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A Review of Emerging Airport Technologies from a Passenger-Centric Perspective

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Abstract

This study examines the transformative role of emerging technologies, particularly the Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML), in modernizing airport operations and enhancing passenger experiences. Using a PRISMA-guided systematic review of 51 peer-reviewed publications, the study integrates bibliometric and content analyses to evaluate applications across passenger navigation, baggage handling, cargo management, and security operations. The findings reveal substantial progress in automation, real-time data analytics, and AI-driven personalization, which collectively improve efficiency, reduce congestion, and elevate service quality. However, challenges persist, including high costs, integration complexity, cybersecurity risks, and regulatory constraints. Emerging but underexplored areas, such as Autonomous Guided Vehicles (AGVs) and IoT-enabled baggage management, highlight critical opportunities for future research and practice. By consolidating insights from diverse studies, this review provides both scholarly and practical contributions, offering a roadmap for airports to evolve into efficient, resilient, and passenger-centric ecosystems aligned with global digital transformation trends.

Keywords: emerging technologies, passenger experience, artificial intelligence, digital transformation in airports

1. Introduction

Airports are critical hubs for global connectivity, trade, and tourism, playing a pivotal role in fostering economic growth and enabling social interaction. With the steady growth in air travel demand, airports face mounting pressure to deliver efficient operations while ensuring passenger comfort and safety. To meet these challenges, airports are increasingly turning to digital transformation. Emerging technologies, including self-service kiosks, biometrics, the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), and deep learning, are reshaping airport functions. These innovations streamline processes such as check-in, security checks, passenger movement, and baggage handling, thereby enhancing service quality and reducing reliance on manual labor. Collectively, they enable airports to adapt to evolving passenger expectations and the demands of fast-paced, highly dynamic environments [1].

Passenger movement has become particularly critical in increasingly crowded and complex terminals, especially in the wake of the COVID-19 pandemic [2]. Emerging technologies are transforming navigation from check-in to boarding, reducing congestion and improving efficiency. Digitization and automation of check-in processes, for example, enhance speed and minimize waiting times [3]. Self-service kiosks, IoT-enabled applications, and mobile solutions not only improve the passenger experience but also strengthen the operational effectiveness of airlines and airport authorities. The pandemic also reinforced

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the importance of adaptability, as these technologies demonstrated resilience in maintaining safe and seamless operations during crises.

Passenger comfort and service have also emerged as central concerns in airport innovation. Beyond efficiency, airports are investing in ergonomic design, environmental controls, and personalized services to create more inclusive and enjoyable travel experiences. AI-driven personalization and sensory-friendly spaces are particularly important in ensuring accessibility and meeting the diverse needs of passengers.

Security remains a parallel priority, given the complex and evolving threats airports face. Protecting passengers, staff, and infrastructure requires robust technologies such as advanced surveillance systems, biometric authentication, and cybersecurity protocols [4]. Yet the challenge persists in balancing rigorous security with passenger privacy and convenience in increasingly digitized environments.

Baggage handling represents another critical area of focus. Inefficient systems contribute to passenger dissatisfaction and high operational costs. IoT- and AI-enabled solutions, along with robotics and Autonomous Guided Vehicles (AGVs), are improving accuracy, speed, and reliability in baggage management. These innovations not only reduce lost or delayed luggage but also optimize logistics and sustainability efforts, pointing toward more integrated smart airport ecosystems.

Despite these advancements, persistent challenges remain. Congestion, high implementation costs, cybersecurity vulnerabilities, and the complexity of system integration continue to hinder large-scale adoption. Moreover, while research often emphasizes individual technologies, comprehensive assessments of their combined impact are limited. There is a need to better understand how these innovations interact, complement one another, and align with diverse airport contexts.

This review addresses these gaps by systematically analyzing 51 publications to provide a holistic overview of how emerging technologies are transforming airport operations and passenger experiences. The study identifies barriers to adoption, explores innovative solutions, and highlights under-researched areas such as AGV deployment and IoT-enabled baggage management. By consolidating findings from diverse sources, this review offers a nuanced understanding of current progress and outlines opportunities for advancing efficiency, safety, and passenger-centric innovation in airports.

While the review systematically examines literature up to February 2024, several more recent studies further extend the trajectories identified. On the passenger side, sentiment analyses confirm that travelers respond positively to smart airport features when usability and trust are ensured [5]. Research on contactless AI services highlights the importance of emotional and performance factors in adoption [6]. On the operational side, predictive analytics and deep reinforcement learning are advancing gate-assignment practices, reducing walking distances, gate conflicts, and delays under real-world conditions [7-9]. In the security domain, recent contributions on deep learning for baggage X-ray screening [10], systematic reviews of biometric e-gates [11], and analyses of cybersecurity vulnerabilities in aviation [12] underscore the urgent need for privacy-aware and resilient frameworks. Collectively, these studies demonstrate that AI and IoT-enabled approaches are not only relevant but accelerating, with strong empirical support across passenger experience, operational efficiency, and security.

The remainder of this paper is organized as follows:

(1) Section 2 details the methodology, including the PRISMA-based screening process, bibliometric analysis, and content analysis.

(2) Section 3 presents the bibliometric findings, mapping research trends in emerging technologies for airports.

(3) Section 4 provides a comprehensive content analysis, focusing on domains such as passenger movement, check-in, passenger comfort and service, security threats, baggage handling, baggage trolleys, and AGVs.

(4) Section 5 concludes by synthesizing the findings, discussing practical and policy implications, outlining study limitations, and offering directions for future research.

2. Methodology

The methodology employed in this study follows a structured, transparent, and systematic process, specifically designed to collect and analyze literature on the integration of emerging technologies in airports. To ensure comprehensive coverage and methodological rigor, the research design was divided into four key stages: Literature Retrieval, Screening, Bibliometric Analysis, and Content Analysis. Each stage was critical to develop a holistic understanding of how technologies such as IoT, AI, and ML are being applied within airport contexts.

2.1 Literature Retrieval

The literature retrieval stage employed a comprehensive and targeted search strategy using the Scopus database, which was selected for its breadth of peer-reviewed publications, multidisciplinary coverage, and robust indexing of high-quality journals in engineering, computer science, management, and transportation. Compared to other databases, Scopus was considered the most suitable for capturing the interdisciplinary scope of this review, ensuring both depth and quality of results.

To identify research at the intersection of airport operations, passenger experience, and emerging technologies, the following Boolean search string was applied:

(“passenger” AND “airport” AND (“AI” OR “artificial intelligence” OR “big data” OR “cloud” OR “deep learning” OR “data analytics” OR “industry 4.0” OR “IoT” OR “internet of things” OR “machine learning” OR “smart” OR “innovation”))

This search string combined the core terms “passenger” and “airport” with a comprehensive list of technology-related keywords, ensuring the inclusion of both general and specific terminology (e.g., *“AI”* and *“artificial intelligence”*; *“IoT”* and *“internet of things”*). Boolean operators (AND/OR) were employed to capture a broad but relevant set of results while excluding irrelevant records.

The search was applied to titles, abstracts, and author-defined keywords to ensure depth and precision, capturing both explicit and implicit intersections between airport operations and technological innovation. To maintain consistency and rigor, only peer-reviewed journal articles were included. Other publication types, such as conference papers, white papers, and industry reports, were excluded, as they often represent preliminary findings or practice-oriented outputs rather than comprehensive peer-reviewed studies.

This process yielded 195 scholarly articles published between January 2014 and February 2024, which were subsequently screened using the PRISMA framework. The resulting dataset provided a robust and replicable foundation for bibliometric and content analyses, offering diverse perspectives on how emerging technologies are shaping airport efficiency, security, and passenger-centric services.

2.2 Literature screening process

Following the principles of the PRISMA statement, a systematic and transparent screening process was applied to ensure methodological rigor in identifying and evaluating relevant studies. After duplicate removal, an initial 195 publications were retrieved from the Scopus database. Each paper was then examined in detail for relevance to the study’s focus on emerging technologies in airport operations. Based on established inclusion and exclusion criteria, 144 articles were excluded, resulting in a refined dataset of 51 relevant publications covering the period from 2014 to February 2024, as shown in Fig. 1.

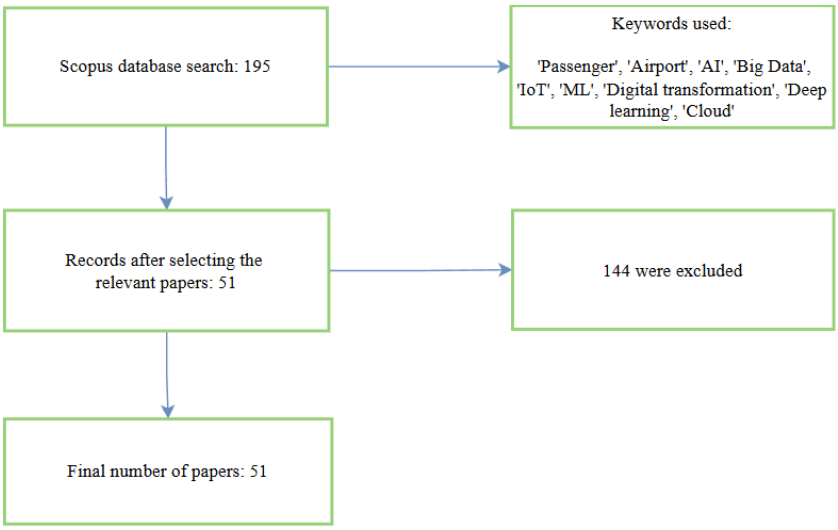

Fig. 1 Literature screening approach

This review specifically targeted studies investigating technologies such as IoT, AI, ML, and biometric systems, with particular emphasis on their potential to transform the passenger experience within airport environments. The comprehensive screening process ensured that only peer-reviewed and conceptually relevant papers were included, thereby enhancing both the reliability and validity of the analysis.

As depicted in Fig. 2, the temporal distribution of publications demonstrates a steady rise in research output from 2014 onwards, reflecting growing scholarly and practical interest in technology-driven airport solutions. A particularly sharp increase was observed from 2020 onwards, coinciding with the COVID-19 pandemic, which led to unprecedented demand for safe, efficient, and contactless solutions. The pandemic acted as a catalyst for innovation, accelerating both academic inquiry and the practical adoption of technologies aimed at ensuring safety, efficiency, and resilience in airport operations.

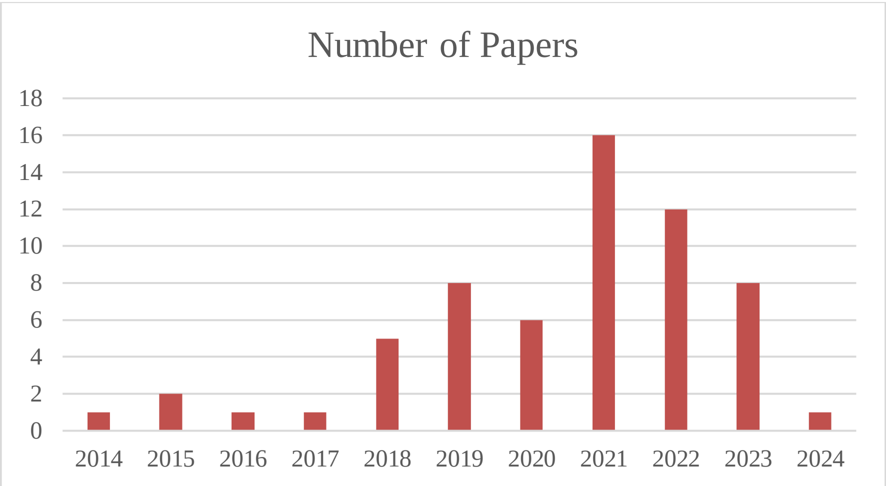

Fig. 2 Number of publications on emerging technologies in airport passenger experience (2014-2024)

The findings reveal that technologies such as AI, IoT, and biometric systems began to gain traction in academic discourse in 2014, with publication volumes increasing significantly in the last five years. The post-pandemic period has been especially influential in shaping research priorities, as airports worldwide sought digital and automated solutions to address heightened safety and efficiency demands. This trajectory underscores the dual role of crises: as drivers of research momentum and accelerators of real-world adoption. Consequently, the current landscape reflects not only the growing maturity of these technologies but also their integration into long-term strategies for redefining passenger experiences and operational resilience.

2.3 Bibliometric Analysis:

Bibliometric analysis was employed as a systematic and rigorous tool to assess the academic literature and map the intellectual structure of research on emerging technologies in airports. By examining citation patterns, co-authorship networks, and keyword co-occurrences, this approach enabled a comprehensive understanding of the field's thematic evolution and scholarly impact.

Using VOSviewer software, the study generated visual representations that revealed thematic clusters and collaboration networks, highlighting linkages between key concepts, authors, and regions. This allowed for the identification of seminal works, influential contributors, and underexplored research areas within the intersection of airport passenger experience and technological innovation.

Beyond quantifying research output, bibliometric analysis provided insights into the developmental trajectory of research themes, illustrating how topics such as AI, IoT, and biometrics gained prominence over time. The resulting visualizations served as an essential foundation for understanding the dynamics of academic discourse, offering a clear map of both prevailing trends and future research opportunities.

2.4 Content Analysis:

Following the bibliometric assessment, content analysis was applied to provide a qualitative and thematic exploration of the selected studies. Each publication was carefully reviewed and systematically organized into themes and sub-themes, allowing for a structured synthesis of findings.

This process facilitated the identification of recurring patterns, emerging themes, and cross-cutting issues related to the integration of new technologies in airport environments. The analysis focused particularly on the interaction between airport passengers and emerging technologies, highlighting how innovations in AI, IoT, biometrics, and automation are reshaping both operational efficiency and passenger experience.

By linking technological adoption to broader organizational and managerial implications, the content analysis offered insights into the strategic significance of innovation in airports. This phase not only deepened the understanding of how technologies affect passenger services but also underscored their potential implications for enterprise management, resource allocation, and long-term strategic planning.

2.5 Theoretical Framework and Philosophical Assumptions:

This study is underpinned by a pragmatic–interpretivist epistemological stance, which recognizes that knowledge about emerging technologies in airports is shaped not only by objective evidence but also by social, organizational, and contextual dynamics.

Pragmatism emphasizes the practical resolution of real-world problems and supports methodological flexibility by combining qualitative and quantitative approaches when appropriate [13]. At the same time, interpretivism assumes that meaning is socially constructed and context-dependent, requiring researchers to uncover how phenomena are experienced and understood by different actors [14]. Within this dual orientation, the systematic review component reflects a pragmatic commitment to methodological rigor, reproducibility, and comprehensive evidence synthesis, whereas the bibliometric and content analyses adopt an interpretivist lens to reveal latent themes, interrelationships, and meanings across the body of literature.

By integrating these perspectives, the study aligns with a mixed methods tradition that combines quantitative mapping with qualitative interpretation to generate richer insights [15]. Explicitly articulating these assumptions strengthens the study's methodological transparency and clarifies that technological adoption in airports is interpreted not merely as a technical process but as a socially embedded phenomenon shaped by stakeholders, institutions, and evolving contexts.

3. Bibliometric Analysis

The integration of advanced technologies such as IoT, AI, ML, and biometric systems into airport operations has attracted growing scholarly attention for their potential to enhance passenger experiences in increasingly complex and dynamic environments. While the benefits of these innovations are widely acknowledged, their passenger-centric applications remain relatively underexplored. To address this gap, a bibliometric analysis was conducted on the curated dataset of 51 publications identified through Scopus, focusing specifically on airport passenger-facing technologies. Using VOSviewer and Microsoft Excel, the analysis mapped research trends, thematic clusters, and conceptual linkages over the past decade, thereby providing a clearer understanding of the intellectual landscape and emerging research trajectories.

3.1. Co-occurrence map based on text data

To map the intellectual structure of research on airport technologies, a keyword co-occurrence analysis was conducted. Fig. 3 visualizes the network of terms appearing together across the dataset: each node represents a keyword (node size = frequency), and links indicate co-occurrence strength; closer nodes reflect stronger conceptual ties.

As shown in Fig. 3 and Table 1, the most central and frequent terms are “airport,” “machine learning,” “airport security,” and “deep learning.” Their prominence signals the core of current scholarship. Strongly connected concepts such as “Internet of Things (IoT),” “biometrics,” and “smart airport” further indicate the growing influence of data-driven and automation-oriented solutions on both operations and the passenger experience. Together, these clusters reflect broader themes of digital transformation, AI-enabled decision support, and data analytics in airport contexts (see Table 1 for the ten most frequent terms and their relevance scores).

The map also reveals emerging niches, including “autonomous vehicles,” “convolutional neural networks,” and “risk assessment,” that are less frequent but strategically positioned, suggesting fertile directions for future inquiry at the intersection of aviation management, data science, and cybersecurity.

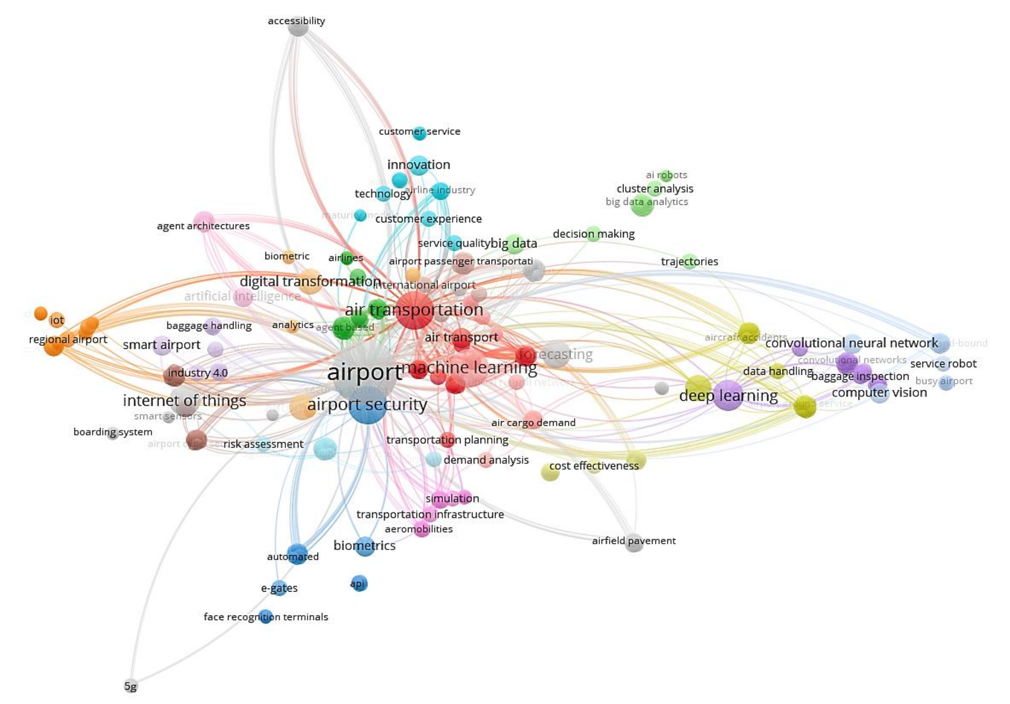

Fig. 3 Co-occurrence analysis

Table 1 Top 10 terms by occurrence

Rank	Term	Occurrences	Relevance Score
1	Airport	30	377
2	Air Transportation	11	171
3	Airport Security	11	170
4	Machine Learning	11	151
5	Forecasting	6	106
6	Deep Learning	7	105
7	Learning Systems	5	88
8	Internet of Things	7	83
9	Convolutional Neural Network	3	54
10	Artificial Intelligence	3	53

Complementing the global view, Fig. 4 focuses on terms that directly connect airports with passengers. Notable nodes, including “Internet of Things,” “Smart Airport,” “Passenger Experience,” and “Regional Airport,” form a tightly linked cluster, underscoring how passenger-centric objectives are driving the adoption of IoT-enabled, interconnected systems. This passenger-facing cluster highlights the field’s shift toward real-time monitoring, service personalization, and integrated smart-airport ecosystems.

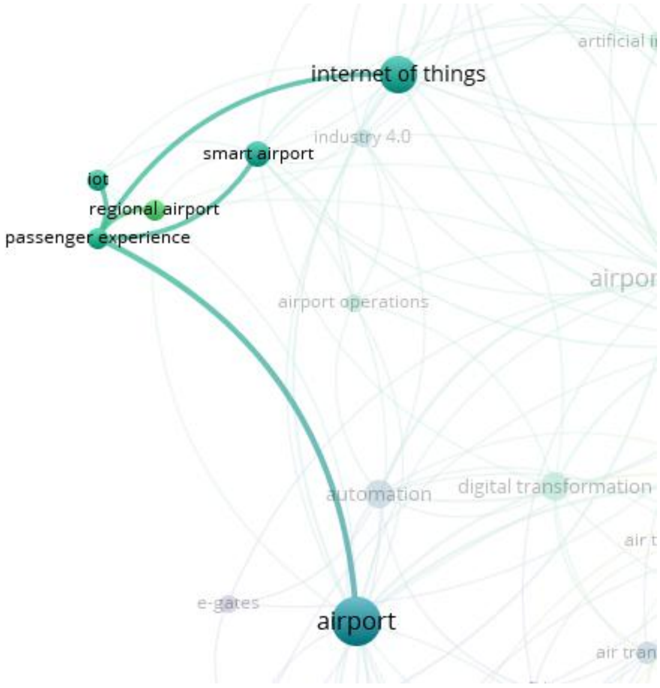

Fig. 4 Terms directly connected with airports and passengers

3.2. Co-occurrences map based on keywords

To further explore the intellectual structure of the field, a keyword co-occurrence analysis was conducted. This approach highlights the most frequently used terms across the 51 publications in the dataset and their thematic interconnections.

Fig. 5 illustrates the global co-occurrence network of keywords. Larger nodes represent higher-frequency terms, while connecting lines capture the strength of their associations. As summarized in Table 2, dominant terms include “Airport” (30 occurrences), “Air Transportation” (11), “Airport Security” (11), and “Machine Learning” (11), which form the backbone of scholarly discourse in this domain. Their central positioning underscores the dual focus on airport functionality and technological transformation. Emerging but increasingly influential keywords, such as “Deep Learning,” “Big Data,” and “Artificial Intelligence,” reflect the growing adoption of advanced analytics to tackle complex challenges in operational efficiency, safety, and passenger experience.

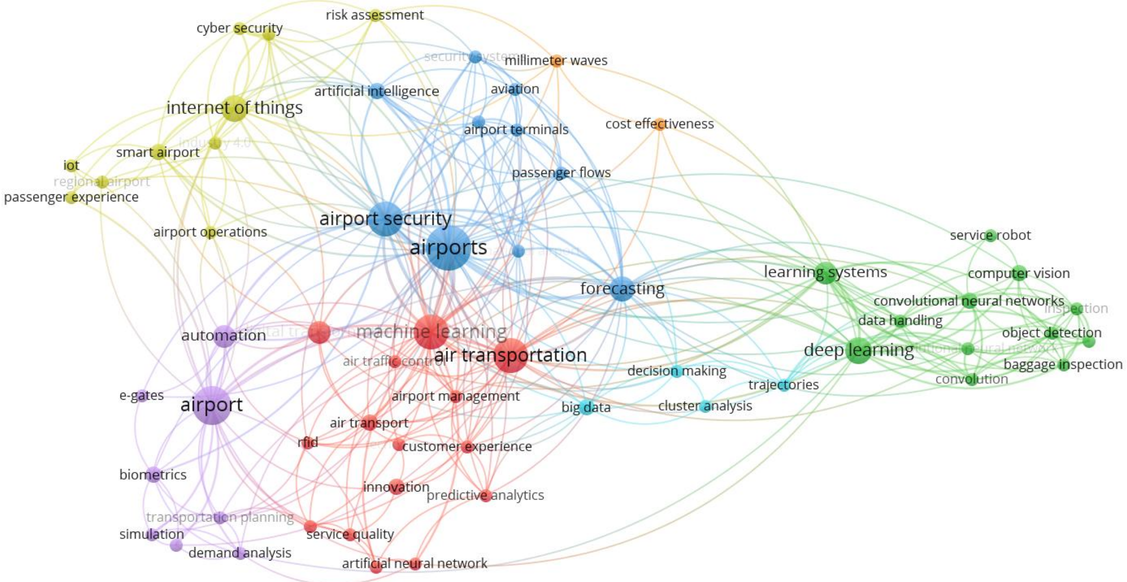

Fig. 5 Co-occurrence map based on all keywords

Table 2 Top 10 keywords by occurrence

Rank	Term	Occurrences	Relevance Score
1	Airport	30	377
2	Air Transportation	11	171
3	Airport Security	11	170
4	Machine Learning	11	151
5	Forecasting	6	106
6	Deep Learning	7	105
7	Learning Systems	5	88
8	Internet of Things	7	83
9	Convolutional Neural Network	3	54
10	Artificial Intelligence	3	53

When filtered by author-defined keywords, Fig. 6 highlights the emphasis scholars place on transformative innovations. Terms such as “Digital Transformation,” “Machine Learning,” and “Automation” appear strongly connected to “Airport,” underscoring the role of emerging technologies in reshaping airport operations. This clustering reflects how authors frame their contributions as part of broader modernization narratives, linking airport functionality with next-generation digital tools.

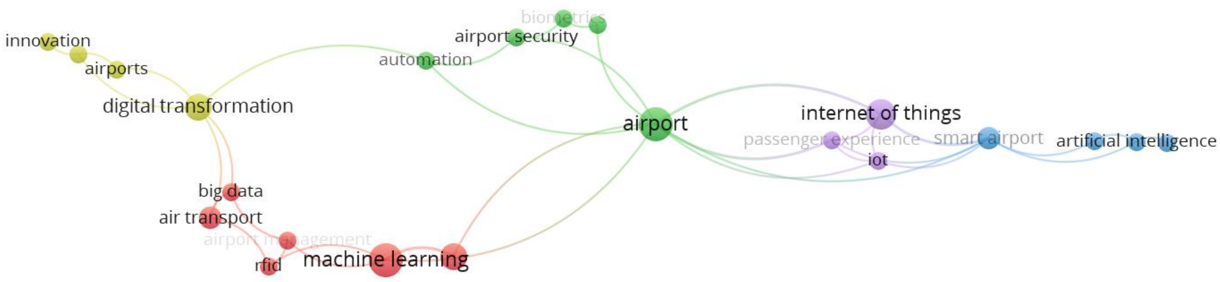

Fig. 6 Co-occurrence map based on author keywords

Expanding the scope to index keywords, Fig. 7 presents a broader view of the field. Central concepts such as “Airport Security,” “Air Transportation,” and “Deep Learning” dominate, illustrating the critical areas where research efforts have been concentrated. Additional terms, including “Passenger Flows” and “Millimeter Waves,” point to specialized domains, ranging from logistical optimization to advanced security technologies, underscoring the interdisciplinary reach of this literature.

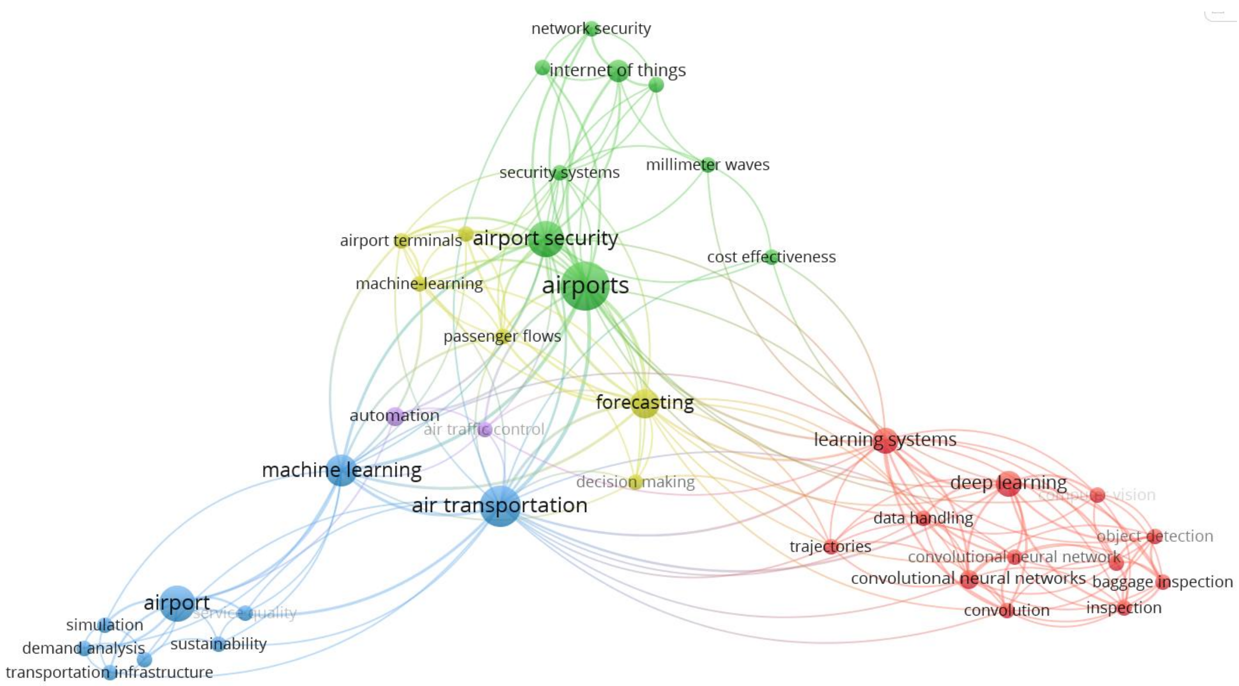

Fig. 7 Co-occurrence map based on index keywords

Finally, Fig. 8 provides a focused view of terms directly linked to “Passenger Experience.” Strong associations are visible with “Internet of Things,” “Smart Airport,” and “Automation,” reflecting their centrality in enhancing service quality and efficiency. However, the relatively smaller size of the “Passenger Experience” node compared to terms like “Machine Learning” or “Airport Security” suggests that this area remains underrepresented in the academic literature. This gap indicates significant scope for future research into how emerging technologies can directly improve passenger-centric outcomes.

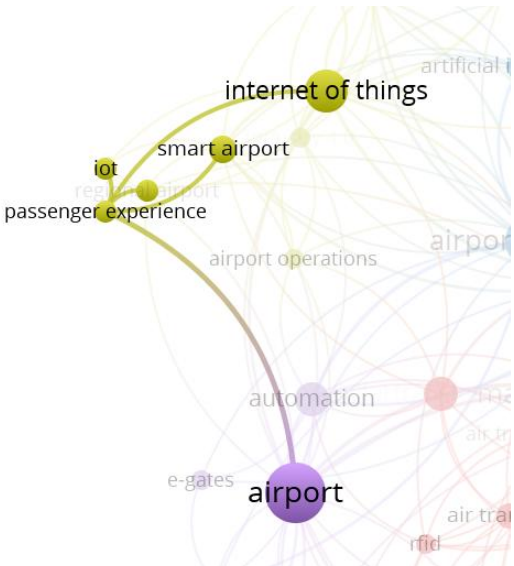

Fig. 8 Keywords linked to passenger experience

3.3. Co-occurrence map based on authorship

To identify key contributors and collaboration patterns in the field, an authorship co-occurrence analysis was conducted. This approach examines how often authors appear together across publications, thereby highlighting collaborative ties and the relative influence of individual researchers. Since most authors in the dataset contributed only one publication, traditional metrics such as publication counts were less meaningful. Instead, citations and total link strength, which capture the intensity of co-authorship connections, were used to assess author prominence.

Fig. 9 presents the co-authorship network, illustrating the complex web of relationships between contributors. Each node represents an author, with node size corresponding to citation count and link thickness indicating the strength of co-authorship ties. The visualization underscores the collaborative nature of research in this domain, with dense interconnections suggesting cross-institutional and multidisciplinary partnerships.

As shown in Table 3, several authors stand out in terms of total link strength, with figures such as Cheng H., Meng M. Q. H., Min Z., Li T., Liu L., Lyu E., and Mai X. all achieving a score of 9. These researchers also exhibit relatively high citation counts, further reinforcing their visibility and influence within the network. Collectively, this suggests that while the field remains fragmented in terms of individual output, a small group of scholars is shaping its intellectual structure through strong collaborative linkages.

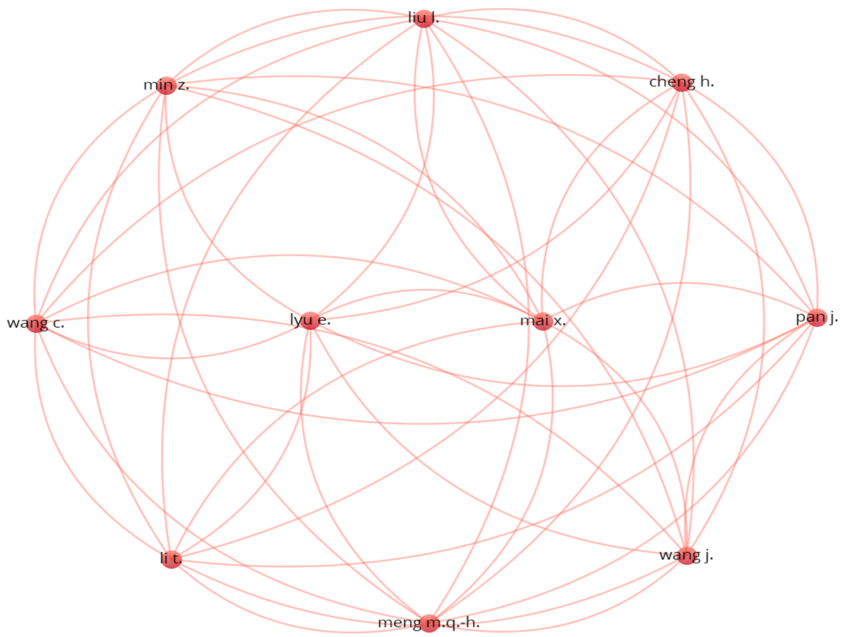

Fig. 9 Co-occurrence map based on authorship

Table 3 Top 10 authors by total link strength

Rank	Term	Citations	Total Link Strength
1	H. Cheng	5	9
2	H. T. Do	2	9
3	D. M. Ha	2	9
4	T. Q. Le	2	9
5	T. Li	5	9
6	L. Liu	5	9
7	E. Lyu	5	9
8	X. Mai	5	9
9	M. Q. H. Meng	5	9
10	Z. Min	5	9

3.4. Co-occurrence map based on country of co-authorship

To capture the geographical distribution and international collaboration in research on airport technologies, a co-occurrence analysis was conducted at the country level. A threshold of at least two publications per country was applied, resulting in 16 out of 38 countries being included in the analysis. Fig. 10 visualizes these co-authorship relationships, where node size reflects the number of publications, and the thickness of connecting lines indicates the strength of cross-national collaboration.

The results highlight the United States as the most influential contributor, with 10 publications and 72 citations, supported by the highest total link strength of 542 (see Table 4). This confirms the central role of the U.S. in advancing airport digitalization and fostering global research partnerships. Spain and Taiwan follow as key contributors. Spain shows strong productivity (5 publications, 96 citations), while Taiwan demonstrates notable international impact despite only 2 publications, evidenced by its high total link strength (241).

Other countries, including Germany, South Korea, Singapore, and the United Kingdom, also occupy significant positions in the collaboration network, reflecting the widespread global interest in applying emerging technologies to airport operations. Importantly, smaller contributors such as Norway and Switzerland, each with only a single publication, nonetheless display high link strengths (139 and 125, respectively), underscoring the quality and collaborative intensity of their research.

Taken together, these findings reveal a globally interconnected research landscape. Strong ties between Europe, Asia, and North America illustrate the collaborative momentum of this field, while the prominence of countries with smaller outputs but high collaboration strength highlights the importance of strategic partnerships in shaping impactful scholarship on airport modernization.

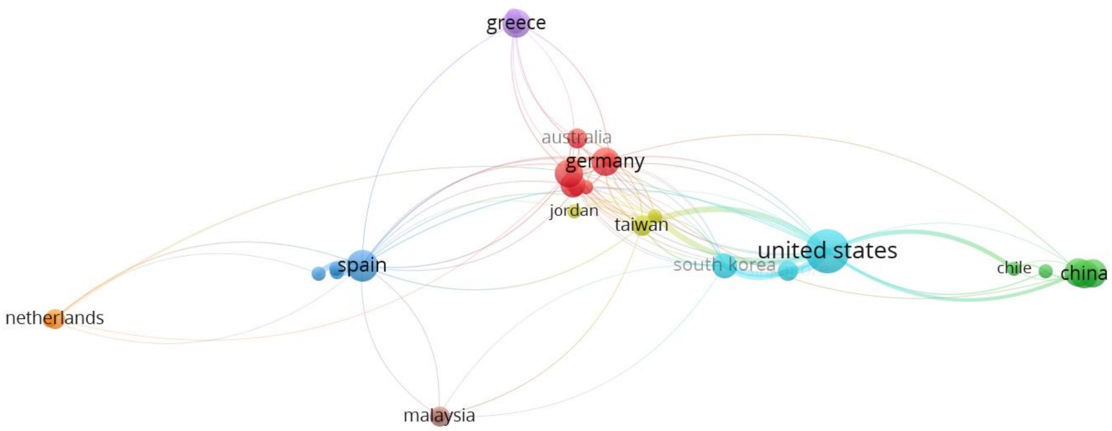

Fig. 10 Co-occurrence map based on country of co-authorship

Table 4 Top 10 countries by total link strength

Rank	Term	Documents	Citations	Total Link Strength
1	United States	10	72	542
2	Taiwan	2	35	241
3	Spain	5	96	232
4	Canda	1	23	226
5	Singapore	2	10	214
6	South Korea	3	13	183
7	United Kingdom	4	27	148
8	Germany	4	25	142
9	Norway	1	15	139
10	Switzerland	1	23	125

3.5. Co-occurrence based on sources

The analysis of publication sources highlights the leading journals contributing to the research on emerging technologies in airport operations. Fig. 11 presents a co-occurrence visualization of these sources, where the node size reflects the number of publications from each journal, and connecting lines indicate thematic overlaps across the research network. This mapping reveals that contributions are spread across a diverse set of journals, reflecting the multidisciplinary nature of this field, spanning transportation, service management, technology, and sustainability.

Fig. 11 Distribution of sources

As shown in Table 5, the *Journal of Airport Management* emerges as the most prolific outlet, publishing 11 documents with a total link strength of 24, underscoring its pivotal role in advancing airport-focused research. The *Journal of Air Transport Management* also holds a central position: while it has published fewer papers (4 documents), these works are highly cited (71 citations), demonstrating strong academic impact and recognition.

Table 5 Top 10 sources by total link strength

Rank	Term	Documents	Citations	Total Link Strength
1	Journal of Airport Management	11	23	24
2	Journal of Air Transport Management	4	71	23
3	Service Industries Journal	1	23	22
4	Netnomics: Economic Research and Electronic Networking	1	23	18
5	Sustainability (Switzerland)	4	45	18
6	Asian Journal of Technology Innovation	4	1	14
7	Service Business	1	12	13
8	European Transport – Trasporti Europi	1	12	9
9	IEEE Access	1	38	6
10	Russian Journal of Nondestructive Testing	1	23	125

Other journals contribute from complementary perspectives. For example, *Sustainability (Switzerland)* and the *Asian Journal of Technology Innovation* reflect global interest in environmental sustainability and technological modernization in airport operations. The *Service Industries Journal* and *Service Business* extend the discussion to service quality and passenger experience, highlighting the relevance of management sciences in shaping airport digitalization strategies. Meanwhile, technology-driven outlets such as *IEEE Access* and *Netnomics* emphasize the role of IoT, big data, and digital platforms in optimizing airport processes.

Fig. 12 further illustrates the distribution of sources by publication volume, clearly positioning the *Journal of Airport Management* as the dominant outlet. However, the presence of specialized journals with smaller outputs but high link strengths (e.g., *Netnomics* and *Service Industries Journal*) highlights the interdisciplinary and cross-domain integration of emerging technologies in airports. Collectively, these findings confirm that research dissemination in this field is not confined to transportation-focused outlets but increasingly spans across sustainability, technology, and service domains, enriching the academic and practical discourse.

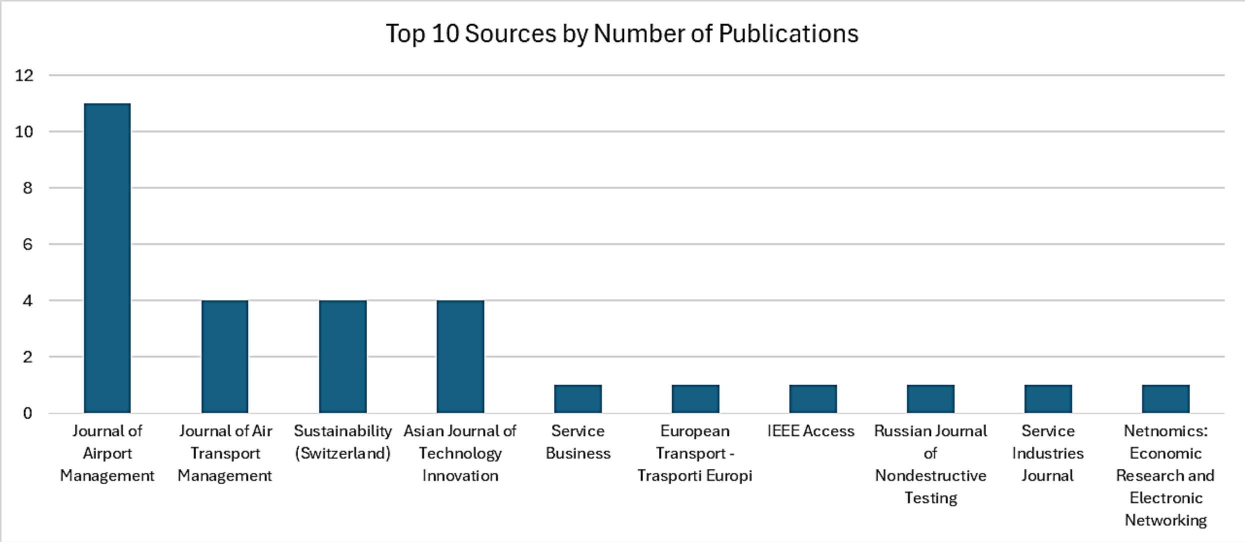

Fig. 12 Bar chart of sources by number of publications

3.6. Data Analysis Based on Document Type and Focus Area

This section examines the distribution of the 51 reviewed journal articles across the primary focus areas of airport operations, as shown in Fig. 13. The objective is to identify the domains where emerging technologies have been most extensively applied and where research gaps persist.

The analysis reveals that Security Check is the most frequently studied domain, with 18 publications, reflecting the critical role of security in safeguarding both passengers and airport infrastructure. The dominance of this area underscores the heightened priority given to security innovation in the context of evolving threats, regulatory compliance, and the growing demand for efficient yet privacy-conscious screening systems.

Passenger Service represents the second most prominent focus area, with 15 publications dedicated to technologies enhancing comfort, accessibility, and customer satisfaction. Research in this domain emphasizes AI-driven personalization, digital amenities, and sensory-friendly services, highlighting the shift toward passenger-centric innovation.

Moderate attention has been directed toward operational areas such as Baggage Trolleys (7 papers), Passenger Movement (7 papers), Check-In (6 papers), and Baggage Handling (5 papers). These studies illustrate efforts to streamline airport logistics, improve resource allocation, and enhance operational efficiency. However, their relatively lower representation compared to security and service indicates that while recognized as important, these areas remain less explored in depth.

Finally, AGVs are the least represented, with only 3 publications. This underrepresentation highlights a nascent research area that carries significant potential for transforming airport logistics, including baggage handling and cargo operations. The limited academic focus on AGVs suggests an urgent need for deeper exploration to harness their benefits in scalability, safety, and automation.

Taken together, the findings show that while security and passenger service dominate the academic landscape, a balanced research agenda is needed. Expanding investigations into underexplored domains such as AGVs, baggage handling, and integrated mobility systems could accelerate the transition toward more holistic, efficient, and passenger-oriented smart airports.

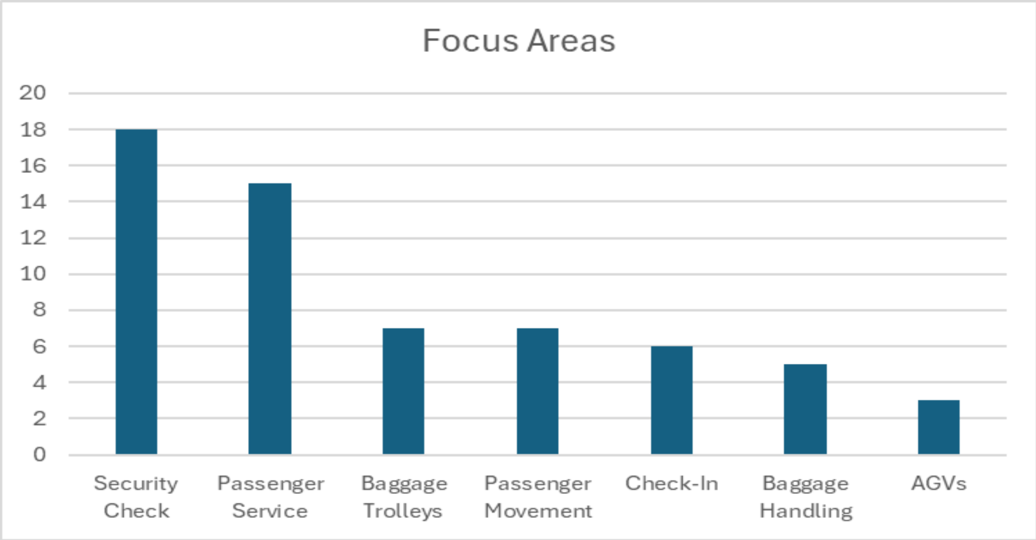

Fig. 13 Bar chart of focus areas

4. Content analysis

Building on the bibliometric insights presented in Section 3, this section analyzes how emerging technologies such as the IoT, AI, and ML are influencing airport operations with a particular focus on enhancing passenger experiences. The review highlights both the benefits and challenges of technology adoption, showing how these innovations contribute to greater efficiency, convenience, and security while also presenting barriers such as cost, integration, and privacy concerns. The subsections that follow examine key operational domains, including passenger movement, check-in, passenger service, security, baggage handling, baggage trolleys, and AGVs, to provide a comprehensive view of how airports are evolving toward smarter, more passenger-centric ecosystems.

4.1 Passenger Movement

Efficient passenger movement is a cornerstone of airport performance, directly affecting both operational flow and the quality of the overall travel experience. As airports grow in scale and complexity, ensuring seamless passenger circulation has become increasingly vital [1]. Emerging technologies, particularly IoT, AI, and robotics, offer transformative solutions to these challenges, reshaping how travelers move through airport spaces from check-in to boarding. These innovations not only enhance efficiency and reduce congestion but also play a crucial role in improving safety and passenger satisfaction.

Recent studies demonstrate the growing importance of integrating IoT and AI to manage passenger flow. For instance, Memika and Polat [1] proposed the “Boarding 4.0” model, which combines fingerprint and facial recognition for secure identification, a mobile application assistant for real-time updates, and an autonomous vehicle equipped with a navigation tablet. Together, these subsystems reduced boarding times and significantly streamlined passenger flow. Similarly, Guo et al. [2] emphasized the potential of real-time data and machine learning in forecasting transfer passenger flows. By dynamically adapting to changing conditions, these models enhance resource allocation and reduce congestion, underscoring the critical role of IoT-enabled analytics in operational resilience.

The adaptability of these technologies during crises has also been highlighted. Drljača et al. [3] showed that IoT sensors and AI-driven analytics were instrumental during the COVID-19 pandemic, improving the management of passenger movement under heightened safety requirements. This illustrates how technological adoption can extend beyond efficiency gains to ensure continuity and safety in extraordinary circumstances.

Optimizing airport layouts has also emerged as a key research focus. Chow et al. [4] proposed an evolutionary algorithm for airport gate assignments to reduce walking distances and improve circulation efficiency, while Rodríguez-Sanz et al. [16] applied machine learning to analyze queue behaviors at security checkpoints and check-in desks. These approaches provide actionable insights for congestion reduction and layout optimization, highlighting how design and technology converge in managing passenger flow.

Technological innovation is also being leveraged to improve ground operations and passenger comfort. Kalakou et al. [17] explored the use of smart glass and environmental monitoring systems to improve passenger comfort while enhancing operational performance. Kovynyov and Mikut [18] examined digitalization in ground operations, demonstrating how process automation improves efficiency and creates new revenue opportunities. In addition, Zhang et al. [19] developed a neural network model for airport surface movement prediction and safety assessment, further extending the role of AI into safety-critical operations.

These studies collectively underscore the transformative potential of IoT, AI, and machine learning in facilitating smoother passenger movement across diverse airport touchpoints. Key advances include AI-driven boarding systems such as "Boarding 4.0," predictive flow management models, and machine learning applications in queue analysis and gate assignment. Complementary technologies like environmental monitoring and robotic or digitalized ground operations further elevate both efficiency and passenger comfort. However, several challenges remain. The high initial investment required for infrastructure modernization, the technical complexity of integrating new systems with legacy platforms, and the need to continually adapt to evolving passenger expectations continue to constrain large-scale adoption. Moreover, the absence of standardization and interoperability across systems presents additional barriers to seamless implementation.

Future research should therefore prioritize scalable and cost-effective solutions that address these challenges. Promising directions include the development of standardized frameworks for system interoperability, more advanced AI-driven predictive models for real-time passenger flow, and broader applications of robotics and automation in baggage handling, ground operations, and security. Addressing these areas will not only improve operational efficiency but also strengthen airports' capacity to deliver resilient, passenger-centric services in increasingly dynamic environments.

4.2 Check-In Processes

Efficient check-in processes are central to enhancing the passenger experience at airports. As the first step in a traveler's journey, check-in strongly shapes perceptions of airport service quality [3]. In recent years, digitization and automation have transformed this process, motivated by the need to improve efficiency, reduce wait times, and enhance overall service. Innovations such as self-service technologies, IoT applications, mobile solutions, and advanced analytics are streamlining check-in while simultaneously improving operational effectiveness for airlines and airport authorities. Particularly in the wake of COVID-19, the importance of adaptable and resilient check-in systems has become even more evident.

A prominent trend in recent research is the adoption of self-service and IoT-based solutions. Shin et al. [20] investigated self-bag-drop (SBD) services, showing that relative advantage and compatibility are key drivers of passenger acceptance. Understanding these perceptions is critical to improving adoption rates and building trust in new technologies. Similarly, Drljač et al. [3] underscored the pivotal role of contactless check-in technologies during the COVID-19 pandemic, arguing that SBD will likely become the dominant standard in post-pandemic operations. These findings illustrate both the efficiency and resilience of automated check-in systems.

IoT applications are also reshaping baggage management within the check-in process. E. Y. C. Wong and W. H. Wong [21] proposed reusable IoT-enabled luggage tags, positioning them as eco-friendly and reliable solutions for baggage handling. Ahmed [22] developed a mobile application that integrates driver booking, GPS tracking, and barcode generation for luggage management, illustrating how mobile technologies can extend passenger convenience beyond the terminal. Together, these innovations highlight the convergence of IoT and mobile platforms in reimagining check-in as a more seamless, integrated experience.

Passenger trust, perceived ease of use, and psychological factors are decisive in the adoption of self-service kiosks. Lien et al. [23] combined the Theory of Planned Behavior with the Technology Acceptance Model, identifying intention as strongly shaped by trust and usability perceptions. Chen and Wu [24] further reinforced this perspective by showing that self-efficacy moderates acceptance of self-service systems. These behavioral insights emphasize that technological success depends not only on system design but also on passengers' confidence in using them.

Advanced IT platforms have also proven transformative. Poulsen et al. [25] described Copenhagen Airport's transition to a modern, data-driven platform that integrates passenger flow management, AI-based forecasting, and resource optimization. The platform reduced staffing inefficiencies and improved both check-in and security throughput. Similarly, Haripriya and Ramyasree [26] applied machine learning and RFID systems to develop a smart management solution addressing counterfeit tickets, baggage loss, and flight delays, achieving high accuracy in predictive modeling. Rodríguez-Sanz et al. [16] also examined queue behavior, producing real-time wait-time estimates that supported more efficient resource allocation and enhanced passenger satisfaction. Finally, Tran et al. [27] presented a smart interactive guiding robot to assist passengers in crowded airports, highlighting the potential role of robotics in elevating service quality during check-in and wayfinding.

The studies reviewed highlight the transformative role of emerging technologies in check-in processes, demonstrating how SBD systems, IoT-enabled baggage tracking, mobile solutions, and predictive analytics can collectively improve efficiency, reduce waiting times, and enhance passenger satisfaction.

Importantly, these innovations respond not only to operational pressures but also to heightened safety concerns in the post-pandemic era. Yet significant challenges remain. Implementation depends heavily on passenger trust, usability, and alignment with existing systems. High investment costs, resistance from less tech-savvy passengers, and concerns around data privacy continue to slow adoption.

Future research should therefore explore strategies to build trust, enhance system accessibility across diverse demographics, and reduce implementation costs. Ethical considerations, particularly data privacy and transparency in AI- and IoT-based solutions, also warrant closer attention. Finally, adaptable check-in technologies that can scale across airports of different sizes and demand levels will be essential to ensure long-term success.

4.3 Passenger Comfort and Service

Passenger comfort and service are critical dimensions of the airport experience, extending beyond operational efficiency to influence traveler satisfaction, well-being, and loyalty. Airports and airlines are investing heavily in innovations that combine ergonomic design, ambient environmental controls, personalized services, and responsive customer support to meet increasingly diverse passenger needs. Recent advancements in AI-driven personalization, sensory-friendly spaces, and digital amenities illustrate how technology is reshaping airports into more inclusive and enjoyable environments. This subsection reviews key studies that explore both the technological and human-centered aspects of passenger comfort, highlighting innovations that are redefining service standards in modern airports.

One strand of research emphasizes the role of robotics and AI in enhancing navigation and assistance. Tran et al. [27] introduced a smart interactive guiding robot that integrates advanced sensors, emotional recognition, and a touchscreen interface to assist travelers in large and complex terminals. By combining design thinking with iterative prototyping, the robot was designed to be both technologically advanced and user-friendly, offering real-time updates and proactive support to passengers who appear lost or distressed. This innovation underscores the potential of robotic solutions to reduce stress, improve accessibility, and streamline airport operations.

IoT-enabled systems have also been applied to enhance passenger comfort and safety. At Queen Alia International Airport in Jordan, Nasereddin and Faqir [28] studied automatic security gates with facial recognition and self-service baggage drops, finding that IoT systems improved scalability while addressing passenger concerns about safety and cost. Similarly, Lien et al. [23] highlighted the benefits of self-service technologies in Taiwan, emphasizing their role in improving convenience and efficiency for travelers, particularly in fast-paced travel environments. Collectively, these findings suggest that IoT adoption not only supports operational resilience but also builds passenger confidence in airport services.

Another line of research addresses how broader travel experiences shape perceptions of comfort. Gunay and Gokasar [29] examined the influence of market segmentation on airport access mode choice at Istanbul’s Atatürk Airport, using MNL and ML models to distinguish between domestic and international travelers. Their results reveal how destination type shapes transportation decisions and highlight the importance of understanding passenger heterogeneity in airport planning. Lennon [30] examined the shift from traditional retail to digital commerce, showing how online pre-ordering services, personalized shopping apps, and intelligent kiosks can simultaneously improve passenger convenience and generate new revenue streams for airports. These studies demonstrate that comfort is not limited to physical facilities but extends to travel planning, airport access, and digital interactions.

Advances in ground operations also contribute to passenger satisfaction. Yıldız et al. [31] proposed an automated turnaround control system using video analytics to detect and record ground service actions in real time, significantly reducing turnaround time and minimizing passenger delays. Rajarajeswar et al. [32] applied AI to predict flight delays in the Indian aviation sector, while Cheevachaipimol et al. [33] proposed a hybrid deep learning model to improve delay prediction accuracy. Both studies highlight how predictive tools not only enhance airline efficiency but also contribute to smoother passenger experiences by reducing uncertainty and disruptions. Similarly, De Bosscher et al. [34] used agent-based modeling and simulation to evaluate airport terminal efficiency and passenger satisfaction, offering insights into the scalability of operations in complex environments.

Human-centric and inclusive approaches also feature prominently in recent research. Almarri et al. [35] examined smart security systems at Dubai International Airport, emphasizing the role of ergonomics, emotion, and behavior in shaping passenger experiences. Their findings support a human-centric model for airport security, which integrates technology with an understanding of passenger needs. Rubio-Andrada et al. [36] contributed further nuance by studying passenger perceptions of airport technologies from a gender perspective, revealing that women place greater value on technologies such as Wi-Fi and smartphones in shaping their satisfaction. These insights underscore the importance of tailoring airport technologies to diverse demographic groups.

Taken together, these studies highlight how emerging technologies are reshaping passenger comfort and service through personalization, automation, and inclusivity. AI-driven personalization, IoT-enabled systems, smart robotics, and predictive analytics all contribute to smoother, more engaging airport experiences. However, several challenges remain. Widespread adoption is constrained by concerns over cybersecurity and data privacy, particularly as IoT and AI applications handle increasing amounts of sensitive passenger data. Additionally, while gender-based and human-centric approaches are gaining attention, broader studies across diverse passenger demographics, including people with disabilities or unique accessibility needs, are still lacking. Furthermore, most studies focus on pilot projects or specific airports, leaving questions about scalability and long-term impact largely unanswered.

Future research should therefore aim to develop secure, scalable, and adaptable systems that accommodate a wide range of passenger needs and contexts. Greater collaboration between technology providers, airport authorities, and researchers is necessary to co-create inclusive solutions that balance efficiency with personalization and security. Longitudinal studies would also provide valuable insights into how these technologies affect passenger satisfaction and operational performance over time. By addressing these challenges, airports can ensure that comfort and service innovations contribute not only to enhanced passenger satisfaction but also to greater resilience and competitiveness in an evolving aviation landscape.

4.4 Security Threats in Airports

Security threats in airports remain a central concern, directly affecting passenger safety, operational continuity, and the overall integrity of aviation systems. As threats become increasingly complex, ranging from cyber-attacks to identity fraud and unauthorized access, the demand for innovative, reliable, and adaptive countermeasures has grown. Recent studies illustrate how airports are leveraging automation, AI, IoT, and advanced screening technologies to enhance security. A recurring theme in this literature is the challenge of striking a balance between robust protective measures and the preservation of passenger privacy and convenience.

Research has highlighted both the opportunities and risks associated with automation. Milbredt et al. [37], together with Viaña et al. [38], examined automation in the aviation industry, noting its potential to streamline processes but also its vulnerabilities, such as bypassing security checks and weaknesses in identity verification. Their findings emphasize that while digitalization and AI are critical for Airport 4.0, they must be combined with stringent safeguards to prevent cyber-attacks, minimize maintenance costs, and ensure compliance with privacy standards. These insights underline the importance of adopting a dual strategy: leveraging automation for efficiency while maintaining robust human oversight and adaptive security protocols.

Cybersecurity has emerged as an equally pressing dimension of airport safety. Koroniotis et al. [39] provided a comprehensive review of cybersecurity challenges in smart airports, underscoring the vulnerabilities of IoT networks and the need for resilient defense mechanisms. Similarly, Papagiannopoulos et al. [40] demonstrated how IoT and edge computing can strengthen airport system integrity by optimizing building automation, energy management, environmental monitoring, and physical security. Collectively, these studies reinforce the necessity of developing adaptive cybersecurity strategies that can evolve alongside digital transformation.

Parallel to digital safeguards, AI and computer vision have been increasingly applied to enhance baggage inspection. Saavedra et al. [41] and Kim et al. [42] investigated deep learning for automated threat detection in X-ray screening, achieving improved accuracy and reduced reliance on manual inspection. Wei and Jing [43] further expanded the role of deep learning by exploring its application in multiairport regional markets, showing how predictive analytics can optimize both operations and resource allocation. Meanwhile, Papagiannopoulos et al. [44] and Chen et al. [45] examined 5G integration at airports, including Athens International Airport, emphasizing its potential to enhance both baggage security and operational efficiency.

Advanced screening technologies also offer promising pathways. Ahmed and Schiessl [46] studied millimeter-wave (mmWave) systems for passenger screening, which combine precision detection of concealed items with reduced invasiveness. Their work on multi-static imaging, sparse antenna arrays, and machine learning-enabled processing demonstrates how mmWave can reduce reliance on manual pat-downs, shorten queues, and improve passenger perceptions of privacy and safety.

This technology reflects a broader trend toward solutions that simultaneously strengthen security and improve passenger experience.

Taken together, these studies highlight the pivotal role of emerging technologies in mitigating complex security threats. Advances in automation, AI, IoT, 5G, and mmWave screening are reshaping how airports secure both passengers and infrastructure. However, adoption is not without challenges. The integration of digital and automated systems introduces new vulnerabilities, including cyber risks, high costs, and continuous maintenance requirements. Privacy and ethical concerns surrounding surveillance technologies further complicate implementation. Moreover, the absence of standardized frameworks for deploying and managing these technologies across global airports limits interoperability and scalability.

Future research should focus on developing scalable, standardized frameworks to guide the integration of advanced security technologies across diverse airport contexts. Strengthening cybersecurity measures, particularly for IoT and AI systems, is essential to address evolving digital threats. Research must also prioritize the ethical balance between enhanced security and passenger privacy, especially in the deployment of invasive technologies like mmWave and biometric surveillance. Finally, longitudinal studies on passenger perceptions and the long-term effectiveness of these systems will provide crucial insights into sustaining both safety and trust in increasingly digitized airport environments.

4.5 Baggage Handling in Airports

Efficient baggage handling is a cornerstone of airport operations, directly influencing both passenger satisfaction and overall operational performance. As one of the most visible aspects of the air travel experience, the reliability and speed of luggage systems strongly shape perceptions of airport service quality. In recent years, technological innovations have sought to overcome long-standing challenges of misrouted or delayed baggage by integrating IoT, AI, and robotics into handling processes. Advances range from vision-based systems and smart luggage tags to automated trolleys and sorting mechanisms, offering greater accuracy, speed, and sustainability. This subsection reviews recent contributions that highlight how emerging technologies are transforming baggage handling while addressing key concerns around security, efficiency, and environmental responsibility.

Several studies have focused on system innovations that improve accuracy and minimize mishandling. Lee et al. [47] introduced *CamScale*, a vision-based solution that combines imaging with a viscoelastic mat to predict passenger weight and optimize baggage allocation, particularly for excess-weight management.

Khattab et al. [48] developed an IoT-based luggage tracker prototype that significantly reduced incidences of lost or mishandled baggage, demonstrating the role of real-time monitoring in building passenger trust. Milbredt et al. [37] emphasized the integration of automated systems for baggage screening and handling, showing how automation improves both efficiency and security.

Similarly, Drljača et al. [3] illustrated the importance of contactless baggage processes during the COVID-19 pandemic, reducing physical interaction and reinforcing operational resilience. Complementing these systems, E. Y. C. Wong and W. H. Wong [21] designed reusable IoT-integrated luggage tags that not only improved traceability but also supported ecological sustainability by reducing disposable materials.

IoT integration has been identified as a particularly transformative enabler. Mrňa et al. [49] conducted a comprehensive study on IoT's role in smart airport development, showing how automation and real-time data updates streamlined luggage management and improved overall efficiency. Their work also highlighted challenges in digital readiness, emphasizing that successful IoT adoption requires supportive infrastructure and interoperability across systems. Similarly, Koenig et al. [50] demonstrated that effective baggage management depends on maintenance quality, as system reliability directly reduces delays and improves passenger satisfaction.

Mobile and robotic solutions also contribute to modernizing baggage handling. Ahmed [46] proposed a mobile application that facilitates luggage handling by enabling passengers to manage baggage logistics more conveniently. Ghadzali and Kamarudin [51] introduced automated smart trolleys for baggage transport, pointing to the growing role of robotics in alleviating congestion and improving the passenger experience. These solutions demonstrate that baggage handling improvements extend beyond backend infrastructure to include passenger-facing innovations that reshape the travel journey.

The literature demonstrates that IoT, AI, and robotics are driving significant improvements in baggage handling, enhancing traceability, speed, and sustainability. Technologies such as vision-based systems (e.g., CamScale), IoT-enabled trackers, and smart trolleys illustrate the potential for both operational efficiency and passenger-centric innovation. However, several barriers remain. Cybersecurity vulnerabilities represent a major concern as IoT-enabled systems expand, and high implementation and maintenance costs continue to restrict scalability. Integrating new systems with legacy infrastructure also presents logistical and financial challenges. Moreover, the absence of standardized frameworks for interoperability across airports hinders global adoption. Ethical concerns related to passenger data use and the still-limited application of sustainable practices, beyond initiatives like reusable tags, further constrain progress.

Future research should prioritize the development of secure, standardized IoT frameworks that ensure both cybersecurity and interoperability across diverse airport contexts. Cost-effective adoption strategies are also essential to enable scalability, especially for small- and medium-sized airports. In parallel, researchers should examine the ethical implications of data-driven baggage systems, ensuring privacy protections remain central. Finally, sustainability deserves greater attention through innovations such as recyclable or reusable baggage technologies. Longitudinal studies assessing the long-term impacts of these technologies on both passenger satisfaction and airport efficiency will provide much-needed evidence to guide broader adoption.

4.6 Baggage Trolleys in Airports

The management and utilization of baggage trolleys play a significant role in enhancing both passenger convenience and airport operational efficiency. Traditionally considered a simple service, trolley systems are increasingly being reimagined as part of broader smart airport initiatives, integrating advanced technologies to streamline operations, reduce costs, and improve passenger experiences. This subsection reviews recent studies that illustrate how IoT, robotics, and mobile applications are transforming baggage trolley services.

At Kuala Lumpur International Airport, Ghadzali and Kamarudin [51] evaluated passenger perceptions of the existing trolley system and the potential introduction of automated smart trolleys. These trolleys, equipped with RFID tags, LCD screens, and autonomous navigation capabilities, were generally well received by passengers in questionnaires and in-depth interviews. The findings suggest that travelers are open to adopting automation in trolley services, indicating a readiness to embrace innovations that enhance convenience and reduce wait times.

Singh et al. [52] developed an IoT-based cloud-integrated system to improve security and convenience in trolley management. By equipping trolleys with tracking sensors and linking them to a mobile application, their system enabled real-time monitoring, location updates, and navigation support for passengers. This not only reduced trolley loss but also improved operational oversight and passenger satisfaction, demonstrating the potential of IoT to add transparency and efficiency to an often-overlooked aspect of airport operations.

A more advanced approach was introduced by Pan et al. [53], who designed robotic systems for automated trolley deployment and collection. Using cameras, analytics, and neural networks, these robots detect, approach, and retrieve idle trolleys, reducing reliance on manual labor and ensuring more consistent availability across terminals. Their work highlights how robotics can be applied to operational bottlenecks, aligning with broader trends in airport automation.

Collectively, these studies illustrate how IoT-enabled tracking, automated smart trolleys, and robotic collection systems are redefining baggage trolley management. By improving passenger convenience, reducing manual workload, and ensuring better utilization of resources, such innovations strengthen both service quality and operational resilience. However, challenges persist. High implementation and maintenance costs limit scalability, while integration with existing airport infrastructure remains complex. Passenger trust in automation, particularly regarding safety and data privacy, must also be addressed. Moreover, the absence of standardized frameworks for interoperability across global airports continues to hinder widespread adoption.

Future research should focus on developing cost-effective, scalable, and interoperable trolley management systems that address privacy and security concerns while maintaining user confidence. Longitudinal studies assessing passenger perceptions and operational efficiency over time will be valuable for understanding long-term impacts. By combining technological innovation with human-centric design, baggage trolley systems can evolve from a basic utility to a strategic component of smart airport operations.

4.7 Autonomous Guided Vehicles AGVs

The integration of Autonomous Guided Vehicles (AGVs) into airport operations offers significant potential to enhance efficiency, safety, and sustainability. Airports, as highly structured and controlled environments, provide an ideal testbed for early adoption of such technologies. This subsection reviews recent contributions exploring AGVs in a variety of operational domains, from baggage and cargo handling to taxi operations and passenger transport.

Gosling and Barton [54] highlighted the implications of autonomous vehicles for airport planning, design, and operations, noting that airports as promising early adopters due to their controlled settings and defined traffic flows. Building on this perspective, Wang et al. [55] presented an autonomous trolley collection solution, integrating hardware and software to create a robust and efficient baggage-handling system. Similarly, Pang et al. [56] proposed a dynamic safe-area detection method for hub airports, combining lane and object detection to improve AGV safety and reliability in complex environments.

AGVs are also being applied to airside operations. Zaninotto et al. [57] introduced a human-in-the-loop approach for optimizing taxi operations through autonomous tow trucks, enabling automation while maintaining oversight from Air Traffic Controllers. Their work demonstrates how AGVs can improve efficiency without compromising operational safety. In the cargo domain, Muros Anguita and Díaz Olariaga [58] developed a deep learning model for autonomous cargo transport, outperforming traditional statistical methods by accounting for disruptions such as economic fluctuations and the COVID-19 pandemic. This study illustrates how intelligent AGVs can enhance the resilience and reliability of cargo operations in uncertain environments.

The potential of autonomous vehicles extends beyond airside operations to landside passenger services. Zhang [59] analyzed the impacts of autonomous vehicles on terminal design, parking requirements, and rental car demand, showing how growing reliance on driverless systems could reshape landside planning. Memika and Polat [1] introduced an Autonomous Vehicle equipped with a tablet to transport passengers and their hand luggage across terminals, reducing boarding times and improving passenger flow.

At Dallas Fort Worth International Airport (DFW), Brinkerhoff [60] and Macnaughton [61] documented the integration of autonomous technologies, including passenger shuttles and maintenance robotics, as part of the airport’s strategic modernization efforts. These case studies underscore the importance of stakeholder engagement and infrastructure adaptation in successful AGV deployment. Finally, Chen [62] examined driverless applications in Chinese airports, highlighting the use of AGVs for tugs, baggage carts, shuttles, and even boarding bridges, while pointing to ongoing challenges such as regulatory barriers, cybersecurity vulnerabilities, and the extensive testing required for safe large-scale adoption.

Collectively, these studies reveal that AGVs are reshaping multiple facets of airport operations, including baggage handling, cargo transport, taxi operations, and passenger movement. By reducing manual labor, improving efficiency, and supporting sustainability objectives, AGVs represent a transformative tool for smart airport development. However, several barriers remain. Integrating AGVs requires substantial infrastructure adaptation, reliable safety systems, and significant capital investment. Concerns over cybersecurity, regulatory approval, and scalability further constrain widespread deployment.

Future research should focus on developing cost-effective and scalable AGV solutions that are adaptable across different airport environments. Advances in safety technologies, including real-time obstacle detection and predictive analytics, will be essential to ensure secure operations. In parallel, collaborative efforts between airports, regulators, and technology developers are needed to establish standardized frameworks that address interoperability, cybersecurity, and regulatory compliance. Long-term studies assessing the operational, financial, and environmental impacts of AGVs will also provide critical insights for guiding their integration into global airport ecosystems.

4.8 Summary of Literature Review of Airport Applications

Fig. 14 provides a comprehensive visualization of the primary research domains in airport applications. The bubble sizes correspond to the number of publications in each domain, highlighting well-established areas such as Security Check, Passenger Service, and Check-In. These domains dominate the literature due to their critical roles in improving passenger safety, service quality, and operational efficiency. Within these, subtopics like biometrics, AI, and IoT are central to the modernization of airport processes and have been extensively studied as key enablers of smart airport transformation.

In contrast, emerging areas such as Baggage Trolleys and Autonomous Guided Vehicles (AGVs) appear with smaller bubble sizes, indicating limited but growing research interest. Despite the smaller body of work, these domains are strategically important, as automation in baggage and ground operations offers opportunities to significantly reduce manual labor, improve logistics, and enhance sustainability. Other niche innovations, including Smart Glass and Boarding 4.0, categorized under Passenger Service and Passenger Movement, highlight ongoing efforts to optimize passenger comfort and streamline flow through digital and sensor-driven tools.

This summary underscores both the diversity and imbalance of research within airport applications. Established areas such as security and passenger service continue to attract significant attention, while other critical components of airport operations, such as logistics automation, trolley systems, and AGVs, remain underexplored. By mapping these areas visually, the literature review highlights not only dominant themes but also clear gaps that warrant deeper scholarly attention. Future studies should address these underrepresented fields to create a more holistic body of knowledge, aligning academic research with the full spectrum of technological innovation occurring in practice.

Beyond distribution trends, the technologies mapped in Fig. 14 demonstrate tangible applicability in real-world airport contexts. For example, check-in systems increasingly employ self-service kiosks, AI-enabled scanners, and IoT solutions to reduce congestion and accelerate processing. Security operations leverage biometrics, facial analytics, and deep learning to improve detection accuracy while maintaining passenger convenience. Passenger movement is being optimized through mobile applications, AI-driven flow prediction, and IoT-enabled boarding systems that reduce delays and improve circulation. Passenger services benefit from personalized digital tools such as smart glasses and responsive IoT platforms that elevate comfort and inclusivity. Baggage handling and trolleys integrate robotics, sensor-enabled tracking, and automated management to increase reliability and transparency. Finally, AGVs are being deployed for both baggage and cargo transport, reducing reliance on manual labor and improving operational safety.

These examples show that the domains highlighted in Fig. 14 represent not only areas of academic inquiry but also practical solutions actively reshaping airport operations. By consolidating established research areas and identifying emerging opportunities, this review offers a roadmap that bridges scholarly insights with real-world applications, encouraging both researchers and practitioners to focus on underrepresented but high-impact domains.

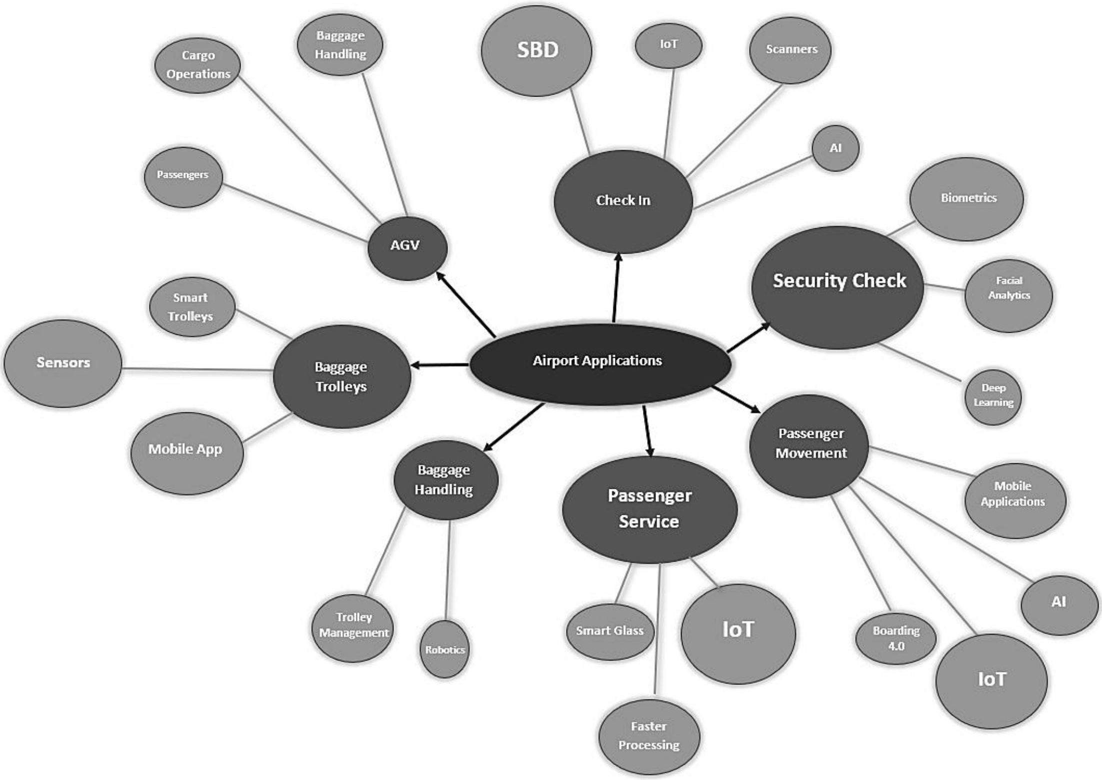

Fig. 14 Summary of Literature Review

5. Conclusion and Future Directions

This study systematically examined how emerging technologies, particularly IoT, AI, and ML, are transforming airport operations and enhancing passenger experiences. Using a PRISMA-guided systematic review of 51 peer-reviewed publications, complemented by bibliometric and content analyses, the study identified patterns of technological application, global research trends, and operational implications across key domains such as passenger navigation, baggage handling, cargo management, and security monitoring. Collectively, the findings provide a comprehensive understanding of how digital transformation is reshaping airports into data-driven, intelligent, and passenger-centric ecosystems.

The conclusions drawn from this review emphasize the major achievements, ongoing challenges, and future priorities for both research and practice:

(1) Operational efficiency and passenger experience: IoT, AI, and ML have significantly improved airport efficiency and service quality through real-time analytics, predictive flow management, and IoT-enabled tracking. However, AGVs remain underutilized, representing untapped potential in logistics automation.

(2) Global research and collaboration: A post-pandemic surge in digitalization, led by the United States, Taiwan, and Spain, highlights the need for broader cross-regional collaboration and data sharing to accelerate smart airport innovation.

(3) Research gaps in AI and logistics automation: While most studies focus on security and passenger services, limited work addresses AI-based decision support, cargo automation, or emergency management, areas requiring deeper empirical validation.

(4) Implementation barriers: High costs, integration complexity, workforce adaptation, and cybersecurity vulnerabilities continue to hinder large-scale deployment, demanding coordinated policies and joint initiatives among stakeholders.

(5) Sustainability and ethics: The transition toward smart airports must integrate sustainability, equity, and data ethics, leveraging AI for carbon monitoring, IoT for energy optimization, and blockchain for accountability.

Although rigorous, this review is limited to peer-reviewed literature up to February 2024 and excludes industry reports that may capture emerging practices.

Looking ahead, researchers and practitioners must collaborate to transform conceptual insights into scalable, inclusive, and sustainable airport solutions. The digitalization of airports is not merely a technological transition but a systemic reimagining of how safety, efficiency, and passenger well-being intersect. By aligning innovation with ethical and policy frameworks, the aviation sector can realize a new generation of smart airports that are resilient, sustainable, and centered on human experience, defining the future of global mobility.

Conflicts of Interest

The authors declare no conflict of interest.

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