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

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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.

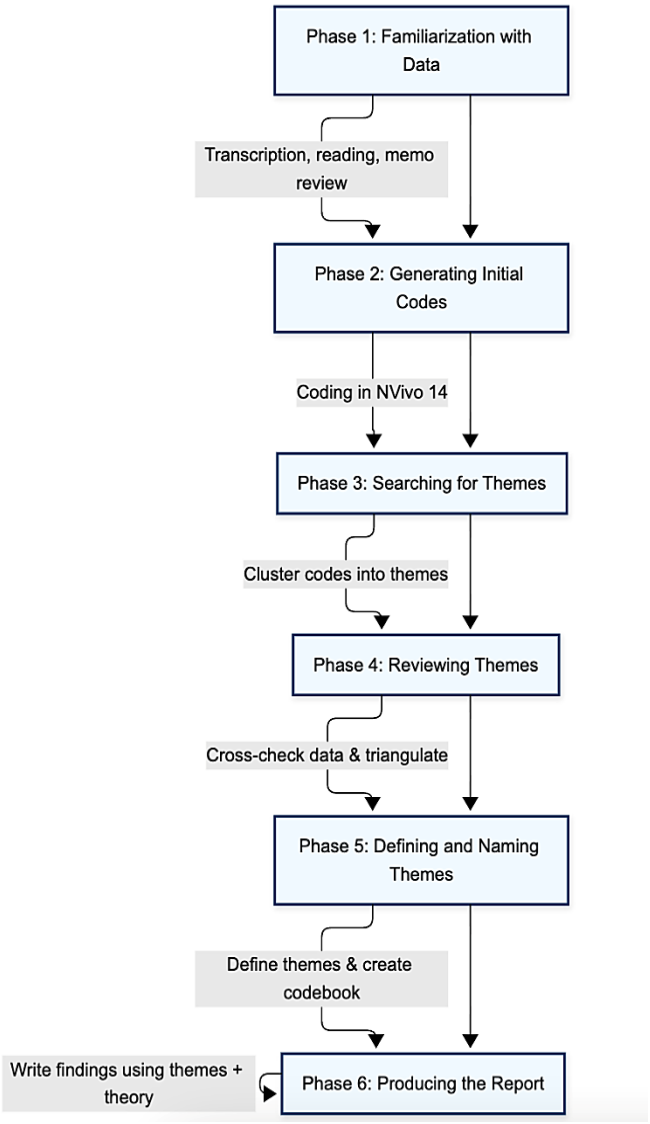
This comprehensive and multi-method data collection strategy ensured depth, accuracy, and contextual validity in exploring how digital transformation manifests within Turkish Cargo's SMARTIST facility.

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.

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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

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