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Technology, people, and management working together: A new way for sustainable airport operations

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Abstract
This paper revisits the Technology–People–Management (TPM) framework for sustainable airport operations and strengthens its scientific grounding through a clearer theoretical foundation, transparent bibliometric methodology, and policy-oriented interpretation. A systematic review of fifty-one peer-reviewed articles published between 2010 and 2025 is complemented by keyword co-occurrence analysis to elucidate interdependencies among technology, human factors, and managerial practices. The study interprets these findings through socio-technical systems theory and innovation diffusion perspectives, and aligns them with strategic aviation roadmaps, including the ICAO Global Air Navigation Plan and the SESAR ATM Master Plan. Methodological rigor is enhanced by explicit criteria for keyword normalization, clustering parameters, and robustness checks, while discussion moves beyond description to analyze causal mechanisms that connect the three TPM components. The paper translates results into practical implications for regulators, air navigation service providers, and technology developers, and proposes a research agenda to address underexplored areas such as human–AI teaming, real-time machine learning in operations, and governance for data interoperability.

Keywords
Sustainable Airport Operations, Technology–People–Management (TPM) Framework, Cognitive Sustainability, Airport Ground Handling, Human Factors and Training

1. Introduction

Airports operate within increasingly complex environments where safety, efficiency, and environmental performance must be achieved concurrently. Prior research has often examined technology, human factors, or management in isolation, which obscures the interdependencies that shape operational outcomes. This paper advances the Technology–People–Management (TPM) framework by integrating established theoretical lenses, clarifying bibliometric procedures, and articulating how technology, people, and management interact to produce sustainable performance. The contribution is threefold: first, the study formalizes the conceptual underpinnings of TPM within socio-technical systems theory and innovation diffusion; second, it reports methodological choices and validation steps for the bibliometric analysis; third, it translates findings into actionable, policy-aligned implications for key stakeholders (Tam, Hoang, 2025; Tang et al., 2025).

In contrast, the rate of improvement in air traffic is also increasing, resulting in making a management organisation's management of an airport more complex and even more complex as time goes by. Research is typically performed either on air traffic control technology and/or air traffic control human factors or management systems (Weiszer et al., 2015; Padrón et al., 2016). There is also a tendency for researchers to focus their studies primarily on AI in the ground handling space (Jimenez et al., 2023; Ku, 2024; Yıldız et al., 2022) or on AI for training employees (Balk et al., 2011), but there is no clear picture of how these applications relate to managing the subcontractor (i.e. Air Traffic Control).

The present study addresses this gap using the Technology–People–Management (TPM) framework. TPM is applied to achieve performance enhancement of cognitive sustainability. Cognitive sustainability is the capacity of an organization to maintain the knowledge, health and decision making of its employees in a continuously evolving work place (Wu et al., 2026; Muecklich et al., 2023). Ultimately, the goal of the research is to ensure technology utilization and implementation enhance the work processes rather than adversely load the employees (Teperi and Leppänen, 2011; Dekker, 2004).

This research used an analytical methodology with the use of a specialized software ptogram – VOSviewer – as a research tool to assess literature relevant to the research focus (Bakır et al., 2022). The results show that there are very strong ties between technology, people and management; these three categories consistently prevailed in the 42 paper body of literature, as illustrated by Figure 1 below. The results indicate a close

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interrelationship of the concepts of technology, training and management; thus, the performance of the airports of Turkey and abroad is dependent upon managing both internal and external elements effectively (Güner and Seçkin Codal, 2022, Dönmez, 2024; Ertek, Taşcı, 2026).

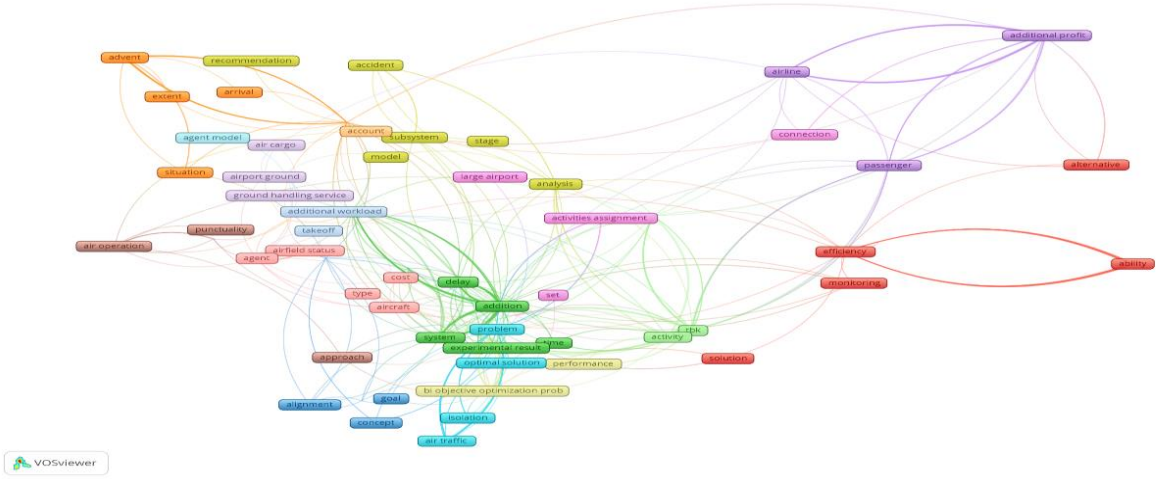

Figure 1. VOSviewer map showing the co-occurrence of keywords in the analyzed literature

Consequently, the following research question is the primary focus of this study: "How does integrating technology, people, and management simultaneously contribute to creating sustainable and supportive working environments for aviation personnel and the general public?"

> H_1: An integrated technology, people and management view (TPM) provides a better understanding of cognitive relatedness, compared to studying each of these components independently, with respect to sustainability, in the context of an airport's operation.

Airports operate within increasingly complex environments where safety, efficiency, and environmental performance must be achieved concurrently. Prior research has often examined technology, human factors, or management in isolation, which obscures the interdependencies that shape operational outcomes. This paper advances the TPM framework by integrating established theoretical lenses, clarifying bibliometric procedures, and articulating how technology, people, and management interact to produce sustainable performance. The contribution is threefold: first, the study formalizes the conceptual underpinnings of TPM within socio-technical systems theory and innovation diffusion; second, it reports methodological choices and validation steps for the bibliometric analysis; third, it translates findings into actionable, policy-aligned implications for key stakeholders.

2. Methods

The empirical basis of this synthesis is a systematic review of 42 journal articles published between 2010 and 2025 that address at least one dimension of technology, people, or management in airport contexts. All articles are given in the Reference list. Articles were retrieved primarily from ScienceDirect and Web of Science and screened for relevance to the TPM framework and cognitive sustainability. Keyword metadata were processed to construct a co-occurrence network in VOSviewer. Keywords were normalized by lowercasing, lemmatization where appropriate, consolidation of acronyms with their expanded forms, and merging of close synonyms. Non-informative terms were excluded, and a minimum occurrence threshold was applied to ensure stability of the network. Clustering used association-strength normalization and the smart local moving algorithm with a resolution parameter selected to balance granularity and interpretability. Methodological transparency is increased by reporting the chosen thresholds and by conducting robustness checks: sensitivity to resolution and minimum occurrence values, and stability assessed through document jackknifing. Where applicable, cluster quality is summarized using modularity and silhouette indices; the study refrains from overstating precision in the absence

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of full-text corpora, and encourages future work to publish detailed metrics and code to support replicability.

2.1 Research design and data collection procedure

Using a systematic literature review, this research has identified and synthesized the results of past research. Academic databases such as ScienceDirect were used for searching for literature published from 2010 through to 2025 using a comprehensive search of literature and the selection of 42 academic articles, which would form the basis of a comprehensive discussion of the topic and the development of a conceptual framework for understanding cognitive sustainability in airport operations, as detailed in Güner and Seçkin Codal, 2022; Bakır et al., 2022.

The search strategy was based on three main keywords: "sustainable airports," "people in aviation," and "airport management." Articles selected by this systematic review utilized strict inclusion criteria; selected articles only included research that demonstrated at least one aspect of the TPM framework. Additionally, strong emphasis was placed on research that illustrated the connection and relationship between all three primary components, to develop a comprehensive understanding of cognitive sustainability in airport operations

2.2 Data analysis

Thematic extraction and synthesis was carried out by using a thematic analysis. The overall findings of this literature review were organized into three themes from the group of articles selected for review. Each article was thoroughly reviewed, and the findings were categorized into three distinct categories (themes) for further analysis. The three categories and the articles that form each category are:

- Technology (T) – includes the use of artificial intelligence (AI), Robotics, and Sensor-Based Technologies (Jimenez et. al, 2023; Ku, 2024; Yildiz et. al, 2022).
- People (P) – includes specialized training, OSHA standards, and human factors (Wu et. al, 2026; Muecklich et. al, 2023; Dekker, 2004).
- Management (M) – includes strategic planning and operational decision making (Güner and Seçkin Codal, 2022; Ripoll-Zarraga and Huderek-Glapska, 2021; Güner and Cebeci, 2021; Hauptvogel, et al., 2024; Hsiao, Li, 2026; Ison, et al., 2025).

During the synthesis phase, the relationships and synergies between the three categories – Technology (T) and People (P), Management (M) – were explored by examining how technological advances affect personnel performance and managerial strategies.

2.3 Bibliometric analysis

The interconnectedness between the various research topics was confirmed visually through the use of bibliometric methods and their corresponding theoretical framework. The keyword co-occurrence (KC) analysis was performed using VOSViewer Software to assess how much strength existed in linking together certain terms that appeared in the 42 selected articles (Bakır et al., 2022). This provided researchers with the ability to build a map that demonstrated where the greatest clusters of related research areas were located within the published literature.

2.4 Coding and data integrity

In order to promote an accurate and clear approach to data synthesis, the inclusion of identified evidence within TPM interactions should occur according to the following guidelines: during the thematic extraction process, an element's dependency or causality was coded against the result's outcome. For instance, management decisions regarding the adoption of specific types of technology directly impact the training of personnel associated with that new technology (Passenier et al., 2015).

Examples from the literature were included wherever possible to assist with a solid conceptualization of the data synthesis. Specific examples collected included the use of Fuzzy Logic for measuring a candidate's subjective qualities such as personality when making a selection for hire (Skorupski et al., 2020; Fitouri-Trabelsi et al., 2013) and how airport bus operators' cooperative scheduling with their fuel suppliers impacts both the safety and

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efficiency of airport refueling operations (AlKheder et al., 2024; Cai et al., 2025).

3. Results

This section presents the key findings derived from the systematic review, structured around the TPM framework.

The analysis confirms that technology, people, and management form an integrated structure in the airport operations literature. Central terms related to airside processes, scheduling, automation, training, and governance appear as hubs that link operational performance with safety and environmental considerations. Three coherent thematic areas emerge: (i) technology-oriented studies that examine automation, sensing, and optimization; (ii) people-centered studies that analyze training, workload, and human performance; and (iii) management-focused studies that evaluate planning, coordination, and organizational culture. Rather than treating these areas as disconnected, the network reveals multiple bridges – particularly between automation and environmental efficiency, and between human factors and capacity management – suggesting that cross-domain solutions are more promising than isolated interventions.

3.1 Bibliometric evidence and core connection structure

Analysis through VOSviewer of the keyword co-occurrence network validated the proposition that technology, governance, and people operate as an integrated system. The VOSviewer map (Figure 1) demonstrates clear connections between keywords (e.g., 'Technology', 'Training', and 'Management') that illustrate the structural basis of the research project's core hypothesis.

The bibliometric mapping analysis produced three major groupings of themes: (i) the Red Cluster, which relates to the concept of 'mobility', 'efficiency', and focusing on the appropriate use of available resources to lessen delays; (ii) the Green Cluster, which focuses on 'problems', 'delays', and 'systems'; this grouping shows substantial research interest towards employing technological solutions like simulators and agent-based models for overcoming operational bottlenecks (i.e., Green Cluster); and (iii) the Orange/Yellow Cluster, which covers human factors in relation to operational processes and procedures by including topics like 'arrival', 'account', and the agent model and includes a variety of models that simulate human factors, procedures, and behaviours (Wei, Gosling, 2013; Muecklich et al., 2023; Lao et al., 2024; Teng, et al., 2026; Wang et al., 2026).

3.2 Connection 1: Technology influences people and management (T → P & M)

The performance of sophisticated technical systems depends not only on the availability of the technology but also on the qualifications of those who support and implement the system as well as how well the technology fits in with existing management practices. According to research on artificial intelligence (AI) and Computer Vision (CV) systems, one area of application of AI is in automating the identification of service activity timestamps performed on the airport terminal. This automation will enable operational personnel to filter out "potentially inaccurate turnaround information" produced by manual entry into systems (Yıldız et al., 2022) and ensure objective documentation.

In addition, AI systems need users trained to interpret the data derived from an AI-generated dataset. Hence, it is critical for management to utilize AI-generated datasets to monitor operational efficiencies of service providers that are delayed through penalties (Sivakumar, 2022; Güner, 2021).

3.3 Connection 2: Employee performance depends on management and technology (P → M & T)

Supportive managers and the proper use of technology result in both increased worker safety and performance. Ground personnel who are confronted with challenging situations (such as Unruly Passenger Behaviour – UPB) must receive training that includes more than just technical skills; they must also be given the authority by their superiors to effectively manage crises (Nounou, Shaban, 2025).

When there are not enough ground handlers, it is often due to low wages and inadequate technology. Therefore, a manager needs to look beyond just keeping costs low and think about implementing integrated strategies, such as "airport depeaking," to alleviate employee stress (Muecklich et al., 2023; Balk et al., 2011). In addition, Fuzzy

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Logic systems are used to measure non-quantitative characteristics (e.g., personality and attention) when selecting operators for high-risk vehicles (Skorupski et al., 2020; Fitouri-Trabelsi et al., 2013).

3.4 Connection 3: Management decisions affect technology and people (M → T & P)

Strategic managerial decisions establish how to allocate resources and determine the level of operational efficiency/safety through the implementation of safety policies within their organisations. The existing "top-down" approach (Systems-Theoretic Accident Model and Processes – STAMP) for developing safety regulations had not been successful in addressing safety due to its simplistic approach. As a result, Passenier et al., (2015) suggest that management should shift their focus from establishing "top-down" policies and procedures, to integrating safety concepts into company culture (Hale and Borys, 2013).

Management's responsibility to balance competing stakeholder interests is complex. Integrated models of optimisation demonstrate that the most expedient solutions are not necessarily the least costly or least damaging to the environment. Therefore, management must make informed strategic choices about time (delay) vs. cost (fuel) for their safety programme. In addition, integrated planning efforts regarding staff rostering and task assignments result in more efficient use of staff resources and reduced staff time idle (Cappanera et al., 2024).

3.5 Coordination and environment (sustainability) findings

Environmental sustainability and efficiency are the two most important benefits of the use of the TPM framework. Model predictions from Game Theory point to the need for a more collaborative approach in the development of strategic decisions, particularly those associated with enabling the movement of cargo through smaller, strategically located transport centres (i.e. airports) using existing road and rail infrastructure thus reducing congestion at the central cargo terminal. In addition, improved predictive maintenance via AI technologies is needed in many sectors where risk is high (e.g., cold chain logistics) to help organizations manage costs and remain compliant with legal requirements.

Research into crisis mitigation, particularly (but not exclusively) in relation to air cargo diversion, indicates that merely adding additional human resources beyond the available runway capacity is not a solution to addressing problem areas during times of increased demand. Management must be able to analyse a bottleneck to determine whether that bottleneck is a result of inadequate staffing, inadequate physical runway capacity, or a combination of both.

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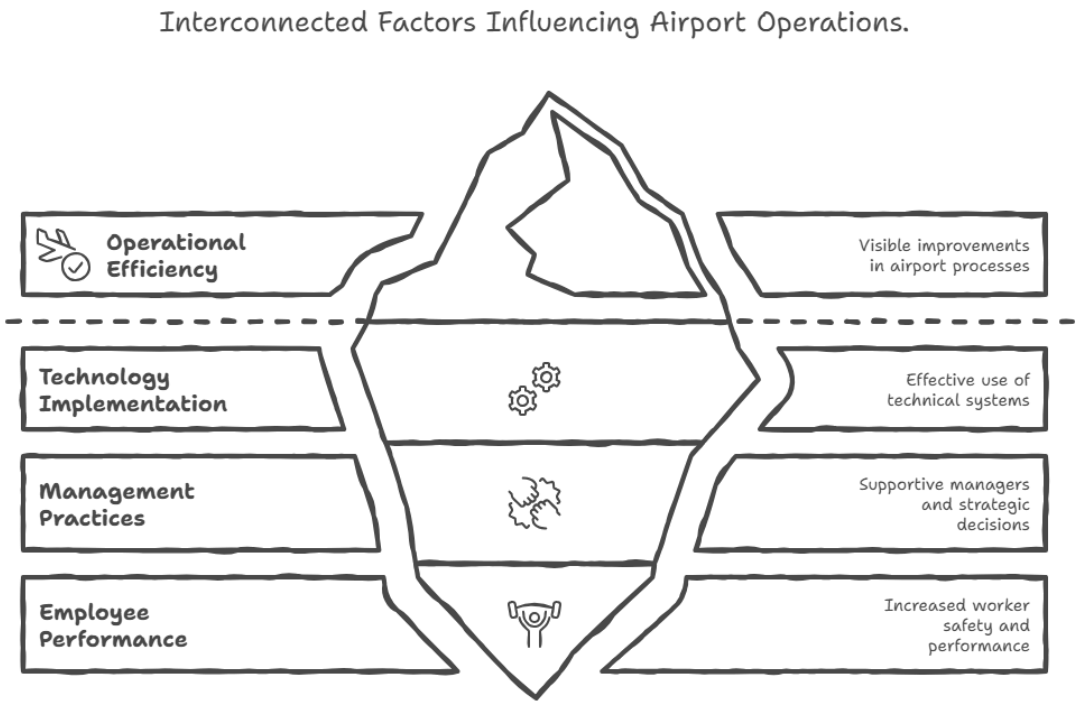

Figure 2. Connection between people, technology and management

4. Discussion

Technology influences people and management by changing information availability, task structure, and decision latencies. For example, computer vision and automated timestamp detection increase data objectivity, but their benefits are realized only when controllers and ground staff are trained to interpret outputs and when managers incorporate these metrics into performance dashboards and contractual oversight. Employee performance depends on supportive management and appropriate technology; scenario-based training, transparent escalation protocols, and modern scheduling reduce stress and error rates, whereas outdated equipment and purely top-down mandates undermine resilience. Management decisions integrate the system by setting deployment priorities, synchronizing training with tooling maturity, and balancing competing objectives such as delay reduction, fuel burn, and workload. Causality thus runs bidirectionally: adoption of new tools changes human work, which in turn feeds back into managerial strategy; conversely, strategic choices about staffing, standards, and governance shape the feasibility and impact of technological solutions.

This study's primary goal was to assess the synergistic relationship between Technology, People, and Management (TPM) within a unified framework for Airport Operations. Through a systematic review of scholarly articles, it has been clearly shown that these three areas do not work independently of each other, but rather are interdependent with each of them in a constant state of supporting and influencing each other (Bakır et al., 2022; Güner, 2021; Yıldız et al., 2022).

4.1 Technology as a driver of human and managerial effectiveness

The analysis confirms that emerging technologies, including Artificial Intelligence (AI), computer vision, and automated monitoring tools, significantly reduce human error and enhance operational accuracy. However, technology in isolation is insufficient for systemic success (Ku, 2024). Employees must be equipped with appropriate training (Oto et al., 2012; Balk et al., 2011), and managers must actively integrate data from these systems into their strategic decision-making processes (Güner and Seçkin Codal, 2022; Güner and Cebeci, 2021). Consistent with previous research, technological efficacy is contingent upon human proficiency and the updating of associated work processes (Taufik and Hanafiah, 2019; Wongyai et al., 2024; Nugroho et al., 2012). Consequently, the success of AI-driven data in airports depends on personnel understanding and managerial

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application (Jimenez et al., 2023; Ku, 2024), reinforcing the premise that technology cannot be effective without the active support of both people and management (Ansola et al., 2011; Ankersmit, Rezaei, Tavasszy, 2014; Burghouwt, Poort, Ritsema, 2014; Padrón et al., 2016,).

4.2 Employee performance as a joint output of management support and technology

The research indicates that employees perform better when provided with adequate support from their supervisors and training and instruction on how to handle stressful situations. Due to the nature of the ground staff's work, they have heavy workloads and deal with customer disputes regularly and require effective leadership support. On the other hand, low compensation and obsolete equipment create barriers to motivation and create staffing shortages. The associated literature indicates that using integrated planning systems, implementing airport de-peaking strategies and applying modern scheduling methods will help lower workplace stress so employees are more productive at work (Wu et al., 2026; Balk et al., 2011). Overall, an individual's capabilities are subordinate to the effect of technological and managerial structures on employee productivity.

4.3 Managerial decisions as the integrating force of the TPM framework

The relationship between management, technology and people is close. Management makes decisions on how best to allocate organizational resources to achieve a given organizational direction. The predominant use of top-down safety mandates has been ineffective because they have not taken into account the complexities of the work environment. A collaborative bottom-up model in which workers contribute to the development of safety rule is more effective for creating a resilient organizational culture (Passenier andet al., 2015; Hale and Borys, 2013). Managers frequently have competing interests, and decisions are often difficult due to competing priorities (Weiszer andet al., 2015). A strategic view of how to balance these competing demands is required to ensure the best use of both human and technological resources.

4.4 System-level coordination and environmental sustainability

The TPM framework goes beyond the airport level, enabling airports to positively collaborate through the implementation of shared planning and enhanced connectivity, thereby easing congestion and enhancing efficiency across the region (Zuo et al., 2025), thereby providing environmental benefits as a result of the improved performance and reduced environmental impacts associated with the implementation of predictive maintenance solutions within specific industries such as cold chain logistics (Mizrak and Cantürk, 2025). Lastly, the results shown in the studies indicate that adding more personnel alone cannot solve the bottleneck problem; however, increasing personnel is only effective when the facility meets its physical limitations of either runway or slot capacity (AlKheder et al., 2024; Malandri et al., 2020). Therefore, managers need to properly identify the root causes of operational issues in order to make informed, educated decisions.

4.5 Integrated interpretation: TPM as an interdependent system

This research indicates that airport sustainability builds on an interdependent, employee-centric framework. Employees' training must adapt as new technology is developed in order for them to make full use of data-driven insights properly (Oto et al., 2012; Ku, 2024). Employees' well-being should be the focus of management, especially in stressful operating contexts (Wu et al., 2026; Muecklich et al., 2023). The development of both operational/functional efficiency and higher levels of environmental sustainability may be accomplished by integrating the functions of personnel management with employee task planning (Cai et al., 2025; Cappanera et al., 2024). A transition to a technology-based approach to monitoring and to strategic collaboration – rather than the mere increase in the number of employees – is necessary for achieving environmental sustainability objectives (Güner, 2021; Weiszer et al., 2015).

4.6 Practical implications

Based on the findings, several practical recommendations are offered for airport managers and stakeholders. Training programs should be developed concurrently with technological implementation to ensure seamless data integration (Oto et al., 2012; Ku, 2024; Balk et al., 2011). Managers are encouraged to prioritize the psychological health and well-being of staff to mitigate burnout in demanding roles (Wu et al., 2026; Muecklich et al., 2023). Additionally, the use of unified systems for personnel and task scheduling is recommended to avoid fragmented

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and inefficient planning (Cai et al., 2025; Cappanera et al., 2024; Padrón et al., 2016). Finally, achieving environmental objectives requires a commitment to strategic collaboration and the use of technology-driven monitoring systems (Güner, 2021; Mizrak and Cantürk, 2025; Weiszer et al., 2015).

The results translate into several practical implications for the principal stakeholder groups. Regulators and policy-makers should align deployment roadmaps with measurable targets that jointly reflect safety, capacity, and environmental performance, and they should encourage data interoperability through standards and governance frameworks that reduce integration friction. Certification pathways for machine-learning decision support need explicit evidence requirements for robustness, explainability, and latency so that operational approval can proceed with confidence. Air navigation service providers should prioritize trajectory-oriented concepts that demonstrably reduce delay and fuel burn while maintaining controller workload within acceptable bounds, and they should invest in resilience through contingency planning and cross-border coordination informed by network-level analytics. Human-in-the-loop evaluations of automation during trials are essential to monitor workload, situational awareness, and mode awareness, thereby mitigating risks associated with automation bias. Technology developers and integrators should design interoperable interfaces and data models that accommodate legacy systems, embed human factors and model transparency to foster user trust, and provide uncertainty-aware optimization that incorporates weather and demand variability together with decision dashboards that make trade-offs explicit. Training organizations should update curricula to include human–AI teaming, mode awareness, and strategies for mitigating automation bias; they should employ scenario-based exercises that expose personnel to varied traffic regimes and automation levels, and they should monitor cognitive workload with validated measures to inform rostering and support tools.

4.7 Limitations and directions for future research

This study has reviewed 42 articles between 2010 and 2025 however, there are limitations regarding the representation of very small airports and newly tested technology in this study. Future research should include an example of how the newly developed technologies can be viewed within an operational environment and an analysis that can be cross-compared between countries. Further utilization of the TPM Framework will determine how interactions in air traffic control and cargo terminals will differ across various aviation environments.

The synthesis draws on a finite corpus of articles and on keyword-level metadata rather than full-text analysis, which constrains granularity and may underrepresent niche topics. Future research should expand the dataset across multiple databases, publish open corpora and code for reproducibility, and integrate full-abstract text mining with topic modeling to capture conceptual nuance. Empirical studies of human–AI teaming in operational settings, certification-constrained real-time machine learning architectures, and governance models for cross-border data sharing represent high-impact avenues for advancing both scholarship and practice.

5. Conclusion

Study results demonstrate that human performance in aviation is a product of not just how much technology can facilitate operational performance (via the provision of AI and automated monitoring systems), but also how well management can support such operations through comprehensive employee training and developing strategic management decisions, thereby achieving success in aviation business activity (Jimenez et al., 2023; Ku, 2024; Yildiz et al., 2022; Oto et al., 2012; Balk et al., 2011; Güner and Seçkin Codal, 2022; Güner and Cebeci, 2021). Thus, TPM represents an appropriate model for the development of cognitive sustainability, as evidenced by the fact that it incorporates all three elements of Technology, People, and Management into a single framework that allows for enhanced coordination between all stakeholders in the aviation industry. A coordinated approach to developing cognitive sustainability through the implementation of the TPM framework provides benefits to both individual airports and the aviation system as a whole. Moreover, a transition from traditional “top-down” management structures toward a more inclusive “bottom-up” safety culture, in which employees have the opportunity to participate in the creation of aviation regulations, is necessary to reduce the stress and pressure associated with ground handling operations in airport environments. Finally, the use of TPM will enable airports to achieve greater environmental and operational sustainability in the long term (Zuo et al., 2025; Weiszer et al.,

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2015).

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