Lecture Notes in Management and Industrial Engineering

Fethi Calisir
Selim Zaim
Enes Eryarsoy
Murat Durucu *Editors*

Industrial Engineering in the Era of Industry 5.0

Selected Papers from the Hybrid Global Joint Conference on Industrial Engineering and Its Application Areas, GJCIE 2025, August 12–15, 2025, Istanbul, Türkiye

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Lecture Notes in Management and Industrial Engineering

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Adolfo López-Paredes, *Escuela de Ingenierias Industriales, University of Malaga, Málaga, Málaga, Spain*

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Editors
Fethi Calisir
Industrial Engineering Department
Istanbul Technical University
Istanbul, Türkiye

Enes Eryarsoy
Sabancı University
Istanbul, Türkiye

Selim Zaim
Faculty of Business Administration
Ibn Haldun University
Istanbul, Türkiye

Murat Durucu
Industrial Engineering Department
Istanbul Technical University
Istanbul, Türkiye

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Preface

This book compiles extended versions of a selection of the best papers presented at the Global Joint Conference on Industrial Engineering and Its Application Areas (GJCIE) 2025, held in Istanbul, Türkiye, on August 12–15, 2025. The conference was organized by Istanbul Technical University (Türkiye). They represent a good sample of the current state of the art in the field of industrial engineering and its application areas.

The GJCIE 2025 is composed of three co-located conferences: the 10th Global Conference on Industrial Engineering (GCIE), the 11th Global Conference on Healthcare Systems Engineering and Management (GCHSEM), and the 12th Global Conference on Engineering and Technology Management (GCETM). The GJCIE 2025 is an internationally renowned forum for researchers, practitioners, and educators to present and discuss the most recent innovations, trends, experiences, and challenges in the field of industrial engineering. It brings together experts from academia and industry to exchange the latest research results and trends and their practical applications in the areas of industrial engineering mentioned earlier. This is accomplished through the following four modes of communication: keynote presentations, parallel sessions, student paper competitions, and poster sessions.

The GJCIE 2025 received 56 contributions from 10 countries. After each submission was reviewed in a double-blind peer review process by 2 reviewers, 22 submissions from 7 countries were accepted for presentation at the conference. The revised and extended versions of 20 papers out of 22 submissions are published in the present book, achieving an acceptance rate of about 36%. The papers presented in this book address methods, techniques, studies, and applications of industrial engineering with the theme of "Industrial Engineering in the Era of Industry 5.0." Industry 5.0, often called the Fifth Industrial Revolution, introduces a paradigm shift toward human-centric, sustainable, and resilient production systems. Building upon the technological advancements of Industry 4.0, it focuses on integrating human creativity and ingenuity with advanced technologies, including artificial intelligence, robotics, the Internet of Things, big data, and cloud computing. This evolution underscores the complementary roles of humans and machines, fostering a collaborative partnership rather than a replacement dynamic. Unlike its predecessor, Industry 5.0 goes beyond technology-driven efficiency and economic growth, prioritizing people's well-being, resilience, and sustainability. It redefines the principles of production and challenges conventional approaches to engineering education and corporate management. By encouraging sustainable practices that also respect the workforce, Industry 5.0 paves the way for more inclusive and adaptable systems. The upcoming conference will delve into the pivotal role of industrial engineering in advancing the vision and practices of Industry 5.0. Putting together this conference was a team effort. First, we thank the authors for providing the program content. We also thank our international scientific committee members and reviewers for their thorough and timely reviewing of the papers. Our international scientific committee members and reviewers represent 22 countries and are affiliated with 66 institutions. In addition, we thank our keynote speakers, Dr. Demet Karaali and Dr. Ali Dogan, for sharing their valuable time and knowledge with us.

We appreciate the partnership with Springer, iThenticate, and Microsoft CMT for their invaluable support for the success of the GJCIE 2025. We thank local organizing committee members who have done an outstanding job by putting their all into meeting the demands of the GJCIE 2025. On a personal note, in particular, we would like to thank our Program Chair, Dr. Murat Durucu, for his immeasurable hours of work on every detail of the conference. Last but not least, we gratefully acknowledge the sponsors of the GJCIE 2025, LC WAIKIKI, the Elginkan Foundation, Nar Innovative Solutions, and Aselsan.

December 2025

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Contents

The Strategic Role of Intelligent Automation Systems in Transforming Airline Operations

Melike Zehir[1] (✉) and Mohamed Ouattara[2]

[1] Management Department, Ibn Haldun University, Istanbul 34480, Türkiye
melike.zehir@ihu.edu.tr
[2] School of Graduate Studies, Ibn Haldun University, Istanbul 34480, Türkiye

Abstract. This study examines the impact of Intelligent Automation (IA) systems, which are increasingly being adopted in the aviation industry, on airline operations within a conceptual framework. In the airline industry, characterized by high operational costs, tight timetables, and intense competition, reducing costs and improving service quality are among the primary objectives of companies. At this point, IA systems are driving significant transformation in the industry through their automation capabilities, data-driven decision support, and potential for process improvement. In the study, basic IA technologies are first introduced, with the functions and interactions of systems such as artificial intelligence (AI), machine learning (ML), robotic process automation (RPA), and natural language processing (NLP) explained. The main application areas of IA systems in airline operations are then discussed. Various examples of how these technologies are applied in operational areas, including flight planning, maintenance and repair processes, customer relationship management, baggage tracking, and security systems, are presented. The challenges faced in implementing IA systems, including system integration, data security, and adapting to employee and airline passenger needs, are also examined. The study offers valuable insights into overcoming these challenges and outlines effective strategies for managing IA systems.

Keywords: Intelligent Automation Systems · Artificial intelligence · Strategic Management · Operation Management · Technology Implementation

1 Introduction

The aviation sector has been preferred by 20% of the world's population so far [1], and it is consistently growing, with expectations to double over the next 20 years, generating new routes, airports, planes, pilots, and other crew and services. IATA estimates a 3.5% annual growth rate, resulting in 8.2 billion passengers using aviation by 2037 [2]. With rising fuel costs, environmental concerns, and increased competition, the airline is more than ever before challenged to become more efficient while maintaining an emphasis on the customer experience. Intelligent Automation (IA) presents an opportunity to implement a new model that is transformative in connecting robotic process automation (RPA), artificial intelligence (AI), the Internet of Things (IoT), and machine learning (ML) to reshape the traditional aviation operations model. IA is increasingly being adopted in various sectors, including manufacturing, healthcare, retail, finance, and agriculture [3].

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The IA market in aviation is undergoing rapid expansion, projected to grow from \$1.87 billion in 2021 to over \$30 billion by 2030, with a compound annual growth rate (CAGR) of 45.5%. This growth is driven by increasing demands for automation, safety, and operational efficiency in a highly regulated industry. Governments worldwide are investing heavily in IA, recognizing its transformative potential.

AI technologies are being integrated across various aviation functions, including flight operations, predictive maintenance, and customer service. Predictive maintenance, in particular, is a key application that allows airlines to anticipate equipment failures and reduce unscheduled downtime, potentially saving up to \$3 billion annually, according to the FAA. This leads to enhanced safety, cost savings, and increased aircraft availability.

Beyond airlines, IA is also enhancing cargo logistics, airport operations, and air traffic management, with applications such as optimized routing, load planning, crowd control, and resource management. These advancements collectively demonstrate IA's versatility and growing importance in revolutionizing aviation through more intelligent and efficient systems.

The majority of past studies in the literature have primarily explored the individual integration of AI and IoT into the aviation sector [4–7] or investigated intelligent automation system applications in other sectors [8–10]. However, their combined integration, often referred to as AIoT, can unlock unique synergies and provide more added value specific to the aviation sector. This paper focuses on how AI and IoT technologies, as part of intelligent automation, can transform aviation sector activities, services, and processes, highlighting the benefits and the challenges. The paper contributes to this growing area of research by comprehensively investigating the integration of AI into pioneering aviation sector use cases in the field, as well as prospective application areas with high potential for benefits.

2 Intelligent Automation Systems

Intelligent Automation (IA) represents a significant advancement over traditional process automation. It is an approach that combines RPA with AI technologies to automate not only repetitive, rule-based tasks but also more complex processes that require contextual understanding and intelligent decision-making. This evolution has enabled the inclusion of capabilities such as machine learning, natural language processing, and image recognition, thereby offering more sophisticated and adaptable automation. This section describes the core technologies encompassed in the emerging framework of intelligent automation.

RPA (Robotic Process Automation) is a technology that allows organizations to automate repetitive, rule-based tasks typically performed by humans [11]. It utilizes software robots, also known as "bots," to mimic human actions when interacting with digital systems and software applications. In a traditional process automation approach, a software developer writes a computer program that performs a set of tasks and interacts with the application's programming interface (API). [12].

In a robotic process automation approach, the system utilizes software bots to learn and execute automated tasks by observing human user behavior. This process, often referred to as imitation learning, enables bots to comprehend the precise steps of workflows in real-time and then reproduce them autonomously, thereby enhancing the efficiency and accuracy of operations [13].

A software bot is a computer program designed to perform specific actions. It is designed to perform simple or complex tasks. Bots automate processes that involve repetitive tasks. Some more advanced versions mimic humans or interact with them. Virtual assistants, such as Google's Alexa, Microsoft's Cortana, and Apple's Siri, are examples of such bots.

Artificial Intelligence, introduced by John McCarthy, was defined as "The construction of computer programs that engage in tasks which, for now, are performed more satisfactorily by humans because they require high-level mental processes such as perceptual learning, memory organization, and critical reasoning.“ Thus, AI combines the "artificial" aspect, represented by the use of computers or sophisticated electronic processes, with the "intelligence" aspect, aiming to mimic human behavior. This imitation can be observed in various fields, such as reasoning (e.g., mathematics), sentiment analysis in text, understanding natural languages, or controlling robots for specific tasks in automated manufacturing environments.

AI encompasses two main subfields: Machine Learning (ML) and Deep Learning (DL). However, AI can be divided into two broad categories, each with distinct characteristics and specific applications. One of these categories is Strong AI. This concept refers to systems that are not only capable of producing intelligent behavior but also of exhibiting a form of self-awareness, "real emotions," and an understanding of their own reasoning processes. In other words, strong AI aims to replicate human intelligence in its entirety, a goal that remains theoretical at this stage.

In contrast, weak AI represents a pragmatic approach focused on creating systems capable of performing specific tasks autonomously. These systems do not possess consciousness or general understanding, but are designed to solve specific problems within limited domains, such as voice assistants or recommendation algorithms.

Machine Learning (ML) is a subfield of Artificial Intelligence (AI) that focuses on the development, analysis, and implementation of automated methods that enable a machine to improve through a learning process. This discipline aims to perform complex tasks that would be difficult or impossible to achieve using traditional algorithmic approaches.

The goal of machine learning is to generate knowledge from raw data automatically [14]. This knowledge, often in the form of models, can then be used to make informed decisions. Since models are built from data, their accuracy generally improves as the amount of available data increases, enabling more reliable and relevant decision-making.

Deep Learning, a branch of artificial intelligence, utilizes artificial neural networks to model and solve complex problems. Deep Learning is a subcategory of machine learning that uses artificial neural networks with multiple layers (hence the term "deep") to model complex data. These neural networks are designed to mimic the structure and functioning of the human brain by learning from vast amounts of data and recognizing patterns [15].

The human brain inspires data processing. Deep learning models can recognize complex patterns in images, text, sounds, and other data to produce accurate insights and predictions.

RPA has proven effective in accelerating and securing the less complex processes within a company. However, when coupled with artificial intelligence, RPA pushes boundaries and enables the handling of new business situations. Their combination propels the company into a new dimension of intelligent automation with enhanced capabilities and deeper process optimization. Together, they enable the ability to go beyond simple script execution, incorporating the processing of complex structured data that is often inaccessible using only connectors or APIs. Intelligent automation profoundly transforms organizations on multiple levels:

- liberating creativity and strengthening employees' analytical capabilities [11],
- promoting collaborative intelligence by removing barriers between front office and back [16],
- improving the customer experience,
- fully automating processes within the company, [11],
- structuring data from diverse and unpredictable sources [17],
- reducing exceptions requiring human intervention by preventing them before they occur [18],
- strengthening data and transaction security by detecting suspicious anomalies from subtle signals [11].

3 The Main Application Areas of IA Systems in Airline Operations

The aviation sector is a leader in technological advancements, with intelligent automation (IA) transforming business performance and enhancing the customer experience. Airlines are constantly facing high competition, driven by factors such as fuel prices, employee shortages, and consumer expectations, making IA one of the most important differentiators. IA is revolutionizing airline operations by shifting from manual, labor-intensive tasks to data-driven automated workflows, thereby improving overall business efficiency and enhancing the customer experience. Flight operations have been remarkably improved by AI-supported optimization algorithms that process many variables in real-time. Modern systems process weather patterns, air traffic congestion, and aircraft performance metrics to generate optimal flight paths, resulting in fuel savings of 3–5% per flight [2]. These systems continually learn from historical data, enhancing their predictive power with each flight cycle. The operational impact is significant; Delta Air Lines reported a 12% increase in on-time performance after introducing machine learning-driven crew scheduling tools, while Lufthansa's predictive maintenance tool helped decrease unscheduled aircraft downtime by 35% [18].

Biometric identification systems are already operational in major transport hubs, such as Dubai International and Singapore Changi airports, achieving an average reduction in boarding time of up to 40%. These innovations utilize facial recognition technology to facilitate a more seamless passenger experience, eliminating the need for document verification at multiple checkpoints.

The implementation of embedded RFID-enabled baggage handling has led to a 25% reduction in mishandled luggage rates across the industry. AI-assisted customer service platforms handle 50% of normal inquiries without human intervention. KLM's virtual assistant, “BB,” handles more than 50,000 customer engagements weekly, with a resolution rate of 92%. This innovation reduces the workload of call centers and associated costs.

Through the application of machine learning, revenue management has escalated to a new level of sophistication. Dynamic pricing algorithms incorporate thousands of factors, including the pricing of competitors, historical demand patterns, local area events, and even weather forecasts, to maximize ticket pricing, often in real-time. Sabre’s AI revenue management system has achieved a 5–10% revenue growth for its partner airlines, and Emirates has tailored upselling algorithms to drive an 18% growth in ancillary revenue. These systems are in an iterative process of improving their models, producing even more accurate demand forecasts and pricing.

Voice assistants powered by AI are now evolving past basic questions to help manage complicated travel disruptions and rebooking processes.

Blockchain technology shows promise for secure, decentralized passenger identity management and loyalty program administration. Most importantly, these technologies are producing genuinely intelligent airports, where passenger flow, security screening, and baggage handling function as a coordinated, continually self-optimizing system. The smart implementation of automation is no longer optional for airlines to develop a competitive position.

Airlines that utilize these technologies and address the challenges of data security, workforce transition, and regulatory compliance will develop a competitive advantage. In a continuously digitally transforming industry, the airlines that thrive will consider intelligent automation an enabler of not only more efficient operations but also a completely re-imagined customer experience.

3.1 Flight Scheduling and Optimization

One of the most impactful applications of IA in aviation is flight scheduling and route optimization. Airlines can make real-time modifications that reduce delays and expenses by utilizing AI algorithms to analyze weather trends, air traffic congestion, and fuel efficiency. For instance, Lufthansa’s AI-powered flight planning system has reduced fuel consumption by up to 5% per flight, resulting in millions of dollars in annual savings [18]. Similarly, Delta Air Lines utilizes machine learning to predict disruptions and optimize crew scheduling, resulting in a 12% improvement in on-time performance.

Anadolu Jet, a subsidiary of Turkish Airlines, offers high-quality, low-cost domestic flights within Turkey. The company operates a fleet of 18 aircraft and services 28 locations. As one of Turkey’s leading low-cost carriers, it carried 5.3 million passengers in 2012. Anadolu Jet operates a hub-and-spoke network, which consists of one or more hubs and segments that connect all other nodes (spokes) to at least one hub. In its current network structure, it designates Ankara’s Esenboga Airport as the main hub primarily because of geopolitical factors. For strategic reasons, the company may also schedule flights through Istanbul. Therefore, Istanbul’s Sabiha Gokcen Airport is considered a secondary hub (Haksoz 2013). Anadolu Jet’s network planning department generates flight schedules twice a year, in both winter and summer. When generating these schedules, the company’s primary concerns are to maximize fleet utilization and minimize the waiting time of transfer passengers. Fleet utilization is defined as the number of total hours all aircraft spend in the air. A transfer passenger is one who travels from one city to another with a connecting flight over a hub; for example, a transfer passenger who travels from Izmir to Erzincan might change flights in Ankara. According to Anadolu Jet, approximately 25% of its passengers state that the transfer service and waiting times in Ankara must be improved.

Balancing the trade-off between fleet utilization and transfer performance (i.e., minimizing waiting times for passengers connecting at a hub) and optimizing both makes the network planning and scheduling problem complex. The schedules generated are critical because they determine the timing and sources of operations, such as the aircraft fleet and crew, that directly affect the company's profitability. However, manually producing flight schedules, while taking additional constraints into account, is time-consuming and unlikely to generate an optimal schedule.

3.2 Baggage Handling and Tracking

The operation and management of baggage are crucial in the aviation industry, involving various players and operators, particularly airports and airlines. The process can vary significantly across different markets and countries, and may even involve distinct types of operations and processes. Typically, the process starts with a passenger checking in their baggage at the airport. This is often at the same time as checking in for a flight. With the increasing use of online check-in, more bags are being dropped off separately, or through self-service check-in kiosks or bag drop counters. Baggage labels (tags) are attached during check-in and contain information such as the airline, flight number, and the destination airport code. A barcode or radio-frequency identification (RFID) tag can be scanned, allowing for the tracking of the bag and providing other information, such as the weight or priority (e.g., business or first-class) of the bag.

Bags need to undergo subsequent security checks, after which they are delivered to the sorting and loading areas to be loaded into containers, known as unit load devices (ULDs). In airports with automatic cargo/baggage handling systems (or early baggage storage), bags can be temporarily stored until shortly before flight departure. Until this point, most operations have been performed within airport terminals, although in many cases, facilities (e.g., check-in counters, kiosks, baggage conveyors, and storage, screening systems) are owned by or leased to airlines. As a result, airports are often the key decision-makers for the design, investment, operation, and upgrading of related facilities.

After being sorted and loaded into ULDs, bags are then delivered and loaded into the aircraft prior to flight departure. These operations are usually performed by ground handling service providers, which the airport, the airline, or independent third-party companies may own.

The above process is reversed, albeit in a more straightforward manner, for arrival flights: baggage ULDs are offloaded from aircraft and delivered to airport terminals. Bags are then loaded and transported by conveyors to the carousels for baggage claim. In the case of connecting or transfer flights, bags may be temporarily stored until they are re-sorted and loaded onto the next flight.

In summary, baggage handling involves different operators at multiple airports, sometimes across country borders. Security and safety standards must be adhered to throughout the entire process, necessitating close coordination and the sharing of information among all stakeholders. Such a need has been well recognized by the aviation industry. For example, the International Air Transport Association (IATA) endorsed resolution 7533. Coming into effect in June 2018, the resolution requires that "IATA members shall maintain an accurate inventory of baggage by monitoring the acquisition and delivery of baggage.". There are four key points at which airlines must track baggage: when passengers hand their baggage over to the airlines; when baggage is loaded onto the aircraft; when baggage is delivered to the transfer area; and when the baggage is returned to the passenger. Depending on the baggage system used, airports may also track and monitor baggage at multiple points.

A key point to note is that the above process is merely an outline of the standard baggage handling procedure. In practice, mishandled bags require numerous additional operations and services from airports, airlines, and ground handling service providers. The International Aeronautical Telecommunications Association (SITA) 2018 Baggage Report4 estimates that a total of 22.7 million bags were mishandled in 2017, at an estimated cost of US$2.3 billion to the aviation industry.

The aviation industry has been investing heavily in baggage handling systems to improve efficiency, reduce costs, increase reliability, and control mishandled baggage.

Although IA has significantly improved its baggage handling procedures, travelers still experience considerable inconvenience due to lost baggage. Radio-Frequency Identification (RFID) tags and IoT sensors enable real-time tracking, reducing mishandled baggage rates by 25%. Airlines such as Air New Zealand and Delta have implemented fully automated baggage sorting systems, which cut processing times by 30% while improving accuracy [19]. These developments enhance passenger trust in airline dependability while also improving operational efficiency.

3.3 Automated Customer Service

Customer service automation using machine learning has been a burgeoning field in recent years. Researchers have explored various aspects, including sentiment analysis of customer queries, chatbot implementations for real-time support, and automated routing of inquiries to appropriate channels or departments. The literature frequently explores the effectiveness of machine learning models in comprehending natural language, processing complex queries, and enhancing response accuracy and efficiency. Some studies focus on the integration of ML algorithms with customer relationship management (CRM) systems to enhance personalized interactions and customer satisfaction. Additionally, researchers have examined the challenges related to data privacy, ethical considerations in automated responses, and the need for continuous model improvement through feedback loops. Overall, this body of literature demonstrates the potential for ML-based automation to revolutionize customer service while highlighting areas that require further exploration and refinement. The progress in speech technology and emotion detection is making it much easier for people when dealing with automated customer service. In the past, waiting on hold on long phone lines was frustrating for both customers and companies. Now, thanks to machine learning, customers can simply talk naturally and use words to explain what assistance they require. Technologies like natural language processing (NLP) enable computers and artificial intelligence to understand and respond to human language, thereby making problem-solving quicker and more efficient.

The rise of AI-powered chatbots and virtual assistants has transformed customer service in aviation. KLM's "BB" chatbot handles over 50,000 customer queries per week, reducing call center costs by 30%. Meanwhile, self-service kiosks and mobile apps allow passengers to check in, select seats, and rebook flights without human intervention, significantly reducing wait times. These technologies reduce operating costs while increasing responsiveness, which is a critical component of customer satisfaction.

3.4 Predictive Maintenance

Predictive maintenance strategies are highly effective in mechanical-failure modes, where the failure probability increases over time, and one or more condition-monitoring techniques (such as vibration analysis, oil analysis, thermography, and sound) can predict failure before it occurs. However, the use of these techniques has always been linked to a very limited type of assets, where unavailability can lead to safety losses (e.g., Aerospace) or significant economic losses (e.g., Energy). One of the most significant challenges in predictive maintenance is the need to handle large amounts of data, as well as the associated cost of personnel training. To overcome this problem, several decision support systems are currently under development and in the research stage. However, the ill-structured nature of predictive data makes it challenging to automate tasks, as there is usually uncertainty in the diagnosis process. Moreover, some diagnosis and monitoring models must be built directly from data, as no prior experience is available. Finally, there are cases where continuous adaptation of diagnostic and monitoring solutions is required, as knowledge of maintenance increases. In order to cope with these problems, several algorithm paradigms coming from the machine-learning field can be applied to a variety of situations, and with diverse requirements and problem characteristics (supervised, unsupervised, reinforcement learning, expert knowledge, data mining). Among these, some have evolved into robust tools for modeling various types of classification problems, such as monitoring and diagnosis. Examples of successful paradigms are CBR systems, neural networks, induction trees & rules, and Bayesian networks. A case study is presented, corresponding to EC partially supported MINICON project (minimum cost, minimum size, maximum benefit condition monitoring system), where a predictive maintenance solution for non-critical machinery (such as elevators and machine tools) was sought.

Aircraft maintenance is a critical yet costly aspect of airline operations. IA enables predictive maintenance, where AI analyzes sensor data from engines and other components to detect potential failures before they occur. Emirates reports a 35% reduction in unscheduled maintenance since implementing AI-driven diagnostics. In addition to improving safety, this reduces aircraft delays and cancellations, which benefits both travelers and airlines.

3.5 AI-driven Pricing and Revenue Optimization

AI-driven dynamic pricing algorithms enable airlines to adjust fares in real-time based on demand, rival pricing, and historical data. Sabre's AI revenue management system has helped airlines increase yields by 5–10%. Additionally, AI enhances loyalty programs by personalizing offers, such as targeted upgrades and rewards, further improving customer retention.

The application areas, along with their details, are illustrated in Fig. 1. In the future, the second wave of aviation automation promises even more revolutionary changes. Autonomous ground vehicles are already being tested to help with baggage handling operations and pushback from the terminal. For instance, Air France is currently piloting autonomous baggage tugs that have shown a 15% fuel savings during taxiing.

4 The Main Application Areas of IA Systems in Airline Operations

Along with its benefits, the implementation of intelligent automation presents significant challenges that require careful navigation.

4.1 Integration with Legacy Systems

Companies working in aviation often have legacy IT systems that are not easily adapted to modern IA technologies. These legacy systems and infrastructures were not designed with interoperability in mind, and the difficulty and resources needed to integrate intelligent automation tools are generally too high. The disruption of service due to integration failure could be expensive and a serious concern (The major Turkish Airlines IT system disruption happened on July 19, 2024, when a global outage caused by a faulty update from cybersecurity firm CrowdStrike impacted Windows systems worldwide, the carrier canceled 84 flights, mostly domestic and to/from Europe; check-in and booking systems failed) particularly in mission critical systems such as flight management or ground handling.

4.2 Data Security and Privacy Concerns

Data security has emerged as a significant challenge for such organizations, as airlines collect even more sensitive passenger biometric data. A Greener System would provide some relief, however, not complete assurance, for issues such as those exposed in the British Airways data breach of 2018, when payment records for 380,000 customers were famously exposed [20], which highlighted the potential vulnerabilities across an array of interdependencies within systems.

4.3 Regulatory and Compliance Barriers

The aviation industry is one of the most strictly regulated industries in the world. Any change involving IA, especially those that impact safety, security, or passenger interaction, will require approval from very strict aviation authorities - both at the international level (e.g., the ICAO) and national bodies (e.g., the Federal Aviation Administration (FAA). Such regulations are primarily unable to keep pace with the rapid development of intelligent technologies, resulting in delays and compromises during the instantiation process. Ensuring regulatory compliance presents yet another level of complexity, especially considering the changes being made to existing GDPR requirements and other international data protection laws.

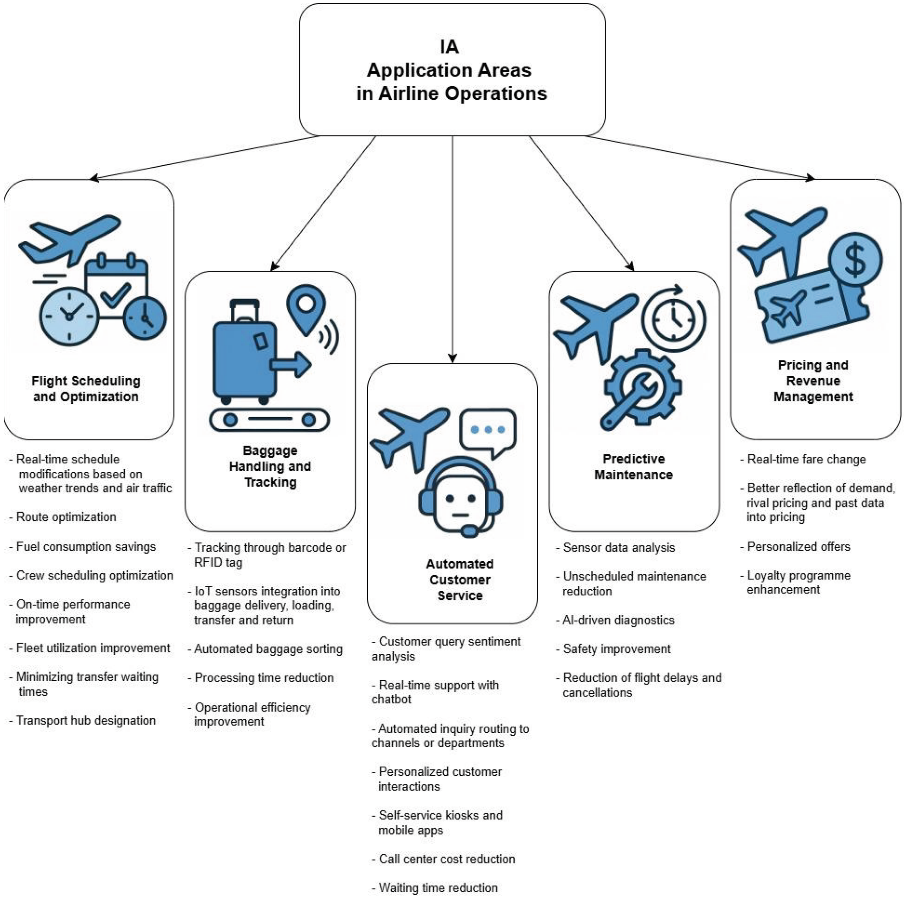

Fig. 1. Intelligent automation application areas in aviation.

4.4 High Implementation and Maintenance Costs

The implementation and development of IA systems require considerable financial investment in the purchase of software, modifications, upgrades to infrastructure, and staff training. With limited budgets, many airlines, particularly in the wake of COVID-19 recoveries, must view IA as an initiative that requires time, research, and ultimately, money and dedication to realize its potential [21]. Additionally, ongoing maintenance and updates to the system contribute to potential ongoing operational costs, as well as cybersecurity expenses.

4.5 Organizational Resistance and Workforce Impact

A cultural shift is necessary within the organization, as employees may be resistant to adopting IA. Employees may fear losing their jobs, and there might be a trust issue with AI-based decision-making. One of the top barriers to IA adoption in service industries is employee resistance [9]. This resistance will slow the transformation process unless the organization actively manages change through effective change management processes, open and transparent communication, and retraining initiatives.

4.6 Skill Gaps and Talent Shortages

Successful implementation of IA requires staff with skills in data science, machine learning, and process automation. The aviation sector has typically not been a technology-first industry, resulting in a shortage of in-house capabilities [2]. Reliance on external vendors entails the potential for vendor lock-in or for vendors not aligning with the company's operational needs.

Changing the workforce is another significant challenge, with estimates suggesting 23% of current flying jobs by airlines could be automated by 2030 [21]. Successful airlines will address this disruptive challenge through reskilling programs, such as Lufthansa's Automation Academy, which has upskilled 12,000 employees for tech-augmented roles.

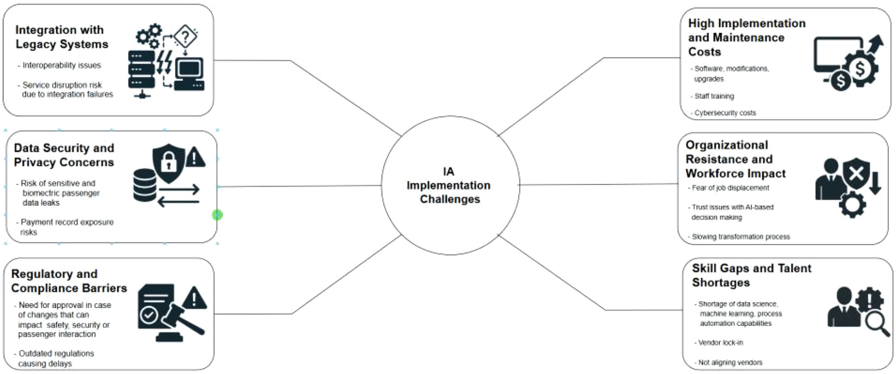

Fig. 2. Overview of IA implementation challenges.

The challenges are illustrated in Fig. 2.

5 Conclusion and Future Research

Intelligent Automation (IA) systems, including Artificial Intelligence (AI), Machine Learning (ML), Robotic Process Automation (RPA), and the Internet of Things (IoT), are significantly influencing airline operations.

Together, these technologies enhance operational efficiency, reduce costs, optimize customer service, and increase responsiveness to the changing dynamics of markets and regulations. IA will assist airlines and airports in transitioning from manual flows to frictionless, agile, data-driven systems, enabling predictive decision-making and various personalized customer experiences. This research has identified that IA is not just a 'tool' for optimizing operations, it is also a strategic capability, able to enable significant digital transformation in the aviation industry. This research presents a multidimensional framework of factors influencing IA adoption, utilizing the Technology–Organization–Environment (TOE) framework and the Technology Acceptance Model (TAM) [22]. The outcomes suggest that to achieve maximum value from IA, technological readiness, organizational leadership, and alignment to customer and regulatory requirements are all key considerations.

The airline industry could consider a range of key topics to add depth and facilitate the successful implementation of IA. One of the important topics is human–technology interaction, since IA is likely going to be the most disruptive aspect of intelligent automation, changing the workforce of an airline, thus resulting in a needed investigation into employees' perceptions of IA, reskilling requirements, and human-machine collaboration [23]. Another important area relates to ethics and regulation, as AI systems are likely to become central to airline operations. Therefore, research must explore issues of data privacy, algorithmic fairness, and compliance with international regulations. Cross-industry and cross-cultural comparisons can also provide valuable insights into how IA adoption strategies can scale and adapt to specific organizational and national contexts. Longitudinal performance measures are required to determine the ongoing impact of IA on operational efficiency, economic effectiveness, and environmental performance. Ultimately, the integration of IA with other emerging technologies, such as digital twins, blockchain, and generative AI, presents exciting possibilities for innovation and resilience. Addressing these various areas within rigorous research will provide additional clarity on the strategic value of IA and how IA can become a more intelligent, effective, and customer-centric operation in the airline industry.

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