SYNEX

Journal of Mobility & Business Research

Year: 2026
Volume: 1
Issue: 1

ISSN: 3149-8647

www.synexjournal.org

ISSN: 3149-8647
SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

BOARD OF JOURNAL

Founder & Publisher

Dr. Ayberk TUTKUN
Dokuz Eylül University

Managing Editor / Layout

Haydar ŞAHİN
Bingöl University

Editor-in-Chief

Assoc. Prof. Dr. Umut AYDIN
Istanbul Ticaret University

Dr. Kağan Çağrı KARACA
Dokuz Eylül University

Associate Editor(s)

Asst. Prof. Dr. Mehmet GÜRTÜRK
Çanakkale Onsekiz Mart University

Asst. Prof. Dr. Ebru BAĞCI
Istanbul Beykent University

Asst. Prof. Dr. Nur ERTÜRK
Beykoz University

Asst. Prof. Dr. Gizem ÇORMAN
İstanbul Nişantaşı University

ISSN: 3149-8647
SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

EDITORIAL BOARD

Assoc. Prof. Dr. Filiz EROĞLU
Canakkale Onsekiz Mart University

Assoc. Prof. Dr. Volkan YAVAŞ
Ege University

Asst. Prof. Dr. Tarık GÜNEŞ
Iskenderun Technical University

Asst. Prof. Dr. Tuncel ÖZ
Istanbul Ticaret University

Dr. Aydan SAVICI POLAT
Kocaeli University

Dr. Itır Ceren MORCOTE SANTOS
Dokuz Eylül University

SCIENTIFIC BOARD

Prof. Dr. Aliye ÇİLAN AKIN
Bolu Abant Izzet Baysal University

Prof. Dr. Ender GEREDE
Eskisehir Technical University

Prof. Dr. Füsun ÜLENGİN
Sabanci University

Prof. Dr. Kemal Burç ÜLENGİN
Istanbul Technical University

Prof. Dr. Umut AVCI
Mugla Sıtkı Koçman University

Prof. Dr. Özgür ÇENGEL
Istanbul Arel University

Prof. Dr. Özlem ATALIK
Eskisehir Technical University

Prof. Dr. Zinaida SMUTCHAK
University of Educational Management

Assoc. Prof. Dr. Mehmet OKAN
Istanbul Bilgi University

Assoc. Prof. Dr. Melis Almula KARADAYI
Medipol University

Asst. Prof. Dr. Ali Emre SARILGAN
Eskisehir Technical University

Asst. Prof. Dr. Caroline MARETE
Purdue University

Asst. Prof. Dr. Elif İDEMEN OKAN
Istanbul University

Assoc. Prof. Dr. Eda AVCI
Dokuz Eylül University

Asst. Prof. Dr. Harun YILMAZ
Iskenderun Technical University

Asst. Prof. Dr. Hidayet BEYHAN
Bitlis Eren University

Asst. Prof. Dr. Mefule ERDOĞAN
Istanbul Ticaret University

Dr. Adnan AKIN
Bolu Abant Izzet Baysal University

Dr. Kubilayhan GÖÇ
Aksaray University

ADVISORY BOARD

Prof. Dr. Zeyneb ÇAĞLIYAN İÇENER
Istabul Ticaret University

Assoc. Prof. Dr. Cemali BUZLUKCU
Balikesir University

Assoc. Prof. Dr. Musa OFLAZ
Balikesir University

Assoc. Prof. Dr. Sinan ÇAVUŞOĞLU
Bingöl University

Dr. Ümmühan Beste YILDIRIM
Burdur Mehmet Akif Ersoy University

Nurcan DURMAZ
Dokuz Eylül University

ISSN: 3149-8647
SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

REFEREES IN THIS ISSUE

Asst. Prof. Dr. Mahmut MOLLAOĞLU
Zonguldak Bulent Ecevit University

Asst. Prof. Dr. Aybike Esra ŞAHİN
İstanbul Gelisim University

Asst. Prof. Dr. Serdar OKAN
Gumushane University

Çağdaş ATEŞ
Sakarya University of Applied Science

Asst. Prof. Dr. Bükra DOĞANER DUMAN
Ankara University

Dr. Arif TUNCAL
International Science and Technology University

Sertaç ZOBU
Amasya University

Asst. Prof. Dr. Ramazan KARAMAN
Dicle University

Asst. Prof. Dr. Selda KARAHAN
Beykoz University

Asst. Prof. Dr. Emre AYKAÇ
Iskenderun Technical University

ISSN: 3149-8647
SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

CONTENTS

SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

Exploring the Impact of Digitalization on Air Cargo Operations through Qualitative Case Study Analysis

Cengiz Kerem KÜTAHYA[1], Ümit KANMAZ[2]*
[1] Kuwait Australian University, School of Aviation Department. (keremkutahya@gmail.com). ORCID: 0000-0002-7222-0921
[2] Istanbul Commerce University, Aviation Management Department. (ukanmaz@ticaret.edu.tr). ORCID: 0000-0003-2186-2737

Article Info

Received: 22.12.2025
Revised: 05.02.2026
Accepted: 20.04.2026
Published: 20.05.2026

Keywords:
Air cargo logistics, Digital transformation, Automation, Predictive analytics, Data governance, Customer satisfaction, Technology-Organization-Environment (TOE), Resource-Based View (RBV)

Jel Code:
L93, O33, M15, C55, D23, M31

Corresponding Author:
Ümit Kanmaz

Research Article
https://doi.org/10.5281/zenodo.20276602

Abstract

This study explores the strategic implementation of digital transformation in the air cargo sector through an in-depth qualitative case analysis of Turkish Cargo's SMARTIST facility—recognized as one of the most advanced cargo hubs globally. Against the backdrop of rising demand for agility, transparency, and efficiency in global logistics, the research investigates how digital technologies such as automation, AI, IoT, and predictive analytics are operationalized in a high-volume, mission-critical environment. Drawing on 25 semi-structured interviews, document analysis, and observational data, the study identifies five core themes: Operational efficiency through digital integration, implementation challenges, the role of data analytics and forecasting, customer transparency and satisfaction, and cybersecurity and governance concerns. Framed within the Technology-Organization-Environment (TOE) framework and the Resource-Based View (RBV), the findings offer both theoretical and practical contributions, emphasizing the dynamic interplay between technological infrastructure, organizational capabilities, and external pressures. The study concludes with strategic recommendations for stakeholders seeking to enhance digital readiness and scalability in aviation logistics, while highlighting avenues for future comparative and longitudinal research.

1. Introduction

The global air cargo sector plays a critical role in enabling international trade by facilitating the rapid movement of high-value and time-sensitive goods, including pharmaceuticals, electronics, and industrial components (Merkert, 2023). In recent years, global supply chain volatility, geopolitical disruptions, and the sustained expansion of e-commerce have intensified operational pressures on air cargo operators, compelling them to deliver speed, reliability, and transparency simultaneously (Wang & Sarkis, 2021; Hong et al., 2025). These developments have exposed the limitations of traditional, paper-based, and labor-intensive cargo processes and have accelerated the sector's shift toward digitally enabled operational models.

Digital transformation in air cargo is increasingly understood as the systematic integration of advanced technologies—such as automation, artificial intelligence (AI), the Internet of Things (IoT), digital platforms, and data analytics—into logistics processes and decision-making structures (Cheung et al., 2023; Mihai et al., 2022). Recent empirical evidence demonstrates that digitalization enhances real-time visibility, improves coordination across logistics actors, and enables predictive planning capabilities within air cargo supply chains. For example, Jurgelāne-Kaldava et al. (2025), in their case study of Latvia, show that digital integration standards significantly improve information flow, traceability, and operational alignment among air cargo stakeholders. Similarly, Wehner et al. (2025) provide comprehensive empirical insights from Germany, demonstrating that automation and digital airport process management contribute to measurable gains in throughput efficiency, process reliability, and cargo handling accuracy at major cargo hubs.

Despite these documented benefits, the implementation of digital transformation in air cargo remains uneven and complex. Empirical studies highlight persistent challenges related to legacy system integration, fragmented digital infrastructures, workforce adaptation, and cybersecurity vulnerabilities (Yavas & Ozkan-Ozen, 2024; Fakhraian et al., 2023). As air cargo operations become increasingly data-intensive and interconnected, risks associated with cyber threats, data governance, and regulatory compliance have grown in parallel (Murinde et al., 2022). These findings indicate that digital transformation in air cargo should not be

viewed merely as a technological upgrade, but rather as a socio-technical process shaped by organizational capabilities, institutional environments, and human factors (Thums et al., 2023).

From a broader logistics perspective, recent scholarship also emphasizes that digital transformation is closely intertwined with platform-based economies and open-source digital infrastructures. Akçacı et al. (2026) argue that logistics digitalization increasingly operates within a "silicon economy," where open-source platforms and digital ecosystems reshape value creation, coordination, and innovation across supply chains. Their findings suggest that digital transformation extends beyond efficiency gains, influencing strategic positioning and collaborative dynamics within logistics networks—an insight that is particularly relevant for air cargo hubs operating as integrators of global trade flows.

Although the existing literature provides valuable insights into digital technologies and logistics performance, several gaps remain. First, much of the research on air cargo digitalization relies on quantitative surveys or technology-focused analyses, offering limited understanding of how digital transformation unfolds within complex operational settings. Second, while recent studies document efficiency and automation outcomes (e.g., Wehner et al., 2025; Jurgelāne-Kaldava et al., 2025), fewer studies examine the organizational, strategic, and governance dimensions of digital transformation in an integrated manner. Third, in-depth qualitative case studies focusing on large-scale, digitally advanced air cargo hubs—particularly in emerging aviation markets such as Türkiye—remain scarce.

This study addresses these gaps by conducting an in-depth qualitative case analysis of Turkish Cargo's SMARTIST facility at Istanbul Airport, one of the most technologically advanced air cargo terminals globally. Drawing on 25 semi-structured interviews, document analysis, and on-site observations, the study examines how digital transformation is operationalized in practice, the challenges and enablers shaping its implementation, and the perceived outcomes in terms of operational efficiency, transparency, customer satisfaction, and data governance. The analysis is theoretically grounded in the Technology–Organization–Environment (TOE) framework and the Resource-Based View (RBV), enabling a holistic examination of how technological infrastructure, organizational capabilities, and environmental pressures interact in shaping digital transformation outcomes.

The contribution of this research is threefold. First, it provides process-level qualitative evidence on digital transformation in air cargo operations, addressing the methodological imbalance in existing research. Second, by integrating TOE and RBV within a real-world cargo hub context, the study advances theoretical understanding of how digital capabilities translate into organizational value in aviation logistics. Third, the findings offer practical insights for air cargo operators, airport authorities, and policymakers by identifying actionable lessons for managing digital implementation, workforce adaptation, and cybersecurity governance in large-scale cargo facilities.

2. Literature Review

2.1. Digital Transformation in Air Cargo: Context and Evolution

The digital transformation of air cargo operations has gained significant momentum over the past decade, driven by the convergence of Industry 4.0 technologies and the increasing demand for speed, transparency, and resilience in global logistics. Historically, air cargo has lagged behind other logistics segments in adopting digital innovations due to legacy systems, fragmented value chains, and complex regulatory requirements. However, recent advancements in digital technologies, coupled with supply chain disruptions such as the COVID-19 pandemic, have catalyzed a paradigm shift toward more agile, integrated, and data-driven cargo ecosystems. Wang and Sarkis (2021) emphasize that digital technologies—ranging from Internet of Things (IoT) and artificial intelligence (AI) to blockchain and cloud computing—are transforming freight transport by enabling real-time tracking, predictive analytics, and automation. These technologies are not only enhancing efficiency and visibility but also driving the strategic reconfiguration of air cargo networks. As a result, air cargo carriers, airport authorities, and logistics service providers are increasingly investing in smart infrastructure and digital capabilities to remain competitive in a rapidly evolving global market.

One of the primary factors contributing to the acceleration of digital transformation in air cargo is the pressing need for enhanced operational agility. Hong, Kim, and Hiatt (2025) highlight that airport agility—

defined as the ability to rapidly adapt to fluctuating cargo volumes and regulatory changes—is becoming a core competency at major cargo hubs. Their empirical study on air cargo hub airports illustrates that digitalization directly supports agility by enabling real-time coordination across multiple stakeholders, streamlining customs clearance, and optimizing terminal throughput. In this context, the evolution of air cargo operations is increasingly characterized by a shift from reactive, paper-based systems to proactive, digitally orchestrated platforms. Similarly, Thums et al. (2023) underscore the significance of digital work environments in air transportation, noting that digital interfaces, automation, and remote management tools are reshaping the way airport personnel engage with cargo handling processes. This transformation not only improves workforce productivity but also fosters safer and more adaptive operational settings—an imperative as cargo volumes continue to grow globally.

Beyond operational efficiency, digital transformation is also seen as a strategic enabler for sustainability and long-term competitiveness in the air cargo industry. Havle and Büyüközkan (2023), using the Intuitionistic Fuzzy Analytic Network Process (IF-ANP), argue that digital transformation is pivotal for evaluating and adopting sustainable technologies in air cargo. Their analysis finds that digital maturity strongly correlates with the successful implementation of green logistics practices, such as optimized route planning, energy-efficient warehouse operations, and paperless documentation. This insight highlights that digital transformation is not merely a technical upgrade but a fundamental shift in business philosophy—one that integrates environmental and strategic objectives. In the same vein, Merkert (2023) positions digitalization as a cornerstone of modern supply chain management, particularly in the air cargo sector, where integrated platforms enable synchronized logistics and end-to-end visibility. The interplay between digital tools and sustainability goals is thus central to understanding the evolution of the industry, especially as environmental regulations and customer expectations become increasingly stringent.

From a broader economic and infrastructural standpoint, the digitalization of air cargo is part of a global trend toward the reconfiguration of logistics networks through Industry 4.0 principles. Richnák (2022), in an empirical study conducted in the Slovak Republic, reveals that logistics companies embracing digital tools such as digital twins, cloud-based ERP systems, and automated decision support experience significant improvements in lead time reduction and inventory accuracy. These findings mirror developments in air cargo, where predictive maintenance, smart cargo routing, and real-time exception management are becoming standard practice. Similarly, Popkova et al. (2021) explore the entrepreneurial opportunities that digital transformation affords in transport and logistics, particularly in emerging markets like Russia. They propose that digitalization not only enhances service quality but also opens new business models based on platform economies, decentralized logistics services, and data monetization. This broader lens affirms that air cargo's digital shift is embedded in a larger narrative of socio-technical transformation—one that reshapes how value is created, captured, and delivered in global supply chains.

In synthesizing the literature, it becomes evident that while the pace and scope of digital transformation in air cargo vary across regions and organizations, the underlying trend is unmistakable: the sector is moving toward a more intelligent, integrated, and innovation-driven future. Kern (2021) provides a meta-analysis of technology implementation across the logistics industry and concludes that successful digital transformation requires a combination of technological readiness, organizational change, and external collaboration. This finding is especially relevant to air cargo, where interoperability among airlines, airports, freight forwarders, and regulatory bodies is essential for realizing the full potential of digital innovation. Moreover, Raza et al. (2023), in their analysis of digital transformation in maritime logistics, offer insights that are equally applicable to air cargo: namely, that digitalization must be aligned with strategic governance, stakeholder buy-in, and a clear roadmap to implementation. Taken together, these studies underscore the multifaceted nature of digital transformation in air cargo—encompassing not only tools and technologies but also culture, strategy, and system-wide coordination. The next sections will delve into the specific technologies, challenges, and theoretical frameworks that shape this transformation in greater detail.

2.2 Enabling Technologies and Operational Challenges

The transformation of air cargo operations in the digital era has been powered by the convergence of several core technologies, most notably Internet of Things (IoT), Artificial Intelligence (AI), blockchain, digital twins, and cloud-based systems. Each of these technologies plays a distinct yet interconnected role in reshaping how cargo is handled, tracked, and managed across the supply chain. IoT devices enable real-time monitoring of cargo conditions—such as temperature, humidity, and location—ensuring transparency and control over the

movement of sensitive goods. AI algorithms, on the other hand, are being deployed for demand forecasting, anomaly detection, and intelligent scheduling, thereby enhancing decision-making across operational layers. Cheung, Li, and Lei (2023) articulate that this technological triad—AI, blockchain, and digital twins—constitutes a paradigm shift in the aviation sector, particularly for cargo operations, as it enhances safety, efficiency, and resilience. Their findings suggest that the integrated use of these technologies facilitates not only automation but also the dynamic reconfiguration of cargo flows in response to disruptions, which is critical in today's volatile global logistics landscape.

Among these innovations, digital twin technology has emerged as a transformative enabler for both operational efficiency and predictive maintenance in transportation systems. A digital twin is a virtual representation of a physical asset, continuously updated with real-time data through sensors and integrated systems. In the context of air cargo, digital twins can simulate the behavior of cargo terminals, aircraft loading systems, and fleet operations, enabling proactive responses to potential bottlenecks or failures. Wu et al. (2025) provide a comprehensive review of digital twin applications in transportation infrastructure, identifying real-time situational awareness, data-driven optimization, and lifecycle management as primary benefits. Similarly, Mihai et al. (2022) emphasize the importance of sensor fusion, AI integration, and cloud connectivity as foundational elements that support the creation of robust digital twins. In air cargo environments, these systems are increasingly used to monitor ULD (Unit Load Device) handling, storage conditions, and apron logistics. Yet, despite these advantages, significant challenges remain, including data interoperability issues, integration costs, and the need for skilled personnel capable of managing complex digital ecosystems. These barriers are particularly relevant for developing countries or mid-tier logistics firms lacking the infrastructure to support advanced digital twin deployment.

Blockchain technology also plays a critical role in addressing long-standing inefficiencies and trust issues within air cargo operations. As an immutable, decentralized ledger, blockchain offers enhanced traceability, security, and transparency in document handling, cargo tracking, and stakeholder communication. Vilas-Boas, Rodrigues, and Alberti (2023) explore the convergence of blockchain with IoT, AI, and digital twins in logistics, particularly in the context of perishables such as fresh food. Their study finds that blockchain can significantly reduce the risk of information tampering and loss in time-sensitive supply chains by ensuring that data recorded at each touchpoint is verifiable and immutable. This benefit extends directly to air cargo, where delays, lost documentation, and customs-related inconsistencies have long plagued international freight flows. However, they also caution that the adoption of blockchain requires broad stakeholder collaboration and standardization—both of which are still lacking across much of the air logistics sector. Furthermore, the technology’s value is diminished if legacy systems and manual workflows remain entrenched, highlighting the need for holistic integration rather than piecemeal deployment of digital tools.

Despite the evident advantages of these technologies, several operational challenges continue to hinder seamless digital adoption in air cargo logistics. Yavas and Ozkan-Ozen (2024), through their content analysis on digital air logistics, highlight fragmented digital infrastructures, resistance to organizational change, and regulatory uncertainty as key impediments to transformation. While some firms have successfully adopted advanced digital platforms, others continue to operate with outdated software or inconsistent data practices, leading to significant performance gaps within the industry. Fakhraian et al. (2023) further draw attention to the regulatory barriers associated with emerging technologies like digital twins and autonomous systems, particularly within the European Union. Their review stresses that compliance with aviation safety and cybersecurity frameworks is often complex and costly, creating hesitation among operators to fully digitize. Additionally, the rapid evolution of technologies often outpaces the regulatory mechanisms needed to govern them effectively, resulting in legal gray areas that complicate implementation. These findings point to a paradox in the digitalization journey of air cargo: while the tools for transformation are increasingly available, their adoption is uneven due to infrastructural, institutional, and cultural constraints.

Finally, it is important to recognize that the successful deployment of these enabling technologies requires a systems-level approach that integrates both the physical and digital dimensions of cargo operations. Hakiri et al. (2024) underscore the necessity of designing future networks that support scalable and secure IoT ecosystems, especially for high-volume and high-frequency transport environments like airports. In air cargo settings, this implies not only upgrading sensors and software but also reengineering workflows, training personnel, and ensuring interoperability across platforms. Sadeghi et al. (2024) extend this argument to aircraft fleet monitoring, where digital twins and condition-based maintenance strategies are increasingly being used

to create more intelligent, electrified aviation systems. As air cargo carriers begin to adopt these systems for real-time fleet health monitoring and predictive diagnostics, they are laying the groundwork for more reliable and sustainable cargo services. Nevertheless, the operationalization of such technologies will depend on overcoming existing limitations—ranging from data silos and integration complexity to capital investment and human resource readiness. Thus, while enabling technologies offer transformative potential, they also bring a host of operational and strategic challenges that must be carefully navigated to realize their full benefits in the air cargo sector.

2.3 Impacts of Digitalization: Opportunities and Risks

The digital transformation of air cargo operations offers a wide array of operational, strategic, and customer-facing opportunities that are reshaping the competitive landscape of the logistics sector. At the operational level, digitalization enables real-time tracking, automation of routine processes, predictive maintenance, and data-driven decision-making—each of which contributes to enhanced efficiency and reduced turnaround times. For example, integrated cargo management systems allow for automated cargo bookings, improved load planning, and optimized ground handling, which together minimize delays and improve capacity utilization. Telukdarie et al. (2023) highlight that for small and medium-sized enterprises (SMEs), digitalization fosters agility and responsiveness by enabling rapid information flows and process flexibility. Applied to air cargo, such capabilities translate into streamlined shipment handling, better coordination among stakeholders, and more resilient logistics flows—critical elements in an industry that is both time-sensitive and volume-intensive. Moreover, digital interfaces provide customers with greater visibility and control over their shipments, enhancing trust and satisfaction. These operational enhancements are particularly impactful in high-volume scenarios, such as during global health emergencies or seasonal e-commerce peaks, where speed and transparency are paramount.

On a strategic level, digitalization also opens new avenues for business model innovation and value creation. Through digital platforms, cargo carriers can offer end-to-end services, integrate third-party logistics providers, and extend their reach to new customer segments. As Baidya et al. (2021) argue in the context of the energy sector, digital transformation can act as a catalyst for cross-sectoral convergence, enabling the formation of platform-based ecosystems that promote collaboration and efficiency. In air cargo, this convergence is evident in the integration of cargo booking platforms, customs clearance APIs, and IoT-based supply chain visibility solutions. Such integration not only reduces transaction costs but also supports dynamic pricing, route optimization, and service differentiation strategies. Furthermore, Lu, Song, and Yu (2023) found that digital capabilities positively influence firms' access to supply chain financing, particularly under conditions of external risk. By extension, air cargo companies that invest in digitalization can improve financial performance and risk management, particularly in volatile or disrupted markets. Strategically, the ability to adapt rapidly to changing customer demands, regulatory requirements, and geopolitical conditions gives digitally mature air cargo operators a significant competitive edge.

However, alongside these benefits, digitalization also introduces a set of complex risks and vulnerabilities that must be carefully managed. Chief among these is the threat of cybersecurity breaches, which can compromise sensitive shipment data, disrupt critical operations, and erode customer trust. As Murinde, Rizopoulos, and Zachariadis (2022) explain in their examination of the FinTech revolution, the increased reliance on digital infrastructure renders organizations more exposed to cyberattacks, data leakage, and system failures. This insight is equally applicable to air cargo, where the digital interfaces connecting carriers, freight forwarders, customs authorities, and end customers must be secured against malicious intrusion. Moreover, the implementation of digital tools often requires significant capital investment and a corresponding cultural shift within the organization. Resistance to change, lack of digital literacy among staff, and poorly executed transformation strategies can hinder adoption and dilute the potential benefits of technological upgrades. These risks are compounded by the complexity of integrating new systems with legacy platforms, especially in globally distributed and heavily regulated environments such as air cargo logistics.

In addition to technological and organizational risks, digitalization poses broader social and ethical concerns that can impact the inclusivity and equity of the logistics workforce. Walkowiak (2024) explores this dimension within the context of human resource management, emphasizing that while digital tools can enable more inclusive practices—such as those aimed at neurodiverse employees—they can also exacerbate inequalities if not implemented thoughtfully. In the air cargo sector, where operational roles have traditionally

been labor-intensive, the transition to digital systems could lead to displacement or marginalization of workers lacking the requisite technical skills. Ensuring that digital transformation initiatives are accompanied by comprehensive reskilling and upskilling programs is therefore critical. Furthermore, Zscheischler et al. (2022) argue that the perceived risks of digitalization are often shaped by social, cultural, and institutional factors, highlighting the importance of context-sensitive implementation. In high-stakes environments like air cargo, the successful adoption of digital technologies depends not only on technical feasibility but also on social acceptance, trust, and stakeholder alignment. A failure to account for these dimensions may lead to resistance, underutilization of systems, or unintended consequences that diminish the overall impact of digital transformation.

In conclusion, while digitalization in air cargo presents transformative opportunities for operational excellence, customer experience, and strategic growth, it also introduces a host of risks that must be proactively addressed. These include cybersecurity vulnerabilities, integration challenges, workforce disruptions, and ethical concerns related to inclusivity and fairness. As Plavčan, Tkachova, and Zeniakin (2022) observe in their study on the digitalization of education, the full potential of digital tools can only be realized when benefits are balanced against inherent risks and contextualized within the broader ecosystem in which they are deployed. In the case of air cargo, this means aligning technological implementation with organizational change management, workforce development, regulatory compliance, and stakeholder engagement. The next section explores how theoretical frameworks such as the Technology-Organization-Environment (TOE) model and the Resource-Based View (RBV) can be employed to systematically analyze these dynamics and guide effective digital transformation strategies in the air cargo industry.

2.4 Theoretical Foundations and Research Gaps

To effectively examine the digital transformation of air cargo operations, it is essential to ground the analysis in robust theoretical frameworks that can capture the multidimensional nature of technology adoption and strategic alignment. Two prominent models—the Technology-Organization-Environment (TOE) framework and the Resource-Based View (RBV)—offer valuable lenses through which to explore the dynamic interplay between technological capabilities, organizational readiness, and external contingencies. The TOE framework, originally developed by Tornatzky and Fleischer, conceptualizes digital adoption as being influenced by three interrelated contexts: technological (i.e., innovation characteristics), organizational (i.e., firm size, culture, and resources), and environmental (i.e., industry competition, regulation, and market pressure) (Baker, 2011). More recent applications of this framework have extended its scope to accommodate emerging technologies such as blockchain, digital twins, and enterprise metaverse platforms. For instance, Kumar and Shankar (2024) employed the TOE model to evaluate digital transformation within the context of enterprise metaverses, concluding that sustainability and agility are increasingly significant drivers of digital adoption in competitive, data-driven environments.

The TOE framework has proven particularly useful in analyzing digital transformation in developing markets, where technological infrastructure and regulatory environments can significantly impact innovation uptake. Nguyen, Le, and Vu (2022), in their study on online retailing in Vietnam, found that while technological readiness and top management support were critical for digital transformation, environmental pressures such as customer expectations and industry standards also played a decisive role. These findings align well with the air cargo sector, which operates in highly dynamic and often fragmented regulatory landscapes across international jurisdictions. In a similar vein, Awa, Ukoha, and Igwe (2017) argue for a re-envisioning of TOE to include behavioral and strategic dimensions—such as leadership mindset and innovation orientation—which are often pivotal in shaping digital trajectories but are underexplored in traditional TOE applications. The growing body of TOE-based studies on logistics and supply chains—including the empirical work by Chittipaka et al. (2023) on blockchain adoption in emerging markets—underscores the relevance of this framework in explaining the organizational complexities and external interdependencies that define air cargo digitalization. However, despite these advances, the TOE framework has not been sufficiently applied to qualitative case studies in the air cargo sector, especially those that explore the nuanced relationship between digital capabilities and organizational transformation from a process-oriented perspective.

Complementing TOE, the Resource-Based View (RBV) offers a strategic perspective on how internal capabilities influence a firm's ability to generate competitive advantage through digital transformation. According to RBV, organizations that possess unique, valuable, inimitable, and non-substitutable (VRIN)

resources are better positioned to sustain long-term performance. In the context of air cargo, these resources may include proprietary digital platforms, advanced automation infrastructure, data analytics expertise, and strong organizational culture supporting innovation. Ferreira and Ferreira (2025), in their comprehensive mapping of RBV research, argue that dynamic capabilities such as knowledge sharing, digital agility, and innovation absorption have become central themes in modern strategic management, particularly as firms navigate the demands of Industry 4.0. Likewise, Gerhart and Feng (2021) emphasize the critical role of human capital in activating resource potential, noting that the alignment between talent capabilities and digital systems is essential for realizing operational benefits. This is highly pertinent for air cargo firms transitioning to smart warehouses and AI-driven logistics, where employee adaptability and digital fluency are as vital as the technologies themselves.

The RBV framework has also been extended to assess knowledge-based capabilities and sector-specific competencies. For instance, Cooper et al. (2023) integrate the RBV with the knowledge-based view (KBV) to explore how firms in rapidly changing environments leverage intellectual assets to create strategic differentiation. In air cargo logistics, where differentiation is increasingly achieved through end-to-end visibility, real-time service responsiveness, and integrated digital platforms, such insights are particularly relevant. Wierzbiński et al. (2023) further support this claim through their study on aviation SMEs, showing that a knowledge management orientation significantly contributes to competitive performance in technologically intensive settings. However, most RBV studies in logistics have been quantitative and industry-generic, often neglecting the specific operational realities and regulatory intricacies of air cargo. There remains a significant gap in literature that qualitatively explores how air cargo firms develop, deploy, and renew digital capabilities in response to sectoral challenges—such as cross-border data governance, infrastructure interoperability, and cargo security standards.

Taken together, both the TOE and RBV frameworks provide comprehensive yet distinct approaches to understanding digital transformation in air cargo logistics. TOE excels in identifying contextual enablers and barriers, while RBV elucidates the internal resource configurations that enable sustainable innovation. Despite their explanatory power, current literature reflects a methodological imbalance, with an overreliance on cross-sectional surveys and a dearth of in-depth, qualitative case studies that investigate how these dynamics unfold over time. As Baker (2011) and Awa et al. (2017) caution, theoretical richness is often diluted when complex organizational behaviors are reduced to discrete variables. This highlights a critical research gap: the need for context-specific, process-driven analyses that uncover the lived realities of digital transformation in air cargo operations. Future research should prioritize longitudinal and comparative case studies that blend TOE and RBV insights, particularly in regions such as Türkiye, where national digital agendas intersect with global aviation ambitions. Such studies can yield actionable knowledge not only for academics but also for practitioners seeking to navigate the multifaceted landscape of digital innovation in air logistics.

3. Methodology

3.1 Research Design and Rationale

This study adopts a qualitative case study design to explore the impact of digital transformation on air cargo operations, with a specific focus on Turkish Cargo's SMARTIST facility at Istanbul Airport. The rationale for choosing a qualitative approach lies in its capacity to capture the complexity, contextual depth, and lived experiences of individuals directly involved in or affected by technological transformation. As Subrahmanyam (2025) emphasizes, qualitative research is particularly valuable in the aviation industry, where many phenomena—such as organizational change, stakeholder perceptions, and operational challenges—are deeply embedded in social, cultural, and institutional contexts. Quantitative models, while useful for measuring outcomes, often fall short in revealing the nuanced processes through which digitalization unfolds in practice. In contrast, a qualitative methodology enables researchers to interrogate the "how" and "why" behind digital implementation, offering richer insights into its multifaceted implications.

The case study method is especially well-suited to this research because it allows for in-depth examination of a bounded system over time, offering an opportunity to holistically analyze digital transformation as it is experienced and managed within a specific organizational setting. Filipowski (2017) notes that qualitative case studies are ideal for investigating leadership behaviors and operational practices during periods of change or crisis—an insight that applies directly to air cargo's transition into the digital era. Moreover, Pearson and Oni

(2024), in their exploratory case study on cybersecurity in aviation, demonstrate how this method allows researchers to identify disconnects, barriers, and unanticipated effects that may not be observable through surveys or experimental designs. Given that air cargo digitalization involves technological, organizational, and environmental dimensions—each interacting in complex ways—the case study approach enables a deep and contextualized understanding of these interdependencies.

The interpretive paradigm underpins this research, guiding both the formulation of research questions and the analytical lens applied to the data. An interpretivist stance recognizes that reality is socially constructed and that meaning is co-produced through interactions between participants and researchers. This paradigm aligns with the research objective of understanding how stakeholders within Turkish Cargo perceive, respond to, and shape the process of digital transformation. As Şen (2025) explains, interpretive qualitative research in aviation is essential for uncovering the subjective dimensions of sustainability, innovation, and operational change—dimensions that are often invisible in more positivist approaches. By prioritizing the perspectives of organizational actors such as IT specialists, cargo planners, operations managers, and digital strategy personnel, this study aims to uncover how digitalization is not only implemented as a technical solution but also negotiated as a cultural and strategic process.

In addition, the aviation context demands methodological rigor due to its safety-sensitive and regulation-intensive environment. Albelo et al. (2022) highlight that qualitative studies in aviation must be designed with attention to ethical responsibility, data triangulation, and role clarity, especially when evaluating workforce competencies or operational systems. This study addresses these concerns by incorporating multiple data sources—interviews, document analysis, and observation—thereby enhancing the credibility and depth of findings. The single-case design focusing on SMARTIST, while limited in generalizability, is justified by its strategic significance: as one of the most technologically advanced cargo terminals globally, it offers a rich and illustrative context for investigating how digital transformation materializes in real-world aviation logistics. Ultimately, the qualitative case study approach provides the methodological flexibility and interpretive depth required to illuminate the transformative dynamics reshaping air cargo operations in the digital age.

3.2 Case Selection and Context

The selection of Turkish Cargo and its flagship facility SMARTIST as the focal case study is rooted in its exemplary integration of digital transformation principles and strategic relevance in global air cargo logistics. As the dedicated cargo arm of Turkish Airlines, Turkish Cargo has embarked on a rapid and expansive transformation journey since 2018, culminating in the development of SMARTIST—Europe's largest and one of the world's most technologically advanced air cargo terminals. Strategically located at the new Istanbul Airport (IST), SMARTIST was designed to anchor Türkiye's ambition of becoming a global logistics hub while enabling Turkish Cargo to climb to the third position globally by freight tonne-kilometers (FTK) in 2023 (STAT Times, 2023; Turkish Airlines Investor Relations, 2024).

SMARTIST exemplifies digital transformation through its deployment of end-to-end automation, Internet of Things (IoT) technologies, artificial intelligence (AI), and robotic process automation (RPA). Phase 1 of the facility, fully operational since February 2022, features 30 automated cranes in a computer-controlled Automated Storage and Retrieval System (ASRS), integrated SmartDock technology for truck flow management, climate-controlled storage zones, and a digital twin of the warehouse ecosystem managed through COMIS and iCargo platforms (Turkish Cargo, 2024; Asia Cargo News, 2023). With over 17,000 pallet positions and 4,000 ULD slots, the ASRS alone is capable of processing the cargo equivalent of 14 wide-body freighters daily with minimal human intervention (Lödige Industries, 2023).Table 1 summarizes key milestones in the SMARTIST digital transformation timeline:

Table 1. Timeline of Major Milestones in SMARTIST Development and Operations

Year	Milestone	Description
2018–2019	Design & Initial Planning	Istanbul Airport opens; SMARTIST envisioned as part of Turkey's new logistics infrastructure.
2019	Phase 1 Construction Begins	Construction of SMARTIST terminal with full automation and capacity for 4 million tonnes.
2020–2021	Tech Integration & Testing	ASRS and SmartDock installed by Lödige Industries; COMIS and iCargo integrated.
Feb 2022	Full Relocation & Go-Live	Cargo operations fully transferred from Atatürk to SMARTIST; 72-hour transition executed.
2023	Ramp-Up Success & Recognition	Achieved #3 global cargo ranking; LEED Platinum & IATA SFOC certifications awarded.
2024–2025	Phase 2 Expansion	Terminal expansion to 340,000 m²; e-commerce sorting hub added; capacity targets 4.5M tonnes.

Source: Turkish Cargo (2024); Asia Cargo News (2023); STAT Times (2023); Lödige Industries (2023); Turkish Airlines Investor Relations (2024)

The case is also uniquely positioned within the national policy context. Türkiye's Vision 2023 and "Digital Türkiye" strategy prioritize logistics modernization and digital infrastructure development. SMARTIST is frequently referenced in national economic and technological forums as a flagship of these initiatives (Gentemizer, 2024; Trade.gov, 2024). Turkish Cargo's strategy of integrating smart warehouse technologies, IoT-based tracking, and data analytics is not merely operational—it reflects a broader vision of positioning Turkey as a digitally competitive trade and logistics hub across Europe, Asia, and Africa.

Furthermore, the SMARTIST facility's emphasis on sustainability and compliance with international standards makes it a leading case for studying how digital transformation can be aligned with global benchmarks. The LEED v4.1 O+M Platinum certification and IATA's Smart Facility Operational Capacity (SFOC) certification confirm SMARTIST's adherence to environmental and operational excellence (Airfreight Logistics, 2024; Air Cargo News, 2024). These recognitions underline the case's representativeness as a benchmark in the intersection of logistics, technology, and policy. In summary, Turkish Cargo's SMARTIST hub offers a comprehensive and contextually rich case for examining digital transformation in the air cargo sector—one that intersects global ambitions, national strategy, and operational execution.

3.3 Data Collection Methods

This study employed a qualitative research design grounded in the interpretive paradigm, with a primary focus on understanding stakeholder experiences and organizational dynamics involved in Turkish Cargo's digital transformation at the SMARTIST facility. The main data collection methods included semi-structured interviews, document analysis, and non-participant observation. This triangulated approach enabled the researcher to capture a holistic view of the transformation process while enhancing data credibility and contextual richness. The core of the empirical data was generated through semi-structured interviews with 25 key stakeholders involved in or affected by the SMARTIST digitalization process. These participants included cargo operations managers, IT and digital systems specialists, warehouse supervisors, logistics planners, customer service representatives, and senior executives. Additionally, external stakeholders from relevant vendor and infrastructure organizations involved in SMARTIST's planning and implementation phases were also interviewed.

Participants were selected using a purposive sampling strategy, designed to capture diverse, role-specific insights across operational, technical, and strategic dimensions of the digital transformation. The selection criteria included (i) direct involvement in SMARTIST's planning or daily operation, (ii) professional engagement with the facility's technological infrastructure, or (iii) decision-making responsibilities related to digitalization strategy. In cases where further expert perspectives were needed—particularly in specialized technology integration or external collaboration—snowball sampling was also employed, wherein initial participants recommended additional knowledgeable contacts.

All interviews were conducted in Turkish, which is the native language of both the participants and the researchers. The interviews were audio-recorded with participants' consent and transcribed verbatim. For the purposes of analysis, coding was initially performed using the original Turkish transcripts to preserve contextual meaning and linguistic nuance. Relevant excerpts used for reporting were subsequently translated into English by the authors. To ensure accuracy and consistency, translations were cross-checked against the original transcripts during the analysis and writing stages, and interpretive meanings were discussed among the research team. This approach helped minimize translation bias while maintaining analytical rigor.

The interview protocol consisted of open-ended questions that explored topics such as technology integration, perceived challenges, organizational adaptation, employee training, and strategic alignment with national digital policies. Interviews were conducted in-person and online, depending on participant availability, and each session lasted between 45 and 90 minutes. Table 2 illustrates the interview topics and some of the questions related.

Table 2. Sample Interview Topics and Example Questions

Topic Area	Example Questions
Technology Integration	How has the adoption of ASRS, SmartDock, and IoT systems affected your daily operations?
Organizational Adaptation	What changes in organizational structure or workflow were required following the digital transition?
Training and Skill Building	What types of training did you or your team undergo to adapt to the new digital systems at SMARTIST?
Strategic Vision	How does SMARTIST align with your organization's broader digital transformation strategy?
Challenges and Solutions	What were the major challenges encountered during implementation, and how were they resolved?
Stakeholder Collaboration	How would you describe the collaboration between internal teams and external technology partners?

In addition to interviews, document analysis was performed on Turkish Cargo's publicly available strategic reports, press releases, SMARTIST facility brochures, and annual performance reviews (2018–2025). Industry news articles, government digitalization policy documents, and vendor white papers provided complementary perspectives and verified factual details about the technology deployments and milestones at SMARTIST. These materials supported contextual understanding and helped corroborate participants' accounts.

The researchers approached this study from an academic and analytical perspective, with professional expertise in aviation management, logistics, and digital transformation. The research team did not hold any formal employment, managerial, or decision-making role within Turkish Cargo or the SMARTIST facility. Access to the case organization was granted solely for research purposes. To mitigate potential bias, data were collected using a semi-structured interview protocol and triangulated with organizational documents and on-site observations. Throughout the analysis, reflexive awareness was maintained, and interpretations were continuously compared across data sources to enhance analytical rigor and credibility.

Non-participant observations were conducted during two site visits to the SMARTIST facility in 2024. Observations focused on workflow automation, smart system interactions (e.g., ASRS, SmartDock, digital kiosks), employee roles, and the layout of special cargo zones (pharma, live animals, perishables). Field notes were recorded and used to validate or challenge findings from interview narratives, contributing to thematic triangulation.

All data collection activities were guided by ethical research principles. Informed consent was obtained from all participants, who were assured confidentiality and the right to withdraw at any stage. Interviews were audio-recorded with permission and transcribed verbatim. A coding scheme was developed and applied using NVivo software, allowing systematic thematic analysis of patterns across different data sources. Trustworthiness was ensured through member checking (participants reviewed summaries of their interviews), peer debriefing, and thick description techniques to support transferability.

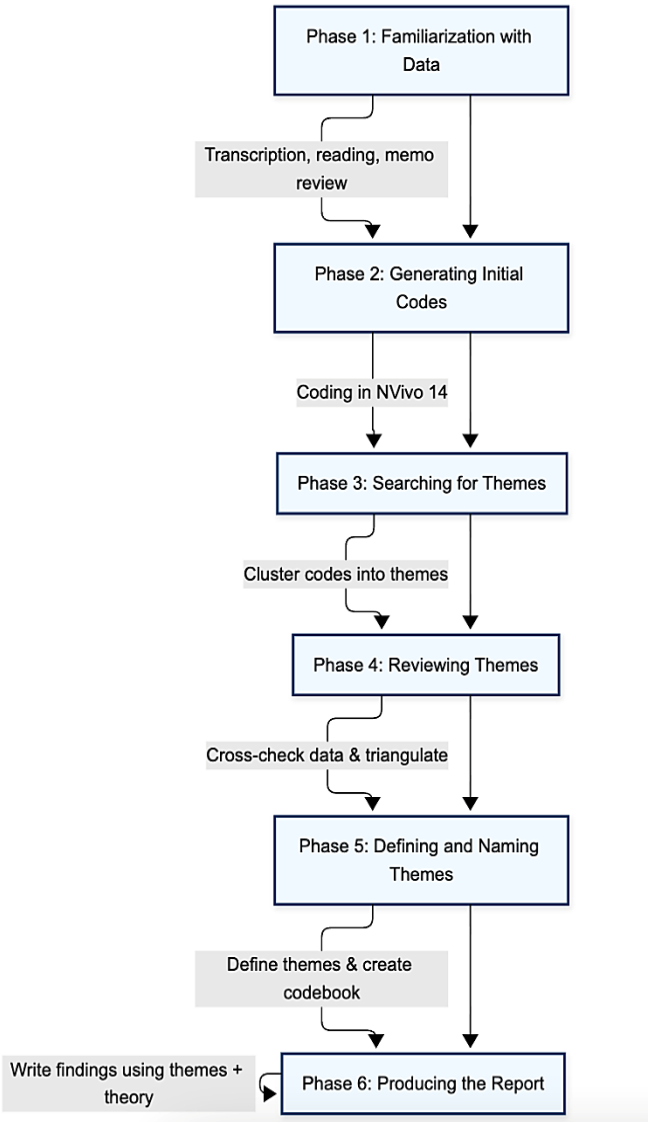
This comprehensive and multi-method data collection strategy ensured depth, accuracy, and contextual validity in exploring how digital transformation manifests within Turkish Cargo's SMARTIST facility.

3.4 Data Analysis Procedures

The qualitative data were analyzed using thematic analysis following the six-phase framework proposed by Braun and Clarke (2006). The analytical workflow, illustrated in Figure 1, reflects the sequential and iterative nature of the process adopted in this study. First, all interview transcripts and field notes were reviewed multiple times to achieve data familiarization and contextual immersion. Second, initial codes were generated through line-by-line open coding, combining inductive insights emerging from the data with deductive elements informed by the research questions and theoretical framework. Third, related codes were clustered into preliminary themes by identifying recurring patterns and conceptual relationships across the dataset. Fourth, these themes were systematically reviewed and refined through comparison with the full dataset and cross-checked against documentary and observational evidence to ensure coherence and analytical consistency. Fifth, finalized themes were clearly defined and named to capture their conceptual scope and

relevance. Finally, the themes were synthesized and interpreted in relation to the Technology–Organization–Environment (TOE) framework and the Resource-Based View (RBV), forming the basis for the empirical findings presented in the subsequent section. As shown in Figure 1, this workflow emphasizes both the sequential progression and the iterative refinement inherent in qualitative thematic analysis.

Figure 1. Workflow Diagram of the Qualitative Data Analysis Process



Phase 1: Familiarization with Data

All interviews were transcribed verbatim and reviewed in detail by the researcher. Transcripts were read multiple times alongside field notes and observational memos to achieve deep immersion and contextual understanding. This phase helped the researcher gain an overview of the dataset and begin identifying preliminary patterns.

Phase 2: Generating Initial Codes- Transcripts were uploaded into NVivo 14, where open coding was conducted line-by-line. Codes were both inductive(emerging from the data) and deductive (informed by the conceptual framework and research questions). Examples of initial codes included "workflow automation benefits," "resistance to change," "training adequacy," and "strategic alignment with national goals."

Phase 3: Searching for Themes- Codes were then grouped into broader thematic clusters using NVivo's node hierarchy features. Themes were developed by identifying shared meanings and relationships among codes. For instance, codes related to AI deployment, smart warehouse interaction, and robotic systems were grouped under the theme "Technology-Driven Operational Efficiency."

Phase 4: Reviewing Themes- Themes were reviewed against the entire dataset to ensure they accurately reflected the data and were meaningfully distinct. Cross-checking occurred between interview, document, and observation data to confirm consistency and enhance triangulation. Weak or redundant themes were merged, and sub-themes were created to provide nuance.

Phase 5: Defining and Naming Themes-Each theme was clearly defined, and its scope refined to capture the essence of the narratives. Final themes included: (1) Technology-Driven Operational Efficiency, (2) Organizational Adaptation and Workforce Readiness, (3) Strategic Alignment and Vision, and (4) Challenges and Mitigation Strategies. Definitions were recorded in a codebook to ensure transparency and replicability.

Phase 6: Producing the Report- The final themes were integrated into the findings chapter, supported by illustrative quotes and evidence from other data sources (e.g., documents, observations). Themes were interpreted in relation to the study's theoretical frameworks—Technology-Organization-Environment (TOE) and Resource-Based View (RBV)—and contextualized within the broader literature on digital transformation in logistics.

3.5 Trustworthiness and Ethical Considerations

The study followed established qualitative research standards to ensure methodological trustworthiness, addressing the four key criteria: credibility, transferability, dependability, and confirmability. Each criterion was systematically considered throughout the research process to promote rigor and transparency. Credibility was achieved by employing multiple data sources (interviews, documents, and observations) to allow for triangulation. Furthermore, member checking was conducted by sharing interview summaries with participants to validate interpretations and ensure that the findings accurately reflected their views. This iterative process enhanced the authenticity of the thematic insights. Transferability was supported through the provision of thick descriptions of the research setting, participant profiles, and contextual factors influencing Turkish Cargo's digital transformation. Detailed accounts of SMARTIST's technological environment, organizational structures, and strategic goals enable readers to evaluate the applicability of findings to other air cargo or logistics settings. Dependability was established through careful documentation of the research process, including coding strategies, analytic decisions, and audit trails maintained in NVivo 14. The use of a standardized thematic analysis protocol (Braun & Clarke, 2006) ensured consistency across phases of data interpretation. Additionally, methodological choices were periodically reviewed with academic peers to reflectively assess the study's design. Confirmability was ensured by maintaining a reflexive journal throughout the study, where the researcher recorded decisions, potential biases, and interpretations. Peer debriefing was used to verify the logic and coherence of emergent themes, thereby minimizing researcher subjectivity. Audit trails were preserved for all analytical steps, from coding to theme development. Importantly, ethical approval for the study was obtained from the Ethical Committee of Istanbul Ticaret University. The application was reviewed and approved prior to the commencement of fieldwork, and all research activities were conducted in accordance with the university's ethical standards for research involving human participants. Informed consent was obtained from all participants, who were assured confidentiality, anonymity, and the voluntary nature of their involvement. Data were securely stored, and identifying information was removed or anonymized during transcription and analysis. Together, these measures ensured that the study upheld ethical integrity and maintained high standards of qualitative research rigor throughout the investigation of digital transformation processes at SMARTIST.

4. Findings

The analysis of qualitative data collected from 25 expert participants revealed five interrelated themes that collectively capture the multifaceted nature of digital transformation at Turkish Cargo's SMARTIST facility. First, participants consistently emphasized significant operational efficiency gains enabled by technologies such as automation, real-time tracking, and integrated warehouse systems. Second, the study uncovered a range of challenges in digital adoption, including system integration issues, staff resistance, and digital skill gaps. Third, the role of data analytics and predictive capabilities emerged as a powerful driver of proactive decision-making, resource optimization, and strategic foresight. Fourth, respondents highlighted how digital systems enhanced transparency and customer satisfaction, fostering trust through real-time visibility and personalized services. Finally, participants raised concerns related to cybersecurity and data governance, particularly in relation to regulatory compliance and platform vulnerabilities. These themes are presented in detail in the

sections that follow, with supporting evidence drawn directly from participant narratives, institutional documents, and industry benchmarks.

Theme 1: Operational Efficiency Gains through Digital Integration

One of the most prominent and consistently echoed themes across all participant groups was the significant operational efficiency achieved through the integration of digital technologies at the SMARTIST facility. Participants described this transformation as a "turning point" in how cargo operations were managed, citing the seamless flow of goods, increased processing speed, and reduction in manual intervention as key benefits.

Several participants highlighted the impact of automation systems on routine operational processes. As one operations manager noted, "The automation system reduced our processing time significantly, especially for outbound cargo. Tasks that used to take 40 minutes now take less than 15" (P5). This sentiment was reinforced by a warehouse supervisor who explained, "With the ASRS, we no longer rely on forklifts for internal transfers. The system knows where everything is and moves it with precision" (P4). Participants also emphasized how SmartDock technology improved the efficiency of ground operations. A logistics coordinator shared that "Using SmartDock streamlined our truck scheduling and minimized congestion at peak hours. There's less waiting, fewer mistakes, and a smoother flow overall" (P7). This integration allowed for dynamic docking assignments and reduced idle time for vehicles, contributing to quicker turnaround and reduced costs. IoT devices were another crucial enabler of real-time operational control. A digital systems engineer stated, "IoT sensors helped us catch temperature deviations in perishable goods much faster than before. This has reduced spoilage and increased trust with our pharma clients" (P21). The ability to monitor and act on live data also contributed to better compliance with international cold-chain standards. Beyond individual technologies, the synergy of systems was frequently cited. According to a senior planner, "What's powerful is how everything connects—the ASRS, the tracking sensors, the management software. It's a digital ecosystem that moves with the cargo" (P11). This systemic integration not only improved speed and accuracy but also enhanced predictability, enabling more efficient workforce and capacity planning. Several participants stressed that efficiency gains were not limited to throughput alone, but also extended to quality and reliability. "We've seen a drop in loading errors, and the damage rate has gone down too. Everything's logged, traced, and validated by the system" (P9). The digitalization thus contributed to both operational excellence and enhanced service quality.

In summary, participants broadly agreed that SMARTIST's digital systems transformed traditional operations into a highly coordinated, automated, and responsive environment. The integration of automation, IoT, and intelligent software tools collectively enabled Turkish Cargo to boost its operational efficiency at scale, setting a benchmark for digitally enabled air cargo terminals. Table 3 presents the subthemes that emerged under this theme, each with associated codes (more than four per subtheme), the frequency of references to that subtheme across the 25 interviews, and an illustrative quote.

Table 3. Subthemes, Codes, Frequencies, and Sample Quotes for Theme 1

Subtheme	Codes	Frequency	Sample Quote
Automation of Cargo Handling	ASRS Efficiency, Internal Logistics Automation, Robotic Movement, Reduced Manual Labor, Auto-Positioning Systems	12	"With the ASRS, we no longer rely on forklifts... it moves cargo with precision" (P4)
SmartDock Scheduling	Dock Congestion Reduction, Real-Time Allocation, Dynamic Assignment, Vehicle Turnaround Time, Scheduling Predictability	9	"SmartDock streamlined our truck scheduling and minimized congestion at peak hours" (P7)
Real-Time Monitoring with IoT	Temperature Control, IoT-Based Alerts, Cargo Condition Data, Real-Time Feedback, Remote Monitoring Capabilities	8	"IoT sensors helped us catch temperature deviations in perishable goods" (P21)
Integrated System Coordination	Digital Ecosystem, Cross-System Interoperability, Unified Platform, End-to-End Visibility, Data-Driven Decision Support	7	"It's a digital ecosystem that moves with the cargo" (P11)
Improved Accuracy and Quality	Reduced Errors, System Validation, Quality Compliance, Damage Tracking, Audit Trail Automation	6	"The damage rate has gone down too. Everything's logged, traced, and validated" (P9)

These subthemes collectively underscore the transformative role of digital integration in achieving operational efficiency at SMARTIST. Participants consistently emphasized that the adoption of automation technologies, IoT-based monitoring, and intelligent scheduling systems not only accelerated cargo processing but also introduced precision and predictability into everyday operations. The frequency and richness of the codes suggest that operational improvements were both tangible and multifaceted—impacting physical workflows, information systems, and service quality. The convergence of these technologies into a unified,

responsive digital ecosystem enabled Turkish Cargo to optimize performance on a large scale. This suggests that SMARTIST serves as a strong model for how smart infrastructure can support sustainable, high-volume logistics operations in the air cargo sector.

Theme 2: Challenges in Digital Adoption

While the integration of digital systems brought substantial gains in operational efficiency, many participants also identified significant challenges encountered during the transition. These challenges spanned technical, organizational, and human dimensions, revealing the complexities of implementing large-scale digital transformation in an operationally intensive sector like air cargo. A recurrent issue reported was system integration and data compatibility. One IT coordinator stated, "Bringing legacy systems into sync with the new automated platforms took much longer than planned. We had to customize a lot of middleware to get them to communicate" (P6). These integration challenges often delayed full system functionality and required extensive internal collaboration and troubleshooting. Another prominent concern was resistance to change among employees. "There was skepticism, especially from older staff. They felt uncertain about their roles and worried that machines might replace them" (P10). To address these fears, several participants emphasized the importance of communication and inclusion. "We involved them in testing and training. That helped ease their concerns" (P13). Participants also expressed challenges related to training and digital competence. While structured training programs were available, some roles required advanced digital literacy that not all personnel initially possessed. "Not everyone was comfortable navigating the software dashboards. We needed multiple training cycles, especially for shift staff" (P17). Concerns regarding cybersecurity also emerged, particularly with increased reliance on cloud platforms and interconnected systems. "We had to revisit our entire cybersecurity policy. The digital expansion meant more potential entry points for breaches" (P14). This prompted a renewed focus on threat monitoring, access control, and staff awareness programs. External dependencies presented additional hurdles. For example, aligning with technology vendors and airport authorities sometimes caused coordination bottlenecks. "We were relying on a vendor's timeline for part of the integration, and that slowed things down internally" (P19). Despite these obstacles, most participants viewed them as expected friction points in a transformation of this scale. As one senior planner reflected, "No digital shift is without bumps. What matters is how quickly you learn and adapt" (P23). Table 4 summarizes the subthemes under this theme, along with multiple associated codes (more than four for each), the frequency of occurrence across interviews, and representative participant quotes.

Table 4. Subthemes, Codes, Frequencies, and Sample Quotes for Theme 2

Subtheme	Codes	Frequency	Sample Quote
System Integration and Compatibility	Legacy Systems, Middleware Development, Data Standardization, Cross-Platform Sync, Testing Delays	14	"Bringing legacy systems into sync... took much longer than planned" (P6)
Human Factors and Resistance	Change Resistance, Role Uncertainty, Generational Gaps, Involvement Hesitation, Morale Impact	13	"There was skepticism, especially from older staff..." (P10)
Training and Digital Literacy	Dashboard Navigation, Digital Skill Gaps, Role-Based Training Needs, Learning Curves, Training Overload	12	"We needed multiple training cycles, especially for shift staff" (P17)
Cybersecurity Concerns	Policy Overhaul, Threat Monitoring, Access Management, Incident Preparedness, Awareness Gaps	11	"The digital expansion meant more potential entry points for breaches" (P14)
Vendor and External Dependencies	Timeline Delays, Dependency Risks, Coordination Gaps, Tech Support Bottlenecks, Resource Misalignment	10	"We were relying on a vendor's timeline... that slowed things down" (P19)

These findings demonstrate that while digital transformation presents significant opportunities, it also introduces multidimensional challenges that require strategic mitigation, continuous learning, and stakeholder engagement. Addressing these factors was essential in ensuring the successful adoption and stabilization of SMARTIST's digital systems.

Theme 3: Role of Data Analytics and Predictive Capabilities

Participants frequently emphasized the growing importance of data analytics and predictive technologies in enhancing decision-making, operational foresight, and strategic agility at SMARTIST. This theme captures how the digital systems implemented at the facility are leveraged not just for efficiency, but also for advanced monitoring, planning, and real-time responsiveness. Many participants described how live data analytics enabled proactive interventions and better control over cargo flows. As one data analyst explained, "With real-time dashboards, we're not just reacting—we're predicting delays and bottlenecks before they happen" (P3).

This predictive capability was especially useful in rerouting cargo during peak hours or adjusting staff allocation dynamically. Predictive maintenance was another major application. "Our equipment sensors generate alerts before breakdowns occur. That's a game changer for minimizing downtime" (P20), shared a warehouse operations manager. These sensor-triggered insights, coupled with historical performance data, allowed for scheduled interventions that reduced disruptions. Several participants noted how big data enabled more informed capacity planning. "We analyze demand patterns by region and time of year to optimize our load planning and fleet assignment" (P16). This data-driven approach replaced intuition-based planning with systematic, evidence-based strategies. Furthermore, AI-powered forecasting tools were also widely praised. "Machine learning models help us forecast cargo trends, from volume projections to seasonal fluctuations. It really sharpens our strategic planning" (P12). These tools provided a competitive edge in pricing, route optimization, and resource forecasting. Lastly, the integration of analytics into customer interfaces improved transparency and service personalization. "Clients now see estimated arrival times and route updates live. It builds trust" (P8). Enhanced visibility across the supply chain contributed to higher customer satisfaction and better stakeholder communication. Table 5 shows the subthemes, codes and frequencies for Theme 3.

Table 5. Subthemes, Codes, Frequencies, and Sample Quotes for Theme 3

Subtheme	Codes	Frequency	Sample Quote
Real-Time Monitoring & Dashboards	Live Analytics, Dashboard Alerts, Decision Support, Delay Prediction, Visual Indicators	15	"With real-time dashboards, we're not just reacting—we're predicting delays..." (P3)
Predictive Maintenance	Sensor Alerts, Downtime Avoidance, Equipment Monitoring, Scheduled Servicing, Automation Triggers	14	"Our equipment sensors generate alerts before breakdowns occur..." (P20)
Data-Driven Capacity Planning	Demand Forecasting, Seasonal Patterns, Load Optimization, Network Modeling, Scenario Analysis	13	"We analyze demand patterns by region and time of year..." (P16)
AI-Powered Forecasting	Machine Learning Models, Trend Prediction, Demand Estimation, Strategic Planning, Route Modeling	12	"Machine learning models help us forecast cargo trends..." (P12)
Customer-Facing Analytics	ETA Visualization, Client Dashboards, Tracking Interfaces, Shipment Insights, Transparency Tools	11	"Clients now see estimated arrival times and route updates live..." (P8)

In summary, participants viewed analytics and forecasting technologies as critical enablers of SMARTIST's transformation into a predictive, agile logistics hub. These capabilities extended the value of digitalization beyond automation—enabling proactive planning, system resilience, and data-informed strategic decision-making.

Theme 4: Enhanced Transparency and Customer Satisfaction

Another significant theme emerging from the interviews was the enhancement of transparency and customer satisfaction through digital transformation. Participants consistently emphasized that the deployment of real-time tracking systems, customer-facing dashboards, and digital feedback loops improved service quality and strengthened client relationships. Several participants highlighted the role of visibility tools in building trust with customers. A customer service officer stated, "Before, clients had to call us to get updates. Now they can see everything in real-time, from check-in to final delivery" (P2). This shift toward proactive transparency reduced workload on staff and increased customer confidence. Digital communication tools were also viewed as crucial for responsiveness. "We use automated alerts and messaging platforms to notify clients about delays or customs status. It makes us look more professional and reliable" (P6), noted a logistics coordinator. These enhancements allowed customers to plan ahead and reduced disputes over missed delivery timelines. Participants also mentioned the empowerment of customers through data access. "Clients now download reports on their shipments, see efficiency metrics, and evaluate our performance like never before" (P18). This was especially valued by corporate clients and freight forwarders who rely on data for their own service evaluations. The personalization of services also contributed to satisfaction. A commercial manager shared, "Some clients want early morning pickups, others need temperature logs—our system lets them choose preferences in advance" (P22). This kind of user-oriented customization, powered by digital infrastructure, was repeatedly linked to higher loyalty.

Transparency was also perceived as a competitive differentiator. "The fact that clients can track their cargo across every checkpoint is something not every airline offers. It gives us a clear edge," remarked a senior strategy analyst (P9). For many, the availability of real-time, accurate, and comprehensive data was the linchpin of a more modern and customer-centric brand. Table 6 gives related subthemes and codes.

Table 6. Subthemes, Codes, Frequencies, and Sample Quotes for Theme 4

Subtheme	Codes	Frequency	Sample Quote
Real-Time Visibility	Live Shipment Tracking, Digital Checkpoints, ETA Updates, Full Route Transparency, Online Dashboards	14	"Now they can see everything in real-time, from check-in to final delivery" (P2)
Proactive Client Communication	Notification Alerts, Delay Messaging, Customs Status Updates, Mobile Integration, E-Communication	13	"We use automated alerts and messaging platforms..." (P6)
Client Empowerment through Data	Shipment Analytics, Downloadable Reports, Self-Service Metrics, Dashboard Access, API Integration	12	"Clients now download reports on their shipments, see efficiency metrics..." (P18)
Personalized Service Options	Client Preferences, Delivery Scheduling, Conditional Alerts, Service Customization, Temp Logs	11	"Our system lets them choose preferences in advance" (P22)
Competitive Transparency Advantage	End-to-End Tracking, Differentiation, Customer Retention, Digital Credibility, Market Perception	10	"Clients can track their cargo across every checkpoint... gives us a clear edge" (P9)

To conclude, enhanced transparency and tailored digital services have significantly improved customer satisfaction at SMARTIST. The integration of these tools enabled Turkish Cargo to redefine client interaction from reactive service provision to a proactive, data-driven experience—strengthening both customer loyalty and operational trust.

Theme 5: Cybersecurity and Data Governance Concerns

As digital technologies and data-intensive systems became increasingly embedded in SMARTIST's operational infrastructure, cybersecurity and data governance emerged as a salient and distinct theme across participant accounts. Interviewees consistently emphasized that the expansion of interconnected digital platforms introduced new vulnerabilities alongside operational benefits, requiring continuous reassessment of security practices and governance mechanisms. One IT supervisor noted that "once everything went digital, we had to reassess how exposed we were to cyber threats" (P7), underscoring how digital integration prompted heightened awareness of system-level risks. Given the scale and complexity of SMARTIST's digital ecosystem, participants highlighted the necessity of frequent risk assessments, access control mechanisms, and real-time monitoring to safeguard operational continuity.

In addition to technical safeguards, several participants pointed to human-related vulnerabilities as a persistent concern. Despite the presence of advanced security systems, interviewees acknowledged that staff awareness and everyday practices could undermine cybersecurity efforts. As one systems analyst explained, "we had strong systems, but human error was still the weak point. A single phishing email can create major disruptions" (P24). This observation reflected a broader recognition that cybersecurity risks are not solely technological but also behavioral, reinforcing the importance of continuous training, internal communication, and organizational vigilance.

Data governance issues were also prominently discussed, particularly in relation to customer data protection, regulatory compliance, and system interoperability. Participants stressed the need to comply with stringent international data protection standards, such as GDPR, while managing large volumes of operational and customer-related data. A compliance officer highlighted that "there are strict standards about how customer and cargo data are handled—we needed to tighten our protocols to avoid violations" (P16). These concerns were further compounded by the integration of external platforms and customer-facing portals, which increased the complexity of defining data ownership, access rights, and accountability across systems.

Several interviewees described ongoing efforts to clarify data governance policies, particularly regarding permissions and responsibilities within integrated digital environments. As one participant noted, "who owns what data, who can edit it, who gets to delete or export it—we needed clear policies and permission layers" (P20). This need for formalized governance structures reflected the challenges of maintaining control and transparency in a highly interconnected logistics ecosystem. At the same time, some participants acknowledged tensions between ensuring robust data security and maintaining operational efficiency. "Sometimes more layers of protection slow things down—it's a tradeoff we're still learning to manage" (P12). This illustrates the practical balancing act between usability and stringent access control in fast-paced air cargo operations. Table 7 summarizes the key subthemes and codes associated with cybersecurity and data governance concerns.

Table 7. Subthemes, Codes, Frequencies, and Sample Quotes for Theme 5

Subtheme	Codes	Frequency	Sample Quote
System Vulnerabilities and Threats	Network Exposure, Platform Risks, Malware Defense, Endpoint Weaknesses, Real-Time Monitoring	13	"Once everything went digital, we had to reassess how exposed we were to cyber threats" (P7)
Human Factors in Cybersecurity	Phishing Risks, Human Error, Awareness Gaps, Social Engineering, Behavioral Training	12	"Human error was still the weak point... a single phishing email can create major disruptions" (P24)
Regulatory and Compliance Issues	GDPR Alignment, Data Retention Policies, Legal Obligations, Audit Requirements, Consent Protocols	11	"We needed to tighten our protocols to avoid violations" (P16)
Access Control and Data Ownership	Permission Levels, Edit Rights, Platform Access Roles, Ownership Clarification, Interoperability Risk	10	"Who owns what data, who can edit it, who gets to delete or export it..." (P20)
Security-Usability Tradeoffs	Efficiency vs. Protection, Multi-Factor Delays, System Friction, Risk vs. Speed, UI Constraints	9	"More layers of protection slow things down—it's a tradeoff we're still learning to manage" (P12)

In summary, participants recognized that the expansion of digital capabilities at SMARTIST must be matched with equally advanced and adaptive cybersecurity strategies. Addressing human factors, technical vulnerabilities, and governance protocols was viewed as essential to sustaining operational integrity and stakeholder trust in an increasingly data-dependent logistics ecosystem.

5. Discussion

The findings of this study provide a detailed and context-sensitive explanation of how digital transformation is enacted within air cargo logistics, grounded in the case of Turkish Cargo's SMARTIST facility. While the results corroborate a substantial body of literature highlighting the efficiency-enhancing and coordination-improving effects of digital technologies, they also reveal organizational, governance, and human-centered dynamics that remain comparatively underexplored in empirical research. In this respect, the study aligns with existing work on digital logistics transformation while extending it by demonstrating that digitalization in air cargo is best understood as a socio-technical and strategic process shaped by technological capabilities, organizational readiness, and environmental constraints rather than as a linear technological upgrade.

A clear area of convergence with prior research lies in the role of automation and digitally integrated process management in enhancing operational performance. The empirical evidence from SMARTIST closely mirrors findings reported in recent air cargo and freight hub studies, which show that automation significantly improves throughput reliability, process transparency, and coordination across operational units (Wehner et al., 2025). From a Technology–Organization–Environment (TOE) perspective, these outcomes reflect the technological dimension of transformation, where advanced systems enable speed and predictability, but only when supported by organizational standardization and coordination. From a Resource-Based View (RBV) perspective, the integration of automation technologies with accumulated operational know-how constitutes a valuable and difficult-to-imitate capability that extends beyond short-term efficiency gains.

The study's findings also resonate strongly with prior work emphasizing the importance of digital integration standards for information flow and traceability across logistics networks. In line with Jurgelāne-Kaldava et al. (2025), the SMARTIST case demonstrates how the integration of IoT sensors, centralized data platforms, and analytics dashboards enhances end-to-end visibility and supports proactive decision-making. Comparable results have been reported in broader digital supply chain research, where integrated data platforms improve coordination, resilience, and responsiveness across complex networks (Dolgui & Ivanov, 2022). Interpreted through the TOE framework, these findings reflect not only technological sophistication but also organizational alignment and environmental pressure arising from customer expectations and regulatory scrutiny. Importantly, the SMARTIST case suggests that the benefits of digital integration observed in smaller or national-level systems can be scaled to larger hubs when governance mechanisms evolve alongside technological investment.

At the same time, the findings nuance and challenge linear representations of digital transformation that assume a smooth progression from technology adoption to performance improvement. While advanced digital systems were widely deployed at SMARTIST, their effective use varied considerably across organizational roles. Technical and analytical teams displayed high levels of digital fluency, whereas frontline operational staff required sustained training and adjustment. This pattern aligns with broader digital transformation research, which emphasizes uneven adoption, skills gaps, and resistance as persistent challenges in large organizations (Chittipaka et al., 2023). From a TOE perspective, this highlights the organizational dimension as a critical constraint on transformation outcomes, while from an RBV standpoint it underscores the role of human capital and learning capabilities as complementary resources necessary to unlock the full value of digital assets.

The findings further contribute to emerging discussions on platform-based digital ecosystems in logistics. Consistent with Akçacı et al. (2026), who conceptualize digital transformation within the broader "silicon economy," the SMARTIST case illustrates how value creation increasingly occurs through interconnected platforms rather than isolated technologies. Digital transformation extended beyond internal efficiency improvements to reshape coordination patterns, data-sharing practices, and customer interaction mechanisms. Similar dynamics have been observed in platform-based logistics ecosystems, where digital orchestration capabilities enable firms to integrate multiple stakeholders and services within a unified operational architecture (Dolgui & Ivanov,2022). From an RBV perspective, the ability to orchestrate such platforms represents a higher-order capability that is difficult to replicate without substantial organizational depth and infrastructural investment.

One of the study's most distinctive contributions lies in its treatment of cybersecurity and data governance as integral components of digital transformation rather than peripheral technical concerns. While prior logistics and transport studies often treat cybersecurity as an external risk or compliance issue (Zolkafli & AlArabiat, 2025), participants in the SMARTIST case framed cybersecurity as a strategic constraint shaping system architecture, access control, and trust relationships. Within the TOE framework, regulatory requirements, cross-border data protection standards, and heightened cyber risk exposure constitute environmental pressures that directly influence technological design and organizational processes. From an RBV perspective, the capability to manage cybersecurity and data governance effectively emerges as a valuable and difficult-to-imitate resource, particularly in large-scale cargo hubs where operational continuity and data integrity are central to competitive positioning.

The findings also carry important implications for practice and policy when interpreted through these theoretical lenses. For air cargo operators and ground handlers, the results suggest that the performance benefits of digital transformation are maximized when technological integration is matched by organizational learning, workforce reskilling, and governance capacity. While digitalization reduced physical workload and manual error, it simultaneously increased demand for analytical skills, system literacy, and cross-functional coordination—echoing findings from Industry 4.0 and logistics workforce studies (Sony & Naik, 2020). For policymakers and regulators, the study highlights the importance of supportive digital infrastructure policies and robust data governance frameworks, particularly as air cargo hubs increasingly function as critical nodes within global digital supply chains.

Although this research is based on a single in-depth case, its insights are analytically transferable to other air cargo and logistics contexts. The SMARTIST facility represents a flagship example of digital maturity, yet the underlying mechanisms identified—automation integration, predictive analytics, platform-based coordination, workforce adaptation, and cybersecurity governance—are relevant to operators at varying scales and stages of digital readiness. Similar challenges and trajectories have been observed across ports, rail freight hubs, and multimodal logistics platforms, suggesting that the findings contribute to broader debates on how digital transformation can be adapted and scaled across heterogeneous infrastructure environments.

In sum, this study demonstrates that digital transformation in air cargo logistics is not a purely technological transition but a multidimensional process shaped by the interaction of technological capabilities, organizational resources, and environmental pressures. By explicitly interpreting empirical findings through the TOE and RBV frameworks and situating them within a broader comparative literature, the study advances understanding of digital transformation as a strategic, socio-technical, and governance-intensive phenomenon within the global air cargo and logistics ecosystem.

6. Conclusion and Recommendations

This study investigated the strategic execution and organizational realities of digital transformation within Turkish Cargo's SMARTIST facility, offering a deeply contextualized and empirically grounded account of how advanced digital technologies are operationalized in a large-scale air cargo hub. While the broader literature has consistently emphasized the efficiency-enhancing potential of automation, analytics, and digital integration in logistics, empirical insights into how these transformations are implemented, governed, and stabilized in practice remain limited. In this respect, the findings of the present study contribute primarily by addressing previously identified gaps related to implementation dynamics, organizational adaptation, and governance complexity, rather than by introducing entirely new performance outcomes. At the same time, the study provides novel process-level insights by revealing how digital transformation unfolds as an ongoing, negotiated, and socio-technical process within a highly regulated and operationally demanding aviation context.

The thematic analysis identified five interrelated themes that collectively illustrate both the enabling and constraining dimensions of digital transformation in air cargo operations. These themes demonstrate that improvements in operational efficiency, transparency, and predictive capability are closely intertwined with challenges related to cybersecurity, data governance, and workforce adaptation. While similar dimensions have been discussed separately in prior studies, this research contributes by showing how they coexist and interact within a single operational ecosystem. In particular, the findings indicate that digital transformation does not generate uniform or linear benefits across organizational units; instead, its impacts vary depending on role, function, and digital readiness. This observation directly addresses a limitation in the existing literature, which often treats digital transformation outcomes as homogeneous or technology-driven, by highlighting the importance of organizational context, human agency, and institutional constraints.

From a theoretical perspective, the study advances existing research by providing empirical depth to the application of the Technology–Organization–Environment (TOE) framework and the Resource-Based View (RBV) in the air cargo domain. While both frameworks are well established, their use in aviation logistics has largely remained conceptual or survey-based. The findings demonstrate how external pressures—such as regulatory requirements, customer expectations for transparency, and cybersecurity obligations—interact with internal organizational capabilities and technological infrastructure to shape digital transformation outcomes. At the same time, the RBV lens explains how Turkish Cargo was able to convert digital investments into sustained competitive advantage through proprietary infrastructure, advanced analytics capabilities, and continuous human capital development. Rather than proposing new theoretical constructs, the study strengthens existing frameworks through contextualized empirical validation.

To enhance clarity and practical relevance, the key managerial and policy implications derived from the findings are summarized below.

Implications for Airline and Air Cargo Managers

- Digital transformation initiatives should be designed as integrated socio-technical programs rather than isolated technology deployments, ensuring alignment between systems, workflows, and human capabilities.
- Investment in automation and analytics must be accompanied by continuous workforce upskilling, particularly for frontline operational staff, to address uneven digital maturity across roles.
- Managers should treat cybersecurity and data governance as strategic priorities embedded in system design and operational decision-making, rather than as compliance-driven afterthoughts.
- Cross-functional coordination mechanisms should be strengthened to ensure that digital tools support end-to-end visibility and collaboration across departments and operational units.

Implications for Ground Handlers and Logistics Service Providers

- Digital integration with airline systems requires clearly defined data governance structures, including access rights, data ownership, and accountability mechanisms.
- Workforce roles are likely to shift from manual handling toward monitoring, exception management, and analytics-based decision support, necessitating proactive role redesign and training strategies.
- Operational efficiency gains should be balanced with usability considerations to avoid excessive system complexity that may hinder real-time decision-making.

Implications for Policymakers and Regulators

- Regulatory frameworks should support digital innovation in air cargo while providing clear guidance on data protection, cybersecurity standards, and cross-border data flows.
- Public–private collaboration can play a critical role in developing secure digital infrastructure and harmonized standards across air cargo ecosystems.
- Given the critical role of air cargo hubs in global supply chains, cybersecurity resilience should be recognized as a component of national and international transport security policy.

Despite its contributions, this study is subject to limitations that also point toward promising directions for future research. As a single-case, cross-sectional analysis, the findings cannot fully capture sectoral heterogeneity or the longitudinal evolution of digital maturity across different organizational and regulatory contexts. The SMARTIST facility represents a technologically advanced and resource-intensive case, which

may not be directly comparable to smaller or less digitally mature cargo operations. Future research would therefore benefit from comparative and longitudinal designs examining how digital transformation pathways differ across airports, airlines, and national systems over time. In addition, emerging technologies such as blockchain-enabled cargo documentation, AI-driven autonomous routing, and digital twins for multimodal logistics networks offer fertile ground for further investigation.

Ultimately, this study demonstrates that while the outcomes of digital transformation may echo familiar themes of efficiency and transparency, the organizational pathways through which these outcomes are realized remain insufficiently understood. By illuminating these pathways, the research contributes original empirical insights that advance scholarly understanding and inform strategic decision-making in the evolving air cargo logistics landscape.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author Contributions

Author 1: Investigation, Validation Conceptualization, Methodology, Formal Analysis, Writing – Original Draft, Supervision, Project Administration, Resources, Writing – Review & Editing.
Author 2: Investigation, Validation, Data Curation, Formal Analysis, Visualization, Writing – Review & Editing, Resources, Writing – Review & Editing.

(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

The field study of this article was approved with the permission of the Ethics Committee, based on the decision taken at the meeting of the İstanbul Ticaret University Scientific Research and Publication Ethics Committee dated 05.11.2025 and numbered E-65836846-044-372521

Reference

Air Cargo News. (2024). *Turkish Cargo's SMARTIST earns IATA certification.* Retrieved from https://www.aircargonews.net

Airfreight Logistics. (2024). *SMARTIST receives LEED Platinum certification.* Retrieved from https://www.airfreight-logistics.com

Akçacı, T., Baydar, M. B., & Bülbül, B. Y. (2026). The Impact of Digital Transformation on Logistics: The Silicon Economy in The Context of Open-Source Platforms. *Gaziantep Üniversitesi Sosyal Bilimler Dergisi*, *25*(1), 189-197.

Albelo, J. L., Cuevas, H. M., Aguiar, M., Piccone, C., Petitt, K., & Villagomez, R. (2022). *Defining aviation "skills" to ensure effective, safe, and efficient evaluations: A qualitative study. International Journal of Aviation Research, 14*(1), 1.

Asia Cargo News. (2023). *Inside SMARTIST: A look at Turkish Cargo's mega hub.* Retrieved from https://www.asiacargonews.com

Awa, H. O., Ukoha, O., & Igwe, S. R. (2017). *Revisiting technology-organization-environment (TOE) theory for enriched applicability. The Bottom Line, 30*(1), 2–22.

Baidya, S., Potdar, V., Ray, P. P., & Nandi, C. (2021). *Reviewing the opportunities, challenges, and future directions for the digitalization of energy. Energy Research & Social Science, 81,* 102243.

Baker, J. (2011). *The technology–organization–environment framework.* In *Information Systems Theory: Explaining and Predicting Our Digital Society* (Vol. 1, pp. 231–245).

Cheung, T., Li, B., & Lei, Z. (2023). *A paradigm shift in the aviation industry with digital twin, blockchain, and AI technologies.* In *Handbook on Artificial Intelligence and Transport* (pp. 323–346). Edward Elgar Publishing.

Chittipaka, V., Kumar, S., Sivarajah, U., Bowden, J. L. H., & Baral, M. M. (2023). *Blockchain technology for supply chains operating in emerging markets: An empirical examination of the technology-organization-environment (TOE) framework. Annals of Operations Research, 327*(1), 465–492.

Cooper, C., Pereira, V., Vrontis, D., & Liu, Y. (2023). *Extending the resource and knowledge-based view: Insights from new contexts of analysis. Journal of Business Research, 156,* 113523.

Dolgui, A., & Ivanov, D. (2022). 5G in digital supply chain and operations management: fostering flexibility, end-to-end connectivity and real-time visibility through internet-of-everything. *International Journal of Production Research*, *60*(2), 442-451.

Fakhraian, E., Semanjski, I., Semanjski, S., & Aghezzaf, E. H. (2023). *Towards safe and efficient unmanned aircraft system operations: Literature review of digital twins' applications and European Union regulatory compliance. Drones, 7*(7), 478.

Ferreira, N. C., & Ferreira, J. J. (2025). *The field of resource-based view research: Mapping past, present and future trends. Management Decision, 63*(4), 1124–1153.

Filipowski, C. R. (2017). *A qualitative case study of airline pilot leadership behaviors and practices during crisis situations.* Grand Canyon University.

Gentemizer. (2024). *Digital transformation strategies in Turkey.* Retrieved from https://www.gentemizer.com

Gerhart, B., & Feng, J. (2021). *The resource-based view of the firm, human resources, and human capital: Progress and prospects. Journal of Management, 47*(7), 1796–1819.

Hakiri, A., Gokhale, A., Yahia, S. B., & Mellouli, N. (2024). *A comprehensive survey on digital twin for future networks and emerging Internet of Things industry. Computer Networks,* 110350.

Havle, C. A., & Büyüközkan, G. (2023, August). *Sustainable future technology evaluation with digital transformation perspective in air cargo industry using IF ANP method.* In *International Conference on Intelligent and Fuzzy Systems* (pp. 389–397). Cham: Springer Nature Switzerland.

Hong, S. J., Kim, W., & Hiatt, B. (2025). *Examining airport agility at air cargo hub airports. Journal of Air Transport Management, 122,* 102710.

Jurgelāne-Kaldava, I., Effenberger, W. V., Batenko, A., & Čižiūnienė, K. (2025). Digitalization of Air Cargo Supply Chains: A Case Study of Latvia. *Systems*, *13*(6), 468.

Kern, J. (2021). *The digital transformation of logistics: A review about technologies and their implementation status.* In *The Digital Transformation of Logistics: Demystifying Impacts of the Fourth Industrial Revolution* (pp. 361–403).

Kumar, A., & Shankar, A. (2024). *Building a sustainable future with enterprise metaverse in a data-driven era: A technology-organization-environment (TOE) perspective. Journal of Retailing and Consumer Services, 81,* 103986.

Lödige Industries. (2023). *Automation at Turkish Cargo SMARTIST hub.* Retrieved from https://www.lodige.com

Lu, Q., Song, L., & Yu, K. (2023). *The effects of operational and digitalization capabilities on SMEs' supply chain financing under supply risk. International Journal of Logistics Research and Applications, 26*(12), 1642–1662.

Merkert, R. (2023). *Air cargo and supply chain management.* In *The Palgrave Handbook of Supply Chain Management* (pp. 1–18). Cham: Springer International Publishing.

Mihai, S., Yaqoob, M., Hung, D. V., Davis, W., Towakel, P., Raza, M., ... & Nguyen, H. X. (2022). *Digital twins: A survey on enabling technologies, challenges, trends and future prospects. IEEE Communications Surveys & Tutorials, 24*(4), 2255–2291.

Murinde, V., Rizopoulos, E., & Zachariadis, M. (2022). *The impact of the FinTech revolution on the future of banking: Opportunities and risks. International Review of Financial Analysis, 81,* 102103.

Nguyen, T. H., Le, X. C., & Vu, T. H. L. (2022). *An extended technology-organization-environment (TOE) framework for online retailing utilization in digital transformation: Empirical evidence from Vietnam. Journal of Open Innovation: Technology, Market, and Complexity, 8*(4), 200.

Pearson, J., & Oni, O. (2024). *Addressing cybersecurity and safety disconnects in United States Army aviation: An exploratory qualitative case study. Security Journal, 37*(1), 153–169.

Plavčan, P., Tkachova, N. O., & Zeniakin, O. S. (2022). *Digitalization of university education: Advantages, risks, and prospects.*

Popkova, E. G., Sergi, B. S., Rezaei, M., & Ferraris, A. (2021). *Digitalisation in transport and logistics: A roadmap for entrepreneurship in Russia. International Journal of Technology Management, 87*(1), 7–28.

Raza, Z., Woxenius, J., Vural, C. A., & Lind, M. (2023). *Digital transformation of maritime logistics: Exploring trends in the liner shipping segment. Computers in Industry, 145,* 103811.

Richnák, P. (2022). *Current trend of Industry 4.0 in logistics and transformation of logistics processes using digital technologies: An empirical study in the Slovak Republic. Logistics, 6*(4), 79.

Sadeghi, A., Bellavista, P., Song, W., & Yazdani-Asrami, M. (2024). *Digital twins for condition and fleet monitoring of aircraft: Towards more-intelligent electrified aviation systems. IEEE Access.*

Sony, M., & Naik, S. (2020). Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model. Technology in society, 61, 101248.

STAT Times. (2023). *Turkish Cargo rises to top 3 in global cargo rankings.* Retrieved from https://www.stattimes.com

Subrahmanyam, S. (2025). *The importance of qualitative research in the aviation industry.* In *Qualitative Research Methods in Air Transport Management* (pp. 1–26). IGI Global Scientific Publishing.

Şen, G. (2025). *Qualitative research methods in sustainability aviation research.* In *Qualitative Research Methods in Air Transport Management* (pp. 153–182). IGI Global Scientific Publishing.

Telukdarie, A., Dube, T., Matjuta, P., & Philbin, S. (2023). *The opportunities and challenges of digitalization for SMEs. Procedia Computer Science, 217,* 689–698.

Thums, J., Künzel, L., Klumpp, M., Bardmann, M. M., & Ruiner, C. (2023). *Future air transportation and digital work at airports – Review and developments. Transportation Research Interdisciplinary Perspectives, 19,* 100808.

Trade.gov. (2024). *Turkey logistics and infrastructure sector overview.* Retrieved from https://www.trade.gov

Turkish Airlines Investor Relations. (2024). *Strategy and performance reports.* Retrieved from https://investor.turkishairlines.com

Turkish Cargo. (2024). *SMARTIST facility overview.* Retrieved from https://www.turkishcargo.com

Vilas-Boas, J. L., Rodrigues, J. J., & Alberti, A. M. (2023). *Convergence of distributed ledger technologies with digital twins, IoT, and AI for fresh food logistics: Challenges and opportunities. Journal of Industrial Information Integration, 31,* 100393.

Walkowiak, E. (2024). *Digitalization and inclusiveness of HRM practices: The example of neurodiversity initiatives. Human Resource Management Journal, 34*(3), 578–598.

Wang, Y., & Sarkis, J. (2021). *Emerging digitalisation technologies in freight transport and logistics: Current trends and future directions. Transportation Research Part E: Logistics and Transportation Review, 148,* 102291.

Wehner, M., Blesing, C., Ullrich, N., Gössner, M., & Klumpp, M. (2025). Air cargo logistics automation and digital airport process management: comprehensive empirical insights from Germany. *Logistics Research*, 1-25.

Werbińska-Wojciechowska, S., Giel, R., & Winiarska, K. (2024). *Digital twin approach for operation and maintenance of transportation system—Systematic review. Sensors, 24*(18), 6069.

Wierzbiński, B., Zaborek, P., Wosiek, M., & Surmacz, T. (2023). *Knowledge management orientation as a driver of competitive performance: Evidence from Polish SMEs in the aviation industry. Entrepreneurial Business and Economics Review, 11*(1), 93–112.

Wu, D., Zheng, A., Yu, W., Cao, H., Ling, Q., Liu, J., & Zhou, D. (2025). *Digital twin technology in transportation infrastructure: A comprehensive survey of current applications, challenges, and future directions. Applied Sciences, 15*(4), 1911.

Yavas, V., & Ozkan-Ozen, Y. D. (2024). *Air logistics in the digital era: A content analysis for current trends and future directions. International Journal of Logistics Systems and Management, 49*(4), 439–461.

Zolkafli, U. K., & AlArabiat, A. (2025). Enhancing cybersecurity readiness in express logistics: the role of cyber-attack features and project team skills. *Acta Logistica (AL)*, *12*(3).

Zscheischler, J., Brunsch, R., Rogga, S., & Scholz, R. W. (2022). *Perceived risks and vulnerabilities of employing digitalization and digital data in agriculture – Socially robust orientations from a transdisciplinary process. Journal of Cleaner Production, 358,* 132034.

SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

Determining The Attitudes and Participation Intentions of Tourism Faculty Students Towards Traditional Games and Sports

Bedriye Çilem SOYLU[1*], Beste DEMİR[2] and Cevdet AVCIKURT[3]
[1*]Independent Researcher (bedriyecilemsoylu@gmail.com). ORCID: 0000-0002-8294-1036
[2] Balıkesir University, Tourism Guiding Department. (beste.demir@ balıkesir.edu.tr). ORCID: 0009-0007-4374-0294
[3] Balıkesir University, Tourism Management Department. (avcikurt@balıkesir.edu.tr). ORCID: 0000-0002-9169-9763

Article Info

Received: 04.02.2026
Accepted: 20.04.2026
Published: 20.05.2026

Keywords:
Traditional games and sports,
Attitude Participation intention,
Intangible cultural heritage,
Tourism students.

Jel Code:
L83, Z32

Corresponding Author:
Bedriye Çilem SOYLU

Research Article

https://doi.org/10.5281/zenodo.20297670

Abstract

The aim of this research is to determine the relationship between the attitudes of tourism faculty students towards traditional Turkish sports and games, which are included in the scope of intangible cultural heritage, and their intentions to participate in these activities. The research population consists of students from the Faculty of Tourism at Balıkesir University, and the study was conducted using 255 valid questionnaires. Attitude scales towards traditional sports and games and intention-to-participate scales were used as data collection tools. The study focused on traditional Turkish archery and the traditional intelligence and strategy game Mangala, both included in the list of intangible cultural heritage. The obtained data were analyzed using normal distribution tests, exploratory factor analysis, and regression analysis. The findings reveal that although students have a relatively high awareness of traditional sports and games, their participation levels in these activities are quite low. According to the regression analysis results, social and cognitive attitudes towards traditional archery have a significant and positive effect on the intention to participate, while cultural attitudes did not have a significant effect. In the Mangala game, socio-cultural attitudes had a significant effect on the intention to participate, while cognitive attitudes did not..

Introduction

The concept of Intangible Cultural Heritage (ICH) is defined in the 2003 Convention on the Intangible Cultural Heritage in Paris as "practices, representations, expressions, knowledge, skills and related instruments, tools and cultural spaces that communities, groups and, in some cases, individuals, identify as part of their cultural heritage" (Ministry of Culture and Tourism, 2026a). ICH values are evaluated in five main groups: oral traditions and expressions along with language, which serves as a carrier in the transmission of cultural heritage; performing arts; social practices; festivals and rituals; practices related to nature and the universe; and finally, handicrafts. As of January 2026, Turkey has 32 registered intangible cultural heritage values. With this rich list, Turkey is the second country in the world after China, to have registered the most intangible cultural heritage values. When the list is examined, it is seen that traditional sports and games are also under protection. In 2010, Kırkpınar oil wrestling, in 2019 traditional Turkish archery, and in 2020 traditional intelligence and strategy games were added to the list. Traditional Turkish sports can be defined as sporting activities passed down from the past to the present, with functions of competition and entertainment, as well as recreational purposes (Turkey Culture Portal, 2026). At the heart of traditional Turkish sports lie themes of friendship, brotherhood, and bravery. Thanks to their functions of fostering togetherness and social cohesion, traditional sports have maintained their existence throughout history (Karahüseyinoğlu, 2008). However, it can be said that the demand for these sports is decreasing day by day. Therefore, the aim of this research is to determine the attitudes and participation intentions of university students towards traditional Turkish sports and games. The research sample consisted of students from the Faculty of Tourism at Balıkesir University. Based on the research findings, suggestions are presented to universities, public institutions and organizations, and researchers to increase students' awareness and interest..

Conceptual Framework / Theory

Culture can be defined as a memory containing the codes of lifestyles that a nation has created throughout its history. Through culture, the interests, perceptions, attitudes, behaviors, and way of life of a society are passed on to future generations as a whole. In short, culture can be described as a distilled summary of a nation's experiences throughout history (Göçer, 2012: 50). Traditional sports and games, which hold an important place in the daily activities of Turks, are an integral part of Turkish folk culture (Karahüseyinoğlu,

2008). Traditional Turkish sports and games are basically divided into two groups: equestrian and non-equestrian sports. Equestrian sports include flat horse racing, beyge, and jump, while non-equestrian sports include games such as bayrak, tomak, çelik-çomak, oil wrestling, and shalvar wrestling. It is known that there are approximately 25 equestrian and 157 non-equestrian sports (İmamoğlu et al., 1997).

The Turkish society has been known as a nomadic people throughout history. Therefore, it has constantly interacted with new cultures in the new geographies it has traveled to. In this way, Turks have carried and taught sports and games, which are a part of their culture, to different geographies (Güven, 1999).

Traditional Oil Wrestling

Oil wrestling is one of the traditional Turkish sports that is believed to have originated in Thrace and the Balkans and has a 4500-year history (World Ethnosport Federation, 2026). The main factor that distinguishes traditional sports from other sports is the customary and ceremonial practices that the sport contains. In this context, oil wrestling, like other traditional sports, consists of cultural concepts. Traditional oil wrestling includes its own unique cultural elements such as oil, the announcer, prayer, greeting, kispet (wrestling attire), peşrev (prelude), music, the institution of the chieftain, and the Kırkpınar tradition (Yıldıran, 2000: 56). What distinguishes oil wrestling from other types of wrestling is that it is a sport that requires balance. In oil wrestling, matches begin with the wrestlers wearing kispet (a leather garment that extends from below the navel to below the knee). Afterwards, the wrestlers are oiled, and the match continues until one wins. During this competition, war tunes are played with drums and zurna (Turkish wind instrument) (Turkish Wrestling Federation, 2026). The traditional Kırkpınar oil wrestling competition was inscribed on the UNESCO Representative List of Intangible Cultural Heritage in 2010, representing Türkiye.

Traditional Turkish Archery

Archery is the effort to hit a specific target while shooting an arrow as far as possible through a bow. This sport is the result of combining posture, grip, and shooting techniques with muscle power (İnan, 1992: 2). In addition to physical attributes such as strength, balance, flexibility, speed, body integrity, gross and fine motor skills, it requires intelligence, attention, and concentration during shooting (Türker, 2022). Archery holds a significant place in Turkish folk culture. Historically, Turks have been known by different nations as an archer nation, a people who wielded bows, and those who shot arrows to the sky. Archery and horsemanship, in particular, are concepts synonymous with Turks. Mounted archery and foot archery were the most effective weapon-wielding methods known during the Ottoman period. What makes them so powerful is the technological superiority of the bows (Tuzcuoğulları, 2022). To ensure the continuation of this sport, lodges called kemankeş were established during the Ottoman Empire. The areas where archery was practiced are still known today as archery fields, maintaining their importance (Karcıoğlu and Söylemez, 2022). Traditional Turkish archery was inscribed on the UNESCO Representative List of Intangible Cultural Heritage in 2019, representing Türkiye.

Traditional Intelligence and Strategy Game Mangala

Mangala is an intelligence and strategy game that dates back to the earliest periods of humanity. In different cities of Turkey, it is known as: altı ev, hane, mele, han, göçmecik, höme, emme, bızıdı, bızıt, çüş, foduk, pıç, meneli taş, guycuk, kuyucuk taşı, evcik, kuytu, yuf, çal, kuy taşı (Uluışık, 2018). In Kazakhstan and Kyrgyzstan, the game is known as togyzqumalaq, toquz korgool, and göçürme (UNESCO, 2026). The game is suitable for two people or two groups. The aim of the game is for players to collect the most stones (seeds, grains, etc.). The duration of the game can vary depending on the players and the rules (Ministry of Culture and Tourism, 2026b). Playing Mangala provides benefits such as cunning, alertness, foresight, flexibility, resilience, prudence, and memory (Kul, 2018: 987). This traditional intelligence and strategy game was registered on the UNESCO Representative List of Intangible Cultural Heritage in 2020 as a joint file with Kazakhstan and Kyrgyzstan.

Literature Review

There are limited studies on traditional Turkish sports in the relevant literature. In the study conducted by Şahin and Evli (2020), theses on traditional Turkish sports were examined and only 11 publications were found. When the subject distribution of the theses is evaluated, it is seen that they focus on general sports or branches in a certain period. In line with the aim of the research, studies that deal with traditional Turkish sports within the framework of intangible cultural heritage are listed below. A review of the international literature also reveals a similarly limited number of studies.

The study conducted by Brankov et al. (2026) examined the assessment and preservation status of traditional sports and games within the scope of intangible cultural heritage. The research findings indicate that the promotion of traditional sports and games is largely carried out through event tourism, but community participation in these events is limited. While a significant portion of participants believe that traditional sports and games can be marketed through tourism, inadequacies in knowledge transfer and weak local community support stand out as key obstacles to the sustainability of this heritage. Furthermore, the study found that women and individuals with lower levels of education exhibited more positive attitudes towards traditional sports and games.

Zhang (2025) examined the cultural capital transformation of Wushu, a traditional Chinese martial art, within the scope of intangible cultural heritage, and the impact of this transformation on individuals' social status. The research argues that intangible cultural heritage transforms traditional cultural practices and becomes an important tool in individuals' social positioning.

A review study was conducted by Genç and Kırdemir (2024) examining the sports branches included in the list of intangible cultural heritage. Within the scope of the research, it was determined that sports such as Kırkpınar oil wrestling, traditional archery and mangala are important cultural heritage elements that reflect history and culture and provide value transfer. In addition, it was concluded that various studies are carried out by official institutions in these areas.

The study conducted by Nalcıoğlu (2024) aims to determine the awareness of professional sports representatives regarding the cultural heritage related to Kırkpınar oil wrestling, traditional Turkish archery, and mangala, and their participation in the processes of protecting, preserving, and transmitting this heritage. According to the findings, it was observed that the participants had a high level of awareness regarding Kırkpınar oil wrestling, but their level of involvement in the nomination file preparation process was low. Furthermore, it was determined that the participants' awareness of traditional Turkish archery and mangala was at a moderate level, and their level of involvement in the nomination file preparation process was also low.

Karcıoğlu and Söylemez (2022) aimed to determine the place and importance of traditional Turkish sports within cultural tourism and to examine the potential contribution of these sports to tourism as a cultural heritage element. As a result of the research, it was determined that traditional Turkish sports are an important historical and cultural heritage, continue to be preserved in different regions, and have high potential in terms of cultural tourism. However, it was determined that these sports are not sufficiently promoted in Turkey and have not yet received the place they deserve in tourism policies.

Luchoro-Parilla et al. (2021) consider traditional sports and games as a component of intangible cultural heritage. In this context, their research examines the cultural heritage nature of traditional games within the framework of an "ethnomotor" approach. The study analyzes 513 traditional games specific to the Canary Islands, evaluating them based on their internal and external characteristics. The research results highlight that traditional games play a significant role in terms of sustainability and environmental harmony due to their use of materials derived from nature. In this respect, traditional games are considered not only recreational activities but also important tools for cultural transmission, social integration, and educational processes.

The aim of the study conducted by Gencay et al. (2018) was to determine the tendencies and awareness of high school students regarding the practice of traditional Turkish sports. The research results show that the sports branches that young people are most interested in and want to practice are sledding and equestrian archery. In contrast, aba wrestling was found to be the least known traditional sport among young people. The research results reveal that young people do not have sufficient knowledge and awareness about some branches of traditional Turkish sports. Overall, the research results show that the level of interest and inclination towards traditional sports is low.

Method

The population of this study consists of students studying at the Faculty of Tourism of Balıkesir University. Due to time and access constraints, the research was limited to a single university, which is considered one of the significant limitations of the study. In sample selection, convenience sampling, a non-probability sampling method, was used. In this context, students who voluntarily participated in the research were included in the sample. A questionnaire was used as the data collection tool in the research. In the creation of the questionnaire, the scale developed by Koçak et al. (2021) to measure attitudes towards traditional sports and games, and the scale used by Akkuş (2013) to measure participation intention, were utilized. However, these scales were not used directly in the current study; instead, they were adapted to traditional archery and mangala games, selected from among the traditional sports and games listed in the ICH list. In the scale adaptation process, the statements were first rearranged to suit the research context, and then the opinions of three academics specializing in tourism and recreation were consulted to ensure content validity. Necessary linguistic and semantic corrections were made in line with expert opinions. In addition, a pilot study was conducted with a limited number of participants to test the comprehensibility of the scale, and the survey form was finalized based on the feedback received. The survey form consists of two sections. The first section includes statements measuring participants' attitudes towards traditional archery and mangala games, and their intention to participate. These statements were rated on a 5-point Likert scale (1=Strongly disagree, 5=Strongly agree). The second section includes questions to determine the demographic characteristics of the participants and their experiences with traditional sports and games. Data were collected between February 1, 2024, and March 30, 2024, using a face-to-face survey method. A total of 300 questionnaires were obtained; after removing incomplete or incorrectly completed questionnaires, 255 valid questionnaires were included in the analyses. Descriptive statistics, normality tests, factor analysis, and regression analysis were applied to the obtained data. The hypotheses developed in line with the relevant literature in this study are as follows:

H1: Attitude towards traditional archery has a significant effect on the intention to participate.
H1a: Social attitudes toward traditional archery have a significant effect on the intention to participate.
H1b: Cognitive attitudes toward traditional archery have a significant effect on the intention to participate.
H1c: Cultural attitudes toward traditional archery have a significant effect on the intention to participate.
H2: Attitudes toward the traditional mangala game have a significant effect on the intention to play the game.
H2a: Socio-cultural attitudes toward the traditional mangala game have a significant effect on the intention to play the game.
H2b: Cognitive attitudes toward the traditional mangala game have a significant effect on the intention to play the game.

Findings

Conclusion and Recommendations

By summarizing the findings, a conclusion section containing theoretical and practical contributions should be created, and suggestions for future studies should be provided.

Various statistical methods were used in the analysis of the data collected in the research. The findings obtained regarding the research are reported in this section.

Table 1. Participant Information

		n	**%**
Gender	Male	159	62,4
	Female	96	37,6
	Total	**255**	**100**
Age	Ages 18-20	152	59,5
	Ages 21-23	93	36,4
	Ages 24 and above	10	4
	Total	**255**	**100**
Department	Tourism Guiding	124	48,6
	Tourism Management	46	18,0
	Recreation Management	38	14,9
	Gastronomy and Culinary Arts	47	18,4
	Total	**255**	**100**

Continuation of the table			
Year of Study	1	102	40,0
	2	80	31,4
	3	45	17,6
	4	28	11,0
Awareness of Traditional Sports and Games	Aba Wrestling	10	3,9
	Mounted Archery	157	61,6
	Traditional Archery	214	83,9
	Traditional Sledding	43	16,9
	Mangala	137	53,7
	Mounted Cirit	137	53,7
	Cirit	175	68,6
	Şalvar Wrestling	20	7,8
	Traditional Oil Wrestling	201	78,8
Sources of Information	Family	109	427
	Friend	115	45,1
	Internet/social media	146	57,3
	TV, newspapers, etc.	146	57,3
	School/faculty	65	25,5
	Other	3	0,8
Previous Participation	Participant	41	16,1
	Non-participant	214	83,9
Sports and games they have previously participated in	Traditional Archery	17	6,7
	Mounted Archery	1	0,4
	Mounted Cirit	1	0,4
	Cirit	3	1,2
	Mangala	22	8,6
	Oil Wrestling	5	2,0
	Traditional Sledding	1	0,4
The sports or games they are currently interested in	Yes	10	3,9
	Equestrian archery, Cirit	1	0,4
	Mangala	3	1,2
	Archery	5	2,0
	No	177	96,7

Table 1 shows the demographic characteristics of the participants and their responses regarding traditional sports or games. 62.4% of the participants were female and 37.6% were male. Regarding age distribution, 59.5% were between 18-20 years old, 36.4% were between 21-23 years old, and 4% were 24 years and older. Looking at the distribution of the departments they were studying, 48.6% were in tourism guiding, 18% in tourism management, 14.9% in recreation management, and 18.2% in gastronomy and culinary arts. 40% of the participants were first-year students, 31.4% were second-year students, 17.6% were third-year students, and 11% were final-year students.

Regarding the sports and games the participants were aware of, archery was the most known sport with 83.9%. Oil wrestling came in second with 78.8%. The least frequent source of information is aba wrestling, at 3.9%. Regarding information sources for traditional sports and games, the internet/social media, TV, newspapers, etc., ranked first with 57.3% of participants. School/faculty came last with 25.5%. It was observed that 16.1% of participants had previously participated in traditional sports or games. Looking at the sports or games they had previously participated in, 8.6% mentioned mangala, 6.7% traditional archery, and 2% oil wrestling. Only 3.9% of participants are currently involved in traditional sports or games.

Factor Analysis

Factor analysis was conducted to examine the construct validity of the variables included in the scale prepared to determine the attitudes and participation intentions of tourism faculty students towards traditional archery and mangala games. For this, it was first checked whether the data were normally distributed. The Kolmogorov-Smirnov test was performed on the research data, and the data were found to be significant at the p>,05 level. Therefore, the kurtosis-skewness values of the data were examined. Since all kurtosis and skewness values were between (+1.5) and (-1.5), it was accepted that the data were normally distributed (Tabachnick and Fidell 2013). The suitability of the data for factor analysis was examined with the sample

adequacy (KMO) coefficient and the Bartlett Sphericity test. In order to perform factor analysis, a KMO sub-value of 0.70 (Altunışık et al. 2012) and a Bartlett's sphericity test value of ≤0.05 were used as the basis (Akkoyunlu et al. 2010).

Table 2. Factor Analysis for Attitudes Towards Traditional Archery.

Items	Factor 1	Factor 2	Factor 3	Communalities	FACTORS
ArcheryA2	,859			,807	**Social**
ArcheryA1	,791			,666	Eigenvalue: 3,027
ArcheryA4	,709			,690	Variance Explained: % 23,286
ArcheryA3	,613			,543	Mean: 3,73
					Cronbach' Alpha: ,842
ArcheryA7		,846		,723	**Cultural**
ArcheryA5		,782		,675	Eigenvalue: 2,889
ArcheryA6		,757		,644	Variance Explained: % 22,221
ArcheryA8		,567		,550	Mean: 4,09
					Cronbach' Alpha: ,805
ArcheryA12			,770	,698	
ArcheryA10			,745	,698	**Cognitive**
ArcheryA13			,683	,655	Eigenvalue: 2,540
ArcheryA11			,556	,535	Variance Explained: % 19,535
ArcheryA9			,468	,571	Mean:3,86
					Cronbach' Alpha: ,800
Total Variance Explained: % 65,041 Kaiser-Meyer-Olkin: 870; Barlett Test: x^2 : 1618,340 s.d.:78, p<.001					

A reliability analysis was conducted for the traditional archery attitude scale, and since Cronbach's Alpha (α) value was determined as .894, it was decided to perform factor analysis. KMO and Bartlett's Sphericity Test were performed on the scale, and the KMO value was found to be .870. According to the Bartlett test, the approximation chi-square (χ2) value was 1618.340, and the significance level was p=.000. Based on these results, it is understood that the scale is suitable for factor analysis. The factor analysis of the traditional archery attitude scale revealed three factors. The first factor has an explained variance of 23.286%, an eigenvalue of 3.027, a mean of 3.73, and a reliability of .842. The second factor has an explained variance of 22.221%, an eigenvalue of 2.289, a mean of 4.09, and a reliability of .805. The third factor has an explained variance of 19.535%, an eigenvalue of 2.540, a mean of 3.86, and a reliability coefficient of 800. These factors are named social, cultural, and cognitive, respectively, as in the original scale. The total explained variance of the scale was determined to be 65.041%.

Table 3. Factor Analysis for Intention to Participate in Traditional Archery.

Items	Factor 1	Communalities	FACTORS
ArcheryI2	,955	,911	**Intention**
ArcheryI3	,945	,893	Eigenvalue: 2,689
ArcheryI1	,941	,885	Variance Explained: % 89,630
			Mean: 2,51
			Cronbach' Alpha: ,942
Kaiser-Meyer-Olkin: ,870; Barlett Test: x^2 : 1618,340 s.d.:78, p<.001			

A reliability analysis was conducted for the traditional archery intention-to-participate scale, and since Cronbach's Alpha (α) value was determined to be .942, it was decided to perform factor analysis. The scale's KMO value was found to be .870, and according to the Bartlett test, the approximation chi-square (χ2) value was 1618.340 with a significance level of p=.000. These results indicate that the scale is suitable for exploratory factor analysis (EFA). According to the factor analysis results, the items were grouped under a

single factor, as in the original scale. Accordingly, the explained variance of the scale was determined to be 89.630%, the mean 2.51, and the eigenvalue 2.2689.

Table 4. Factor Analysis of Attitudes Towards Traditional Mangala Game

Items	Factor 1	Factor 2	Communalities	FACTORS
MangalaA6	,879		,782	**Social-Cultural** Eigenvalue: 4,631 Variance Explained: % 35,619 Mean: 3,69 Cronbach' Alpha: ,912
MangalaA5	,869		,763	
MangalaA7	,802		,659	
MangalaA4	,719		,668	
MangalaA8	,668		,504	
MangalaA2	,659		,657	
MangalaA1	,636		,650	
MangalaA3	,621		,523	
MangalaA11		,880	,788	**Cognitive** Eigenvalue: 4,127 Variance Explained: % 31,744 Mean: 4,19 Cronbach' Alpha: ,900
MangalaA10		,869	,794	
MangalaA12		,838	,742	
MangalaA13		,791	,677	
MangalaA9		,651	,549	
Total Variance Explained: % 67,364 Kaiser-Meyer-Olkin: ,898; Barlett Test: x^2 : 2410,106 s.d.:78, p<.001				

A reliability analysis was conducted for the attitude scale towards the Mangala game. Since Cronbach's Alpha (α) value was determined to be .922, it was decided to perform factor analysis. KMO and Bartlett's Sphericity Tests were performed on the scale, and the KMO value was found to be .898. According to the Bartlett test, the approximation chi-square (χ2) value was 2410.106, and the significance level was p=.000. Based on these results, it is understood that the scale is suitable for factor analysis. The factor analysis revealed two factors. The first factor has an explained variance of 35.619%, an eigenvalue of 4.631, a mean of 3.69, and a reliability of .912. This factor was named social-cognitive. The second factor has an explained variance of 31.744%, an eigenvalue of 4.127, a mean of 4.19, and a reliability of .900. This factor was named cultural. The total explained variance of the scale was determined to be 67.364%.

Table 5. Factor Analysis for Intention to Play Traditional Mangala Game

Items	Factor 1	Communalities	FACTORS
MangalaI3	,946	,894	**Intention** Eigenvalue: 2,635 Variance Explained: % 87,836 Mean: 1,81 Cronbach' Alpha: ,942
MangalaI2	,935	,874	
MangalaI1	,931	,867	
Kaiser-Meyer-Olkin: ,764; Barlett Test: x^2 : 617,725 s.d.:3 , p<.001			

A reliability analysis was conducted for the intention to participate in the Mangala game scale, and since Cronbach's Alpha (α) value was determined as .931, it was decided to perform factor analysis. The KMO value of the scale is .764, and according to the Bartlett test, the approximation chi-square (χ2) value is 617.725 and the significance level is p=.000. These results show that the scale is suitable for factor analysis. According to the factor analysis results, the items were grouped under a single factor, as in the original scale. Accordingly,

the explained variance of the scale was determined as 87.836%, the mean as 1.81, and the eigenvalue as 2.635. These values are given in Table 8.

Hypothesis Tests (Regression Analysis)

Table 6 presents the results of the regression analysis conducted to measure the effect of social, cultural, and cognitive attitudes towards traditional archery on the intention to participate in traditional archery. The multiple regression model established for the dependent variable (intention to participate) and predictor variables (social, cultural, cognitive) is statistically significant (F [3;251] =10.538 p<0.001). Social, cultural, and cognitive attitude dimensions explain approximately 10% of the variation in intentions to participate in archery. Social and cognitive attitude dimensions have a positive effect on intention to participate in archery (0.392; 0.289), and these relationships are statistically significant (tsocial= 3.014 psocial <0.01; tcognitive= 2.022 pcognitive<0.05). The cultural attitude dimension (t= -1.196, p=,232) did not have a statistically significant effect on intention to participate in archery. In line with these results, H1a and H1b are supported, and H1c is not supported.

Table 6. Effects of Attitude Towards Traditional Archery on Participation Intention.

S, K, B ➔ Intention	**β**	Std. **β**	**t**	**p**	**R**	Adjusted **R^2**	**F**	**p**	**VIF**
Constant	,584	-	1,197	,232					-
Social	,392	,244	3,014	,003	**,334**	**,101**	**10,538**	***	1,849
Cultural	*-,158*	*-,088*	*1,198*	*,232*					1,510
Cognitive	,289	,169	2,022	,044					1,974
*p<0.05, **p<0.01, ***p< 0.001; regression-residual: 17,862 / 1,695 s.d.:3 - 251									

Table 7 presents the results of the regression analysis conducted to measure the effect of socio-cultural and cognitive attitudes towards the mangala game on the intention to participate in the mangala game. The multiple regression model established for the dependent variable (intention to participate) and the predictor variables (socio-cultural, cognitive) is statistically significant (F [2;251] =9.555 p<0.001). The socio-cultural and cognitive attitude dimensions explain approximately 6% of the variation in intentions to participate in the mangala game. The socio-cultural dimension has a positive effect on the intention to participate in the mangala game (0.401), and this relationship is statistically significant (tso-cultural = 3.710 pso-cultural <0.001). The cognitive attitude dimension (t = -0.187, p = 0.852) did not have a statistically significant effect on the intention to participate in the mangala game. Based on these results, H2a is supported and H2b is not supported.

Table 7. Effects of Attitude Towards Traditional Mangala Game on Intention to Play.

S-K, B ➔ Intention	**β**	Std. **β**	**t**	**p**	**R**	Adjusted **R^2**	**F**	**p**	**VIF**
Constant	1,037	-	2,312	,022					-
Social-Cultural	,401	,273	3,710	,000	**,266**	**,063**	**9,555**	***	1,468
Cognitive	-,023	-,014	-0,187	,852					1,468
*p<0.05, **p<0.01, ***p< 0.001; regression-residual: 16,898 / 1,768 s.d.:2 - 252									

Conclusion and Recommendations

The research results show that tourism faculty students are generally familiar with traditional Turkish sports and games, but their level of active participation in these activities remains quite limited. It is noteworthy that, despite relatively high awareness of elements such as traditional archery and mangala, which are included in the UNESCO Intangible Cultural Heritage List, their intention to participate is at a low level. This situation reveals a disconnect between awareness and experience of cultural heritage elements.

When attitudes towards traditional archery were examined, it was found that social and cognitive dimensions significantly influenced the intention to participate, but the cultural dimension did not have a statistically significant effect. This finding shows that although students perceive archery as a cultural value, this perception does not directly translate into a behavioral intention. In the mangala game, socio-cultural

attitude was found to be decisive in the intention to participate, while the cognitive dimension was ineffective. Overall, the results reveal that the intention to participate in traditional sports and games is shaped more by social interaction and experience-oriented elements. In this context, the study contributes to the literature by drawing attention to the role of young people in preserving intangible cultural heritage. Based on the research findings, various suggestions can be developed to ensure the transmission and sustainability of traditional Turkish sports and games to younger generations. Firstly, it is recommended that universities, especially tourism faculties, include more practical courses or workshops on traditional sports and games in their curricula. This would allow students not only to acquire theoretical knowledge but also to experience these cultural heritage elements firsthand.

Public institutions and local governments organizing festivals, promotional days, and practical events in cooperation with universities can encourage students to participate in these activities through social interaction. Furthermore, the effective use of social media and digital platforms can be considered an important tool for attracting the interest of young people. For researchers, conducting similar studies at different universities and with different sample groups will increase the generalizability of the results. In addition, it is recommended that qualitative research methods be used to examine the motivations behind students' intentions to participate in greater depth. Such studies will contribute to the preservation of traditional sports and games and their more effective utilization in the field of tourism.

Acknowledgements

The authors would like to express their sincere appreciation to all individuals and institutions who contributed to the development of this study. Special thanks are extended to [insert name or institution, if applicable] for their valuable guidance and constructive feedback. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author Contributions

Author 1: Conceptualization, Methodology, Formal Analysis, Writing – Original Draft, Supervision, Project Administration.

Author 2: Data Curation, Formal Analysis, Visualization, Writing – Review & Editing.

Author 3: Investigation, Validation, Resources, 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.

If the authors do have any financial interests or personal relationships that could be considered as potential competing interests, they should be clearly stated here

Ethical approval

Not applicable.

Reference

Brankov, J., Milanović Pešić, A. and Bjeljac, Ž. (2026). Can They Endure? The Role of Tourism and Community Engagement in Preserving Traditional Sports and Games. In *Compromised Geography: Spreading a New World* (pp. 407-429). Cham: Springer Nature Switzerland

Dünya Etnospor Federasyonu, https://worldethnosport.org/etnosporlar/oil-wrestling, (Access date: 01.02.2026).

Genç, F. A. & Kırdemir, A. (2024). Somut Olmayan Kültürel Miras Listesinde Yer Alan Spor Branşlarının İncelenmesi. *Journal of History School,* 72, 2507-2534.

Gençay, Ö. A., Gür, Y., Gençay, S., Gür, E., Özaltaş, H. N., & Gençay, E. (2019). Liseli Gençlerde Geleneksel Türk Sporlarının Farkındalığının İncelenmesi. *MANAS Sosyal Araştırmalar Dergisi*, *8*(1), 566-575.

Göçer, A. (2012). Dil-Kültür İlişkisi ve Etkileşimi Üzerine. *Türk Dili*, *729*(1), 50-57.

Güven, Ö. (1999). Türklerde Spor Kültürü. (Geliştirilmiş 2. Basım). Ankara: Atatürk Kültür Merkezi Başkanlığı, 1-357.

İmamoğlu, O., & Taşmektepligil, M. Y. (1997). Türk Kültüründe Spor. *Ondokuz Mayis University Journal of Education Faculty*, *10*(1), 145-150.

İnan, M. (1992). *Osmanlı İmparatorluğu'nda Okçuluk Sporu ve Temel Teknikleri* (Yayınlanmamış Doktora Tezi), Marmara Üniversitesi.

Karahüseyinoğlu, M. F. (2008). Geleneksel Türk Spor Kamuoyunun Profilinin Belirlenmesi. *Sport Sciences*, *3*(2), 66-74.

Karcıoğlu, U. ve Söylemez, B. (2022). Kültür Turizminde Geleneksel Sporların Yeri ve Önemi. *Anasay*, (20), 215-238.

Kul, M. (2018). Türk'ün Strateji ve Zekâ Oyunu "Mangala". *Electronic Turkish Studies*, *13*(18).

Kültür ve Turizm Bakanlığı, https://teftis.ktb.gov.tr/TR-294289/somut-olmayan-kulturen-mirasin-korunmasi-sozlesmesi.html (Access date: 01.02.2026a).

Kültür ve Turizm Bakanlığı, https://yakegm.ktb.gov.tr/TR-345148/geleneksel-zeka-ve-strateji-oyunu-mangala--gocurme-togyzqumalaq-toguz-korgool.html (Access date: 01.02.2026b).

Luchoro-Parrilla, R., Lavega-Burgués, P., Damian-Silva, S., Prat, Q., Sáez de Ocáriz, U., Ormo-Ribes, E. and Pic, M. (2021). Traditional games as cultural heritage: The case of Canary Islands (Spain) from an ethnomotor perspective. *Frontiers in psychology*, 12, 586238.

Nalcıoğlu, Z.S.B. (2024). Somut Olmayan Kültürel Mirasın Korunması Sözleşmesi Listelerinde Geleneksel Sporlar ve Oyunlar: Türkiye Örneği. Cumhuriyet'in Kuruluşundan Türkiye Yüzyılına Türk Sporu Kongresi, Ankara, Türkiye, 25 - 27 Nisan 2024, pp. 249-272.

Şahin, E., & Evli, F. (2020). Investigation of Graduate Thesis with Different Variables About Traditional Turkish Sports in Turkey Between 2009-2019. *International Journal of Physical Education Sport and Technologies* 1(1), 34-41.

Türker, Ü. (2022). Temel Okçuluk Eğitiminin Dikkat ve Konsantrasyon Yetisine Etkisi. *Gümüşhane Üniversitesi Sağlık Bilimleri Dergisi*, *11*(4), 1491-1506.

Türkiye Güreş Federasyonu, https://tgf.tr/tarihçe (Access date: 01.02.2026).

Türkiye Kültür Portalı, https://www.kulturportali.gov.tr/portal/halk-sporlari?utm, (Access date: 01.02.2026).

Tuzcuoğulları Ö.T. (2022). Archery in Turks. In; Alıncak, F ve Vural, M. (Ed.) The Current Studies in Sport Science (ss.40-51), ISRES Publishing.

Uluışık, Y. P. (2018). Mangala Oyunu Hakkında Bir Değerlendirme. *Turan-Sam*, *10*(39), 173-186.

UNESCO, https://ich.unesco.org/en/RL/traditional-intelligence-and-strategy-game-togyzqumalaq-toguz-korgool-mangala-gocurme-01597 (Access date: 01.02.2026).

Yıldıran, İ. (2000). Geleneksel Yağlı Güreşin, Kültürel, Yapısal ve Bilimsel Açıdan Modern Minder Güreşiyle Farklılıklarının Değerlendirilmesi. *Gazi Beden Eğitimi ve Spor Bilimleri Dergisi, 5*(1), 53-62.

Zhang, H. (2025). The influence of the cultural capital transformation of Wushu Intangible Cultural Heritage on status acquisition: The case of Sichuan Province. *International Journal of Heritage Studies*, *31*(2), 257-271.

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.

SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

Analysing Maritime Piracy Reports Using a Text Mining–Based Frequency and Thematic Approach

Üstün ATAK[1*].
[1]Bandırma Onyedi Eylül University, Maritime Vocational School. (uatak@bandirma.edu.tr). ORCID: 0000-0002-1513-7371

Article Info

Received: 30.01.2026
Accepted: 20.04.2026
Published: 20.05.2026

Keywords:
Text Mining, Maritime Piracy, Porter Stemming, Maritime Security, Incident Analysis.

Jel Code:
R49

Corresponding Author:
Üstün ATAK

Research Article

https://doi.org/10.5281/zenodo.20297788

Abstract

Maritime piracy poses various risks to shipping operations and the efficiency of global trade. This study applies a text mining-based analysis to maritime piracy reports published between 2021 and 2023 by the International Maritime Bureau's (IMB) Piracy Reporting Centre to identify potential trends in piracy incidents. The Porter Stemming algorithm was used to preprocess unstructured textual data and extract high-frequency terms related to piracy incidents. Categories were created based on word frequency distributions and semantic similarity. These were grouped into thematic categories representing recurring terms, attack characteristics, locations, operational methods, and incident timelines. The results show that piracy reports primarily emphasize attack locations, threat execution, boarding actions, and the temporal progression of events. Furthermore, relatively less attention is paid to post-incident response measures. The study demonstrates that a purely data-driven text mining approach can effectively reveal structural patterns in maritime piracy reports and support situational awareness without relying on expert opinion or multi-criteria decision-making models.

Introduction

Maritime transport forms the backbone of global trade, offering a cost-effective method of transporting goods while generally producing lower greenhouse gas emissions compared to many alternative modes of transport. However, piracy remains a significant and ongoing threat to ship security, crew safety, and the reliability of global supply chains. With historical roots stretching back to antiquity, piracy continues to disrupt maritime transport routes despite significant technological, regulatory, and security advances. Beyond direct security implications, piracy can also influence operational decisions such as changing routes or opting for alternative modes of transport.

Therefore, a comprehensive understanding of the characteristics and trends of piracy incidents is of paramount importance for developing effective maritime security strategies. Traditional analyses of piracy often rely on statistical summaries, regional comparisons, or case-based assessments. While these approaches offer valuable insights, they are limited in capturing recurring linguistic patterns, thematic structures, and implicit meanings within large volumes of incident narratives. In this context, advances in text mining enable the systematic analysis of unstructured textual data and the extraction of meaningful information from piracy reports.

The Porter Stemming algorithm, also known as Porter Stemmer, is a widely used preprocessing technique in text mining and information retrieval. Developed in 1979 by computer scientist Martin F. Porter, this algorithm reduces English words to their roots by removing suffixes. It reduces the size of the vocabulary and increases computational efficiency in terms of storage, processing time, and retrieval performance. However, the stemming process has some limitations. In particular, Porter Stemmer can encounter the fit problem associated with over-stemming and under-stemming errors. Over-stemming occurs when words with different meanings or different roots are incorrectly reduced to the same root, resulting in a false positive association. In contrast, under-stemming occurs when semantically related words cannot be reduced to a common root leading to a false negative result.

This study is guided by the following research question: To what extent can a Porter Stemming-based text mining approach reveal dominant themes, operational patterns, and emerging trends in piracy incident reports published by the International Maritime Bureau between 2021 and 2023?

The rest of the paper is organised as follows: the theory is presented in Section 2; the methodology of the study is discussed in Section 3; the case study is defined in Section 4; the findings and discussions are presented in Section 5; and the conclusions are described in the final section.

Theory

Maritime piracy attacks adversely affect importer-exporters, shippers, ship owners, and international trade. Moreover, the shipping costs are dramatically increases because of the attacks. The International Maritime Bureau's (IMB) Piracy Reporting Centre stated that there is a significant increase in Q2 2023 events as 25% compared to the previous year report. The increase of the piracy attacks could affect global shipping in the future besides than the lowest attack record is dated in Q1 2023 as per IMB. The annual report of the IMB revealed that 120 incidents of maritime piracy and armed robbery occurred in 2023 compared to 115 incidents in 2022.

In this view, the literature section of the study is aimed to analyse previous research paper that are related to accident or incident reports using text mining techniques. The selected papers are investigated for the idea of finding any trend of previous reports or data.

S. Shi et al. (2019) analysed inland waterway ship collision for 419 collision accidents using text mining. The results revealed that human factors are the primary factors of ship collision. In similar, Zhong et al. (2020) is focused on learning from past accidents. The authors studied a novel framework that mixes deep learning and text mining technologies to analyse hazard records automatically. The results demonstrated that hazard records could be automated by a proper model. Moreover, insightful patterns of hazards could be presented to decision makers using a systematic and data-driven approach. Similarly, Ahadh et al. (2021) is proposed a semi-supervised keyword extraction approach for analysing accident reports. The proposed approach provided a domain specific predictive model that identify the cause of pipeline accidents. Besides, Chintalapudi et al. (2021) collected medical records from Italian Telemedical Maritime Assistance System (TMAS) for three years to analyse using lexicon and Naïve Bayes algorithms. The results indicated that visualization of symptomatic information is completed through word clouds and the sentiment analysis. In the same view, XU et al. (2021) studied text mining approach to identify safety risk factors from accident reports. The authors proposed an information entropy weighted term frequency to extract useful factors from accident reports. The results revealed that the proposed approach performs well to obtain importance degree of factors. In similar, Liu & Yang (2022) analysed historical railway reports to clarify risk factors using text mining. The results showed that potential relationship between hazards, faults, and accidents with proposed approach. It is important to note that, Bai et al. (2021) used a structural topic model (STM) to analyse research trends and themes in the maritime domain. As a text mining-based methodology, the proposed approach revealed that STM could provide more informed decisions. Besides, Tirunagari (2015) applied text mining methods to gather causal relations for maritime investigation reports. The authors employed pattern classification and connectives methods. The causal patterns were compared to human expert opinions. The results showed that text mining methods could be used to extract causal relations from maritime accident reports. Furthermore, He et al. (2023) analysed Piracy and Armed Robbery dataset to analyse the piracy behaviour patterns and characteristics of shipping risk using sentiment analysis, risk analysis, point/kernel density analysis, and word cloud analysis. The results provided that the proposed research could help to strengthen the monitoring of shipping risk.

On the other hand, Papadimitriou et al. (2018) aimed to address the strategic planning of short-haul maritime transport from a maritime cluster perspective and to examine the complementary relationships between these two areas. Paul (2012) studied to automatically classify a corpus of near-miss incidents consisting of 17,846 textual event descriptions. The findings showed that classification accuracy varies from 62% in the detailed event category to 95% in the high-level event category. These results demonstrated that automated text classification offers an effective method for structuring and analyzing large volumes of event data. Zhou et al. (2021) examined the implicit information in the sustainability reports of publicly traded container shipping companies using a hierarchical and unsupervised text mining method. As a result of the research, an integrated sustainability statement framework was developed consisting of three core dimensions: employee training and management, sustainable business management, and sustainable transportation operations.

Text mining studies are used for analysing accident reports and provided valuable insights regarding maritime domain. Moreover, artificial intelligence approach provided possible influential factors regarding insightful patterns of maritime security. Text mining approach could extract insights such as identifying common accident causes, extracting threat levels from incident reports, extracting threat levels from incident reports, prioritizing response strategies.

Method

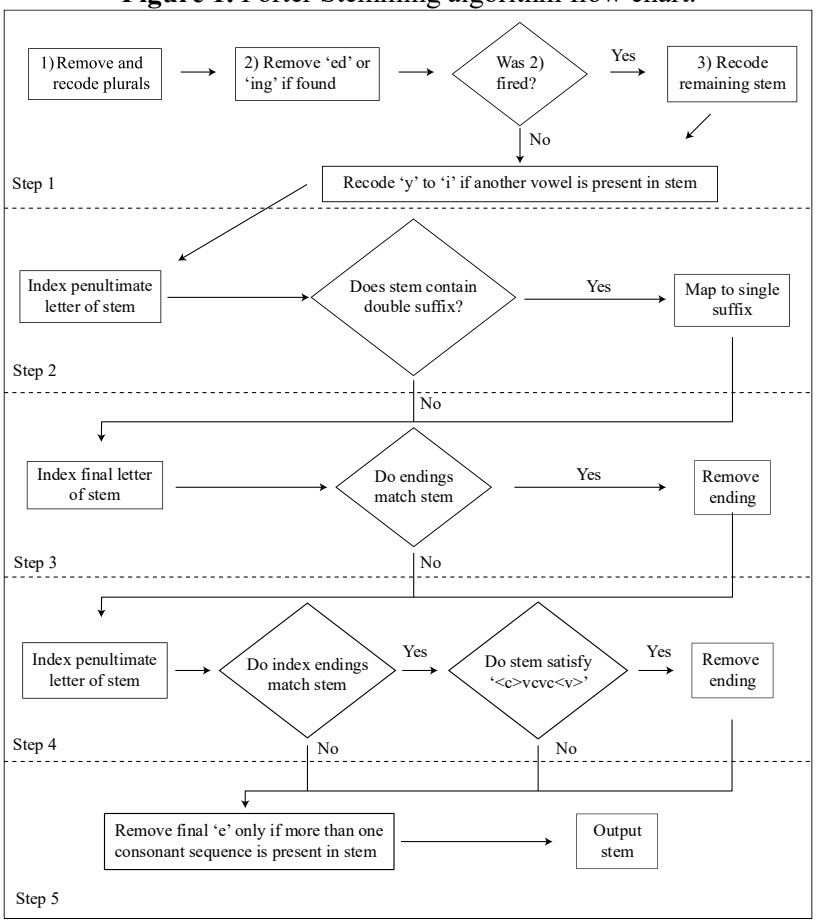
Porter Stemming

The Porter Stemming algorithm (referred to as the Porter Stemmer) is used to extract an English word's stem from its suffixes. The main idea of obtaining its stem is to reduce space and time complexity for Information Retrieval (IR). The algorithm was developed in 1979 by Martin F. Porter who is a Computer Scientist.

The main disadvantage of the porter algorithm is the fitting problem. Over-stemming and under-stemming are mainly two errors in stemming approach. If two words with different stems are stemmed to the same root, over-stemming or a false positive problem arises. On the other hand, under-stemming is not to reduce two words semantically related to the same root which called as a false negative.

The flowchart of the algorithm is as follows (Ali & Ibrahim, 2012):

Figure 1. Porter Stemming algorithm flow chart.



The Porter Stemming algorithm flowchart illustrates a rule-based process that reduces English words from their suffixes to their stem forms. The process begins by examining an input word according to predefined morphological rules. If the relevant suffix meets the necessary conditions, it is removed or transformed. Otherwise, the word is passed to the next processing step. The simplified stem of the word is obtained by progressively processing plural suffixes, tense suffixes, derivation suffixes, and suffixes. In this study, the flowchart represents the text preprocessing stage where word variations in piracy incident reports are standardized and pattern identification processes.

Case Study

The study data is collected from maritime events of 2021, 2022, and 2023 reported in web site of The International Maritime Bureau (IMB) Piracy Reporting Centre. Piracy reports are gathered monthly basis to create a one total year report. For three years, the reports are converted into "txt/pdf" file format to upload Google COLAB IDE.

The reports contain a comprehensive overview of piracy and robbery incident reported against ships from 2021 to 2023. The incidents are divided into three categories that international waters, territorial waters, and

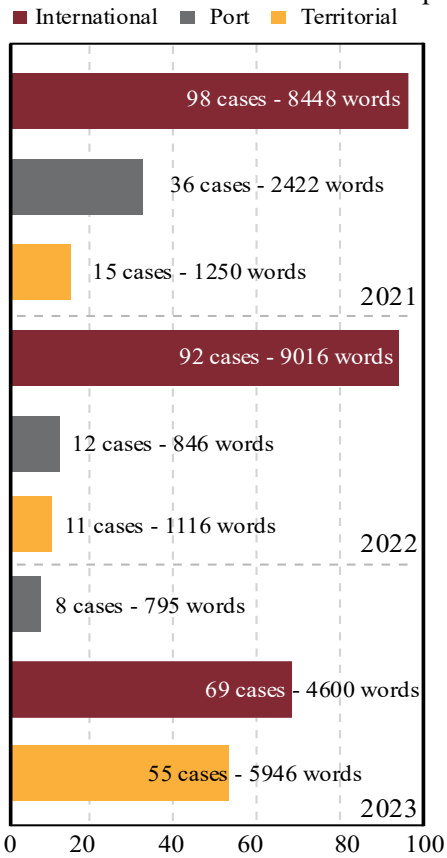
port areas. Moreover, geographic distributions and types of ships are provided. Nature of incidents, response actions, and consequences are other valuable information in piracy and robbery reports.

Total 396 piracy attacks which occurred in international waters, port area, and territorial waters are analyzed with Porter Stemmer for stemming using text mining approach. The reports are divided into three years to reveal any trend of frequencies of pirate attacks. The types of the vessels are ignored not to provide biased results, since the speed or freeboard height prevent vessels from attacks.

The incidents include a wide variety of ship types such as supply ships, tugboats, product tankers, bulk carriers, container ships, chemical tankers, general cargo ships, and fishing boats. Such incidents may occur in many different forms from large-scale hijackings to full-scale hijackings, often involving armed perpetrators. The examples indicate the variety of hazards that different kinds of vessels confront in different seaways around the world.

In 2021, total 98 different pirate attacks (8448 words in reports) occurred in international waters. Similarly, 36 pirate attacks (2422 words in reports) in port area and 15 pirate attacks (1250 words in reports) in territorial area occurred. In 2022, there was slight decrease by 6 percent (92 cases-9016 words in reports) in international area attacks. Furthermore, attacks in port area decreased by 67 percent (12 cases-846 words in reports) and attacks in territorial area decreased by 27 percent (11 cases -1116 words in reports). In similar, attacks in international waters decreased by 91 percent (8 cases -795 words in reports) in 2023. On the contrary, attacks in port area increased by 475 percent (69 cases -4600 words in reports) and attacks in territorial area increased by 400 percent (55 cases -5946 words in reports).

Figure 2. Accident numbers and word count in piracy reports



In the first step of the study, the text mining approach is applied to three years of pirate attack reports from 2021 to 2023 on yearly basis. The porter stemming algorithm is used for each year of pirate attack reports gathered from The International Maritime Bureau's (IMB) Piracy Reporting Centre portal to determine which word is used most by removing affixes from words. By removing unnecessary suffix or affixes, the algorithm could find meaningful insights regarding differences between year basis attacks. The stemming text mining approach is used to eliminate unnecessary information that jeopardize the result of the study. In this view, porter text mining algorithm is used to analyze piracy and robbery reports using default algorithm settings not to reveal biased results. The reason for selecting porter stemming algorithm is considered superior to other stemming algorithms in the scope of effectiveness, simplicity, efficiency, compactness, language independence, and customizability.

Top 100 words of text mining approach (and more than 25) are selected to analyze with experts' choices. As seen in Table 1, text mining results provided insightful results regarding piracy attacks with words as "alarm, inform, robber, perpetr, incid, escap, rais, duti, search, crew, board, boat, singapor, anchor, report, muster, etc.".

Table 1. Text mining results.

	2021	2022	2023		2021	2022	2023
alarm	103	112	112	robber	86	104	61
alert	35	39	27	perpetr	137	93	150
inform	63	102	87	stolen	76	61	65
sight	85	89	74	incid	104	126	127
unauthoris	24	34	25	knive	0	35	31
investig	27	23	31	arm	62	46	48
escap	77	88	59	crew	300	238	242
rais	78	82	72	master	86	106	127
duti	91	74	60	person	73	76	62
search	90	67	79	offic	28	24	24
boat	65	110	64	onboard	52	23	37
barg	31	73	28	underway	77	73	59
tug	0	46	0	board	159	160	171
small	26	34	0	navig	36	40	36
coast	59	74	90	singapor	97	146	161
port	50	57	45	indonesian	24	29	36
anchor	79	53	71	republ	25	29	28
guard	66	77	90	broadcast	29	37	42
author	63	45	54	report	152	162	142
polic	38	63	65	notifi	41	44	53
secur	51	40	52				
maritim	30	30	29				
safe	75	34	36	conduct	56	32	51
muster	55	60	57	initi	27	36	37
safeti	37	32	0	there	31	23	25
investig	27	23	31	share	0	25	36
while	67	47	66				
upon	36	32	37				
immedi	0	24	30				
further	31	29	46				
hr	0	0	38				

Findings and Discussions

A total of 396 incidents of piracy and armed robbery across international, port, and territorial waters were examined using a text mining methodology. Data were sourced from the International Maritime Bureau (IMB) Piracy Reporting Centre and categorised into three annual subsets to evaluate temporal developments.

The data reveal a significant shift in the geography of piracy. In 2021, activity was concentrated in international waters (98 incidents). By 2022, while international incidents saw a marginal 6% decline, port and territorial water incidents fell sharply. However, 2023 marked a dramatic pivot: attacks in international waters plummeted by 91%, while port-based and territorial water incidents surged by 475% and 400%, respectively. This suggests that perpetrators have modified their operational strategies, moving away from the high seas toward nearshore environments.

The Porter stemming algorithm was utilised to standardise the data, extracting the 100 most frequent stems. While core terms such as "crew", "board", and "robber" remained constant, specific yearly variations emerged:

- Human Factor: The persistence of "crew" and "master" underscores the continued focus on human targets.
- Weaponry: A notable increase in stems such as "knive" and "arm" after 2021 suggests either an escalation in violence or more granular reporting.
- Location Focus: In 2023, stems like "singapor", "anchor", and "port" trended upwards, mirroring the statistical shift toward anchorage zones.
- Narrative Complexity: Despite fewer high-seas attacks in 2023, the word count for port-side reports increased, indicating more detailed descriptions of complex encounters or multi-party response actions.

Overall, the findings indicate a redistribution of maritime security risk from international sea corridors to port and nearshore areas. This trend may be related to increased naval presence and surveillance activities in the open sea, as such security measures can direct perpetrators to less protected and more complex areas in terms of jurisdiction. Given that previous studies have mostly focused on geographical concentration areas or incident frequencies, this study reveals both spatial and narrative shifts in piracy and armed robbery incidents by evaluating statistical trends together with text mining outputs. In this respect, the study shows that modern piracy is becoming increasingly opportunistic and perpetrators can exploit lack of coordination between crews, port authorities, coastal security units, and particularly targeting vessels anchored at sea. The use of a data-driven text mining framework allows for the objective and scalable identification of latent patterns in maritime threats.

The findings suggest that maritime security policies should prioritize port area surveillance, monitoring of anchorages, and strengthening coordination between ship crews and port authorities. In this context, the study contributes to the existing literature by demonstrating that textual analysis of incident reports can complement traditional quantitative approaches and offer a deeper understanding of the changing nature of maritime security risks.

Conclusion and Recommendations

This research examines global piracy and armed robbery by applying a text mining framework to 396 incident reports spanning 2021 to 2023. By utilising the Porter stemming algorithm, the study systematically evaluates unstructured narrative data from international, port, and territorial waters to uncover latent temporal and spatial trends.

The analysis identifies a significant transition in the geographical distribution of maritime threats. While offshore incidents predominated in 2021 and 2022, a precipitous decline in international water attacks occurred in 2023. This was mirrored by a surge in incidents within port areas and territorial waters.

Linguistic evidence confirms that piracy remains a "crew-centred" phenomenon. Consistently high frequencies of stems related to boarding, onboard presence, and emergency protocols (e.g., alarms and mustering) highlight the human element of these encounters. Furthermore, an increase in weapon-related and location-specific terminology suggests either an escalation in the severity of threats or a shift toward more granular reporting standards.

Methodologically, this study demonstrates that narrative-based analytics can successfully augment traditional statistical counts. By deliberately omitting vessel-specific variables such as design or speed. The framework avoids potential biases, focusing instead on the raw dynamics of the incidents and subsequent response behaviours.

The results showes a shift in maritime security priorities, specifically toward enhanced anchorage surveillance, port-area access control, and crew readiness in jurisdictionally complex coastal zones. Text mining serves as a scalable, data-driven tool that enables stakeholders to detect emerging risk patterns that aggregate statistics might overlook.

Despite the contributions, the study has some limitations:

• Reporting Bias: Reliance on IMB data brings with it a sectoral limitation, particularly in small-scale incidents such as underreporting.

• Root Finding Sensitivity: Although the Porter stemmer method provides consistency, it can sometimes lead to the loss of semantic nuances by combining words with different contextual meanings under the same root.

• Scope and Time Interval: Excluding ship-specific technical data and limiting the analyses to a three-year time interval restricts the profiling of individual ship vulnerabilities, the identification of long-term cyclical trends, and the strengthening of the validity of the findings. Therefore, analyses covering longer-term data (5–10 years) would increase the validity and robustness of the findings.

Future work could consider integrating Advanced Natural Language Processing (NLP), such as transformer-based models or topic modelling, to capture deeper semantic layers. Additionally, cross-referencing text mining outputs with AIS (Automatic Identification System) data or port congestion metrics could provide a multi-dimensional view of the operational environments that facilitate piracy.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author Contributions

Author 1: Conceptualization; Methodology; Software; Validation; Formal analysis; Investigation; Resources; Data curation; Writing – Original draft; 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.

Reference

Ahadh, A., Binish, G. V., & Srinivasan, R. (2021). Text mining of accident reports using semi-supervised keyword extraction and topic modeling. Process Safety and Environmental Protection, 155, 455–465. https://doi.org/10.1016/j.psep.2021.09.022

Ali, N. H., & Ibrahim, N. S. (2012). Porter Stemming Algorithm for Semantic Checking. Iccit, June, 253–258.

Bai, X., Zhang, X., Li, K. X., Zhou, Y., & Yuen, K. F. (2021). Research topics and trends in the maritime transport: A structural topic model. Transport Policy, 102(November 2020), 11–24. https://doi.org/10.1016/j.tranpol.2020.12.013

Chintalapudi, N., Battineni, G., Canio, M. Di, Sagaro, G. G., & Amenta, F. (2021). Text mining with sentiment analysis on seafarers' medical documents. International Journal of Information Management Data Insights, 1(1), 100005. https://doi.org/10.1016/j.jjimei.2020.100005

He, Z., Wang, C., Gao, J., & Xie, Y. (2023). Assessment of global shipping risk caused by maritime piracy. Heliyon, 9(10), e20988. https://doi.org/10.1016/j.heliyon.2023.e20988

Liu, C., & Yang, S. (2022). Using text mining to establish knowledge graph from accident/incident reports in risk assessment. Expert Systems with Applications, 207(June), 117991. https://doi.org/10.1016/j.eswa.2022.117991

Papadimitriou, S., Lyridis, D. V., Koliousis, I. G., Tsioumas, V., Sdoukopoulos, E., & Stavroulakis, P. J. (2018). Strategic planning of short sea shipping within maritime clusters. In The Dynamics of Short Sea Shipping: New Practices and Trends (pp. 37-59). Cham: Springer International Publishing.

Paul, K. (2012). Classifying maritime near-miss and injury report using text mining. Lamar University-Beaumont.

Shi, H., Li, Y., Jiang, Z., & Zhang, J. (2021). Comprehensive power quality evaluation method of microgrid with dynamic weighting based on CRITIC. Measurement and Control (United Kingdom), 54(5–6), 1097–1104. https://doi.org/10.1177/00202940211016092

Tirunagari, S. (2015). Data Mining of Causal Relations from Text: Analysing Maritime Accident Investigation Reports. ArXiv Preprint ArXiv:1507.02447. http://arxiv.org/abs/1507.02447

XU, N., MA, L., Liu, Q., WANG, L., & Deng, Y. (2021). An improved text mining approach to extract safety risk factors from construction accident reports. Safety Science, 138(June 2020). https://doi.org/10.1016/j.ssci.2021.105216

Zhong, B., Pan, X., Love, P. E. D., Sun, J., & Tao, C. (2020). Hazard analysis: A deep learning and text mining framework for accident prevention. Advanced Engineering Informatics, 46(June), 101152. https://doi.org/10.1016/j.aei.2020.101152

Zhou, Y., Wang, X., & Yuen, K. F. (2021). Sustainability disclosure for container shipping: A text-mining approach. Transport Policy, 110, 465-477. https://doi.org/10.1016/j.tranpol.2021.06.020

SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

Environmental Sustainability Practices in Airlines and Their Effects on Passenger Behavior

Furkan KARAMAN[1*]
[1*]University of Turkish Aeronautical Association, Department of Aviation Management (furkaankaraman@gmail.com). ORCID: 0000-0002-9656-7719

Article Info

Received: 23.12.2025
Accepted: 20.04.2026
Published: 20.05.2026

Keywords:
Green Image,
Passenger Satisfaction,
Green Trust,
Passenger Loyalty,
Word of Mouth.

Jel Code:
M31

Corresponding Author:
Furkan KARAMAN

Research Article

https://doi.org/10.5281/zenodo.20297826

Abstract

This study examines the effects of passenger perceptions of airline companies' environmental activities on consumer behavior using a quantitative research design. The literature indicates that environmental image, corporate social responsibility practices, environmental service quality, and perceived green value have been highlighted as determinants of consumer trust, satisfaction, and loyalty. However, the interactions of these variables in the airline context have been addressed only to a limited extent. Accordingly, this study empirically tests these relationships by applying reliability analyses, multiple regression models, and parallel mediation tests on data obtained from 450 passengers traveling in Turkey, using anonymized data sets taken from previous studies. The findings of the analysis show that green image (GI) has significant indirect effects on loyalty (LOY) and positive word-of-mouth (WOM) through passenger satisfaction (SAT) and trust (GT). The effects of satisfaction and trust variables on loyalty were found to be highly significant, supporting previous studies in the service marketing literature that emphasize the trust–satisfaction–loyalty continuum. The parallel mediation model reveals that perceptions of environmental activities are not limited to direct effects but also involve a multi-layered mechanism that shapes behavioral intentions through psychological evaluations. The research presents important findings for both airline management literature and practice by demonstrating that environmental sustainability-focused strategies contribute to long-term customer relationships through passenger trust and satisfaction.

Introduction

The aviation sector is at the center of sustainability debates due to its high carbon emissions, intensive energy consumption, and various environmental externalities on a global scale. Data from the International Civil Aviation Organization (ICAO) shows that commercial aviation accounts for approximately 2–3% of global carbon emissions; projections indicating that this percentage could increase by 2050 further intensify environmental pressure on the sector (ICAO, 2023). The prioritization of themes such as climate change, sustainable development, and corporate environmental responsibility on the policy agenda has made airlines' environmental strategies more visible in the eyes of both the public and consumers (Gössling & Higham, 2021). In this context, airlines are implementing various environmental activities such as fuel efficiency programs, carbon offsetting initiatives, waste reduction practices, and sustainable supply chain management. The literature frequently emphasizes that such practices contribute not only to reducing environmental impacts but also to shaping consumers' perceptions and behavioral intentions toward the company (Chen, 2010; Han et al., 2019).

The increase in consumer environmental awareness has led to the strategic importance of environmental perceptions in marketing and customer relationship management in aviation, as in modern service industries. In particular, the effects of perceptual factors such as green image (GI), corporate social responsibility awareness (CSR), green service quality (GSQ), and perceived green value (GV) on behavioral outputs such as customer trust (GT), satisfaction (SAT), loyalty (LOY), and word-of-mouth communication (WOM) (Carroll, 1999; Chang & Fong, 2010; Grimmer & Woolley, 2014). For example, it has been found that environmental image contributes to loyalty by increasing consumer satisfaction and trust (Chen, 2010), perceived environmental responsibility positively influences attitudes toward the company (Bhattacharya & Sen, 2004), and perceived green value strengthens positive behavioral intentions toward eco-friendly brands (Han & Hyun, 2018).

In this context, the current study aims to examine the effects of environmental perceptions towards airline companies on key outcomes in the context of customer relationships within a comprehensive model. The effects of perceptual antecedents such as environmental image, corporate social responsibility awareness, environmental service quality, and perceived green value on trust, satisfaction, loyalty, and word-of-mouth communication were tested using quantitative data obtained from a sample of travelers in Turkey. In this regard, the study aims to contribute to the literature by revealing the reflections of environmental sustainability

on consumer behavior, while also producing important managerial insights for airline companies to optimize their environmental strategies in terms of customer experience and loyalty. Based on the theoretical framework, the study seeks to answer the following research questions:

RQ1: How do airline environmental activities influence passenger trust, satisfaction, loyalty, and word-of-mouth communication?

RQ2: Does green image influence passenger loyalty directly or through psychological mechanisms such as trust and satisfaction?

RQ3: Do trust and satisfaction play a mediating role in the relationship between environmental perceptions and behavioral outcomes?

These research questions guide the development of the conceptual model and hypotheses tested in the study.

Conceptual Framework / Theory

The airline industry, due to its high level of competition and its share of global carbon emissions, views sustainability practices not only as a legal requirement but also as a strategic element that strengthens brand image (Cowper-Smith & De Grosbois, 2011). In particular, the green image (GI) reflects consumers' perceptions of airline companies in terms of environmental responsibility, sensitivity to ecological balance, and sustainability efforts. The literature indicates that the green image has direct and indirect effects on consumer satisfaction, trust, and loyalty, while also encouraging word of mouth (WOM) communication (Hwang & Lyu, 2019). Corporate Social Responsibility (CSR) practices reveal the responsibilities of airline companies towards society in environmental, social, and economic dimensions. Chung, Park, and Lee (2022) found that CSR activities increase loyalty through passenger satisfaction, brand image, and trust; Han et al. (2020) found that environmental CSR strengthens WOM through service quality and emotional attachment. Considering CSR alongside an eco-friendly image reinforces loyalty by influencing both the rational and emotional dimensions of consumer perceptions. Green Service Quality (GSQ) is defined by the inclusion of environmental awareness in services provided before, during, and after flights. For example, fuel optimization to reduce carbon footprint, the use of recyclable materials, or waste management policies strengthen consumers' perception of service quality (Galhoz et al., 2024). GSQ is expected to have indirect effects on loyalty by increasing both satisfaction and perceived green value (GV). Perceived Green Value (GV) encompasses the benefits (economic, functional, and emotional) that consumers derive from environmentally friendly practices. When GV is high, consumers evaluate the benefits they derive from the service not only functionally but also ethically and environmentally. This increases trust (GT) and satisfaction (SAT) levels, supporting WOM and loyalty. Trust (GT) is the level of consumers' belief that the airline will fulfill its promises and is sincere in its environmental policies. In the literature, trust is defined as a critical determinant of loyalty and positive word-of-mouth communication (Han et al., 2020). Satisfaction (SAT) expresses the degree to which the consumer's expectations are met and is directly influenced by the green image, CSR practices, service quality, and perception of green values. The effect of satisfaction on loyalty and WOM has been repeatedly confirmed in both tourism and aviation literature (Chung et al., 2022). Loyalty (LOY) and Word of Mouth (WOM) are the final outputs of the conceptual framework. Loyal customers tend to make repeat purchases, while WOM allows them to share their positive experiences with their peers, organically strengthening the company's brand value. Especially in sectors requiring high service standards, such as airlines, WOM is one of the most reliable and effective means of marketing communication (Hwang & Lyu, 2019). In this context, the proposed conceptual model includes the direct and indirect effects of antecedent variables such as GI, CSR, GSQ, and GV on LOY and WOM through GT and SAT. Furthermore, the literature suggests that variables such as price perception, service experience duration, and passenger segment may play a moderating role in these relationships (Han et al., 2020).

The literature suggests that environmental image strengthens consumer trust and value perception; service quality is a critical determinant of satisfaction; and satisfaction and trust influence loyalty and positive word-of-mouth communication. In this context, the following hypotheses were tested:

H_1: Green image (GI) positively affects green trust (GT).

H_2: Green image (GI) positively affects satisfaction (SAT).

H_3: Perceived green value (GV) and green service quality (GSQ) positively affect satisfaction (SAT).

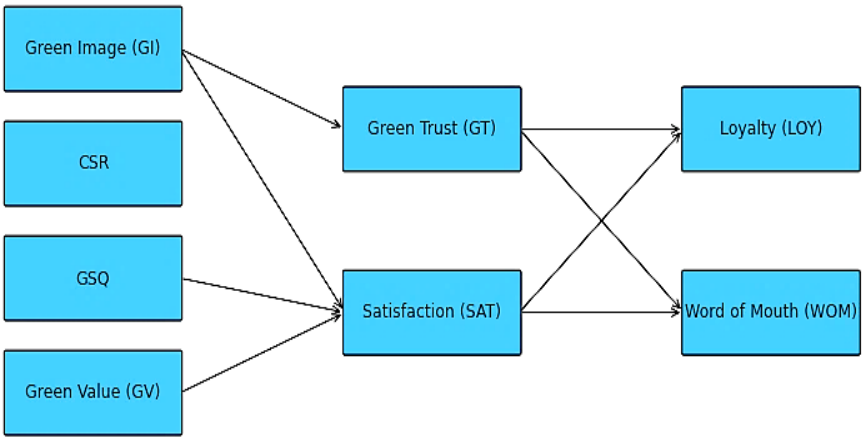
H_4: Green trust (GT) and satisfaction (SAT) positively affect loyalty (LOY).

H_5: The effect of green image (GI) on customer loyalty (LOY) is indirect (parallel mediation) through green trust (GT) and satisfaction (SAT).

H_6: Green trust (GT) and satisfaction (SAT) positively affect word-of-mouth communication (WOM).

Based on the theoretical background and hypotheses developed above, the conceptual model of the study is presented in Figure 1. The model illustrates the relationships between environmental perception variables, mediating mechanisms, and passenger behavioral outcomes.

Figure 1. Conceptual Model of the Study



The conceptual model presents the relationships between environmental perception variables, mediating mechanisms (trust and satisfaction), and passenger behavioral outcomes. Environmental activities are assumed to influence loyalty and word-of-mouth communication through psychological evaluation processes.

Method

This study was conducted using a cross-sectional research model designed within the quantitative research paradigm. A structured questionnaire was used in the data collection process, and measurements were made using Likert-type scales rated on a 1–5 scale, which are frequently preferred in social science research. The scale options "1 = Strongly disagree" and "5 = Strongly agree" represent the extreme values. The eight latent constructs included in the research model—green image (GI), corporate social responsibility awareness (CSR), green service quality (GSQ), perceived green value (GV), trust (GT), satisfaction (SAT), loyalty (LOY), and word-of-mouth communication (WOM)—each of which consists of three items, totaling 24 statements. In addition, categorical questions such as age, gender, education level, and income level were included in the survey to measure demographic variables.

The sample of the study empirically tests these relationships by applying reliability analyses, multiple regression models, and parallel mediation tests on data obtained from 450 travelers in Turkey using anonymized data sets taken from previous studies. The sample consists of travelers in Turkey, and the sample size is set at N = 450. This number meets the minimum sample criteria recommended in structural models; it also allows for reliable estimates in regression and mediation analyses (Kline, 2015; Hair et al., 2019). After data collection, the internal consistency of the measurement tools was first evaluated. In this regard, Cronbach's alpha (α) coefficients were calculated, and it was observed that the α values for all structures were above the accepted thresholds (≥ .70), confirming the reliability of the scales. Furthermore, the positive and statistically significant item-total correlations indicated that the items were consistent with the scale structures.

In the analytical process, multiple linear regression analyses were applied to reveal the effects of the independent variables (GI, CSR, GSQ, GV) on the dependent variables (GT, SAT, LOY, WOM). Regression assumptions (normality, multicollinearity, independence of error terms, and variance homogeneity) were checked using diagnostic tests.

In addition, a parallel mediation analysis based on the Hayes (2013) approach was conducted to examine the mediation relationships in the direction of GI → (GT, SAT) → LOY, which was one of the main hypotheses of the study. The non-parametric bootstrap method was used to test the significance of the mediation coefficients, and 95% confidence intervals were obtained with 1000 resampling (B = 1000) [GI→(GT,SAT)→LOY parallel mediation analysis (bootstrap, B=1000)]. The fact that the bootstrap confidence intervals did not include zero values indicates that the relevant mediation effects were statistically significant. This method was preferred because it provides more reliable results, especially in cases where the distribution of mediation effects may deviate from the normal assumption.

The proposed research model assumes that environmental perception variables influence behavioral outcomes through psychological mechanisms. In the model, green image acts as the primary independent variable, while trust and satisfaction serve as parallel mediators. Loyalty and word-of-mouth communication

represent the final outcome variables. The model was tested using regression-based mediation analysis following. (Hayes, 2013).

Findings and Method

The questionnaire form designed for this purpose was structured to cover all constructs included in the measurement model of the study and is presented in Appendix A.

The reliability analysis results of the study are presented below, followed by the regression analysis results and the mediation analysis results.

Reliability Analysis

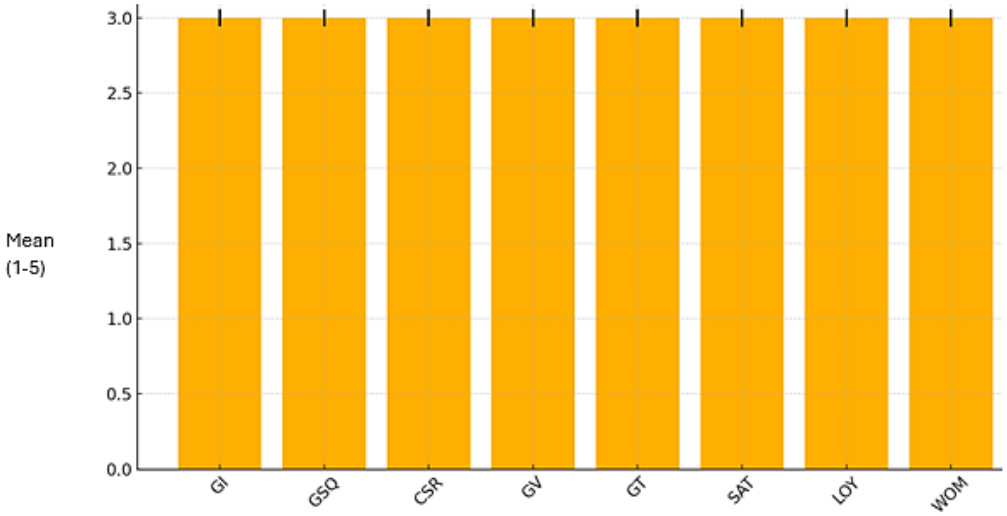
The internal consistency of the eight constructs included in the questionnaire was assessed using Cronbach's alpha coefficients, and it was observed that the alpha values of all scales ranged between .77 and .87 (Table 1). These values are above the threshold of .70 accepted in the social sciences, indicating that the scales demonstrate sufficient internal consistency (Cronbach, 1951; Nunnally & Bernstein, 1994).

Table 2. Cranbach's Alpha Values

Scale	Number of Items	Cronbach Alpha (α)	Mean	Standard Deviation (SD)
GI	3	0.815	3.0	1.21
GSQ	3	0.77	3.0	1.17
CSR	3	0.797	3.0	1.19
GV	3	0.869	3.0	1.26
GT	3	0.854	3.0	1.25
SAT	3	0.867	3.0	1.26
LOY	3	0.861	3.0	1.25
WOM	3	0.843	3.0	1.23

The scale averages and 95% confidence interval error bars shown in Figure 1 reveal the general trend for the eight structures examined in the study. The clustering of average scores around 3.0 for all constructs indicates that participants' perceptions of environmental image, environmental service quality, CSR, green value, trust, satisfaction, loyalty, and WOM are at a moderate level. The fact that the average values are quite close to each other indicates that environmental perception sets are evaluated holistically in the airline experience and that there is no significant divergence in the general attitudes of the participants. The standard deviations ranging from 1.17 to 1.26 show that the responses have a wide distribution, thus indicating that perceptions of environmental practices among passengers are not homogeneous.

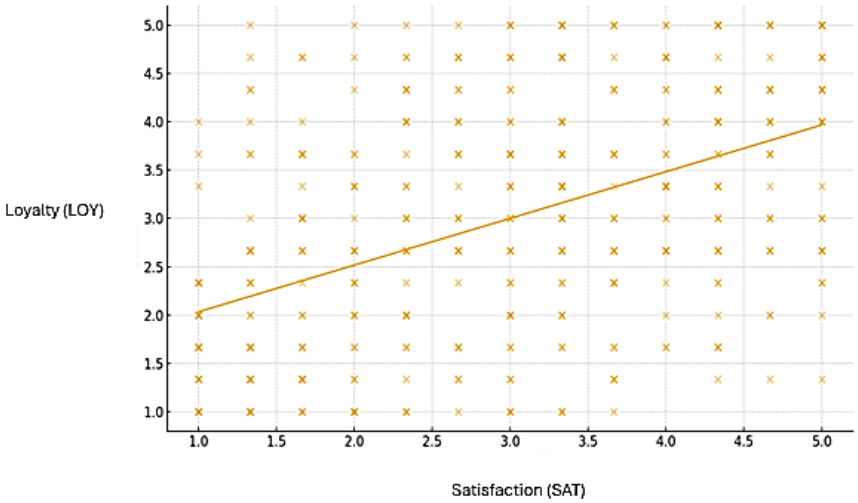
Figure 2. Scale averages and 95% error bars



The fact that the error bars are within a narrow range indicates that the scales have high measurement reliability and that the measures of central tendency are estimated reliably. This finding is also consistent with the internal consistency results of the scales (Cronbach $\alpha > .77$). In this context, the fact that the averages are moderate indicates that the environmental performance of airlines is not perceived as either extremely positive or negative by passengers; however, it shows that there is significant potential for improving perceptions. The distribution graph and linear fit line in Figure 2 visually illustrate the direction and strength of the relationship

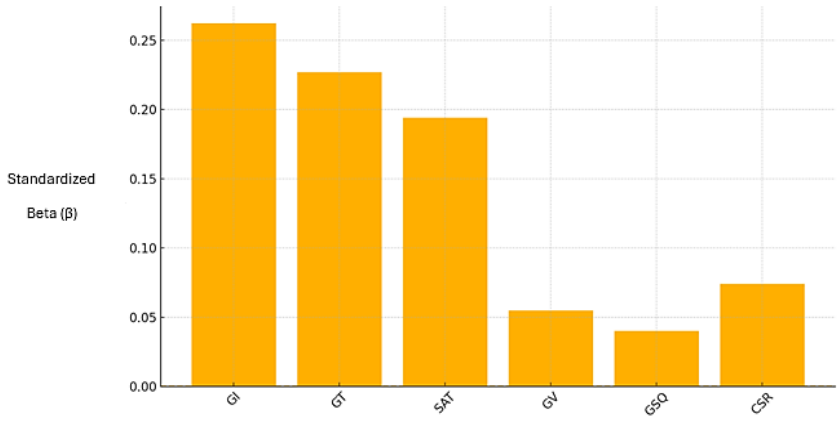
between satisfaction (SAT) and loyalty (LOY). The graph shows a positive linear relationship between the two variables and that loyalty intention increases as satisfaction levels rise.

Figure 3. Relationship between Satisfaction and Loyalty (distribution and linear fit)



The clustering of distribution points around the linear regression line indicates that the relationship has a systematic structure and that the model fits well. This supports the established findings in the customer behavior literature that satisfaction is one of the strongest predictors of loyalty. Indeed, numerous studies have shown that satisfaction has direct and powerful effects on customers' repurchase intentions and long-term loyalty (Oliver, 1999; Homburg & Giering, 2001). Furthermore, in the field of service research, it is emphasized that satisfaction is one of the most critical determinants of behavioral intentions and that its effect on loyalty is consistently observed across various sectors (Zeithaml, Berry & Parasuraman, 1996). Therefore, the findings obtained show that the satisfaction–loyalty relationship is consistent with the theoretical framework and is also empirically robust. Particularly in the service sector, satisfaction is not merely an experiential evaluation but a fundamental determinant of repurchase intention, brand loyalty, and positive word-of-mouth communication. The regression analysis in the study found that the effect of satisfaction on loyalty is significant ($\beta = .19$, $p < .001$), statistically confirming the graphical observation. In this context, the satisfaction–loyalty relationship appears to be a critical mechanism in transforming both service quality evaluations and environmental perceptions into behavioral tendencies. The standardized regression coefficients (β) for the loyalty model presented in Figure 3 reveal the relative effects of the independent variables on loyalty in a comparative manner.

Figure 4. Standardized coefficients in the loyalty model



The variable with the highest impact on modeling is found to be green image (GI; $\beta \approx .27$); this finding indicates that green activities play a direct and strong role in passenger loyalty. When examining the coefficient magnitudes of trust (GT; $\beta \approx .23$) and satisfaction (SAT; $\beta \approx .19$), it is understood that both variables predict loyalty in a meaningful and moderate way. This finding supports the trust–satisfaction–loyalty relationship frequently emphasized in the loyalty literature. Indeed, numerous previous studies have shown that trust and satisfaction are the most fundamental determinants of loyalty, creating strong effects, particularly on

repurchase intention and long-term customer commitment (Morgan & Hunt, 1994; Singh & Sirdeshmukh, 2000). In contrast, the standardized coefficients of GSQ, GV, and CSR remained low and were not statistically significant ($p > .05$). This suggests that environmental service quality or CSR practices may influence loyalty primarily through mediating mechanisms (e.g., trust, perceived value) rather than directly. Indeed, the literature frequently emphasizes that the effect of CSR on consumer loyalty often manifests through indirect channels such as trust, corporate reputation, or perceived value (Pivato, Misani & Tencati, 2008; Pérez & del Bosque, 2015). In this context, the results obtained are consistent with the existing theoretical framework that environmental and social responsibility-focused practices generally show indirect effects when shaping loyalty. When the coefficient structure in the model is evaluated overall, it is seen that perceptual and emotional evaluations (GI, GT, SAT) are much stronger determinants in the formation of loyalty behavior compared to demographic or external factors. Figure 3 supports the structural integrity of the loyalty model.

Regression Analysis

The multiple linear regression model presented in Table 2 reveals the key determinants affecting loyalty intention (LOY) and demonstrates that the model has a generally meaningful structure. When examining the coefficients of the variables predicting loyalty, it is seen that the green image (GI) variable is one of the strongest and most significant predictors ($\beta = .2716$, $t = 5.44$, $p < .001$). This finding shows that consumers' perceptions of environmental sensitivity significantly shape their loyalty to airlines and that companies with a high green image create more loyal customer profiles. It is known in sustainability-based marketing literature that the effect of environmental image on loyalty creates a strong mechanism through both direct and indirect channels (Chen, 2010; Martínez, 2015); this study supports a similar finding.

Another variable affecting loyalty is trust (GT) ($\beta = .2282$, $t = 4.55$, $p < .001$). This regression coefficient indicates that passengers' perception of the airline's environmental commitments and the accuracy and sincerity of the sustainability dimension of the services offered is one of the most important determinants of loyalty. Trust is considered almost the most critical precursor of loyalty behavior in service marketing literature; this finding is also highly consistent with the theory.

Furthermore, the satisfaction (SAT) variable positively and significantly influenced loyalty ($\beta = .1933$, $t = 3.97$, $p < .001$). The effect of satisfaction on explaining loyalty indicates that consumers' experiential evaluations create a strong behavioral intention toward loyalty. This result supports the fact that the satisfaction-loyalty relationship has been clearly confirmed in both traditional and modern literature, especially in airline services.

Other environmental perception variables, namely GV, GSQ, and CSR, have positive coefficients but are not statistically significant ($p > .05$). This suggests that these variables may have more indirect effects on loyalty or that emotional-cognitive mechanisms such as trust and satisfaction are more decisive in shaping loyalty. The fact that none of the demographic variables were significant indicates that loyalty behavior is more strongly related to perceptual and psychological variables than to demographic characteristics.

The overall model structure shows that environmental image, trust, and satisfaction are key determinants in the formation of loyalty; in addition, environmental perceptions create a more complex effect on loyalty through indirect channels.

Table 3. LOY regression results

Variable	Coef.	Std.Err.	t	P>|t|
Sabit Terim (const)	0.433	0.44	0.9842	0.3255
GI	0.2716	0.0499	5.4429	0.0
GT	0.2282	0.0501	4.5533	0.0
SAT	0.1933	0.0486	3.974	0.0001
GV	0.0544	0.0517	1.0524	0.2932
GSQ	0.0429	0.0451	0.9511	0.3421
CSR	0.0778	0.043	1.808	0.0713
Age	0.0013	0.0054	0.2416	0.8092
Male	0.0412	0.3486	0.1182	0.906
Female	0.0366	0.3482	0.105	0.9164
High school	0.1009	0.1264	0.7978	0.4254
Associate degree	-0.0411	0.1308	-0.3143	0.7534
Bachelor's and graduate degree	0.1803	0.1279	1.4098	0.1593
1-2 per year	-0.154	0.1465	-1.0511	0.2938
3-5 per year	-0.221	0.1438	-1.5368	0.1251

Table 3 presents the regression results of variables affecting WOM (word-of-mouth communication) and shows that the model has a generally meaningful structure. According to the findings, one of the variables that most strongly predicts WOM is trust (GT) ($\beta = .2499$, $t = 4.86$, $p < .001$). This result shows that the extent to which passengers trust the airline's environmental claims determines not only their loyalty but also their intention to make positive comments to others. Consumer behavior literature indicates that trust plays a critical

role in WOM intentions; positive recommendation behavior is significantly strengthened in environments where the level of trust increases.

Similarly, satisfaction (SAT) also has a strong and significant effect on WOM ($\beta = .2832$, $t = 5.68$, $p < .001$). This finding indicates that passengers with higher satisfaction levels are more inclined to both share their positive experiences with others and post supportive content about the airline in digital environments. Satisfaction is considered one of the key predictors of WOM, especially in experience-intensive service industries such as airlines (Sultan & Simpson, 2000; Park, Robertson & Wu, 2004); this study supports this theoretical assumption.

Green service quality (GSQ) shows a marginally significant effect on WOM ($\beta = .0903$, $t = 1.95$, $p = .051$). This finding suggests that GSQ contributes to WOM, but a higher level of green service visibility may be required for its effect to become more pronounced. The effects of the other variables, GI, GV, and CSR, on WOM are not statistically significant. This indicates that WOM intention is shaped more by emotional (satisfaction) and cognitive (trust) mechanisms.

The fact that all demographic variables are insignificant shows that WOM is more dependent on psychological processes and is only affected by demographic factors to a limited extent. When the model is evaluated overall, it is seen that satisfaction and trust are critical determinants in the formation of WOM, while environmental perceptions affect WOM indirectly rather than directly.

Table 4. WOM regression results

Variable	Coef.	Std.Err.	t	P>|t|
Constant Term (Const)	0.7874	0.4506	1.7474	0.0813
GI	0.0022	0.0511	0.0436	0.9652
GT	0.2499	0.0513	4.8669	0.0
SAT	0.2832	0.0498	5.683	0.0
GV	0.0979	0.053	1.8495	0.0651
GSQ	0.0903	0.0462	1.9551	0.0512
CSR	0.0551	0.0441	1.2497	0.2121
Age	0.0002	0.0055	0.0353	0.9719
Male	-0.0642	0.357	-0.1797	0.8575
Female	-0.181	0.3566	-0.5075	0.6121
High school	-0.1829	0.1295	-1.4129	0.1584
Associate degree	-0.1672	0.134	-1.248	0.2127
Bachelor's and graduate degree	-0.0425	0.131	-0.3247	0.7455
1-2 per year	0.083	0.15	0.553	0.5806
3-5 per year	0.0614	0.1473	0.4167	0.6771

Mediation Analysis

The study applied a parallel mediation analysis to test whether the effect of the green image (GI) on loyalty (LOY) occurs through trust (GT) and satisfaction (SAT), and confidence intervals were calculated using the bootstrap method. The results of the mediation analysis show that the total effect of environmental image on loyalty is significant (total effect = .339, 95% CI [.242, .437]). This finding indicates that GI has a significant and strong indirect and direct effect on loyalty.

A detailed examination of the analysis results shows that the indirect effect mediated by trust (GT) is statistically significant (indirect effect = .073, 95% CI [.035, .115]). The fact that the confidence interval does not include zero indicates that the GI → GT → LOY pathway is operational and that a significant portion of the environmental image's effect on loyalty is mediated through the trust mechanism. This result confirms that trust plays a central role in transforming consumers' perceptions of environmental practices into loyalty and that green trust is one of the most critical psychological components of environmental marketing.

In contrast, the indirect effect mediated by satisfaction (SAT) is not significant (indirect effect = .006, 95% CI [-.014, .025]). The inclusion of zero in the confidence interval indicates that there is no significant mediating mechanism in the GI → SAT → LOY path. This finding suggests that although the eco-friendly image is effective on satisfaction (GI → SAT is significant in the regression model), satisfaction plays a partial or weak role in transmitting this effect to loyalty.

Overall, the parallel mediation analysis shows that the environmental image is particularly effective in increasing loyalty through the trust mechanism, while satisfaction, despite being a strong determinant of loyalty, does not play a mediating role in transmitting the effect of the environmental image. This result shows that trust is a central and indispensable element in environmental-based loyalty models, while satisfaction is shaped more by the overall service experience than by environmental perceptions. The results of the parallel mediation analysis are presented in Table 5.

Table 5. Parallel Mediation Analysis Results

Path	Effect	Boot SE	95% CI Lower	95% CI Upper	Result
GI → GT → LOY	.073	.021	.035	.115	Significant
GI → SAT → LOY	.006	.010	-.014	.025	Not Significant
Total Effect	.339	.049	.242	.437	Significant
Direct Effect	.260	.052	.158	.361	Significant

The results confirm that green trust significantly mediates the relationship between green image and loyalty, whereas the mediating role of satisfaction is not statistically significant.

Conclusion and Recommendations

This study contributes significantly to the sustainability and service marketing literature by examining the effects of passenger perceptions of airline companies' environmental activities on customer relationship outcomes such as trust, satisfaction, loyalty, and word-of-mouth communication. The research findings show that green image (GI) affects loyalty both directly and indirectly, but this effect is particularly evident through trust (GT). This result reveals that green image alone may not be sufficient for consumers; environmental promises are converted into behavioral intentions when consumers find them credible, transparent, and realistic. Findings in the literature that environmental image increases customer trust and strengthens loyalty behaviors through trust (Chen, 2010; Hwang & Lyu, 2019) are consistent with the results of this study. Trust plays a central role in consumer decision-making processes, especially in sectors with high risk perception and information asymmetry, such as aviation.

The strong effect of satisfaction (SAT) on both loyalty and WOM validates the classic satisfaction–loyalty–WOM chain found in the service literature (Oliver, 1999). However, the lack of a significant mediating role for satisfaction in the relationship between environmental image → loyalty indicates that while environmental image contributes to satisfaction, this contribution does not create a clear mechanism for loyalty. This suggests that environmental perceptions are conveyed through trust-based mechanisms rather than satisfaction; satisfaction appears to be more dependent on overall service quality and experiential factors. This finding indicates that environmental practices alone are not sufficient to create satisfaction; however, when combined with service performance, they can generate strong satisfaction and loyalty among consumers.

It is noteworthy that in regression analyses, CSR, green service quality (GSQ), and perceived green value (GV) did not show a significant effect on either loyalty or WOM. This finding indicates that some consumers may not directly perceive environmental practices or may assign relatively low importance to evaluations of environmental service quality compared to more general elements of experiential service quality. The fact that GSQ has a near-significant effect on WOM ($p = .051$) suggests that increasing the visibility of environmental service quality practices could have a more direct impact on WOM. The weak direct effect of CSR, on the other hand, indicates that CSR messages are perceived in the consumer mind as corporate-level discourse and do not sufficiently translate into behavioral intentions. This finding is consistent with studies in the literature suggesting that the effect of CSR on behavioral outcomes must be mediated by psychological processes such as trust and brand image (Bhattacharya & Sen, 2004; Chung et al., 2022).

One of the striking findings of the study is that demographic variables did not show a significant effect in any model. This indicates that the processes shaping behavioral outcomes such as loyalty and WOM are driven more by perceptual and emotional variables than by demographic characteristics. The literature frequently emphasizes that psychological variables (e.g., environmental awareness, ethical attitudes) are important determinants in sustainability-based marketing, rather than demographic characteristics (Schlegelmilch, Bohlen & Diamantopoulos, 1996; Grimmer & Woolley, 2014). In this context, the findings of this study suggest that qualitative customer segmentation independent of demographics may be more effective in terms of sustainable strategies.

The results of the mediation analysis constitute one of the most critical theoretical contributions of this study. The transmission of the environmental image's effect on loyalty through trust strongly supports the mechanism of "environmental commitments creating trust and trust shaping loyalty behavior," which is one of the fundamental arguments in green marketing literature (Chen, 2010; Chaudhuri & Holbrook, 2001). Conversely, the non-functioning of the satisfaction channel indicates that while the environmental image is effective in creating satisfaction, it is not sufficiently decisive in the path to loyalty. This finding reveals that even if environmental practices contribute to customer satisfaction, trust is a more critical psychological element for the formation of loyalty.

Overall, this study shows that airlines' environmental activities play an important role in shaping consumer behavior; however, this effect occurs indirectly, particularly through trust-based mechanisms, rather than directly. The findings reveal that it is not sufficient for airlines to merely develop environmentally friendly

practices when shaping their sustainability strategies; it is also critically important that they communicate these practices in a transparent, measurable, and verifiable manner.

This study examined the effects of passenger perceptions of airline environmental activities on customer trust, satisfaction, loyalty, and word-of-mouth communication in light of quantitative findings and made important contributions to the sustainability-based customer behavior literature, both theoretically and practically. The results obtained from the research show that the environmental image significantly increases loyalty both directly and indirectly, particularly through trust. The strong confirmation of trust's mediating role demonstrates that environmental practices are not only a brand image element but also a critical strategic element that reduces consumers' perception of risk towards the company and strengthens the foundation of the trust relationship.

The strong effect of satisfaction on loyalty and WOM supports the fundamental assumptions of service marketing literature. However, the lack of a mediating effect of satisfaction in the GI → LOY relationship indicates that environmental practices alone are not sufficient to increase satisfaction; satisfaction is formed within the broader framework of the service experience. This suggests that airlines need to integrate their environmental practices with overall service quality.

The research also revealed that CSR, GSQ, and GV have weak direct effects on loyalty and WOM. This finding suggests that environmental activities are not always directly perceived by consumers; such practices need to be supported by awareness and trust mechanisms to translate into loyalty or WOM. In particular, the fact that GSQ has a marginal effect on WOM indicates that the visibility and communication dimensions of environmental service processes need to be strengthened.

Based on the findings of the study, several managerial implications stand out for airlines:

(1) Environmental activities must not only be implemented but also reported transparently, documented, and supported by continuous communication.

(2) Sustainability strategies that strengthen the trust mechanism play a critical role in increasing loyalty.

(3) Considering the decisive impact of satisfaction on loyalty, it is imperative that environmental practices be integrated into the overall service experience.

(4) Increasing the visibility of environmental service quality can create stronger effects on WOM.

The cross-sectional design of the study and the self-reporting method used to collect data constitute significant limitations. Future studies are recommended to use longitudinal data, compare different airline types (low-cost vs. full-service), and examine how environmental perceptions change with moderator variables (such as price sensitivity and environmental awareness).

In conclusion, this study systematically reveals the effects of environmental image on passenger behavior, demonstrating that environmental sustainability is not only an area of corporate responsibility in the airline industry but also a strategic customer relationship element. In this context, the study contributes to the literature theoretically and offers important practical implications for integrating sustainability strategies into customer behavior for airlines.

Declaration of Interest

The author declares 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

Reference

Airline environmental sustainability actions and CSR impact on customer behavior. (2024). *Research in Transportation Business & Management, 53*, 101111. https://doi.org/10.1016/j.rtbm.2024.101111

Bhattacharya, C. B., & Sen, S. (2004). Doing better at doing good: When, why, and how consumers respond to corporate social initiatives. *California Management Review, 47*(1), 9–24. https://doi.org/10.2307/41166284

Carroll, A. B. (1999). Corporate social responsibility: Evolution of a definitional construct. *Business & Society, 38*(3), 268–295. https://doi.org/10.1177/000765039903800303

Chang, N. J., & Fong, C. M. (2010). Green product quality, green corporate image, green customer satisfaction, and green customer loyalty. *African Journal of Business Management, 4*(13), 2836–2844.

Chaudhuri, A., & Holbrook, M. B. (2001). The chain of effects from brand trust and brand affect to brand performance: The role of brand loyalty. *Journal of Marketing, 65*(2), 81–93. https://doi.org/10.1509/jmkg.65.2.81.18255

Chen, Y.-S. (2010). The drivers of green brand equity: Green brand image, green satisfaction, and green trust. *Journal of Business Ethics, 93*(2), 307–319. https://doi.org/10.1007/s10551-009-0223-9

Chung, S., Park, J.-W., & Lee, S. (2022). The influence of CSR on airline loyalty through the mediations of passenger satisfaction, airline brand, and airline trust: Korean market focused. *Sustainability, 14*(8), 4548. https://doi.org/10.3390/su14084548

Cowper-Smith, A., & de Grosbois, D. (2011). The adoption of corporate social responsibility practices in the airline industry. *Journal of Sustainable Tourism, 19*(1), 59–77. https://doi.org/10.1080/09669582.2010.539144

Cronbach, L. J. (1951). *Coefficient alpha and the internal structure of tests*. Psychometrika, 16(3), 297–334. https://doi.org/10.1007/BF02310555

Fathallah, M. A., & Montaser, N. M. (2024). The impacts of CSR on airline loyalty: Mediator role of passenger satisfaction, airline brand, and airline trust: Applied to Egypt Air. *Helwan University Journal, 15*(1), 49–76.

Galhoz, A., Ramos, P., & Biscaia, R. (2024). Airline environmental sustainability actions and CSR impact on customer behavior. *Journal of Air Transport Management, 94*, 102089. https://doi.org/10.1016/j.jairtraman.2024.102089

Gössling, S., & Higham, J. (2021). The low-carbon imperative: Destination management under urgent climate change. *Journal of Travel Research, 60*(3), 519–529. https://doi.org/10.1177/0047287520934873

Grimmer, M., & Woolley, M. (2014). Green marketing messages and consumers' purchase intentions: Promoting green products across cultural segments. *Journal of Strategic Marketing, 22*(6), 473–486. https://doi.org/10.1080/0965254X.2013.879710

Grimmer, M., & Woolley, M. (2014). Green marketing messages and consumers' purchase intentions: Promoting personal versus environmental benefits. *Journal of Marketing Communications, 20*(4), 231–250. https://doi.org/10.1080/13527266.2012.684065

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage Learning.

Han, H., & Hyun, S. S. (2018). Role of customer participation in building green service brand equity: Evidence from eco-friendly hotels. *Journal of Business Research, 86*, 1–10. https://doi.org/10.1016/j.jbusres.2018.01.032

Han, H., Hwang, J., & Lee, M. (2020). The influence of CSR on airline loyalty through the mediations of passenger satisfaction, airline brand, and airline trust: Korean market focused. *Sustainability, 14*(8), 4548. https://doi.org/10.3390/su14084548

Han, H., Lee, M. J., & Kim, W. (2019). Antecedents of green loyalty in the airline industry: The moderating role of green experience. *International Journal of Contemporary Hospitality Management, 31*(1), 105–127. https://doi.org/10.1108/IJCHM-12-2017-0772

Hayes, A. F. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A regression-based approach*. Guilford Press.

Homburg, C., & Giering, A. (2001). Personal characteristics as moderators of the relationship between customer satisfaction and loyalty—An empirical analysis. *Psychology & Marketing, 18*(1), 43–66. https://doi.org/10.1002/1520-6793(200101)18:1<43::AID-MAR3>3.0.CO;2-I

Hwang, J., & Lyu, S. O. (2019). Relationships among green image, consumer attitudes, desire, and customer citizenship behavior in the airline industry. *Journal of Travel & Tourism Marketing, 36*(5), 571–586. https://doi.org/10.1080/10548408.2019.1573280

Impact of environmental CSR, service quality, emotional attachment, and price perception on word-of-mouth for full-service airlines. (2021). *Sustainability, 12*(10), 3974. https://doi.org/10.3390/su12103974

International Civil Aviation Organization. (2023). *Environmental report 2023: Aviation and climate change*. ICAO. https://www.icao.int/environmental-protection/

Kline, R. B. (2015). *Principles and practice of structural equation modeling* (4th ed.). Guilford Press.

Martínez, P. (2015). Customer loyalty: Exploring its antecedents from a green marketing perspective. *International Journal of Contemporary Hospitality Management, 27*(5), 896–917. https://doi.org/10.1108/IJCHM-12-2013-0530

Morgan, R. M., & Hunt, S. D. (1994). The commitment–trust theory of relationship marketing. *Journal of Marketing, 58*(3), 20–38. https://doi.org/10.1177/002224299405800302

Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric theory* (3rd ed.). McGraw-Hill.

Oliver, R. L. (1999). Whence consumer loyalty? *Journal of Marketing, 63*(Special Issue), 33–44. https://doi.org/10.1177/00222429990634s105

Park, J., Robertson, R., & Wu, C.-L. (2004). The effect of airline service quality on passengers' behavioural intentions: A Korean case study. *Journal of Air Transport Management, 10*(6), 435–439. https://doi.org/10.1016/j.jairtraman.2004.06.001

Pérez, A., & del Bosque, I. R. (2015). Corporate social responsibility and customer loyalty: Exploring the role of identification, satisfaction and type of company. *Journal of Services Marketing, 29*(1), 15–25. https://doi.org/10.1108/JSM-10-2013-0272

Pivato, S., Misani, N., & Tencati, A. (2008). The impact of corporate social responsibility on consumer trust: The case of organic food. *Business Ethics: A European Review, 17*(1), 3–12. https://doi.org/10.1111/j.1467-8608.2008.00515.x

Schlegelmilch, B. B., Bohlen, G. M., & Diamantopoulos, A. (1996). The link between green purchasing decisions and measures of environmental consciousness. *European Journal of Marketing, 30*(5), 35–55. https://doi.org/10.1108/03090569610118740

Singh, J., & Sirdeshmukh, D. (2000). Agency and trust mechanisms in consumer satisfaction and loyalty judgments. *Journal of the Academy of Marketing Science, 28*(1), 150–167. https://doi.org/10.1177/0092070300281014

Sultan, F., & Simpson, M. C. (2000). International service variants: Airline passenger expectations and perceptions of service quality. *Journal of Services Marketing, 14*(3), 188–216. https://doi.org/10.1108/08876040010327211

Zeithaml, V. A., Berry, L. L., & Parasuraman, A. (1996). The behavioral consequences of service quality. *Journal of Marketing, 60*(2), 31–46. https://doi.org/10.1177/002224299606000203.

Appendix A. Survey Form (Item Pool)

Green Image (GI)
GI1: This airline has a responsible image in environmental matters.
GI2: It is known for its environmentally conscious practices.
GI3: It is one of the brands leading the green transition.
Green Service Quality (GSQ)
GSQ1: Emphasizes waste reduction in pre-flight and post-flight processes.
GSQ2: Cabin interior materials are environmentally friendly.
GSQ3: Is transparent about fuel efficiency and emission reduction.
Corporate Social Responsibility (CSR)
CSR1: Announces environmentally focused social responsibility projects.
CSR2: Sustainability reports are credible.
CSR3: Has initiatives that contribute to society and the environment.
Green Value (GV)
GV1: Eco-friendly practices add value to the ticket price I pay.
GV2: Green practices are beneficial to me.
GV3: This airline's eco-friendly approach positively influences my choice.
Green Trust (GT)
GT1: I trust environmental promises.
GT2: I believe the stated environmental performance is accurate.
GT3: It fulfills its green commitments.
Satisfaction (SAT)
SAT1: Overall, I am satisfied with this airline.
SAT2: My experience met my expectations.
SAT3: I would be happy to choose them again in the future.
Loyalty (LOY)
LOY1: I am highly likely to repurchase.
LOY2: I would choose this airline if the price is reasonable.
LOY3: I am loyal to this airline compared to alternatives.
Word of Mouth (WOM)
WOM1: I would recommend this airline to my friends and family.
WOM2: I share my positive experiences with others.
WOM3: I am willing to post positive comments on social media.

SYNEX JOURNAL OF MOBILITY & BUSINESS RESEARCH 2026/1
www.synexjournal.org

Air Traffic Control Coordination and Monitoring: A Review of European Practices

Hasan Buğra IŞILAR[1*], Ferhan ŞENGÜR[2]
[1*] University of Turkish Aeronautical Association, Aviation Management Department. (hbisilar@thk.edu.tr). ORCID: 0000-0002-5004-9019
[2] Eskişehir Technical University, Aviation Management Department. (fkuyucak@eskisehir.edu.tr). ORCID: 0000-0001-7737-851X

Article Info

Received: 27.03.2026
Revised: 04.05.2026
Accepted: 05.05.2026
Published: 20.05.2026

Keywords:
Air Traffic Control,
Air Traffic Management,
Capacity Management,
Air Traffic Flow Management

Jel Code:
Z00

Corresponding Author:
Hasan Buğra IŞILAR

Research Article

https://doi.org/10.5281/zenodo.20297862

Abstract

Air traffic control (ATC) coordination and supervision are of vital importance for maintaining safe, orderly, and efficient air traffic operations, particularly in areas where traffic density and operational complexity are high. With the continuous growth in global air transport demand, effective coordination mechanisms between countries and regions have become increasingly important. The primary aim of the study is to evaluate the current methods used in the control and management of European airspace and through a literature-based review to provide a general framework explaining existing coordination. To achieve this objective, the study first establishes a conceptual framework for air traffic control based on a comprehensive literature review. It then examines the roles of international and regional aviation organizations, such as ICAO, EUROCONTROL, and IATA, in the coordination and monitoring of airspace operations. Using a descriptive analysis approach, the study reviews current air traffic control services in Europe and evaluates the operational procedures, regulatory frameworks, and technological developments that support air traffic management. Emphasis is placed on key issues such as capacity management, the complexity of air traffic, controllers' workload, and air traffic flow management, digitalization and automation, artificial intelligence and machine learning, Single European Sky, remote/digital towers, UTM integration, green ATM and trajectory-based operations (TBO). Furthermore, recent operational initiatives and technological tools, including the COCA (Complexity and Capacity) project, the CAPAN capacity analysis method, and Airport Collaborative Decision-Making (A-CDM) applications, are addressed. The reviewed literature indicates that increasing traffic demand, system complexity, and air traffic controllers' workload remain the primary challenges in air traffic management. This study contributes to the current literature by offering a thorough and contemporary literature analysis of air traffic control coordination and surveillance techniques in Europe. The findings of this study suggest that the increasing complexity and traffic demand in European airspace require more integrated, adaptive, and technology-driven policy frameworks. From a policy perspective, strengthening coordination mechanisms among national air navigation service providers (ANSPs) should be prioritized to reduce airspace fragmentation and enhance cross-border interoperability. Consequently, technological innovation, collaborative decision-making processes, and coordinated regulatory frameworks are of vital importance to ensure the safe and efficient management of European airspace.

1. Introduction

Air traffic control services are of vital importance for the smooth and safe operation of air traffic. Maintaining the safety of this service necessitates constant coordination through mutual communication. In recent times, research domains within the field of air traffic management have expanded to encompass both established disciplines and novel advancements in science and technology. To maintain a satisfactory level of congruence with such rapid changes, effective communication and coordination between all sections of air traffic management is an essential prerequisite. The increasing demand and air traffic associated with the shift in passenger preferences towards air travel is increasing the workload of air traffic management within the projected timeframe (Nolan, 2011). The commissioning of new airports and increased investment from the Asia-Pacific and Middle East regions to upgrade airports in North America and Europe are also increasing the need for air traffic control. The International Air Transport Association (IATA) has stated that it is anticipated that air passenger traffic will exceed 7 billion by 2035, with an annual growth rate projected to exceed 3.5 percent. In developed regions, airport authorities are concentrating on the modernization of existing airport infrastructure through the introduction of advanced air traffic management systems, with the objective of enhancing the efficiency of air traffic services (IATA, 2019). The increased investment in the enhancement of airport infrastructure within developed regions of North America and Europe is a key factor in the growing demand for effective traffic management solutions. The increase in demand and flight numbers has created a need for investment in new tools and equipment for air traffic management. For instance, in 2017, Seattle-Tacoma Airport in the United States initiated an expansion program with an investment of 1.6 billion US dollars; the airport's systems for managing air traffic accounted for the second-largest share of this expansion (FAA, 2010).

The airport terminal control and ground control systems received approximately one-third of the investment. The lighting and signaling equipment associated with these systems is also included in this category (IATA, 2019).

Current estimations suggest that hardware components will account for in excess of 75% of the air traffic management market by 2025, a development that will be driven by the commissioning of new airports and the increasing digitalization of existing airports. The majority of developed regions, including North America and Europe, are concentrating on the enhancement of existing air traffic management systems with the objective of providing superior air traffic services to airlines (EUROCONTROL, 2000). The field of air traffic management has undergone significant expansion, driven by the development of existing systems and the commissioning of new airports. The increasing use of artificial intelligence in air traffic systems has led to a growing demand for more advanced software (Wickens, Mavor, & McGee, 2013). For instance, in 2019, the Irish Aviation Authority (IAA) utilized Iridium NEXT satellites equipped with Aireon space-based Automatic Dependent Surveillance-Broadcast (ADS-B) payloads (Eurocontrol, 2017). This innovative software facilitates real-time air traffic surveillance and tracking and the provision of air navigation services. Concurrently, air traffic control assumes a pivotal function within the overarching framework of air traffic management, a development primarily attributable to two interrelated factors. Firstly, the escalating volume of passenger traffic, and secondly, the market entry of a multitude of new airlines (Rantanen, 2005). The demand for more advanced communication and navigation systems is driving further growth in the field of air traffic control (ATC). For instance, in January 2019, the National Air Traffic Services (NATS), the body responsible for air traffic management in the United Kingdom, installed an AI-supported digital control tower at Heathrow Airport. The principal objective of the control tower is to minimize delays in flight. The expansion primarily stems from the emergence of remote and virtually controlled towers. For instance, countries such as India and China are providing cost-effective solutions for air traffic management services by focusing on regional connectivity and long-haul flights (IATA, 2019; Sengur, 2022).

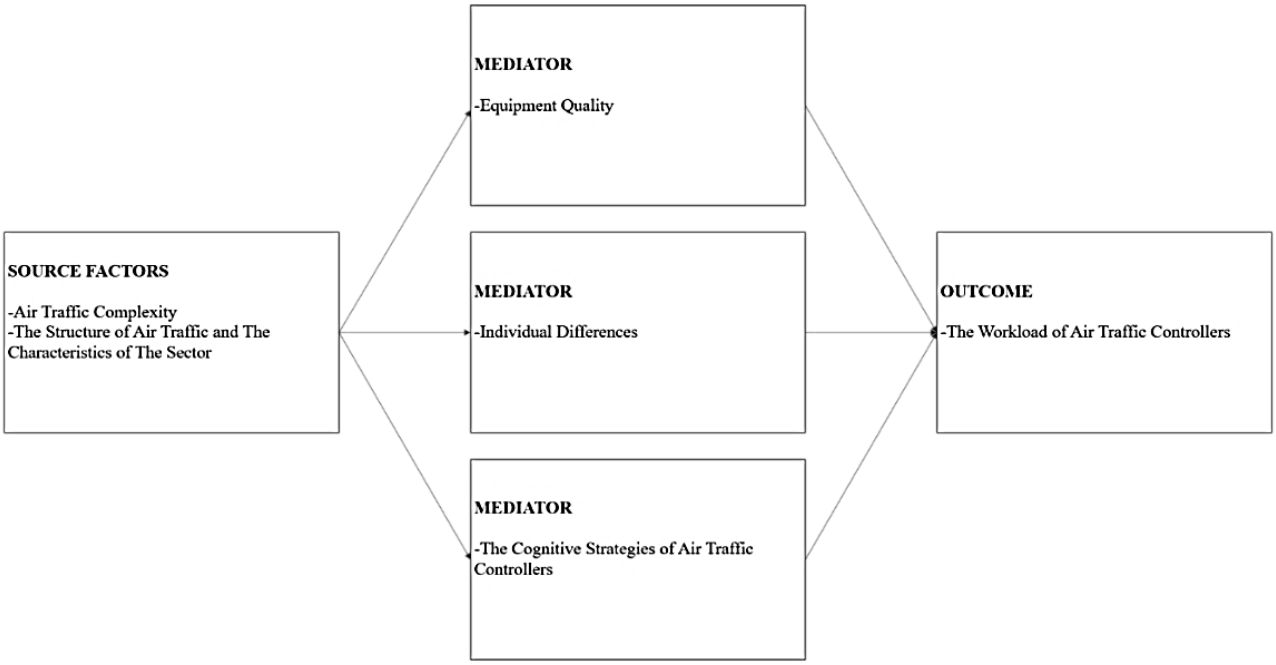
In this context, the study examines how air traffic control in Europe has evolved in response to changing demands and how current practices are being implemented. A plethora of recommendations have been proposed concerning how air traffic control can manage the increasing volume of traffic in an efficient and safe manner. The literature review revealed that a thorough examination of European air traffic management had not been conducted, and existing research was limited to appraisals of the topic. A complete literature review of ATM has not been conducted, and contributions have been made to the literature concerning advancements in the field and potential deficiencies. The study is significant in terms of identifying emerging practices in Europe and their evolution or differentiation.

2. Literature

The study's framework is predicated on government and contractor technical reports, scientific journal articles, book chapters, and operational reviews. The relevant references are primarily drawn from the fields of ATM research, human factors, safety management systems, air traffic control management, and cognitive psychology and computer modeling. While the primary focus is on the examination of practices regarding air traffic control coordination and monitoring, theoretical and empirical studies on workload assessment have also been utilized, given the importance of human factors in ensuring this coordination. The majority of the established factors related to air traffic management have been published by EUROCONTROL, IATA, and ICAO or drawn from the relevant literature. Recently, a series of significant reports and articles on the ATC problem have been published, including various in-depth reviews of the complexity factor literature (Malakis, 2019). Complexity has been defined as a situation or event being complex and incomprehensible, with many parts coming together to form a more complex situation, and furthermore, each unit combining to make the existing situation even more difficult (Cambridge Dictionary, 2020). In the context of air traffic control, however, numerous distinct definitions of complexity have been proposed (Radišić, Andraši, Novak, Juričić, & Antulov-Fantulin, 2020). The most perspicuous definition was provided by Meckiff and colleagues as the difficulty in monitoring and managing a specific air traffic situation (Meckiff, Chone, & Nicolaon, 1998). Air traffic complexity can also be defined as a series of potential aircraft-to-aircraft and aircraft-to-environment interactions occurring within a specific time frame. It is important to note that not all of these interactions require the same level of attention, urgency, or workload (Radišić, Andraši, Novak, Juričić, & Antulov-Fantulin, 2020). It is important to note that complexity does not bear the same significance as air traffic density. The number of aircraft in a sector has been shown to influence complexity; however, treating this number as the sole indicator is not a valid approach, particularly when comparing two different sectors (Kirwan, Scaife, & Kennedy, 2001; Mogford, Guttman, & Morrow, 1995; Athènes, Averty, & Puechmorel, 2002). It is noteworthy that two disparate sectors may exhibit analogous traffic density, yet significantly disparate levels

of complexity. Numerous studies have demonstrated that complexity generally increases workload (Christien, Benkouar, Chaboud, & Loubieres, 2002). Mogford et al. (1995) posited that complexity is a pivotal factor in the workload of controllers (see Figure 1). However, it should be noted that complexity and workload are not directly correlated. A range of mediating factors have been identified, including equipment quality, individual differences, and controllers' cognitive strategies.

Figure 1. Factors affecting controller workload



The study refers to the work of Mogford and colleagues (1993) on the subject of complexity. Given the anticipated increases in traffic, alongside corresponding developments in ATC (Air Traffic Control) procedures and technologies, there is a growing need to understand the capabilities of control systems and controllers and to determine the 'safe' limits of their workload (Schmidt, 1976). In this context, studies on how air traffic control adapts to the increasing demand and traffic have been evaluated in this section. The literature review revealed that issues of capacity and complexity in relation to air traffic are frequently encountered in various studies. Another frequently encountered topic is how EUROCONTROL and various organizations across Europe are responding to the increasing traffic and the projects they have developed for monitoring and coordinating this traffic. It is reported that the greatest limitation of air traffic management lies in the increasingly complex operations (Mogford, Guttman, & Morrow, 1995). It is thought that improved measures to address ATC complexity could provide benefits such as the evaluation of ATM productivity, the comparison of cost-effectiveness, and the assessment of the impact of new tools and procedures (Mills, 1998). In this regard, EUROCONTROL's Network Capacity and Demand (NCD) initiative is implementing the Complexity and Capacity (COCA) project. The primary objective of COCA is to identify, develop, and evaluate factors related to air traffic control complexity; to validate and test complexity factors; and to identify those linked to controller workload and sector capacities. The aim of the application is to create a model of air traffic, compare this model with factors causing complexity in air traffic, design the airspace according to this model to determine the optimum capacity, and apply the existing capacity to sector classification and air traffic flow management (EUROCONTROL, 2000). In the majority of studies conducted to date, attempts have been made to draw conclusions whilst disregarding the cognitive structure of air traffic controllers. However, recent advancements in technology and increasing human-machine interaction have led to little discussion on how to reduce cognitive load, aside from a few studies and reports. It has been observed that with increasing automation technologies, the cognitive load on controllers can be reduced, thereby ensuring a safer air traffic flow. Within the context of the COCA project, EUROCONTROL acknowledges the necessity of incorporating controllers' cognitive aspects into the complexity of air traffic.

Recent advancements in air traffic management (ATM) and air traffic control (ATC) systems have been significantly shaped by rapid technical progress, escalating traffic demand, and the rising complexity of airspace operations. The digital transformation of ATM systems has become a significant trend marked by the integration of automation, data-driven decision-making, and sophisticated decision-support technologies.

ATM systems are progressively integrating artificial intelligence (AI) applications and automation technologies to improve operational efficiency and assist controllers in managing intricate traffic scenarios (Xia et al., 2026; EUROCONTROL, 2020). The SESAR Joint Undertaking emphasizes that the "Digital European Sky" goal is heavily reliant on the deployment of intelligent technology that can provide predictive traffic management and real-time decision assistance which contributes to safe implementation of ATM operations (SESAR JU, 2026).

In this regard, artificial intelligence and machine learning have been employed particularly in domains such as traffic flow forecasting, conflict identification, and workload evaluation. Current advancements focus on a "human-in-the-loop" model, emphasizing the enhancement of human operators rather than their complete replacement, with AI systems serving as assistive tools to supplement human decision-making capabilities (Whig et al., 2024). FAA (2023) underscores that next-generation ATM systems seek to enhance the interplay between automation and human proficiency to guarantee safety and operational resilience.

A significant trend is the heightened emphasis on the intricacies of air traffic and the administration of controller duty. Capacity management now transcends mere traffic volume considerations. Advanced models incorporating complexity measurements and dynamic sectorization tactics are supplanting conventional capacity management. Reports from EUROCONTROL (2006) and CANSO (2022) emphasize the importance of managing controller workload and operational complexity for ensuring safety and efficiency in high-density airspace.

Moreover, collaborative decision-making procedures and network-centric operations have become essential components of contemporary ATM systems. The execution of Airport Collaborative Decision-Making (A-CDM) programs signifies a shift from centralized control systems to coordinated efforts among air navigation service providers, airlines, and airport managers. ICAO (2021) indicates that collaborative frameworks enhance information exchange, augment predictability, and bolster overall system performance.

Significant European-scale modernization initiatives, like the Single European Sky and SESAR programs, play a crucial role in influencing ATM advancements at the European level. These projects seek to diminish airspace fragmentation, enhance interoperability, and establish performance-based management systems. The European Commission and the SESAR Joint Undertaking highlight developments such as Free Route Airspace and trajectory-based operations, which provide more flexible and efficient flight planning (SESAR, 2025).

Technological innovations have facilitated the creation of remote and digital tower concepts, enabling air traffic services to operate independently of the physical location of control towers. This is especially advantageous at low-traffic airports where cost advantages can be achieved without jeopardizing operational safety. Research conducted within the SESAR framework indicates that digital towers are becoming viable and scalable options for the existing air traffic management environment (SESAR JU, 2026; SESAR, 2025.

The incorporation of unmanned aerial vehicles into regulated airspace has generated both obstacles and opportunities for air traffic management. U-Space and unmanned traffic management (UTM) technologies represent a significant advancement in the safe and effective integration of drones into current airspace frameworks. EASA (2021) delineates a legal framework that facilitates this integration, emphasizing the necessity for solutions that are harmonized and scalable (EASA, 2021).

Environmental sustainability is now a crucial catalyst for ATM innovation. The significance of decreasing fuel usage, limiting emissions, and improving flight paths is increasing. Trajectory-based operations and performance-based navigation are essential for attaining these environmental goals (ICAO, 2022). The transition to trajectory-based operations (TBO) in air traffic management represents a significant paradigm shift. TBO is not a conventional sector-based control; rather, it is a four-dimensional aircraft trajectory management system that incorporates time, facilitating more accurate and efficient traffic management. This approach, broadly supported by the International Civil Aviation Organization and the Federal Aviation Administration, is anticipated to serve as the foundation for future ATM systems.

The research indicates that contemporary ATM systems are evolving towards a highly integrated, data-centric, and collaborative framework. Technological innovation, particularly in artificial intelligence and digitalization, alongside coordinated regulatory initiatives and stakeholder collaboration, is essential for tackling the problems posed by increasing traffic demand and operational complexity (ICAO, 2020).

Another issue encountered in the domain of air traffic management pertains to the management of air traffic flow. The flow management system is regarded as one of the most promising short-term approaches for alleviating the serious congestion problems currently affecting the air traffic network across the United States and Europe. As Amedeo (1987) noted, congestion is having a significant impact on air traffic in both the United States and Europe. This situation is still, to a certain extent, limited to the busiest commercial airports and a few 'sectors' of the air traffic control (ATC) network. However, the distribution of traffic is such that the effects are practically felt by passengers using both North American and Northern European air routes (Nolan, 2011).

The increase in demand has resulted in heightened congestion in air traffic, leading to various challenges at several airports. Airlines have asserted that the direct financial burden of airport and air traffic control delays in the United States alone amounts to 2 billion dollars. It is evident that the cost in question represents a significant proportion of the net profit of the US airline industry, which was 26.4 billion dollars in 2019 (United States Department of Transportation, 2019).

Situational awareness is examined as another key factor influencing air traffic control. Situational awareness is recognized as a fundamental element affecting an effective air traffic control system and the decision-making and performance of controllers (Endsley & Rodgers, 1994). Air traffic controllers are responsible for the coordination and monitoring of a large number of aircraft to ensure minimum separation and safe and efficient take-off, en route, and landing operations (Dailey, 1984). The successful execution of this complex and demanding task is contingent upon situational awareness (Endsley & Rodgers, 1994). Controllers must be cognizant of and monitor numerous factors, such as aircraft positions, fuel status, approach and descent procedures, and flight routes (Rodgers, 1993). Despite the plethora of definitions of situational awareness, the most generally applicable definition was provided by Endsley (1987). According to the aforementioned definition, "situational awareness is defined as the perception of elements in the environment within a given time and spatial volume, the understanding of their meanings, and the reflection of their states within an immediate timeframe" (Endsley & Rodgers, 1994). The objective of this study is to identify these elements—including perception, comprehension, and projection—to ensure the safety requirements for air traffic control during flight and to enhance efficiency. The issues engendered by an absence of situational awareness are substantial, not only from a material and financial standpoint but, above all, because human lives are at risk (Dailey, 1984). The potential for errors to arise in practice can be mitigated through the implementation of coordination and monitoring mechanisms supported by technological solutions. Furthermore, the employment of alerts and proactive measures can serve to minimize human error.

3. Methodology

Air traffic control can be defined as an operational element in which the human factor, safety management systems, air traffic management, cognitive psychology, and technical infrastructure interact (Schmidt, 1976). However, analyzing the cause and effect of a specific phenomenon in air traffic control services can be challenging due to the presence of multiple variables where numerous factors interact (Gerede, 2015).

This research employs a structured literature review methodology to analyze air traffic control (ATC) coordination and monitoring practices in Europe. Instead of employing an empirical research design, the study conducts a systematic examination of existing academic and institutional literature to cultivate a thorough grasp of current air traffic management (ATM) systems and their operational dynamics. The review is both narrative and systematic, seeking to synthesize information from various sources within a cohesive analytical framework. This approach is particularly appropriate for topics like ATC coordination, where information is dispersed among scholarly articles, regulatory documents, and technical reports. The aim is to synthesize current research and identify main themes, patterns, and gaps in literature. The literature utilized in this study was gathered from many sources to guarantee academic structure and practical significance. Academic publications were retrieved from prominent scientific databases, including Web of Science, Scopus, and Google Scholar. Moreover, comprehensive evaluations were performed on institutional reports and policy documents from prominent aviation entities, including International Civil Aviation Organization, EUROCONTROL, International Air Transport Association, EASA, CANSO, and SESAR Joint Undertaking. These sources have been selected because of the decisive role they play in shaping global and European air traffic management (ATM) policies and practices. The literature was chosen based on specific inclusion criteria to guarantee both its relevance and quality. Studies were included if they:

- Focus on air traffic control (ATC) or air traffic management (ATM)
- Coordination, capacity, complexity or controller workload,
- Check out European airspace or give ATM insight relevant to the world,
- Published in peer-reviewed journals or by recognized aviation institutions.

Recent advancements in technology and operations, including digitalization, artificial intelligence, and collaborative decision-making procedures, were also taken into consideration. A thematic analysis was performed to analyze the literature collected. An iterative process of reading and coding the selected sources resulted in key themes. This analysis covered four key dimensions: (1) ATC coordination practices, (2) capacity management strategies, (3) air traffic complexity and controller workload, and (4) technological and operational innovations, such as digital ATM systems and collaborative decision-making frameworks.

The study does not present empirical findings but synthesizes insights from the literature to highlight common patterns, emerging trends and areas of convergence and divergence across different sources. This method makes it possible to gain a conceptual understanding of how the ATC coordination is structured and managed in the European context.

The study's most significant limitation is the inaccessibility of primary sources, which hinders the ability to substantiate claims and verify information. In the context of literature review, data obtained from secondary sources is of paramount importance for the accurate observation of the phenomenon under study (Vassala, 2006). The data obtained is based on a comprehensive review of the extant literature, regulatory authorities' guidelines, company reports, and internet data. The capacity of air traffic control to orchestrate air traffic in an orderly and secure manner is predominantly realized through mutual communication and adherence to legislation. The present study examines compliance with regulations and operational procedures to ensure the proper functioning of air traffic management in Europe.

4. Synthesis of Findings from Literature

4.1. Innovation and Technological Developments in ATM; Principles and Improvement Initiatives

The literature on current ATC/ATM advances indicates that European air traffic management is progressing towards a more digital, integrated, and performance-oriented framework. Current research and institutional reports indicate that digitization, automation, artificial intelligence, and data-driven decision-support systems are essential elements of ATM modernization. EUROCONTROL emphasizes the growing utilization of AI-driven applications to improve forecasting, decision-making, resource allocation, and human performance in air traffic management operations (Xia et al., 2026). The SESAR Digital European Sky vision identifies digital transformation as a crucial facilitator for enhancing the safety, security, sustainability, and efficiency of European air traffic management (EUROCONTROL, 2020; SESAR, 2025).

The body of literature also recognizes the increasing importance of trajectory-based operations. Future ATM systems are expected to control aircraft trajectories in four dimensions (including time), as opposed to sector-based control. FAA’s NextGen program considers trajectory based operations (TBO) as an important transition in modern air traffic management, where all stakeholders and automation systems share the same understanding of aircraft movement and future trajectory. Though this example is from the United States, it is indicative of the larger trend of predictive ATM based upon data-sharing, worldwide (FAA, 2023).

Recent literature indicates that the ATM domain is expanding beyond conventional manned flight. The advancement of U-space in Europe signifies the increasing necessity to include unmanned aircraft systems into both controlled and uncontrolled airspace. The U-space regulatory framework was implemented in January 2021 to facilitate the safe segregation and effective utilization of airspace between manned and unmanned aircraft, according to EASA. This indicates that future Air Traffic Control coordination will increasingly involve hybrid traffic scenarios, where conventional aircraft, drones, and even sophisticated air mobility vehicles will function inside interconnected airspace systems (EASA, 2021).

Sustainability has finally emerged as a pervasive issue in ATM literature. Digitalization, free-route airspace, performance-based navigation, and trajectory optimization are increasingly being seen not only as efficiency instruments but also as methods to diminish fuel consumption and emissions. The literature generally suggests a transition of European ATM from a fragmented and capacity-limited system to a more collaborative, automated, interoperable, and environmentally conscious system. This transformation introduces new issues in controller workload, AI governance, cybersecurity, human-machine interface, and the regulatory integration of new airspace users.

Air traffic encompasses all aircraft in flight or maneuvering and taxiing at an aerodrome. The Air Traffic Control service is a service provided to prevent collisions between aircraft, to ensure maneuvering clearance between aircraft and obstacles, and to expedite, maintain, and ensure the orderly flow of air traffic (Annex 11). In Annex 11, the objectives of air traffic services are defined as preventing collisions between aircraft, preventing collisions between an aircraft and another aircraft in the maneuvering area, and preventing collisions with objects, bodies, or obstacles on the ground; maintaining air traffic in a swift and orderly manner; providing the necessary information and advice to ensure flights are conducted safely and efficiently; and to inform the relevant authorities and providing support where necessary in emergency situations and when search and rescue operations are required. Air traffic services are divided into sections to ensure these objectives are met. They consist of three sections: Area Control (ACC), Approach Control, and Aerodrome Control. ACC is responsible for controlling air traffic at high altitudes within a specific airspace (FIR) during the period between takeoff and approach. It controls traffic originating from the approach control service. The separation of aircraft is carried out in two different ways: VFR (Visual Flight Rules) and IFR (Instrument

Flight Rules). In addition to flight separation, it transmits various information to aircraft, such as weather conditions, altitude, speed, and no-fly zones. Airspace is divided into classes, with different flight rules applying to each class. Approach Control takes over control once the aircraft has reached a specific altitude, providing control services within a radius ranging from 56 to 93 km. This situation varies depending on the characteristics of the airport (Osamba, 2012). Takeoff control assumes control from the tower once the aircraft has passed an altitude of 500 meters; at this stage, it issues instructions for the aircraft to climb and reach its flight level. Local control, on the other hand, is responsible for the active runways at the airport; landing and takeoff clearances are issued at this stage. Its duties include runway separation, maintaining gaps between flights, and ensuring the maximum utilization of the runways.

The International Civil Aviation Organization (ICAO) has instituted the Global Air Navigation Plan Strategy (GANP) to establish a global air navigation system that is secure, sustainable, efficient, and interoperable. It is primarily grounded in the A-CDM initiatives of IATA and EUROCONTROL. Socio-economic concerns arising from the aviation industry are encountering numerous obstacles due to evolving and escalating demand. Passenger and cargo travel is anticipated to quadruple global aviation traffic within the next 15 years (ICAO, 2020). Over 120,000 flights are conducted safely and securely each day (ATAG, 2018). Projections indicate significant air traffic expansion over the next two decades, attributed to favorable economic, political, and social developments (ICAO, 2018). Simultaneously, emerging demands on the aviation system, advancing technology, novel methodologies, and the expanding role of personnel require not only the resolution of difficulties but also the transformation of the global air navigation system to guarantee the continuity of aviation. The International Civil Aviation Organization (ICAO) has released a framework known as the Global Air Traffic Management Operational Concept (GATMOC, Doc 9854) to facilitate systematic and sustainable oversight of global air traffic.

The International Civil Aviation Organization (ICAO) has released a framework known as the Global Air Traffic Management Operational Concept (GATMOC, Doc 9854) to facilitate the systematic and sustainable oversight of worldwide air traffic. GATMOC establishes the basis for a unified operational framework for an integrated, sustainable, cohesive, and internationally interoperable air traffic management (ATM) system. The operational concept functions autonomously from technology and is characterized as a representation of what is anticipated. The prompt advancement of a sustainable aviation system founded on GATMOC necessitates a cooperative, coordinated, and enduring planning instrument like GANP. Thus, the vision, performance objectives, and conceptual framework outlined in GANP explicitly reference GATMOC. By persistently advancing supplementary guidance documents, such as the Air Traffic Management System Requirements Manual (Doc 9882) and the Global Performance Guide for Air Navigation Systems (Doc 9883), while establishing solid conceptual frameworks and emphasizing an integrated, sustainable, compatible, and globally interoperable air navigation system. ICAO standards predominantly emphasize seven specific components of the ATM procedure. To elucidate the delivery of these services, the seven conceptual components have been summarized in conjunction with conceptual modifications. The initial aspect is to the organization and management of airspace. Airspace organization creates airspace frameworks to facilitate various types of air operations, traffic densities, and service levels.

Airspace management is the procedure by which airspace alternatives are chosen and executed to fulfill ATM requirements. All airspace is under the jurisdiction of air traffic management (ATM) and serves as the foundation of the system. Air traffic management possesses a flexible and dynamic framework to effectively coordinate airspace. Any limits placed on airspaces of a specific volume are regarded as a temporary condition for air traffic management (ATM). Airspace borders ought to be modified in accordance with the density and flow conditions of air traffic; national or procedural limits should not impede the flow.

The second element pertains to airport operations. Airport operators play a crucial role in the air traffic management system. Safety, security, and efficiency are guaranteed under all circumstances, while concurrently aiming to uphold airport capacity at its maximum level. This scope includes services such as lighting, taxiways, exits, runways, and precision ground guiding. The ATM system is tasked with optimizing the utilization of the airport's airside infrastructure capabilities. The primary objectives are to minimize runway occupancy duration, ensure aircraft can maneuver safely in all weather conditions while maintaining capacity, direct aircraft on taxiways, sensitive zones, and transition surfaces under all circumstances, and to accurately ascertain the purpose and location of all vehicles and aircraft in the movement area, disseminating this information to ATM stakeholders.

The third component has been recognized as the equilibrium between demand and capacity. Demand and capacity balancing systematically assesses traffic patterns and airport capabilities throughout the system to mitigate conflicting requirements for airspace and airport resources, while enabling users to decide when, where, and how they will operate. The utilization of data regarding air traffic patterns, meteorological

conditions, and system facilities facilitates the effective management of air traffic flow in collaborative processes. Demand and capacity management establishes a basis for predictable allocation and scheduling by optimizing assets through collaborative decision-making at the strategic level to enhance efficiency. During the pre-tactical phase, collaborative decision-making facilitates adjustments to assets, resource allocations, anticipated trajectories, airspace restrictions, and the scheduling of entry and leave times for airports and airspace volumes to mitigate imbalances whenever feasible. During the tactical phase, efforts encompass adaptive modifications in airspace organization to optimize capacity, real-time alterations in airport and airspace entry/exit timings, and diverse user interventions in the schedule.

The fourth operational component is designated as traffic synchronization. Traffic synchronization refers to the strategic implementation and upkeep of air traffic flow in a secure, systematic, and efficient manner (Pawełek, Lichota, Dalmau, & Prats, 2018). Flight paths are assessed in a clear and unequivocal manner, from multiple dimensions. Narrow bottlenecks causing traffic congestion are detected and eradicated by proactive approaches. Traffic optimization guarantees the enhancement of runway efficiency.

The fifth component is designated as airspace user operations. Airspace user operations pertain to the ATM-related components of flight operations. This scope addresses the synchronization of global practices and criteria to improve safety and efficiency. Relevant ATM data is utilized for an airspace user's general, tactical, and strategic situational awareness and conflict management, while pertinent operational information from the airspace user is sent to the ATM system. Collaborative decision-making seeks to promptly assess the effects of aircraft and airspace user system design on air traffic management (ATM), emphasizing the necessity of evaluating aircraft as a core element within the ATM framework.

The sixth component is identified as conflict management. Conflict management encompasses three tiers: strategic conflict management through airspace organization and administration, demand and capacity equilibrium, and traffic synchronization. Conflict management mitigates the risk of aircraft collisions and hazards to an acceptable threshold. Potential hazards that may jeopardize an aircraft encompass: collision, topography, meteorological conditions, turbulence, conflicting airspace operations, and ground vehicles or other impediments in the apron and maneuvering area during ground operations. Strategic conflict management mitigates risk and alleviates constraints to a certain extent. The notion of conflict can be broadened within the confines of established procedures, safety protocols, and relevant information. Collision avoidance systems are integral to ATM safety management; yet they are excluded from the assessment of the calculated safety level necessary for maintaining separation.

The seventh and concluding component is the management of ATM service delivery. The objective of ATM service provision management is to provide seamless operation from gate to gate across all phases of the flight and among all service providers. The ATM service provision management component governs the equilibrium and integration of decisions from several processes, together with the schedule and criteria for these decisions. Flight trajectories and agreements significantly influence the decision-making processes within Air Traffic Management (Wickens, Mavor, & McGee, 2013). The services offered by the ATM service provision management component are developed according to the ATM system design and are delivered upon request. The design of the ATM system is conducted through collaborative decision-making and the implementation of safety and operational processes throughout the system. The plans established by management include all physical phases of operations, and processes and practices are executed accordingly.

4.2. Capacity Management Approaches

Delays in air transportation result in customer dissatisfaction and substantially impact carriers' financial performance. EUROCONTROL data indicates that the airline industry experiences an annual financial deficit ranging from 1.3 to 1.9 billion Euros attributable to delays (EUROCONTROL, 2003). Airspaces are categorized into distinct portions known as sectors. A sector is a segment of airspace delineated by geographical coordinates and a designated radio frequency, overseen by a control crew. Various sectors converge to establish the FIR (Flight Information Region) line, which denotes the flight information area (EATM, 2004). During peak demand periods, the number of flights operated must not be above the predetermined limit, known as sector capacity. The capacity for managing air traffic refers to the capability of delivering air navigation services to a specific amount of air traffic while maintaining a high safety standard and avoiding substantial operational, economic, or environmental issues under normal circumstances (EUROCONTROL, 2002). Sector capacity refers to the regulation of aircraft within a designated area by a controller, ensuring safety while preventing undue congestion or capacity deficits during a specified timeframe (Jaurena, 2009).

It is essential to assess the increased sector capacities and their effect on controller workload in light of the revised airspace laws, modifications in air traffic control procedures, and the technologies devised to address

the expected rise in air traffic. EUROCONTROL has created the CAPAN (Air Traffic Control Capacity Analyzer Tool) and COCA (Complexity and Capacity) software for this objective. CAPAN is a capacity assessment methodology established by EUROCONTROL (EUROCONTROL, 2006). This approach relies on a simulation engine that assesses the controller's workload and estimates air traffic density for a designated air traffic sample. CAPAN employs two capacity values derived from two methodologies (peak and regression approaches) to predict the controller's workload through simulation (EUROCONTROL, 2006). The ideas of capacity, complexity, and workload are significantly interrelated. The intricacy elevates the controller's workload, whereas the workload constrains capability. Sector capacity encompasses not only the quantity of aircraft within the sector but is also significantly influenced by the interactions among aircraft across several sectors. With the escalation of interconnections, the complexity correspondingly intensifies. Consequently, it is essential to identify the reasons or conditions that complicate controllers' tasks and contribute to an increased workload. The COCA project has defined aims to elucidate the link among complexity, workload, and capacity. These objectives are (EUROCONTROL, 2006);

- The analysis of ATM complexity must encompass both macroscopic and microscopic perspectives, incorporating elements such as route segments, airspace volumes, traffic flows, and converging or crossing locations across several levels, including sector, center, or state.
- The supply of pertinent complexity indicators and capacity evaluators for designated complexity analyses and additional studies has been identified as ATFM (Air Traffic Flow Management), airspace design, ATFM performance and efficiency, and economic studies for ATM, among others.

The COCA project has mostly concentrated on macroscopic analyses and methodological advancement. Throughout the development process, comprehensive procedures and processes were established, and the outcomes were executed extensively in environmental applications, validated by operational experts.

The CAPAN approach is in development as part of the COCA (Complexity and Capacity) project. One of COCA's objectives is to establish a straightforward, rapid, and precise technique for estimating workload and capacity that incorporates complexity as an inherent aspect (Christien, Benkouar, Chaboud, & Loubieres, 2002). The Complexity and Capacity (COCA) project was launched by the EUROCONTROL Experimental Center (EEC) at the conclusion of 2000. The main objective is to delineate the correlation between capacity and complexity using precise performance measurements. The COCA project employs two distinct methodologies: identifying and assessing the elements that contribute to complexity in air traffic control, and verifying, testing, and analyzing the correlation between these complexity factors and controller workload (EUROCONTROL, 2006). The objective of the CAPAN method is to create an effective approach for assessing sector capacity. Efficiency is assessed by three distinct criteria in the air traffic method: compatibility, usability, and precision. For the approach to be effective, specific procedures must be adhered to (Christien, Benkouar, Chaboud, & Loubieres, 2002).

- Calculation of parameters: Air Traffic Flow Management (ATFM), Wide Object-Oriented Data Standard Traffic Observable Complexity Knowledge (WOODSTOCK), ATFM Modeling Capacity Tool (AMOC)
- Classification of sectors according to their complexity level
- Preparation of a large-scale workload model for each classification
- The use of a regression model to predict sector capacities

The workload of controllers refers to the duration required by a controller to accomplish all responsibilities within a designated time period (Majumdar & Ochieng, 2002). Workload assessment necessitates a definition of airspace, pertinent flight plans or radar tracks, aircraft performance data, and the selection of a representative traffic sample. This requires a database encompassing diverse information, including the working conditions and hours of controllers, within the air traffic service system sanctioned by operational specialists. In the CAPAN system, predictions are generated by two methods:

4.2.1. Peak Method

Real-time simulation studies and operational trials have categorized numerical boundary values and their qualitative interpretations as delineated in Table 1 according to the CAPAN methodology (EUROCONTROL, 2006).

Table 1. Peak Method

Boundaries	Workload	Working Hours
%70 and above	Excessive Load	42 min.
%54-%69	High Level Load	32-41 min.
%30-%53	Medium Level Load	18-31 min.
%18-%29	Low Level Load	11-17 min.
%0-%17	Very Low Level Load	0-10 min.

4.2.2. Regression Analysis

An identical quantity of flights can generate varying workloads. In the event that the traffic sector's circumstances have become intricate, the controller's responsibilities for that sector may increase. In the peak method, assessing complexity and workload purely based on the overall time expended by a controller may prove inadequate. The regression model analyzes the distribution of time spent on each flight independently, yielding four distinct scenarios (EUROCONTROL, 2003).

1. Regression analysis indicates that the capacity value typically exceeds the CAPAN capacity value when the sector's peak hour aligns with the most intricate traffic conditions.
2. The regression capacity number is typically inferior to the CAPAN capacity value, establishing a conventional ATC workload when the sector's peak hour aligns with uncomplicated traffic conditions.
3. When the regression capacity number approaches the CAPAN capacity value, it signifies that the sector's peak hour reflects the average traffic complexity for the entire day.
4. If the workload documented throughout the 24-hour simulation is little, the capacity estimate may significantly exceed this regression analysis result. This indicates the presence of surplus capacity.

4.3. A-CDM Implications in Air Traffic Management

The Airport Collaborative Decision Making (A-CDM) function is a component of a broader collaborative decision-making and action-taking framework (ICAO, 2020). The objective of the procedure is to oversee the aircraft's turnaround period, execute it transparently, and enhance service across all pertinent domains. A-CDM was initially introduced in Europe in 2004 in the context of air traffic control, as ATFM (ATM network management) necessitates greater airline involvement for fleet-level management at certain airports. Subsequent to Europe, the FAA (Federal Aviation Administration) started analogous programs targeting more interfaces. Conversely, ICAO has embraced and extended the concept. It has developed applications mostly based on the EUROCONTROL paradigm, including the GANP and Aviation System Block Upgrades (ASBU) (ICAO, 2021). A-CDM primarily focuses on fostering collaborative situational awareness among air traffic management, airlines, and airport operations (IATA, 2018). A-CDM enhances air traffic services through three phases. Initially, in incoming traffic, air traffic management (ATM) notifies Airport Collaborative Decision Making (A-CDM) of the aircraft's arrival and its corresponding time, while ATM supervises the aircraft until control is transferred to apron control or until the aircraft comes to a complete stop. Secondly, during the turnaround phase, A-CDM exercises control over the aircraft. It supplies the requisite information to the ATM for the turnaround. It modifies priorities and procedures in accordance with the stated temporal target information. A-CDM relinquishes control of the aircraft to the ATM when the aircraft is off-block (engine start) or enters the taxiway. During the concluding phase of departing traffic, the ATM supplies the A-CDM with the TSAT (Target Start-up Approval Time) to meet the necessary requirements. TSAT denotes Target Start-up Approval Time. The IATA (2012) defines TOBT (Target Off-Block Time), CTOT (Calculated Take Off Time), and the traffic conditions under which an aircraft anticipates receiving authorization for engine start or pushback as the timeframes issued by ATC. ATM oversees the aircraft's departure procedures from the airport and communicates the projected landing time at the destination. These self-replicating processes facilitate enhanced demand forecasting. Furthermore, the ATM can compute estimated departure and arrival times with enhanced accuracy and precision. In certain tough and atypical circumstances, flexibility is afforded. Upon a re-evaluation and collective request, operations may be reassessed utilizing alternative approaches, including slot modifications and reduced turnaround durations (IATA, 2016).

A-CDM is responsible for coordination both in the control tower and at the airport. It offers services at three distinct tiers. Initially, it executes supportive and implementation duties to enhance efficiency in local airport operations through resource management, particularly by alleviating congestion on airport aprons, taxiways, and runways. ATFM is present at the second level. The ATFM function is executed within the ACC (Area Control Center), necessitating collaboration between A-CDM and ACC. This level monitors and records ATM movement timings and can impose limitations on departures and arrivals if required. Airport operations and the turnaround procedure may also be encompassed within these limitations. At the third and final level, ACC/ATFM communicates with other Flight Information Regions (FIR), ensuring inter-regional cooperation. This stage is designated as the regional ATFM network (EUROCONTROL, 2002). When slot exchanges transpire across regions, alerts are issued, and estimated arrival and departure times are conveyed to the pertinent regions. The airlines' operation control centers (OCC) are increasingly actively engaged in the ATFM processes.

5. Discussion and Result

Air traffic management is facing capacity congestion due to the rising demand for air travel. To address the growing demand and guarantee air transportation, novel technologies are being devised, and infrastructural enhancements are being executed. Projections for future air traffic are crucial for the advancement of these technologies and the establishment of requisite rules (EUROCONTROL, 2000). The factors contributing to the heightened demand, the locations experiencing this rise, and the present condition of air traffic are crucial for formulating precise forecasts. The objective of the study is to investigate and evaluate the existing methods and strategies for managing European airspace within this context and to provide a comprehensive framework. The administration of safe, secure, efficient, and orderly airspace, considering the rising demand and capacity density, has been analyzed through directives, protocols, and newly developed applications. The study assessed the current and evolving practices in Europe and their variations or transformations.

The literature review indicates that air traffic management (ATM) systems in Europe are experiencing a significant shift, stimulated by digitalization, automation, and heightened operational complexity. This study presents an integrated perspective on air traffic control (ATC), indicating that technical innovation, coordination mechanisms, and workload management constitute a complex interconnected framework within a broader systemic transformation, despite prior research concentrating on individual aspects.

A significant finding from the literature is the transition from traditional management, which was sector-oriented and focusing on traffic volume, to a more dynamic and complexity-oriented management approach. This change reflects the inadequacies of traditional capacity models, which are unable to address the growing variability and unpredictability of contemporary air traffic. The emphasis is increasingly on complexity metrics and workload-sensitive instruments. These advancements provide significant operational advantages, while also introducing new obstacles, particularly with human-machine interface and controller adaptability. The reliance on automation and AI-based decision support systems prompts significant inquiries over trust, transparency, and the potential hazards of excessive rely on automated technologies.

A significant topic of discussion is the evolving function of air traffic controllers in progressively automated settings. The literature constantly underscores a "human-in-the-loop" model, contending that complete automation is neither practical nor preferable in the short run. The controllers are intended to serve as supervisors of intricate systems rather than as direct operators. This alteration has significant ramifications for training, skill prerequisites, and cognitive demands. While automation may diminish ordinary tasks, it may concurrently elevate cognitive complexity, necessitating controllers to handle infrequent but significant scenarios. Consequently, next ATM systems must be developed with a robust human-centered approach to ensure that automation enhances rather than undermines operational safety.

The findings emphasize the significance of collaborative and network-centric strategies in the management of European airspace. The instances of Airport Collaborative Decision-Making (A-CDM) and the Single European Sky framework illustrate a distinct transition towards integrated and multi-stakeholder coordination. This move resolves persistent problems associated with airspace fragmentation and inefficiency across national borders. Nonetheless, despite these initiatives, institutional and political impediments continue to pose substantial challenges to complete integration. Nonetheless, the efficacy of pan-European ATM coordination remains constrained by disparities in national regulations, operating protocols, and technology infrastructures.

The emergence of new technology, including unmanned aircraft systems (UAS) and digital towers, presents both opportunities and challenges for air traffic management (ATM) systems. These improvements, although enhancing flexibility and scalability, also contribute to increased system complexity and introduce new safety issues. The research indicates that legislative frameworks are still developing and may not be entirely

congruent with the operational reality of hybrid airspace situations where manned and unmanned aircraft coexist. This indicates the necessity for more adaptable and proactive regulatory strategies.

Environmental sustainability constitutes a significant facet of the discourse. The heightened focus on trajectory-based operations and performance-based navigation signifies a wider movement towards environmentally optimal air traffic management. The literature indicates that technology solutions alone are inadequate for attaining sustainable goals, necessitating coordinated policy frameworks and stakeholder alignment. If they are misaligned, the potential advantages of these innovations may be constrained.

The literature addresses the topic of air traffic management in relation to capacity, complexity, time, and workload. The newly created methodologies and technologies are designed to address issues in these four dimensions, enhance system performance, and augment capacity. The complexity element is identified as the primary issue of ATM service. The complexity of air traffic is determined by the configuration of air traffic and its geographic positioning. The quality of equipment, cultural and individual disparities, and the cognitive constraints of controllers significantly influence the complexity of the issue and, consequently, the workload of the controllers. The research undertaken and the innovative techniques devised seek to diminish complexity and lessen the burden on controllers. EUROCONTROL, IATA, and ICAO have created multiple apps aimed at enhancing capacity and optimizing air traffic management. EUROCONTROL has initiated the Complexity and Capacity (COCA) project, which has produced a suite of software designed to identify the determinants of complexity in air traffic and to facilitate enhancements in this domain. COCA constructs an air traffic model that analyzes various traffic patterns across different sectors based on complexity-inducing elements, and utilizes this model to ascertain the appropriate capacity level. Furthermore, it categorizes capacity by sectors and implements this in air traffic flow management (ATFM). The COCA study indicates that new technology can alleviate the cognitive load on controllers, hence enhancing the safety of air traffic services. EUROCONTROL employs a program named CAPAN (ATC Capacity Analyzer Tool) to assess capacity and workload. Technology employs a simulation method that assesses controller workload and air traffic density. Two distinct methodologies, specifically regression and peak analysis, are employed to assess the controller's workload according to the circumstances and intensity.

ICAO Annex 11 delineates the procedures and implementation methods for air traffic management; however, ICAO is formulating new global norms in response to evolving environmental conditions. ICAO has established a concept identical to the A-CDM implementations executed by IATA and EUROCONTROL, referred to as GANP (Global Air Navigation Strategy). The airport collaborative decision-making function (A-CDM) is an element of a comprehensive collaborative operation and decision-making framework founded on cooperation. Under the GANP, a law known as the Global Air Traffic Management Operational Concept (GATMOC, Doc 9854) has been issued, offering guidelines for the systematic management of global air traffic. The regulation has analyzed the fundamental components necessary for time and capacity management in air traffic control. The analysis indicates that the ICAO standards on air traffic management are found on seven distinct core factors. The components include airspace regulation and management, airport operations, demand and capacity balance, traffic synchronization, airspace user operations, conflict management (complexity), and ATM service provision management. The study finally reveals that the most commonly encountered challenges in air traffic management pertain to constraints regarding capacity, complexity, workload, and time. The paper aims to elucidate the strategies implemented by regulatory authorities and organizations such as ICAO, IATA, and EUROCONTROL to address these restrictions. Due to heightened demand and emerging capacity challenges, along with advancements in technology, various applications may be developed to address this issue. The augmentation of capacity immediately influences the intricacy of air traffic.

The discussion indicates that, despite the shift of European ATM systems to a more integrated, automated, and collaborative architecture, significant obstacles persist. The challenges include escalating system complexity, ensuring efficient human–machine interaction, addressing institutional fragmentation, and integrating new airspace users. Consequently, forthcoming research ought to concentrate on the empirical validation of complexity and workload models, the advancement of human-centered AI systems, and the assessment of regulatory frameworks that facilitate cross-border coordination and technological integration.

In this context, it is essential to develop innovative applications to mitigate complexity. In literature, aside from a few studies, there is a scarcity of research dedicated to developing innovative approaches and technologies to tackle complexity and capacity difficulties; the initiatives of regulatory authorities may be insufficient to identify the principal impacting factors. Thus, upcoming research addressing these concerns will yield benefits for air traffic management and air traffic flow management.

Acknowledgements

I wish to convey my appreciation to the Turkish Aeronautical Association University and Eskişehir Technical University for their steadfast assistance in this study. I extend my gratitude to my respected adviser, Prof. Dr. Ferhan Şengür, for his assistance and criticism during the research.

Author Contributions

Author 1: Conceptualization, Methodology, Formal Analysis, Writing – Original Draft
Author 2: Supervising, Writing – Review & Editing.

Declaration of Interest

Ethical approval

Not applicable.

References

Amedeo, R. O. (1987). The Flow Management Problem in Air Traffic Control. *Flow Control of Congested Networks*, 269-288.

ATAG (2018). *Aviation Benefits Beyond Borders.* Geneva: Air Transport Action Group.

Athènes, S., Averty, P., & Puechmorel, S. (2002). Complexity and controller workload: trying to bridge the gap. *International Conference on Human-Computer Interaction in Aeronautics.* Cambridge, MA: Massachusetts Institute of Technology.

Cambridge Dictionary (2020). *Cambridge Dictionary*. Retrieved from Cambridge Dictionary : https://dictionary.cambridge.org/dictionary/english/complexity

CANSO (2022). *Global Air Navigation Services Performance Report.* CANSO Global Benchmarking Workgroup.

Christien, R., Benkouar, A., Chaboud, T., & Loubieres, P. (2002). Air traffic complexity indicators & ATC sectors classification. *The 21st Digital Avionics Systems Conference* (pp. 2D3-2D3). Irvine, CA: Digital Aviaonics Systems Conference.

Dailey, J. T. (1984). *Characteristics of the air traffic controller.* Washington, D. C: FAA. .

EASA. (2021). *Easy Access Rules (EAR) for U-space (Regulation (EU) 2021/664)* . EASA.

EATM (2004). *Eurocontrol*. Retrieved from European Air Traffic Management: http://www.eurocontrol.int/eatmp/terms.pdf

Endsley, M. R. (1987). A methodology for the measurement of situation awareness. *NOR-DOC*, 83-87.

Endsley, M. R., & Rodgers, M. D. (1994). Situation Awareness Information Requirements Analysis for En Route Air Traffic Control. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 71-75.

Eurocontrol (2003). *Pessimistic Sector Capacity Estimation.* Bruxelles: EUROCONTROL.

EUROCONTROL (2000). *Investigating the air traffic complexity: Potential impacts on workload and costs.* EUROCONTROL.

EUROCONTROL. (2002). *Assesing Future ATC Capacity Requirements-A User Guide.* Bruxelles: EUROCONTROL Capacity Enhancement Function.

EUROCONTROL. (2006). *A Complexity Study Of The Maastricht Upper Airspace Centre.* Brussels: Eurocontrol Experımental Centre .

Eurocontrol (2017). *realistic-air-traffic-control-airport-and-flow-management-systems-simulations-and-training*. Retrieved from eurocontrol: https://www.eurocontrol.int/service/realistic-air-traffic-control-airport-and-flow-management-systems-simulations-and-training

EUROCONTROL. (2020). *Fly AI Report - Demystifying and Accelerating AI in Aviation/ATM.* EUROCONTROL/European Aviation/ATM AI High Level Group (EAAI HLG).

FAA. (2023). *Nextgen Advisory Committee Nextgen Priorities Joint Implementation Plan 2023 Update.* Washington DC: Federal Aviation Admnisitration.

Gerede, E. (2015). *Havayolu Taşımacılığı Ve Ekonomik Düzenlemeler Teori Ve Türkiye Uygulaması.* Ankara : SHGM.

IATA. (2012). *ATC Handbook.* Montreal: IATA.

IATA. (2016). *Seen through an IATA lens A-CDM Globally.* IATA.

IATA. (2018). *Airport – Collaborative Decision Making (A-CDM): IATA RECOMMENDATIONS.* IATA.

IATA. (2019). *IATA*. Retrieved from IATA: https://www.iata.org/en/publications/standards-manuals/

ICAO. (2018). *Economic Development of Air Transport*. Retrieved from ICAO Economic Development: https://www.icao.int/sustainability/Pages/eap-fp-forecast-scheduled-passenger-traffic.aspx

ICAO. (2020). *ASBU Elelements Integration with ATM Network function.* Montreal: ICAO.

ICAO. (2020). *Global Air Navigation Plan Strategy*. Retrieved from ganpportal: https://www4.icao.int/ganpportal/GanpDocument#/lessons/Uk5BykeNFeA4P01MGxec7WevUtylNlpR?_k=1yaymn

ICAO. (2021). *ICAO GANP PORTAL*. Retrieved from GANP PORTAL: https://www4.icao.int/ganpportal/

ICAO. (2022). *Innovation For A Green Transition.* ICAO.

Jaurena, R. A. (2009). *Guıde For The Applıcatıon Of A Common Methodology To Estımate Aırport And Atc Sector Capacıty For The Sam Regıon.* Peru: ICAO RLA/06/901.

Kirwan, B., Scaife, R., & Kennedy, R. (2001). Investigating complexity factors in UK. *Human Factors and Aerospace Safety*, 125-144.

Majumdar, A., & Ochieng, W. Y. (2002). Factors Affecting Air Traffic Controller Workload: Multivariate Analysis Based on Simulation Modeling of Controller Workload. *Transportation Research Record*, 58-69.

Malakis, S. (2019). Classification of Air Traffic Control scenarios using decision trees: insights from a field study in terminal approach radar environment . *Cognition Technology and Work*, 14-22.

Meckiff, C., Chone, R., & Nicolaon, J. (1998). The tactical load smoother for multi-sector planning. In: Proceedings of the 2nd USA/Europe. *Air Traffic Management Research and*.

Mills, S. (1998). *The combination of flight count and control time as a new metric of air traffic control complexity.* Oklahoma City: FAA.

Mogford, R., Guttman, J., & Morrow, S. (1995). *The Complexity Construct in Air Traffic Control: A.* McKee City: CTA Inc.

Mogford, R., Murphy, E., & Guttman, J. (1993). The use of direct and indirect techniques to study airspace complexity factors in air traffic control. *Proceedings of the First Mid-Atlantic Human Factors Conference* (pp. 196-202). Norfolk, Virginia: Old Dominion University.

Nolan, M. S. (2011). *Fundamentals of Air Traffic Control* . Indiana: Purdue University.

Osamba, S. (2012). *Global Tourısm & The Envıronment: The Necessıtıes For Clean Energy And Clean Transportatıon Usages.* Hamburg: Dr phil. Esomba; 1st Edition.

Pawełek, A., Lichota, P., Dalmau, R., & Prats, X. (2018). Fuel-Efficient Trajectories Traffic Synchronization. *Aerospace Research Central*, 478-512.

Radišić, T., Andraši, P., Novak, D., Juričić, B., & Antulov-Fantulin, B. (2020). Air Traffic Complexity as a Source of Risk in ATM. In J. A. Castán, & Á. R. Sanz, *Risk Assessment in Air Traffic Management.* Sao Paulo: Corrigendum.

Rantanen, E. (2005). Hierarchical Conflict Detection in Air Traffic Control International. *Journal of Aviation Psychology*, 339-362.

Rodgers, M. D. (1993). Situation assessment through the re-creation of. *Journal of Air Traffic Control*, 10-14.

Schmidt, C., & Kohlmann, T. (2008). When to use the odds ratio or the relative risk? *International Journal of Public Health*, 165–167.

Schmidt, D. (1976). On modeling atc work load and sector capacity. *Journal of Aircraft*, 531-537.

Sengur, F. (2022). Air Traffic Management. In D. Buhalis, *Encyclopedia of TourismManagement and Marketing.* Cheltenham: Edward Elgar Publishing.

SESAR. (2025). *DigitalSky SESAR research and innovation digest – 2025 Embracing innovation: key to a sustainable and competitive European aviation sector.* Luxemburg: Sesar Joint Undertaking.

SESAR JU. (2026). *Smart ATM Artifical Intelligence.* Retrieved from Sesar Joint Undertaking: https://www.sesarju.eu/ai

United States Department of Transportation (2019). *BTS*. Retrieved from Bureau of Transportation Statistics: https://www.bts.gov/newsroom/third-quarter-2019-us-airline-financial-data

Vassala, P. (2006). The Fıeld Study As An Educatıonal Technıque. *Turkish Online Journal of Distance Education*, 10-17.

Whig, P., Kasula, B. Y., Yathiraju, N., Jain, A., & Sharma, S. (2024). Transforming aviation: the role of artificial intelligence in air traffic management. *New Innovations in AI, Aviation, and Air Traffic Technology*, IGI Global Scientific Publishing.

Wickens, C. D., Mavor, A. S., & McGee, J. P. (2013). Flight to the Future:Human Factors in Air Traffic Control. *National Academy of Sciences*.

Xia, Z., Chen, C. H., Hsieh, M. H., Ma, G., Liu, B., Yu, X., & Dong, L. (2026). A systematic review on human-AI hybrid systems and human factors in air traffic management. *Journal of Engineering Design,*, 871-919.