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Charting the Trajectory of Artificial Intelligence Agents in Air Traffic Control

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Abstract

The aim of the study was to chart the evolution and the current research landscape of artificial intelligence (AI) agents within the domain of air traffic control. Using bibliometric analysis, the study identified major research trends and gaps and provided a consolidated reference for researchers. The analysis included 58 publications retrieved from the Web of Science Core Collection. The findings showed that the earliest publication in the dataset appeared in 1998 and that research output increased noticeably after 2022. Publication output peaked in 2025, with 16 articles, indicating growing scholarly interest in AI agents for air traffic control. Citation analysis identified Agogino and Tumer's (2012) article as the most influential publication, with 68 citations. The article introduced a multi-agent approach to air traffic flow management. Brittain and Wei's (2022) article ranked second, with 54 citations, highlighting the increasing role of reinforcement learning. At the country level, the United States had the highest total citation count, followed by China, France, England, and Spain. By examining AI agents as a distinct research topic, the study provides a focused overview of an underexplored area relevant to researchers, practitioners, and regulators.

Introduction

Global aviation relies on air traffic controllers whose cognitive performance is essential to operational efficiency and safety. As traffic demand increases, maintaining this performance becomes more challenging. According to data released by the International Air Transport Association (IATA) (2026), the year 2025 witnessed record-high global aviation demand with a 5.3% increase in total revenue passenger kilometers (RPKs) and a 5.2% rise in capacity. International traffic increased by 7.1%, while the global passenger load factor reached a record 83.6% (IATA, 2026). Rising traffic demand may increase operational complexity and controller workload across routes and sectors. To support human performance and maintain operational safety, the aviation sector is increasingly exploring artificial intelligence (AI)-based solutions.

This growing interest is also reflected in industry investment. The integration of AI into aviation has attracted substantial investment and accelerated the shift toward advanced automation. The global market for AI in aviation was valued at approximately USD 7.45 billion in 2025. It is projected to reach USD 36.68 billion by 2034, corresponding to a compound annual growth rate of 19.48% (Fortune Business Insights, 2026). This projected growth reflects increasing efforts to improve operational efficiency, including the use of algorithms in air traffic management (ATM). AI-based architectures may support ATM capacity through real-time data processing, predictive traffic modeling, and proactive conflict resolution.

AI has become an important part of the air traffic control modernization agenda. This development is supported by the Single European Sky ATM Research (SESAR) program, a major European initiative for ATM modernization. Recent studies show that SESAR projects increasingly examine the integration of AI and machine learning into key ATM functions (Çeken, 2025; Tuncal, 2025). Autonomous AI agents are increasingly being investigated as tools for reducing controller workload, improving safety, and optimizing traffic flow across different airspace systems (Ali et al., 2025; Brittain & Wei, 2019; Brittain & Wei, 2022; Mohamed et al., 2026; Wang et al., 2019). Furthermore, the operational integration of these autonomous agents relies heavily on several related socio-technical concepts. Human-AI teaming refers to collaboration between human operators and intelligent systems in the management of safety-critical tasks (Kirwan, 2025). Explainable AI (XAI) aims to make the reasoning of complex learning algorithms more transparent and

verifiable for human controllers. This transparency may support appropriate trust in AI-based systems (Degas et al., 2022; Mohamed et al., 2026).

The growth of this research agenda has attracted increasing attention from the bibliometric community. In recent years, many mapping studies have explored the landscape of AI in aviation and transportation. Chen et al. (2023) mapped the knowledge diffusion and network characteristics of AI applications specifically in traffic flow prediction. Demir (2026) analyzed a decade of literature to highlight the integration of autonomous systems and the critical need for sustainable, ethical AI. Demir et al. (2024) reviewed AI's role in aviation safety, identifying key trends in accident analysis and pilot behavior. Similarly, Ertekin et al. (2024) mapped scientific collaborations to underscore the central role of machine learning in improving both safety and operational efficiency. Karakavuz (2025) categorized the intellectual structure of the air transportation sector, distinguishing between core foundations like deep learning and driving themes such as air traffic control and unmanned aerial vehicles. Lopes et al. (2025) provided a comprehensive mapping that culminated in a novel conceptual framework spanning human factors, environmental initiatives, and flight operations. Sadou and Njoya (2023) identified five dominant research clusters in air transport, revealing that prediction and optimization account for the vast majority of current studies. Şahin (2024) evaluated recent publication metrics, demonstrating that the performance-enhancing impact of AI has become the primary focus of aviation literature. Despite this growing literature, a structural gap remains. Most of these studies treat AI in aviation or transportation as a broad, aggregate category. With the exception of Sadou and Njoya (2023), who briefly mention the "agent" concept without incorporating it into their analytical framework, existing mapping studies largely overlook this specific domain. The AI agent paradigm relies on unique theoretical features, such as autonomous perception, goal-directed reasoning, reinforcement learning, and multi-agent coordination. Agent-based approaches are fundamentally different from conventional machine learning (Abou Ali et al., 2025). They have distinct operational logic, safety/security implications, and regulatory needs (Abou Ali et al., 2025; Adabara et al., 2025; Biswas & Sarkar, 2026; Raza et al., 2025). Today, these systems are moving from academic simulations to real-world applications. A clear understanding of the research community developing these systems is therefore needed. Mapping its collaborative architecture, thematic clusters, and emerging frontiers is essential for coherent scientific planning and governance. The existing literature lacks a systematic bibliometric evaluation dedicated to the AI agent paradigm.

The study addresses the gap through a focused bibliometric analysis of research at the intersection of air traffic control and AI agents. The findings provide a structured overview of an emerging and underexplored field for researchers, practitioners, and regulators. To establish a theoretical foundation for the analysis, the study initially reviews the extant literature to conceptualize the core elements.

Literature Review

AI agents and conceptual foundations

The transition from specialized rule-based programs to dynamic autonomous systems has brought the concept of the AI agent to the forefront of contemporary technological research (Qu et al., 2025). Broadly defined, an AI agent is a computational system capable of autonomously perceiving its environment, reasoning over contextual information, and taking goal-directed actions without continuous human intervention (Krishnan, 2025; Sapkota et al., 2025). The concept is based on the perception-action loop, in which an agent receives information from its environment and responds through appropriate actions. Modern AI agents may also integrate large language models (LLMs) and large image models (LIMs). These models can support complex reasoning, decision-making, and planning (Sapkota et al., 2025). The concept of "agency" in this context refers to the degree to which an AI system can directly impact the world and achieve long-horizon goals with minimal external specification on how to do so (Chan et al., 2024).

Modern AI agents rely on several fundamental capabilities, including perception, reasoning, memory, and tool use. Perception mechanisms form the interface between an agent and its environment, allowing the system to process unstructured inputs such as text and visual data. After receiving input, the reasoning and decision-making modules evaluate available alternatives and select an appropriate action. This process may draw on the inference capabilities of foundation models (Krishnan, 2025). Furthermore, because foundational models inherently suffer from constraints like static knowledge and limited computational precision, agents are augmented with "tools" or external application programming interfaces (APIs). These tools enable agents to execute operations such as web searches, code interpretation, or calendar management, fundamentally transforming passive language models into interactive problem-solvers (Qu et al., 2025; Sapkota et al., 2025). To perform these operations, agents rely on supporting structures known as scaffolding. This concept involves

structural methodologies like strategic prompting, systematic planning routines, and memory frameworks that help them achieve complex goals (Chan et al., 2024).

Memory enables AI agents to preserve context and learn across extended interactions (Sapkota et al., 2025). Agentic memory systems are generally categorized into short-term (or working) memory, which maintains task-relevant information during active execution, and long-term (or parametric and episodic) memory, which stores interaction histories, factual knowledge, and procedural skills for future retrieval (Krishnan, 2025; Qu et al., 2025). Without these memory architectures, agents would be relegated to stateless, single-session interactions; with them, agents can reflect on past actions, recognize patterns, and iteratively refine their behaviors through self-evaluation and feedback loops (Nisa et al., 2025). Combined with dynamic memory access, this reflective capability can help agents recover from errors and maintain coherence during complex multi-step tasks (Sapkota et al., 2025).

As the complexity of tasks escalates, the paradigm shifts from isolated, single-agent systems to the broader concept of "Agentic AI". While an AI agent typically refers to an individual entity executing a narrowly defined task with external tools, Agentic AI refers to broader collaborative and distributed systems (Jiang et al., 2025; Sapkota et al., 2025). In an Agentic AI framework, a complex goal is dynamically decomposed into smaller sub-tasks, which are then assigned to an ensemble of specialized sub-agents acting cooperatively (Sapkota et al., 2025; Zhang et al., 2026). This orchestration is managed by meta-agents or central controllers that regulate inter-agent communication, resolve conflicts, and ensure that the collective actions align with the overarching objective (Sapkota et al., 2025). Agentic AI encapsulates not just individual autonomy, but system-level social ability, negotiation, and emergent intelligence, moving beyond basic reactive automation toward coordinated, proactive problem-solving (Nisa et al., 2025; Sapkota et al., 2025). The classification and evaluation of AI agents and Agentic AI systems are fundamentally tied to their levels of autonomy and goal complexity (Kasirzadeh & Gabriel, 2025). Autonomy, originating conceptually from philosophical notions of negative and positive freedom (Berlin, 2017), measures the capacity of the AI to perform actions without human direction or control. This spectrum ranges from restricted autonomy, where humans closely supervise automated tasks, to full autonomy, where systems operate independently in dynamic environments. Similarly, the sophistication of an agent is defined by its goal complexity, representing the shift from simple stimulus-response behaviors to the unbounded ability to generate, interpret, and decompose underspecified objectives (Kasirzadeh & Gabriel, 2025). Together, these concepts describe the transition from automated software tools to reasoning-capable, adaptable, and collaborative digital systems (Krishnan, 2025).

AI agents in air traffic control

Modernizing air traffic control systems is an important challenge in contemporary aviation, particularly because of growing traffic demand and the integration of new aerial vehicles. To manage this growing complexity, the aviation sector is increasingly examining AI-based methods that may reduce controller workload and support the safe and efficient management of aircraft. In this domain, automated decision-support systems and intelligent algorithms are generally classified into four primary categories based on their underlying operational logic: 1) Rule-based agents, 2) Optimization agents, 3) Reinforcement learning agents, and 4) Hybrid agents (Mohamed et al., 2026). Rule-based agents use predefined expert logic, decision trees, and heuristics to generate clearance recommendations. Although these agents are generally interpretable and consistent with standard operating procedures, they may be too rigid for unexpected or highly complex traffic situations. The Hawk agent is an example of this approach. It uses a decision tree to apply safety and conflict-resolution rules derived from expert interviews. Optimization agents, conversely, plan trajectories dynamically by treating the airspace as a mathematical problem subject to hard constraints, such as sector containment and safe separation limits. The Falcon agent illustrates the optimization approach. It uses algorithmic search to recalculate efficient trajectories while maintaining safety constraints (Carvell, Thomas, et al., 2026). Reinforcement learning agents use a different approach based on repeated interaction with an environment and feedback from a reward function. Hybrid agents combine different architectures. Their purpose is to integrate the safety constraints of explicit rules with the adaptability of machine-learning methods (Mohamed et al., 2026).

Within the realm of learning algorithms, reinforcement learning and multi-agent reinforcement learning (MARL) have received increasing research attention for resolving both local conflict detection and broader demand-capacity balancing problems. In highly dynamic en-route sectors, individual aircraft or traffic management units are modeled as autonomous agents that must navigate stochastic environments. For instance, the K-Control Actor-Critic algorithm processes two-dimensional continuous action spaces to generate precise heading changes, effectively resolving potential collisions while minimizing the required

number of tactical interventions (Wang et al., 2019). When scaled to high-density airspaces with multiple intersecting routes, deep distributed MARL (DD-MARL) frameworks, utilizing simulators like BlueSky, have successfully demonstrated the ability to decentralize policy execution and resolve nearly all conflicts autonomously (Brittain & Wei, 2019). The success of these agents mirrors the breakthroughs seen in other complex AI domains, such as DeepMind's AlphaGo (Silver et al., 2016). To comprehensively prevent MARL policies from overfitting to specific, rigid airspace geometries, researchers have introduced polar state representations and transformer-based encoder architectures; by encoding ownship and intruder data as computational tokens, these models adapt robustly to unstructured airspaces and varying intersection angles, successfully outputting speed advisories that prevent near mid-air collisions (Aziz & Wei, 2026).

As these multi-agent systems evolve, they must accommodate the operational realities of the aviation industry, which involves competing airlines and heterogeneous objectives. Advanced frameworks, such as the Multi-Agent Autonomous Separation Assurance (MAASA) model, specifically address heterogeneous environments where agents optimize entirely different, often proprietary, reward functions. By employing intention-learning mechanisms, these agents can infer the planned maneuvers of intruder aircraft without requiring explicit knowledge of their underlying algorithms, facilitating cooperation across diverse commercial entities (Brittain & Wei, 2022). This cooperative capability reflects earlier theoretical models of principled negotiation, wherein intelligent agents utilize overlapping declarative functions to optimize flight operations through mutually beneficial trajectory proposals (Wangermann & Stengel, 1998). In the context of the ground holding problem and air holding problem, the careful design of reward functions is equally critical; RL models that balance safety separation imperatives with financial fairness among airlines have proven highly effective in mimicking human traffic manager decisions (Cruciol et al., 2013). The use of difference rewards may reduce localized congestion more effectively than simple global reward signals (Agogino & Tumer, 2012). To manage the immense computational complexity of these tasks, hierarchical MARL schemes dynamically partition state and action spaces into multiple levels of abstraction, allowing agents to efficiently adhere to airspace capacity constraints while reducing overarching operational delays (Spatharis et al., 2023).

Despite their potential, unconstrained RL and MARL policies may generate outputs that are inconsistent with operational requirements. Standard RL agents tend to issue high-frequency, micro-adjustments that induce severe cognitive load on pilots and congest radio communication frequencies. To address this problem, online action-stacking can be used as an inference-time wrapper. It combines multiple primitive actions into a single clearance that is more consistent with operational practice (Carvell, De Ath, et al., 2026). Furthermore, to ensure that the strategic preferences of AI agents align with expert behavior, intelligent interactive conflict solvers have been deployed to digitally capture human demonstrations during separation tasks; by integrating these human-provided trajectory change points into the reward signal, RL agents learn to issue resolutions that closely mirror human cognitive strategies (Tran et al., 2020). Understanding the behavioral dynamics of these interactions is equally critical. Recent large-scale experimental evidence highlights how AI fundamentally reshapes teamwork. Compared to traditional human-human pairs, collaboration with AI agents fosters highly task-oriented communication and significantly increases task delegation. This dynamic enhances overall productivity and specific quality metrics, although it can introduce a risk of output homogeneity (Ju & Aral, 2025). Within complex operational environments, these underlying mechanisms of delegation and task-orientation become vital for managing human cognitive capacity.

These operational requirements have increased interest in human-AI teaming and human-AI hybrid systems. A human-AI hybrid combines human judgment, ethical oversight, and situational adaptability with the computational capabilities of AI (Ali et al., 2025). Regulatory frameworks, such as those established by the European Union Aviation Safety Agency (EASA), classify these interactions into distinct levels of AI autonomy, ranging from simple machine learning support to highly collaborative agents that can dynamically negotiate tasks with human operators. The Horizon Europe HAIKU project has examined these concepts through several applied case studies. The FOCUS (Flight Operational Companion for Unexpected Situations) system acts as an intelligent assistant in the cockpit, utilizing psychophysiological sensors and eye-tracking to detect a pilot's startle response during sudden emergencies, dynamically highlighting critical flight displays to accelerate the recovery of situational awareness. The COMBI agent serves as a collaborative teammate for flight crews, instantly computing optimal diversion airports during severe weather events by balancing fuel constraints and passenger connections, reducing a 15-minute manual task to less than a minute. Similarly, the Intelligent Sequence Assistant (ISA) operates in air traffic control towers, using neural networks to optimize runway utilization by dynamically resequencing arriving and departing aircraft based on live radar data (Kirwan, 2025).

The operational viability of human-AI teaming is intrinsically dependent on the systemic transparency of the AI, elevating the necessity of XAI. For controllers to rely appropriately on AI-supported tactical recommendations, the system must communicate the basis of its decisions clearly. Comprehensive XAI models in aviation utilize a Descriptive, Predictive, and Prescriptive (DPP) framework. Descriptive XAI elucidates the algorithmic logic behind a specific decision; predictive XAI anticipates how changes to inputs will affect future trajectories; and prescriptive XAI identifies systemic flaws and suggests actionable remedies to mitigate errors (Degas et al., 2022). While traditional rule-based systems inherently possess high interpretability through auditable decision trees, complex deep reinforcement learning agents require sophisticated post-hoc analytical techniques. The mathematical computation of Shapley values allows developers to isolate and visualize the specific state features that drive a neural network's clearance recommendation. For instance, they can identify how the conflicting altitude of an intruder affects the outcome. This process establishes a verifiable logic for decisions that would otherwise remain opaque (Mohamed et al., 2026). Additionally, sophisticated visual analytics tools are heavily integrated into MARL pipelines to render the dense decision-making outputs interpretable, allowing human supervisors to visually inspect how large swarms of agents distribute delays and resolve localized demand-capacity hotspots (Kravaris et al., 2023).

Before any intelligent agent can be safely deployed, it must undergo exhaustive human-in-the-loop testing within simulated environments that faithfully replicate real-world uncertainties. Within the UK's Project Bluebird, researchers have engineered BluebirdDT, a probabilistic digital twin of the London Area Control Centre's en-route airspace. By fusing live surveillance feeds, historic flight plans, meteorological data, and physics-informed machine learning models, this digital twin accurately models both epistemic and aleatoric uncertainties, such as wind speed variability and pilot response delays (Pepper et al., 2026). Within this simulated environment, Agent Mallard operates as a forward-planning, rule-based agent designed for systemized airspace. Agent Mallard follows a 'simulate before you commit' approach. Using a depth-limited backtracking search, the agent simulates each proposed tactical resolution in the digital twin before implementation to assess whether it could create secondary conflicts (Kent et al., 2026). Furthermore, to rigorously validate these agents, they are exposed to the exact regulator-certified formative and summative assessment scenarios utilized in actual human controller training curricula, ensuring that machine competence meets strict operational safety standards (Carvell, Thomas, et al., 2026).

The successful integration of autonomous agents into air traffic control extends beyond pure technical validation; it is profoundly influenced by public perception, algorithm aversion, and the complex psychological dynamics of trust and blame attribution. Empirical analyses comparing autonomous vehicles and air traffic control environments reveal a pronounced cognitive bias among the general public, who tend to attribute significantly greater foundational trust to human operators while disproportionately assigning blame to AI agents for equivalent operational errors. Notably, within an AI trainee model configuration, the human supervisor often absorbs substantially more blame for failing to intervene than the AI itself, highlighting the complex socio-legal nuances of shared responsibility in human-AI interactions (Mei et al., 2025). The modernization of air traffic control is a multidisciplinary process. It requires reliable multi-agent learning, transparent XAI interfaces, human-in-the-loop validation, and careful consideration of human-machine interaction.

Method

The study employs a bibliometric analysis to map the intellectual structure, thematic evolution, and collaborative architecture of research on AI agents in air traffic control. Bibliometric analysis is a well-established quantitative methodology that enables systematic examination of scientific literature through the measurement of publication outputs, citation patterns, co-authorship networks, and keyword co-occurrence structures (Donthu et al., 2021). Its application in the present context is particularly appropriate given the interdisciplinary and rapidly evolving nature of the field, where large volumes of dispersed publications cannot be adequately synthesized through conventional narrative review.

Research purpose

The study aims to provide a comprehensive bibliometric account of scholarly work at the intersection of AI agents and air traffic control, with the goal of identifying key publication trends, influential contributors, leading countries, and emerging thematic clusters. The findings are intended to serve as a structured reference for researchers entering this domain and to inform research prioritization efforts by highlighting areas of intellectual concentration as well as gaps that remain underexplored. Specifically, the study seeks to answer the following research questions:

1. How has the annual volume of publications on AI agents in air traffic control evolved over time, and what temporal patterns characterize the field's development?
2. What are the collaboration structures among authors, and which scholars occupy central positions within the co-authorship network?
3. Which publications and countries have accumulated the highest citation counts, and what do these patterns reveal about the field's intellectual foundations and geographic distribution?
4. Which authors share the strongest bibliographic similarities, and what research clusters emerge from bibliometric coupling analysis?
5. Which keywords appear most frequently across the corpus, and what thematic clusters and conceptual relationships do co-occurrence analyses reveal?

Data collection

Data were retrieved from the Web of Science (WoS) Core Collection, which is widely regarded as one of the most comprehensive and rigorously curated multidisciplinary scientific databases and is extensively employed in bibliometric research (Mongeon & Paul-Hus, 2016). The search was conducted on June 7, 2026, using the following query string applied to topic fields (title, abstract, author keywords, and Keywords Plus): TS=("air traffic control*" OR "air traffic management" OR "air traffic controller*") AND TS=("artificial intelligence" OR "machine learning" OR "reinforcement learning") AND TS=("AI agent*" OR "MARL" OR "multi-agent*" OR "multiagent*" OR "intelligent agent*" OR agent). These specific keywords and search criteria were systematically derived from a preliminary literature review and expert consultations to align directly with the aim of the study. No restriction was initially imposed on WoS categories, allowing the search to capture the interdisciplinary nature of research on AI agents in air traffic control. The retrieved records were distributed across several WoS categories, predominantly including Computer Science, Artificial Intelligence; Engineering, Aerospace; Engineering, Electrical & Electronic; Transportation Science & Technology; Automation & Control Systems; Computer Science, Interdisciplinary Applications; Computer Science, Theory & Methods; and Operations Research & Management Science. The records were covered by the Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Emerging Sources Citation Index (ESCI), and Conference Proceedings Citation Index. The results were subsequently restricted to the document type "Article", and all publications retained for analysis were in English. The initial search of the WoS Core Collection identified 101 records. The results were first restricted by document type to articles, reducing the dataset to 65 records. The titles and abstracts of these records were then screened for relevance to the scope of the study. Following this relevance assessment, 7 records were excluded, resulting in a final dataset of 58 publications included in the bibliometric analysis.

Data analysis

The exported dataset was analyzed using VOSviewer (version 1.6.20), a widely adopted software tool for constructing and visualizing bibliometric networks (van Eck & Waltman, 2010). Prior to analysis, the dataset was cleaned to resolve author name ambiguities and standardize keyword variants. Five analytical procedures were applied in alignment with the research questions.

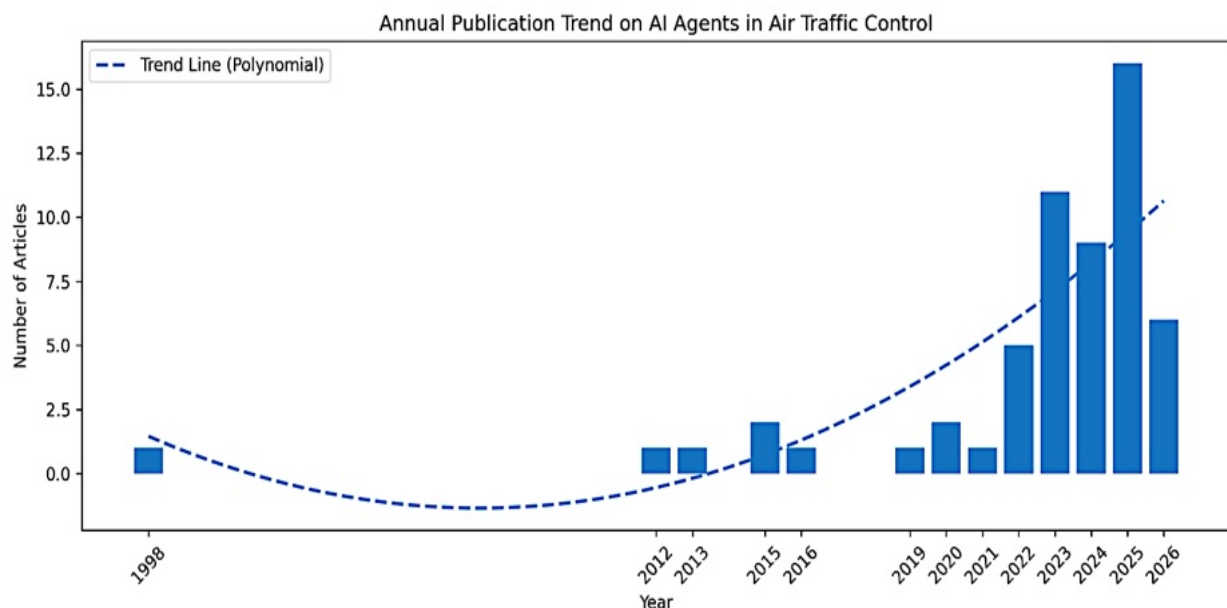
Annual publication output was examined through descriptive statistics to characterize temporal trends in research activity. Co-authorship network analysis was conducted at the author level to map collaborative structures and identify central actors within the field, with a minimum threshold of one publication and one citation per author. Citation analysis was performed at both the article and country levels to identify the most influential contributions and assess the geographic distribution of research impact; the minimum threshold was set to one publication and one citation per unit of analysis. Bibliographic coupling analysis was conducted at the author level to identify intellectual similarities among researchers based on shared reference lists, applying the same minimum threshold criteria. Keyword co-occurrence analysis was performed on author-assigned keywords, with a minimum occurrence threshold of two, to identify dominant thematic clusters and trace conceptual linkages across the corpus. All network maps were generated using the VOS layout algorithm, with cluster assignments determined by the modularity-based community detection method implemented within VOSviewer.

Findings

Annual distribution of articles

A total of 58 publications related to AI agents in air traffic control, published between 1998 and June 2026, were analyzed. Figure 1 presents the annual distribution of these publications. Although only sporadic publications were observed during the early years of the field, a noticeable increase in research output emerged after 2022. The publication gap between the 1998 and 2012 studies could be linked to the technological limitations of early AI models and the conservative nature of the aviation industry. The number of publications reached its highest level in 2025 ($n = 16$), indicating substantial growth in scholarly attention toward the application of AI agents in air traffic control environments. The upward trajectory observed in recent years suggests that the integration of advanced AI technologies, including intelligent agents, multi-agent systems, and reinforcement learning approaches, has become an increasingly prominent research topic within the ATM domain.

Figure 1. Distribution of articles per year



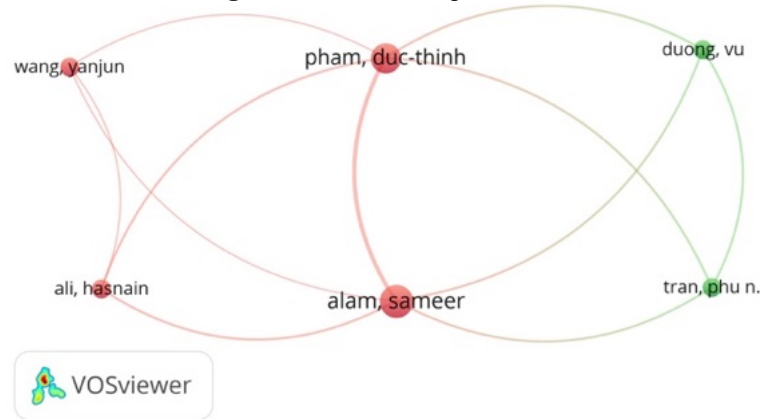
Co-authorship analysis of authors

Co-authorship analysis is one of the most widely used bibliometric techniques for examining the intellectual and social structure of a research field by identifying collaboration patterns among scholars (Melin & Persson, 1996; van Eck & Waltman, 2010). In the study, author collaboration networks were analyzed using VOSviewer. The inclusion thresholds were set at one publication and one citation per author. Based on these threshold values, six authors met the inclusion criteria and were incorporated into the co-authorship network.

As illustrated in Figure 2, the network included six authors and 11 collaboration links, with a total link strength of 22. The six authors formed two clusters. The relatively small size of the network indicates that research on AI agents in air traffic control remains an emerging and highly specialized domain, with a limited number of recurring collaborations among scholars. Similar patterns are commonly observed in developing research areas where the knowledge base is still forming and the number of active contributors remains relatively low (Donthu et al., 2021). The largest collaboration cluster is composed of Pham Duc-Thinh, Sameer Alam, Yanjun Wang, and Hasnain Ali, who demonstrate the highest degree of interconnectedness within the network. Among these authors, Pham Duc-Thinh and Sameer Alam occupy central positions, maintaining collaborative ties with authors from both clusters and thereby functioning as important connectors within the network structure. According to social network theory, such central actors facilitate knowledge diffusion and contribute to the integration of otherwise fragmented research communities (Borgatti & Halgin, 2011). The second cluster consists of Vu Duong and Phu N. Tran, whose collaboration appears relatively isolated from the broader network. Although these authors maintain strong intra-cluster collaboration, their connections with the remaining authors are comparatively limited. This finding suggests the existence of geographically or institutionally concentrated research groups that operate with limited interaction across the broader scientific community.

The co-authorship structure reveals a fragmented but gradually developing collaboration landscape. The presence of only two small clusters and a limited number of authors indicates that scholarly collaboration in the field of AI agents for air traffic control is still at an early stage of development.

Figure 2. Co-authorship network of authors



Citation-based findings

Citation analysis is a widely used bibliometric technique for identifying the most influential studies within a research field and assessing their intellectual impact on subsequent research (Bornmann & Daniel, 2008). In the study, citation performance was evaluated for 58 publications, and the ten most cited articles are presented in Table 1.

The most cited publication was Agogino and Tumer (2012) with 68 citations, introducing a multi-agent approach for air traffic flow management. The study is considered one of the foundational contributions demonstrating how autonomous agents can collaboratively manage traffic flow and reduce congestion. The second most cited article, Brittain and Wei (2022) with 54 citations, focused on scalable autonomous separation assurance using heterogeneous MARL, highlighting the growing role of reinforcement learning in air traffic control applications. Similarly, Cruciol et al. (2013) and Tran et al. (2020) contributed to the literature by addressing learning-based traffic flow control and conflict resolution problems, receiving 37 and 34 citations, respectively.

Several highly cited studies, including Wang et al. (2019), Pham et al. (2022), and Spatharis et al. (2023), focused on reinforcement learning-based conflict detection, conflict resolution, and ATM optimization. In contrast, the study by Wangermann and Stengel (1998) represents one of the earliest publications in the dataset and examines negotiation mechanisms between intelligent agents for ATM. More recent publications, such as Chen et al. (2024) and Kravaris et al. (2023), have already attracted considerable citation attention despite their recent publication dates, reflecting the increasing scholarly interest in XAI, urban air mobility, and MARL applications.

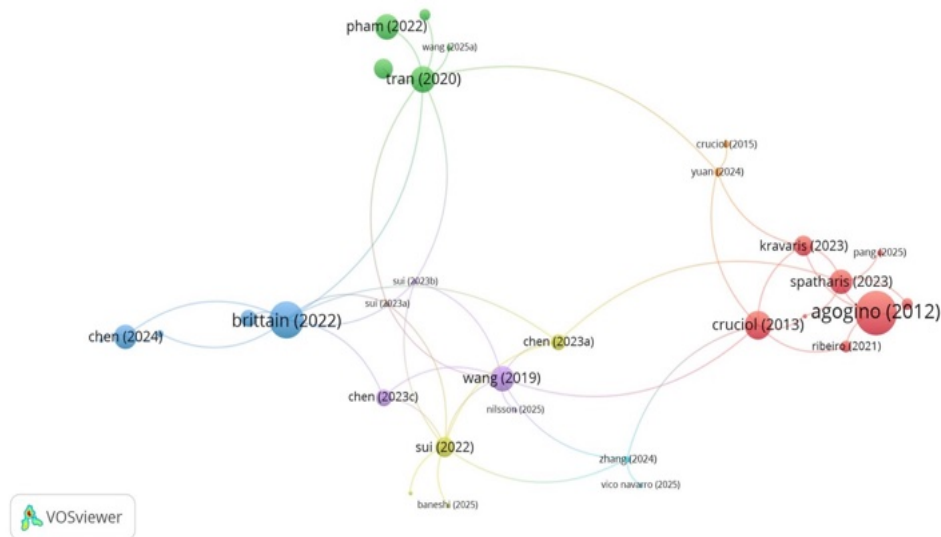
The most influential publications in the field predominantly focus on multi-agent systems, reinforcement learning, conflict management, and autonomous decision-making, indicating that these themes constitute the intellectual foundation of research on AI agents in air traffic control.

Table 1. Most cited articles on AI agents for air traffic control

Ranking	Article	Citations
1	Agogino & Tumer (2012)	68
2	Brittain & Wei (2022)	54
3	Cruciol et al. (2013)	37
4	Tran et al. (2020)	34
5	Wang et al. (2019)	33
6	Pham et al. (2022)	32
7	Chen et al. (2024)	30
8	Spatharis et al. (2023)	30
9	Wangermann & Stengel (1998)	24
10	Kravaris et al. (2023)	23

A citation network analysis was conducted to identify the intellectual structure of the literature on AI agents in air traffic control. The minimum threshold was set to one publication and one citation. Based on these criteria, 31 interconnected publications were included in the network visualization. The resulting citation network consisted of 8 clusters, 49 links, and several highly connected publications that form the intellectual core of the field as shown in Figure 3. Among the analyzed publications, Agogino and Tumer (2012) emerged as the most influential study, occupying the most central position within the citation network. Other prominent publications include Brittain and Wei (2022), Cruciol et al. (2013), Tran et al. (2020), Pham et al. (2022), Wang et al. (2019), and Spatharis et al. (2023). These studies exhibit strong citation connections and constitute the primary knowledge base upon which subsequent research has been developed.

Figure 3. Citation network of articles

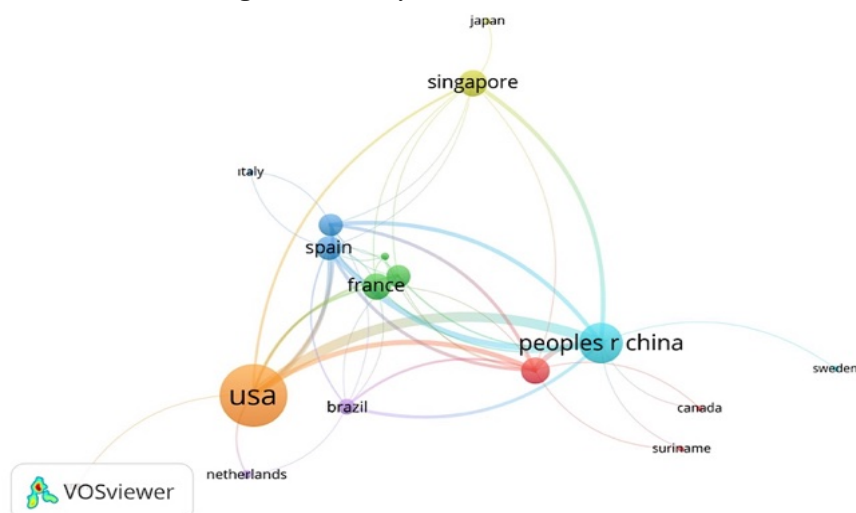


Country-level citation analysis

The citation network of publications was analyzed at the country level using VOSviewer. The minimum threshold was set at one publication and one citation per country. Based on these criteria, 17 countries met the inclusion requirements and were incorporated into the citation network. The resulting network consisted of 7 clusters, 49 links, and a total link strength of 114, indicating a moderate level of citation connectivity among contributing countries as shown in Figure 4.

Among the countries represented in the network, the United States emerged as the most influential contributor with 281 citations, followed by the People's Republic of China (157 citations), France (90 citations), England (89 citations), and Spain (79 citations). These countries occupy the most central positions within the citation map and exhibit strong citation connections with multiple countries, reflecting their significant influence on the development of research concerning AI agents in air traffic control.

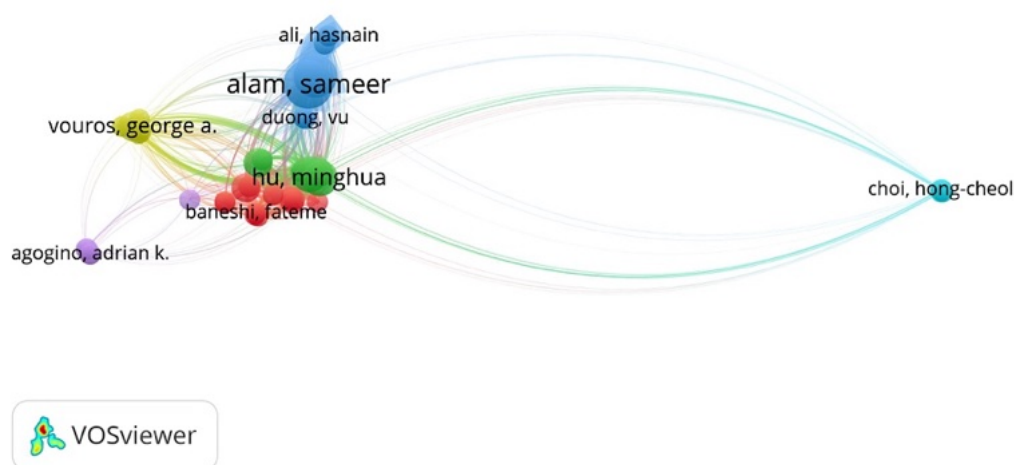
Figure 4. Country-level citation network



Bibliographic coupling of authors

Bibliographic coupling analysis is a widely used bibliometric technique that identifies intellectual similarities among authors based on the extent to which they cite the same references (Zupic & Čater, 2015). Authors sharing a substantial proportion of references are considered to have similar research interests and knowledge foundations. Within the scope of this analysis, the minimum threshold was set to one publication and one citation. As a result, 40 authors met the inclusion criteria and were incorporated into the bibliographic coupling network. The resulting network consisted of 6 clusters, 593 links, and a total link strength of 10,372, indicating a highly interconnected intellectual structure within the field as shown in Figure 5. The relatively high number of links and total link strength suggest that researchers frequently rely on a common body of literature, reflecting the emergence of a shared knowledge base in research on AI agents in air traffic control. Among the authors, Sameer Alam, Minghua Hu, George A. Vouros, Hasnain Ali, and Hong-Cheol Choi occupy prominent positions within the network. Their central locations and strong bibliographic connections indicate that their publications share substantial similarities in referenced literature and contribute significantly to the intellectual development of the field. The cluster structure further reveals several interconnected research streams focusing on topics such as multi-agent systems, reinforcement learning, conflict resolution, autonomous decision-making, and intelligent ATM.

Figure 5. Bibliographic coupling of authors



Keyword co-occurrence analysis of author keywords

Keyword co-occurrence analysis is a widely used text mining technique that identifies conceptual relationships among terms by examining their simultaneous occurrence within scientific publications. The method enables the visualization of thematic structures, research hotspots, and intellectual trends within a research domain (Cobo et al., 2011). In VOSviewer maps, the proximity between keywords indicates the strength of their conceptual association, while node size reflects the frequency of occurrence.

In the study, a keyword co-occurrence analysis was performed on publications related to AI agents in air traffic control. The resulting network consisted of 44 keywords, 6 clusters, 214 links, and a total link strength of 301, revealing several interconnected thematic areas within the literature as shown in Figure 6. Among all keywords, “air traffic control” emerged as the most frequently occurring term (19 occurrences), followed by “reinforcement learning” (16 occurrences) and “air traffic management” (14 occurrences). The prominence of these terms indicates that the literature is primarily focused on the application of intelligent learning algorithms to operational air traffic control and management challenges.

The keyword cluster map further illustrates the conceptual structure of the field. The central green cluster is organized around “air traffic control”, “deep reinforcement learning”, “conflict resolution”, and “urban air mobility”, highlighting research related to autonomous decision-making and conflict management in increasingly complex airspace environments. The blue cluster is dominated by “reinforcement learning”, “decision support systems”, and “conflict detection and resolution”, reflecting studies that employ learning-based approaches to enhance operational decision support. The yellow cluster centers on “air traffic management” and “multi-agent reinforcement learning”, emphasizing optimization, coordination, and intelligent traffic flow management. The red cluster includes terms such as “decision making”, “real-time

systems”, “reinforcement learning”, and “graph neural networks”, indicating growing interest in advanced AI techniques for dynamic and real-time air traffic applications. Finally, the turquoise cluster, represented by “machine learning” and “ETA prediction”, reflects predictive analytics and forecasting applications within air traffic operations. The density visualization further supports these findings by identifying “air traffic control”, “reinforcement learning”, and “air traffic management” as the most conceptually dense and interconnected areas within the literature, confirming their central role in shaping research on AI agents in air traffic control as shown in Figure 6 and Figure 7.

Figure 6. Author keyword co-occurrence network

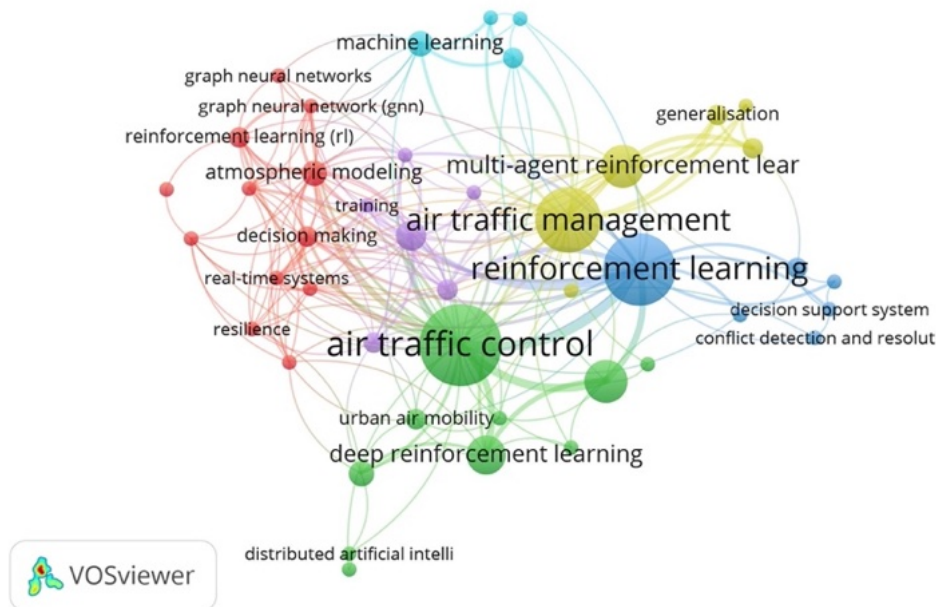
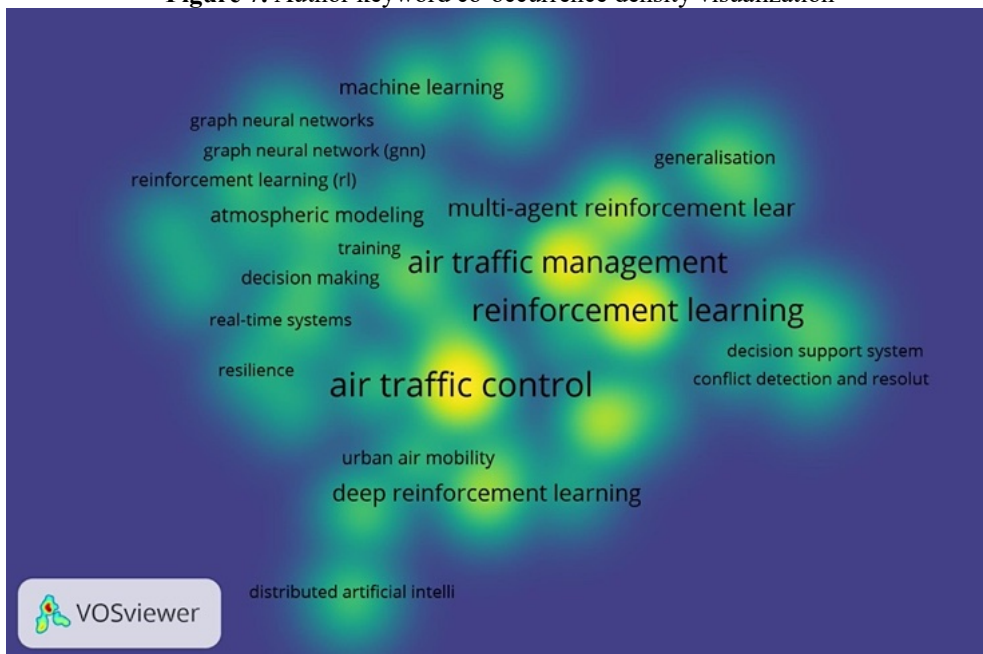


Figure 7. Author keyword co-occurrence density visualization



Discussion and Conclusion

The study set out to chart the intellectual trajectory of AI agent research within the domain of air traffic control by conducting a systematic bibliometric analysis of the available scholarly corpus. The research questions examined the development of the field, its main thematic and methodological foundations, and its leading contributors. The findings provide a structured quantitative overview of these dimensions.

The temporal distribution of publications reflects a broader transition in the field from exploratory inquiry to applied research. The foundational work of Wangermann and Stengel (1998) established the conceptual

premise of autonomous negotiation among intelligent agents in ATM, yet sustained scholarly engagement did not materialize for over two decades. The acceleration observed after 2022 aligns with concurrent advances in deep reinforcement learning architectures and the growing recognition that rule-based automation is insufficient for managing the complexity of increasingly dense airspace environments. The dominance of reinforcement learning as a methodological paradigm is evident in both citation patterns and keyword co-occurrence structures. This trend is consistent with findings reported in adjacent bibliometric surveys of AI in aviation (Degas et al., 2022; Karakavuz, 2025). Nevertheless, the present analysis shows that narrowing the unit of inquiry specifically to AI agents yields distinct results. Under this focused scope, the thematic concentration around conflict resolution, separation assurance, and multi-agent coordination becomes considerably more pronounced. The concentration of citation impact in the United States and China reflects not only the scale of national research investment in autonomous systems but also the alignment of these countries' aviation authorities with modernization programs that create institutional demand for agent-based solutions. The increasing focus on explainability and human-AI collaboration in the relevant literature, as evidenced in Kravaris et al. (2023) and Kirwan (2025), indicates that the field is beginning to address the operational and regulatory aspects of deployment. The co-authorship and bibliographic coupling networks further reinforce this picture of an early-stage research community. The presence of only two small co-authorship clusters and a limited number of recurring collaborators indicates that cross-institutional and cross-national collaboration remains underdeveloped. Nevertheless, the considerable total link strength observed in the bibliographic coupling network suggests that, despite fragmented collaboration structures, researchers increasingly draw from a shared intellectual foundation. This pattern is consistent with that observed in fields in which a common methodological core precedes the formation of broader collaborative ties (Donthu et al., 2021).

The primary contribution of the study is its specific analytical focus. Previous bibliometric studies on AI in aviation generally examined machine learning, optimization, and agent-based approaches within broad AI categories. In contrast, the present study examines AI agents as a distinct research topic. AI agents are characterized by autonomy, perception–action reasoning, and goal-directed behavior rather than by a specific technical method alone. This targeted approach reveals thematic clusters and citation structures often hidden in broader analyses. Key areas uncovered include the importance of human-AI teaming, the role of XAI in operational acceptance, and the use of probabilistic digital twins for validating autonomous agents. Consequently, these findings provide researchers with a clear map of an underexplored subfield. Furthermore, the identified themes highlight critical transition points from simulation to real-world deployment for practitioners and regulators working on system certification.

The study has several limitations that warrant consideration. The analysis is restricted to publications indexed in the WoS Core Collection. Databases such as Scopus and PubMed, national repositories including TÜBİTAK ULAKBİM and the Council of Higher Education Thesis Archive, and non-indexed grey literature fall outside the scope of the present corpus. This reflects a deliberate choice to prioritize source quality and longitudinal comparability, but it may underrepresent certain research communities. Additionally, despite systematic data cleaning, the possibility that a small number of relevant records were inadvertently excluded during duplicate removal or keyword standardization cannot be fully ruled out. The relatively small final corpus of 58 publications, a function of the query's specificity rather than a methodological weakness, does impose constraints on the robustness of network-level analyses.

Future studies could replicate this analysis using Scopus or a combined database approach to broaden coverage and enable cross-database comparison. Systematic reviews or meta-analyses built around the thematic clusters identified here would allow for deeper synthesis of methodological choices and empirical findings within specific sub-areas, such as MARL for separation assurance. Periodic updates to this bibliometric map would also be valuable, given the pace at which the field is developing.

Author Contributions

Author 1: Conceptualization, Writing – Original Draft, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – Review & Editing, Visualization

Author 2: Conceptualization, Writing – Original Draft, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – Review & Editing, Visualization.

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval

Not applicable.

References

- Abou Ali, M., Dornaika, F., & Charafeddine, J. (2025). Agentic AI: a comprehensive survey of architectures, applications, and future directions. *Artificial Intelligence Review*, 59(11), 1-37. <https://doi.org/10.1007/s10462-025-11422-4>
- Adabara, I., Olaniyi Sadiq, B., Nuhu Shuaibu, A., Ibrahim Danjuma, Y., & Maninti, V. (2025). Trustworthy agentic AI systems: a cross-layer review of architectures, threat models, and governance strategies for real-world deployment. *FI000Research*, 14, 905. <https://doi.org/10.12688/fi000research.169927.1>
- Agogino, A. K., & Tumer, K. (2012). A multiagent approach to managing air traffic flow. *Autonomous Agents and Multi-Agent Systems*, 24(1), 1-25. <https://doi.org/10.1007/s10458-010-9142-5>
- Ali, H., Pham, D. T., Alam, S., Schultz, M., Li, M. Z., Wang, Y., Itoh, E., & Duong, V. N. (2025). Human-AI hybrids in safety-critical systems: concept, definition and perspectives from air traffic management. *Advanced Engineering Informatics*, 65, 103256. <https://doi.org/10.1016/j.aei.2025.103256>
- Aziz, A., & Wei, P. (2026). Transformer-based Multi-agent Reinforcement Learning for Separation Assurance in Structured and Unstructured Airspaces. *arXiv preprint arXiv:2601.04401*. <https://doi.org/10.48550/arXiv.2601.04401>
- Berlin, I. (2017). Two concepts of liberty. In *Liberty reader* (pp. 33-57). Routledge.
- Biswas, B., & Sarkar, S. (2026). Responsible agentic artificial intelligence governance: Risk, safety, and ethical challenges in autonomous systems. *International Journal of Applied Resilience and Sustainability*, 2(2), 142-167. <https://doi.org/10.70593/deepsci.0202005>
- Borgatti, S. P., & Halgin, D. S. (2011). On network theory. *Organization science*, 22(5), 1168-1181. <https://doi.org/10.1287/orsc.1100.0641>
- Bornmann, L., & Daniel, H. D. (2008). What do citation counts measure? A review of studies on citing behavior. *Journal of documentation*, 64(1), 45-80. <https://doi.org/10.1108/00220410810844150>
- Brittain, M., & Wei, P. (2019). Autonomous air traffic controller: A deep multi-agent reinforcement learning approach. *arXiv preprint arXiv:1905.01303*. <https://doi.org/10.48550/arXiv.1905.01303>
- Brittain, M., & Wei, P. (2022). Scalable autonomous separation assurance with heterogeneous multi-agent reinforcement learning. *IEEE Transactions on automation science and engineering*, 19(4), 2837-2848. <https://doi.org/10.1109/TASE.2022.3151607>
- Carvell, B. J., De Ath, G., Benjamin, E., & Everson, R. (2026). Online Action-Stacking Improves Reinforcement Learning Performance for Air Traffic Control. In *AIAA SCITECH 2026 Forum* (p. 2746). <https://doi.org/10.2514/6.2026-2746>
- Carvell, B. J., Thomas, M., Pace, A., Dorney, C., De Ath, G., Everson, R., Pepper, N., Keane, A., & Cannon, R. (2026). Human-In-The-Loop Testing of AI Agents for Air Traffic Control with a Regulated Assessment Framework. In *AIAA SCITECH 2026 Forum* (p. 2558). <https://doi.org/10.2514/6.2026-2558>
- Çeken, S. (2025). Hava Trafik Yönetiminde Yapay Zekâ Uygulama Süreci. In Önen, V. (ed.) 2025. Havacılık Yönetiminde Yapay Zeka Uygulamaları, 113-146. <https://doi.org/10.58830/ozgur.pub1142.c4710>
- Chan, A., Ezell, C., Kaufmann, M., Wei, K., Hammond, L., Bradley, H., ... & Anderljung, M. (2024, June). Visibility into AI agents. In *Proceedings of the 2024 ACM conference on fairness, accountability, and transparency* (pp. 958-973). <https://doi.org/10.1145/3630106.3658948>
- Chen, S., Evans, A. D., Brittain, M., & Wei, P. (2024). Integrated conflict management for UAM with strategic demand capacity balancing and learning-based tactical deconfliction. *IEEE Transactions on Intelligent Transportation Systems*, 25(8), 10049-10061. <https://doi.org/10.1109/TITS.2024.3351049>
- Chen, Y., Wang, W., & Chen, X. M. (2023). Bibliometric methods in traffic flow prediction based on artificial intelligence. *Expert Systems with Applications*, 228, 120421. <https://doi.org/10.1016/j.eswa.2023.120421>

- Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study among tools. *Journal of the American Society for information Science and Technology*, 62(7), 1382-1402. <https://doi.org/10.1002/asi.21525>
- Cruciol, L. L., de Arruda Jr, A. C., Weigang, L., Li, L., & Crespo, A. M. (2013). Reward functions for learning to control in air traffic flow management. *Transportation Research Part C: Emerging Technologies*, 35, 141-155. <https://doi.org/10.1016/j.trc.2013.06.010>
- Degas, A., Islam, M. R., Hurter, C., Barua, S., Rahman, H., Poudel, M., Ruscio, D., Ahmed, M. U., Begum, S., Rahman, M. A., Bonelli, S., Cartocci, G., Di Flumeri, G., Borghini, G., Babiloni, F., & Arico, P. (2022). A survey on artificial intelligence (AI) and explainable AI in air traffic management: Current trends and development with future research trajectory. *Applied Sciences*, 12(3), 1295. <https://doi.org/10.3390/app12031295>
- Demir, G. (2026). Bibliometric analysis in artificial intelligence and transportation: Evaluation of research and future perspectives. In *Reliable Decision-Making for Sustainable Transportation* (pp. 255-273). *Academic Press*. <https://doi.org/10.1016/B978-0-443-33740-6.00005-0>
- Demir, G., Moslem, S., & Duleba, S. (2024). Artificial intelligence in aviation safety: Systematic review and biometric analysis. *International Journal of Computational Intelligence Systems*, 17(1), 279. <https://doi.org/10.1007/s44196-024-00671-w>
- Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133, 285–296. <https://doi.org/10.1016/j.jbusres.2021.04.070>
- Ertekin, R., Rodoplu, H., & Gürsel, S. (2024). The use of artificial intelligence in aviation: A bibliometric analysis. *International Journal of Computational and Experimental Science and Engineering*, 10(4). <https://doi.org/10.22399/ijcesen.747>
- Fortune Business Insights. (2026). Artificial intelligence (AI) in aviation market size, share & industry analysis. Retrieved from <https://www.fortunebusinessinsights.com/ai-in-aviation-market-113289>
- International Air Transport Association (IATA). (2026). Strong 2025 Passenger Demand Masks Ongoing Capacity Constraints. <https://www.iata.org/en/pressroom/2026-releases/2026-01-29-02/>
- Jiang, P., Lin, J., Shi, Z., Wang, Z., He, L., Wu, Y., ... & Han, J. (2025). Adaptation of agentic ai. A Survey of Post-Training, Memory, and Skills. *arXiv preprint arXiv:2512.16301*. <https://doi.org/10.48550/arXiv.2512.16301>
- Ju, H., & Aral, S. (2025). Collaborating with ai agents: Field experiments on teamwork, productivity, and performance. *arXiv preprint arXiv:2503.18238*. <https://doi.org/10.48550/arXiv.2503.18238>
- Karakavuz, H. (2025). Bibliometric Analysis of Studies on Artificial Intelligence in the Air Transportation Sector. *Journal of Aviation*, 9(1), 118-136. <https://doi.org/10.30518/jav.1583144>
- Kasirzadeh, A., & Gabriel, I. (2025). Characterizing AI agents for alignment and governance. *arXiv preprint arXiv:2504.21848*. <https://doi.org/10.48550/arXiv.2504.21848>
- Kent, P., De Ath, G., Carvell, B. J., Everson, R., Layton, M., & Hart, A. (2026). A future capabilities agent for tactical Air Traffic Control. In *AIAA SCITECH 2026 Forum* (p. 1203). <https://doi.org/10.2514/6.2026-1203>
- Kirwan, B. (2025). Human factors requirements for human-AI teaming in aviation. *Future Transportation*, 5(2), 42. <https://doi.org/10.3390/futuretransp5020042>
- Kravaris, T., Lentzos, K., Santipantakis, G., Vouros, G. A., Andrienko, G., Andrienko, N., ... & Martinez, E. I. (2023). Explaining deep reinforcement learning decisions in complex multiagent settings: towards enabling automation in air traffic flow management. *Applied Intelligence*, 53(4), 4063-4098. <https://doi.org/10.1007/s10489-022-03605-1>
- Krishnan, N. (2025). Ai agents: Evolution, architecture, and real-world applications. *arXiv preprint arXiv:2503.12687*. <https://doi.org/10.48550/arXiv.2503.12687>
- Lopes, N. M., Aparicio, M., & Neves, F. T. (2025). Challenges and prospects of artificial intelligence in aviation: a bibliometric study. *Data Science and Management*, 8(2), 207-223. <https://doi.org/10.1016/j.dsm.2024.11.001>

- Mei, P., Cannon, R., Everett, J., Liu, P., & Awad, E. (2025). Public trust and blame attribution in human-AI interactions: a comparison between air traffic control and vehicle driving. *Transportation Research Interdisciplinary Perspectives*, 32, 101545. <https://doi.org/10.1016/j.trip.2025.101545>
- Melin, G., & Persson, O. (1996). Studying research collaboration using co-authorships. *Scientometrics*, 36(3), 363-377. <https://doi.org/10.1007/BF02129600>
- Mohamed, E., Carvell, B. J., Procter, R., Benjamin, E., De Ath, G., & Everson, R. (2026). Towards Transparent AI Agents for Air Traffic Control. In *AIAA SCITECH 2026 Forum* (p. 2869). <https://doi.org/10.2139/ssrn.6042354>
- Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics*, 106(1), 213–228. <https://doi.org/10.1007/s11192-015-1765-5>
- Nisa, U., Shirazi, M., Saip, M. A., & Pozi, M. S. M. (2025). Agentic AI: The age of reasoning—A review. *Journal of Automation and Intelligence*, 5, 69-89. <https://doi.org/10.1016/j.jai.2025.08.003>
- Pepper, N., Keane, A., Hodgkin, A., Gould, D., Henderson, E., Lauritsen, L., Vlahos, C., De Ath, G., Everson, R., Cannon, R., Sierra Castro, A., Korna, J., Carvell, B. J., & Thomas, M. (2026). A Probabilistic Digital Twin of UK en Route Airspace for Training and Evaluating AI Agents for Air Traffic Control. In *AIAA SCITECH 2026 Forum* (p. 1794). <https://doi.org/10.2514/6.2026-1794>
- Pham, D. T., Tran, P. N., Alam, S., Duong, V., & Delahaye, D. (2022). Deep reinforcement learning based path stretch vector resolution in dense traffic with uncertainties. *Transportation research part C: emerging technologies*, 135, 103463. <https://doi.org/10.1016/j.trc.2021.103463>
- Qu, X., Damoah, A., Sherwood, J., Liu, P., Jin, C. S., Chen, L., ... & De Souza, C. (2025). A comprehensive review of AI agents: Transforming possibilities in technology and beyond. *arXiv preprint arXiv:2508.11957*. <https://doi.org/10.48550/arXiv.2508.11957>
- Raza, S., Sapkota, R., Karkee, M., & Emmanouilidis, C. (2025). Trism for agentic ai: A review of trust, risk, and security management in llm-based agentic multi-agent systems (2025). *arXiv preprint arXiv:2506.04133*. <https://doi.org/10.48550/arXiv.2506.04133>
- Sadou, A. M., & Njaya, E. T. (2023). Applications of artificial intelligence in the air transport industry: a bibliometric and systematic literature review. *Journal of Aerospace Technology and Management*, 15, e2223. <https://doi.org/10.1590/jatm.v15.1312>
- Şahin, Y. (2024). Havacılık ve yapay zeka alanındaki çalışmaların bibliyometrik analizi. *International Journal of Social and Humanities Sciences Research (JSHSR)*, 11(110), 1637-1648. <https://doi.org/10.5281/zenodo.13732160>
- Sapkota, R., Roumeliotis, K. I., & Karkee, M. (2025). Ai agents vs. agentic ai: A conceptual taxonomy, applications and challenges. *Information Fusion*, 126, 103599. <https://doi.org/10.1016/j.inffus.2025.103599>
- Silver, D., Huang, A., Maddison, C. J., Guez, A., Sifre, L., Van Den Driessche, G., ... & Hassabis, D. (2016). Mastering the game of Go with deep neural networks and tree search. *nature*, 529(7587), 484-489. <https://doi.org/10.1038/nature16961>
- Spatharis, C., Bastas, A., Kravaris, T., Blekas, K., Vouros, G. A., & Cordero, J. M. (2023). Hierarchical multiagent reinforcement learning schemes for air traffic management. *Neural Computing and Applications*, 35(1), 147-159. <https://doi.org/10.1007/s00521-021-05748-7>
- Tran, P. N., Pham, D. T., Goh, S. K., Alam, S., & Duong, V. (2020). An interactive conflict solver for learning air traffic conflict resolutions. *Journal of Aerospace Information Systems*, 17(6), 271-277. <https://doi.org/10.2514/1.1010807>
- Tuncal, A. (2025). Artificial Intelligence Integration in Air Traffic Management: A Qualitative Content Analysis of the SESAR Research. *AIPA's International Journal on Artificial Intelligence: Bridging Technology, Society and Policy*, 1(2), 61-72. <https://doi.org/10.5281/zenodo.17391128>
- van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. <https://doi.org/10.1007/s11192-009-0146-3>
- Wang, Z., Li, H., Wang, J., & Shen, F. (2019). Deep reinforcement learning based conflict detection and resolution in air traffic control. *IET Intelligent Transport Systems*, 13(6), 1041-1047. <https://doi.org/10.1049/iet-its.2018.5357>

-
- Wangermann, J. P., & Stengel, R. F. (1998). Principled negotiation between intelligent agents: a model for air traffic management. *Artificial Intelligence in Engineering*, 12(3), 177-187. [https://doi.org/10.1016/S0954-1810\(98\)80001-0](https://doi.org/10.1016/S0954-1810(98)80001-0)
- Zhang, R., Qin, P., Cao, Q., Zhang, L., & Xie, P. (2026). AIBuildAI: An AI Agent for Automatically Building AI Models. *arXiv preprint arXiv:2604.14455*. <https://doi.org/10.48550/arXiv.2604.14455>
- Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. *Organizational research methods*, 18(3), 429-472. <https://doi.org/10.1177/1094428114562629>

Human Values in Social Integration: A Sociological Study on Religion, Family, Respect, Love, Tolerance, Responsibility, Empathy and Patience

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Received: 17.06.2026 Accepted: 23.07.2026 Published: 15.10.2026 Keywords: Social Values, Religion, Empathy, Responsibility, Tolerance. Jel Code: Z00 Corresponding Author: İlhan BİNGÖL Research Article https://doi.org/10.5281/zenodo.23372950	The value system is one of the most fundamental and indispensable elements of human history, ensuring the continuity of social structure, regulating interpersonal relationships, and enabling communal life. Values that guide individuals' attitudes and behaviors also form the spirit of society, serving as a unifying glue. The transformation wrought in the social fabric by modernization, digitalization, and global change has led to greater questioning of value systems today; consequently, rethinking the function of values in social cohesion has become a necessity. This study examines the values that ensure the continuity of social structure and play a regulatory role in individualsociety relations within the framework of the "social glue" metaphor. Based on a qualitative approach and literature review, the study emphasizes that values are not only individual ethical principles but also the fundamental pillars of social stability, belonging, and cultural transmission. Fundamental social values such as religion, family, respect, love, tolerance, empathy, patience, and responsibility are examined within a theoretical framework, revealing how these values shape individual attitudes and contribute to the continuity of social structure. While the central role played by institutions such as religion and family in the transmission of values is underscored, the functions of values such as love, tolerance, and empathy in fostering peace and solidarity in interpersonal relationships are highlighted. Furthermore, it is stated that values such as patience and responsibility are decisive not only for personal development but also for social functioning.

1. Introduction

Social values are defined as the totality of fundamental beliefs and principles that shape the behavior of individuals and groups and play a decisive role in maintaining social order. Within this framework, values are generalized moral assumptions formed by a society's historical accumulation, passed down from generation to generation through acceptance, and reflecting shared feelings and thoughts (Köse and Direkçi, 2022). This structure, which functions as a criterion in evaluating individuals' actions, consists of rules and opinions that offer a reference point for what is good, right, and beneficial (Akkaya, 2017). Values also function as deep and abstract sources of motivation that enable people to give meaning to their lives (Avcı and Faiz, 2019). This structure, which plays an important role in ensuring social harmony and continuity, expresses behavioral patterns shaped around common meanings adopted by the majority (Aydın, Öztürk, and Küçükoglu, 2020). In this respect, the value system provides a fundamental framework that guides individuals in determining their priorities in the face of situations they encounter in social life (Kavıracı, 2020). Social values, as fundamental beliefs that guide individual behavior and ensure the continuity of social order, are central to both individual and collective life. These values, forming the shared meaning of society, strengthen social cohesion by offering individuals a guide to correct and acceptable behavior.

Social values, as fundamental beliefs that guide individual behavior and ensure the continuity of social order, are central to both individual and collective life. These values, which construct society's shared worldview, contribute to strengthening social cohesion by providing individuals with a frame of reference for correct and acceptable behavior. In this context, examining the concrete manifestations of values is crucial for understanding social integration.

Societies are not merely structures formed by the physical presence of individuals; they also possess a social cohesion. This social cohesion depends on the existence of spiritual, cultural, and moral elements that bring individuals together and bind them around a shared ideal of life. The most prominent of these elements are values. Values are fundamental belief systems that guide individual behavior, shape social norms, and make individual-society interaction meaningful. In establishing and maintaining social order, values function like an invisible "social glue," building bonds of belonging, trust, responsibility, and solidarity among individuals. In this context, understanding the position of values within society from a sociological perspective becomes crucial.

Social values are defined in sociological literature as the totality of shared normative criteria, belief systems, and value judgments that a society has regarding what is 'good', 'right', and 'desirable' (İnce, 2017). These values, which are not merely individual preferences, are social criteria that shape the social structure, enabling individuals and groups to establish a "logic of choice" among their options for action (Ersoy, 2018). Shaped throughout historical processes and reflecting social memory, values, due to their abstract nature, lay the groundwork for the formation of social norms. According to the Parsonian approach, social values are among the main cultural elements that support the integration of the social system, ensure the continuity of social order, and contribute to the establishment of common consensus (Aksan, 2016).

From a sociological perspective, values are not merely criteria that determine an individual's inner world and ethical orientations, but rather cornerstones of the social structure that ensures the continuity of collective life. Values play a unifying, guiding, and balancing role for societies. The continuity and cultural transmission of a society across generations are largely ensured through the value system. However, processes such as modernization, urbanization, globalization, individualization, and digitalization have transformed the traditional form of social structures and led to significant erosion in value systems. In this new era, where cultural hybridization is accelerating, individual-centered lifestyles are coming to the forefront, and digital culture is pervading daily life, the weakening of shared value areas can lead to loosening of social bonds, identity fragmentation, and intergenerational rupture. Therefore, the fundamental problem of this study is: 'Can values still play a unifying and integrative role in contemporary societies?'

The rapid processes of social change, individualistic trends, and the spread of digital culture in today's world are leading to a weakening of shared values and a loosening of social bonds. In this context, re-examining the role of values in social cohesion has become an important need for both sociological theory and social practices. This study aims to highlight the constitutive and unifying role that values play in the sustainability of social order by examining values through the metaphor of "social glue."

This study aims to demonstrate that values function not only as ethical orientations at the individual level, but also as a mechanism that enables social integration, structures the rule-making order, and places social relations within an institutional framework. In this context, the "social glue" nature of values is examined within a conceptual perspective. Designed in accordance with a qualitative research approach, the study is a theoretical review based on a literature review. In this theoretically grounded review, the main human values that play a decisive role in the construction of social cohesion—religion, family, respect, love, tolerance, responsibility, empathy, and patience—are examined, and the aim is to contribute to the relevant literature in this regard.

2. Conceptual Framework

2.1. The Concept of Value

Values, which are generalized fundamental moral principles that maintain the existence, integrity, and functioning of society, reflect the common feelings, thoughts, and interests of individuals, and are accepted by the majority of society members (Aytaç, 2002: 182), are shared criteria or ideas that determine which social behavior is good, right, and desirable. Composed of abstract and general concepts, values are of great importance in terms of influencing the norms of the society in which they exist (Özkalp, 2017: 93). Shaped within the framework of social consensus processes that occur among individuals, values emerge not only as a reflection of individual preferences but also as a decisive regulatory force in the organization of co-existence.

Values, which are phenomena that enable individuals to rationally internalize their behavior, necessitate the presence of elements of belief and acceptance in every context in which they exist. Conceptually, a value refers to things that are desired, preferred, and considered important (Topçuoğlu, 1996: 2). The existence of values, which can change over time and are affected by the structural transformations of societies, is directly related to the existence of individuals at the micro level and cultures and civilizations at the macro level. However, the hierarchy of importance of values differs between societies and also changes over time within the same society in parallel with social transformations (Yazıcı, 2013: 1491).

Values, addressed from various theoretical perspectives by different disciplines of the social sciences, are examined in each field according to its own methodological and conceptual framework. Values are studied in fields such as philosophy, theology, ethnology, anthropology, psychology, and sociology within their own conceptual and methodological contexts (Şahin, 2022: 30). As can be seen, the subject of values has an interdisciplinary nature, and values are a multi-dimensional object of study in different scientific fields.

According to the prevailing view in sociological literature, social behaviors are goal-oriented, and values define the behavioral patterns that individuals desire, consider important, or adopt as a necessity. Social order is generally organized around certain fundamental values; the sharing and continuity of these values play a critical role in establishing social stability and strengthening intra-community integration (Korkmaz, 2013: 54). From this perspective, values are not only the motivational source of individual behaviors but also play a central role in ensuring social stability. Philosophically, values are concepts addressed in relation to both morality and the understanding of knowledge and existence, stemming from the question of how a person should live their life. Value is not only derived from objective facts but also gains meaning through emotional experiences, virtues, and moral judgments (Tüfenkci, 2023: 14-18).

From a theological perspective, religious beliefs and value systems provide a guiding conceptual framework for individuals in the process of making sense of life and directing their behavior. Although different religions have some differences on issues such as creation, the purpose of life, ethical principles, and the afterlife, they largely serve a common function in explaining human existence and giving it a life orientation (Koç, 2018, p. 2). Therefore, religions as social values play a decisive role in the formation of believers' worldview and philosophy of life.

2.2. Characteristics of Values

Values, which are among the fundamental elements that give meaning to culture and society, are guiding principles that ensure the continuity of the social structure. Fichter (2006: 167) systematically explains the distinctive characteristics of values under various headings. Accordingly, values are structures shared by broad segments of society and largely agreed upon. Values possess characteristics such as being shared, taken seriously, existing with enthusiasm, and being abstractable from other valuable objects in society.

Values, which are general principles and belief systems that guide individuals' behavior, provide motivation in achieving goals, and extend beyond a specific situation or action, serve as a bridge between individual identity and social norms. These abstract criteria, which shape individuals' tendencies and serve as guides in social life, also have a hierarchical structure. In an individual's value system, some values may be more dominant and prioritized than others. For example, the 'value of responsibility' may hold a more decisive position for a person than some other values (Yaşaroğlu, 2020).

Values, which are abstract belief systems and ideals that guide individuals' attitudes and behaviors, contribute to the development of feelings of unity and solidarity in society (Aytaç, 2002: 182). Values, which are part of society's collective memory, not only serve to maintain social order but also play a central role in the construction of individuals' identities, the development of a sense of belonging, and the ensuring of cultural continuity.

The value system that shapes an individual's intellectual, moral, and behavioral world also makes profound contributions to humanity's existential search for meaning. Values not only create a sense of identity and belonging at the individual level, but also serve as a cornerstone of cultural structure, playing a vital role in the construction and preservation of the social fabric (Türkyılmaz et al., 2020). Social values, which play a central role in the continuity of social life as shared standards or judgments among members of society, are transmitted to individuals through intergenerational interaction within the socialization process. Intergenerational communication is of great importance for the preservation and sustainability of social culture (Canatan, 2008: 62).

Values, which are regulatory structures shared and agreed upon by a large segment of society, ensure the preservation of order while also enabling social harmony, integration, and the realization of the ideal of shared life. The internalization of values at both individual and societal levels is an indispensable requirement for the long-term stability and development of society. Therefore, the recognition, transmission, and preservation of values must be continuously supported through education, cultural production, and social practices. While societal values guide the behavior of individuals and groups, they can also create a basis for disagreements and conflicts at the societal level. Disagreements, particularly those arising from moral, religious, or ideological issues, often stem from differences in values. However, values play a decisive role in the formation of cultural identity by determining what behaviors are expected of members of a culture and what behaviors should be avoided. Accordingly, different value systems lead to the emergence of different social practices and behavioral patterns.

Social change, accelerated by globalization and digitalization, increases the risk of losing traditional knowledge and cultural heritage passed down from previous generations. The erosion of social values weakens

existing social structures; therefore, the transmission of experiences and values from previous generations to new ones plays a critical role in preserving cultural continuity.

3. Social Values

Social values are fundamental principles and beliefs that express shared understandings of what is right, good, beautiful, and desirable within a society. These values transcend individual preferences, forming collective frames of reference that contribute to the maintenance of social order, solidarity, and continuity. Possessing a moral authority that surpasses the individual, values enable the integration of the social system and guide social roles. They also shape the individual's world of meaning, determining the direction of social actions. In this respect, social values act as intermediaries between social structure and individual action. This study examines, within a theoretical framework, the concepts of religion, family, respect, love, tolerance, responsibility, empathy, and patience as fundamental values that ensure social integration and hold society together.

3.1. Religion: Meaning and Social Integration

Religion, which offers God-centered answers to existential questions, is not only a metaphysical belief system but also a fundamental social institution that shapes individual attitudes and behaviors, determining the set of values and guiding daily life (Kirman, 2004: 61). In this function, religion guides the individual's search for meaning while playing a dominant role in the formation of social norms, the establishment of moral order, and the construction of cultural identity. Humans are by nature inclined to believe. This tendency to believe often leads to the creation of religion, directed towards a transcendent being. Even in cases where an individual denies God, traces of this tendency can be found. In this context, whether religion manifests as belief or denial, it plays a decisive role in the individual's life (Arslantürk and Amman, 2017: 283).

Religion, present in all human societies from primitive to modern, is a universal phenomenon. Each society has developed its own unique belief systems, rituals, and traditions in accordance with its historical and cultural context. Religion, born and developed within a social context, strengthens community consciousness by integrating individuals around a common spiritual belonging (Coşkun, 2024). As one of the institutional structures arising from the basic needs of society, religion is a universal, necessary, and functional institution. Both in traditional and modern societies, individuals and communities turn to religious beliefs and need this institution (Yavuzer and Cihan, 2023: 111).

Religion offers individuals and societies not only a belief system but also a comprehensive worldview and way of life. In this respect, religion has consistently influenced the shaping of daily life; it has played roles such as ensuring the continuity of the social structure, resisting change, or acting as a driving force for transformation. The reciprocal interaction between society and religion has been a decisive factor in the rise and fall of civilizations throughout history. Therefore, it is impossible to consider religion independently from the social structure (Abuzar, 2011: 143).

Religion, which played a significant role in the construction of civilizations, has also been decisive in shaping cultural structures. World religions have contributed to the institutionalization of unified cultures by bringing different communities together around shared values. Belief systems that have become universal over time have extended an individual's sense of belonging beyond tribal or national boundaries, paving the way for the formation of more inclusive identities. Etymologically, the concept of 'religion' encompasses meanings such as obligation, obedience, and judgment, functioning as a system of values that regulates an individual's responsibilities towards God and society (Frankel, 2012: 313).

Religion, which plays an effective role in building social justice, peace, and integrity, undertakes functions of both transforming and uniting society, while also being influenced by social structures. The continuity of society and the preservation of moral order depend on religious values and divine authority to which sanctity is attributed (Cilacı, 1995).

From a sociological perspective, religion, like other social norms, presents a functional structure. Its most fundamental function is to ensure individual peace and establish social cohesion. By bringing individuals together through shared rituals, it contributes to the strengthening of collective consciousness and emotions. The sacred values built around these rituals create a symbiotic bond between individuals, reinforcing social solidarity (Dönmezer, 1984: 261-264). Furthermore, religion, through its reward and punishment mechanisms, guides individual consciences, limiting social deviance and thus enabling the continuity of social harmony (Günay, 1998: 323).

Religion, one of the fundamental institutions ensuring the continuity of social structure, is not merely a realm of individual belief. It also contributes to the internalization of social norms by bringing individuals together around shared values. By providing a moral framework for establishing social order, religion guides individual behavior. Furthermore, it enhances psychological resilience by offering individuals a world of meaning during periods of crisis, uncertainty, and trauma. This demonstrates that religion plays a role in supporting both mental balance at the individual level and harmony and stability at the societal level.

Religion, a realm of thought where individuals seek answers to their existential questions, also functions as a structural institution ensuring the continuity of society, operating on both philosophical and sociological levels. From a philosophical perspective, humanity's search for meaning and its answers to fundamental ontological questions such as death, freedom, responsibility, and transcendence are often shaped through religion.

From a sociological perspective, religion is more than just a matter of individual belief; it is a powerful institution that contributes to the preservation of social order, the internalization of moral norms, and the formation of collective identity. As old as human history itself, religion, despite the secularization processes that emerged with modernity, has not ceased to attract individuals and societies; on the contrary, it has continued to exist through reinterpretations in various forms. In the postmodern era, religion has emerged not as a fixed structure, but as a flexible source of meaning in the construction of individual identity. This has paved the way for the development of an understanding of religion that emphasizes both individual freedom and social pluralism.

In conclusion, religion holds an indispensable place both in giving meaning to individual existence and in the construction of social structure. It should be considered not only as a dogmatic belief system, but also as a multifaceted field of thought and practice that shapes the ways in which humans relate to the universe, society, and themselves.

3.2. The Family as the Primary Space for Value Transmission

The family, which plays a central role in the process of individuals acquiring values, is the most fundamental institution of society. The family environment, where initial socialization takes place, is of vital importance as it is the first area where individuals' self-perception is formed and where they internalize social norms and moral rules (Kağıtçıbaşı, 2007).

Compared to other institutions in society, the family is an institution with a stronger social dimension (Aydın, 2016). Its value system, which shows individuals what is good, right, beautiful, and beneficial, forms the fundamental frame of reference that determines the direction of individual behavior. The family institution is not only a vehicle for carrying values but also possesses a cultural and moral value in itself. In terms of internalizing, living, and transmitting values to subsequent generations, the family stands out as the primary and most effective environment for socialization (Doğan, 2023). A multifaceted institution that enables both the biological continuity and social construction of human life, the family is the first environment in which an individual takes their first steps in the socialization process. The family, the first place an individual is born, is not only a union based on blood ties; it is also an area of interaction where cultural values, social norms, and historical accumulations are passed down from generation to generation. Beyond biological relationships, the family is a multi-layered social structure through psychological bonds, economic functions, legal regulations, and social roles (Sayın, 1990: 2).

Historically, the family institution, occupying a central position in almost every society as the individual's first area of socialization and the fundamental space for identity construction, has played a functional role in the internalization of social norms and the achievement of social integration. Rather than a static structure, the family is a dynamic institution shaped by historical and social processes, and within this context, it has experienced various ruptures and transformations in its structure and functions along with economic transformations, cultural differentiations, and changes in social values (Turgut, 2017: 93).

In the family institution, which is highly valued in individuals' lives and considered one of the fundamental building blocks of social life, individuals encounter phenomena such as difference, power relations, hierarchy, and belonging for the first time (Adak, 2015). The family functions as the smallest universe reflecting the value judgments, belief system, aesthetic understanding, and overall cultural structure of the society in which it exists. Although the relationships between family members may vary in intensity, these relationships are generally continuous (Erkan, 2010: 3). In short, the family is a multifaceted sociological institution that goes

beyond being a biological entity, undertaking fundamental functions in the internalization of social values and their transmission across generations, encompassing psychological, economic, legal, and cultural aspects.

The family, as a sociological institution, has been studied within the framework of various theoretical approaches. According to Hill and Hansen's classification, five main approaches stand out in family research: The interactionist approach examines the family through the dynamic interaction between individuals; the structural-functionalist approach considers it as a static subsystem of society; the situational approach focuses on the individual's responses to their social and psychological environment; the institutional approach positions the family within its historical and cultural context, viewing it as the basic unit of the social structure; and the developmental approach analyzes the family as a dynamic structure based on roles that transform over time (Yazan, 1989: 150-152).

The family, the primary institution where an individual experiences their first socialization process, can be considered a small model reflecting society. The forms of interaction, role distributions, and communication dynamics observed within the family structure are small-scale reflections of the broader social structure. The family stands out not only as a private sphere but also as a space where social relations are produced and reproduced. However, the family institution changes depending on historical conditions. The modernization process has led to radical transformations in the structural and functional characteristics of social institutions; one of the institutions most affected by this transformation has been the family. While in traditional societies the family was a central structure that ensured not only the biological reproduction of individuals but also economic production, social solidarity, and cultural transmission; with modernization, this multi-functional structure began to disintegrate (Bingöl, 2025).

Modernization dynamics such as industrialization and urbanization have detached the family from traditional solidarity networks, shifting it towards a more individual-centered and flexible structure (Kongar, 1985). In this process, the inclusion of women in the workforce has reshaped family authority and communication styles (Karşlı, 2019). Dynamics accompanying modernization, such as women's participation in the workforce, increased education levels, and globalization, have transformed both the internal workings and the social position of the family institution. This transformation has had a wide-ranging impact, from intra-family authority relations and gender roles to communication styles and individuals' expectations of the family. Today's family structures have moved away from traditional solidarity-based patterns towards more individual-centered, flexible, and pluralistic models. This change has brought with it value conflicts, intergenerational tensions, and institutional disintegration. With these fundamental functions, the family plays a decisive role not only in the individual's identity formation but also in their active participation in social life. The individual, born naked into the world, puts on a garment within the family. In this context, the family is not only a biological union but also a center for the production of values where cultural and social codes are transmitted. Essentially, the family is the first institution where the individual is transformed into a political being.

The family, besides being a fundamental institution that serves as a bridge between the individual and society, has been in constant and strong interaction with religion throughout history because it naturally constitutes a religious community. The family, which is at the center of religious life, complements religion in the preservation, perpetuation, and transmission of religious and moral values to future generations. Parents setting an example for their children facilitates both the upbringing of healthy individuals and the sustainability of these values (Selman, 2018: 13). Religion plays a decisive role in the functioning of the family institution and the relationships between individuals. To understand this influence, it is necessary to consider individuals' religious values, belief systems, and religious lives. Key milestones in family life, such as marriage, wedding ceremonies, birth, death, circumcision, fertility, and divorce, are often shaped by religious rules and traditions. This interaction reveals the regulatory effect of religion on the family and the mutual determinative role of the religion-family relationship in maintaining social functioning.

Many events within the family are reinforced and given a spiritual dimension through religious rituals. For example, in many societies, marriage is not limited to a civil ceremony; a religious ceremony is also performed to emphasize the sacred aspect of the marital relationship. In the process of choosing a spouse, individuals generally prefer those compatible with their religious beliefs, and society supports this preference through social norms and expectations (Adak, 2015: 26).

The role attributed to religion in maintaining social order has strengthened the relationship between religion and family throughout history. The family plays a decisive role in the transmission of religious values, while religion has a decisive influence in protecting the family. Indeed, many religions aim to ensure the continuity of both the family and the religious structure through regulations that encourage procreation and make divorce

more difficult (Tekin, 2011). There is a significant and positive relationship between religiosity and healthy family relationships. Religious beliefs and practices support trust and loyalty between spouses, and love and responsibility in parent-child relationships. There is a two-way and complementary relationship between religion and family.

Studies on the effects of religion and spirituality on marriage and family reveal that these two elements shape the family structure both directly and indirectly. Sharing common spiritual values, strengthening emotional bonds, increasing communication opportunities, and the socialization environment provided by religious activities stand out as important factors supporting family relationships. Furthermore, religious beliefs enhance psychological resilience by increasing the capacity of family members to cope with difficulties, and contribute to the sustainability of the marital bond (Glidden, 2016). In conclusion, there is a strong, reciprocal relationship between religion and family. While religious beliefs shape and strengthen intra-family relationships, the family functions as a fundamental means of transmission, ensuring the social continuity of religious values. This provides both spiritual support at the individual level and contributes to the stability of the social structure.

3.3. Respect as a Universal Ethical Value

Respect is a concept that expresses an individual's attitude towards a person or value, including appreciation, admiration, care, and reverence (TDK, 1998: 1268). Respect is expressed through words and actions that convey to individuals that they are valued and respected. As long as it conforms to general moral principles, it involves approaching people's opinions, beliefs, worship practices, traditions, customs, and lifestyles with understanding, attention, consideration, and moderation.

Respect, a universal ethical principle, holds significant value in social life. For people to survive and coexist, healthy co-existence requires individuals to treat each other with care, moderation, and respect. Neglecting the principle of respect leads to various problems in shared living spaces. However, individuals knowing their boundaries in shared living spaces and being respectful in their attitudes and behaviors towards others contributes to a healthier social order (Kıral, 2018: 4).

Therefore, it should be noted that respect is not only a necessity of daily life, but also a value grounded at the intellectual and theoretical level. Respect, a central value in many fields such as moral philosophy, political theory, human rights, education, and human relations, forms the basis of many moral theories. Indeed, Kant's categorical imperative, based on the principle of "never seeing man merely as a means, but always as an end," clearly demonstrates the importance given to human dignity and respect (Yazıcı and Yazıcı, 2015: 772). It is observed that respect has significant consequences not only at the social level but also at the individual level. Respect is a fundamental attitude reflecting an individual's desire to establish healthy and harmonious relationships with those around them; as a result of this attitude, it is observed that friendships are strengthened (Altunsoy and Namlı, 2021: 318).

Beyond its theoretical framework, respect plays a crucial role in the sustainability of social structures in daily life practices. It fosters healthy social relationships through individuals valuing each other, striving to understand differences, and showing tolerance. In a society where respect prevails, individuals express themselves more freely, conflicts are resolved constructively, and social peace becomes sustainable. Respect also contributes to the preservation of fundamental principles such as equality, justice, and democracy. Considering all these aspects, establishing a culture of respect in every environment, from education and family life to workplaces and public spaces, strengthens social solidarity and trust. Raising children and young people in line with these values contributes to the formation of more sensitive, understanding, and responsible individuals in the future. Thus, respect is not only essential for the sustainability of the existing social order but also a cornerstone for building a more inclusive and peaceful future. Ultimately, respect, one of the values that forms the foundation of social life, enables people to value each other, strive to understand differences, and show tolerance, fostering healthy social relationships. Respect also contributes to the preservation of fundamental principles such as equality, justice, and democracy. Therefore, individuals treating each other with respect is fundamental to peace and cooperation, both in personal relationships and at the societal level. Furthermore, respect is the cornerstone of healthy communication, a peaceful living environment, and strong social relationships.

3.4. Love as a Fundamental Human Value

One of the most fundamental human values that gives meaning to life, improves quality of life, and supports spiritual integrity is love. Love plays a unifying role by establishing emotional closeness and attachment between individuals; it also has a transformative function in meeting psychological needs and ensuring inner peace (Yolcu, 2022: 59). Love is a dominant value that forms the foundation of the family institution, and it possesses a constitutive quality that both develops in interaction with other moral and social values and makes it possible to internalize and sustain these values (Doğan, 2023: 542).

Love, as a societal value, is a universal emotion that forms the foundation of interpersonal relationships and makes it possible to establish and maintain social bonds. Beyond being an individual feeling, love is a multifaceted value intertwined with concepts such as solidarity, empathy, tolerance, and belonging, which ensure the integrity of society. In the continuity of the social structure and the construction of healthy human relationships, love is passed down from generation to generation, starting with the family and continuing through institutions such as education, religion, and culture.

Love is defined as a state of deep attachment and interest that an individual directs towards an object or person; however, it encompasses not only an emotional orientation but also a whole range of meaningful relationships that an individual establishes while preserving their sense of self. This emotional closeness, established without compromising individual integrity, strengthens interpersonal interaction, reinforces the sense of belonging, and deepens social bonds. In this respect, love has a direct and decisive influence not only on social integration but also on the individual's psychological well-being and emotional balance (cited in Doğan, 2023). By providing balance in the individual's inner world, love extends this influence to human-nature and human-society relationships, thus gaining meaning in a broader context.

The foundation of establishing healthy relationships with nature and other living beings lies in a love-based bond developed towards everything that exists in the universe. Human relationships shaped by love and respect not only strengthen interaction between individuals but also play a decisive role in establishing social peace and harmony. Indeed, a lack of love can lead to the development of negative attitudes such as resentment, anger, alienation, and selfishness in an individual, causing pathological tendencies that threaten both psychological health and social relationships. This situation is reflected in the individual's personality structure and behavioral patterns, leading to various adjustment problems at both individual and societal levels in the long term (Yolcu, 2022).

Love, a social and human value, is a fundamental principle that makes human life meaningful at both individual and societal levels, supports spiritual integrity, and enables the healthy continuation of social relationships. Transmitted through social institutions, starting from the family, love plays a decisive role in an individual's identity formation, capacity for empathy, and social adaptation skills. Its presence strengthens social bonds and reinforces social peace; its absence can lead to negative consequences such as conflict, alienation, and psychological disorders at both individual and societal levels. Therefore, developing the value of love in individuals from an early age and strengthening it at the societal level is an indispensable necessity for both individual well-being and societal stability. The impact of love on the individual, family, and society is undeniably significant.

Maslow, stating that humans cannot sustain themselves solely through physiological needs, placed the need for love and belonging at the third level of his hierarchy of needs. When individuals cannot adequately meet these needs, they may face feelings of loneliness, worthlessness, alienation, and abandonment. This situation can damage the individual's psychological balance and negatively affect their self-actualization process. As a social being, humans can improve their quality of life by strengthening both their inner peace and social bonds through love and belonging (Maslow, 1987).

Establishing a love-based connection with nature, animals, and all living things contributes to the development of empathy and the healthy progress of social relationships. In individuals lacking love and respect, negative attitudes such as resentment, hatred, and selfishness come to the forefront; this can lead to various behavioral and personality problems at both individual and societal levels. The first condition for an individual to develop love and empathy in their social relationships is to be raised in a healthy family environment where the foundations of these values are laid.

The family is defined as an environment where spiritual feelings such as love, affection, compassion, peace, and happiness are experienced, far from the stresses of daily life (Teyfurov, 2014). In this space where love first blossoms, the process of family members acquiring an understanding of love plays a significant role in

the individual's ability to establish healthy social relationships later in life (Gül, 2020). Children learn behaviors that will enable them to adapt to social life at an early age, and these learnings become deeply ingrained in the individual's personality structure. Indeed, many character traits, commonly referred to as "temperament," are shaped through the family during childhood (Aydın, 2003). In this context, the family's influence on the child is decisive in ensuring order, peace, and development in society. Because the family, which is the child's first socialization environment, contributes to the strengthening of the social structure by enabling individuals raised with love and attention to be happier, healthier, more self-confident, and more successful.

Achieving peace, reconciliation, and integration in society; preventing injustices; and preserving the social structure depend on love-based values being the determining factor in social relations. Values such as loyalty, honesty, tolerance, solidarity, sharing, and compassion only gain meaning within the framework of love. In today's rapidly changing society, where values are eroding, establishing relationships on a foundation of love has become essential. Establishing a climate of love in society requires the adoption of certain ethical behaviors. Avoiding fault-finding, controlling anger, forgiving, avoiding suspicion, refraining from mockery and offensive attitudes, being patient, and showing respect and compassion in family and social relationships form the basis of this process (Akın, 2007: 137-147). In addition to all this, the impact of love on education is undeniable.

Love is one of the most fundamental building blocks of education. However, teachers need to maintain balance in their attitudes in the classroom; they should avoid overly lenient or overly harsh behaviors (Çelebi, 2016). Authoritarian and harsh approaches, in particular, can lead to adjustment problems in students, the development of feelings of resentment and hatred, and even alienation from school. This situation can negatively affect both the psychological and physical development of students, as well as prevent the formation of a healthy learning process in the classroom (Bayraktar, 1994). Therefore, it is of great importance that the relationship between teacher and student in classroom management is shaped by a discipline based on love and tolerance. In such an environment, the learning process becomes more effective, and the emergence of undesirable behaviors can be largely prevented. Furthermore, students' development of self-confidence, acquisition of self-control skills, and internalization of critical thinking are possible through maintaining a flexible, supportive, and trust-based classroom atmosphere (Yeşilyurt, 2008).

Love-based bonds foster empathy and strengthen social relationships. The first and most effective environment for acquiring these values is the family. The family plays a decisive role in a child's personality development and social adaptation. Individuals raised with love and attention lead healthier and more successful lives, both individually and socially; this contributes to social peace and development.

3.5. A Value in Social Integration: Tolerance

Concepts such as tolerance, forbearance, and indulgence, while appearing etymologically similar, are phenomena with a deep historical background in terms of their content. Although these terms have been defined and conceptualized within modern thought systems, traces of these attitudes can be found in the earliest periods of human history, especially in the processes where social life and human relations began to develop. Therefore, although these concepts have found their place in the theoretical realm in later periods, they have existed in practice since the very beginning of human life (Aslan, 2001). The concept of tolerance is generally used in Turkish as the equivalent of the English word "tolerance." The word 'tolerance' is derived from the Latin verb "tolerare" and is used in the meanings of 'to endure', 'to allow', or 'to tolerate an unavoidable evil' (Batuhan, 1959). The Turkish word 'hoşgörü' (tolerance) is formed from the combination of the Persian word 'huş', meaning 'beautiful, pleasant, sweet', and the verb 'görmek' (to see). In terms of meaning, it signifies evaluating differences with a positive perspective and accepting them as having aesthetic value (Aslan, 2001).

Tolerance can be defined as the state of not perceiving the existence of individuals with different languages, genders, religions, beliefs, and thought structures as a threat and not feeling discomfort in the face of these differences. This concept is addressed in various disciplines such as philosophy, religion, sociology, psychology, and philology, and is generally associated with an individual's ability to exercise their fundamental rights and freedoms independently of external interference. On a philosophical level, the concept of tolerance means that an individual does not only close themselves off to their own inner world, but also accepts views outside their own thought system as legitimate and existential, approaching these views with respect and humility. In this context, avoiding the understanding that "mine is absolutely correct" forms the basis of a tolerant stance (Aslan, 2001: 363). With this understanding, tolerance is not only a form of intellectual

acceptance, but also considered a constructive communication process established in interpersonal relationships based on love, respect, and empathy.

Tolerance is a functional form of social interaction that involves an individual understanding the feelings, thoughts, and behaviors of those they perceive as similar or different from themselves; establishing a partnership based on love, respect, trust, and empathy without expecting anything in return (Büyükkaragöz, 1995: 22). In short, tolerance means "tolerating" individuals whose views and feelings contradict our own. Accepting different feelings and thoughts as natural, allowing these feelings and thoughts to be freely expressed, accepting differences without resorting to force or coercion, and perhaps most importantly, loving people are necessary preconditions for tolerance to be realized (Kavcar, 1995: 1-2). Tolerance is a fundamental value not only in interpersonal relationships but also for the peace and stability of social life. Accepting differences not as a cause of conflict but as an indicator of social richness is only possible with the establishment of a tolerant perspective. In this context, tolerance is considered an indispensable precondition for the development of a democratic society and the realization of the principle of pluralism. In an environment where people can freely express their thoughts, beliefs, and lifestyles, achieving social peace becomes more likely. Therefore, tolerance is not only an individual virtue but also a cornerstone of social integration and a sustainable peace.

The contribution of spiritual values to tolerance is directly related to an individual's ability to achieve inner harmony and balance. Individuals with inner peace exhibit more understanding and flexible approaches to environmental differences. In this respect, tolerance is the visible reflection of an individual's spiritual world in social relations. This is also emphasized in studies conducted within the context of religious education. For example, Kesimoğlu's (2019) study states that Islam highlights the principle of tolerance towards differences and others through written sources, and that this principle should be instilled in individuals through education. These findings show that spiritual education is not limited only to individual development; it is also an important factor that strengthens social harmony and the culture of coexistence.

In all respects, tolerance is a fundamental social value that refers to individuals developing a respectful attitude towards different belief systems, thought patterns, lifestyles, and identities. In today's societies, where cultural pluralism has become more pronounced due to the impact of globalization, tolerance plays an indispensable role in building a culture of coexistence. Considering that people have no control over elements such as ethnicity, language, religion, or cultural affiliation, these differences should be evaluated not as a cause of conflict, but as resources that nourish social development and cultural richness. Social relationships built on respect for diversity strengthen both individual learning and social solidarity. Tolerance, when considered both in terms of its place in interpersonal relationships and its function in the holistic structure of society, is an important value that contributes to social harmony and peace.

3.6. The Value of Responsibility as an Element of Social Structure

The concept of responsibility is defined by the Turkish Language Association (TDK) (2020) as an individual's assumption of the consequences of their own actions or any situation within their area of authority. It is observed that there are various deficiencies in value awareness in daily life; although there is awareness of values at the societal level, there are shortcomings in translating these values into behavior. In this context, it is noteworthy that individuals exhibit insensitivity towards the value of responsibility, avoid self-criticism, and do not make a meaningful effort towards their moral development. The fact that humans are social beings necessitates that they be aware of their responsibilities and shape their attitudes and behaviors in accordance with this awareness (Öncel, 2020: 873).

Responsibility means that an individual takes responsibility for the consequences of their own actions and fulfills their duties correctly and on time. As a social value, responsibility enables individuals to act with a sense of duty not only to themselves but also to their families, communities, and environments. A sense of responsibility contributes to individuals becoming reliable, consistent, and respectful; it also ensures the continuation of social order and cooperation. Education, family, and social environment play a major role in the development of this value.

The concept of responsibility is closely related to conscious awareness of the consequences of actions and the will to be accountable. According to Başaran (1974), the sense of responsibility is an internal attitude shaped by an individual's commitment to completing a given or undertaken task, despite all difficulties, and assuming responsibility for explaining the consequences of that action when necessary. This feeling develops as a result of the interaction between an individual's experiences from the social environment and ideals based on reason and ethical values. Similarly, Civelek (2006) defines responsibility as the awareness of complying

with rules, the use of intellectual capacity, and the obligation to act respectfully and carefully towards others and their rights.

Individuals with a sense of responsibility tend to exhibit more sensitive and considerate behaviors in pursuit of betterment. This attitude contributes not only to individual development but also to social well-being and leaving a more livable world for future generations. In this respect, education in the value of responsibility aims to enable individuals to become aware of their responsibilities and to contribute to the development of behaviors in line with this awareness (Aktepe, 2015: 151). The basic stages of responsibility can be listed as: showing sensitivity to the rights and feelings of others, being diligent, being able to manage one's own behavior (self-management), and being helpful. For the development of social responsibility awareness, it is primarily necessary for the individual to have internalized a sense of personal responsibility (Ay and Dal, 2014: 81).

As a social value, responsibility refers not only to individuals bearing the consequences of their own actions, but also to acting with a sense of duty towards their families, communities, and environments. This value forms the basis of virtues such as trustworthiness, consistency, and respect, and plays a vital role in maintaining social order and cooperation. A sense of responsibility develops through the influence of education, family, and social environment, and is strengthened by individuals demonstrating sensitivity to rights, utilizing self-governance abilities, and acting with the common good in mind. In this way, responsibility becomes an indispensable value contributing to both individual and societal development.

3.7. The Value of Empathy in Social Interaction

Empathy is the process by which an individual puts themselves in the place of another person, evaluates events from their perspective, accurately understands and internalizes the feelings and thoughts of the other party, and effectively reflects this understanding. Just as intelligence is a crucial factor in cognitive development, empathy plays a similarly critical role in interpersonal communication. Especially for children, social skills and positive social behaviors are fundamental requirements for healthy individual and social development (Ersoy and Köşger, 2016: 9).

Empathy, conceptually, is the process of an individual putting themselves in another's place and accurately perceiving and understanding their feelings and thoughts. An empathetic person sets aside their own thoughts and judgments, directing their attention and mental energy towards understanding the inner world of the other individual (Özbek, 2005: 9). The capacity of individuals to feel the joys and sorrows of others as if they were their own, which underlies empathy, highlights the necessity of a love-based approach in human relationships (Ayten, 2010: 79). Empathy is not only a skill that strengthens interpersonal understanding, but also plays a critical role in building social harmony and peace. Empathetic individuals are more adept at reducing conflicts, respecting differences, and developing cooperation. In this respect, empathy forms the basis of healthy relationships in social institutions such as family, school, and society. Empathy-based approaches in education develop children's emotional intelligence, enable them to gain a sense of responsibility, and contribute to their becoming more sensitive individuals to social values.

Empathy is a multifaceted concept with spiritual, ethical, and moral dimensions, beyond its function of regulating individual and social relationships. As an emotional faculty, empathy is situated within a value system and, associated with virtues such as compassion, justice, and empathy, supports an individual's spiritual maturation and sense of social responsibility.

Empathy, a process in which an individual tries to understand another's feelings and thoughts by putting themselves in that person's place, plays a fundamental role in establishing healthy interpersonal relationships (Derman and Bağ, 2021). An empathetic approach not only strengthens interpersonal understanding but also contributes to the development of social harmony, peace, and mutual respect. In the modern world, the increase in individualism and superficial relationships further increases the importance of empathy skills. Individuals who practice empathy are more sensitive to the needs of others, reduce interpersonal conflicts, and can communicate more effectively.

Furthermore, empathy benefits not only the other person but also the empathetic individual. It supports psychological development, facilitates self-expression, increases social adaptation, and develops a sense of responsibility (Derman and Bağ, 2021). Ultimately, empathy-based relationships are considered key to a healthy and sustainable life, both individually and socially.

In short, empathy as a social value is the ability of an individual to put themselves in the place of others, understand and internalize their feelings and thoughts, and effectively reflect this understanding. This value enables individuals to respect differences, reduce conflicts, and increase cooperation. Furthermore, empathy

supports individual psychological development while contributing to the strengthening of a sense of responsibility and social sensitivity.

3.8. The Concept of Patience and its Social Value

Patience is generally considered the virtue of waiting patiently for difficult and challenging situations to end without reacting. In the context of ethics, patience is defined as the fortitude shown in the face of sorrow, hardship, and calamities, with the aim of transforming negative conditions into positive ones (Çağrı, 2008: 337). The concept of patience appears in many verses of the Quran. Among these verses, there are recommendations regarding the importance of being patient, as well as explanations of what kind of situations patience should be shown. For example, in verse 155 of Surah Al-Baqarah, it is stated, "And We will surely test you with a little fear, hunger, and loss of wealth, lives, and crops. But give good tidings to those who are patient," emphasizing that patience is a test and that this test should be shown in the face of various difficulties. In general, patience is recommended in enduring trials and tribulations, and in adhering to religious commands and prohibitions. The verses immediately follow the plea for help from God with the command to "be patient," emphasizing that patience is only possible "with God's help."

The term patience, in its dictionary definition, is described as a virtue and resilience that refers to remaining silent in the face of negative and challenging situations such as suffering and poverty, and patiently waiting for these situations to end (Parlatır, 2011). The word "patience," which came into Turkish from Arabic, is derived from the verb "sabera." The word "sabera" includes the meanings of patience, endurance, calmness, inner peace, self-control, and keeping one's ego under control in accordance with reason and the requirements of Sharia (Mutçali, 2012:576). The word "sabr" is of Arabic origin and its basic meanings include imprisoning, restraining oneself or others from something, arresting someone to kill them (e.g., al-masburah: a person imprisoned to be killed), seizing tightly (e.g., katelehu sabran: he seized him tightly and killed him), binding someone, taking revenge on someone, punishing, retaliating, applying retaliation, and guaranteeing someone's safety (Demirci, 2002: 264).

The concept of patience, which entered Turkish from Arabic, originates from the verb "sabera." This concept specifically refers to self-control in the face of hardship and difficult circumstances. Furthermore, in Arabic, actions such as "intizar," meaning waiting or patiently observing, are also expressed with the word "sabr" (Doğan, 2017: 135). In line with these definitions, patience is not merely a state of waiting, but also expresses a conscious and determined stance in the face of difficulties.

Patience is defined as a strategy for rationally and effectively dealing with problems, rather than passively waiting in the face of life's difficulties, challenges, and obstacles. It also encompasses qualities such as resilience, fortitude, calmness, and courage. While some individuals may be more predisposed to patience due to their personality traits, in general, patience is considered a virtue acquired through time and experience.

In Islamic thought and Sufi literature, the concept of patience is addressed from various perspectives. For example, Ghazali (1976) examined patience in three distinct dimensions: cognitive (scientific), emotional (state), and behavioral (action), and defined two types of patience according to its difficulty level. The first type, easy patience, refers to the mental, emotional, and behavioral attitudes displayed in the face of relatively less challenging situations that do not place a heavy burden on the individual's self. The second type, called "tasabbur," is the state of patience that arises after experiences that are difficult for the individual to bear, usually from a spiritual and mental standpoint.

Patience is the ability to consistently and resolutely work towards achieving a goal believed to be attainable, and to calmly and steadfastly await the necessary process. It also involves resisting temptation and easy paths, and enduring difficulties and hardships without complaint. Patience, as the capacity to withstand hardship and suffering, is a manifestation of spiritual maturity. Various hardships in life, such as loss of life, loss of property, fear of death, illness, war, and hunger, are tests that an individual faces during their maturation process. Patience, then, is the expression of successfully overcoming these tests.

Patience, a multifaceted concept encompassing both individual virtue and profound religious and moral dimensions, is frequently emphasized in the Quran and holds a significant place in Islamic thought. The concept of patience is not merely a passive waiting in the face of difficulties, but also an expression of a conscious, determined, and resilient stance. Definitions from dictionaries, ethics, and Sufi contexts demonstrate that patience is a virtue shaped by cognitive, emotional, and behavioral dimensions, manifesting both in a person's inner world and social life.

When considered holistically, patience is not merely an individual trait but also a fundamental value that contributes to the establishment of order, solidarity, and peace in social life. Individuals acting patiently in the face of conflicts, crises, injustices, and difficulties in social relationships serves both to maintain social harmony and to foster a culture of coexistence. Patience, especially during processes of social transformation, enables individuals to exhibit sensible attitudes by avoiding impulsive reactions; it is also closely related to other values such as social solidarity, empathy, and tolerance.

As a societal value, patience enables the development of intergenerational understanding, especially within families, facilitates students' adaptation to learning processes in educational settings, and allows society to act together without disintegration during times of crisis. It also contributes to sound decision-making processes by preventing hasty and prejudiced attitudes in the administration of justice.

4. Methodology

4.1. Purpose of the Study

The primary objective of this study is to examine the functions of social values within individual and societal life from a sociological perspective and to elucidate their contributions to social integration. The study addresses the roles of fundamental social values—such as religion, family, respect, love, tolerance, empathy, patience, and responsibility—in shaping individual behavior, internalizing social norms, and sustaining the social order. Furthermore, by evaluating the impacts of modernization, globalization, digitalization, and individualization processes on social values, the study discusses whether these values retain their unifying and integrating functions in contemporary societies.

4.2. Significance of the Study

The sustainability of social life is largely dependent on the presence of shared values among individuals. However, the rapid processes of social change experienced today are causing significant transformations in traditional value systems. Concurrently, increasing tendencies toward individualization and the proliferation of digital culture can lead to the erosion of shared value spheres. This situation necessitates a re-evaluation of concepts such as social belonging, solidarity, and integration. By approaching social values through the metaphor of "social cement," this study aims to highlight their functions in preserving the social order and strengthening social bonds. In this regard, the research is expected to contribute to theoretical debates within the sociology of values and aid in the understanding of contemporary social issues.

4.3. Research Method

This study is designed as a theoretical inquiry based on a qualitative research paradigm, employing a systematic literature review as the primary data collection technique. Social values were examined in their conceptual and theoretical dimensions through a comprehensive review of relevant books, peer-reviewed articles, and dissertations. As a non-empirical study lacking field research, the obtained theoretical data were analyzed using a descriptive analysis approach. The impact of fundamental values on social integration was subsequently interpreted from a sociological perspective. Accordingly, the research aims to synthesize the existing literature to explain, on a theoretical level, the functions of social values in regulating individual-society relations, reinforcing solidarity, and ensuring cultural continuity.

5. Conclusion and Recommendations

This study was prepared to explain the regulatory and unifying role of values in individual-society relations; in particular, the effects of fundamental values such as religion, family, responsibility, empathy, patience, tolerance, love, and respect on the social structure were evaluated within a theoretical framework. Based on the findings, it was concluded that social values have functions in guiding individual behavior, strengthening social bonds, and ensuring cultural continuity.

Values not only provide moral guidance but also form a common ground that holds society together. The transmission of values, beginning in the family and continuing through institutions such as education, religion, and culture, plays a significant role in the formation of an individual's identity and the development of social belonging. Emotionally based values such as love, respect, and tolerance reinforce empathy and understanding in interpersonal relationships, while behavioral values such as responsibility and patience contribute to maintaining social order.

However, in today's world, processes such as modernization, individualization, digitalization, and globalization are causing the dissolution of traditional value systems and the emergence of new value forms. This transformation also affects individuals' orientations and social affiliations; it can lead to a loss of values

and identity confusion, especially among younger generations. Therefore, values should be considered not only as a legacy of the past but also as dynamic elements that play an active role in building the future.

The metaphor of social glue suggests that values are not merely individual attitudes or abstract principles; they are a binding force that enables society to remain together and ensures harmony among different elements. For social cohesion and peace, preserving, reinterpreting, and actively integrating values into social life is essential. Otherwise, in societies where values weaken or are disregarded, trust between individuals decreases, social disintegration accelerates, and the functionality of social institutions is damaged.

Values represent a society's identity, cultural continuity, and moral integrity, going beyond individual behavior. The fundamental view advocated in this study is that values should not only be learned but also internalized, lived, and passed on to future generations. Upholding values as the social glue should be seen as a guarantee of both individual well-being and societal stability.

Based on the findings of this study, it is essential to approach values education holistically in order to preserve and transmit societal values from generation to generation. Values should be learned not only theoretically but also through experience in the individual's daily life. In this sense, each of the fundamental areas of socialization, such as family, school, media, and religious institutions, should play a complementary role in the transmission of values; teaching values should be based not only on words but also on behavior and example. In particular, individuals' introduction to and internalization of values during childhood and adolescence will contribute to their development as individuals who uphold these values and contribute to society in their later lives.

In today's world, rapid social changes, technological advancements, and the influence of digital media are transforming individuals' perceptions of values. Therefore, reinterpreting traditional values in a contemporary context and giving them meaning according to the demands of the age is crucial. Values should not be treated as fixed and static principles, but rather as social phenomena that can evolve and deepen over time, thus creating a structure that can be reproduced at both individual and societal levels. In this process, institutions such as universities, think tanks, and civil society organizations have a responsibility to conduct value-oriented studies. Furthermore, it is a vital need and necessity that media content be structured in a way that strengthens values and supports social cohesion, rather than undermining them.

To ensure the continuation of values, individual sensitivity alone is insufficient; this process must also be supported by public policies. Values education should be incorporated into educational curricula in a more systematic and applicable manner, and teachers should be equipped with the necessary skills in this area. Furthermore, awareness campaigns and social projects aimed at promoting fundamental values such as tolerance, respect, responsibility, patience, and justice at the societal level should be encouraged. These values, which guide society towards the common good, should be seen not only as an individual achievement but also as the foundation of societal resilience and unity. Preserving and strengthening values means not only protecting the legacy of the past but also building the future.

This study reveals that societal values are not merely value-based principles guiding individual behavior, but fundamental structural dynamics that play a decisive role in the construction of institutional continuity and collective identity through social integration. In this context, the sustainability of values necessitates holistic and strategic interventions across various fields, including education systems, family structures, cultural policies, and digital communication environments, extending beyond individual acquisitions. In particular, re-imagining values education not merely as theoretical content, but as an experience-based process integrated with practice, is critically important for individuals to internalize these values and reflect them in their daily lives. The preservation and intergenerational transmission of societal values should not be limited to cultural continuity; it should also be considered a strategic necessity for establishing social trust and maintaining social stability.

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Author Contributions

This study was conducted with equal contributions from both authors (50% – 50%)

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

This study was designed as a theoretical research based on a literature review, and no fieldwork or applied research involving human participants was conducted. Therefore, ethical committee approval was not required, and no ethics committee approval was obtained for this study.

References

- Abuzar, C. (2011). Dinin toplumsal yaşam üzerindeki etkisi. *Harran Üniversitesi İlahiyat Fakültesi Dergisi*, 26(26), 143-153.
- Adak, N. (2015). Toplumun Temel Yapı Taşı: Aile. *Kurumlara Sosyolojik Bakış*, (Ed: S. Güçlü.), İstanbul: Kitapevi, 27-60.
- Akın, S. (2007). İslam'da insan sevgisi. *Harran Üniversitesi İlahiyat Fakültesi Dergisi*, 17(17), 137-147.
- Akkaya, N. (2017). Kıbrıs Türk Masallarında Değerler. *Folklor/Edebiyat*, 23(90), 231-244.
- Aksan, G. (2016). Max Weber ve Değerler Sosyolojisi: Bir Metodolojik İkilemin Düşündürdükleri/Max Weber And Sociology of Values: Reflections On A Methodological Dilemma. *Selçuk Üniversitesi Edebiyat Fakültesi Dergisi*, (35), 427-446.
- Aktepe, V. (2015). 5. Sınıf Öğrencilerinin Sorumluluk Değerinin Geliştirilmesine Yönelik Bir Performans Görevi Uygulaması. *Kastamonu Eğitim Dergisi*, c. 23, s. 4, ss. 1511-1534.
- Altunsoy, Y., & Namlı, Z. B. (2021). Duygu ve düşüncelere saygı değerinin etkinlik temelli öğretiminin saygı eğilimine etkisi. *Değerler Eğitimi Dergisi*, 19(42), 305-335.
- Arslantürk, Z. , Amman, M., T. (2017). *Sosyoloji, giriş, kuramlar, kurumlar, süreçler, teoriler*, İstanbul: Çamlıca Yayınları, 11. Baskı.
- Aslan, Ö. (2001). Hoşgörü ve tolerans kavramlarına etimolojik açıdan analitik bir yaklaşım. *Cumhuriyet Üniversitesi İlahiyat Fakültesi Dergisi*, 5(2), 357-380.in
- Avcı, E. K., & Faiz, M. (2019). Sosyal bilgiler öğretmen adaylarının çok boyutlu sosyal değerler düzeylerinin çeşitli değişkenler açısından incelenmesi. *Erzincan Üniversitesi Eğitim Fakültesi Dergisi*, 21(3), 108-128.
- Ay, T. S. & Dal, S. (2014). İlköğretim Öğrencilerinin Yazılı Anlatım Ürünlerine Göre Sorumluluk Değeri Algıları. *Dicle Üniversitesi Ziya Gökalp Eğitim Fakültesi Dergisi*, (22), 78-93.
- Aydın, M. (2016). *Kurumlar Sosyolojisi: Kurumlara Başlangıç Çerçevesinde Bir Çalışma*. Dördüncü Baskı, Açılım Kitap: İstanbul.
- Aydın, M. Z. (2003). Ailede ahlak eğitimi. *Cumhuriyet Üniversitesi İlahiyat Fakültesi Dergisi*, 7(2), 125-158.
- Aytaç, Ö. (2002). *Sosyoloji: Bir Giriş Denemesi*. Üniversite Kitabevi, Elazığ.
- Ayten A. (2009), *Prososyal Davranışlarda Dindarlık ve Empatinin Rolü*, (Tamamı Yayımlanmamış Doktora Tezi), M. Ü. Sosyal Bilimler Enstitüsü, İstanbul.
- Başaran, İ. E. (1974). *Eğitim psikolojisi* (3. Baskı). Ankara: Yargıçoğlu.
- Batuhan, H. (1959). *Batıda Tolerans Fikrinin Gelişmesi*. İstanbul: İstanbul Matbaası.
- Bayraktar, L. (2021). Yunus emre düşüncesinde medeniyet değerleri. *Ankara Üniversitesi Dil ve Tarih-Coğrafya Fakültesi Dergisi*, Yunus Emre Özel Sayısı, 48-56. <https://doi.org/10.33171/dtcfjournal.2021.61.3.4>
- Bingöl, İ. (2025). Communication In The Family As A Social Microcosm: Communication Problems And Solutions, 14th International Mardin Artuklu Scientific Researches Conference, June 1-3, 2025 / Mardin, Türkiye
- Büyükkaragöz, S. (1995). "Hoşgörü Demokrasi ve Eğitim" *Sağlıkta Hukukta Eğitimde Demokraside Hoşgörü*. Konya: Konya Sağlık Eğitim Enstitüsü Yayınları.
- Canatan, A. (2008). Toplumsal değerler ve yaşlılar. *Yaşlı Sorunları Araştırma Dergisi*, 1(1), 62-71.
- Cilacı, O. (1995). *Günümüz dünya dinleri*. Ankara, Diyanet İşleri Başkanlığı.

- Civelek, B. (2006). Çocuklara sorumluluk bilinci kazandırmak. Çoluk Çocuk Aylık Anne Baba Eğitimci Dergisi, 58, 20-22.
- Coşkun, H. (2024). Dini Gruplar Sosyolojisi (Ed: Emine Öztürk, Din Sosyolojisi içinde, Ankara: Akademisyen Kitabevi, ss. 237-254.
- Çağrı, M. (2008). Sabır. Diyanet İslam Ansiklopedisi, (35). 337-339.
- Çelebi, K. A. (2016). Ahlak-ı Ala'i. (Çev: Murat Demirkol) Ankara: Fecr Yayınları.
- Demirci, M. (2002). Kur'an-ı Kerim ışığında sabır kavramı. Erciyes Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 1(12), 263-285.
- Derman, G. S., Bağ, V. (2021). Kişilerarası İlişkilerde Empati: İnsanın Manevi Dünyası ile Empati Arasındaki İlişkinin İncelenmesi. International Journal of Social and Economic Sciences, 11(1), 1-11.
- Doğan, M. (2017). Karakter gücü olarak sabır ve psikolojik iyi oluş ilişkisi. The Journal of Happiness & Well-Being, 5(1), 134-153.
- Doğan, M. (2023). Ailede Değerlerin İnşasına Psikolojik ve Pedagojik Yaklaşım: Sevgi, Saygı, Sabır, Hoşgörü Değerleri Örneği. Kocatepe İslami İlimler Dergisi, 6(2), 541-565.
- Dönmezer, S. (1984). Sosyoloji, Ankara.: Savaş Yayınları.
- Erkan, S. (2010). Aile ve Aile Eğitimiyle İlgili Temel Kavramlar. (Ed: F. Temel.). Aile Eğitimi ve Erken Çocukluk Eğitiminde Aile Katılım Çalışmaları. Ankara: Anı Yayıncılık.
- Ersoy, E. (2018). Sosyolojide Değerler ve Değer Araştırmaları. Journal of International Social Research, 11(56).
- Ersoy, E. G., Köşger, F. (2016). Empati: Tanım ve Önemi. Osmangazi Tıp Dergisi/ Osmangazi Journal of Medicine,, 38 (2), 9-17 DOI: <http://dx.doi.org/10.20515/otd.33993>
- Fichter, J. H. (2016). Sosyoloji Nedir? (Çev. N. Çelebi), Ankara: Anı Yayıncılık, 3. Baskı
- Frankel, J. D. (2012). Medeniyet (ler) in Küresel Çağında Din (ler) in Rolü. Medeniyet ve Değerler içinde, (Ed. Recep Şentürk) İstanbul Ticaret Odası Yayınları, Yayın No: 2012-33 ss.313-331.
- Gazali, M. (2007). İhya'u Ulumi'd-Din (Çev. Mehmed A. Müftüoğlu), İstanbul: Vefa Yayınları.
- Glidden, M. (2016). Culture, religion/spirituality, and marriage: What does the research say?. Azusa Pacific University.
- Gül, H. (2020). Değişen kent ailesinde sevgi anlayışları ve ilişkilerine sosyolojik bir yaklaşım. Din ve bilim. Muş Alparslan Üniversitesi İslami İlimler Fakültesi Dergisi, 3 (2), 83-96.
- Günay, Ü. (1998). Din sosyolojisi, İstanbul: İnsan Yayınları.
- İnce, A. (2017). "Değer" İle "Sorun" Arasında Türkiye'de Yaşlılarla İlgili Toplumsal Değer Yargıları (Din Bilimleri Perspektifinden Bir İnceleme). Sakarya Üniversitesi İlahiyat Fakültesi Dergisi (SAUIFD), 19(36), 83-112.
- Kağıtçıbaşı, C. (2010). Benlik, aile ve insan gelişimi-kültürel psikoloji. Koç Üniversitesi Yayınları, İstanbul.
- Karlı, E. (2019). Modernleşme Sürecinde Çözülen Aile Yapısı ve Kadının Yeniden İnşası. Uluslararası Hukuku ve Sosyal Bilimler Araştırmaları Dergisi, 1 (1), 1-14.
- Kavcar, C. (1995). Hoşgörü ve eğitim toplantısı açılış konuşması (Yayına haz: İ. Pehlivan), Ankara: UNESCO Türkiye Milli Komisyonu ve Ankara Üniversitesi Eğitim Bilimleri Fakültesi Ortak Yayın No: 2, ss. 1-4.
- Kavıracı, O. (2020). Toplumsal değerler çerçevesinde kamu hizmetleri ve profesyonel polislik. OPUS International Journal of Society Researches, 15(1), 5308-5337.
- Kesimoğlu, M. (2019). Din eğitimi açısından tolerans kavramı. (Yüksek lisans tezi, Bursa Uludağ Üniversitesi).
- Kıral, E. (2018). Kayıp giden bir değer: Saygı. Çağdaş Yönetim Bilimleri Dergisi, 5(1), 4-10.
- Kirman, M. A. (2004). Din Sosyolojisi Terimleri Sözlüğü, İstanbul: Rağbet Yayınları.
- Koç, M. (2018). Psikolojik ve pedago-sosyo-teolojik açıdan güven: din ve değerler psikolojisi perspektifinden analizler. Hitit Üniversitesi İlahiyat Fakültesi Dergisi, 17(33), 1-38.
- Kongar, E. (1985). Türkiye'nin toplumsal yapısı. İstanbul: Remzi Kitabevi.
- Korkmaz, A. (2013). Değerler sosyolojisi. Toplum Bilimleri Dergisi, 7(14), 51-78.

- Köse, Ü., & Direkci, B. (2022). Şehbenderzâde Filibeli Ahmed Hilmi'nin Eserlerinin Kök Değerler Açısından İncelenmesi. *Turkish Academic Research Review*, 7(4), 1005-1023.
- Küçükoglu, A., Albayrak, F., & Serin, N. (2020). Değerler Eğitimi Bağlamında Türkçe Dersi: Program ve Ders Kitaplarının Karşılaştırmalı İncelenmesi. *Journal of Mother Tongue Education/Ana Dili Eğitim Dergisi*, 8(4), 1499-1518.
- Maslow, A. (1987). *Motivation and Personality*, 3rd Edition, Frager, R., Fadiman, J., McReynolds, C., & R. Cox (Editors), Longman; (January 1, 1987).
- Mutçalı, S. (1995). *Arapça - Türkçe sözlük*. İstanbul: Dağarcık. El-İsfahani, R. (2012). *Müfredat Kur'an kavramları sözlüğü* (3. baskı). İstanbul.
- Öncel, H. (2020). Sorumluluk Değeri ve Pratiğe Yansıması-Etik Yaklaşım-. *Journal of International Social Research*, 13(75). ss. 870-878.
- Özbek, M. (2005). İnsan ilişkilerinde empatinin yeri ve önemi. In *Journal of Social Policy Conferences* (No. 49). İstanbul University.
- Özkalp, E. (2017). *Sosyolojiye giriş*, Ekin Yayınevi: Bursa. 27. Baskı.
- Parlatır, İ. (Ed.). (2011). *Türkçe sözlük* (11. baskı). Ankara: Atatürk Kültür, Dil ve Tarih Yüksek Kurumu, Türk Dil Kurumu.
- Sayın, Ö. (1990). *Aile Sosyolojisi- Ailenin Toplumdaki Yeri*, Ege Üniversitesi Basımevi: İzmir.
- Selman, A. (2018). Aile-din ilişkisi ve aile içi roller. *Akademia Doğa ve İnsan Bilimleri Dergisi*, 4(1), 13-20.
- Şahin, M. (2022). *Değerler Sosyolojisi*. Ankara: Net Kitaplık Yayıncılık.
- TDK (1998). *Türkçe Sözlük*, Ankara, Cilt:2, s:1268
- Tekin, M., (2011). "Dinlerin Perspektifinden Aile Kurumu", (Ed. Kadir Canatan,-Ergün Yıldırım), *Aile Sosyolojisi içinde, Açılım Kitap: İstanbul*
- Teyfurov, M. (2014). Kur'an-ı Kerim'de aile yapısı. *Iğdır Üniversitesi İlahiyat Fakültesi Dergisi*, (3), 183-200.
- Topçuoğlu, A. (1996). Üniversite gençliğinin sosyal değerleri. Selçuk Ü. Fen-Edebiyat Fakültesi, Konya,(Yayınlanmamış doçentlik tezi).
- Turğut, F. (2017). Tarihsel Süreçte Aile Kurumunun Dönüşümü ve Geleceğine Yönelik Çıkarımlar. *Medeniyet ve Toplum Dergisi*, 1(1), 93-117.
- Tüfenkci, S. (2023). "Felsefede Değer Kavramı", (Ed: Semra Tüfenkci, Fatma Balcı Aras), *Farklı Disiplinlerde Değer Kavramı içinde, Palet Yayınları: Konya*.
- Türk Dil Kurumu. (2020). Sorumluluk. <http://www.tdk.gov.tr> (Erişim Tarihi: 28.07.2025).
- Türkyılmaz, H., Canbulat, T., Arapoğlu, H., & Çıraklı, Y. (2020). Toplumsal Değerlerin Aktarılmasında Farklı Bir Yöntem: İzcilik1. *Journal of History School (JOHS)*, ss. 2901-2915.
- Yaşaroğlu, C. (2024). Sınıf Öğretmenlerinin Sürdürülebilir Değerler Eğitiminine İlişkin Görüşlerinin İncelenmesi. *Social Sciences Studies Journal (SSSJJournal)*, 6(72), 4626-4640.
- Yavuzer, H., & Cihan, E. (2023). Din Toplum İlişkisi. *Uluslararası Türk Dünyası Araştırmaları Dergisi*, 6(4), 109-124.
- Yazan, Ü. M. (1989). İleri Endüstri Toplumlarında Aile Kurumu Üzerine Bir Araştırma. *İstanbul University Journal of Sociology*, 3(1), 147-174.
- Yazıcı, A., & Yazıcı, S. (2015). Saygı Ölçeğinin Geçerlik ve Güvenirlik Çalışması. *Electronic Turkish Studies*, 10(14), ss.769-780.
- Yazıcı, M. (2013). Toplumsal Değişim ve Sosyal Değerler. *Electronic Turkish Studies*, 8(8). ss. 1489-1501.
- Yeşilyurt, E. (2008). Eğitim programlarının hedeflerine ulaşılması bağlamında sınıf yönetimi dersinin öğretmen adaylarına olan kazanımları. *Kuramsal Eğitimbilim Dergisi*, 1(2), 23-42.
- Yolcu, A. (2022). Sevginin birey, aile, toplum ve eğitim üzerindeki etkileri. *Academic Platform Journal of Halal Lifestyle*, 4 (2), 59-71.
- <https://www.habereguven.com/toplum-ve-saygi-insan-iliskilerinin-temel-kose-tasi> (Erişim Tarihi: 09.06.2025).

Artificial Intelligence Agents and Consumer Behavior: A Bibliometric Analysis of an Emerging Research Field

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Abstract

Recent dynamic advances in AI technologies have brought about profound transformations in the marketing paradigm and in consumer behavior and interactions. At the heart of this transformation, the relationship between AI agents and consumer behavior stands out as a timely area calling for in-depth investigation in the literature. This study constitutes a bibliometric analysis undertaken to reveal the intellectual accumulation of knowledge in this conceptual domain and to examine the evolution of the literature systematically. To this end, 438 articles indexed in the Web of Science (WoS) database between 2020 and 2026 were subjected to a comprehensive examination. The research first conducted a performance analysis to resolve the quantitative structure of the field, mapping annual publication distributions, the most prolific authors, the most highly cited studies, leading countries, and institutional collaborations. It then carried out citation, co-citation, and co-occurrence analyses using science mapping techniques in order to structure the intellectual framework of the field. The findings show that the AI agent literature emerging in the context of consumer behavior is following a growth trend that is gaining momentum in both quantitative and qualitative terms. Thematically, the literature was found to concentrate on the transparency and interpretability of AI algorithms, the implications of these algorithms for consumer attitudes and behavior, the strengthening of human-AI interaction through anthropomorphic design elements, the dark side encompassing ethics, privacy, and trust, and sectoral reflections in the service industry.

1. Introduction

Over the past few years, AI has moved to the center of business innovation, owing to its capacity to anticipate consumer behavior and optimize organizational processes. By delivering operational efficiency across a wide range of domains, from logistics to customer relationship management, the technology is fundamentally reshaping how firms and consumers interact (Haque et al., 2024; Hoyer et al., 2020; Ma & Sun, 2020). In the course of this shift, AI has ceased to be merely a mechanical tool that executes routine tasks and has evolved into autonomous agents capable of making their own decisions and engaging in social interaction (Humberd & Latham, 2026; Li et al., 2026).

The evolution of generative AI (GenAI) and large language models (LLMs) has made agent-based systems the new reality in the marketplace, systems that can perceive, reason, and form an emotional connection with the customer, thereby exhibiting “feeling AI” and “artificial empathy” (Huang & Rust, 2022; Liu-Thompkins et al., 2022). The growing prevalence of natural language interfaces has reshaped human-computer interaction by giving rise to autonomous entities that can act on behalf of users (Rothschild et al., 2025). The hyper-personalization these systems afford is fundamentally transforming how firms approach market segmentation and targeting (Haque et al., 2024). By enabling the right offer to reach the right customer at the precise moment of need, this capacity maximizes both immediate and future consumption opportunities (Raja et al., 2026).

The launch of ChatGPT marked a turning point in the commercial adoption of AI, and the retail and e-commerce sectors, with their rich data infrastructures, have become primary testing grounds for these technologies (Khoi & Phuc, 2026: 13). The consumer journey has become an active cognitive-support mechanism that AI optimizes in real time (Acar & Schweidel, 2026; Ma & Sun, 2020). Concerns about algorithmic transparency, together with the belief that AI lacks the capacity to “feel” in emotionally charged hedonic contexts, nonetheless sustain a continued preference for human advice (Huang et al., 2025: 1415-1416; Nizette et al., 2025: 50-51). As purchase decisions are delegated to autonomous systems, traditional frameworks have proven inadequate, ushering in a new era that Taşkın (2025: 43) terms the “agentic customer experience.” This evolution offers operational efficiency and personalization across diverse sectors (Dwivedi et al., 2026; Parthiban & Adil, 2023) and is shaped by multidimensional psychological dynamics, including

consumers' preference for receiving bad news from AI (Garvey et al., 2023) and their susceptibility to artificial emotional cues (Han et al., 2023).

Bibliometric and systematic review studies on the role of AI in business and marketing have made notable contributions to the literature. This body of work has examined market research (Loureiro et al., 2021), retail applications (Haque et al., 2024), e-commerce (Zhang & Liu, 2026), banking (Parthiban & Adil, 2023), and customer experience from a sensory marketing perspective (Mouammine, 2026). Consumer-AI interaction (Riandhi et al., 2025) and the use of GenAI in retail (Khoi & Phuc, 2026) have likewise been examined in detail. However, most studies treat conventional automation processes as equivalent to agentic AI. They investigate how variables such as anthropomorphism, artificial empathy, and perceived intelligence shape consumer attitudes toward AI agents, yet they do so within a fragmented framework (Pillai & Sivathanu, 2020; Adam et al., 2021; Moussawi et al., 2021; Riandhi et al., 2025). A comprehensive mapping of how autonomous, decision-making AI agents affect consumer behavior has yet to appear. Addressing this gap, the present study sets out to map the role and theoretical contributions of AI agents within the consumer behavior literature in a holistic manner through bibliometric analysis. To this end, it seeks to answer the core research questions presented below, with the aim of revealing the intellectual structure of the existing literature.

RQ1: What are the research trends and performance patterns in the study of AI agents within the context of consumer behavior?

RQ2: What insights does the literature on AI agents in the context of consumer behavior offer to academic scholarship and practitioners?

RQ3: Which research gaps have been identified in the literature examining AI agents in the context of consumer behavior, and in what areas and in what ways might researchers contribute to this field in the future?

To address the research questions outlined above, the remainder of the study is organized as follows. The second section, following this introduction, presents the conceptual framework. The third section sets out the research methodology and the data collection process. The fourth section reports the results of the performance analysis and science mapping conducted as part of the bibliometric analysis. The study concludes with a discussion section that interprets the findings in light of the existing literature.

2. Conceptual Framework

2.1. The Concept of an Artificial Intelligence Agents

AI rests on transferring distinctively human cognitive faculties to machine systems (Ma & Sun, 2020: 482) and on the capacity of computational machines to emulate the multifaceted abilities of humans. With the rise of ChatGPT in particular, GenAI has become a focal point of intense interest in both academic circles and society at large. Underlying this interest is the fact that such systems have begun to surpass human performance along certain dimensions. Indeed, as Hermann & Puntoni (2024) emphasize, efforts to grasp the capacity of GenAI and its socioeconomic implications remain in their early stages.

AI agents are defined as a concrete instantiation of programs, algorithms, and systems endowed with the capacity to exhibit intelligence (Lei et al., 2025: 599). Having gained visibility, tools such as ChatGPT, DeepSeek, and Google Gemini have moved into the mainstream (Hasselwander et al., 2026), and autonomous AI agents have become technological entities that perceive and interpret environmental data without external oversight and carry out their assigned tasks independently (Gonzalez et al., 2026). Conceptualizing AI agents as representations of the digital human is closely tied to the notion of the digital twin. A digital twin is a virtual counterpart of a physical object, system, or process; sustained by a continuous flow of data, it updates in synchrony with its real-world equivalent and affords real-time monitoring, analysis, and optimization (Korzynski et al., 2025).

The purchase journey of today's consumers is shaped by the multilayered coordination of AI agents operating in the background. From digital search engines to dynamic pricing systems, every touchpoint is optimized in real time through machine learning algorithms. Through this systemic integration, AI ceases to be a tool that passively observes consumer behavior and becomes an active infrastructure that steers and reconfigures behavioral patterns at scale (Ma & Sun, 2020: 481-482). Such a transformation sets the stage for reassessing this emerging body of literature through a range of theoretical lenses.

AI systems, whose economic and functional impact is expanding rapidly, are taking on an increasingly anthropomorphic character across a broad range of domains from education to retail, displaying human-like appearances, emotional expressions, and personality traits (Alabed et al., 2022: 1-2). The “digital humans” that have emerged with the rise of LLMs in particular blur the human-AI boundary in roles ranging from business representation to brand ambassadorship. This shift points to a fundamental paradigm change, one in which AI moves beyond being a purely functional tool and evolves into a social entity capable of forming emotional bonds with users (Kim & McGill, 2025: 363-364). In the specific case of chatbots, however, it should be borne in mind that linguistic anthropomorphism can exert adverse effects on persuasiveness, and that machine language may prove more effective than human language in utilitarian contexts. This calls for designers to deploy anthropomorphic features deliberately and in moderation (Yang et al., 2026). By attributing human qualities to non-human entities, anthropomorphism offers users a multidimensional experience. Anthropomorphic conversational AI is profoundly reshaping how firms manage customer relationships and interactions (Chaturvedi et al., 2025). Anthropomorphic features integrated into AI systems, such as gender, voice, and appearance, positively influence consumers’ brand perceptions and attitudes. Among these features, gender plays a particularly decisive role. Female AI agents tend to be perceived as warmer and more trustworthy, whereas male agents are associated with rationality and task performance. Female agents also appear more persuasive for hedonic products, and male agents for utilitarian ones (Huang et al., 2025: 1416-1417).

Within Social Cognitive Theory, the dimensions of warmth and competence provide a foundational basis for explaining human-robot interaction. Under Social Response Theory and the Computers as Social Actors (CASA) paradigm, users approach these systems according to human norms even when they are aware that the systems possess no consciousness. From the standpoint of Social Presence Theory, the personalized responses and anthropomorphic features that AI provides strengthen the user’s sense of social connection. Alongside these, acceptance models such as the Technology Acceptance Model (TAM), the Service Robot Acceptance Model (SRAM), and the Extended Unified Theory of Acceptance and Use of Technology (UTAUT-2) indicate that perceived ease of use, social interaction, benefit, and trust play a decisive role in the adoption of service robots (De Keyser & Kunz, 2022: 173-174). The proliferation of AI agents has led consumers’ relationship with technology to acquire an emotional dimension that extends beyond functional use. Consumers turn to AI to meet needs such as companionship, support, and personal growth, a development that is transforming expectations of human relationships and patterns of social behavior (Alabed et al., 2024). AI, in transforming both business and society, thus enhances personalization while improving efficiency (Loureiro et al., 2021: 911). It should not be overlooked, however, that excessive reliance on algorithms dulls individual skills and weakens decision-making capacity (Theoharakis & Mylonopoulos, 2026).

2.2. Artificial Intelligence Agents in Consumer Behavior

Across a broad spectrum of sectors such as retail, e-commerce, healthcare, and finance, AI is restructuring corporate decision-making mechanisms and the ways in which value is created (Khoi & Phuc, 2026: 12; Zhang & Liu, 2026). The integration of this technology into advisory and decision-support processes is likewise transforming the dynamics of how consumers interact with the digital service ecosystem (Tang & Son, 2026). Agents powered by GenAI and LLMs in particular, unlike traditional recommendation systems and static platforms, can interpret user intent in real time and synthesize contextual data. Integrated across all channels, from websites to smart devices, these systems are coming to occupy an increasingly central place in consumers’ search, decision-making, and post-purchase experiences (Nguyen et al., 2026).

AI-based recommendation mechanisms optimize consumers’ access to personalized products and services (Huang et al., 2025: 1415). Because agent design directly affects the service experience and decision-making processes, understanding the psychological dynamics of user-system interaction has become critical for the marketing field (Nguyen et al., 2026). Avatar-based assistants tailored to individual expectations serve as effective tools in personalized advertising strategies and in driving the adoption of new products (Park et al., 2025). This turns AI into a guiding reference point that shapes consumer behavior (Theoharakis & Mylonopoulos, 2026). Consumers who form an emotional bond with AI agents ultimately exhibit greater satisfaction and loyalty, along with a sustained orientation toward the service provided (Yim et al., 2024).

The impact of agent technology on consumer behavior is particularly evident in price tracking and agent-assisted payment applications. AI agents can autonomously perform specific stages of the purchasing process, such as price tracking, identifying suitable alternatives, and completing purchases after approval, within the

goals and boundaries set by consumers (Srinivasan, 2025). Moreover, a recent example of AI agents' potential influence on consumer behavior is Universal Cart, introduced by Google on May 19, 2026. This system consolidates products encountered across platforms such as Google Search, Gemini, YouTube, and Gmail into a single smart shopping cart and tracks prices, deals, and stock status. By making decisions aligned with consumer preferences and executing actions at various stages of the purchasing process on the consumer's behalf, Universal Cart highlights the active role of AI agents (Srinivasan, 2026).

Although AI's acquisition of anthropomorphic features enables more natural interaction with consumers, once this process crosses a certain threshold, it can evoke unease and discomfort in users (Poushneh & Gearhart, 2025). Voice-based AI, in this respect, can mitigate such discomfort and heighten purchase intention by creating a stronger sense of independence and social closeness than text-based systems (Poushneh & Gearhart, 2025). AI's capacity to remember past preferences (memory), for its part, strengthens favorable attitudes by fostering a sense of uniqueness, yet in privacy-sensitive domains such as health and personal care, it can have the opposite effect, prompting discomfort and adversely affecting service evaluations (Chai et al., 2026). When service failures occur, consumers appear more forgiving of algorithmic systems than of human representatives (Chacon et al., 2025). These attitudes toward AI are not uniform, however. Indeed, while consumers welcome the pursuit of efficiency, they may display marked resistance in service encounters that involve self-relevant judgments bearing on appearance, identity, or personal competence (Anagha et al., 2026). A study by Wang et al. (2026) shows that consumers favor AI over humans in situations that require the disclosure of highly sensitive data, such as financial and health information, while prioritizing human warmth and advice in low-sensitivity situations.

The Internet, self-service technologies, and AI have substantially altered consumer behavior, and consumers now expect faster, easier, and more personalized shopping experiences. Businesses, in turn, draw on these technologies to anticipate consumer needs more accurately. Privacy concerns, distrust of algorithms, and a sense of discomfort with automated systems nonetheless complicate technology adoption. This transformation has also created conditions conducive to a rise in certain negative behaviors, such as consumer theft (Giroux et al., 2022: 1027-1028).

3. Research Methodology

This study aimed to provide a comprehensive mapping of the role and theoretical contributions of AI agents within the consumer behavior literature through bibliometric analysis. Frequently adopted to analyze the intellectual, conceptual, and social network dynamics of a research field (Aria & Cuccurullo, 2017), this methodology offers researchers a holistic perspective by identifying the historical development and thematic trends of disciplines (Rojas-Lamorena et al., 2022). In contrast to the subjective nature of traditional literature reviews, this technique approaches the subject within a quantitative framework and, at the same time, eliminates the operational and temporal constraints entailed by manual screening (Li et al., 2017). In light of the reasons outlined, bibliometric analysis was therefore identified as the method best suited to the aim of the study, and the research design was structured accordingly.

3.1. Literature Review Strategy and Data Collection

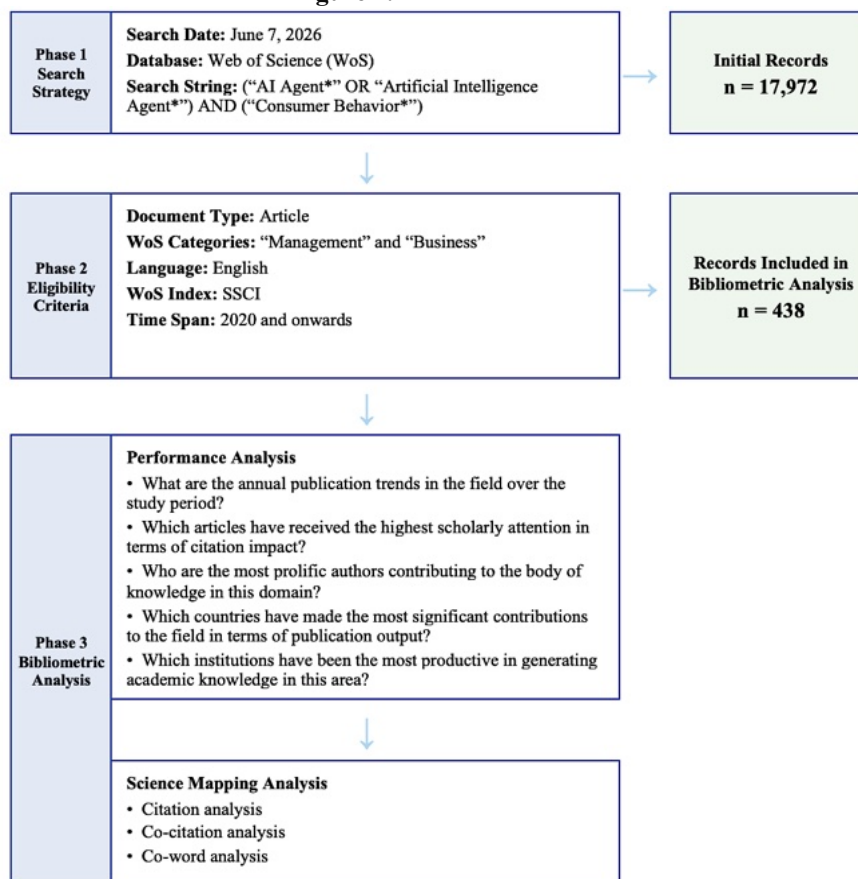
Constructing a dataset for bibliometric research and identifying pioneering studies, influential researchers, and dominant themes in a field begins with a comprehensive literature search (Kayhan & Arslan, 2024; Baştuğ & Kayhan, 2023). This process involves two main stages: first, identifying relevant studies using specific databases and keywords; and second, screening studies based on predefined inclusion and exclusion criteria (Ozturk, 2021). The choice of database is critically important for a reliable bibliometric analysis. Platforms such as WoS, Scopus, Google Scholar, Microsoft Academic, and Dimensions are particularly widely preferred in the literature (Moral-Muñoz et al., 2020). Accordingly, the databases and keyword combinations adopted in comparable studies were examined and are presented in Table 1.

As shown in Table 1, although prior studies have predominantly favoured the Scopus database, WoS is the platform most frequently consulted for bibliometric studies in the field of management and organization (Zupic & Čater, 2015). Moreover, WoS is one of the most comprehensive interdisciplinary citation indices worldwide (Van Raan, 2014). For the present study, framed within the context of consumer behavior, WoS was therefore determined to be the most appropriate database.

Table 1. Databases and Search Parameters Used in Previous Studies

Article	Database	Keywords
Zhang & Liu, 2026	Scopus and WoS	((ai OR (generative AND ai) OR (artificial AND intelligence) OR (intelligence) OR (large AND language AND model) OR (machine AND learning)) AND TITLE-ABS-KEY (fashion OR apparel OR clothes OR clothing OR textile*OR outfit OR wardrobe OR garment*))
Khoi & Phuc, 2026	Scopus	((“generative AI” OR “generative artificial intelligence” OR “large language model*” OR “LLM” OR “ChatGPT” OR “GPT-3” OR “GPT-4” OR “BERT” OR “transformer*” OR “retrieval augmented generation” OR “agentic AI”) AND (“retail*” OR “e-commerce” OR “electronic commerce” OR “online shopping” OR “consumer” OR “customer experience” OR “recommender system*”))
Badiu et al., 2025	Scopus	((“AI agent” OR “chatbot” OR “virtual assistant” OR “intelligent agent”) AND (“business performance” OR “organizational performance” OR “efficiency” OR “productivity”) AND (“customer support” OR “customer interaction” OR “customer service” OR “customer experience”))
Riandhi et al., 2025	Scopus	“AI” OR “Artificial Intelligence” AND “Consumer Behavior” OR “Consumer Behaviour”
Haque et al., 2024	Scopus	“Artificial Intelligence” OR “AI” AND “Retail Marketing”

Once the database had been determined, the search string executed on the WoS platform was structured, with reference to the studies in Table 1, as (“AI Agent*” OR “Artificial Intelligence Agent*”) AND (“Consumer Behavior*”). In addition, to ensure the reliability of the selected keywords, the opinions of four independent researchers specializing in consumer behavior and artificial intelligence were obtained, and the search string was revised accordingly. An initial search conducted on this basis on 07.06.2026 retrieved a total of 17,972 documents from the database. The methodological flow followed throughout the research process is depicted in Figure 1.

Figure 1. Research Process

To obtain a more homogeneous dataset in keeping with the aim of the research, specific filtering criteria were applied within the WoS database. These restrictions narrowed the focus and scope of the present study in line with the relevant literature (Bilgiseven & Arslan, 2025). Accordingly, the document type was limited to “Article,” the language to “English,” the WoS index group to the “Social Sciences Citation Index (SSCI),” and the research categories to “Business” and “Management.” To ensure the relevance of the search results to the scope of this study, the WoS category filter “Business” and “Management.” Since “AI” and “consumer behavior” are an interdisciplinary fields, unfiltered searches also return publications from unrelated areas such as engineering, computer science, psychology. As this study focuses specifically on the business and management literature, the search was restricted to these two categories. Furthermore, one of the most tangible precursors of the paradigm shift in AI research from 2020 onward was OpenAI’s GPT-3 model, which, with

its 175 billion parameters, can perform a wide variety of language tasks without additional training and exhibits the potential to generate text at a human level (Mucci, 2026). With reference to this radical development and acceleration in the AI literature, only articles published in 2020 or later were included in the analysis. Following application of the inclusion and exclusion criteria, analyses were conducted on the 438 articles evaluated for the bibliometric analysis.

3.2. Bibliometric Analysis of the Literature on Artificial Intelligence Agents and Consumer Behavior

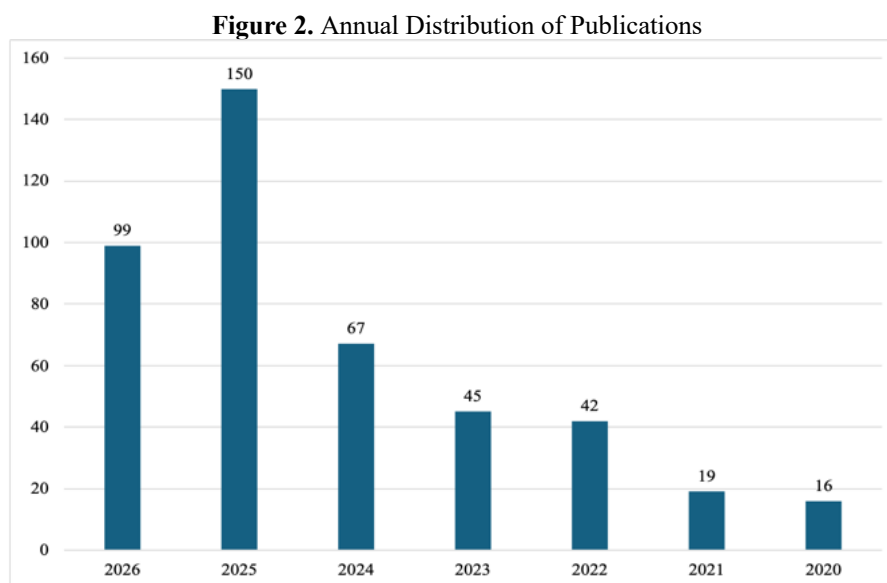
The bibliometric analysis process of this research, which sought to examine the role of AI agents within the consumer behavior literature, comprised two principal methodological stages. A performance analysis was conducted to quantify publication trends in the literature, and science mapping was carried out to reveal the intellectual and conceptual structure of the discipline (Zupic & Čater, 2015). The bibliometric method was ultimately adopted in this study for its considerable capacity to delineate the boundaries of intellectual structure, identify mainstream themes, and trace the historical development of the literature in business and social science research (Ozturk, 2021).

3.2.1. Performance Analysis

A performance analysis was conducted on the 438 articles obtained from the WoS database. Within this scope, assessments were made on the basis of core bibliometric indicators, including annual publication trends, the most highly cited articles, the most prolific authors, and the leading countries and institutions.

3.2.1.1. Annual Publication Trend

The annual publication productivity and distribution trend of the articles included in the analysis between 2020 and 2026 are visualized in Figure 2.



When the annual distribution of publications in the relevant literature (2020-2026) is examined, academic interest is seen to follow a pattern of steady growth. The relatively limited number of publications during the 2020-2022 period, which constituted the field's nascent phase, indicates that the topic was still in the early stages of development. Publication productivity gained appreciable momentum from 2023 onward, however, reaching levels of 45 and 67 respectively. In 2025, it peaked at 150 publications, thereby attaining mainstream status. Even in 2026, an incomplete year, the 99 publications recorded so far (up to 07.06.2026) demonstrate that the high output trend of recent years is continuing robustly.

When the annual distribution of publications is considered, the 2020-2021 period may be regarded as the formative phase of the relevant literature. The pioneering studies published during this period primarily examined the transformative effects of AI, machine learning, and chatbots on customer experience and business, bringing phenomena such as chatbot adoption onto the discipline's core research agenda (Pillai & Sivathanu, 2020; Ma & Sun, 2020; Hoyer et al., 2020; Adam et al., 2021; Moussawi et al., 2021; Loureiro et al., 2021).

The 2022-2023 period of the literature concentrated on the emotional dimension of human-AI interaction, analyzing AI's role in service (Song et al., 2022), artificial empathy (Liu-Thompkins et al., 2022), emotional expressions (Han et al., 2023), and the effects of service messages (Garvey et al., 2023). The 2024-2025 phase, in turn, witnessed considerable growth in publications driven by the momentum of GenAI. During this period, contemporary topics such as feeling AI (Huang & Rust, 2024) and chatbot-based information sharing (Al-Emran et al., 2024) came to the fore.

The 2026 literature points to a paradigmatic shift in AI from an instrumental role toward agentic systems defined by a capacity for autonomy and collaboration. During this period, the research agenda for agentic systems (Dwivedi et al., 2026), human acceptance in the transition from tool to agent (Li et al., 2026), and the organizational dimensions of this transformation within the framework of agency theory (Humberd & Latham, 2026) were examined in depth. These temporal patterns make concrete how the field has evolved from concerns centered on simple adoption toward questions of trust and empathy, and from there toward a new analytical frontier in which human-AI collaboration takes center stage. This reflects both technological progress and the broadening conceptual depth of AI agents within the consumer behavior literature.

3.2.1.2. Most Cited Articles

On the assumption that citation count reflects scholarly impact and significance in the relevant field, the top 10 articles with the highest WoS citation counts among the 438 examined are presented in Table 2.

Table 2. Top 10 Most Cited Articles

Articles	WoS Citation Count
Pillai & Sivathanu, 2020	633
Adam et al., 2021	630
Hoyer et al., 2020	588
Moussawi et al., 2021	302
Jussupow et al., 2021	298
Loureiro et al., 2021	291
Ma & Sun, 2020	280
Song et al., 2022	244
Liu-Thompkins et al., 2022	241
Schanke et al., 2021	237

In the literature addressing the impact of AI technologies on business and consumer behavior, a pioneering group of studies has shaped the field by developing broad conceptual frameworks. Hoyer et al. (2020), in this regard, proposed an integrated taxonomy that links the role of technologies such as IoT (Internet of Things), AR (Augmented Reality), VR (Virtual Reality), and chatbots across three distinct stages of the shopping journey to the cognitive, sensory, and social value dimensions. In a similar vein, Loureiro et al. (2021) analyzed 404 articles compiled from WoS and Scopus through text mining, focusing on a structural and conceptual examination of the AI literature in business. The analysis identified 18 latent topics representing the conceptual structure of the literature. These themes were classified into four main strategic clusters that provide analytical coherence: the social and organizational impact of AI, AI systems, and AI methodologies. On the methodological side, Ma & Sun (2020) compared machine learning approaches with traditional econometric models and presented an integrated, innovative analytical framework for marketing research.

Studies addressing adoption behavior have enriched TAM with AI-specific variables. In this context, Pillai & Sivathanu (2020) analyzed chatbot adoption in the hospitality and tourism industry using Partial Least Squares Structural Equation Modeling (PLS-SEM) and showed that anthropomorphism and perceived intelligence exerted a positive influence on acceptance, whereas stickiness toward traditional agents exerted a negative moderating effect. In an experimental study examining the adoption of the Personal Intelligent Agent (PIA), Moussawi et al. (2021) analyzed laboratory data using Structural Equation Modeling (SEM). That research sought to determine the role of perceived intelligence and anthropomorphism in acceptance. Its distinctive contribution lies in positioning PIAs as “dual-purpose systems” that combine task-oriented and social dimensions, and in integrating these two dimensions within a single model for the first time. Drawing on the CASA paradigm, Song et al. (2022) examined the effects of different service agents on communication quality and the perception of privacy risk, along with the moderating role of users' need for human interaction in this process. Findings from five scenario-based experiments revealed that the type of service agent directly affected adoption intention, while perceived communication quality and privacy risk mediated this relationship.

In the area of chatbot design, Adam et al. (2021) demonstrated that anthropomorphic design cues and the Foot-in-the-Door (FITD) technique enhanced user compliance through social presence. Schanke et al. (2021), for their part, provided causal evidence that humanizing robots benefited the firm by increasing transaction conversions and information sharing, yet also heightened price sensitivity by inducing a bargaining mindset in consumers. Investigating the role of artificial empathy, Liu-Thompkins et al. (2022) modeled perspective-taking, empathic concern, and emotional mimicry as holistic design inputs and offered a framework aimed at closing the human-AI gap. Finally, Jussupow et al. (2021) examined physicians' interactions with AI-assisted systems through a mixed-methods approach and developed a typology of five distinct decision-making patterns.

When the reflections of AI agents in the consumer behavior literature are assessed as a whole, the publications examined are seen to address the multidimensional effects of AI on customer interactions, adoption dynamics, design features, and decision-making processes through a variety of theoretical frameworks. This methodological diversity, ranging from conceptual reviews and bibliometric syntheses to field experiments, reflects both the theoretical depth and the methodological pluralism of the existing literature. These articles are regarded, for this reason, as important cornerstones in the relevant research field.

3.2.1.3. Most Prolific Authors

To identify the leading researchers shaping the consumer behavior literature focused on AI agents, scholars with at least 4 publications are listed in Table 3 according to their academic output and citation performance.

Table 3. Most Prolific Authors

Authors	Number of Publications	Total Citation Count
Alan R. Dennis	6	195
Debolina Dutta	5	125
Yogesh K. Dwivedi	4	162
Jochen Wirtz	4	122

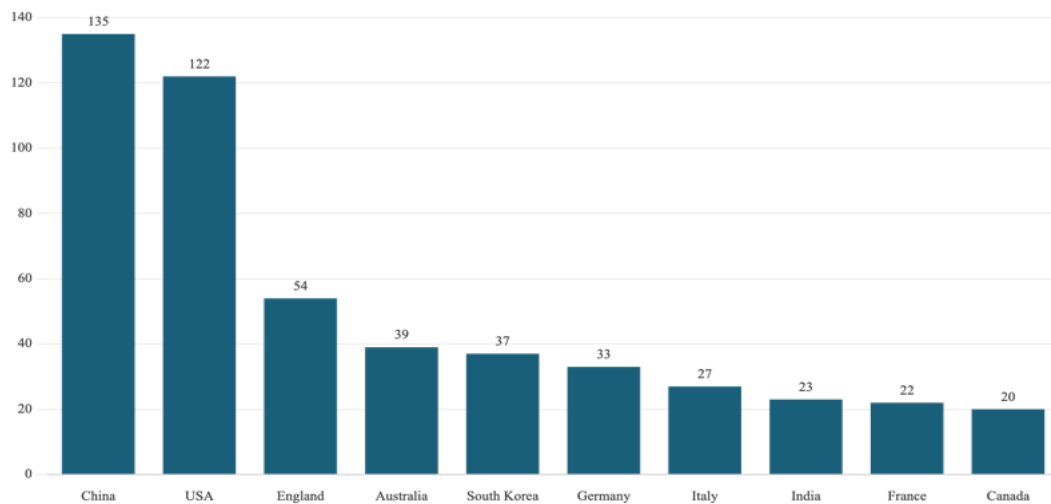
In line with the findings in Table 3, Alan R. Dennis stands out as the most dynamic and central figure in the field, with 6 publications and 195 citations. Debolina Dutta ranks second with 5 publications (125 citations), while Yogesh K. Dwivedi (162 citations) and Jochen Wirtz (122 citations) continue to contribute to the literature with 4 publications each. The high citations-per-publication ratio of Yogesh K. Dwivedi, in particular, attests to the conceptual and theoretical depth of his work in this field.

Overall, Table 3 shows that the intellectual accumulation of this emerging field is in the process of clustering around a handful of pioneering authors. At the same time, the fact that even the most prolific authors cluster within the range of 4 to 6 publications indicates that the literature remains in an “early growth and maturation” phase. This reveals that the field under examination has not yet reached saturation; on the contrary, it retains an exploratory and niche character.

3.2.1.4. Leading Countries

The countries to which the articles assessed in the study belong were examined in terms of the number of publications. In this regard, the top 10 countries with the most publications in this field are shown in Figure 3.

When the geographical distribution of the studies assessed in the analysis is examined, the literature is seen to be shaped largely by China (135) and the United States (122). The fact that these two countries account for roughly half of all publications indicates that knowledge production is being driven from a particular geographical perspective. The strong position of China and South Korea (37) on the list draws attention to an Asia-centered acceleration in AI research and to the research capacity generated by these countries' national AI policies.

Figure 3. Leading Countries in the Literature

The comparatively limited contribution of European countries, which possess well-established research infrastructures, by contrast, suggests that the continent has yet to make full use of its potential in this area. Moreover, the presence of India (23) and Australia (39) on the list shows that research interest is spreading across an increasingly broad geography.

3.2.1.5. Leading Institutions

The institutional distribution of studies examining the consumer behavior literature focused on AI agents was analyzed. Accordingly, a list of the most productive universities that have contributed at least 8 publications to the field is presented in Table 4.

Table 4. Institutional Distribution of Publications

Institutions	Number of Publications	Country
University of London	19	United Kingdom
The Indian Institutes of Management IIM System	14	India
State University System of Florida	11	USA
University System of Georgia	10	USA
California State University System	9	USA
University of Texas System	9	USA
Renmin University of China	8	China
Sichuan University	8	China
Sun Yat-Sen University	8	China
Sungkyunkwan University	8	South Korea
University of Cambridge	8	United Kingdom

When the most productive institutions are examined, the University of London stands out clearly with 19 publications, followed by the Indian Institutes of Management (IIM) System with 14, confirming India's strong research capacity at both the national and institutional levels. The United States is represented through broad-based university systems rather than individual central institutions, namely the State University System of Florida (11), the University System of Georgia (10), the California State University System (9), and the University of Texas System (9). From China, Renmin University of China, Sichuan University, and Sun Yat-Sen University each contribute 8 publications, extending the country's national dominance to a polycentric institutional structure. The presence of Sungkyunkwan University (8) and the University of Cambridge (8) further shows that scholarly leadership is shared by long-established institutions on a global scale. Encompassing both large state university systems and elite research universities, the list indicates that consumer behavior research focused on AI agents exhibits no tendency toward institutional monopolization.

3.2.2. Scientific Field Mapping

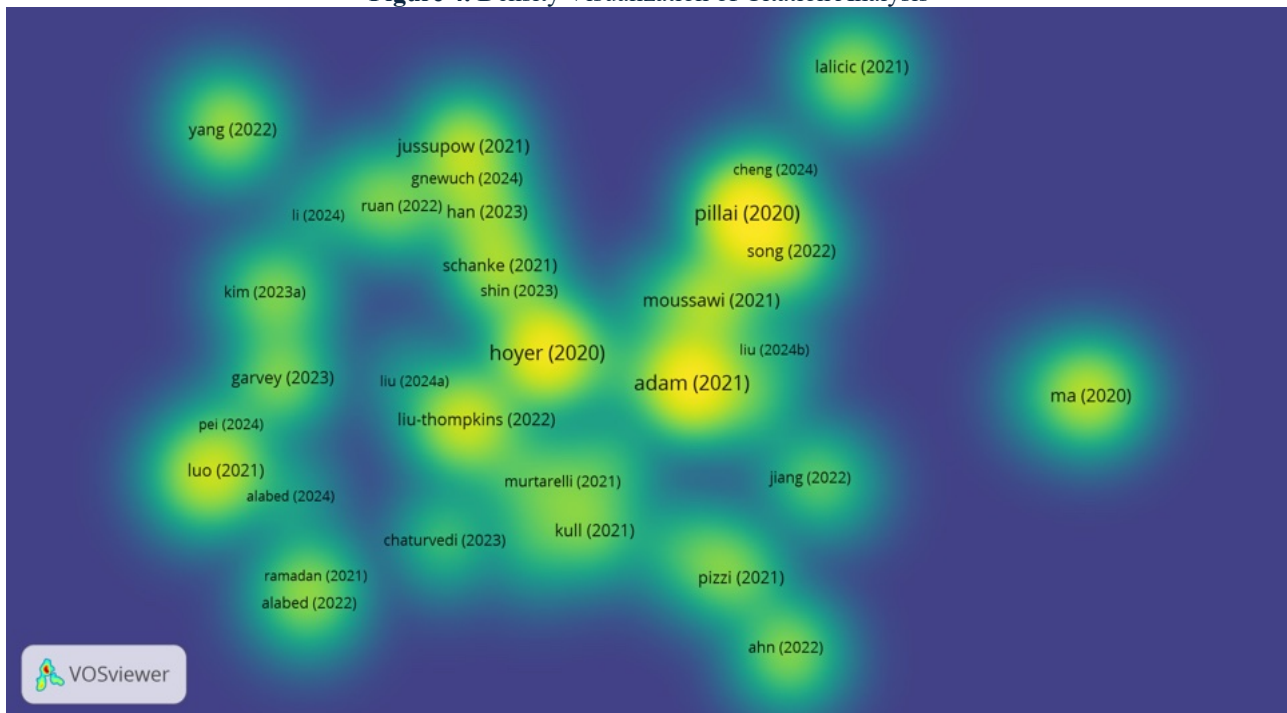
Science mapping, alongside performance analysis, is one of the two principal processes of bibliometric research. By analyzing the relationships between the components of a research field and its intellectual structure (Baker et al., 2021: 1028; Donthu et al., 2021: 288), it reveals the evolutionary dynamics of the relevant literature and exposes the relational network among disciplines, areas of specialization, studies, and

authors (Passas, 2024), thereby making hidden patterns visible, revealing gaps, and offering a guiding framework for future research. Among the various software programs available for this purpose, including CitNetExplorer, SciMAT, BibExcel, Pajek, and Bibliometrix (Gutierrez-Salcedo et al., 2018; Orhan, 2022: 111), VOSviewer was preferred for its high-quality visualization and its capacity to process large datasets (Sinkovics, 2016: 332). Citation, co-citation, and keyword co-occurrence analyses were carried out using the software.

3.2.2.1. Citation Analysis

Publications form mutual citation relationships because they share similar theoretical content and methodologies or assume similar roles in the flow of knowledge (Pieters & Baumgartner, 2002). In this respect, citation data enable identification of the leading article, author, and journal in a given field (Block & Fisch, 2020). As a fundamental technique of science mapping, citation analysis rests on the assumption that the intellectual link between publications is reflected through citations (Donthu et al., 2021).

Figure 4. Density Visualization of Citation Analysis



To construct the network map of the 438 articles assessed within the scope of the citation analysis, a specific threshold was applied. Accordingly, 56 articles meeting the criteria of having received at least 50 citations and possessing a minimum total link strength of 1 were included in the analysis. The density map produced with the VOSviewer software, which displays the link density of these studies, is presented in Figure 4. On the basis of this map, a list of publications connected to at least 5 articles is provided in Table 5.

When the studies in Table 5 with the highest citation and link strength are examined, the literature follows a clear theoretical trajectory anchored by umbrella studies that map the field holistically. Through the Theory-Context-Characteristics-Methodology (TCCM) approach, De Keyser & Kunz (2022) map agent-based AI technologies, such as service robots and chatbots, within the consumer behavior literature. Drawing together 88 articles and 79 expert opinions, they identify the field's dominant theories (Anthropomorphism Theory, the CASA paradigm, Algorithm Aversion Theory, Uncanny Valley Theory, and others), contexts, and methodological preferences. Their study summarizes the theoretical foundation underlying major empirical investigations (Adam et al., 2021; Pillai & Sivathanu, 2020; Schanke et al., 2021; Moussawi et al., 2021; Song et al., 2022) and flags a key research gap: the need to move beyond robot-human comparison toward collaboration. Similarly, Hoyer et al. (2020) argue that emerging technologies such as AI, IoT, AR, VR, and Mixed Reality (MR) are transforming customer experience across all business lines, reconfiguring existing dynamics by generating new touchpoints throughout consumers' pre-transaction, transaction, and post-transaction journeys.

Table 5. Most Linked Articles in the Citation Analysis

Article	Number of Links	WoS Citation Count
Adam et al., 2021	16	630
Pillai & Sivathanu, 2020	9	633
Hoyer et al., 2020	6	588
Li et al., 2024	6	63
Liu-Thompkins et al., 2022	5	241
Garvey et al., 2023	5	231
Murtarelli et al., 2021	5	119
De Keyser & Kunz, 2022	5	108
Gnewuch et al., 2024	5	93
Mari et al., 2024	5	56

The second group of high-impact studies focuses on the adoption dynamics of AI-based agents. Drawing on TAM, Pillai & Sivathanu (2020) examine the adoption of AI-based chatbots in hospitality and tourism. Interviews with travel agency managers and customer surveys reveal that perceived ease of use, benefit, trust, intelligence, and anthropomorphism directly determine usage intention, whereas attachment to traditional agencies and human representatives negatively affects the intention to use chatbots.

A further set of studies turns to the persuasion mechanisms that secure user compliance. Adam et al. (2021) examine the integration of Natural Language Processing (NLP)-equipped AI chatbots into customer service in place of human representatives, showing that verbal anthropomorphic design leads users to perceive chatbots as social entities in line with social response theory, while small confirmations elicited through the FITD technique increase compliance with larger requests in accordance with commitment-consistency theory. Similarly, Gnewuch et al. (2024) find that, in hybrid systems, users adopt a more human-oriented communication style when they know a real person is involved, which raises background staff workload and undermines automation.

Anthropomorphism, lying at the center of persuasion processes, constitutes a distinct thematic axis in the literature. It is defined as the attribution of distinctively human qualities (voice, image, gestures and facial expressions, action, or emotion) to non-human entities or products (Epley et al., 2007; Airenti, 2015), becoming concrete when consumers name the products they own, assign them a gender, and form bonds with them (Sönmez & Nart, 2022). As technology advances, software, robots, and chatbots are likewise humanized through anthropomorphic design and human-like forms and voices. Liu-Thompkins et al. (2022) and Mari et al. (2024) showed that endowing AI-based technologies with emotional empathy improved the user experience and influenced purchase decisions. Garvey et al. (2023), in turn, found that users infer intentions from AI agents much as they do from humans, evaluating price offers differently by their nature (favorable/unfavorable or good/bad) and by whether the source is an AI agent or a human representative.

Finally, the spread of anthropomorphic and persuasion-oriented applications opens up a debate over the ethical dimension. Li et al. (2024) focus on the potential of AI technologies to trigger unethical consumer behavior, showing that users engage in more unethical behavior in the absence of identity disclosure than when their identities are evident. Murtarelli et al. (2021), in turn, note that two principal frameworks, the technological and the anthropomorphic, have so far been adopted in the value-creation processes arising from human-chatbot interaction. They emphasize, however, that AI applications also introduce new ethical challenges, including information asymmetry, heightened consumer risk perception, loss of trust and reputation, network security, and privacy, and accordingly formulate a holistic model that incorporates an ethical approach alongside the technological and anthropomorphic dimensions to create value through chatbots.

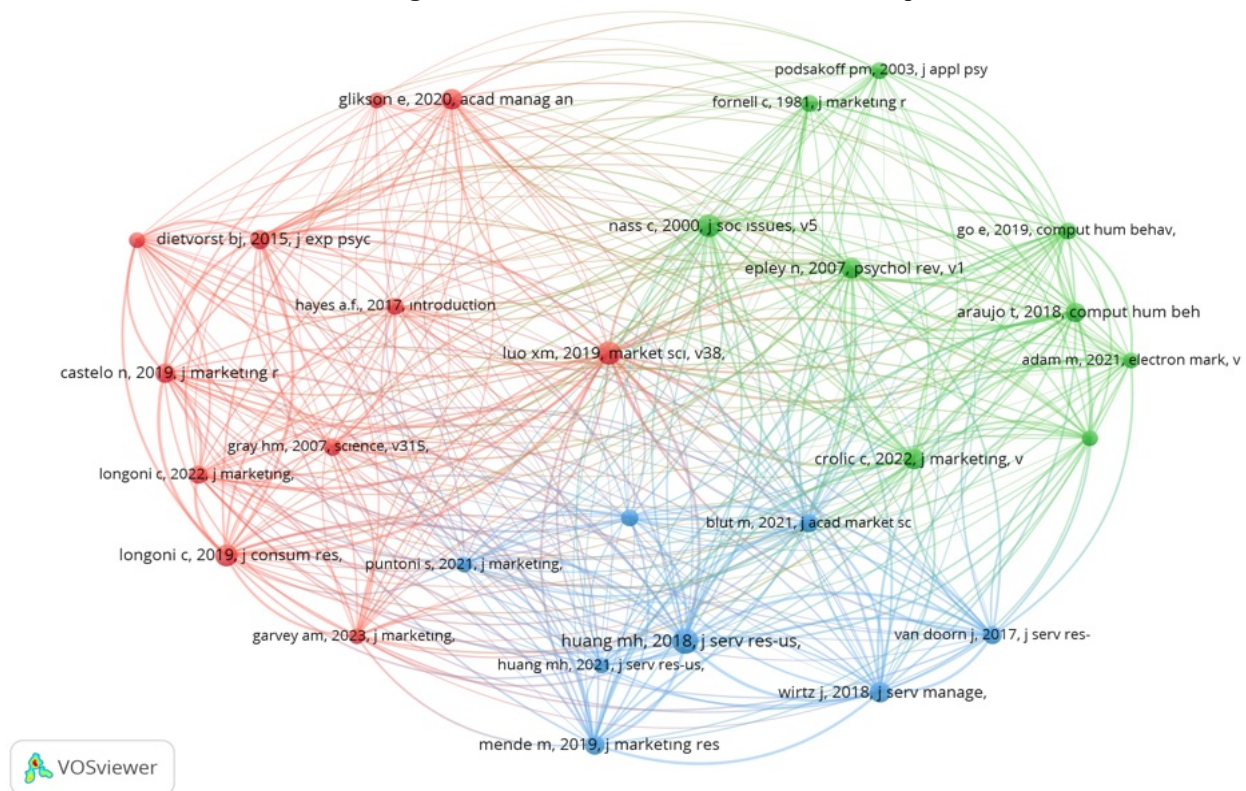
3.2.2.2. Co-citation Analysis

Co-citation analysis reveals the themes and similarities in a given field through the frequency with which two studies are cited together (Small, 1997) and maps scholarly relationships and interdisciplinary interactions (Leydesdorff, 1998). An increase over time in the number of co-citations between studies signals conceptual similarity between them and likewise produces a higher co-citation link strength (Zan, 2019). This analytical method makes it possible to identify the most influential publications in the literature and to uncover thematic clusters (Donthu et al., 2021).

A total of 25,962 references were identified in the bibliographies of the 438 articles examined within the scope of the co-citation analysis. To derive meaningful and interpretable patterns from this extensive citation

matrix, the network map of the 28 seminal studies meeting the threshold criterion of at least 30 co-citations is visualized in Figure 5.

Figure 5. Co-citation Network Visualization Map



When the visualization presented in Figure 5 is examined, the studies in question are seen to cluster into three principal groups. Summary information and details regarding these clusters are presented in Table 6.

The studies within Cluster 1 (Red) in Table 6 focus predominantly on user attitudes and behaviors toward algorithms, whose perception triggers mechanisms of either trust in or resistance to AI technologies. Dietvorst et al. (2015) examined the concept of “algorithm aversion,” finding that users lose trust in a system the moment they encounter an error, even when they know its predictive performance exceeds that of humans; individuals show far lower tolerance for machine errors than for human ones, even when algorithms remain the more consistent performers. Examining the nature of algorithmic tasks, Castelo et al. (2019) argue that resistance depends on whether a task is objective or subjective, with individuals turning to algorithms for data-driven processes while seeking human expertise in emotional and personal domains. Logg et al. (2019), by contrast, relax the assumption of an innate resistance, holding that individuals place greater trust in algorithm-generated suggestions and rationalize them, though experts caught between their own prediction and an algorithm’s output approach such guidance with greater reserve.

Beyond these studies of basic algorithm-user interaction, Longoni et al. (2019), Luo et al. (2019), Raisch & Krakowski (2021), Longoni & Cian (2022), and Garvey et al. (2023) have problematized the effects of human-machine design in AI algorithms on user judgments. Longoni et al. (2019), for instance, found that patients prefer human doctors to algorithms in diagnosis and treatment despite the AI revolution in medicine. Chatbots, among the most frequently simulated tools in the literature, illustrate this: the moment consumers recognize that they are interacting with an artificial agent, they restrict or terminate the dialogue, since chatbots, though seen as successful in objective tasks, are perceived as lacking empathy and accumulated knowledge on the subjective plane (Castelo et al., 2019; Luo et al., 2019). Similarly, Longoni & Cian (2022) noted that users endorse AI competence in utilitarian and practical decisions but resist AI recommendations in hedonic domains oriented toward emotional gratification.

Table 6. Co-citation Analysis Clusters

Clusters	Main Point of The Clusters	Number of Items	Articles	Keywords and Themes
Cluster 1 (Red)	Investigation of users' attitudes toward AI and algorithms (trust, resistance, aversion, etc.)	10 ¹	Glikson & Woolley (2020); Dietvorst et al. (2015); Castelo et al. (2019); Gray et al. (2007); Longoni & Cian (2022); Longoni et al. (2019); Logg et al. (2019); Garvey et al. (2023); Luo et al. (2019); Raisch & Krakowski (2021)	Algorithms, AI, technology, consumer behavior, aversion, trust
Cluster 2 (Green)	Anthropomorphism and humanization in AI-based technologies	7 ²	Adam et al. (2021); Araujo (2018); Crolie et al. (2022); Epley et al. (2007); Go & Sundar (2019); Nass & Moon (2000); Sheehan et al. (2020)	AI, antropomorphism, social presence, humanizing, chatbots
Cluster 3 (Blue)	Examination of AI-based service robots from the perspective of consumer experience and behavior	8	Blut et al. (2021); Davenport et al. (2020); Huang & Rust (2018); Huang & Rust (2020); Mende et al. (2019); Puntoni et al. (2021); van Doorn et al. (2017); Wirtz et al. (2018)	Service robots, consumer behavior, AI, customer experience, antropomorphism, service strategy, replacement

Garvey et al. (2023), in turn, demonstrated that perceived value differs according to whether an offer originates from AI or from a human: because consumers regard AI as devoid of free will and intention, they find AI offers less “self-interested,” while interpreting a better human offer as motivated by “goodwill.” To synthesize, this cluster yields strategic insights into how firms should integrate algorithms and humans. Glikson & Woolley (2020) treat trust as the principal determinant of human-AI collaboration, showing that systems built with reliable, transparent, and real-time feedback mechanisms enable far more successful human-AI teaming. Raisch & Krakowski (2021) likewise stress that sharp, dichotomous distinctions should be avoided; faced with these two organically interconnected approaches, firms should adopt a holistic organizational perspective rather than reductively focusing on a single methodology.

When the studies within Cluster 2 (Green) are examined, common themes come to the fore: anthropomorphic designs for AI applications, the endowment of systems with human-like qualities, and the attribution of a social-entity dimension to these technologies. Anthropomorphism, one of the literature's core concepts, is generally defined as the process by which individuals attribute human characteristics to non-human figures to reduce surrounding uncertainty and relieve loneliness. Epley et al. (2007) treated this tendency as a psychological process that gave theoretical direction to subsequent work, while Nass & Moon (2000), in their pioneering early study, observed that individuals project human behavioral patterns onto computers and perceive them almost as social actors. More recently, Araujo (2018) revealed that human-like names and conversational styles heighten users' tendency to view chatbots as human. Designed with appropriate human-like features, such technologies yield critical outcomes for the user, including brand loyalty and satisfaction.

Similarly, Go & Sundar (2019) found that e-commerce chatbots designed in a more human-like fashion, through visual figures, identity cues, and interactive dialogue structures, evoked a strong sense of social presence and closeness in consumers. Even when they commit an operational error, chatbots incorporating human cues are tolerated more readily than mechanical ones when they attempt to repair it. Firms should therefore develop interactive error-repair capabilities rather than pursue perfection in AI technologies (Sheehan et al., 2020).

In parallel with earlier studies, Adam et al. (2021) likewise proposed that verbal anthropomorphic designs build a sense of social presence and strengthen users' motivation to cooperate with the system. Offering an antithetical view, Crolie et al. (2022) contend that excessive humanization raises user expectations asymmetrically, so that when chatbots fail to meet these heightened expectations, users are inevitably seized by negative emotions such as dissatisfaction, disappointment, and anger.

The final group, Cluster 3 (Blue), concentrates on consumer experience and behavior in the context of service robots (Davenport et al., 2020; Puntoni et al., 2021; Blut et al., 2021). In advancing the SRAM, Wirtz

¹The co-citation analysis identified 11 studies belonging to Cluster 1 (Red). One of these, however, the study by Hayes et al. (2017), is concerned specifically with scientific analysis methods rather than the AI agent literature. It has therefore been excluded from this table.

² The second cluster (Green) obtained from the co-citation analysis contains 9 studies in total. Two of these, by Fornell & Larcker (1981) and Podsakoff et al. (2003), have been kept outside this table, which was constructed within the scope of the AI agent literature, since they are studies concerned with scientific analysis methods.

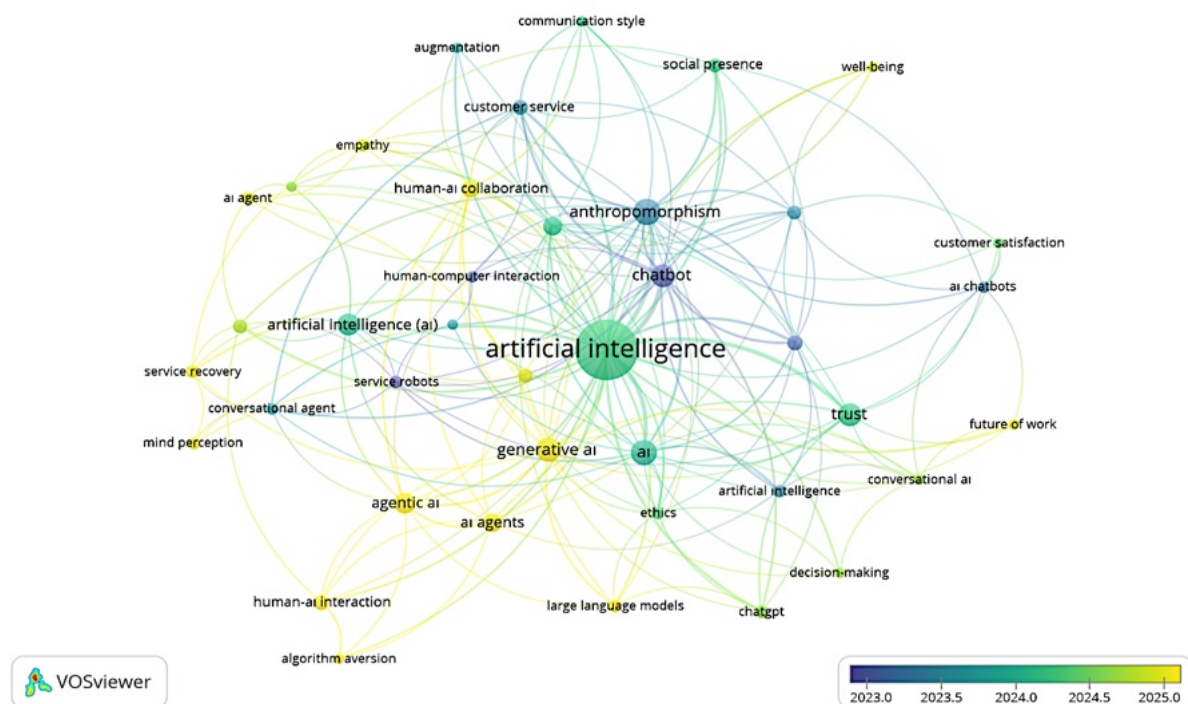
et al. (2018) emphasized that social norms and trust are at least as critical as functional benefit, noting that firms must dynamically reassess their strategies and service processes to build sustainable competitive advantage.

Huang & Rust (2018), for their part, sketched a theoretical roadmap in which service robots pass through a four-stage hierarchy of mechanical, analytical, intuitive, and empathetic intelligence toward full human-machine integration. Mende et al. (2019) then empirically examined the psychological effects of humanoid service robots on consumer behavior and their strategic consequences for firms, while Huang & Rust (2020) clarified how AI technologies should be positioned strategically to enhance customer loyalty and optimize the user experience in services.

3.2.2.3. Keyword Co-occurrence Analysis

Co-occurrence analysis is a type of bibliometric analysis based on words that appear together in studies, aimed at revealing the semantic structure of the literature and constructing the relationships among themes (Aria & Cuccurullo, 2017). Whereas other analyses link studies indirectly through citations, it draws on the direct, original content of the articles as a measure of similarity (Callon et al., 1983), assuming that frequently co-occurring words stand in a thematic relationship (Donthu et al., 2021). Carried out to determine the conceptual structure of the literature, the analysis yielded 1,739 unique keywords across the 438 articles examined. To derive more focused themes, a layered network map formed by the 40 keywords appearing in at least 5 studies is visualized in Figure 6.

Figure 6. Co-occurrence Network Overlay Visualization of Keywords



The overlay visualization in Figure 6 shows the evolution of keywords over time through their average publication year, which indicates the chronological periods in which the co-occurring words are concentrated (Van Eck & Waltman, 2023). The 2023-2025 range thus reflects where the examined terms cluster: the rapid development and proliferation of AI technologies and AI agents in recent years drove work in this area to gather momentum across these years. The network map further shows that “artificial intelligence” and “artificial intelligence agent,” along with their variants “ai” and “ai agent,” are frequently used together. The dense connections around these terms indicate that the field still revolves around what artificial intelligence is and how it should be defined, with the effort to conceptualize the technology carrying appreciable weight in the literature.

Another central phenomenon prominent in the literature is anthropomorphism, that is, humanization: the use of human elements such as image, voice, emotion, and empathy in AI-based software, AI agents, and

robots. The effects of such designs on consumer behavior rank among the field's most important research topics, and endowing AI technologies with "social presence" so as to bring them into interaction and collaboration with humans recurs frequently as a theme. It is unsurprising that chatbots and ChatGPT are the two most heavily used AI applications in consumer behavior research, since they are the most visible examples in which debates over anthropomorphism and social presence take concrete form. Yet, like every technological development, artificial intelligence has dark sides of its own. Figure 6 shows ethics and trust appearing on the map as two elements representing this dark side: the ethical concerns AI raises among consumers, and the attendant trust problems, are being investigated with steadily growing interest.

Assessed as a whole, the map reveals that the agent-based AI literature has undergone a rapid paradigm shift within a short span. The center of gravity of research is moving from the classical chatbot toward agentic AI capable of autonomous decision-making and toward large language models. Anthropomorphism retains its theoretical centrality throughout, but is now reinterpreted in terms of human-like decision-making and intention rather than appearance. That behaviorally critical concepts such as trust, ethics, and decision-making remain at the periphery, by contrast, shows that the literature still tends toward defining the technology, with research grounded in consumer psychology relatively in the background. The growing prominence of ethics and algorithm aversion nonetheless suggests that, as AI agents proliferate, these debates are maturing into a distinct axis of research. The literature is thus advancing toward a new agenda, one evolving from how to converse with artificial intelligence toward how much decision-making authority it should be granted and how consumers come to trust autonomous agents.

4. Conclusion and Discussion

This research set out to provide a holistic mapping of the role and theoretical contributions of AI agents in the consumer behavior literature through bibliometric analysis. A two-stage examination was conducted to decipher the field's quantitative ecosystem and intellectual structure. The performance analysis identified chronological publication productivity, citation leaders, the most prolific authors, and the pioneering countries and institutions, while the subsequent science mapping, drawing on citation, co-citation, and co-occurrence analyses, made visible the mainstream debates and latent thematic relationships within the literature.

The citation analysis shows Adam et al. (2021) leading in both link strength and total citations, followed by Pillai & Sivathanu (2020) and Hoyer et al. (2020). Overall, the literature converges on several theoretical axes: TCCM-based umbrella studies, adoption dynamics, persuasion mechanisms, anthropomorphic design strategies, and ethical risks. The co-citation clusters sharpen this picture. Cluster 1 (Red) examines trust in versus resistance to algorithms, indicating that users tolerate machine errors poorly, resist AI in their areas of expertise, and view it as lacking genuine empathy and intention, which supports a symbiotic, interdependent model of human-machine design over rigid distinctions. Cluster 2 (Green) shows that anthropomorphic cues evoke social presence and closeness, enhancing satisfaction, loyalty, and error tolerance, yet warns that over-humanization breeds unmet expectations and negative responses, underscoring balanced design and interactive repair capabilities. Cluster 3 (Blue) addresses service robots, holding that social norms and trust matter as much as functional benefit, and traces AI's developmental hierarchy from mechanical to analytical, intuitive, and ultimately empathetic intelligence.

The co-occurrence analysis reveals a high frequency among the keywords "artificial intelligence," "artificial intelligence agents," "ai," and "ai agents," suggesting that this emerging field remains oriented toward ontological inquiry, conceptual definition, and theory-building. Anthropomorphism stands at the center of this map. Notably, the literature attends not only to optimization-oriented benefits but also to the "dark side of technology," where unethical behavioral tendencies, perceived risk, and trust-building recur as clustered themes.

4.1. Theoretical Contributions

By tracing the dynamic evolution of the AI agent and consumer behavior literature in recent years through a bibliometric approach, this study aims to redraw, restructure, and map the conceptual boundaries of the field. The empirical findings obtained bring together the human-AI interaction literature, which presents a rather scattered, fragmented, and siloed appearance in the existing body of work, within a holistic, integrated, and multidimensional theoretical framework. In this respect, the study clarifies the field's intellectual structure by organizing the cumulative body of knowledge. The results of the analysis conducted reveal, in an original

manner, the algorithm-based processes, anthropomorphic design features, and service-experience-oriented thematic clusters that constitute the literature's fundamental building blocks and ontological ground. Moving beyond presenting these thematic structures as static data, the research dynamically traces conceptual shifts and paradigmatic transformations over time, thereby addressing RQ2 by offering scholars a structured conceptual map to guide future theory-building on the algorithmic and anthropomorphic dimensions of AI agents, and providing multidimensional theoretical contributions to both the historical trajectory of the literature and its future conceptual orientations.

4.2. Practical Implications

The bibliometric findings presented by this study offer important strategic roadmaps for firms, market analysts, marketers, and technology managers seeking to integrate AI applications and AI agents into their business processes. The empirical research examined in the literature clearly shows that focusing solely on developing a “flawlessly functioning technology” in technical and operational terms is not sufficient for commercial and sustainable success. Real success lies in proactively managing users' psychological barriers, the limits of their trust, their inclination to accept the technology, and their perceptual dynamics. Accordingly, the study provides practitioners with concrete, actionable insights for optimizing the customer experience in AI integration processes, building consumer trust, and overcoming the potential consumer resistance that may develop toward technological innovations.

One of the most critical issues that must be managed with strategic precision at the institutional and operational levels is the paradoxical nature that anthropomorphic design strategies hold within market dynamics. Endowing virtual assistants and chatbots with human-like names, conversational styles, language patterns, or visual figures triggers a sense of social closeness and psychological bonding (social presence) in consumers, and this directly and positively affects customer satisfaction and brand loyalty. Indeed, findings in the literature reveal that potential operational errors an AI system displaying human cues may make during a process can be tolerated by users more readily and with greater empathy. The greatest risk factor managers face at this point, however, is falling into the error of “over-anthropomorphism.” If an interface asymmetrically fosters the perception that the user is interacting with a real person, thereby creating an inflated architecture of expectations, and then proves inadequate in meeting that expectation, an “expectancy disconfirmation” scenario comes into play, and the consumer's disappointment, alienation, and anger increase exponentially. In this context, rather than attempting to mislead the user through a flawless imitation of a human, managers' adoption of “algorithmic explainability” and “ethical transparency” policies that clearly declare from the outset that the system is an AI application emerges as a strategic imperative for long-term trust-building and crisis management.

4.3. Limitations and Future Research Directions

Although this study offers a comprehensive theoretical framework for revealing the intellectual structure and historical evolution of the AI agent and consumer behavior literature, it carries certain methodological constraints stemming from the nature of bibliometric methods and from the data selection process. It is of considerable methodological importance that future researchers bear these limitations in mind when evaluating the present findings and when building new empirical or theoretical models upon this work. The most salient constraint of the research concerns the restrictions placed on the database, index type, subject category, language, and time span included in the analysis. The bibliometric data in this study were obtained from the WoS database, which houses the most prestigious indices of international academic scholarship, by filtering for journals indexed within the SSCI alone and by selecting only the “Business” and “Management” subject categories from among the WoS categories. The dataset was further limited to studies published in “English” alone and covering the period from 2020 onward.

This filtering strategy shapes the macro-level constraints of the study and, in turn, the new avenues of inquiry it opens for future work. First, owing to the database and index restriction, qualified scholarly studies, book chapters, sectoral reports, and articles written in other languages that fall outside the scope of WoS, in indices such as Scopus or Google Scholar, could not be incorporated into the analysis set. In this respect, it would be valuable for future studies to conduct cross-database bibliometric analyses encompassing platforms such as Scopus and Google Scholar rather than relying on the WoS database alone, so as to minimize publication bias in the literature. Second, because of the WoS category restriction, the output of multidisciplinary fields that make substantial contributions to the human-machine interaction and AI agent

literature, such as Computer Science, Information Systems, and Psychology, fell outside the scope of the study. This may have confined the technological and deeper psychological dimensions of consumer behavior to a business-centered perspective. Future bibliometric and systematic review studies would therefore do well to adopt an interdisciplinary filtering strategy that also encompasses the computer science and psychology categories, in order to map the technical dimension of AI and algorithm design together with user psychology; this stands out as a critical requirement for the intellectual depth of the literature.

The third and methodologically most dynamic constraint is the restriction on the time span. The analysis's focus on 2020 onward precluded a longitudinal tracking of the early phases of AI and chatbot technologies; while it successfully captured the literature's current and disruptive period of technological transformation, it gave rise to the risk that the field's historical, cumulative line of development might not be fully reflected. To overcome this constraint, future studies are encouraged to conduct longitudinal analyses with a broad temporal projection covering the past 15 to 20 years from the very emergence of the AI agent literature. The theoretical ruptures between the field's paradigmatic roots and today's GenAI revolution could thereby be traced more clearly. Finally, to complement the macro-level map of the literature that this bibliometric analysis provides, it is anticipated that empirically testing prominent themes such as "over-anthropomorphism" and "interactive repair capabilities" through laboratory or field experiments (experimental designs) or mixed-methods research in future studies would support the theoretical depth of the literature with practical and empirical findings.

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Author Contributions

All authors contributed equally to the conceptualization, methodology, data analysis, and writing of this article. All authors have read and approved the published version of the article.

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

Ethical approval was not required for this study as it is based entirely on the review and synthesis of published literature.

Reference

- Acar, O. A. & Schweidel, D. A. (2026). Preparing Your Brand for Agentic AI. *Harvard Business Review*.
- Adam, M., Wessel, M., & Benlian, A. (2021). AI-based chatbots in customer service and their effects on user compliance. *Electronic Markets*, 31, 427–445. <https://doi.org/10.1007/s12525-020-00414-7>
- Airenti, G. (2015). The Cognitive Bases of Anthropomorphism: From Relatedness to Empathy. *International Journal of Social Robotics*, 7(1), 117-127. <https://doi.org/10.1007/s12369-014-0263-x>
- Alabed, A., Javornik, A., & Gregory-Smith, D. (2022). AI anthropomorphism and its effect on users' self-congruence and self-AI integration: A theoretical framework and research agenda. *Technological Forecasting and Social Change*, 182, 121786. [10.1016/j.techfore.2022.121786](https://doi.org/10.1016/j.techfore.2022.121786)
- Alabed, A., Javornik, A., Gregory-Smith, D., & Casey, R. (2024). More than just a chat: A taxonomy of consumers' relationships with conversational AI agents and their well-being implications. *European Journal of Marketing*, 58(2), 373-409. <https://doi.org/10.1108/EJM-01-2023-0037>
- Al-Emran, M., AlQudah, A. A., Abbasi, G. A., Al-Sharafi, M. A., & Iranmanesh, M. (2024). Determinants of Using AI-Based Chatbots for Knowledge Sharing: Evidence from PLS-SEM and Fuzzy Sets (fsQCA). *IEEE Transactions on Engineering Management*, 71, 4985-4999. <https://doi.org/10.1109/TEM.2023.3237789>

- Anagha, R. B., Sreejesh, S., & Sankaranarayanan, V. (2026). When the self meets the machine: self-schemas, symbolic fit, and engagement in AI-human service systems. *Journal of Retailing and Consumer Services*, 92, 104841. <https://doi.org/10.1016/j.jretconser.2026.104841>
- Araujo, T. (2018). Living up to the chatbot hype: The influence of anthropomorphic design cues and communicative agency framing on conversational agent and company perceptions. *Computers in Human Behavior*, 85, 183-189. <https://doi.org/10.1016/j.chb.2018.03.051>
- Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11, 959-975. <http://dx.doi.org/10.1016/j.joi.2017.08.007>
- Badiu, I., Anagnoste, S., & Savastano, M. (2025). Mapping the Impact of AI Agents on Business Performance: A Bibliometric Approach. *Proceedings of the International Conference on Business Excellence*, 19(1), 3492-3510. DOI: 10.2478/picbe-2025-0267
- Baker, H. K., Kumar, S., & Pandey, N. (2021). Forty Years of the Journal of Futures Markets: A Bibliometric Overview. *Journal of Future Markets*, 41(7), 1027-1054. <https://doi.org/10.1002/fut.22211>
- Baştuğ, M., & Kayhan, R. (2023). Dijital Tedarik Zinciri Literatürünün Bibliyometrik Analiz Yöntemiyle İncelenmesi. *Journal of Research in Business*, 8(2), 453-481. DOI: 10.54452/jrb.1269354
- Bilgiseven, B., & Arslan, F. M. (2025). Dünden Bugüne Pazarlama Literatüründe Ortak Değer Yaratma Kavramı: Bir Bibliyometrik Analiz. *Marmara Üniversitesi İktisadi ve İdari Bilimler Dergisi*, 47(2), 196-228. DOI: 10.14780/muiibd.1533587
- Block, J. H., & Fisch, C. (2020). Eight tips and questions for your bibliographic study in business and management research. *Management Review Quarterly*, 70, 307-312. <https://doi.org/10.1007/s11301-020-00188-4>
- Blut, M., Wang, C., Wunderlich, N. V., & Brock, C. (2021). Understanding anthropomorphism in service provision: a meta-analysis of physical robots, chatbots, and other AI. *Journal of the Academy of Marketing Science*, 49(4), 632-658. <https://doi.org/10.1007/s11747-020-00762-y>
- Callon, M., Courtial, J.-P., Turner, W. A., & Bauin, S. (1983). From Translations to Problematic Networks: An Introduction to Co-Word Analysis. *Social Science Information*, 22(2), 191-235. <https://doi.org/10.1177/053901883022002003>
- Castelo, N., Bos, M. W., & Lehmann, D. R. (2019). Task-dependent algorithm aversion. *Journal of Marketing Research*, 56(5), 809-825. <https://doi.org/10.1177/0022243719851788>
- Chacon, A., Martínez-Troncoso, C., & Kausel, E. E. (2025). Customer behavior in the presence of algorithmic marketing agents: The role of hedonic values. *Technological Forecasting and Social Change*, 220, 124322. [10.1016/j.techfore.2025.124322](https://doi.org/10.1016/j.techfore.2025.124322)
- Chai, D., Ma, Y., Le, Y., & Li, J. (2026). AI memory expression: mitigating AI aversion through perceived uniqueness. *International Journal of Contemporary Hospitality Management*, 38(6), 1910-1926. DOI: 10.1108/IJCHM-08-2025-1237
- Chaturvedi, R., Verma, S., Srivastava, V., & Khot, S. S. (2025). Exploring the frontier of anthropomorphism in AI agents: Trends and way forward. *Business and Society Review*, 130(1), 42-80. DOI: 10.1111/basr.70002
- Crolic, C., Thomaz, F., Hadi, R., & Stephen, A. T. (2022). Blame the bot: Anthropomorphism and anger in customer-chatbot interactions. *Journal of Marketing*, 86(1), 132-148. <https://doi.org/10.1177/00222429211045687>
- Davenport, T., Guha, A., Grewal, D., & Bressgott, T. (2020). How artificial intelligence will change the future of marketing. *Journal of the Academy of Marketing Science*, 48(1), 24-42. <https://doi.org/10.1007/s11747-019-00696-0>
- De Keyser, A., & Kunz, W. H. (2022). Living and working with service robots: a TCCM analysis and considerations for future research. *Journal of Service Management*, 33(2), 165-196. <https://doi.org/10.1108/JOSM-12-2021-0488>
- Dietvorst, B. J., Simmons, J. P., & Massey, C. (2015). Algorithm aversion: people erroneously avoid algorithms after seeing them err. *Journal of Experimental Psychology: General*, 144(1), 114. <http://dx.doi.org/10.1037/xge0000033>

- Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to Conduct a Bibliometric Analysis: An Overview and Guidelines. *Journal of Business Research*, 133, 285-296. <https://doi.org/10.1016/j.jbusres.2021.04.070>
- Dwivedi, Y. K., Helal, M. Y., Elgendy, I. A., Albashrawi, M. A., Hughes, L., Shawosh, M., . . . Jeon, I. (2026). Artificial intelligence agents and agentic systems in hospitality and tourism: challenges, opportunities and research agenda. *International Journal of Contemporary Hospitality Management*, 38(1), 27-52. DOI [10.1108/IJCHM-02-2025-0287](https://doi.org/10.1108/IJCHM-02-2025-0287)
- Epley, N., Waytz, A., & Cacioppo, J. T. (2007). On seeing human: a three-factor theory of anthropomorphism. *Psychological review*, 114(4), 864. <https://psycnet.apa.org/doi/10.1037/0033-295X.114.4.864>
- Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of marketing research*, 18(1), 39-50.
- Garvey, A. M., Kim, T., & Duhachek, A. (2023). Bad News? Send an AI. Good News? Send a Human. *Journal of Marketing*, 87(1), 10-25. <https://doi.org/10.1177/00222429211066972>
- Giroux, M., Kim, J., Lee, J. C., & Park, J. (2022). Artificial intelligence and declined guilt: Retailing morality comparison between human and AI. *Journal of Business Ethics*, 178(4), 1027-1041. DOI: [10.1007/s10551-022-05056-7](https://doi.org/10.1007/s10551-022-05056-7)
- Glikson, E., & Woolley, A. W. (2020). Human trust in artificial intelligence: Review of empirical research. *Academy of management annals*, 14(2), 627-660. <https://doi.org/10.5465/annals.2018.0057>
- Gnewuch, U., Morana, S., Hinz, O., Kellner, R., & Maedche, A. (2024). More Than a Bot? The Impact of Disclosing Human Involvement on Customer Interactions with Hybrid Service Agents. *Information Systems Research*, 35(3), 936-955. <https://doi.org/10.1287/isre.2022.0152>
- Go, E., & Sundar, S. S. (2019). Humanizing chatbots: The effects of visual, identity and conversational cues on humanness perceptions. *Computers in human behavior*, 97, 304-316. <https://doi.org/10.1016/j.chb.2019.01.020>
- Gonzalez, G. R., Habel, J., & Hunter, G. K. (2026). AI agents, agentic AI, and the future of sales. *Journal of Business Research*, 202, 115799. [10.1016/j.jbusres.2025.115799](https://doi.org/10.1016/j.jbusres.2025.115799)
- Gray, H. M., Gray, K., & Wegner, D. M. (2007). Dimensions of mind perception. *Science*, 315(5812), 619-619. DOI: [10.1126/science.1134475](https://doi.org/10.1126/science.1134475)
- Gutierrez-Salcedo, M., Martinez, M. A., Moral-Munoz, J. A., Herrera-Viedma, E., Torres-Albero, C., & Cobo, M. J. (2018). Some Bibliometric Procedures for Analyzing and Evaluating Research Fields. *Applied Intelligence*, 48(5), 1275-1287. <https://doi.org/10.1007/s10489-017-1105-y>
- Han, E., Yin, D., & Zhang, H. (2023). Bots with Feelings: Should AI Agents Express Positive Emotion in Customer Service? *Information Systems Research*, 34(3), 1296-1311. doi.org/10.1287/isre.2022.1179
- Hasselwander, M., Sunio, V., Lah, O., & Mogaji, E. (2026). Toward agentic AI: User acceptance of a deeply personalized AI super assistant (AISA). *Journal of Retailing and Consumer Services*, 89, 104620. <https://doi.org/10.1016/j.jretconser.2025.104620>
- Haque, A., Akther, N., Khan, I., Agarwal, K., & Uddin, N. (2024). Artificial Intelligence in Retail Marketing: Research Agenda Based on Bibliometric Reflection and Content Analysis (2000-2023). *Informatics*, 11(74), 1-30. <https://doi.org/10.3390/informatics11040074>
- Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford publications.
- Hermann, E., & Puntoni, S. (2024). Artificial intelligence and consumer behavior: From predictive to generative AI. *Journal of Business Research*, 180, 114720. [10.1016/j.jbusres.2024.114720](https://doi.org/10.1016/j.jbusres.2024.114720)
- Hoyer, W. D., Kroschke, M., Schmitt, B., Kraume, K., & Shankar, V. (2020). Transforming the Customer Experience Through New Technologies. *Journal of Interactive Marketing*, 51, 57-71. <https://doi.org/10.1016/j.intmar.2020.04.001>
- Huang, M. H., & Rust, R. T. (2018). Artificial intelligence in service. *Journal of service research*, 21(2), 155-172. <https://doi.org/10.1177/1094670517752459>
- Huang, M. H., & Rust, R. T. (2020). Engaged to a robot? The role of AI in service. *Journal of Service Research*, 24(1), 30-41. <https://doi.org/10.1177/1094670520902266>

- Huang, J., Gu, R., Feng, Y., & Luo, W. (2025). Gendered artificial intelligence in marketing: behavioral and neural insights into product recommendations. *Psychology & Marketing*, 42(5), 1415-1431. <https://doi.org/10.1002/mar.22186>
- Huang, M. H., & Rust, R. T. (2022). AI as customer. *Journal of Service Management*, 33(2), 210-220. <https://doi.org/10.1108/JOSM-11-2021-0425>
- Huang, M. H., & Rust, R. T. (2024). The Caring Machine: Feeling AI for Customer Care. *Journal of Marketing*, 88(5), 1-23. <https://doi.org/10.1177/00222429231224748>
- Humberd, B. K., & Latham, S. F. (2026). When AI Becomes an Agent of the Firm: Examining the Evolution of AI in Organizations Through an Agency Theory Lens. *Journal of Management Studies*, 63(2), 668-694. [doi:10.1111/joms.13274](https://doi.org/10.1111/joms.13274)
- Jussupow, E., Spohrer, K., Heinzl, A., & Gawlitza, J. (2021). Augmenting Medical Diagnosis Decisions? An Investigation into Physicians' Decision-Making Process with Artificial Intelligence. *Information Systems Research*, 32(3), 713-735. <https://doi.org/10.1287/isre.2020.0980>
- Kayhan, R., & Arslan, F. M. (2024). Tedarik Zinciri Dirençliliğinin Şimdisi ve Sonrası: Bir Bibliyometrik Analiz. *Pazarlama ve Pazarlama Araştırmaları Dergisi*, 17(2), 369-416. [Doi: 10.15659/ppad.17.2.1395674](https://doi.org/10.15659/ppad.17.2.1395674)
- Khoi, H. M., & Phuc, T. T. (2026). Mapping the Intellectual Structure of Generative AI Research in Retail and E-commerce: A Bibliometric Review. *SSR Journal of Artificial Intelligence (SSRJAI)*, 12-36. [DOI: 10.5281/zenodo.20072313](https://doi.org/10.5281/zenodo.20072313)
- Kim, H. Y., & McGill, A. L. (2025). AI-induced dehumanization. *Journal of Consumer Psychology*, 35(3), 363-381. <https://doi.org/10.1002/jcpy.1441>
- Korzynski, P., Edwards, A., Gupta, M. C., Mazurek, G., & Wirtz, J. (2025). Humanoid robotics and agentic AI: reframing management theories and future research directions. *European Management Journal*. <https://doi.org/10.1016/j.emj.2025.06.002>
- Lei, S., Xie, L., & Peng, J. (2025). Unethical consumer behavior following artificial intelligence agent encounters: The differential effect of AI agent roles and its boundary conditions. *Journal of Service Research*, 28(4), 598-613. [10.1177/10946705241278837](https://doi.org/10.1177/10946705241278837)
- Leydesdorff, L. (1998). Theories of Citation? *Scientometrics*, 43(1), 5-25. <https://doi.org/10.1007/bf02458391>
- Li, T.-G., Zhang, C.-B., Chang, Y., & Zheng, W. (2024). The Impact of AI Identity Disclosure on Consumer Unethical Behavior: A Social Judgment Perspective. *Journal of Retailing and Consumer Services*, 76. <https://doi.org/10.1016/j.jretconser.2023.103606>
- Li, B., Lai, E. Y., & Wang, X. (2026). From Tools to Agents: Meta-Analytic Insights into Human Acceptance of AI. *Journal of Marketing*, 90(3), 13-33. <https://doi.org/10.1177/00222429251355266>
- Li, X., Wu, P., Shen, G. Q., Wang, X., & Teng, Y. (2017). Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach. *Automation in Construction*, 84, 195-206. [http://dx.doi.org/10.1016/j.autcon.2017.09.011](https://doi.org/10.1016/j.autcon.2017.09.011)
- Liu-Thompkins, Y., Okazaki, S., & Li, H. (2022). Artificial empathy in marketing interactions: Bridging the human-AI gap in affective and social customer experience. *Journal of the Academy of Marketing Science*, 50, 1198-1218. <https://doi.org/10.1007/s11747-022-00892-5>
- Logg, J. M., Minson, J. A., & Moore, D. A. (2019). Algorithm appreciation: People prefer algorithmic to human judgment. *Organizational Behavior and Human Decision Processes*, 151, 90-103. <https://doi.org/10.1016/j.obhdp.2018.12.005>
- Longoni, C., Bonezzi, A., & Morewedge, C. K. (2019). Resistance to medical artificial intelligence. *Journal of Consumer Research*, 46(4), 629-650. <https://doi.org/10.1093/jcr/ucz013>
- Longoni, C., & Cian, L. (2022). Artificial intelligence in utilitarian vs. hedonic contexts: The “word-of-machine” effect. *Journal of Marketing*, 86(1), 91-108. <https://doi.org/10.1177/0022242920957347>
- Loureiro, S. M., Guerreiro, J., & Tussyadiah, L. (2021). Artificial intelligence in business: State of the art and future research agenda. *Journal of Business Research*, 129, 911-926. <https://doi.org/10.1016/j.jbusres.2020.11.001>

- Luo, X., Tong, S., Fang, Z., & Qu, Z. (2019). Frontiers: Machines vs. humans: The impact of artificial intelligence chatbot disclosure on customer purchases. *Marketing Science*, 38(6), 937-947. <https://doi.org/10.1287/mksc.2019.1192>
- Ma, L., & Sun, B. (2020). Machine learning and AI in marketing – Connecting computing power to human insights. *International Journal of Research in Marketing*, 37, 481–504. <https://doi.org/10.1016/j.ijresmar.2020.04.005>
- Mari, A., Mandelli, A., & Algesheimer, R. (2024). Empathic Voice Assistants: Enhancing Consumer Responses in Voice Commerce. *Journal of Business Research*, 175. <https://doi.org/10.1016/j.jbusres.2024.114566>
- Mende, M., Scott, M. L., van Doorn, J., Grewal, D., & Shanks, I. (2019). Service robots rising: How humanoid robots influence service experiences and elicit compensatory consumer responses. *Journal of Marketing Research*, 56(4), 535-556. <https://doi.org/10.1177/0022243718822827>
- Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. *El profesional de la información*, 29(1), 1-20. <https://doi.org/10.3145/epi.2020.ene.03>
- Mouammine, Y. (2026). AI in customer experience and digital marketing: a bibliometric and thematic review (2004–2025) with sensory marketing lens. *Cogent Business & Management*, 13(1), 2613596. <https://doi.org/10.1080/23311975.2026.2613596>
- Moussawi, S., Koufaris, M., & Benbunan-Fich, R. (2021). How perceptions of intelligence and anthropomorphism affect adoption of personal intelligent agents. *Electronic Markets*, 31, 343–364. <https://doi.org/10.1007/s12525-020-00411-w>
- Mucci, T. (2026). *The history of AI*. IBM. Retrieved June 11, 2026, from <https://www.ibm.com/think/topics/history-of-artificial-intelligence>
- Murtarelli, G., Gregory, A., & Romenti, S. (2021). A Conversation-Based Perspective for Shaping Ethical Human-Machine Interactions: The Particular Challenges of Chatbots. *Journal of Business Research*, 129, 927-935. <https://doi.org/10.1016/j.jbusres.2020.09.018>
- Nass, C., & Moon, Y. (2000). Machines and mindlessness: Social responses to computers. *Journal of social issues*, 56(1), 81-103. <https://doi.org/10.1111/0022-4537.00153>
- Nguyen, M., Barari, M., & Zhang, Y. (2026). The voice or the script? Unlocking AI agent persuasion through modality and mental imagery. *Journal of Retailing and Consumer Services*, 92, 104775. <https://doi.org/10.1016/j.jretconser.2026.104775>
- Nizette, F., Hammedi, W., van Riel, A. C., & Steils, N. (2025). Why should I trust you? Influence of explanation design on consumer behavior in AI-based services. *Journal of Service Management*, 36(1), 50-74. <https://doi.org/10.1108/JOSM-05-2024-0223>
- Orhan, U. (2022). Bibliyometrik Araştırmalarda Kullanılan Paket Programlar: Bir Karşılaştırma. O. Öztürk & G. Gürlü içinde, *Bir Literatür İncelemesi Olarak Bibliyometrik Analiz*. Ankara: Nobel
- Ozturk, O. (2021). Bibliometric review of resource dependence theory literature: an overview. *Management Review Quarterly*, 71, 525–552. <https://doi.org/10.1007/s11301-020-00192-8>
- Podsakoff, P. M., MacKenzie, S. B., Lee, J. Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: a critical review of the literature and recommended remedies. *Journal of applied psychology*, 88(5), 879–903. DOI: 10.1037/0021-9010.88.5.879
- Park, S., Chu, Y., & Chung, J. H. (2025). Designing AI Agents for New Product Endorsement: Do Human-Like or Cartoon-Like AI-Generated Endorsers Evoke More Positive Ad Engagement from Consumers? *Journal of Advertising Research*, 65(2), 259-277. [10.1080/00218499.2025.2497615](https://doi.org/10.1080/00218499.2025.2497615)
- Parthiban, E. S., & Adil, M. (2023). Trends in the AI-based Banking Conversational Agents Literature: A Bibliometric Review. *Asia Pacific Journal of Information Systems*, 33(3), 702-736. <https://doi.org/10.14329/apjis.2023.33.3.702>
- Passas, I. (2024). Bibliometric Analysis: The Main Steps. *Encyclopedia*, 4(2). <https://doi.org/10.3390/encyclopedia4020065>
- Pieters, R., & Baumgartner, H. (2002). Who talks to whom? Intra- and interdisciplinary communication of economics journals. *Journal of Economic Literature*, 40(2), 483–509.

- Pillai, R., & Sivathanu, B. (2020). Adoption of AI-based chatbots for hospitality and tourism. *International Journal of Contemporary Hospitality Management*, 32(10), 3199-3226. DOI [10.1108/IJCHM-04-2020-0259](https://doi.org/10.1108/IJCHM-04-2020-0259)
- Poushneh, A., & Gearhart, R. S. (2025). Semi-human artificial intelligence: The effect of search modality (text vs. voice) on perceived eeriness and consumers' purchase intention. *Journal of Consumer Behaviour*, 24(4), 1854-1876. <https://doi.org/10.1002/cb.2496>
- Puntoni, S., Reczek, R. W., Giesler, M., & Botti, S. (2021). Consumers and artificial intelligence: An experiential perspective. *Journal of Marketing*, 85(1), 131-151. <https://doi.org/10.1177/0022242920953847>
- Raisch, S., & Krakowski, S. (2021). Artificial intelligence and management: The automation–augmentation paradox. *Academy of Management Review*, 46(1), 192-210. <https://doi.org/10.5465/amr.2018.0072>
- Raja, S. V. S., Orazi, D. C., Cheng, Y., & Belli, A. (2026). A meta-analysis of the effects of AI agent implementation on customer-level outcomes. *Journal of Business Research*, 210, 116172. [10.1016/j.jbusres.2026.116172](https://doi.org/10.1016/j.jbusres.2026.116172)
- Riandhi, A. N., Arviansyah, M. R., & Sondari, M. C. (2025). AI and consumer behavior: Trends, technologies, and future directions from a scopus-based systematic review. *Cogent Business & Management*, 12(1), 2544984. <https://doi.org/10.1080/23311975.2025.2544984>
- Rojas-Lamoren, Á. J., Barrio-García, S. D., & Alcántara-Pilar, J. M. (2022). A review of three decades of academic research on brand equity: A bibliometric approach using co-word analysis and bibliographic coupling. *Journal of Business Research*, 139, 1067–1083. <https://doi.org/10.1016/j.jbusres.2021.10.025>
- Rothschild, D. M., Mobius, M., Hofman, J. M., Dillon, E. W., Goldstein, D. G., Immorlica, N., Jaffe, S., Lucier, B., Slivkins, A., & Vogel, M. (2025). The agentic economy. *arXiv preprint arXiv:2505.15799*. DOI: [10.48550/arXiv.2505.15799](https://doi.org/10.48550/arXiv.2505.15799)
- Schanke, S., Burtch, G., & Ray, G. (2021). Estimating the Impact of “Humanizing” Customer Service Chatbots. *Information Systems Research*, 32(3), 736–751. <https://doi.org/10.1287/isre.2021.1015>
- Sheehan, B., Jin, H. S., & Gottlieb, U. (2020). Customer service chatbots: Anthropomorphism and adoption. *Journal of Business Research*, 115, 14-24. <https://doi.org/10.1016/j.jbusres.2020.04.030>
- Sinkovics, N. (2016). Enhancing the Foundations for Theorising Through Bibliometric Mapping. *International Marketing Review*, 33(3), 327-350. <https://doi.org/10.1108/IMR-10-2014-0341>
- Small, H. (1997). Co-Citation in the Scientific Literature: A New Measure of the Relationship Between Two Documents. *Journal of the American Society for Information Science*, 24(4), 265-269. <https://doi.org/10.1002/asi.4630240406>
- Song, M., Xing, X., Duan, Y., Cohen, J., & Mou, J. (2022). Will artificial intelligence replace human customer service? The impact of communication quality and privacy risks on adoption intention. *Journal of Retailing and Consumer Services*, 66(102900). <https://doi.org/10.1016/j.jretconser.2021.102900>
- Sönmez, F., & Nart, S. (2022). Antropomorfizm: Kavramın Tarihi, Teoriler ve Tüketici Davranışları Bağlamında Bir Literatür İncelemesi. *İnönü Üniversitesi Uluslararası Sosyal Bilimler Dergisi (İNİJOSS)*, 11(2), 580-613. <https://doi.org/10.54282/inijoss.1121405>
- Srinivasan, V. (2026). Introducing the Universal Cart and more ways to help you shop. *Google Blog*
- Srinivasan, V. (2025). Let AI do the hard parts of your holiday shopping. *Google Blog*
- Tang, Y., & Son, H. (2026). How the Sociality of AI Digital Human Advisors Shapes User Experience Value in Digital Finance: The Mediating Role of Social Presence. *Journal of Theoretical and Applied Electronic Commerce Research*, 21(3), 79. <https://doi.org/10.3390/jtaer21030079>
- Taşkın, T. (2025). *Agentic Şirket*. Ceres Yayınları.
- Theoharakis, V., & Mylonopoulos, N. (2026). AI Epistemic Disengagement and Consumer Dependence: An Augmentation-Substitution Framework. *Psychology & Marketing*. DOI: [10.1002/mar.70136](https://doi.org/10.1002/mar.70136)
- van Doorn, J., Mende, M., Noble, S. M., Hulland, J., Ostrom, A. L., Grewal, D., & Petersen, J. A. (2017). Domo arigato Mr. Roboto: Emergence of automated social presence in organizational frontlines and customers' service experiences. *Journal of service research*, 20(1), 43-58. <https://doi.org/10.1177/1094670516679272>

- van Eck, N. J., & Waltman, L. (2023). VOSviewer Manual. *Center for Science and Technology Studies, Leiden University, The Netherlands*.
- van Raan, A. F. (2014). Advances in bibliometric analysis: research performance assessment and science mapping. *Bibliometrics Use and Abuse in the Review of Research Performance*, 87(4), 17-28.
- Wang, H., Wang, N., Wang, H., & Wang, J. (2026). Unraveling the influence mechanism: how context sensitivity affects consumers' choice of artificial intelligence recommendations. *Asia Pacific Journal of Marketing and Logistics*, 1-18. <https://doi.org/10.1108/APJML-06-2025-1104>
- Wirtz, J., Patterson, P. G., Kunz, W. H., Gruber, T., Lu, V. N., Paluch, S., & Martins, A. (2018). Brave new world: service robots in the frontline. *Journal of Service Management*, 29(5), 907-931. <https://doi.org/10.1108/JOSM-04-2018-0119>
- Yang M., Peng X., Wang Q., Zhao Y. C., Wang, X. (2026), Is being human-like beneficial? The effect of anthropomorphism on chatbot persuasion in e-commerce. *Internet Research*, Vol. 36 No. 4 pp. 1358–1379, doi: <https://doi.org/10.1108/INTR-10-2023-0866>
- Yang, M., Peng, X., Wang, Q., Zhao, Y. C., & Wang, X. (2025). Is being human-like beneficial? The effect of anthropomorphism on chatbot persuasion in e-commerce. *Internet Research*. <https://doi.org/10.1108/INTR-10-2023-0866>
- Yim, A., Cui, A. P., & Walsh, M. (2024). The role of cuteness on consumer attachment to artificial intelligence agents. *Journal of Research in Interactive Marketing*, 18(1), 127-141. <https://doi.org/10.1108/JRIM-02-2023-0046>
- Zan, B. U. (2019). Doğrudan Atıf, Ortak Atıf ve Bibliyografik Eşleşme Yaklaşımlarına Dayalı Olarak Araştırma Alanlarının Değerlendirilmesi. *Sosyal Bilimler Araştırma Dergisi*, 14(2), 501-516.
- Zhang, Y., & Liu, C. (2026). AI-Driven Consumer Research in Fashion: A Systematic and Bibliometric Review (2022–2025) and Future Research Agenda. *Journal of Theoretical and Applied Electronic Commerce Research*, 21(3), 1-26. <https://doi.org/10.3390/jtaer21030074>
- Zupic, I., & Čater, T. (2015). Bibliometric Methods in Management and Organization. *Organizational Research Methods*, 18(3), 429-472. doi: [10.1177/1094428114562629](https://doi.org/10.1177/1094428114562629)

A Qualitative Study on Food Waste Management in Food and Beverage Businesses: The Case of Beykoz District

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Article Info	Abstract
Received: 02.07.2026 Revised: 22.09.2026 Accepted: 23.09.2026 Published: 15.10.2026 Keywords: Gastronomy, Food Waste, Internet of Thing (IoT), Food and Beverage Industry, Sustainability. Jel Code: Z00 Corresponding Author: Nur ERTÜRK Research Article https://doi.org/10.5281/zenodo.23373367	Sustainability and food waste management have become central to the global agenda in response to the rapid depletion of natural resources and escalating environmental challenges. The food and beverage sector, in particular, constitutes a critical component of these discussions due to its intensive consumption of energy and water, as well as the substantial amounts of waste generated throughout production and consumption processes. The aim of this study is to conduct an in-depth qualitative analysis of food waste management practices within food and beverage establishments, alongside an examination of their potential for digital transformation. In this context, the study explores businesses' levels of awareness regarding waste management, their digital infrastructures, their engagement with smart technologies such as the Internet of Things (IoT), and their perceptions of sustainability. The research population comprises restaurants and cafés operating in the Beykoz district of Istanbul. Data were collected through semi-structured, face-to-face interviews conducted with the managers or owners of eight establishments selected via purposive sampling. The data obtained were analyzed using qualitative content analysis. The principal findings indicate that waste management practices within these establishments are generally confined to compliance with legal requirements and the implementation of ad hoc practical measures. Systematic approaches such as source separation of waste and technology-supported inventory management remain limited. Furthermore, the findings reveal a low level of awareness concerning digitalisation and IoT technologies, while cost pressures and operational intensity emerge as significant barriers to the adoption of sustainable practices. These results suggest that local authorities should develop incentive-based policies, organise targeted training programmes, and provide support for digital infrastructure in order to facilitate the transition towards sustainable and smart restaurant models within the sector.

Introduction

Within the global economy, the food service sector employing millions of people and providing daily meals to consumers also emerges as a significant source of food waste. According to the 2021 Food Waste Index Report published by the United Nations Environment Programme (UNEP), 61% of food waste occurs at the household level, 26% within the food service sector, and 13% in the retail sector (Yalçınkaya, 2025). It is estimated that global food waste amounts to 1.05 billion tonnes, of which approximately 20% originates from the food service sector (Kip, 2025). Data from the Food and Agriculture Organisation (FAO, 2016) indicate that the economic cost of food loss and waste in industrialised countries is approximately USD 680 billion annually, while in developing countries this figure reaches USD 310 billion. Across farm-to-table supply chains particularly in developed economies the proportion of edible food lost or wasted each year is estimated to correspond to approximately 30–50% of total global food production intended for human consumption. In the Turkish context, UNEP data suggest that approximately 7.7 million tonnes of food are wasted annually. The average annual household food waste per capita is estimated at 93 kg (Seçer et al., 2023). Furthermore, Tekiner et al. (2021) report that total annual food waste in Türkiye reaches approximately 26 million tonnes, with an estimated economic impact exceeding TRY 555 billion.

In studies examining the impact of waste management within the food service sector, food waste is commonly categorised into three types: preventable waste (food that could have been consumed prior to disposal), potentially preventable waste, and unavoidable waste (typically consisting of inedible components) (Papargyropoulou et al., 2014). Within restaurants and catering establishments, food waste has been found to occur most frequently during the production stage, which accounts for the highest volume of waste. This is primarily attributed to overproduction, improper portioning, and the use of inappropriate food preparation and processing techniques (Güner and Çirişlioğlu, 2021).

On the one hand, the persistent levels of waste within the food and beverage industry, and on the other, the ongoing crises of global hunger and food insecurity, increasingly constitute a paradox that countries are struggling to address. According to reports published in 2025, 8.2% of the global population experienced hunger in 2024 (WHO, 2025). However, the fact that trillions of dollars' worth of food are wasted globally each year an amount sufficient to feed 821 million people four times over underscores a critical contradiction

at the core of the United Nations 2030 Agenda for Sustainable Development and its Sustainable Development Goals (FAO, 2018). In this context, food waste management is not merely an economic issue, but also represents a profound social justice and humanitarian concern. Data from the United Nations Framework Convention on Climate Change (UNFCCC, 2024) indicate that food waste accounts for approximately 8–10% of global greenhouse gas emissions. Consequently, the world is confronted not only with a challenge as severe as hunger, but also with significant environmental degradation. A key driver of this climate impact is the accumulation of organic waste in landfills, where it generates methane emissions. Methane is the second most potent greenhouse gas after carbon dioxide and contributes significantly to global warming (Mar et al., 2022). In the specific case of Türkiye, the carbon footprint associated with waste in the food and beverage sector is estimated at approximately 2.3 million tonnes of CO₂ annually (Hastaoğlu, 2025). These figures suggest that achieving the Paris Agreement target of limiting global warming to 1.5–2°C will be extremely challenging, given that up to 10% of global greenhouse gas emissions are attributed to food loss and waste (World Resources Institute, 2025).

In today's food and beverage industry, which is increasingly difficult to manage through traditional methods, food waste primarily arises from losses during the preparation stage, operational inefficiencies such as inadequate storage, menu and portion planning errors, and plate waste generated by environmentally unaware consumers (Kızarıklı et al., 2025). Within this context, the concept of "Gastronomy 4.0" reflects how digital transformation has introduced a new phase in the optimisation of such operational processes (Yıldız & Davutoğlu, 2020; Akay & Karaçeper, 2024). Internet of Things (IoT) systems technologies enabling sensor-based communication between interconnected objects render food waste visible within kitchen operations while simultaneously revealing new opportunities for improving waste management practices (Wen et al., 2018). In addition, IoT-based smart refrigerators and storage systems reduce spoilage-related waste by enabling real-time monitoring of product freshness and environmental conditions such as temperature and humidity (Protopappas et al., 2025).

More recently, artificial intelligence and computer vision technologies have further advanced food waste management practices within the food industry. In a study conducted by Sigala et al. (2025), the effectiveness of AI-based automated waste-tracking systems in reducing food waste was examined. The study employed deep learning-based monitoring devices capable of tracking food waste in real time across restaurants, institutional catering services, and hotels in different European countries (Germany, Switzerland, and Greece). Initial measurements indicated that food waste ranged between 76.2 and 151.9 g per meal across different establishments. Following implementation, the AI-enabled tracking system enhanced staff awareness, resulting in a reduction of food waste by 23–51% during the food preparation stage.

Against this backdrop, the present study aims to conduct a qualitative and in-depth analysis of food waste management practices in food and beverage establishments and to explore their potential for digital transformation. Beyond assessing the role of digitalisation in operational efficiency and waste reduction, the study also considers its possible implications for customer experience and the expectations of external stakeholders, including local authorities, within this transformation process. Furthermore, it seeks to examine managerial awareness of smart technologies such as the Internet of Things (IoT), existing digital infrastructure capacities, and future technology investment intentions. The findings are expected to provide a comprehensive perspective on the sustainability and digitalisation challenges facing the sector and to contribute to the conceptual foundation for future "sustainable smart restaurant" models.

Conceptual Framework / Theory

The Concept of Sustainability and Its Historical Development

The concepts of sustainability and sustainable development have become among the most widely discussed themes in recent years, largely due to increasing concerns over environmental degradation. As sustainability is inherently a multidimensional concept, different academic disciplines have developed a variety of definitions and interpretative frameworks to address it. Although early concerns related to sustainability can be traced back to eighteenth- and nineteenth-century economists, the emergence of the notion of "sustainable development" is closely associated with the rise of environmental awareness in the twentieth century (Beder, 1994). The growing prominence of this awareness was significantly shaped by the first wave of modern environmentalism in the 1960s and 1970s, which extended global understanding of environmental crises beyond traditional nature conservation perspectives.

During this period, *The Limits to Growth*, published by the Club of Rome, was among the first works to explicitly highlight the tension between unlimited economic growth and the finite nature of global resources, thereby drawing attention to alternative pathways for sustainable development (Meadows, Meadows, Randers,

& Behrens III, 1972). The concept GenAIned widespread international recognition in 1987 with the publication of *Our Common Future* by the World Commission on Environment and Development (WCED). In this report, sustainable development was defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). Over time, scholarly analyses of sustainable development have become more comprehensive, with increasing emphasis on its economic, social, and environmental dimensions. Munasinghe (2001) underlined the necessity of an interdisciplinary approach to achieving sustainability. From this perspective, the economic dimension focuses on improving human welfare through the consumption of goods and services, while the environmental dimension prioritises the protection of ecosystem integrity. The social dimension, in turn, emphasises the enhancement of human relationships and the enabling of individuals to achieve their aspirations (Munasinghe, 2009). Addressing critical global challenges such as poverty, inequality, and climate change situated at the intersection of these three dimensions requires their balanced and integrated consideration.

Sustainable Gastronomy

Sustainability is defined as ensuring the continuity of systems without causing the excessive exploitation of natural resources (Kaypak, 2012). Sustainable gastronomy, in this regard, encompasses a holistic assessment of the environmental, economic, and social impacts associated with food production, consumption, and post-consumption processes, beginning from pre-agricultural stages. This approach represents a culinary philosophy that considers the origin of food, the methods of production, its distribution to markets, and its presentation to consumers (United Nations, n.d.). Accordingly, sustainable gastronomy is conceptualised as an approach that integrates economic, social, and environmental dimensions while prioritising the well-being of future generations (Strezov, 2017; Malinowska et al., 2024).

Within the context of restaurant management, sustainable gastronomy extends beyond a sole focus on profitability to include the reduction of environmental impacts, the enhancement of social benefits, and the strengthening of collaboration with stakeholders (Malinowska et al., 2024). In this respect, restaurants are considered key actors in the implementation of the Sustainable Development Goals. The food and beverage industry is regarded as one of the service sectors with the highest environmental impact due to its intensive consumption of energy and water, as well as its substantial waste generation. Research indicates that restaurants are among the most energy-intensive enterprises within the retail sector, and that kitchen operations constitute a major determinant of overall water consumption. Moreover, a significant proportion of food waste is reported to originate from food and beverage establishments (Deng & Burnett, 2002).

These environmental impacts have brought sustainable gastronomy and environmentally responsible practices to the forefront of restaurant management. Within the scope of sustainable gastronomy, key areas of implementation include the use of local and seasonal products, environmentally responsible supply chain management, improved energy and water efficiency, food waste prevention, and overall waste reduction (Malinowska et al., 2024). While the economic dimension emphasises the support of local supply chains and long-term business resilience, the social dimension highlights fair working conditions, staff training, and the preservation of local gastronomic heritage as essential components of sustainable restaurant management (Malinowska et al., 2024).

Sustainable Restaurant Management

Sustainable restaurant management can be analysed within the framework of the Triple Bottom Line (TBL) approach, which encompasses environmental, social, and economic dimensions (Alhaddi, 2015). Within the existing literature, the environmental dimension is the most prominently emphasised aspect of sustainability (Apak & Gürbüz, 2022).

Economic sustainability, by contrast, is associated with the long-term financial viability of restaurant enterprises. Reductions in energy, water, and raw material consumption generate cost savings, while the adoption of environmentally and socially responsible practices enhances brand reputation and strengthens customer loyalty. In turn, these factors contribute to competitive advantage and the creation of new market opportunities for businesses (Apak & Gürbüz, 2022).

A content analysis conducted by Apak and Gürbüz (2022) revealed that sustainability research in Türkiye predominantly concentrates on the environmental dimension. In particular, issues such as energy and water conservation, waste management, and the development of sustainable menu offerings are given significant emphasis within the literature.

Waste Management and Food Waste in Restaurants

Restaurants represent a critical node within the global food supply chain, where food waste and associated management challenges are particularly prevalent. Food waste not only results in economic losses but also poses significant risks to environmental and social sustainability (Coşkun & Özgün, 2019).

Food waste generated in restaurants is generally categorised into three main groups: preparation waste, service (plate) waste, and spoilage waste. Preparation waste refers to both edible and inedible residues such as vegetable peels, bones, and fats generated during food preparation processes. Plate waste consists of uneaten food left on customers' plates, whereas spoilage waste arises from raw materials that expire or deteriorate due to deficiencies in storage and inventory management. Research indicates that vegetables constitute the food group with the highest waste generation in restaurants, and that the majority of food waste (79.3%) occurs during the service stage (Çirişoğlu & Akoğlu, 2021).

The causes of food waste in restaurants vary depending on the complexity of operational processes. When analysed through the service blueprint framework, these causes emerge at different stages, including physical evidence (e.g., menu design and portion sizing), customer actions (e.g., over-ordering), front-of-house staff activities (e.g., incorrect order taking), and back-of-house kitchen operations (e.g., preparation errors and staff negligence) (Coşkun & Özbük, 2019). In particular, staff negligence and insufficient training are identified as significant contributors to food waste generation (Çirişoğlu & Akoğlu, 2021).

The impacts of food waste are multidimensional. From an economic perspective, food waste represents the loss of embedded resources such as raw materials, labour, energy, and water. From an environmental perspective, the decomposition of food waste in landfill sites produces methane, a highly potent greenhouse gas that contributes significantly to climate change. Furthermore, the unnecessary use of water and land resources in the production of discarded food intensifies environmental pressures (Çirişoğlu & Akoğlu, 2021).

The most effective strategy for preventing food waste is the adoption of zero-waste and waste-free kitchen practices grounded in the Zero Waste philosophy, which prioritises waste reduction at source, reuse, and recycling (Tavus, 2025). Key waste reduction strategies that restaurants can implement include:

1. Waste tracking and measurement: Conducting systematic waste audits to identify the type, timing, and location of waste generation as a foundational step for improvement.

2. Menu engineering: Revising high-waste menu items and applying holistic cooking approaches such as "root-to-stalk" use.

3. Technological solutions: Employing smart scales and digital monitoring systems to track waste data in real time.

4. Staff training and awareness: Providing continuous training for kitchen and service staff on effective waste management practices.

5. Valorisation: Supporting circular economy practices through composting organic waste or redirecting it to animal welfare facilities (Tavus, 2025).

The Internet of Things (IoT) Impacts In Restaurants

The Internet of Things (IoT) is defined as a socio-technical system that enables physical objects to generate data through sensors, software, and network connectivity, and to integrate this data into automated or semi-automated decision-making processes (Atzori, Iera, & Morabito, 2010). In the service industry, IoT applications have created transformative effects on operational efficiency, resource management, customer experience, and sustainability. Within this context, the restaurant sector has become an increasingly important focus of IoT-related research due to its high labour intensity, fluctuating demand patterns, and significant levels of food waste generation.

The existing literature predominantly examines IoT adoption in restaurants from the perspective of operational optimisation. Applications such as inventory tracking, temperature and humidity control, cold-chain monitoring, and energy consumption management via sensor-based systems are primarily designed to reduce costs and improve efficiency (Ben-Daya, Hassini, & Bahroun, 2019). In this respect, IoT contributes to sustainability by enhancing food safety, reducing spoilage, and thereby minimising food waste, as demonstrated in studies focusing on smart kitchen technologies and automated inventory management systems.

In Türkiye, digital transformation and smart city policies are developed within a comparable framework. The draft National Smart Cities Strategy and Action Plan (2024–2030) envisions an "advanced society, advanced technology, and a sustainable and resilient world," aiming to translate digital infrastructure into economic, social, and environmental benefits. This strategy emphasises stakeholder collaboration, innovative

solutions, and sustainability principles in order to promote the diffusion of digital technologies across various sectors (Republic of Türkiye Ministry of Environment, Urbanisation and Climate Change, 2024).

Nevertheless, research indicates that IoT applications in restaurants often remain limited and fragmented. While sensor-based lighting systems, contactless payment solutions, and basic digital infrastructures are relatively common, these systems frequently lack integrated data strategies that would support strategic decision-making. In particular, in small and medium-sized enterprises (SMEs), including family-run restaurants, cost pressures, limited technical expertise, cybersecurity concerns, and staff adaptation challenges are identified as key barriers to the strategic adoption of IoT technologies (Ahmetoglu et al., 2022). IoT applications in restaurants are also widely discussed in relation to customer experience and satisfaction. Digital ordering systems, smart menus, and feedback mechanisms enhance customer experience by improving speed, convenience, personalisation, and transparency (Pantano & Di Pietro, 2012). However, some studies suggest that excessive digitalisation may reduce face-to-face interaction, resulting in neutral or limited effects on customer experience in certain hospitality contexts (Ivanov & Webster, 2019).

Finally, the literature identifies several barriers to the wider diffusion of IoT, including limited digital awareness, insufficient training, infrastructural deficiencies, high implementation costs, and inadequate public support. The National Smart Cities Strategy and Action Plan (2024–2030) seeks to address these challenges and promote more inclusive digital transformation at the local level, formally recognising IoT as strategically important for both economic development and sustainability objectives (Republic of Türkiye Ministry of Environment, Urbanisation and Climate Change, 2024).

Method

This study is designed as a qualitative, field-based investigation aimed at examining the current state of waste management, digitalisation, and sustainability practices within restaurant businesses. The research constitutes the first phase in the development process of the “Sustainable Smart Restaurant Kit” and adopts an exploratory approach that prioritises understanding the operational, cultural, and structural dynamics of the sector prior to proposing solution-oriented interventions. Accordingly, the methodology conceptualises waste generation and digital practices in restaurants not merely as technical processes, but as multi-layered phenomena embedded within workload distribution, habitual behaviours, cost pressures, and organisational culture. The study was conducted in restaurants and cafés operating in the Beykoz district of Istanbul. Using a purposive sampling method, interview requests were extended to 21 businesses representing different scales and organisational structures. However, due to field constraints and institutional limitations, semi-structured, face-to-face interviews were ultimately conducted with 8 businesses.

Data were collected through a semi-structured interview guide covering participants’ knowledge of waste management practices, food waste generation, digital infrastructure, IoT-based solutions, sustainability perceptions, and perceived barriers. In the development of the interview form, the studies of Karakuş (2020), Erik & Pekerşen (2019), Eter (2024), and Akay & Karaçeper (2024) were utilised, alongside a comprehensive review of the relevant literature. The interviews were conducted with individuals who held multiple operational responsibilities within their establishments and possessed direct knowledge of day-to-day processes, predominantly managers or owners. This ensured that the data obtained were closely aligned with routine practices and decision-making processes, particularly within kitchen and service operations. In cases where interviews could not be conducted due to time constraints and institutional barriers, these limitations were documented as contextual data, contributing to a broader understanding of the sector’s approach to sustainability and digital transformation. Data saturation was assessed progressively throughout the interview process. Following each interview, the researchers reviewed the emerging codes and compared them with those identified in previous interviews. Saturation was considered to have been reached when successive interviews no longer generated substantively new codes, categories, or dimensions relevant to the research questions. By the eighth interview, the analysis primarily produced repetitions or further elaborations of previously identified codes rather than substantively new categories. Therefore, the eighth interview was considered the point at which data saturation was reached.

The collected data were analysed using qualitative content analysis. During the coding process, key themes such as insufficient waste separation practices, systemic inadequacies, limited digital literacy, cost pressures, and operational intensity emerged prominently. This methodological approach aims to provide a reliable and context-sensitive foundation for translating the findings into design-, policy-, and practise-oriented sustainability solutions. Ethics Approval: For this study, ethics committee approval was obtained from the Beykoz University Scientific Research and Publication Ethics Committee in its meeting numbered 10 on 28.06.2024, with decision number 7.

Reliability

The trustworthiness of the study was assessed in accordance with the qualitative research criteria of credibility, dependability, confirmability, and transferability (Lincoln & Guba, 1985). Credibility was supported through the use of a pre-prepared semi-structured interview guide across all interviews. Using the same interview guide ensured consistency in the topics addressed while allowing participants to elaborate on their experiences and perspectives. Before data collection, the interview guide was reviewed by two subject-matter experts, and their feedback was incorporated into the final version of the guide. This process helped ensure that the questions were relevant to the research objectives and appropriate to the context of food and beverage businesses. Credibility was further supported through maximum variation in the participating businesses and participant profiles. Interviews included participants with different roles, such as business owners and managers, and were conducted across establishments with different characteristics, including cafés and restaurants. This diversity was used to capture a range of perspectives rather than to treat participant diversity as a form of triangulation. Dependability was addressed by providing a systematic and transparent account of the data collection and analysis procedures. The same semi-structured interview guide was used across interviews, while the stages of participant selection, interviewing, coding, and category development were documented and followed consistently. Emerging codes were reviewed in relation to the research questions and compared with previously identified codes throughout the analytical process. Confirmability was enhanced by grounding the findings in participants' accounts and by repeatedly reviewing the original interview transcripts during the coding and interpretation stages. The researchers compared emerging codes and categories with the original data to ensure that the findings remained closely connected to participants' statements. This process also helped distinguish participants' reported experiences from the researchers' subsequent interpretations. Transferability was addressed through a detailed description of the research context, participating businesses, participant roles, and data collection procedures. The study does not seek statistical generalisation; rather, the contextual details provided allow readers to assess the extent to which the findings may be applicable to other food and beverage businesses or comparable settings. The findings are therefore interpreted within the specific context of the participating businesses in Beykoz.

Findings

Table 1. Please Briefly Describe Yourself and Your Role Within the Business

Question Directed to Participants	Please briefly describe yourself and your role within the business.	
Theme	Code	Frequency
Job Role	Multitasking	6
	Operational Responsibilities	7
	Managerial Role	4
	Financial Responsibilities	2
Industry Experience	Extensive Industry Experience (10+years)	5
	New Employee (1-3 years)	3
	Long-Term Employment within the Business	4
Business Structure	Restaurant/Cafe	3
	Service Quality	3
	Family-Owned Business	2
Workload	Not Performing All Tasks	5
	Operational Competence	5
Personal Background	Educational Background	2
	Nationality	1
	Age	1

The majority of participants reported performing operational responsibilities (n=7) and showed a propensity to conduct multiple tasks (n=6), as indicated in Table 1. This could be explained by the varied workload structure that is inherent in restaurant and café operations. A significant percentage of the participants had extensive industry experience (n=5) and demonstrated a high degree of expertise with their companies' operational procedures (n=4). All phases of business operations were actively participated in by the four participants who held managerial or owner positions.

The least frequently reported categories, on the other hand, were age (n=1), nationality (n=1), and educational background (n=2), suggesting that participants defined themselves primarily through their professional roles and work-related experiences.

Table 2. How do you manage waste in your restaurant?

Question Directed to Participants	How do you manage waste in your restaurant?	
Theme	Code	Frequency
Waste Separation Practice	Limited or No Separation	5
	Partial Separation	3
	Reuse	1
Management of Organic Waste	Donating to Stray Animals	6
	Composting	1
	Inability to Utilize Due to Hygiene Concerns	1
Waste Oil Management	Collected by Licensed Companies	8
Recycling Practices	Waste Separation	4
	Lack of Separation Facilities	2
	Lack of Knowledge	1
Waste Reduction Strategies	Efforts to Reduce Food Loss	2
	Use of Ready-Made Products	1
	Reuse	1
Operational Constraints and Barriers	High Workload / Operational Intensity	2
	Lack of Recycling Infrastructure	2
	Low Volume of Food Waste	1

Table 2 shows that whereas organic waste was typically provided to stray animals (n=6), waste oils were collected by licensed companies in the majority of enterprises (n=8). These procedures might be favoured due to operational convenience and hygiene considerations. Recycling methods were only partially implemented (n=4), which may be related to insufficient infrastructure and awareness, whereas waste separation practices were mostly limited or nonexistent (n=5). Reuse (n=1), composting (n=1), and the use of ready-made products (n=1) were among the least frequently reported codes, offering insight into the low adoption of sustainable waste management practices.

Table 3. How do you evaluate the effectiveness of your current waste management practices?

Question Directed to Participants	How do you evaluate the effectiveness of your current waste management practices?	
Theme	Code	Frequency
Insufficiency of Waste Management System	System Insufficiency	6
	Lack of Waste Separation	5
	Need for Improvement	4
	Staff Shortage	3
	Limited Implementation	3
Strengths	Feeding Animals	4
	Waste Oil Management	3
	Prevention of Food Waste	2
	Social Benefit	1
Role Ambiguity	Limitations of Family-Owned Businesses	2
	Lack of Employee Involvement	1
Emotional Perspective	Moral Satisfaction	2
	Experienced Chefs	1

Nearly all participants assessed the current waste management system as weak (n=6), insufficient (n=5), or in need of improvement (n=4), as shown in Table 3, with the absence of waste separation (n=5) emerging as the most significant problem. The most effective practise was identified as the collection of waste oils by licensed companies (n=8), while donating organic waste to animals (n=6) was perceived as both a strength and a source of moral satisfaction, particularly in small-scale establishments. Operational intensity (n=2), staff shortages (n=3), and the small-scale nature of the businesses (n=2) were regarded as the main barriers to establishing a more professional waste management system.

Table 4. How knowledgeable are you about smart waste management and IoT (Internet of Things)-based solutions?

Question Directed to Participants	How knowledgeable are you about smart waste management and IoT (Internet of Things)-based solutions?	
Theme	Code	Frequency
Lack of Knowledge	No Formal Training	8
	Lack of Practical Experience	8
	Insufficient Knowledge	8
	No Prior Awareness	4
Traditional Approaches	Traditional Methods	2
	Lack of Record-Keeping and Digital Systems	1
Environmental Awareness	Biodegradability / Decomposition in Nature	1

As presented in Table 4, a lack of knowledge regarding smart waste management and IoT-based solutions was observed among the majority of participants, with no formal training (n = 8), lack of practical experience (n = 8), and insufficient knowledge (n = 8) emerging as the most frequently reported codes. The least frequently cited codes were the lack of record-keeping and digital systems (n = 1) and environmental awareness (n = 1), indicating that participants were more accustomed to traditional approaches (n = 2).

Table 5. Are IoT (Internet of Things) or sensor-based systems used in your restaurant?

Question Directed to Participants	Are IoT (Internet of Things) or sensor-based systems used in your restaurant?	
Theme	Code	Frequency
Sensor-Based Systems	Sensor-Enabled Equipment (e.g., lighting, soap dispensers, faucets, towel dispensers, air fresheners, timers)	9
	Security Cameras	2
	Automatically Operated Equipment	2
	Refrigeration Failure Alarm System	1
Digitalisation and Automation in Inventory Management	Use of Digital Ordering Systems	4
	Digital Inventory Management System	4
	Development of Proprietary Software	1
Energy Efficiency	LED Lighting	3
	Energy-Efficient Use of Machinery	2
Lack of IoT Systems	Basic (Sensor-Level) Use Only	5
	Not Used	4

As shown in Table 5, the use of sensor-enabled equipment (e.g., lighting systems, soap dispensers, faucets) was widespread among the majority of participants (n=9), indicating that IoT applications were largely limited to basic and simple implementations. The use of digital ordering and inventory management systems was moderate (n=4 each). Refrigeration failure alarm systems (n=1) and the development of proprietary software (n=1) were the least frequently reported codes, indicating that advanced digitalisation and automation techniques are still lacking.

Table 6a. Perceived Impact of Smart Technologies and Digital Solutions on Customer Experience

Question Directed to Participants	Perceived Impact of Smart Technologies and Digital Solutions on Customer Experience	
Theme	Code	Frequency
Customer Experience	Speed	6
	Convenience	4
	Comfort	3
	Transparency	2

The majority of participants thought that smart technologies would improve customer experience mainly in terms of speed (n=6) and convenience (n=4), as shown in Table 6a. Comfort (n=3) and transparency (n=2) were also perceived as favourable outcomes. Malfunction (n=1), application-related problems (n=1), cost reductions (n=1), and real-time features (n=1) were the least frequently reported codes, suggesting that participants tended to focus primarily on basic experiential benefits.

Table 6b. How would you evaluate the impact of smart technologies and digital solutions on customer satisfaction if they were implemented in your restaurant?

Question Directed to Participants	How would you evaluate the impact of smart technologies and digital solutions on customer satisfaction if they were implemented in your restaurant?	
Theme	Code	Frequency
Customer Satisfaction	Satisfaction	5
	Service Quality	3
Customer Interaction	Feedback	2
	Communication	2
Operational Efficiency	Order Speed	3
	Order Accuracy and Organisation	2

As shown in Table 6b, most participants indicated that smart technologies would enhance customer satisfaction primarily in terms of overall satisfaction (n=5) and service quality (n=3). Another notable operational benefit was order speed (n=3). The least frequently reported codes included feedback (n=2), communication (n=2), and order accuracy and organisation (n=2), suggesting that the primary focus remained on satisfaction and service quality.

Table 6c. How do you evaluate the impact of the smart technologies and digital solutions currently used in your restaurant on customer experience?

Question Directed to Participants	How do you evaluate the impact of the smart technologies and digital solutions currently used in your restaurant on customer experience?	
Theme	Code	Frequency
Enhancement of Customer Experience	Convenience	2
	Speed	2
	Modern Appearance	1
	Transparency	1
Limited Impact	Limited Use	2
	Minor Advantage	1
	Standardized Systems	1
Perceived Risks and Limitations	Environmental Degradation / Biodegradability Concerns	1

Participants stated that the current smart technologies had limited impact on customer experience, as shown in Table 6c. The restricted scope of these impacts was associated with factors such as limited use (n=2) and organisational constraints (n=2), even though speed (n=2) and convenience (n=2) improvements were noted. Modern appearance (n=1), transparency (n=1), and risk of malfunction (n=1) were the least frequently reported codes, indicating that the reach and influence of existing systems remain limited. Overall, the results demonstrate that although current digital applications have the potential to enhance customer experience, the extent and functionality of the technologies employed directly determine their effectiveness. Positive impact / enhancement of customer experience was the most commonly cited theme, with most participants indicating that digitalisation improves the dining experience.

Table 6d. How do you evaluate the impact of the smart technologies and digital solutions currently used in your restaurant on customer satisfaction?

Question Directed to Participants	How do you evaluate the impact of the smart technologies and digital solutions currently used in your restaurant on customer satisfaction?	
Theme	Code	Frequency
Customer Satisfaction	Faster Service	2
	Operational Convenience	2
	Feedback Monitoring	1
	Modern Environment	1
Neutral Impact	Digitalisation Makes a Difference	2
	Mismatch with Digitalisation	2
	Standardization of Sensor-Based Systems	1
Technical Infrastructure Issues	Technical Infrastructure Issues	1
	Increased Risk of Malfunction	1

As presented in Table 6d, participants evaluated the impact of existing smart technologies on customer satisfaction as limited. Faster service (n=2) and operational convenience (n=2) emerged as positive effects, whereas incompatibility with digitalisation (n=2) and the perception that digitalisation does not create a significant difference (n=2) highlighted existing limitations. The least frequently reported codes included feedback monitoring (n=1), modern environment (n=1), standardization of sensor-based systems (n=1), insufficient internet connectivity (n=1), and increased risk of malfunction (n=1), indicating that current technologies have a constrained impact and involve certain risks. In some establishments, it was emphasized that digitalisation may not align with organisational culture due to customers' preference for face-to-face interaction, potentially resulting in adverse effects on customer satisfaction rather than improvements. Technical issues were also reported, including poor internet speed and overuse of technology, which could increase the likelihood of system breakdowns and negatively affect service reliability and speed. Overall, although digitalisation shows potential for enhancing customer satisfaction, its effectiveness appears to depend on the type of organisation, client profile, technical infrastructure, and the scope and quality of implementation.

Table 7. How do you evaluate your restaurant's current digital infrastructure and technological equipment?

Question Directed to Participants	How do you evaluate your restaurant's current digital infrastructure and technological equipment?	
Theme	Code	Frequency
Digital Infrastructure	Functional	6
	Problematic	2
Digital Systems	POS System	3
	Sensors	2
	Customer Loyalty Programmes	1
	Online Ordering Systems	1
Business Characteristics	Small-Scale Business	4
	Family-Owned Business	2
Customer Interaction	Face-to-Face Interaction	3
	Customer Loyalty	2
Cost Efficiency	Sensors	1
	Security Systems	1

Table 7 shows that most participants considered their restaurants' digital infrastructure to be functional (n=6), with small-scale business structures (n=4) and the use of POS systems (n=3) being frequently mentioned. Customer loyalty programmes (n=1), online ordering systems (n=1), cost reductions through sensors (n=1), and security systems (n=1) were the least frequently reported codes, suggesting that the range of technological equipment remains limited. In this context, the digital infrastructure appears to primarily support fundamental operational functions rather than extending to a more comprehensive, organisation-wide technology framework, and its use is largely determined by business type and organisational culture.

Table 8. Does your business have plans to invest in or implement new technologies and digital transformation initiatives?

Question Directed to Participants	Does your business have plans to invest in or implement new technologies and digital transformation initiatives?	
Theme	Code	Frequency
Technological Investment	No investment plan	3
	Limited investment	2
	Strategic investment	1
Robotics and Automation	Robot waiter	2
	Opposition to robotic technologies	1
Labour and Cost Factors	Efficiency and labour	3
	Staff shortage	2
Gastronomic Values	Handcraft and culinary mastery	2
	Traditional production	1

According to Table 8, most participants reported that they either have no plans to invest in new technologies (n=3) or intend to make only limited investments (n=2). This tendency can largely be explained by concerns related to labour and cost factors, including workforce and operational efficiency challenges (n=3) and staff shortages (n=2), which are particularly common in small-scale restaurant operations. Although some participants indicated that they are considering robot waiter applications (n=2), there appears to be no explicit opposition to robotic technologies (n=1). The least frequently mentioned codes—traditional production (n=1), strategic investment (n=1), and aversion to robotic technology (n=1)—suggest that long-term and large-scale technological investments were not frequently mentioned by the participating businesses. Another notable finding is the emphasis on gastronomic values, such as handcraft, culinary expertise, and traditional production, which appears to be associated with some reservations regarding technology integration. These findings may suggest that, for some participants, perceptions of digital transformation are related not only to economic considerations but also to the perceived value of traditional culinary practices. Accordingly, the integration of technology in gastronomy may involve a balance between maintaining traditional culinary practices and pursuing operational efficiency.

Table 9. Which practices do you implement in your restaurant to reduce food waste?

Question Directed to Participants	Which practices do you implement in your restaurant to reduce food waste?	
Theme	Code	Frequency
Portion Management	Standardized portion sizes	5
	Flexible portioning	1
Inventory Management	Minimum stock / use of fresh products	2
Reuse and Redistribution	Donation to stray animals	4
	Consumption by staff	3
	Donation to people in need	3

Table 9 shows that portion control, particularly the use of standardized portion sizes (n=5), is the most commonly employed approach to prevent food waste. This suggests that restaurant operators consider portion control an efficient and manageable strategy. However, flexible portioning (n=1) appears to be used less frequently, indicating limited operational flexibility in portion control procedures. Regarding reuse and redistribution of food waste, the most common methods are donation to stray animals (n=4), staff consumption (n=3), and donation to individuals in need (n=3). Rather than formalized waste reduction strategies, these activities reflect a tendency toward informal, socially oriented solutions. Maintaining minimal stock levels and prioritizing the use of fresh products (n=2) are examples of inventory management practices observed at relatively low frequency, suggesting that systematic planning and forecasting methods are generally not employed. Overall, the results indicate that, instead of comprehensive, technology-supported, or policy-driven methods, food waste reduction efforts are primarily based on pragmatic, experience-driven, and ethically motivated approaches.

Table 10a. What are the most significant barriers you encounter in the process of reducing food waste?

Question Directed to Participants	What are the most significant barriers you encounter in the process of reducing food waste?	
Theme	Code	Frequency
Cost Pressure	Rising food prices	3
	Difficulty reflecting costs on the menu	2
	Investment costs	1
Cultural Barriers	Lack of waste separation habits	1
	Waitstaff behaviour	1
	Customer demand behaviour	1
Operational Barriers	Staff habits	1
	Infrastructure deficiencies	1
	Franchise approval process	1
	Uneaten food	1

The majority of participants face cost-related pressures in their efforts to prevent food waste, as shown in Table 10a. The most significant obstacles are rising food prices (n=3) and challenges in reflecting these expenses on menu prices (n=2). Cultural and operational hurdles were reported less frequently (each n=1), suggesting that issues such as customer demand, staff habits, and infrastructural deficiencies have a relatively smaller impact. Inadequate waste separation procedures, expectations of unlimited consumption, and excessive bread consumption are examples of habitual behaviours influenced by cultural factors among both customers and employees. Conversely, operational impediments are linked to institutional limitations that hinder the implementation of waste reduction strategies, such as inadequate municipal waste services and lengthy franchise approval processes. On the other hand, effective operational control mechanisms and increased staff knowledge play a significant role in preventing food waste in certain establishments, where barriers are considered minor.

Table 10b. What are the most significant opportunities you encounter in the process of reducing food waste?

Question Directed to Participants	What are the most significant opportunities you encounter in the process of reducing food waste?	
Theme	Code	Frequency
Stock and Order Management	Accurate quantity planning	6
	Cost-quality balance	3
Efficiency and Profitability	Cost advantage	4
	Increased profitability	2
Sustainability and Environmental Impact	Recycling	1
	Environmental benefits	1

Accurate quantity determination (n=6) emerges as the most commonly cited opportunity in the process of reducing food waste, as shown in Table 10b. Participants primarily mentioned issues related to stock and order management. Waste reduction strategies are also considered to be significantly influenced by factors related to cost and profitability (cost advantage (n=4); increased profitability (n=2)). The least frequently reported codes were those related to recycling (n=1) and environmental benefits (n=1), suggesting that environmental factors had limited influence on actual implementation. However, some businesses highlighted sustainability-related advantages, such as improved customer satisfaction and environmental benefits. Overall, rather than being motivated solely by environmental concerns, the identified opportunities are primarily focused on operational efficiency, cost control, and maintaining product quality.

Table 11a. How should central and/or local governments (e.g., Beykoz Municipality) contribute to the digital transformation process in the restaurant industry?

Question Directed to Participants	How should central and/or local governments (e.g., Beykoz Municipality) contribute to the digital transformation process in the restaurant industry?	
Theme	Code	Frequency
Education and Awareness	Digital awareness	2
	System usage training	2
Role of the Municipality	Incentives	2
	Support mechanisms	2
Monitoring and Process Management	System use	2
	Waste reduction	2

As shown in Table 11a, participants emphasized that education and awareness programmes should be the primary means by which central and local governments support the digital transformation process, particularly through enhancing digital awareness (n=2) and providing system usage training (n=2). Another important factor in promoting technology adoption in the restaurant industry is the municipality's role in offering institutional support and incentives (n=2 each). Additionally, participants highlighted the use of digital technologies and their significance in reducing food waste, identifying process management and monitoring as key areas for public involvement (n=2 each). Consequently, companies are considered to have opportunities to enhance productivity, reduce costs, and minimize waste through improved digital infrastructure and tracking systems. Participants perceived the involvement of public authorities in this context as focusing on raising awareness, providing supportive interventions, and delivering technology infrastructure to facilitate sustainable, long-term digital transformation.

Table 11b. How should central and/or local governments (e.g., Beykoz Municipality) contribute to the sustainability process in the restaurant industry?

Question Directed to Participants	How should central and/or local governments (e.g., Beykoz Municipality) contribute to the sustainability process in the restaurant industry?	
Theme	Code	Frequency
Waste Management	Recycling	4
	Food waste reduction	2
Inspection and Regulation	Inspections and penalties	2
	Licensing and capacity control	1
Lack of Institutional Initiative	Insufficient local government involvement	2
	Lack of commitment / goodwill	2

Participants emphasized that recycling programmes (n=4) and food waste management practices (n=2) should be among the primary ways in which local governments contribute to sustainability in the restaurant industry, as shown in Table 11b. Although reported less frequently, codes related to institutional initiative deficiencies (insufficient local government involvement [n=2]; lack of commitment or goodwill [n=2]) and inspection and regulation (inspections and penalties [n=2]; licensing and capacity control [n=1]) collectively indicate perceptions of insufficient existing institutional support. Consequently, participants recommended a combination of regulatory control, awareness-raising initiatives, and supportive infrastructure to advance sustainable practices in restaurants. These findings suggest that local government support should extend beyond conventional waste management measures and encompass broader sustainability-oriented initiatives, including the development of appropriate infrastructure and support mechanisms for digital and technological solutions. In this regard, a more coordinated and proactive approach by public authorities may facilitate the integration of sustainability practices with the digital transformation of restaurant operations.

Table 12a. What are the major challenges you encounter in the field of digital transformation, and what solutions do you propose to address these challenges?

Question Directed to Participants	What are the major challenges you encounter in the field of digital transformation, and what solutions do you propose to address these challenges?	
Theme	Code	Frequency
Human Resources and Competencies	Lack of digital awareness	2
	Lack of experienced personnel	2
Adaptation to Technology	Difficulty in adaptation	1
	Technological knowledge gap	1
Development and Solution Proposals	Education and awareness-raising	2
	Optimisation	1

The results indicate that, in order to effectively support digital transformation in the restaurant industry, both local and central governments should focus on human resources and competency development, as shown in Table 12a. The most prominent challenges identified by participants were a lack of digital awareness (n=2) and a lack of skilled personnel (n=2). The least frequently reported codes related to technology adaptation, including difficulty in adaptation (n=1), technological knowledge gaps (n=1), and optimisation proposals (n=1). This pattern suggests that development and improvement initiatives related to digital transformation remain limited. Overall, the findings indicate that advancing digital transformation in the restaurant industry requires greater attention to human capital, digital awareness, and technological competencies.

Table 12b. What are the major challenges you encounter in the field of sustainability, and what solutions do you propose to address these challenges?

Question Directed to Participants	What are the major challenges you encounter in the field of sustainability, and what solutions do you propose to address these challenges?	
Theme	Code	Frequency
Cost	High costs	5
	Product spoilage	4
	Opportunities for savings	4
	Workforce management	3
Awareness	Sustainability awareness	4
	Employee awareness	4
	Government support	3
	Customer awareness	2
Customer Interaction	Customer demand and expectations	3
	Face-to-face communication	3
	Loyalty programmes	2

Participants perceive high operational costs (n=5), product spoilage (n=4), and limited opportunities for cost savings (n=4) as the most significant challenges in the sustainability domain, as shown in Table 12b. Awareness deficits also stand out, with employee awareness (n=4) and sustainability awareness (n=4) identified as major issues. Codes reported less frequently, such as customer awareness (n=2) and loyalty programmes (n=2), suggest that internal organisational practices and financial constraints, rather than external

factors, are the primary drivers of these challenges. These findings underscore the economic, operational, and social dimensions of sustainability and highlight the need for active engagement of both internal and external stakeholders for successful implementation.

Conclusion and Recommendations

The aim was to reveal the levels of knowledge, perceptions, and challenges faced by restaurant and cafe businesses in the Beykoz district of Istanbul regarding waste management, digitalisation, and sustainability through a qualitative study. The findings of the research indicate that the practices in the businesses are shaped particularly by cost concerns and operational efficiency perspectives, and that a strategic understanding of sustainability has not yet been adopted. Research findings on waste management have revealed that in the majority of the businesses interviewed, waste management practices are limited to legal obligations (such as giving waste oils to licensed firms) and practical solutions (such as giving organic waste to street animals). The almost non-existent practise of waste separation at the source (Table 2) is consistent with the participants' assessment of the current waste management system as "inadequate" (Table 3). This situation contradicts the emphasis in the literature that food waste in all operations of restaurant management should be reduced in a planned and systematic manner (McAdams et al., 2019; Pirani & Arafat, 2016; Vizzoto et al., 2021). However, in the study conducted by Çirişoğlu and Akoğlu (2021) in restaurants in Istanbul, it is also observed that there are systemic deficiencies in waste management and that the issue is a widespread problem.

Although feeding animals with organic waste, which is among the sustainable waste management methods, is considered a social responsibility, it ranks lower in the waste hierarchy. Zero waste hierarchy, it is stated that in cases where waste is unavoidable, methods such as recycling, composting, energy recovery, and as a last resort, disposal, should be preferred in that order (ZWIA, 2022; Tavus, 2025). The fact that it was observed in only one establishment in the present study indicates both a lack of knowledge and insufficient infrastructure (support for municipal composting applications, physical space, etc.) necessary for such practices. In Table 9, portion control is preferred as the most common method for reducing food waste, while the limited use of stock management and technology-supported methods indicates that waste management is conducted through traditional practices. This finding aligns with studies that indicate cost pressure and operational challenges are among the greatest barriers to reducing food waste (Pirani & Arafat, 2016).

The extremely low level of knowledge among participants regarding smart waste management and Internet of Things (IoT) based solutions is one of the most striking findings of the research (Table 4). The current technology usage is largely limited to basic sensor-equipped equipment (lighting, faucets, etc.) and POS systems (Table 5, 7). This situation indicates that despite Akay and Karaçeper (2024) stating that the restaurant industry has high potential for digital transformation, there is a significant "knowledge and application gap" in the industry.

The reasons underlying the participants' reluctance to invest in new technologies (Table 8) are the perception of high costs, the lack of qualified personnel, and the current operational intensity. These barriers are frequently mentioned in the literature as the main challenges faced by SMEs in developing countries during their technology adaptation processes. Despite the abundance of theoretical and up-to-date information on the benefits of adopting the Internet of Things (IoT), most businesses continue to refrain from using it due to the lack of existing empirical evidence and the slow or non-adoption of new technologies. (Ali et al., 2023). One important finding is that resistance to technology is based not only on economic but also on cultural foundations. The emphasis on gastronomic values such as "handcrafted" and "mastery" (Table 8) reflects concerns that automation and robotic technologies may conflict with the "traditional" experience of restaurants. As seen in Tables 6a, 6b, and 6d, participants acknowledge that technology can improve customer experience in terms of speed and convenience, but they believe that the current limited applications do not make a significant difference in customer satisfaction. This finding indicates that financial investment alone is not sufficient for the successful integration of technology; a strategic approach that is also aligned with the business culture, customer profile, and service understanding is necessary.

When participants were asked about opportunities to reduce food waste, the prominence of topics such as inventory management and cost advantages over environmental benefits (Table 10b) indicates that the perception of sustainability among participants is largely shaped by economic motivations like "reducing costs" and "increasing efficiency." The lower awareness of the environmental and social dimensions of sustainability (Table 12b) suggests that sustainability is perceived in the industry not as a holistic business model but rather as an operational efficiency tool. This finding aligns with the study by Sünnetçioğlu and Yılmaz (2015), which indicated that some restaurant managers in İzmir lack knowledge about sustainability, while others are heavily focused on time and cost due to pressure from their management stemming from their limited authority. Participants have very high expectations from central and local governments in sustainability

and digital transformation processes. Especially the expectations for strengthening education and awareness efforts, incentives, and inspection mechanisms (Table 11a, 11b) indicate that businesses are struggling to achieve this transformation on their own and need a corporate roadmap. This situation highlights once again the importance of corporate support and guidance, as businesses are either unaware of or do not participate in such programmes. In the literature, as an example of green restaurant initiatives within this corporate roadmap, it is also noted that environmentally friendly practices in restaurants can contribute to customer growth and provide a competitive advantage as a marketing element (Şahingöz & Güleç, 2019).

In conclusion, this study has shown that the practices of sustainability and digitalisation in the examined restaurants and cafes are still in the initial stages, with implementations generally limited to individual efforts, legal obligations, and cost concerns. Waste management is far from a systemic approach, and the adaptation of digital technology is limited due to low awareness and high cost perception. Sustainability, on the other hand, is evaluated more for its economic benefits rather than its environmental and social dimensions.

Conclusion and Implications

In line with these findings, the recommendations for the industry and its stakeholders have been classified under two main headings: practical results and theoretical implications.

Practical Implications

The research findings provide various recommendations to stakeholders such as food and beverage establishments, as well as local and central governments.

Recommendations for Food and beverage establishments

- In-house training programmes on food waste management, composting, circular economy, and current digital technologies should be organized.
- Platforms should be created where businesses with successful sustainability and technology practices can share their experiences.
- Businesses should develop strategic plans that view sustainability not as a cost issue, but as a tool for creating long-term value and strengthening brand image.

Recommendations for Local and Central Governments

- Municipalities should establish the necessary infrastructure for the separate collection and composting of organic waste and encourage businesses to participate in this system.
- Energy-efficient equipment procurement, digital technology investments, and participation in green certification programmes should be incentivized for small-scale businesses.
- Guides should be prepared for the use of "Sustainable Restaurant" standards, and inspections should be conducted within this framework.

Theoretical Implications

This study offers several theoretical contributions to the literature on sustainability and digitalisation and suggests new directions for future research.

Recommendations for Academics

- This study was conducted in a limited geographical scope with a qualitative approach. In future studies, measuring the industry's sustainability and digitalisation levels in a broader geography and with mixed methods will deepen the findings.
- In terms of customer experiences also guiding the industry, "Examining consumers' attitudes and expectations toward sustainable and technology-focused restaurants" will be beneficial in directing businesses to make investments.
- The Internet of Things and the development of new technological systems at lower cost through collaboration between universities and the industry will also promote the widespread use of digitalisation by making it less cost-focused.

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Author Contributions

Author 1: Formal Analysis, Methodology, Formal Analysis, Visualization, Writing – Review & Editing.

Author 2: Conceptualization, Writing – Original Draft, Supervision, Project Administration.

Author 3: Data Curation, Investigation, Methodology.

Author 4: Writing – Original Draft, Writing – Review & Editing.

(The author contribution statements are defined according to the CRediT taxonomy as follows: Conceptualization; Methodology; Software; Validation; Formal analysis; Investigation; Resources; Data curation; Writing – Original draft; Writing – Review & Editing; Visualization; Supervision; Project administration; Funding acquisition.)

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

Yes. This study was approved by the Beykoz University Scientific Research and Publication Ethics Committee (Decision No. 7, Meeting No. 10, Date: 28 June 2024).

Reference

- Ahmetoglu, S., Che Cob, Z., & Ali, N. (2022). A systematic review of Internet of Things adoption in organizations: Taxonomy, benefits, challenges and critical factors. *Applied Sciences*, 12(9), 4117. <https://doi.org/10.3390/app12094117>
- Akay, E., & İnce Karaçeper, E. (2024). Zincir yiyecek içecek işletmelerinde dijital dönüşüm: İstanbul örneği. *Journal of Gastronomy, Hospitality and Travel*, 7(2), 527–549. <https://doi.org/10.33083/joghat.2024.418>
- Alhaddi, H. (2015). Triple bottom line and sustainability: A literature review. *Business and Management Studies*, 1(2), 6–18. <https://doi.org/10.11114/bms.v1i2.752>
- Ali, I., Aboelmaged, M., Govindan, K., & Malik, M. (2023). Understanding the key determinants of IoT adoption for the digital transformation of the food and beverage industry. *Industrial Management & Data Systems*, 123(7), 1887–1910. <https://doi.org/10.1108/IMDS-02-2022-0082>
- Apak, Ö. C., & Gürbüz, A. (2022). Sürdürülebilir restoran işletmeciliği uygulamaları üzerine bir içerik analizi. *Güncel Turizm Araştırmaları Dergisi*, 6(1), 194–209. <https://doi.org/10.32572/guntad.1002109>
- Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, 54(15), 2787–2805. <https://doi.org/10.1016/j.comnet.2010.05.010>
- Beder, S. (1994). Revoltin' developments: The politics of sustainable development. *Arena Magazine* (Fitzroy, Vic), (11), 37–39. <https://search.informit.org/doi/10.3316/informit.030208176825273>
- Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of things and supply chain management: A literature review. *International Journal of Production Research*, 57(15–16), 4719–4742. <https://doi.org/10.1080/00207543.2017.1402140>
- Birleşmiş Milletler. (t.y.). *Sustainable Gastronomy Day*. <https://www.un.org/en/observances/sustainable-gastronomy-day> (Erişim tarihi: 22.04.2026)
- Coşkun, A., & Özbük, R. Y. (2019). Restoranlardaki atık gıda oluşum sebeplerinin hizmet planı üzerinden incelenmesi. *Business and Management Studies: An International Journal*, 7(5), 2556–2576. <https://doi.org/10.15295/bmij.v7i5.1283>
- Çirişoğlu, E., & Akoğlu, A. (2021). Restoranlarda oluşan gıda atıkları ve yönetimi: İstanbul ili örneği. *Akademik Gıda*, 19(1), 38–48. <https://doi.org/10.24323/akademik-gida.927664>

- Deng, S.-M., & Burnett, J. (2002). Water use in hotels in Hong Kong. *International Journal of Hospitality Management*, 21(1), 57–66. [https://doi.org/10.1016/S0278-4319\(01\)00015-9](https://doi.org/10.1016/S0278-4319(01)00015-9)
- Erik, U., & Pekerşen, Y. (2019). Restoran işletmelerinde gıda israfının önlenmesi ve ihtiyaç fazlası yemeğin değerlendirilmesine yönelik bir mobil uygulama modelinin geliştirilmesi: LUSE. *Seyahat ve Otel İşletmeciliği Dergisi*, 16(3), 569–586. <https://doi.org/10.24010/soid.605045>
- Eter, E. (2024). *Restoranlarda sıfır atık yönetimi ve uygulamaları: Elazığ ili örneği* [Yüksek lisans tezi, Ordu Üniversitesi Sosyal Bilimler Enstitüsü]. <https://earsiv.odu.edu.tr/xmlui/handle/11489/5580> (Erişim tarihi: 13.04.2026)
- Food and Agriculture Organization of the United Nations. (2016a). *Food wastage footprint: Full-cost accounting — Final report*. <https://openknowledge.fao.org/items/90a41e2b-b089-4f30-8361-2024bbce08bd>
- Food and Agriculture Organization of the United Nations. (2016b). *Key facts on food loss and waste you should know! FAO SAVE FOOD Initiative*. <https://www.fao.org/documents/card/en/c/CA1354EN/>
- Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme, & World Health Organization. (2018). *The state of food security and nutrition in the world 2018: Building climate resilience for food security and nutrition*. FAO. <http://www.fao.org/interactive/state-of-food-security-nutrition/2018/en/>
- Güner, D., & Çirişoğlu, E. (2021). Birinci sınıf restoranlarda oluşan gıda atıklarının oluşum süreci üzerine bir inceleme (Ankara-Çankaya örneği). *Sanat ve Tasarım Dergisi*, 1(1), 64–90. <https://izlik.org/JA33KM24BD>
- Hastaoğlu, E. (2025). Gıda israfını önleme eğitimi. *Turkish Journal of Agriculture - Food Science and Technology*, 13(2), 682. <https://turjaf.com/index.php/TURSTEP/article/download/682/1112>
- Ivanov, S., & Webster, C. (2019). Robots in tourism: A research agenda for tourism economics. *Tourism Economics*, 26(7), 1065–1085. <https://doi.org/10.1177/1354816619879583>
- Karakuş, F. (2020). *Endüstri 4.0 sürecinde lojistiğin yiyecek ve içecek endüstrisine etkisi* [Yüksek lisans tezi, Balıkesir Üniversitesi]. <https://acikerisim.balikesir.edu.tr/items/3d2c38a3-e435-4fbe-a474-92c85a5c1142> (Erişim tarihi: 05.03.2026)
- Kaypak, Ş. (2012). Ekolojik turizm ve sürdürülebilir kırsal kalkınma. *Karamanoğlu Mehmetbey Üniversitesi Sosyal ve Ekonomik Araştırmalar Dergisi*, 2012(1), 11–29. <https://izlik.org/JA73ZG53LC>
- Kıp, M., Sarıtaş, M. K., Kaldırım, B., & Şahin, G. A. (2025). Gıda kaybı ve israfında güncel durum ve azaltma stratejileri. *Food and Health*, 11(2), 186–196. <https://doi.org/10.3153/FH25015>
- Kızanıklı, M. M., Arslan, P. T., & Kızı, M. B. (2025). Otel işletmelerinde gıda israfı üzerine bir araştırma: İstanbul örneği. *İşletme Araştırmaları Dergisi*, 17(1), 641–661. <https://doi.org/10.20491/isarder.2025.1994>
- Malinowska, E., Płoska, R., Chmielewski, M., & Śledzik, K. (2024). Sustainable gastronomy – A model approach. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 193, 1–16. <https://doi.org/10.29119/1641-3466.2024.193.4>
- Mar, K. A., Unger, C., Walderdorff, L., & Butler, T. (2022). Beyond CO2 equivalence: The impacts of methane on climate, ecosystems, and health. *Environmental Science & Policy*, 134, 127–136. <https://doi.org/10.1016/j.envsci.2022.03.027>
- McAdams, B., von Massow, M., Gallant, M., & Hayhoe, M. A. (2019). A cross industry evaluation of food waste in restaurants. *Journal of Foodservice Business Research*, 22(5), 449–466. <https://doi.org/10.1080/15378020.2019.1637220>
- Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). *The limits to growth: A report for the Club of Rome's project on the predicament of mankind*. Universe Books. <https://www.donellameadows.org/wp-content/userfiles/Limits-to-Growth-digital-scan-version.pdf> (Erişim tarihi: 27.02.2026)
- Munasinghe, M. (2009). *Sustainable development in practice: Sustainomics methodology and applications*. Cambridge University Press. DOI: [10.1017/CBO9780511626777](https://doi.org/10.1017/CBO9780511626777)
- Munasinghe, M. (2001). Sustainable development and climate change: Applying the sustainomics transdisciplinary meta-framework. *International Journal of Global Environmental Issues*, 1(1), 13–55. <https://doi.org/10.1504/IJGENVI.2001.000970>
- OECD. (2021). *The digital transformation of SMEs*. OECD Publishing. <https://doi.org/10.1787/bdb9256a-en>

- Pantano, E., & Di Pietro, L. (2012). Understanding consumer's acceptance of technology-based innovations in retailing. *Journal of Technology Management & Innovation*, 7(4), 1–19. <https://doi.org/10.4067/S0718-27242012000400001>
- Papargyropoulou, E., Lozano, R., Steinberger, J. K., Wright, N., & Ujang, Z. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production*, 76, 106–115. <https://doi.org/10.1016/j.jclepro.2014.04.020>
- Pirani, S. I., & Arafat, H. A. (2016). Reduction of food waste generation in the hospitality industry. *Journal of Cleaner Production*, 132, 129–145. <https://doi.org/10.1016/j.jclepro.2015.07.146>
- Protopappas, L., Bechtsis, D., & Tsotsolas, N. (2025). IoT services for monitoring food supply chains. *Applied Sciences*, 15(13), 7602. <https://doi.org/10.3390/app15137602>
- Republic of Türkiye Ministry of Environment, Urbanisation and Climate Change. (2024). *National smart cities strategy and action plan 2024–2030 (Draft)*. <https://csb.gov.tr/2024-2030-ulusal> (Erişim tarihi: 30.12.2025)
- Secer, A., Masotti, M., Iori, E., & Vittuari, M. (2023). Do culture and consciousness matter? A study on motivational drivers of household food waste reduction in Turkey. *Sustainable Production and Consumption*, 38, 69–79. <https://doi.org/10.1016/j.spc.2023.03.024>
- Sigala, E. G., Gerwin, P., Chroni, C., Abeliotis, K., Strotmann, C., & Lasaridi, K. (2025). Reducing food waste in the HORECA industry using AI-based waste-tracking devices. *Waste Management*, 198, 77–86. <https://doi.org/10.1016/j.wasman.2025.02.044>
- Strezov, V., Evans, A., & Evans, T. J. (2017). Assessment of the economic, social and environmental dimensions of the indicators for sustainable development. *Sustainable Development*, 25(3), 242–253. <https://doi.org/10.1002/sd.1649>
- Sünnetçiöğlu, S., & Yılmaz, B. (2015). İzmir'deki restoran yöneticilerinin sürdürülebilir restoran işletmeciliği üzerine yaklaşımlarının değerlendirilmesi. *Karabük Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 5(1), 94–114. <https://izlik.org/JA57AJ56LZ>
- Şahingöz, S. A., & Güleç, E. (2019). Green generation restaurant movement in restaurants: An example of "La Mancha Restaurant". *Journal of Tourism Theory and Research*, 5(2), 292–300. DOI: 10.24288/jtr.527512
- Tavus, İ. Z., & Kurnaz, A. (2025). Yiyecek içecek işletmelerinde atıksız mutfakın değerlendirilmesi: İstanbul ili örneği. *Journal of Gastronomy, Hospitality and Travel*, 8(3), 965–977. <https://doi.org/10.33083/joghat.2025.538>
- Tekiner, İ. H., Mercan, N. N., Kahraman, A., & Özel, M. (2021). Dünya ve Türkiye'de gıda israfı ve kaybına genel bir bakış. *İstanbul Sabahattin Zaim Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 3(2), 123–128. <https://doi.org/10.47769/izufbed.884219>
- United Nations Framework Convention on Climate Change. (2024). *Food loss and waste account for 8-10% of annual global greenhouse gas emissions; cost USD 1 trillion annually*. <https://unfccc.int/news/food-loss-and-waste-account-for-8-10-of-annual-global-greenhouse-gas-emissions-cost-usd-1-trillion> (Erişim tarihi: 22.04.2026)
- Vizzoto, F., Testa, F., & Iraldo, F. (2021). Strategies to reduce food waste in the foodservices industry: A systematic review. *International Journal of Hospitality Management*, 95, 102933. <https://doi.org/10.1016/j.ijhm.2021.102933>
- Wen, Z., Hu, S., De Clercq, D., Beck, M. B., Zhang, H., Zhang, H., et al. (2018). Design, implementation, and evaluation of an Internet of Things (IoT) network system for restaurant food waste management. *Waste Management*, 73, 26–38. <https://doi.org/10.1016/j.wasman.2017.11.054>
- World Health Organization. (2025, 28 Temmuz). *Global hunger declines, but rises in Africa and western Asia: UN report*. <https://www.who.int/news/item/28-07-2025-global-hunger-declines-but-rises-in-africa-and-western-asia-un-report> (Erişim tarihi: 22.04.2026)
- World Resources Institute. (2025). *The global benefits of reducing food waste*. <https://www.wri.org/insights/reducing-food-loss-and-food-waste> (Erişim tarihi: 22.04.2026)
- World Commission on Environment and Development. (1987). *Our common future*. Oxford University Press.
- Yalçınkaya, M. (2025). Türkiye'de gıda israfı: Değer rejimleri ve müdahale sorunları. *Avrasya Uluslararası Araştırmalar Dergisi*, 13(45), 287–303. <https://doi.org/10.33692/avrasyad.1696568>

- Yıldız, E., & Davutoğlu, N. A. (2020). Turizm 4.0'dan gastronomi 4.0'a giden yolda: Geleceğin restoranları ve yönetimi. *Akademik Sosyal Araştırmalar Dergisi*, 8(109), 301–318. <https://doi.org/10.29228/ASOS.45504>
- Zero Waste International Alliance. (2022). *Zero waste hierarchy of highest and best use 8.0*. <https://zwia.org/zwh/> (Erişim tarihi: 22.04.2026)

All works cited within the study must be included in the references section. Moreover, no publication not cited in the study should be included in the references section. The references section is extremely important in terms of scientific ethics, and authors must select their references with great care. This is a requirement that falls under the responsibility of the authors.

Pilots Perception of Flight Safety: An Analysis Based On A Flight Data Monitoring System

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Abstract

Flight Data Monitoring (FDM) has become an essential component of modern Safety Management Systems by enabling the proactive identification of operational risks and supporting continuous safety improvement. While previous studies have primarily focused on the technical and analytical capabilities of FDM systems, limited attention has been given to pilots' perceptions of FDM and its contribution to operational decision-making. Therefore, this study aims to investigate pilots' perceptions of flight safety in relation to the use of FDM systems and to examine whether these perceptions differ according to demographic and professional characteristics. The study employed a quantitative research design. Data were collected through a structured questionnaire consisting of 24 items administered to 33 volunteer captain pilots and first officers employed by Air Albania. Statistical analyses were performed using SPSS 26. Independent samples t-tests and analysis of variance (ANOVA) were conducted to identify differences among demographic groups. The results revealed statistically significant differences in pilots' perceptions of FDM based on rank and age. Significant differences were identified between captains and first officers regarding their observations of safety and operational improvements resulting from FDM analyses. Furthermore, age-related differences were found in perceptions concerning the influence of FDM on operational decision-making processes. Unlike previous studies that predominantly focused on technical aspects of flight data analysis, this research examines the human and operational dimensions of FDM systems through pilots' perceptions. The findings contribute to the literature by demonstrating that the effectiveness of FDM systems depends not only on technological capabilities but also on pilots' acceptance, organizational support mechanisms, and safety culture.

Introduction

Flight safety is one of the most critical concerns in modern aviation, requiring pilots to accurately perceive, process, and respond to a wide range of information. Human factors, particularly pilot perception, significantly influence decision-making and operational performance during flight. To maintain their operations at a certain level, airlines must expand their scope and develop fuel-efficient solutions. Civil aviation has become a sector of interest within the transportation industry due to the use of advanced technology and a competitive environment. The concept of safety refers to the state of not encountering undesirable situations that could cause significant harm or lead to destruction or that have the potential to occur. In other words, it is defined as the state of being free from situations that could cause injury, damage, or death; it is also described as the absence of danger or immunity from injury, damage, or death (International Civil Aviation Organization ICAO Annex 19, 2011). However, it is difficult to say that situations posing no danger will never occur, especially during flight and when considering aircraft manufactured with advanced technology. Therefore, safety is a relative term that reflects the perceived and accepted level of risk, and it is a condition that exists and is possible in the aviation sector (Başak and Gülen, 2008). In its simplest sense, situational awareness is an individual's ability to understand what is happening in their surroundings. When considering the aviation industry, the environment is dynamic. In this environment, operations are constantly in flux, and at times, multiple tasks are performed simultaneously. It is of vital importance to maintain control over this entire process and take the necessary actions at the right time.

To fully develop situational awareness, one must master three fundamental stages. These stages (Endsley, 1999) are:

- The first stage is the perception of the environment,
- The second stage involves processing information into meaningful knowledge and synthesizing it,
- The third stage is making predictions about the future.

Safety can also be defined as the avoidance of loss of life, bodily injury, occupational disease, property damage, loss of facility usability and adverse environmental impacts (Aksoy, 2006). Various obligations, responsibilities to be fulfilled, authorities, and accountabilities should be established in safety management system procedures, and additional measures should be taken in this regard.

A safety management system consists of the scope of the safety management system, safety policy and objectives, safety obligations, the safety manager, documentation and control procedures, coordination of emergency action plans, hazard identification and risk management plans, safety assurance, safety performance monitoring, safety audits, change management, safety incentives, and contracted activities (ICAO Annex 19).

The concept of human factors is a discipline that examines the physical, cognitive, and social factors affecting human performance, safety, and efficiency in the civil aviation sector. Human factors contribute to areas such as aircraft design, training, operations, maintenance, ergonomics, communication, safety culture, human errors, and risk management skills. Human factors analysis examines the interaction between people and other system stakeholders, such as the environment, facilities, and equipment. It aims to ensure harmonious cooperation between people and the system (Bayat, 2008). The topic of human factors is considered mandatory training by ICAO. These training programs cover processes ranging from aircraft design to the manufacturing stage. Certification training encompasses all activities performed by cockpit and cabin crews, as well as the technical teams responsible for aircraft maintenance (Campbell & Jardine, 2001).

It is widely accepted worldwide that aircraft are the most reliable mode of transportation. However, although statistically rare, the accidents that do occur highlight the need to review safety measures and implement innovations. When examining the causes of accidents, the accident-fatality rate resulting from human errors—often considered minor—is quite high. Eliminating the causes of accidents—which are examined under headings such as flight crew, aircraft maintenance personnel, weather conditions during flight, and the geographical conditions of the airport or seaport—is the goal of all stakeholders involved in aviation (Yavuz, 2013).

These situations can stem from various factors, such as malfunctions in aircraft systems, weather conditions or human error. In aviation, abnormal situations that are unexpected may lead to undesirable events or conditions which pose potential threat to flight safety. Strategies for identifying and preventing abnormal conditions, used in the aviation industry to reduce accidents and incidents, manage risks, improve performance, and foster a culture of safety are as follows.

Safety Management System (SMS): This strategy involves a management approach used to systematically plan, implement, monitor, and improve safety in aviation operations. The SMS consists of four main components: safety policy, safety risk management, safety assurance, and safety promotion (Gemici, 2019).

Threat and Error Management (TEM): This strategy is a set of skills that pilots use to identify, prevent or manage threats (external factors) and errors (internal factors) they encounter during flight. TEM is used to enhance flight safety, reduce human-factor-related errors and improve crew resource management (Başdemir, 2020).

Flight Data Analysis (FDA): This strategy is a method used to analyses flight data recorded during a flight, evaluate flight performance, identify flight regimes, detect abnormal conditions, and take necessary measures. FDA is used to improve flight safety, quality, efficiency, and environmental impact. The FDA program ensures that flight analyses are regularly downloaded and recorded. As a result, a database related to this field is maintained, and information is shared. With advancing technology, many innovations have emerged, foremost among them being FDM (Flight Data Monitoring). Along with these technological advancements, FDM systems have evolved. The development of FDM systems will play a significant role in the future of the aviation industry. In the future, FDM systems will become even more complex and will be developed to further enhance flight safety, efficiency, and convenience (Wang B., Liu, Peng, & Peng, 2019). For example, the tremendous progress made in fields such as artificial intelligence (AI), Data analytics, the Internet of Things (IoT), and virtual reality (VR) has enabled FDM systems to become smarter, faster, more accurate, and more effective.

FDM is one of the proactive and predictive safety management tools included in the safety management system defined by ICAO. FDM directly contributes to risk management and safety assurance dimensions, which are fundamental components of the safety management system. By enabling the systematic identification of operational deviations and potential hazards through data collected during flights, the system

can develop regulatory and preventive measures before accidents and serious incidents occur. Furthermore, using the data obtained for the purpose of learning and improvement rather than punishment contributes to a culture of safety.

These technologies have improved the data collection, processing, analysis, interpretation, reporting, and feedback processes of FDM systems. They also play an effective role in the processes related to pilot training, performance evaluation, human factors analysis, resource analysis, and the efficient use of resources within FDM systems, as well as around error management within flight operations (European Aviation Safety Authority EASA, 2020).

The technologies used include:

Artificial Intelligence (AI): This technology is used to analyse flight data, evaluate flight performance parameters, determine flight regimes, detect abnormal conditions, and take the necessary measures. AI utilizes subfields such as machine learning, deep learning, natural language processing, computer vision, and speech recognition systems to understand, learn from, and predict flight data (Şen et al., 2020).

Modern aircraft collect data from numerous sensors during flight. This data is voluminous and complex. Artificial intelligence supports aviation safety efforts by analyzing this big data in areas such as data filtering and classification, and anomaly detection.

The machine learning algorithms learn normal operational values from historical flight data and use this information to detect future abnormalities. By proactively identifying potential hazards, swift action can be taken. For example, an algorithm that detects sudden increases in engine vibrations can ensure maintenance is performed before a failure occurs. AI-based systems can alert pilots in real time to dangerous situations. Additionally, these systems can simulate events to understand cause-and-effect relationships.

Internet of Things (IoT): This technology is used to collect, transmit, and store flight data, and consists of sensors, devices, networks, and cloud systems located on aircraft, at airports, at ground stations and in other relevant facilities.

Cloud computing: This technology is used to process, analyse, interpret, and report on flight data, as well as provide feedback. Cloud computing is a service that stores, processes, and delivers flight data on remote servers. This technology can enhance the security, accessibility, scalability, and cost-effectiveness of flight data (Keleş and Keleş, 2018). Cloud computing plays a crucial role in the aviation sector by significantly contributing to the digitization of operational processes, enabling more secure data management, and ensuring a seamless flow of information among various stakeholders without disruptions (Tutkun and Bilal, 2025).

IoT devices ensure that the numerous sensors and systems on board an aircraft remain in constant communication. Thanks to real-time data stream, pilot control inputs, weather conditions, and aircraft system information can be obtained instantly, and since all systems on board are interconnected, data monitoring systems can gather more comprehensive information.

Pilots' Concerns and Solutions Regarding FDM

When viewed from the outside, decision-making appears to be a very simple action. However, the act of decision-making is the result of a process. During this process, the pilot generates a wide range of options. They evaluate all options and select the most appropriate course of action. Since the resulting decision is made under time pressure, this increases the likelihood of making a wrong decision. Pilots generally implement the first viable decision rather than comparing many options to make the best one (Simpson, 2001).

The concerns and solutions of pilots and airlines are an important issue in the aviation industry. Pilots and their respective airlines may encounter various issues that can affect flight safety and security, the smooth operation of flights, company efficiency, and all performance metrics. These issues include the following:

Pilots' health: It is crucial for flight safety that pilots are in good health. Pilots receive their flight fitness certificates after undergoing health checks before, during, and after flights. However, pilots' health status can change over time, and factors such as stress, fatigue, sleep disorders, depression, and alcohol or substance abuse encountered during flight can negatively affect pilots' performance and flight safety. For this reason, pilots' health-related conditions must be continuously monitored and addressed (Oğuz, 2015).

Pilot education and development: Pilot training and development are crucial for flight quality and efficiency. Pilots receive theoretical and practical training at flight schools or airlines. However, pilot training and development are not limited to flight skills alone. Pilots must also possess non-technical competencies

such as human factors, crew resource management, threat and error management, communication, leadership, decision-making, problem-solving, and stress management. Training programs for pilots should incorporate and implement the latest methods, technologies, and standards to enhance their education and development (Hartzler, 2013).

Airline costs and competition: Airlines implement various strategies to manage costs and competition. They strive to control their fixed and variable costs, such as fuel, personnel, maintenance, insurance, taxes, and airport fees. In addition, airlines compete with their rivals to maintain or increase their market share. For this reason, airlines use cost reduction to increase revenue, enhance customer satisfaction, and improve operational efficiency and quality (Davis et al., 2008).

Automated Reporting Processes

Automated reporting systems and notification mechanisms are technological tools used to collect and process data, analyses and interpret the resulting data, and following all these processes, generate reports and present them to the relevant individuals or organizations. Automated reporting systems and notification mechanisms are used across various industries and fields for purposes such as data-driven decision-making, performance measurement, quality improvement, risk management, auditing, compliance, training, and feedback. Automated reporting systems and notification mechanisms encompass data sources, report design, report format, report distribution, report security, report monitoring, and report updates.

In automated reporting processes, data is collected via the FDR (Flight Data Recorder) and QAR (Quick Access Recorder). The collected raw data is checked for accuracy. Incorrect, incomplete, or corrupted data is detected and filtered out by the system. The data obtained here is compared against defined flight limits and safety parameters. The reporting process is carried out according to predefined templates. Report types may include a daily operations report (a summary for each flight), a systematic limit violation report (analysis of recurring errors), and a safety performance report (long-term trends and risk analysis).

FDM Applications for Airlines

The European Union (EU) Flight Data Monitoring (FDM) regulation is defined under Commission Regulation (EU) No 965/2012 (specifically Annex III, Part-ORO, rule ORO.AOC.130), requiring commercial air transport aeroplane operators with a maximum certificated take-off mass over 27,000 kg to run a proactive, non-punitive digital flight data analysis program (Commission Regulation (EU) No 965/2012)

Safety is the state in which risks associated with aviation activities, related to or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level. (ICAO 2022)

The development of FDM systems will play a significant role in the future of the aviation industry. In the future, FDM systems will become even more complex and will be developed to further enhance flight safety, efficiency, and convenience (Wang et al., 2019). Aircraft must obtain a flight permit to conduct aviation operations, and this permit can be obtained with an Airworthiness Inspection Certificate confirming that the aircraft has undergone regular maintenance.

The purpose of this study is to identify the perceptions of pilots working in the aviation industry worldwide regarding the FDM system, to examine the effects of flight safety improvement initiatives on airline safety, and to use the findings as a reference for both the aviation industry and future research.

A review of the literature reveals that research on FDM systems is quite limited. This gap highlights the importance of the present study and its potential to fill a gap in literature. A literature review on this topic has been conducted, and the studies examined are summarized in the table below.

Although previous studies have demonstrated the effectiveness of Flight Data Monitoring (FDM) systems in anomaly detection, operational performance monitoring, machine learning applications, and proactive safety management, limited attention has been paid to pilots' perceptions of FDM systems. The studies conducted by Li (2009; 2015; 2016), Chrysanthos (2014), Walker (2017), Oehling and Barry (2019), and Zhao et al. (2021) primarily focused on the technical capabilities of FDM systems and their contribution to operational safety. In contrast, the present study examines the human dimension of FDM by exploring pilots' perceptions regarding the effectiveness, usefulness, and operational impact of these systems. Therefore, this research extends the existing literature by addressing a relatively underexplored area, namely the interaction between pilots and FDM systems, and the extent to which pilots perceive FDM as a tool supporting flight safety and operational decision-making

Study Name	Author	Date	Purpose	Conclusion	Reference
Anomaly Detection in Airline Routine Operations Using Flight Data Recorder Data	Li	2009	The aim of this study is to develop a new anomaly detection approach that will support proactive safety management by utilizing routine flight data recorder (FDR) data. To this end, the study aims to use clustering analysis to identify risks before accidents occur, detect performance deviations early, and identify new types of anomalies that existing methods cannot detect.	The results of the study demonstrated that the cluster-based anomaly detection approaches developed (ClusterAD-Data Sample and Clustered-Flight) can detect operationally significant and novel anomalies, surpassing the capabilities of existing methods. It was determined that different algorithms specialize in detecting different types of deviations (pattern-based, instantaneous, or discrete parameter sequences); therefore, it was concluded that a “hybrid” approach combining these methods would offer superior performance. Furthermore, it was observed that visualization tools significantly reduced the time required for expert review; in summary, it was concluded that this new system offers a promising tool for airlines in the areas of early detection of hidden safety risks, predictive maintenance, and improving education.	Li, 2009
Kernel Methods for Flight Data Monitoring.	Chrysanthos	2014	To investigate machine learning methods for detecting “atypical flights”—which cannot be identified using traditional methods and may lead to operational safety issues—and to develop new “kernel methods” for this purpose. Accordingly, the goal is to create an unsupervised and robust anomaly detection model (using dimension reduction and dynamic time warping techniques) that is suited to the nature of the Flight Data Monitoring (FDM) system.	The results of the study show that, using a new unsupervised anomaly detection method developed based on information theory (Rényi entropy), outliers in clusters containing a high proportion of anomalous data were successfully detected. In addition, a new kernel was constructed that is mathematically well-defined and capable of performing computations faster than existing methods for analyzing flight data. Testing these developed techniques on real airline datasets (Airline1 and Airline2) demonstrated that the approach complements classical event-based detection systems and produces highly beneficial results.	Chrysanthos, 2014
An Analysis of the Effects of Air Traffic Management on Aircraft Fuel Consumption and Emissions Based on Actual Flight Data, and a Proposed Model	Canarslanlar	2015	In this study, the relationship between both fuel consumption and emission levels on domestic flights and ATM was demonstrated based on actual data. To this end, fuel consumption and the resulting emission levels were determined for the airport vicinity, the Terminal Maneuvering Area (TMA), and the taxi phase. To determine ATM flight inefficiencies at and around airports, the phase durations of the Landing and Take-off Cycle (LTO) were determined for each airport included in the study and compared with the ICAO LTO. To determine ATM flight inefficiencies in the TMA and en-route phases, horizontal and vertical flight inefficiency analyses were conducted for domestic flights. As a result of these analyses, an ATM flight inefficiency model was developed to enable the easy measurement of ATM inefficiencies without the need for complex calculation methods.	The study found that the operational LTO cycle, calculated using actual flight data, showed significant differences from the ICAO standard cycle; compared to the standards, taxi-out (59%), climb (45%), takeoff (29%), and taxi-in (26%) times were shorter compared to the standards, while the approach phase took 15% longer due to vertical separations. It was observed that the route with the highest horizontal inefficiency—IST-DNZ (44.9%)—was the one most in need of improvement, and that significant differences in efficiency (e.g., ESB-IST 28.3%, IST-ESB 15.2%) arose in reciprocal flights between airport pairs due to procedural differences. Furthermore, it was concluded that vertical inefficiencies stem primarily from approach plans and procedures during the descent phase, as opposed to the climb phase.	Canarslanlar, 2015

Alircraft Performance Monitoring from Flight Data	Krajček, Nikolić, & Domitrović	2015	The purpose of this study is to provide an overview of existing performance monitoring methods and to offer initial insights into new research opportunities for determining the physical characteristics of operational aircraft using flight data, in order to track “actual aircraft performance” that deviates from the theoretical values in the flight manual due to factors such as structural aging and high dynamic loads.	The research found that existing methods, which rely solely on fuel consumption measurements derived from steady-state flight data, are insufficient for determining other important performance parameters, such as the aircraft’s maximum climb rate or service ceiling. Instead, it has been demonstrated that aerodynamic coefficients can be estimated using “system identification methods” based on data recorded by the QAR (Quick Access Recorder) unit during flight. It has been concluded that this newly developed aerodynamic monitoring system can provide a much more accurate and comprehensive calculation of “actual aircraft performance” by offering additional information on the types of physical disturbances on the aircraft fuselage.	Krajček, Nikolić, & Domitrović, 2015
Analysis of Flight Data Using Clustering Techniques for Detecting Abnormal Operations	Li, Das, Hansman, Palacios, & Srivastava	2015	The purpose of this study is to address the shortcomings of current methods in the airline industry that limit proactive risk management efforts and fail to identify new issues because they rely solely on predetermined criteria. Accordingly, by applying clustering techniques to data obtained from flight data recorders, this study aims to introduce a new method called “cluster-based anomaly detection” that can identify abnormal flights (unique data patterns) without requiring predefined criteria or domain knowledge, thereby supporting domain experts.	The results of the study demonstrated that the “Cluster AD-Flight” method, developed to analyze routine flight data, can successfully detect abnormal flights and hidden risks without requiring prior knowledge of anomalies. Comparisons revealed that Cluster AD-Flight is more sensitive in detecting abnormal patterns in continuous parameters and known safety issues, while the MKAD method performs better in identifying unusual sequences in discrete parameters. Considering these findings, it was concluded that a “hybrid” approach combining the strengths of both methods should be adopted in the future; furthermore, reinforced learning models supported by expert reviews should be developed to reduce false alarms, and the system should be extended to cover all phases of flight.	Li, Das, Hansman, Palacios, & Srivastava, 2015
An Incremental Clustering Method for Anomaly Detection in Flight Data	Li, Hansman, Palacios & Welsch	2016	This article presents a new approach to applying data mining in flight data analysis that enables aviation safety experts to identify hidden risks in daily operations without specifying in advance what to look for.	It has been observed that the ‘ClusterAD-DataSample’ method, tested on real-world datasets, can detect operationally significant anomalies without requiring extensive initial setup and successfully represents increasing risk levels. When compared to other data-driven methods, it has demonstrated superior performance in detecting known security incidents. However, it has been noted that further research is needed to comprehensively evaluate the method’s performance in detecting unknown issues.	Li, Hansman, Palacios, & Welsch, 2016
Monitoring Safety During Airline Operations: A System Approach.	Scarinci	2017	This study presents a new approach to monitoring and analyzing flight data to help airlines identify unsafe system behavior during operations.	The research found that traditional event-based overrun analysis is insufficient for processing the ever-growing volume of FOQA (Flight Operations Quality Assurance) data; therefore, the STAMP and STPA approaches—which are accident causality models—were used to improve this analysis. The study took a holistic approach to hardware, software, and human-automation interaction (pilot practices); by combining STPA concepts with “hypothesis-driven engineering,” it established a systematic method that enables the identification of new “leading indicators” (events) with	Scarinci, 2017

				proactive characteristics for FOQA data analysis.	
Redefining the incidents to learn from: Safety science insights acquired on the journey from black boxes to Flight Data Monitoring	Walker	2017	This article briefly examines the history of black boxes and relates it to the fundamental knowledge base of safety science. It then discusses Flight Data Monitoring (FDM) as an example of the paradigm shift from lagging indicators to leading indicators, which is necessary to continue learning from incidents.	The study revealed that the vast amounts of routine operational data collected in aviation are not yet being utilized to their full potential; however, integrating this Big Data with Flight Data Monitoring (FDM) processes offers significant opportunities, particularly in understanding “human factors.” It was emphasized that in safety science, a shift from “lagging indicators” (learning from disasters) to “leading indicators” (a proactive model) that detect weak signals in routine operations is essential. Furthermore, it was concluded that the data monitoring architecture successfully implemented in the aviation sector could be adapted to other industries with modern data collection infrastructure.	Walker, 2017
Using machine learning methods in airline flight data monitoring to generate new operational safety knowledge from existing data.	Oehling and Barry	2019	The purpose of this study is to investigate the potential of using machine learning (ML) methods to generate new safety-related insights from existing flight data. Airlines routinely generate large amounts of flight data through routine monitoring, but the concept of deriving safety insights from this data still relies on detecting when expert-defined thresholds are exceeded. This system cannot conceptually recognize new patterns that do not fit these filters. Machine learning techniques can address this gap.	The results of the study demonstrated that the application of the LoOP algorithm can enhance existing FDM (Flight Data Monitoring) analyses and detect approach anomalies even in the absence of a specific incident. It has been demonstrated that the developed method can be used not only to detect safety anomalies but also to identify anomalies related to the economic operation of aircraft and to analyze large flight data sets by higher-level authorities such as national aviation authorities. This study, which successfully identifies safety-related events that typical FDM systems cannot detect, suggests that future research should include comparisons with the performance of other outlier detection methods.	Oehling & Barry, 2019
An Incremental Clustering Method for Anomaly Detection in Flight Data	Zhao, Li, Alam, & Wang	2021	The aim of this study is to overcome the time and memory constraints arising from the need to cluster the data from scratch each time when using existing offline anomaly detection methods for the analysis of ever-growing flight data (FDR/QAR). To solve this problem, we aim to develop and propose a new Gaussian Mixture Model (GMM)-based anomaly detection method that can incrementally update clusters based on newly arriving data, rather than processing the entire dataset from the beginning.	The results of the study demonstrated that the new “incremental clustering method” proposed for detecting anomalies in flight data can identify new clusters in dynamically growing datasets, update existing ones, and merge redundant clusters. Tests conducted on both labeled simulation data and unlabeled real-world data have proven that this new method can produce results comparable to those of the traditional “one-time GMM clustering” method. Furthermore, it was noted that additional validation and the development of new tools will be required in the future for the method to be used in airline safety management and pilot training.	Zhao, Li , Alam, & Wang, 2021
Analysis of Data from Flight Data Recorders (FDRs) and Similar Devices Used to Determine the Causes of Aircraft Accidents and Incidents Through Case Studies, and the Development of a New Method for This Purpose	İnan	2021	The aim is to demonstrate the role of a new method—which enables the transmission of data from an aircraft in flight to a ground station via an RF (radio frequency) data linking identifying the causes of aircraft accidents and incidents. The study also aims to present a statistical summary of commercial flight accidents between 1959 and 2016, examine human factors theory, analyze the critical impact of FDR/CVR devices on civil aviation accidents through case studies, and investigate FDA	The results of the study revealed the critical importance of “human factors” and CRM (Crew Resource Management) training in aviation accidents, as demonstrated by the two comparative accident analyses examined. While FDR and CVR data definitively established that inadequate crew coordination caused the civilian jet accident, the root cause of the military training aircraft (T-37C) accident—in which no FDR or CVR devices remained speculative despite four separate investigations. In this context, it has been concluded that equipping all training aircraft—including military training aircraft—	İnan, 2021

		(Flight Data Analysis) processes in routine flights.	with FDR and CVR devices is mandatory to clearly determine the causes of accidents.
Pilot Flying Versus Pilot Monitoring: The Effect of Role Assignment on Pilots' Perceived Risk in Flight Simulation Experiment	Gao, S., Wang, L., Zhang, N., Bai, Y., Tian, 2025 Y., Chen, S., . . . Zhou, H	The purpose of this study is to examine how two different roles in the cockpit (the pilot flying—PF—and the pilot monitoring—PM) shape pilots' perception of risk in the aviation field. Accordingly, perceived risks were measured through psychophysiological responses in simulation experiments designed with professional pilots, with the goal of comparing the differences between the two distinct cockpit roles.	The study found that when pilots were in the pilot flying (PF) role, they exhibited greater physiological arousal and reported a higher perceived level of risk compared to when they were in the pilot monitoring (PM) role. This finding, which reveals an “asymmetric risk perception process” between cockpit roles, indicates that traditional aviation risk perception models must also incorporate the effects of controllability and responsibility. From a practical perspective, it was concluded that scenario-based specialized training—including strategies such as role-swapping—is needed to mitigate the negative effects of differing risk perceptions among crew members, enhance cooperation, and improve flight safety.

Method

This study employed a quantitative, cross-sectional research design to examine pilots’ perceptions of Flight Data Monitoring (FDM) within the contexts of flight safety, operational decision-making, organizational practices, and pilot performance. The study further investigated whether perceptions of FDM varied according to selected demographic and professional characteristics of the participants. The questionnaire included variables with different levels of measurement and addressed distinct aspects of FDM. Each variable was therefore evaluated according to its measurement characteristics and substantive meaning. Numerical values assigned to categorical responses were used for data coding and did not imply equal quantitative distances between response categories. In particular ordinal categories represent an inherent ordering of responses, while the intervals between consecutive categories cannot necessarily be considered equivalent (Sullivan & Artino, 2013).

The accessible population consisted of pilots employed by Air Albania during the data collection period. No sampling procedure was applied, as the study sought to reach the entire pilot population within the airline. All 33 pilots, comprising captains and first officers, voluntarily participated in the research. The resulting dataset therefore covered the accessible pilot population of the airline during the study period. As the research was conducted within a single airline, the findings were interpreted within the organizational and operational context of Air Albania. Generalization of the results to broader pilot populations was approached with caution.

Data were collected through a structured questionnaire designed to examine pilots’ experiences with and perceptions of FDM. The research instrument comprised 23 variables. Three variables addressed participants’ demographic and professional characteristics, while the remaining 20 questions focused on different aspects of FDM.

The questionnaire addressed FDM training and interaction with the system, its perceived contribution to flight safety, identification of potential safety hazards, perceived effectiveness, operational improvements associated with FDM analysis, organizational support, implementation challenges, safety culture, strengths and weaknesses of existing FDM practices, usability, privacy and confidentiality, data access and security, organizational policies and procedures, operational decision-making, changes in flight practices, pilot performance, and the use of FDM data in pilot training.

The questions employed different response formats in accordance with the characteristics of the information being collected. The questionnaire therefore contained dichotomous and multicategorical nominal variables as well as ordinal variables representing ordered levels of perception or evaluation. Numerical codes assigned to nominal categories were treated exclusively as coding conventions and were not interpreted as indicators of magnitude.

Combining multiple items into a composite scale requires evidence that the items represent a common underlying construct and that the resulting measurement structure demonstrates adequate dimensionality,

validity, and reliability (Boateng et al., 2018). The questions used in the present study addressed distinct operational, organizational, and individual aspects of FDM. Consequently, the substantive questionnaire items were analyzed as separate variables according to their respective measurement characteristics, and an overall FDM perception score was not calculated.

Participation in the research was voluntary. Participants were informed about the purpose and scope of the study before completing the questionnaire. The questionnaire was subsequently administered to pilots employed by Air Albania. Responses were numerically coded to facilitate statistical analysis. The measurement characteristics of each variable were preserved during the coding process. Numerical codes assigned to nominal responses were treated as category identifiers, whereas the inherent ordering of response options was retained for ordinal variables. Following data collection, the dataset containing responses from 33 participants was screened for valid cases, coding consistency, and conformity with the predefined response categories. Data were analyzed using IBM SPSS Statistics version 26. The analytical procedures were selected according to the level of measurement and distributional characteristics of the variables. Descriptive statistics were initially used to summarize participant characteristics and response distributions. Nominal and ordinal variables were reported using frequencies (*n*) and percentages (%). The inherent ordering of ordinal response categories was retained throughout the analyses. Numerical category codes were not treated as continuous measurements because numerical coding does not establish equal intervals between adjacent response categories (Sullivan & Artino, 2013).

Inferential analyses were conducted to examine relationships between FDM-related responses and relevant demographic and professional characteristics. Associations between categorical variables were evaluated using Pearson's chi-square test when the assumptions concerning expected cell frequencies were satisfied. Fisher's exact test was used when small, expected cell frequencies limited the appropriateness of the chi-square approximation. Fisher's exact test provides an appropriate method for examining associations between categorical variables in small samples and sparse contingency tables (Warner, 2013). For ordinal outcomes involving two independent groups, the Mann-Whitney U test was applied when the structure and distribution of the data supported a meaningful comparison. Comparisons involving more than two independent groups were conducted using the Kruskal-Wallis test where appropriate. These rank-based procedures were selected in accordance with the ordinal nature of the relevant variables and the absence of an assumption of equal intervals between adjacent response categories (Sullivan & Artino, 2013).

Inferential testing was restricted to comparisons that were conceptually relevant to the research objectives and statistically interpretable within the available data. Variables characterized by highly concentrated response distributions or insufficient observations across comparison groups were evaluated descriptively when inferential testing could not provide a stable or meaningful estimate. This analytical strategy was adopted to reduce the risk of overinterpreting unstable statistical results within the study population of 33 pilots.

All statistical tests were two-tailed, and the level of statistical significance was set at $p < .05$. Exact p values were reported where applicable. Inferential findings were interpreted cautiously in consideration of the number of participants and the single-airline research setting. Ethical approval for the study was granted by the Ethics Committee of the Rectorate of Eskişehir Technical University under Decision No. E-87914409-050.04-94948, dated August 14, 2025. Participation was voluntary, and the collected data were used for scientific research purposes. The findings were reported in a manner that did not permit the identification of individual participants.

Findings

The findings are presented in accordance with the measurement characteristics of the variables and the analytical framework defined in the study. The analysis first describes the demographic and professional characteristics of the participants, followed by the distribution of responses concerning the safety, operational, organizational, and performance-related aspects of FDM. Subsequently, selected FDM-related perceptions are examined across demographic and professional groups using appropriate non-parametric statistical procedures.

Table 1. Demographic and Professional Characteristics of the Participants

Variable	Category	n	%
Age	21–30 years	10	30.3
	31–40 years	6	18.2
	41–50 years	9	27.3
	50 years and above	8	24.2
	Total	33	100.0
Flight experience	1–5 years	13	39.4
	6–10 years	5	15.2
	10 years and above	15	45.5
	Total	33	100.0
Current rank	Commander	17	51.5
	Co-pilot	16	48.5
	Total	33	100.0

Table 1 presents the demographic and professional characteristics of the participants. The largest age group consisted of pilots aged 21–30 years (30.3%), followed by those aged 41–50 years (27.3%) and those aged 50 years or above (24.2%). Pilots aged 31–40 years represented 18.2% of the participants. In terms of flight experience, 45.5% had 10 years or more of professional experience, while 39.4% had between 1 and 5 years of experience. The remaining 15.2% reported 6–10 years of flight experience. The distribution by current rank was nearly balanced, with commanders accounting for 51.5% of the participants and co-pilots for 48.5%.

Table 2. Descriptive Findings on Pilots' Perceptions and Experiences Regarding FDM

Variable	Response	n	%
FDM Training	Yes	13	39.4
	No	20	60.6
	Total	33	100.0
Interaction with FDM Data	Often	3	9.1
	Rarely	19	57.6
	Upon request by the Safety Department	11	33.3
	Total	33	100.0
Perceived Benefits of FDM	Identifying weaknesses	4	12.1
	Identifying the overall safety level	14	42.4
	Improving overall safety	2	6.1
	Identifying overall trends	11	33.3
	Monitoring all flights	2	6.1
	Total	33	100.0
Proactive Identification of Safety Issues	Yes	13	39.4
	No	12	36.4
	Maybe	8	24.2
	Total	33	100.0
Effectiveness in Performance and Decision-Making	Very effective	13	39.4
	Effective	12	36.4
	Somewhat effective	8	24.2
	Total	33	100.0

Table 2 presents descriptive findings concerning the participants' previous FDM training, interaction with FDM data, and perceptions of its contribution to flight safety and pilot performance. Of the 33 participants, 39.4% reported having received training on the functioning of FDM and its importance for aviation safety, whereas 60.6% had received no such training. Interaction with FDM data during daily operations was generally limited: 57.6% of the participants reported interacting with FDM data rarely, 33.3% did so upon request by the Safety Department, and 9.1% reported frequent interaction. Regarding the perceived benefits of FDM for flight safety, identifying the overall safety level was the most frequently reported benefit (42.4%), followed by identifying overall trends (33.3%). Responses were more heterogeneous when participants were asked whether FDM could identify potential safety issues before they developed into accidents or incidents. While 39.4% agreed with this statement, 36.4% disagreed and 24.2% selected the uncertain response.

Table 3. Descriptive Findings on FDM-Related Safety and Organizational Perceptions

Variable	Response	n	%
Observed Safety or Operational Improvements	Yes	31	93.9
	No	1	3.0
	Maybe	1	3.0
	Total	33	100.0
Effectiveness in Identifying Safety Hazards	Very effective	11	33.3
	Effective	17	51.5
	Somewhat effective	5	15.2
	Total	33	100.0
Organizational Support for FDM	Yes	19	57.6
	No	3	9.1
	Maybe	11	33.3
	Total	33	100.0
Perceived Barriers to FDM Implementation	Yes	9	27.3
	No	10	30.3
	Maybe	14	42.4
	Total	33	100.0
Impact on Organizational Safety Culture	Improved safety awareness	4	12.1
	Reduced safety risks	12	36.4
	Increased reporting of safety concerns	8	24.2
	Encouraged a proactive safety approach	9	27.3
	Total	33	100.0

As presented in Table 3 participants reported predominantly favorable perceptions of the safety-related functions of FDM. A substantial majority of the pilots (93.9%) indicated that they had observed an instance in which FDM data analysis contributed to a safety or operational improvement. Only 3.0% reported that they had not observed such an improvement, while a further 3.0% selected the uncertain response. Participants also evaluated FDM positively in terms of identifying and addressing safety hazards. More than half (51.5%) considered FDM effective for this purpose, 33.3% rated it as very effective, and 15.2% described it as somewhat effective.

Evaluations of organizational support for FDM were more varied. While 57.6% of the participants considered the organizational support provided for FDM to be adequate, 33.3% were uncertain and 9.1% considered it inadequate. Responses concerning potential barriers to effective FDM implementation also showed a less concentrated distribution. Specifically, 27.3% of the participants reported the presence of such barriers, 30.3% reported no barriers, and 42.4% were uncertain.

Table 4. Descriptive Findings on FDM System Characteristics, Usability, and Data Confidentiality

Variable	Response	n	%
Strengths of FDM Systems	Identification of individual pilot errors	9	27.3
	Identification of systematic pilot errors	3	9.1
	Identification of operational errors	6	18.2
	Identification of overall trends	14	42.4
	Identification of individual aircraft-related issues	1	3.0
	Total	33	100.0
Weaknesses of FDM Systems	Data security concerns	1	3.0
	Risk of data misuse	16	48.5
	Inadequate analysis of collected data	13	39.4
	Limited organizational feedback	3	9.1
	Total	33	100.0
User-Friendliness of FDM Systems	User-friendly	5	15.2
	Moderately user-friendly	18	54.5
	Slightly user-friendly	2	6.1
	Not user-friendly	8	24.2
	Total	33	100.0
Privacy and Confidentiality Concerns	Yes	2	6.1
	No	16	48.5
	Maybe	15	45.5
	Total	33	100.0
Secure Management and Access to FDM Data	Access restricted to the Safety Department and use in accordance with safety procedures	19	57.6
	Cloud-based security to prevent unauthorized third-party access	6	18.2
	No direct access for the Flight Operations Department	5	15.2
	Pilot consent required for the use of FDM data in investigations	3	9.1
	Total	33	100.0

Table 4 summarizes participants' evaluations of the strengths and weaknesses of FDM systems, their user-friendliness, and issues related to data privacy and management. The identification of overall trends was the

most frequently reported strength of FDM systems (42.4%), followed by the identification of individual pilot errors (27.3%) and operational errors (18.2%). Systematic pilot errors and individual aircraft-related issues were identified less frequently, accounting for 9.1% and 3.0% of responses, respectively. The risk of data misuse emerged as the most frequently reported weakness of FDM systems (48.5%), while 39.4% of the participants identified inadequate analysis of collected data as a principal limitation. Regarding usability, more than half of the participants (54.5%) described the FDM systems as moderately user-friendly. In comparison, 24.2% considered them not user-friendly, while smaller proportions reported more favorable assessments.

Table 5. Descriptive Findings on FDM Policies, Decision-Making, Pilot Performance, and Training

Variable	Response	n	%
Privacy and Confidentiality Policies	Yes	24	72.7
	No	1	3.0
	Maybe	8	24.2
	Total	33	100.0
Influence on Operational Decision-Making	Significantly influences	4	12.1
	Influences	24	72.7
	Does not influence	5	15.2
	Total	33	100.0
Adjustments to Flying Techniques or Procedures	Yes	18	54.5
	No	15	45.5
	Total	33	100.0
Relationship with Pilot Performance Improvement	Weakly correlated	3	9.1
	Moderately correlated	22	66.7
	Strongly correlated	8	24.2
	Total	33	100.0
Use of FDM Data in Pilot Training	Providing regular updates to flight crews	11	33.3
	Tailoring training to individual pilots	10	30.3
	Updating training syllabi based on FDM events	9	27.3
	Incorporating FDM events into check flights and simulator sessions	1	3.0
	Revising procedures according to operational requirements	2	6.1
	Total	33	100.0

Table 5 presents the findings concerning FDM-related policies, operational decision-making, pilot performance, and training. Most participants (72.7%) reported that policies or procedures addressing the privacy and confidentiality of FDM data were in place within their organization. A further 24.2% were uncertain about the existence of such arrangements, while 3.0% reported that no relevant policies or procedures were available.

FDM was also perceived to influence operational decision-making. While 72.7% of the participants reported that FDM influenced their decision-making processes, 12.1% indicated a significant influence. In contrast, 15.2% reported no influence. In addition, 54.5% of the participants stated that they had made adjustments to their flying techniques or procedures based on insights obtained from FDM data analysis, whereas 45.5% reported no such adjustments. The perceived relationship between FDM data analysis and pilot performance improvement was predominantly moderate to strong. A moderate relationship was reported by 66.7% of the participants and a strong relationship by 24.2%, while 9.1% perceived the relationship as weak. No participant selected the “not correlated” response.

Group-Based Comparisons of FDM Perceptions

Variations in pilots’ perceptions of Flight Data Monitoring (FDM) were examined across selected demographic and professional characteristics. Given the measurement properties of the questionnaire items, group comparisons were conducted using statistical procedures appropriate to the level of measurement of each variable. For ordinal FDM-related variables, differences between commanders and co-pilots were assessed using the Mann–Whitney U test.

The Mann–Whitney U analyses revealed no statistically significant differences between commanders and co-pilots across the ordinal FDM-related variables examined (all $p > .05$). Although some variation was observed in the mean ranks, none of these differences reached statistical significance. Thus, the findings did not indicate a systematic rank-based differentiation in pilots’ evaluations of the examined FDM-related aspects. In contrast, a statistically significant association was identified between current rank and previous FDM training, $\chi^2(1, N = 33) = 9.41, p = .002$. Among commanders, 64.7% (11 of 17) reported having received training on the operation of FDM and its importance for aviation safety, compared with 12.5% (2 of 16) of co-

pilots. Fisher's exact test also indicated a statistically significant association (two-sided $p = .004$). The distribution therefore suggests that previous FDM training was more frequently reported by commanders than by co-pilots in the study sample.

Table 6. Kruskal–Wallis H Test Results for FDM Perceptions by Flight Experience

FDM-related perception	H	df	p
Effectiveness in improving pilot performance and decision-making	1.636	2	.441
Effectiveness in identifying and addressing safety hazards	0.829	2	.661
User-friendliness of FDM systems	3.730	2	.155
Influence on operational decision-making	2.699	2	.259
Perceived relationship with pilot performance improvement	1.853	2	.396

Flight-experience groups were defined as 1–5 years, 6–10 years, and 10 years or more. Statistical significance was evaluated at $p < .05$.

The Kruskal–Wallis H test was used to examine whether selected FDM-related perceptions differed across flight-experience groups. As presented in Table 6, no statistically significant differences were identified for any of the examined variables (all $p > .05$). The largest variation across experience groups was observed for the perceived user-friendliness of FDM systems ($H(2) = 3.73$, $p = .155$); however, this difference did not reach statistical significance. Overall, the findings provide no evidence that the selected FDM perceptions varied systematically according to flight experience within the study sample.

Table 7. Kruskal–Wallis H Test Results for FDM Perceptions by Age

FDM-related perception	H	df	p
Effectiveness in improving pilot performance and decision-making	1.318	3	.725
Effectiveness in identifying and addressing safety hazards	0.533	3	.912
User-friendliness of FDM systems	0.248	3	.969
Influence on operational decision-making	4.792	3	.188
Perceived relationship between FDM data analysis and pilot performance improvement	0.780	3	.854

Discussion, Conclusion and Recommendations

The findings of this study provide a multidimensional view of how pilots perceive Flight Data Monitoring (FDM) within an operational airline environment. Rather than portraying FDM solely as a technical system for recording and analysing flight parameters, the results indicate that pilots associate the system with safety improvement, operational decision-making, performance monitoring, organizational practices, and training. This broader perception is consistent with the contemporary understanding of FDM as a proactive component of an airline's Safety Management System (SMS), through which routine operational data can be transformed into information for identifying emerging hazards, monitoring operational trends, and informing preventive interventions. In this respect, FDM represents a transition from learning primarily from adverse events toward identifying precursors and deviations within normal operations (Walker, 2017; Lager & Melin, 2022).

One of the clearest findings concerns pilots' perceptions of the safety contribution of FDM. Almost all participants (93.9%) reported having observed a specific instance in which FDM data analysis contributed to a safety or operational improvement. In addition, 84.8% rated FDM as either effective or very effective in identifying and addressing safety hazards. These findings suggest that the perceived value of FDM among the participating pilots was grounded in observable operational outcomes rather than being limited to an abstract acceptance of the system. This interpretation is consistent with the proactive safety function attributed to FDM in previous research. Walker (2017) conceptualized FDM as a shift toward the use of leading safety indicators derived from routine operations, while Lager and Melin (2022) emphasized the complementary value of FDM and incident-reporting systems for identifying operational risks before they develop into more serious safety outcomes. Studies based directly on operational flight data have similarly demonstrated that FDM can identify

changes in the frequency and severity of operational occurrences and thereby provide evidence for targeted risk mitigation (Efthymiou et al., 2023).

The perceived contribution of FDM extended beyond hazard identification to pilot performance and operational decision-making. In the present study, 75.8% of participants considered FDM effective or very effective in improving pilot performance and decision-making, while 84.8% reported that FDM influenced or significantly influenced operational decision-making. Moreover, 54.5% indicated that they had adjusted their flying techniques or procedures on the basis of insights obtained from FDM data. These findings are particularly relevant because they point to a potential feedback mechanism through which recorded operational data are translated into behavioral or procedural adaptation. FDM is therefore perceived by many of the participating pilots as having practical implications for subsequent flight operations rather than functioning exclusively as a retrospective monitoring mechanism.

Empirical evidence based on operational FDM data supports the relevance of this connection between monitoring, performance, and training. Research examining the disruption of flight operations during the COVID-19 period demonstrated that FDM data could identify changes associated with manual flying proficiency, procedural practice, and automation-related performance, with the authors emphasizing targeted training as a response to identified risks (Efthymiou et al., 2023a, 2023b). More recently, Balkan et al. (2026) used 15 months of operational FDM data to compare pilots from different training pathways and identified statistically significant differences in several safety-critical flight parameters, including hard landing and long touchdown events. Although these studies analyse actual FDM records rather than pilots' perceptions and therefore cannot be treated as direct validation of the present survey responses, they demonstrate that FDM-derived information can distinguish operational performance patterns that are relevant to training and proficiency.

The organizational dimension of the findings requires a more differentiated interpretation. Although 57.6% of participants considered organizational support for FDM adequate, one-third (33.3%) remained uncertain. Similarly, 42.4% were uncertain about whether barriers to effective FDM implementation existed. These distributions suggest that favorable perceptions of the safety utility of FDM do not necessarily imply equally clear perceptions of the organizational processes surrounding its implementation. This distinction is important because the effectiveness of an FDM programme depends on how data are integrated into organizational safety processes, how findings are communicated, and whether personnel regard the system as a mechanism for learning rather than surveillance or punishment. Lager and Melin (2022), for example, identified organizational and procedural considerations affecting the effective joint use of FDM and incident-reporting systems. More recent evidence from pilots also indicates that reporting behaviour and engagement with safety systems are strongly conditioned by organizational culture. Spragg and Efthymiou (2026) found that Just Culture perception was strongly associated with pilots' willingness to report safety events, whereas demographic characteristics showed no significant association with reporting attitudes.

This organizational interpretation is also consistent with established FDM governance principles. Guidance from the UK Civil Aviation Authority defines FDM as the systematic and proactive use of routine flight data within an intrinsically non-punitive and just safety culture, while current European guidance emphasizes management commitment, non-punitive policies, specialized FDM personnel, confidentiality safeguards, and effective internal communication as characteristics of a mature FDM programme (UK CAA, 2013; EASA, 2026). These principles are relevant to the present findings because uncertainty regarding organizational support or implementation barriers may reflect aspects of FDM governance and communication that are less visible to line pilots, even when the operational safety value of the programme itself is recognized. The present data do not permit identification of the causes of this uncertainty; therefore, such an explanation should be regarded as an interpretive possibility rather than a demonstrated organizational deficiency.

Data privacy and confidentiality constitute another important aspect of FDM acceptance. Nearly half of the participants (48.5%) reported no privacy or confidentiality concerns; however, 45.5% selected an uncertain response. At the same time, 72.7% stated that organizational policies or procedures addressing the privacy and confidentiality of FDM data were in place. When asked how FDM data should be securely managed, 57.6% favored restricting access to the Safety Department and using the data in accordance with established safety procedures. Taken together, these findings indicate that the formal existence of privacy-related policies does not necessarily eliminate uncertainty among pilots regarding the governance and use of FDM data.

This distinction has substantial implications for the functioning of FDM programmes. European FDM guidance requires clear procedures concerning data access, security, retention, crew feedback, confidentiality, and the circumstances under which remedial training may be initiated; importantly, such training is expected to be constructive and non-punitive (EASA, 2026). The importance of these safeguards is also supported by empirical studies of pilot reporting behaviour. Kiouleoglou et al. (2025) found that fear of blame, stigmatization, and concerns regarding career progression were prominent barriers to incident reporting among pilots, while participants emphasized the importance of trustworthy reporting systems and Just Culture. Spragg and Efthymiou (2026) likewise showed that pilots' perception of Just Culture was more closely associated with reporting willingness than demographic characteristics. Although voluntary reporting and FDM are distinct safety mechanisms, they share an important organizational requirement: pilots must have confidence in how safety information is collected, protected, interpreted, and subsequently used. The training-related findings reveal an important contrast. Although participants generally evaluated FDM favorably, 60.6% reported that they had not received specific training concerning how FDM operates and its importance for aviation safety. Moreover, previous FDM training was significantly associated with current rank: 64.7% of commanders reported having received such training, compared with 12.5% of co-pilots, $\chi^2(1, N = 33) = 9.41, p = .002$; Fisher's exact $p = .004$. This was the clearest group-based association identified in the study. The finding should not be interpreted as evidence that rank itself causes differences in access to FDM training, as rank is likely to covary with seniority, organizational responsibilities, previous training opportunities, and other unmeasured professional factors. Nevertheless, the magnitude of the observed difference indicates a potential imbalance in pilots' exposure to formal FDM education within the study setting.

This result deserves particular attention because effective use of FDM depends on more than the technical collection of flight data. Pilots need to understand the purpose of monitoring, how events and trends are interpreted, how data are protected, and how FDM findings feed back into safety and training processes. Regulatory guidance accordingly identifies staff training, communication, data protection, and constructive feedback as integral elements of FDM implementation (UK CAA, 2013; EASA, 2026). The training implication is also consistent with empirical evidence demonstrating the potential of FDM data to inform targeted interventions. Efthymiou et al. (2023a) argued for tailored training in response to operational risks identified through FDM, while Balkan et al. (2026) demonstrated that FDM metrics can reveal performance differences associated with different pilot training pathways. The present study extends this discussion from operational FDM outcomes to pilots' exposure to FDM education itself and suggests that access to such training may warrant greater organizational attention, particularly among co-pilots.

Finally, the absence of statistically significant differences in the selected ordinal FDM perceptions across age, flight experience, and rank provides an additional perspective on the findings. The results do not establish equivalence between demographic or professional groups, particularly given the limited sample size; rather, they indicate that this study did not detect systematic group-based differences in the evaluated FDM perceptions. This pattern is broadly consistent with recent evidence suggesting that attitudes toward aviation safety systems may be influenced more strongly by organizational and cultural conditions than by individual demographic characteristics. Spragg and Efthymiou (2026), in a study of 117 commercial airline pilots, similarly found no significant role for demographic characteristics in reporting attitudes and emphasized the stronger relevance of Just Culture perception. Taken together, the findings suggest that the central issue may be less whether pilots of different ages, experience levels, or ranks perceive the technical and operational value of FDM differently, and more how the organization converts FDM into a trusted and accessible learning process. The coexistence of broadly favorable safety and performance evaluations with comparatively limited formal FDM training, uncertainty regarding organizational support and implementation barriers, and substantial uncertainty regarding privacy and confidentiality points to an important distinction between the perceived utility of FDM and the organizational conditions under which that utility is realized. For airlines, the effectiveness of FDM may therefore depend on combining technically robust data analysis with transparent governance, equitable training opportunities, protected data use constructive feedback, and a credible non-punitive safety culture

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Author Contributions

Author 1: Conceptualization, Methodology, Formal Analysis, Writing, Project Administration.

Author 2: Supervision, Project Administration, Review & Editing.

Author 3: Data Curation, Validation, Resources, Review & Editing.

Author 4: Methodology, Writing, Resources, Review & Editing.

Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

The ethics committee report for this study was approved by the Ethics Committee of the Rectorate of Eskisehir Technical University pursuant to Decision No. E-87914409-050.04-94948 dated August 14, 2025.

Reference

- Aksoy, E. (2006). *The human factor in ensuring flight safety and the importance of vocational training in this process* [In Turkish]. Istanbul University Institute of Social Sciences.
- Bakır, M., Bal, H. T., & Akan, Ş. (2017). Evaluation of the Turkish civil aviation sector using an integrated SWOT-AHP approach [In Turkish]. *Journal of Aviation*, 1(2), 154–169.
- Balkan, M. O., Soran, S., Gunessen, N. M., & Yildirim, G. (2026). A quantitative analysis of the impact of traditional vs. MPL (Multi-Crew Pilot License) training pathways on operational performance: A 15-month FDM data study. *Human Factors in Aviation and Aerospace*, 3(1), 34–42. doi:10.26650/hfaa.2026.1893289
- Başak, H., & Gülen, M. (2008). A risk assessment and management model for preventing unmanned aerial vehicle accidents [In Turkish]. *Mühendislik Bilimleri Dergisi*, 14(1), 55–65.
- Başdemir, M. M. (2020). *Crew resource management for all aviation professionals* [In Turkish]. Beta Publishing.
- Bayat, B. (2008). The strategic nature of human resource management [In Turkish]. *Gazi University Journal of Economics and Administrative Sciences*, 10(3), 67–91.
- Birgören, N. (2015). *A study on the effects of crew resource management practices on cabin crew from a flight safety perspective* [Master's thesis, Istanbul Gelisim University Institute of Social Sciences].
- Boateng, G. O., Neilands, T. B., Frongillo, E. A., Melgar-Quinonez, H. R., & Young, S. L. (2018). Best practices for developing and validating scales for health, social, and behavioral research: A primer. *Frontiers in Public Health*, 6, Article 149. doi:10.3389/fpubh.2018.00149
- Büyüköztürk, Ş. (2017). *Handbook of data analysis for social sciences* [In Turkish]. Pegem Academy.
- Campbell, J., & Jardine, A. (2001). *Maintenance excellence*. Marcel Dekker.
- Canarslanlar, A. O. (2015). *Hava trafik yönetiminin uçaklarda yakıt tüketimi ve emisyonu olan etkilerinin gerçek uçuş verilerine dayalı analizi ve bir model önerisi* [Doctoral dissertation, Anadolu University].
- Ceruti, P., Marzocca, A., Liverani, A., & Bil, C. (2019). Maintenance in aeronautics in an Industry 4.0 context: The role of augmented reality and additive manufacturing. *Journal of Computational Design and Engineering*, 6, 516–526.
- Chrysanthos, V. (2014). *Kernel methods for flight data monitoring* [Doctoral dissertation, Massachusetts Institute of Technology].

- Davis, J. R., Johnson, R., & Stepanek, J. (Eds.). (2008). *Fundamentals of aerospace medicine*. Lippincott Williams & Wilkins.
- Endsley, M. R. (1999). Situation awareness in aviation systems. In J. Wise, D. Hopkin, & D. Garland (Eds.), *Handbook of aviation human factors* (pp. 257–276). Lawrence Erlbaum Associates.
- European Aviation Safety Agency. (2012). *Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council*.
- European Aviation Safety Agency. (2020). *Guidance for the implementation of flight data monitoring precursors*.
- European Union Aviation Safety Agency. (2026). *Easy Access Rules for Air Operations* (Revision 24, March 2026). EASA.
- Gao, S., Wang, L., Zhang, N., Bai, Y., Tian, Y., Chen, S., Zhang, Y., & Zhou, H. (2025). Pilot flying versus pilot monitoring: The effect of role assignment on pilots' perceived risk in flight simulation experiment. *Risk Analysis*, 45(9), 2759–2770. doi:10.1111/risa.70048
- Gemici, E., & Yılmaz, H. (2019). Aviation security in terms of security strategies and management [In Turkish]. *Journal of Aviation*, 3(1), 15–27. doi:10.30518/jav.550123
- Hartzler, B. M. (2014). Fatigue on the flight deck: The consequences of sleep loss and the benefits of napping. *Accident Analysis & Prevention*, 62, 309–318.
- International Civil Aviation Organization. (2018). *Annex 6 to the Convention on International Civil Aviation: Operation of aircraft, Part I—International commercial air transport—Aeroplanes* (11th ed.). ICAO.
- International Civil Aviation Organization. (2022). *Safety management manual (SMM)* (Doc 9859, 5th ed.). ICAO.
- Karaoğlu, A. C. (2021). Maintenance, repair and overhaul activities in civil aviation, Aviation 4.0 and emerging trends [In Turkish]. *Manufacturing Technologies and Applications*, 2(1), 61–74.
- Keleş, A., & Keleş, A. (2018). Innovations and challenges brought by the Internet of Things [In Turkish]. *Electronic Turkish Studies*, 13(13).
- Kiouloupoglou, P., Nikolaidis, V., David, K. M., & Makris, I. (2025). Investigating incident under-reporting in aviation: Qualitative insights among Greek pilots. *Research in Transportation Business & Management*, 59, Article 101309. doi:10.1016/j.rtbm.2025.101309
- Korul, V., & Küçükönel, H. (2003). Structural analysis of the Turkish civil aviation system [In Turkish]. *Ege Academic Review*, 3(1), 24–38.
- Krajček, K., Nikolić, D., & Domitrović, A. (2015). Aircraft performance monitoring from flight data. *Technical Gazette*, 22(5), 1337–1344. doi:10.17559/TV-20131220145918
- Lager, E., & Melin, M. (2022). Proactive flight safety—A feasibility study on optimal use of flight data monitoring and incident reports in an airline. *International Journal of Occupational Safety and Ergonomics*, 28(2), 1311–1315. doi:10.1080/10803548.2021.1899608
- Li, L. (2013). *Anomaly detection in airline routine operations using flight data recorder data* [Doctoral dissertation, Massachusetts Institute of Technology].
- Li, L., Das, S., Hansman, R. J., Palacios, R., & Srivastava, A. N. (2015). Analysis of flight data using clustering techniques for detecting abnormal operations. *Journal of Aerospace Information Systems*, 12(9), 587–598.
- Li, L., Hansman, R. J., Palacios, R., & Welsch, R. E. (2016). An incremental clustering method for anomaly detection in flight data. *Journal of Aerospace Information Systems*, 13(12), 464–481.
- Oehling, J., & Barry, D. J. (2019). Using machine learning methods in airline flight data monitoring to generate new operational safety knowledge from existing data. *Aerospace*, 6(6), Article 62. doi:10.3390/aerospace6060062
- Oğuz, A. K. (2015). Aviation medicine and hypertension [In Turkish]. *TKS*, 15(3).

- Scarinci, A. (2017). *Monitoring safety during airline operations: A systems approach* [Master's thesis, Massachusetts Institute of Technology].
- Simpson, P. (2001). *Naturalistic decision making in aviation environments*. DSTO Aeronautical and Maritime Research Laboratory.
- Spragg, D., & Efthymiou, M. (2026). Airline pilots' perception of Just Culture and their willingness to submit safety reports within the context of flight data monitoring (FDM). *Transportation Research Interdisciplinary Perspectives*, 39, Article 102207. doi:10.1016/j.trip.2026.102207
- Sullivan, G. M., & Artino, A. R., Jr. (2013). Analyzing and interpreting data from Likert-type scales. *Journal of Graduate Medical Education*, 5(4), 541–542. doi:10.4300/JGME-5-4-18
- Şen, M., Dalcı, A., & Temurtaş, F. (2020). Past, present, and future trends of technologies used in the aviation industry [In Turkish]. *Journal of Intelligent Transportation Systems and Applications*, 3(2).
- Tutkun, A., & Bilal, Ç. (2025). Industry 4.0 and smart operational systems in the aviation sector [In Turkish]. In A. Tutkun (Ed.), *Global trends and strategic directions in air transportation* (pp. 1–24). Nobel Academic Publishing.
- UK Civil Aviation Authority. (2013). *CAP 739: Flight data monitoring*. Civil Aviation Authority.
- Walker, G. H. (2017). Redefining the incidents to learn from: Safety science insights acquired on the journey from black boxes to flight data monitoring. *Safety Science*, 99, 14–22. doi:10.1016/j.ssci.2017.05.010
- Wang, B., Liu, D., Peng, Y., & Peng, X. (2019). Multivariate regression-based fault detection and recovery of UAV flight data. *IEEE Transactions on Instrumentation and Measurement*, 69(6), 3527–3537.
- Warner, P. (2013). Testing association with Fisher's exact test. *Journal of Family Planning and Reproductive Health Care*, 39(4), 281–284. doi:10.1136/jfprhc-2013-100747
- Yavuz, İ. (2013). THK Etimesgut aircraft factory (1939–1950) [In Turkish]. *Mühendis ve Makina*, 32–36.
- Zhao, Y., Li, L., Alam, S., & Wang, J. (2021). An incremental clustering method for anomaly detection in flight data. *Transportation Research Part C: Emerging Technologies*, 129, Article 103236.