or type ratings (Mızrak, 2023). Evidence from aviation organizations further indicates that leadership climate, workload design, and stress regulation are decisive moderators of performance, underscoring HR's influence through job design, staffing ratios, and coaching infrastructures that sustain CRM-compatible norms (Daga & Samad, 2025). Strategic competency frameworks should therefore encode CRM-aligned KSAs across flight deck, cabin, maintenance, and operations control so that hiring pipelines and promotion criteria reinforce a shared language for coordination and mutual monitoring (Demirok, Bagherpour, & Ulgen, 2024). Closing the loop, HR should channel FOQA/LOSA insights, line-check trends, and debrief data into profile definitions and advancement rules, ensuring that the very behaviors that intercept threats and manage errors are systematically selected and rewarded (Mızrak, 2023). Where organizations underperform, root causes frequently trace to mis-specified role profiles and uneven reinforcement of non-technical skills—not a lack of technical training—again highlighting HR's leverage over both the who and the how of safe performance (Demirok et al., 2024). Taken together, these practices move HRM from administrative processing to stewardship of the "people system" that makes CRM scalable across phases of flight and organizational seams (Mızrak, 2023). By aligning Safety Management System (SMS) expectations with lived incentives, HRM creates coherent conditions in which speaking up, cross-checking, and mutual monitoring are expected, measured, and rewarded (Daga & Samad, 2025). The outcome is a workforce composition and cultural substrate that render CRM behaviors routine rather than exceptional, lowering variance in safety-critical teamwork outcomes across both normal and abnormal operations (Mızrak, 2023; Demirok et al., 2024).

Training and development constitute HRM's second pillar for operationalizing CRM, shifting emphasis from one-off compliance to a lifecycle of competency building, evaluation, and reinforcement that spans initial qualification, recurrent checks, and line operations. Contemporary programs weave CRM foundations through LOFT-style simulation, structured pre-briefs, disciplined callouts, and post-event debriefs so that closed-loop communication, mutual performance monitoring, and time-critical decision-making are practiced under varying automation states and meteorological complexities (de Andreis et al., 2022). HR's design task is curricular coherence: advocacy–inquiry scripts, graded assertiveness, and "stop-the-line" triggers should appear in both technical and non-technical syllabi so that behaviors are observable, coachable, and tied to progression criteria and promotion gates (de Andreis et al., 2022). Innovations such as serious games and

micro-simulations can accelerate transfer; studies on situational awareness training indicate that gamification strengthens cue detection, attention management, and rapid plan revision—competencies central to CRM's threat-and-error management logic (Mizrak, 2025). To protect fidelity, HR should institutionalize multi-source feedback (peers, instructors, data-driven observables) and adopt behaviorally anchored rating scales that reduce halo effects while highlighting growth targets in briefing discipline, graded assertiveness, and leadership under stress (de Andreis et al., 2022). Importantly, cabin, ramp, and turnaround contexts require tailored CRM adaptations that preserve core principles while addressing domain-specific contingencies such as passenger dynamics, gate pressure, and cross-functional handoffs (de Andreis et al., 2022). When cadence (e.g., quarterly refreshers), modality (simulator, e-learning, in-situ drills), and evaluation (pre/post measures and on-the-job observations) are synchronized, training outcomes propagate into line behaviors rather than dissipating after audits (de Andreis et al., 2022). This ecosystemic approach reframes training as capability building with measurable effects on error interception and recovery trajectories, not as periodic box-ticking (Mizrak, 2025). In doing so, HRM ensures that the behaviors most predictive of resilience are both taught and evidenced in daily operations through feedback, recognition, and advancement rules aligned to CRM (de Andreis et al., 2022; Mizrak, 2025). By anchoring these mechanisms in data and deliberate practice, HRM converts non-technical skills into reliable performance assets that withstand workload spikes and ambiguity (de Andreis et al., 2022).

As technology reshapes flight decks and operations centers, HRM must recalibrate talent and learning strategies to preserve human–automation complementarity rather than drifting into accidental substitution of judgment by tools. Recruitment profiles now prioritize digital fluency, data literacy, and human–automation teaming skills so crews can interrogate algorithmic outputs, manage mode awareness, and avoid complacency while preserving the communication and leadership behaviors central to CRM (Alkan & Sunar, 2024). On the process side, digital HR technologies—ATS with structured scoring, skills taxonomies, learning-experience platforms, and analytics dashboards—can streamline hiring and personalize learning pathways, but they require explicit governance to prevent bias drift and to keep human oversight where safety is implicated (Pisitkasem & Pairoj-Boriboon, 2023). Learning analytics can surface weak signals—such as recurrent debrief flags on plan-continuation bias or attentional tunneling—and trigger targeted micro-interventions before patterns crystallize in line operations (Pisitkasem & Pairoj-Boriboon, 2023). Where organizations face technology choices, multi-criteria decision methods help HR and operations jointly evaluate digital solutions against usability, transparency, workload impact, and training burden—criteria that determine whether tools amplify or erode CRM (Alkan & Sunar, 2024). Mixed-reality simulation and e-learning enable just-in-time refreshers and rare-event practice, with HR curating content that couples technical procedures to communication scripts and leadership moves in time-critical situations (Pisitkasem & Pairoj-Boriboon, 2023). Equally, change-management routines—stakeholder mapping, pilot cohorts, staged rollouts, and post-implementation audits—are needed to ensure new tools reinforce, rather than displace, established CRM habits (Pisitkasem & Pairoj-Boriboon, 2023). Scheduling and fatigue-risk policies should be tuned to the cognitive realities of automation monitoring, protecting attention budgets on long sectors while sustaining vigilance, which links talent strategy to operational risk control (Alkan & Sunar, 2024). Through this intentionality, HR steers the socio-technical balance by hiring for, training to, and rewarding the integration of human and digital strengths rather than privileging one at the other's expense (Alkan & Sunar, 2024). In turn, line supervisors and check airmen become amplifiers of these choices when HR embeds the digital-era competencies into appraisal, coaching, and promotion (Pisitkasem & Pairoj-Boriboon, 2023). The cumulative effect is a workforce capable of leveraging automation as a team member within CRM, not a brittle replacement for human sense-making (Alkan & Sunar, 2024).

Finally, HRM increasingly anchors aviation's social and environmental commitments, integrating safety, wellbeing, and sustainability into people practices that reinforce CRM's ethos of shared responsibility and proactive risk management. Socially responsible HRM embeds pro-safety and eco-helping behaviors into competency models, recognition systems, and training, aligning daily micro-decisions with broader stakeholder obligations and operational efficiency (Nguyen & Nguyen, 2024). Green HRM research in aviation suggests that aligned bundles—green recruitment, development, participation, and rewards—can foster engagement with sustainability goals without diluting safety priorities, thereby creating complementarities with CRM's communication and coordination routines (Faeni & Faeni, 2025). Wellbeing policies that address fatigue risk, workload fairness, and psychological safety strengthen the preconditions for speaking up and

mutual monitoring, which determine whether threats are voiced and jointly managed in time (Nguyen & Nguyen, 2024). Because CRM thrives in climates where diverse perspectives are heard, HR's inclusion initiatives broaden perspective-taking and reduce groupthink during abnormal operations, improving decision quality under uncertainty (Nguyen & Nguyen, 2024). At the same time, targeted research on training design shows that gamified and analytics-enabled approaches can enhance situational awareness and team coordination, offering HR additional levers to embed CRM behaviors efficiently at scale (Mizrak, 2025). For organizations seeking integrative measurement, PLS-SEM and fsQCA studies in aviation demonstrate how HR bundles co-produce safety, sustainability, and performance outcomes, giving HR an evidence-based toolkit for portfolio design and evaluation (Faeni & Faeni, 2025). By systematizing these dimensions—talent pipelines, learning architectures, digital adoption, wellbeing, and sustainability—HRM ensures the workforce is aligned with both technological change and societal expectations that shape license to operate (Nguyen & Nguyen, 2024). In cumulative terms, HR functions as the integrator that keeps CRM coherent as conditions evolve, translating strategic intent into observable behaviors and stable team cognition. Accordingly, HR in aviation is best understood as a strategic partner that curates the capabilities, climates, and incentives through which CRM delivers its safety and performance dividends (Nguyen & Nguyen, 2024; Faeni & Faeni, 2025).

2.4. Emerging Technologies in Aviation

Emerging technologies—most notably artificial intelligence (AI), advanced automation, and digitalized maintenance ecosystems—are transforming aviation's operational core and reconfiguring the patterns of interaction that Crew Resource Management (CRM) seeks to stabilize. These technologies now permeate maintenance, repair, and overhaul (MRO) functions through sensor-rich assets, condition-based monitoring, and algorithmic work-order prioritization, thereby altering information flows between engineers, flight crews, and operations control (Goritiyal et al., 2021). In parallel, cross-industry diffusion of disruptive tools such as robotics, immersive visualization, and digital platforms expands the design space for error interception and recovery, but also introduces new coordination demands when human and machine agents share control (Dreković, Teofilović, & Karabegović, 2025). The result is a socio-technical landscape in which efficiency improvements increasingly depend on how well organizations choreograph handoffs among people, procedures, and computational systems rather than on any single component's performance. Within this landscape, CRM's behavioral anchors—briefing discipline, closed-loop communication, mutual monitoring—provide the connective tissue that helps mixed human–machine teams maintain shared situational awareness. Yet these anchors must be adapted to reflect new cues and latencies generated by digital subsystems, especially when predictive signals appear earlier and more ambiguously than traditional technical warnings. Consequently, technical upgrades without parallel recalibration of roles and teamwork routines risk creating "silent failures" in which critical insights do not propagate to decision points in time. Strategic integration therefore requires governance that treats technology introduction as a change in team cognition, not merely as equipment refresh, keeping CRM at the center of operational design (Goritiyal et al., 2021; Dreković et al., 2025). This framing positions CRM as the primary translator between digital capability and resilient line performance, rather than as a legacy training artifact that technology will eventually supersede.

AI capabilities are expanding from back-office analytics into real-time operational decision support, reshaping how crews perceive, interpret, and act under uncertainty across the full flight envelope. Machine-learning models now power predictive maintenance, anomaly detection, trajectory optimization, and fuel planning, while decision-aid interfaces surface recommendations that can compress time-to-action when events unfold rapidly (Kabashkin et al., 2023). These gains materialize only when crews understand model intent, assumptions, and reliability bounds, which requires explicit CRM-aligned protocols for questioning recommendations, escalating discrepancies, and resolving human–automation conflicts. In manufacturing and operations, advancing automation increasingly reallocates tasks from manual execution to supervisory control and exception handling, which elevates the cognitive demands of monitoring and "mode awareness" in ways that classic CRM curricula did not fully anticipate (Xue et al., 2021). At the same time, the connective infrastructure that makes AI-enabled collaboration possible—networks, data pipelines, and integrated avionics—expands the attack surface for cyber threats, turning cybersecurity into a first-order safety consideration for flight operations and training design (Eleimat & Őszi, 2025). A coherent approach therefore couples AI adoption with cyber-hygiene behaviors (e.g., authentication discipline, anomaly reporting, cross-checking data provenance) embedded within CRM's communication and leadership norms, so that digital

trust is produced socially as well as technically. When these elements align, AI can reduce human error by augmenting cue discovery and supporting disciplined decision-making; when they do not, automation complacency or adversarial interference can degrade the very safety margins AI promises to expand. Thus, CRM's role evolves from compensating for human limitations to orchestrating human–machine complementarity, ensuring that algorithmic insights sharpen, rather than blunt, team cognition (Kabashkin et al., 2023; Xue et al., 2021; Eleimat & Őszi, 2025). The net effect is a reframing of proficiency to include both technical flying skills and data-literate judgment about when and how to rely on computational partners in the loop.

Because technology changes the relations among actors as much as it changes tasks, value creation in aviation now hinges on careful socio-technical integration that preserves human oversight while leveraging automation's speed and scale. Industry analyses describe how digital programs deliver efficiency and safety improvements when they are embedded in governance that clarifies roles, escalation paths, and handoff protocols—precisely the organizational scaffolding CRM has cultivated for decades (Pereira et al., 2022). As infrastructure modernizes, energy and systems innovations must be synchronized with operating practices, regulatory expectations, and workforce capabilities so that new assets can be managed as part of coherent operational narratives rather than as isolated technical projects (Alharasees, Kale, & Rohacs, 2025). This synchronization requires change-management routines—pilot cohorts, staged rollouts, structured debriefs—that convert technology introduction into iterative learning cycles, allowing crews to surface surprises, recalibrate procedures, and stabilize new patterns of teamwork. In practice, such routines extend CRM beyond the cockpit to include engineers, dispatchers, and airport partners, thereby aligning cross-functional collaboration with the realities of networked, data-driven operations (Pereira et al., 2022; Alharasees et al., 2025). Importantly, integration also entails specifying boundaries of autonomy for machine agents and codifying human veto rights to protect against automation bias, while training crews to interpret model confidence and failure modes. When organizations neglect these relational details, technology can generate coordination brittleness: information may exist, but it does not reach the right person at the right time in a form that supports action. Conversely, when CRM principles guide digital deployment, the same technology amplifies shared situational awareness and reduces error cascades by making intent and state visible across the team. In short, the socio-technical balance remains the critical mediator between promise and peril in aviation's digital transition (Pereira et al., 2022; Alharasees et al., 2025).

Training ecosystems are adapting to equip personnel with the hybrid competencies needed to manage increasing complexity, with simulation and high-fidelity emulation playing central roles in this shift. Simulated air traffic control environments (SATCE) and integrated scenario sets expose crews to dense, multi-actor traffic pictures, emergent anomalies, and variable automation behaviors, translating abstract digital concepts into embodied teamwork practices that CRM can coach and assess (Ziakkas et al., 2024). These environments enable rehearsal of communication protocols with algorithmic teammates, practice in disputing and reconciling recommendations, and disciplined use of "time-outs" when cues conflict—skills foundational to reliable human–automation teaming. Coupled with data-rich debriefs, organizations can now trace how recommendations propagate through the team, where misunderstandings arise, and which CRM behaviors most effectively resolve ambiguity, thereby feeding targeted improvements back into training. Beyond operational decision-making, digital training architectures also support competency development for maintenance and ground operations, where collaborative robots, mobile diagnostics, and augmented reality introduce new handoff points and verification steps (Ziakkas et al., 2024). As curricula mature, proficiency standards expand to include interpretability literacy (understanding model outputs and limits), cyber-situational awareness (recognizing and reporting anomalies in data integrity), and escalation leadership (deciding when to slow or halt operations to protect margins). In effect, training becomes the institutional pathway for converting technological potential into stable team cognition, ensuring that CRM's behavioral repertoire remains fit for purpose as systems evolve. By aligning assessment rubrics, recurrent cadence, and scenario design with these hybrid demands, organizations can sustain performance under surprise and high workload while accelerating safe adoption of new tools (Ziakkas et al., 2024). Thus, learning architectures function as the bridge between technological novelty and operational reliability, with CRM providing the grammar of interaction that makes that bridge traversable.

Sustainability imperatives further broaden the technology agenda and intersect with CRM by adding new planning horizons, risk factors, and coordination partners to everyday decision-making. Rapid advances in battery technologies suggest new regional flight concepts and hybrid-electric configurations that will alter weight, range, and energy-management profiles, requiring crews and engineers to adopt unfamiliar cues and contingency plans (Pattanayak & Mavris, 2025). Infrastructure-level innovations—from charging systems to hydrogen logistics—demand tightly coordinated procedures across airports and operators, reinforcing the need for CRM-style communication standards that extend beyond the flight deck (Alharasees et al., 2025). In parallel, the sustainable aviation fuel (SAF) ecosystem is scaling through diverse pathways, each with distinct handling, performance, and supply-chain characteristics that must be communicated, verified, and integrated into operational planning (Lau et al., 2024; Peters et al., 2023). Meta-reviews show that while SAF offers substantial decarbonization potential, it introduces technical and organizational challenges—feedstock variability, certification, storage, and blending—that intersect with training, maintenance, and dispatch practices (Wandelt, Zhang, & Sun, 2025). These sustainability transitions therefore create new configurations of uncertainty and interdependence, making CRM's emphasis on shared mental models, explicit contingency articulation, and cross-boundary coordination even more salient. Moreover, digitalization is critical to credible sustainability claims, tying emissions data, fuel provenance, and performance tracking into audit-ready records that teams must interpret and act on under schedule pressure. When sustainability technology, data governance, and CRM align, organizations can pursue environmental goals without eroding safety margins; when misaligned, they can amplify workload and coordination risk during already demanding phases of operation. In sum, sustainability technologies are not a parallel agenda but a new theater in which CRM's collaborative discipline must operate (Lau et al., 2024; Peters et al., 2023; Pattanayak & Mavris, 2025; Wandelt et al., 2025).

In conclusion, AI, automation, and allied systems are recasting aviation's socio-technical balance by redistributing attention, authority, and uncertainty across human and machine actors in ways that directly implicate CRM. The benefits—accelerated detection, predictive insights, efficiency, and decarbonization—are real, but they accrue only when organizations treat technology introduction as a change in team cognition and governance rather than as a purely technical upgrade (Kabashkin et al., 2023; Pereira et al., 2022). CRM therefore evolves from compensatory training into the operating system for human–automation teaming, specifying how recommendations are challenged, how conflicts are escalated, and how cyber and safety signals are integrated into a shared picture (Eleimat & Őszi, 2025; Xue et al., 2021). Training architectures, from SATCE to data-rich debriefs, provide the laboratory where these practices are learned and stabilized, ensuring that new tools expand rather than erode safety margins (Ziakkas et al., 2024). Sustainability technologies add further layers of interdependence and verification, demanding CRM's cross-boundary discipline to connect technical feasibility with operational credibility (Lau et al., 2024; Wandelt et al., 2025). Across these fronts, the through-line is intentional integration: hiring for data-literate crews, governing automation with clear veto rights, rehearsing hybrid contingencies, and extending communication standards into partner ecosystems so that value creation does not outpace error control. When these elements cohere, emerging technologies and CRM become mutually reinforcing, producing operational resilience that is faster, cleaner, and safer than either could deliver alone (Dreković et al., 2025; Alharasees et al., 2025; Pattanayak & Mavris, 2025). Conversely, when they diverge, organizations inherit brittle complexity in which signals do not flow, roles are ambiguous, and the promise of technology remains unrealized—precisely the conditions CRM was designed to prevent.

3. Methodology

3.1. Research Design

This study employs a qualitative research design grounded in Socio-Technical Systems (STS) theory, which emphasizes the interaction between social systems (people, communication, teamwork) and technical systems (technology, processes, tools). The qualitative approach was selected to gain in-depth insights into how emerging technologies are reshaping Crew Resource Management (CRM) and Human Resource Management (HRM) strategies in the aviation sector. Semi-structured interviews were chosen to explore both the human and technological aspects of CRM practices, allowing for flexible yet focused conversations with participants.

The sample consisted of 15 experts from various sectors within aviation, including pilots, HR professionals, operations managers, safety officers, and other relevant roles. The diversity in roles provided a comprehensive understanding of how different aspects of aviation operations are influenced by emerging technologies and how HR strategies are evolving to support CRM in this context. Table 1 provides information about the experts who participated the interviews.

Table 1. Information about Participants of the Interviews

Expert No.	Position	Experience (Years)	Area of Expertise
1	Pilot	15	Flight operations, CRM
2	HR Professional	12	Recruitment, training, HRM
3	Operations Manager	18	Logistics, AI integration
4	Safety Officer	20	Safety protocols, CRM
5	Technical Engineer	14	Maintenance, predictive systems
6	Pilot	22	CRM, AI in aviation
7	HR Consultant	17	HR strategy, tech adaptation
8	Air Traffic Controller	15	Real-time systems, CRM
9	Training Manager	16	Crew training, AR technologies
10	CRM Trainer	12	CRM education, tech interaction
11	HR Director	19	HR strategy, tech integration
12	Maintenance Lead	21	Maintenance systems, AR
13	Aviation Consultant	24	CRM, automation
14	Aviation Safety Officer	18	Safety systems, CRM
15	Operations Manager	20	Operations, automation

3.2. Data Collection

Data were collected through semi-structured interviews conducted either in person or virtually, depending on the availability of the participants. Each interview lasted between 45 minutes to an hour. The semi-structured format allowed for open-ended responses while maintaining a focus on key themes related to the socio-technical dynamics in aviation. Interview questions were designed to explore the interactions between human and technological systems within CRM and HR practices. These questions were informed by the research's grounding in STS theory, focusing on the impact of emerging technologies like AI, automation, and augmented reality on crew management, communication, and decision-making.

The interview questions addressed topics such as:

- The role of AI, automation, and augmented reality in daily operations.
- How these technologies are impacting CRM and HR strategies.
- Challenges in balancing human oversight with technological systems.
- The evolution of training and recruitment practices in response to technological advancements.

The formation of these questions was based on existing literature and the need to capture both the technical and human elements of aviation management, aligning with STS theory's focus on balancing social and technical systems.

3.3. Data Analysis

The data collected from the interviews were analyzed using thematic analysis with NVivo, a software tool specifically designed for qualitative data analysis. NVivo was chosen due to its robust capabilities for organizing, coding, and analyzing large amounts of qualitative data. The thematic analysis involved multiple stages, beginning with the transcription of interviews and the generation of initial codes. As suggested by

Welsh (2002) and Mortelmans (2019), the data were then categorized into broader themes and subthemes, focusing on key issues such as CRM effectiveness, HR strategies, and the integration of emerging technologies.

NVivo was used to systematically code the data, enabling the identification of patterns and themes across the interviews. Codes were grouped under major themes, including "Impact of Automation," "Human Oversight," "Training and Development," and "Risks and Challenges." This approach allowed for a structured yet flexible analysis, consistent with best practices in qualitative data analysis using NVivo (Edwards-Jones, 2014). The analysis also included subthemes, such as the benefits and risks of automation, the importance of manual intervention, and the evolving role of HR in managing technological changes.

The thematic analysis process in NVivo began with coding, where interview transcripts were imported into the software, and initial codes were assigned to key statements aligned with the research questions. These codes included categories such as "automation benefits," "manual oversight," and "training evolution." Next, the codes were grouped into broader themes, such as "Crew Communication" and "Training and Development," to capture the overarching patterns in the data. The thematic structure was then refined through repeated review, ensuring that all relevant information was accurately captured and coherently organized. Finally, the results of the thematic analysis were reported as meaningful insights, offering a detailed understanding of how CRM and HR strategies are adapting to technological advancements.

To ensure reliability in thematic analysis, the coding process was systematically conducted using NVivo software. Two researchers independently coded 30% of the transcripts, achieving an inter-coder agreement rate of 85%, which ensured consistency. Discrepancies were resolved through discussion and consensus.Validity was enhanced through triangulation by comparing emergent themes with existing literature. Member checking was employed, where participants were invited to review and confirm the accuracy of the findings. Additionally, the iterative coding process, which involved multiple rounds of theme refinement, ensured comprehensive coverage of the data. An audit trail was maintained to document key decisions made during coding and theme development, improving the transparency and replicability of the analysis. Reflexivity was incorporated by reflecting on potential biases, with regular peer debriefings to mitigate their impact.

3.4. Ethical Considerations

Ethical considerations were a fundamental aspect of this study, ensuring adherence to the highest standards of research integrity. Approval for the research was obtained from the Ethics Committee of Istanbul Nişantaşı University, as reviewed during the 21.11.2024 meeting (document number 20241221-055). This approval confirmed the study's compliance with ethical guidelines. Before conducting interviews, all participants were provided with detailed information about the research, its objectives, and how their data would be used, ensuring fully informed consent. Participants' confidentiality was preserved by anonymizing their identities and referring to them only by their assigned expert numbers (e.g., Expert 1, Expert 2) in all reports and analyses. They were also informed of their right to withdraw from the study at any time without facing any consequences. This ethical approach aligns with standard practices in qualitative research, safeguarding participant rights and confidentiality while facilitating the collection of reliable and meaningful data for the study. The commitment to ethical standards underscored the integrity and credibility of the research process.

4. Findings

Thematic analysis of the data gathered from 15 experts in aviation revealed key themes related to the integration of emerging technologies in Crew Resource Management (CRM) and Human Resource Management (HRM). The findings highlight the socio-technical dynamics between human factors (teamwork, communication) and technological factors (AI, automation, augmented reality). The analysis focused on how HR strategies are adapting to these changes, the challenges faced, and the opportunities for improving CRM. Table 2 demonstrates the themes, subthemes, codes and frequency of the codes in the interviews, also a quote from the experts as an example is provided for each code.

Table 2. Thematic Analysis Results Table

Theme	Subtheme	Codes	Frequency	Example Quote
Impact of Automation	Benefits of Automation	Efficiency, Time-saving, Precision	13	"AI systems now handle real-time flight path adjustments, freeing the crew to focus on safety." (Expert 2)
		Optimized decision-making	9	"Automation has reduced the cognitive load on crew members by handling routine tasks like fuel management." (Expert 6)
	Risks of Over-reliance	Complacency, Manual oversight, Failures	12	"One challenge is ensuring that crew members don't become overly reliant on automated systems." (Expert 4)
		Reduced situational awareness	8	"When autopilot is in control, there's a risk that crew members may disengage and miss critical signs." (Expert 9)
	Communication Decline	Reduced verbal interaction, Less teamwork	8	"Automation reduces the need for constant verbal updates, but it can lead to a breakdown in communication." (Expert 3)
Human Oversight	Importance of Manual Intervention	Manual skills retention, Training for control	11	"We've introduced more rigorous manual control training to ensure that crew members can step in during AI failure." (Expert 5)
	Vigilance	Active monitoring, Alertness	10	"The crew still needs to be vigilant and monitor automated decisions closely, especially during critical phases." (Expert 1)
Crew Communication	Verbal Confirmation	Verbal protocols, Communication clarity	12	"Even when automation is working, we ensure that all critical actions are verbally confirmed." (Expert 4)
	Teamwork and Collaboration	Coordination, CRM exercises	14	"We train crew members to communicate effectively in high-pressure situations where automation fails." (Expert 3)
	Decision-making Under Pressure	Real-time collaboration, Crisis management	9	"During AI failure drills, the crew must work together to resolve the issue manually and make quick decisions." (Expert 8)
Training and Development	Technology Integration	AI and AR-based training, Tech skills	14	"AR-based training allows crew members to practice emergency procedures virtually before real-world application." (Expert 11)
	Continuous Learning	Lifelong learning, Tech proficiency	11	"HR has introduced continuous learning programs to keep crew members up-to-date on the latest systems." (Expert 14)

	Balancing Tech and Manual Skills	Scenario-based training, Simulation	13	"We run drills where crew must manually intervene when the AI system fails, ensuring they can balance both skills." (Expert 10)
Recruitment and HR Strategy	Tech-Savvy Recruitment	Recruitment criteria, Tech expertise	10	"We prioritize candidates who are comfortable using advanced systems like AI." (Expert 6)
	Continuous Skill Development	Lifelong learning, Ongoing training	13	"HR ensures that crew members have regular opportunities to update their technical and manual skills through refresher courses." (Expert 7)
	Adapting to Emerging Technologies	Flexibility, Adaptability	9	"HR plays a key role in helping crew adapt to the fast-changing landscape of AI and automation." (Expert 12)
Risks and Challenges	Over-reliance on Technology	Tech-dependence, Loss of manual skills	11	"We've seen cases where the crew hesitates to take control because they trust the automation too much." (Expert 15)
	Technology Failures	System malfunctions, Incorrect data	10	"An AI system once failed to detect a weather anomaly, and the crew had to manually adjust the flight path." (Expert 8)
	Reduced Crew Engagement	Disengagement, Boredom	8	"Automation can lead to disengagement during long flights, where crew members become too passive." (Expert 9)

The findings indicate that the integration of emerging technologies like AI and automation has had a profound effect on CRM practices. Efficiency and time-saving were the most frequently mentioned benefits, with AI taking over routine tasks and allowing crews to focus more on critical decision-making. One participant noted, "AI systems optimize our routes and fuel usage, leaving us more bandwidth to focus on safety and monitoring." (Expert 6). However, experts also expressed concerns about over-reliance on automation. "When AI makes a wrong decision, the delay in taking manual control can lead to risky situations," warned another participant (Expert 15).

HR strategies are evolving to support the integration of these technologies in CRM. Many experts emphasized the importance of tech-savvy recruitment and continuous skill development. "We prioritize candidates who are adaptable to emerging technologies, and HR ensures continuous learning opportunities to keep them proficient," explained one expert (Expert 7). HR is also playing a critical role in balancing technical and manual skills. Several respondents mentioned the importance of scenario-based training that integrates both manual control and AI system management (Expert 10). Another expert highlighted how HR ensures "crew members don't lose their manual skills while adapting to increasing automation." (Expert 12).

A recurring theme was the challenge of maintaining the socio-technical balance—ensuring that human oversight remains strong while relying more on technological systems. Multiple participants identified reduced crew engagement as a risk of automation, particularly during long flights where "crew members may become passive, assuming the system has everything under control" (Expert 9). Additionally, technology failures were cited as a significant challenge. For example, one participant shared an instance where an AI system failed to detect a weather anomaly, and the crew had to intervene manually, which could have led to a major issue if not caught early (Expert 8).

Despite these challenges, the findings also revealed several opportunities for HRM to enhance CRM by aligning training programs more closely with technological advancements. The incorporation of AI and AR into training is seen as a positive step, with one expert noting, "AR-based simulations give us the chance to practice emergencies virtually, preparing us for real-life scenarios in a way traditional training couldn't" (Expert 11). HR departments are also leveraging AI for more personalized learning, with one participant explaining that AI systems can "track individual crew member performance and recommend specific training modules based on their weaknesses" (Expert 14).

The following insights highlight the perspectives shared by these experts, shedding light on the opportunities and challenges associated with integrating technological advancements into aviation practices;

- Pilots generally expressed enthusiasm about the efficiency brought by AI, but they also highlighted the need for ongoing manual control training. One pilot shared, "AI makes flying safer, but I've seen instances where over-reliance on autopilot led to near misses that could have been avoided with quicker manual intervention" (Expert 6).
- HR Professionals emphasized the importance of adapting recruitment and training strategies to support technological change. "It's not just about hiring the right people; it's about continuously developing their skills to match the demands of modern aviation," said one HR director (Expert 11).
- Operations and Safety Experts were focused on the balance between automation and manual intervention**.** One safety officer pointed out, "Our goal is to ensure that technology enhances safety, but human oversight will always be the final safeguard" (Expert 4).

The thematic relationship diagram illustrated in Figure 1 encapsulates the intricate interplay between various elements identified in the qualitative analysis of interviews with aviation experts.

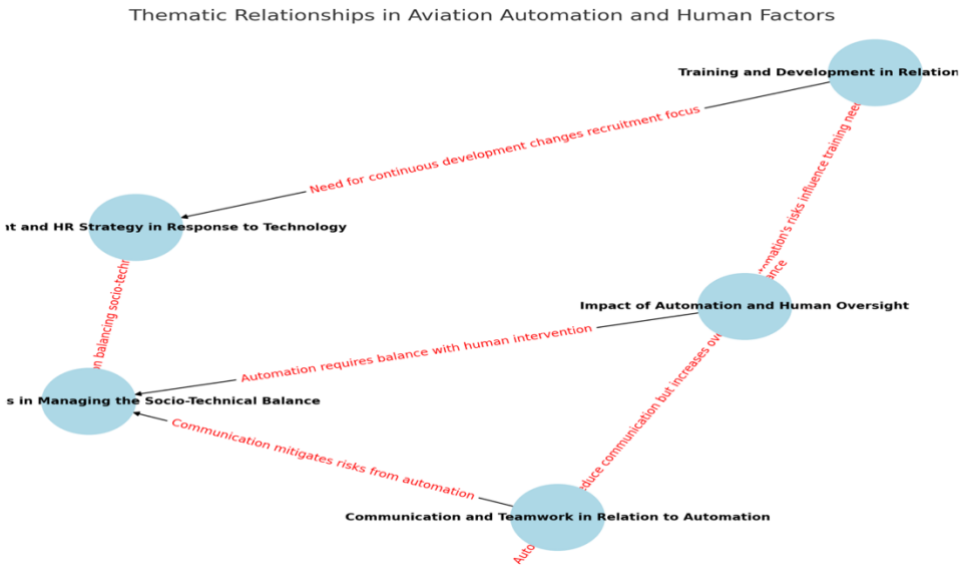

Figure 1. Thematic Relationship

In conducting a themes relation analysis, the focus is on identifying the intricate relationships between major themes that emerged from interviews with aviation experts. This analysis sheds light on how themes such as technology, human oversight, training and development, and communication are interconnected and influence each other within the context of Crew Resource Management (CRM) and Human Resource Management (HRM). The integration of AI and automation in aviation, for instance, enhances efficiency by optimizing decision-making processes and reducing the cognitive load on crew members, allowing them to focus on higher-level tasks. However, this growing reliance on automation also introduces risks related to human oversight, suggesting a need for balanced human intervention to mitigate these risks.

Training and development are crucial in this context, as they ensure crew members maintain the manual skills needed for situations where technology fails. This is particularly important as HR strategies adapt to technological changes by emphasizing continuous learning, thus fostering a workforce that can balance both manual control and the management of technological systems. On the other hand, as automation handles more

routine tasks, the potential for reduced communication between crew members emerges as a risk, highlighting the need for ongoing CRM training to reinforce interpersonal dynamics, especially during emergencies.

Furthermore, recruitment and HR strategies are evolving to meet the demands of a tech-enhanced aviation industry, focusing on finding candidates who are not only skilled in aviation but also adaptable to advanced technologies like AI and automation. This adaptation is critical to ensure that crew members can effectively manage the socio-technical balance between human and technological systems. However, over-reliance on technology can lead to challenges in maintaining this balance, necessitating vigilance and manual intervention to ensure safety.

Overall, the thematic relationships illustrate that while technology can enhance aviation operations, it must be balanced with critical human oversight. Effective communication and teamwork are vital in managing the risks posed by automation, and HR strategies are key in ensuring crew members remain adaptable and skilled. This balanced approach is essential for managing the socio-technical system, where technology supports but never replaces human decision-making.

5. Discussion

The findings of this study indicate that the accelerating infusion of Artificial Intelligence (AI), Augmented Reality (AR), Internet of Things (IoT), advanced automation, and biometrics is reconfiguring aviation's socio-technical equilibrium, and that Crew Resource Management (CRM) together with Human Resource Management (HRM) are the principal organizational levers for keeping that equilibrium stable as complexity rises. Interviewed experts converged on a dual message: data-driven maintenance, trajectory optimization, and biometric-enabled passenger flows create measurable efficiency and safety headroom, yet they also introduce novel coordination demands and vigilance traps that traditional procedures do not fully anticipate (Aeologic, 2023; Future Travel Experience, 2024). This pattern mirrors sectoral evidence showing that predictive analytics compress time-to-decision in maintenance and operations, while AR expands training realism without operational risk, but both shift when and how information reaches crews and supervisors (Goritiyal et al., 2021). Thematic codes such as "automation over-reliance," "manual re-engagement latency," and "communication displacement" map directly onto these shifts, underscoring that each technology introduction must be treated as a change in team cognition and role boundaries, not merely as an equipment refresh. In this respect, CRM's behavioral anchors—closed-loop communication, mutual monitoring, and graded assertiveness—remain necessary but insufficient unless they are explicitly re-targeted to algorithmic cues, model confidence, and cyber-integrity signals that now mediate operational awareness. A socio-technical reading of the results therefore suggests that value emerges when digital capability is braided with redesigned handoffs, escalation paths, and debrief routines that make algorithmic intent and limits collectively visible. Where this braiding is weak, organizations risk "silent failures," in which salient information exists but does not propagate to the right actor at the right moment in an actionable format. Conversely, when governance clarifies veto rights, questioning protocols, and data-provenance checks, the same tools amplify shared situational awareness rather than blunting it, strengthening the claim that emerging technologies raise performance ceilings if—and only if—social processes and technical affordances are co-designed from the outset.

A structured comparison with the literature shows strong alignment on opportunities and hazards while adding mechanism-level granularity, boundary conditions, and points of adaptation for practice. Canonical CRM scholarship cautions that automation can induce complacency, attentional tunneling, and authority bias unless teams rehearse explicit countermeasures, including advocacy–inquiry, time-outs, and clear escalation rules (Helmreich et al., 2001; Helmreich & Merritt, 2017). Convergent with these accounts, the present evidence emphasizes manual-skill preservation during high-automation phases, verbal confirmation of critical actions, and disciplined challenge of recommendations, now extended to AI contexts where model confidence intervals and data lineage must be interrogated before acceptance. Training science similarly argues that continuous, scenario-rich practice sustains non-technical skills in communication, teamwork, leadership, and decision-making, a position operationalized here through LOFT-style exercises that embed digital anomalies, cyber cues, and mixed-autonomy traffic pictures (Salas et al., 2006; O'Connor et al., 2008; Ziakkas et al., 2024). Technology syntheses demonstrate that gains materialize when socio-technical interfaces—engineers, flight crews, dispatch, and airport partners—are jointly orchestrated rather than when tools are introduced in

isolation, aligning with the emphasis on cross-boundary coordination and staged rollouts (Pereira et al., 2022). In parallel, sector reviews of AI and connectivity warn that the infrastructures enabling collaboration expand attack surfaces, elevating cybersecurity from an IT concern to a first-order safety variable that must be normalized within CRM routines (Kabashkin et al., 2023; Eleimat & Őszi, 2025). Sustainability literatures add complementary pressure: the introduction of sustainable aviation fuels (SAF), emerging battery systems, and energy-infrastructure innovations multiplies verification tasks and inter-organizational handoffs, reinforcing the need for CRM-style standardization of communication and escalation beyond the cockpit (Lau et al., 2024; Peters et al., 2023; Pattanayak & Mavris, 2025; Alharasees, Kale, & Rohacs, 2025; Wandelt, Zhang, & Sun, 2025). Taken together, the concordance across sources and the present results is high, while the contribution is to specify concrete behaviors—mandatory uncertainty callouts, human-veto logging, and data-provenance checks—that translate general warnings into auditable practice across routine and abnormal operations.

The implications for HRM are multi-layered and require translating high-level principles into implementable routines across selection, development, evaluation, and organizational design so that CRM becomes a reproducible organizational capability under increasing automation. Recruitment should prioritize hybrid profiles—technical proficiency paired with interpersonal competence and data literacy—assessed via scenario-based interviews and work samples that probe graded assertiveness with algorithmic teammates, responses to conflicting cues, and willingness to exercise veto rights under time pressure (Mızrak, 2023; Demirok, Bagherpour, & Ulgen, 2024). Development must shift from periodic compliance to deliberate practice that couples manual-reversion drills with "interpretability literacy" (reading model assumptions, confidence, and limits) and baseline cyber hygiene embedded in pre-briefs and checklists (de Andreis et al., 2022; Eleimat & Őszi, 2025). Learning analytics and debrief repositories should mine FOQA/LOSA and post-event narratives for weak signals—plan-continuation bias during stable automation, attentional tunneling around opaque alerts—and trigger targeted micro-interventions at the individual and crew levels (Pisitkasem & Pairoj-Boriboon, 2023). Performance management can make CRM behaviors observable and coachable using behaviorally anchored ratings that include human–automation-teaming markers (challenge–response on AI outputs, explicit uncertainty callouts, timely escalation), linking them to progression gates and recurrent checks (de Andreis et al., 2022). Organizationally, cross-functional pilot cohorts and staged rollouts convert surprises into SOP updates before fleet-wide deployment, while scheduling and fatigue-risk policies protect attention budgets for high-monitoring segments (Alkan & Sunar, 2024; Daga & Samad, 2025). Where sustainability is strategic, Green HRM bundles align incentives for eco-helping and accurate data capture without diluting safety priorities, leveraging CRM's communication discipline to keep environmental claims auditable under schedule pressure (Nguyen & Nguyen, 2024; Faeni & Faeni, 2025). In aggregate, these measures reposition HR from administrative backbone to socio-technical architect, institutionalizing the people-system through which CRM makes human–machine collaboration reliable at scale across diverse operational contexts.

Operational and training implications follow directly from this architecture and require explicit design choices across tooling, procedures, and assessment to prevent the "silent failures" identified in the evidence, thereby extending the practical contribution of the study to line operations. Training ecosystems should incorporate SATCE and mixed-autonomy scenarios that rehearse not only technical responses but also the conversation around algorithmic outputs—when to query, when to defer, how to reconcile dissent, and how to document human vetoes for feedback and learning (Ziakkas et al., 2024). Pre-briefs ought to include an "automation plan" (anticipated modes, model confidence, known failure modes), a "manual-reversion plan" (roles, triggers, balk criteria), and a "cyber posture" (authentication discipline, anomaly reporting, data-provenance checks), with debriefs auditing how recommendations propagated and where they stalled (Eleimat & Őszi, 2025). Standard operating procedures should foreground transparency in EFB and decision-aid interfaces—exposing uncertainty, data lineage, and rationale—so that trust can be calibrated under workload rather than assumed, while human-veto rights are codified and verbally acknowledged at decision points to strengthen accountability. Sustainability transitions (SAF blends, battery-electric turnarounds, hydrogen logistics) imply joint drills and shared escalation paths with airport and ground partners, extending CRM's grammar to partner ecosystems where verification and timing are critical (Lau et al., 2024; Pattanayak & Mavris, 2025; Alharasees et al., 2025; Wandelt et al., 2025). Organizations should measure "engagement under automation" as a performance variable—frequency of proactive cross-checks and time-outs during stable cruise—to detect drift toward passivity and to reinforce active monitoring in long, low-stimulus segments. Finally, staged

deployment with fast feedback loops should be treated as a safety control, ensuring that anomalies discovered by early cohorts are converted into procedure and interface refinements before broad exposure, thereby operationalizing socio-technical integration recommended in prior syntheses (Pereira et al., 2022). Collectively, these steps translate abstract principles into a practical, auditable operating system for resilient human–machine teaming in day-to-day operations.

Theoretical implications extend the application of Socio-Technical Systems (STS) theory to a granular, design-oriented account of how technical systems (AI, AR, IoT, automation) and social systems (communication norms, leadership, HR practices) co-produce safety and efficiency in modern aviation, while clarifying limitations and future research pathways that follow from the present evidence. STS appears to contribute most when articulated as governance rules for human–automation teaming—uncertainty disclosure, challenge–response protocols, cross-boundary escalation, and cyber-situational awareness—embedded within CRM routines rather than as a generic call for "balance," which aligns with CRM and training literatures while specifying mechanisms that contemporary technologies render necessary: interpretability literacy, veto codification, and data-provenance checks (Helmreich & Merritt, 2017; Salas et al., 2006; O'Connor et al., 2008). Limitations include expert sample size and commercial-aviation concentration, which may overweight certain operational constraints; nonetheless, triangulation with sector syntheses on technology, cybersecurity, and sustainability supports robustness and situates the themes within current practice (Kabashkin et al., 2023; Eleimat & Őszi, 2025; Wandelt et al., 2025). Future research should adopt longitudinal designs to examine retention of interpretability and cyber skills, quantify manual-reversion latency across automation cohorts, and test external validity in military, regional, and ultra-long-haul contexts that face distinct workload profiles (Ziakkas et al., 2024; Pereira et al., 2022). Cross-industry comparisons with healthcare and emergency services—domains adapting CRM-like frameworks—could identify transportable practices for disputing algorithmic recommendations and managing mode confusion under time pressure, while sustainability transitions merit empirical programs linking SAF logistics, battery charging windows, and hydrogen safety cases to new coordination and verification tasks (Lau et al., 2024; Pattanayak & Mavris, 2025; Alharasees et al., 2025). In sum, CRM and HRM should be understood as design disciplines for human–automation teaming, yielding testable propositions for socio-technical integration that keep safety and performance gains tightly coupled across the industry's next technology waves.

6. Conclusion

The significance of this study lies in the rapid technological advancements within the aviation industry, particularly how emerging technologies such as AI, AR, and biometrics are reshaping Crew Resource Management (CRM) and Human Resource Management (HRM). As aviation becomes more reliant on these technologies to improve safety, efficiency, and decision-making, it becomes crucial to investigate the effects of automation on human oversight, training, and crew performance. The motivation behind this study was to bridge the gap between technological integration and the preservation of essential human skills, ensuring that technological tools complement rather than replace human expertise in high-stakes environments like aviation.

This study conducted thematic analysis through interviews with 15 aviation experts, including pilots, HR professionals, and operations managers. These interviews uncovered several key themes. First, while AI and automation have been praised for optimizing decision-making and streamlining operations (as seen in AI-driven predictive maintenance), there are inherent risks tied to over-reliance. For instance, the analysis revealed that crew members might become disengaged or less vigilant when routine tasks are automated. One expert highlighted that while AI can handle real-time flight adjustments, it's critical to ensure manual skills are regularly practiced to prevent over-dependence on automation. Similarly, the application of AR in pilot training—though immersive and effective for simulating real-world emergencies—still requires reinforcement of manual control techniques in the event of system failure.

The study provided several actionable recommendations for HR departments in the aviation sector. Comprehensive training programs were suggested to ensure crew members stay adept at both manual and automated systems, with AR-based training scenarios being one approach to simulate high-pressure situations where technology fails. Additionally, HR departments should adopt AI-powered learning platforms to create personalized learning pathways, ensuring that crew members continually enhance both their technological

skills and manual oversight capabilities. Recruitment strategies also need to evolve, focusing on identifying candidates with a balanced skill set that includes both technological proficiency and the interpersonal, teamwork-driven skills required for effective CRM.

From a theoretical standpoint, this study makes a valuable contribution to the application of Socio-Technical Systems (STS) theory in aviation. It emphasizes that successful integration of technology into CRM is not solely about leveraging advanced tools but also about maintaining a socio-technical balance where human intervention remains pivotal. The findings underline the importance of this balance, particularly in environments where automation might induce complacency if not adequately counterbalanced by human oversight. This study highlights how HR strategies can sustain this equilibrium through targeted recruitment, continuous development, and tailored training programs.

While the study provides valuable insights, it is not without limitations. The sample size of 15 experts, though informative, limits the generalizability of the findings across the entire aviation industry. Furthermore, the focus on specific emerging technologies, such as AI and AR, may not cover the full scope of technological transformations occurring in the industry. Future research should consider a broader range of technologies and conduct longitudinal studies to assess the long-term impact of automation on CRM and HRM. Additionally, cross-industry studies could provide insights into how other sectors, like healthcare or manufacturing, manage the balance between human oversight and automation. This would expand the practical applicability of STS theory across diverse industries experiencing rapid technological change.

In conclusion, this study underscores the critical need for a balanced approach to technology and human expertise in aviation. While AI, AR, and biometrics offer tremendous potential for enhancing safety and efficiency, maintaining strong human oversight, robust training programs, and adaptive HR strategies is essential for ensuring that these technologies serve to complement, rather than undermine, the human elements that remain crucial to safe and effective aviation operations.

References

Aeologic. (2023). *Roles of AI in predictive maintenance and asset optimization*. Retrieved from https://www.aeologic.com/blog/roles-of-ai-in-predictive-maintenance-and-asset-optimization/

Aframchuk, O. (2025). Effectiveness of Crm (Crew Resource Management) In Preventing Aviation Accidents. *The American Journal of Engineering and Technology*, *7*(04), 43-48.

Alexander, D. J. (2025). The genesis of crew resource management: The NASA Experience. In *Trauma Team Dynamics: A Trauma Crisis Resource Management Manual* (pp. 7-11). Cham: Springer Nature Switzerland.

Alharasees, O., Kale, U., & Rohacs, D. (2025). Advancing Sustainable Aviation: Integration of Emerging Energy Technologies in Aviation Infrastructure. In *Energy Rationality and Management for Decarbonization* (pp. 507-521). Cham: Springer Nature Switzerland.

Alhawsawi, A., & Macedo, M. S. (2024). Implementing Crew Resources Management Principles to Improve Perioperative Safety. In *Principles of Perioperative Safety and Efficiency* (pp. 251-268). Cham: Springer International Publishing.

Alkan, A. D., & Sunar, O. N. (2024). Human Resources Management in the Civil Aviation Sector: A General Overview. *Strategic Management and Policy in the Global Aviation Industry*, 1-15.

Alonso, A. D., Vu, O. T. K., Nguyen, T. Q., McClelland, R., Nguyen, N. M., Huynh, H. T. N., ... & Nguyen, T. T. (2025). Beyond technology: A socio-technical lens on Industry 4.0 value-adding across industries. *Technological Forecasting and Social Change*, *221*, 124355.

Azmi, N. A., & Ismail, N. A. A. (2025). Integrating Socio-Technical Systems (STS) and Knowledge Management (KM) theories in BIM-FM context: a literature review. *Malaysian Journal of Sustainable Environment (MySE)*, *12*(1), 47-76.

Bayazıtoğlu, A. A., & Güngör, H. (2023). Effects of meteorology data on crew resource management in aviation. *Journal of Aviation*, *7*(2), 300-309.

Bayramova, A., Edwards, D. J., Roberts, C., & Rillie, I. (2023). Enhanced safety in complex socio-technical systems via safety-in-cohesion. *Safety science*, *164*, 106176.

Ciriello, R. F., Richter, A., & Mathiassen, L. (2024). Emergence of creativity in IS development teams: A socio-technical systems perspective. *International Journal of Information Management*, *74*, 102698.

Curcio, J. (2023). Preventing and Managing Human Error Using CRM: Crew resource management reduces human error. Adding it to EMS training and operations improves crew dynamics and patient safety. *Firehouse Magazine*, *48*(4), 38-43.

Daga, R., & Samad, A. (2025). Analysis of The Influence of Leadership Style, Workload and Work Stress on Employee Performance: Empirical Study from The MATSC Branch of Aviation Navigation Service Provider Institution. *Golden Ratio of Human Resource Management*, *5*(2), 383-405.

Dahabiyeh, L., & Mowafi, O. (2023). Challenges of using RPA in auditing: A socio-technical systems approach. *Intelligent Systems in Accounting, Finance and Management*, *30*(2), 76-86.

de Andreis, F., Comite, U., Sottoriva, F. M., & Cova, I. (2022, October). Human resources management and training in aviation. In *International Conference on Reliability and Statistics in Transportation and Communication* (pp. 510-522). Cham: Springer International Publishing.

Demirok, A., Bagherpour, M., & Ulgen, S. (2024, August). Enhancing Human Resource Management in the Aviation Sector: A Comprehensive Analysis. In *Global Joint Conference on Industrial Engineering and Its Application Areas* (pp. 210-231). Cham: Springer Nature Switzerland.

Dreković, E., Teofilović, Ž., & Karabegović, I. (2025, June). The Application of Disruptive Technologies in the Aviation Industry. In *International Conference "New Technologies, Development and Applications"* (pp. 602-611). Cham: Springer Nature Switzerland.

Edwards-Jones, A. (2014). Qualitative data analysis with NVIVO.

Eleimat, M., & Őszi, A. (2025). Cybersecurity in Aviation: Exploring the Significance, Applications, and Challenges of Cybersecurity in the Aviation Sector. *Periodica Polytechnica Transportation Engineering*, *53*(2), 169-183.

Faeni, D. P., & Faeni, R. P. (2025). Green HRM for sustainable aviation: An integration evaluation using PLS-SEM and fsQCA. *Environmental Challenges*, 101232.

Ford, J., Henderson, R., & O'Hare, D. (2014). The effects of Crew Resource Management (CRM) training on flight attendants' safety attitudes. *Journal of safety research*, *48*, 49-56.

Future Travel Experience. (2021). *Dubai Airports introduces facial recognition to fast-track immigration processes*. Retrieved from https://www.futuretravelexperience.com/2021/02/dubai-airports-introduces-facial-recognition-to-fast-track-immigration-processes/. Access date: 25.11.2025

Future Travel Experience. (2021). *How Lufthansa is enabling biometrics adoption across different touchpoints and airports of all sizes*. Retrieved from https://www.futuretravelexperience.com/2021/10/how-lufthansa-is-working-with-its-partners-to-enable-biometrics-adoption-across-different-touchpoints-and-airports-of-all-sizes/. Access date: 25.11.2025

Gambo, I., Ogundare, T., & Oluyide, O. (2023, August). Towards a Framework for Improving Quality of User-Centered Services in Socio-technical Systems: A Case Study of Airport System. In *International conference on WorldS4* (pp. 367-380). Singapore: Springer Nature Singapore.

Goritiyal, C., Bairolu, A., & Goritiyal, L. (2021). Application of emerging technologies in aviation MRO sector to optimize cost utilization: the Indian case. *Intelligent Sustainable Systems: Selected Papers of WorldS4 2021, Volume 2*, 161-176.

Govers, M., & van Amelsvoort, P. (2023). A theoretical essay on socio-technical systems design thinking in the era of digital transformation. *Gruppe. Interaktion. Organisation. Zeitschrift für Angewandte Organisationspsychologie (GIO)*, *54*(1), 27-40.

Hanafizadeh, P., & Mehrasa, S. (2025). Governance system design model in platform ecosystems by a socio-technical systems theory. *Digital Policy, Regulation and Governance*.

Helmreich, R. L., & Merritt, A. C. (2017). Safety and error management: The role of crew resource management. In *Aviation resource management* (pp. 107-119). Routledge.

Helmreich, R. L., Wilhelm, J. A., Klinect, J. R., & Merritt, A. C. (2001). Culture, error and crew resource management. *Improving teamwork in organizations: Applications of resource management training*, *305331*.

Jakonen, A., Mänty, M., & Nordquist, H. (2023). Applying Crew Resource Management tools in Emergency Response Driving and patient transport—Finding consensus through a modified Delphi study. *International emergency nursing*, *70*, 101318.

Kabashkin, I., Misnevs, B., & Zervina, O. (2023). Artificial intelligence in aviation: New professionals for new technologies. *Applied Sciences*, *13*(21), 11660.

Lau, J. I. C., Wang, Y. S., Ang, T., Seo, J. C. F., Khadaroo, S. N., Chew, J. J., ... & Sunarso, J. (2024). Emerging technologies, policies and challenges toward implementing sustainable aviation fuel (SAF). *Biomass and Bioenergy*, *186*, 107277.

Lu, J., García-Badell, G., & Rodriguez, J. B. (2025). Digital Heritage from a Socio-Technical Systems Perspective: Integrated Case Analysis and Framework Development. *Heritage*, *8*(9), 348.

Mizrak, K. C. (2025). Exploring Human Resource Strategies for Improving Situational Awareness Training through Gamification. *Business and Economics Research Journal*, *16*(2), 159-178.

Mızrak, F. (2023). Evaluation of non-type rated pilot selection criteria in the civil aviation industry with AHP and TOPSIS methods. *Research Journal of Business and Management*, *10*(1), 1-11.

Mortelmans, D. (2019). Analyzing qualitative data using NVivo. *The Palgrave handbook of methods for media policy research*, 435-450.

Muehlberger, C. M., Gruen, L., Liefner, I., & Losacker, S. (2024). Socio-technical imaginaries of climate-neutral aviation. *Energy Research & Social Science*, *114*, 103595.

Nguyen, T. L. P., & Nguyen, T. T. H. (2024). The link between socially responsible human resource management and eco-helping behavior in aviation industry–a moderated mediation model. *International Journal of Law and Management*.

O'Connor, P., Campbell, J., Newon, J., Melton, J., Salas, E., & Wilson, K. A. (2008). Crew resource management training effectiveness: a meta-analysis and some critical needs. *The international journal of aviation psychology*, *18*(4), 353-368.

Öz, T., & Kütahya, C. K. (2025). INTEGRATING DIGITAL SOLUTIONS FOR CREW RESOURCE MANAGEMENT IN AVIATION: A FUZZY BWM-COCOSO APPROACH. *Journal of International Trade, Logistics & Law*, *11*(1).

Pattanayak, T., & Mavris, D. (2025). Battery technology for sustainable aviation: a review of current trends and future prospects. *Applied Energy*, *397*, 126356.

Pereira, B. A., Lohmann, G., & Houghton, L. (2022). Technology trajectory in aviation: Innovations leading to value creation (2000–2019). *International Journal of Innovation Studies*, *6*(3), 128-141.

Peters, M. A., Alves, C. T., & Onwudili, J. A. (2023). A review of current and emerging production technologies for biomass-derived sustainable aviation fuels. *Energies*, *16*(16), 6100.

Pisitkasem, A., & Pairoj-Boriboon, T. (2023). Digital HR: The Digital Transformation in Human Resources Management in the Aviation Business. *Social Science Asia*, *9*(3), 11-20.

Salas, E., Wilson, K. A., Burke, C. S., & Wightman, D. C. (2006). Does crew resource management training work? An update, an extension, and some critical needs. *Human factors*, *48*(2), 392-412.

Shmelova, T., & Sikirda, Y. (2021). Analysis of Decision-Making of Operators in Socio-Technical Systems. In *Research Anthology on Reliability and Safety in Aviation Systems, Spacecraft, and Air Transport* (pp. 768-792). IGI Global.

Subedi, A., Bucelli, M., & Paltrinieri, N. (2025). Reframing safety barriers as socio-technical systems: a review of the hydrogen sector. *Safety Science*, *192*, 106995.

Thomas, A. (2024). Digitally transforming the organization through knowledge management: a socio-technical system (STS) perspective. *European Journal of Innovation Management*, *27*(9), 437-460.

Wandelt, S., Zhang, Y., & Sun, X. (2025). Sustainable aviation fuels: A meta-review of surveys and key challenges. *Journal of the Air Transport Research Society*, 100056.

Welsh, E. (2002, May). Dealing with data: Using NVivo in the qualitative data analysis process. In *Forum qualitative sozialforschung/Forum: qualitative social research* (Vol. 3, No. 2).

Xie, Y., Pongsakornsathien, N., Gardi, A., & Sabatini, R. (2021). Explanation of machine-learning solutions in air-traffic management. *Aerospace*, *8*(8), 224.

Xue, J., Esangbedo, M. O., Zhang, Q., Zhang, W., & Wu, L. (2021). The impact of emerging technologies in the aviation manufacturing industry: a case study of the gradual-change factors in shaanxi, pr china. *IEEE Transactions on Engineering Management*, *71*, 220-232.

Yuan, M., Lin, H., Zhang, Z., Ji, L., & Yu, M. (2025). Savior or saboteur? Big data and company employees innovative behavior: a socio-technical systems theory perspective. *Information Technology & People*, 1-23.

Zhang, X., Nutakor, F., Minlah, M. K., & Li, J. (2023). Can Digital Transformation Drive Green Transformation in Manufacturing Companies?—Based on Socio-Technical Systems Theory Perspective. *Sustainability*, *15*(3), 2840.

Ziakkas, D., Waterman, N., & Flores, A. (2024). Emerging Technologies in Aviation: The Simulated Air Traffic Control Environment (SATCE) application in Competency Based Training and Assessment. *Intelligent Human Systems Integration (IHSI 2024): Integrating People and Intelligent Systems*, *119*(119).a