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Article

The role of smart technology in airport facilitation and security control (ICAO Annex 9 and 17 requirements)

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Abstract: The aviation industry is experiencing over and over again a technological revolution, nowadays with airports at the forefront of embracing smart technologies to enhance operational efficiency, security and passenger experience. This article comprehensively analyzes the benefits, challenges, and legal implications of adopting smart technologies in airport facilitation and security control. It examines the regulatory framework established by the International Civil Aviation Organization (ICAO) on an international level and by sovereign states on a national level. It explores using smart solutions such as automated systems, data and biometric verification, artificial intelligence (AI), and the Internet of Things (IoT) devices in airport operations. The authors' purpose is to highlight the improvements in airport facilities and security measures brought about by these technologies, while addressing concerns over privacy, cost, technological limitations and human factors. By emphasizing the importance of a balanced approach and considering innovation alongside legal and operational imperatives, the article underscores the transformative potential of smart and integrated technologies in shaping the future of air travel.

Keywords: airport facilitation; airport security; smart technology; automatization; Internet of Things (IoT); artificial intelligence (AI)

1. Introduction

The aviation industry is mass transportation. The aviation industry is an integral part of the global transport network and is undergoing technological transformation. Airports, serving as the primary gateways [there are 3780 airports used for scheduled flights, further 41,764 airports are at the disposal of civil, military (state) and commercial transport (ATAG Report, 2024)] for international travel are at the center of this transformation, embracing smart technologies to enhance operational efficiency, security, and passenger experience. The adoption of these technologies comes in response to several challenges facing airports today, including increased passenger volumes, heightened security threats and the growing demand for faster, more efficient services.

However, integrating smart technologies is not without complexities. To understand these new challenges, we must comprehensively analyze the benefits, challenges and legal implications associated with adopting these technologies in airport facilitation and security control. By assessing the current challenges in airport operations, the article will first establish the context for the necessity of technological advancement. After exploring various smart technologies, such as automated systems, biometric verification, and artificial intelligence (AI) in security, we will highlight the ongoing adaptations in airport services.

The authors intend to explain and analyze these technologies, which dramatically enhance airport facilities and security measures. They also assess the operational benefits, such as increased throughput and enhanced threat detection, as well as potential drawbacks, including concerns over privacy. Moreover, the authors address the limitations inherent in adopting these technologies, considering technological (the system can shut down), financial (high implementation costs) and human factors (risk of failure). This article summarizes the benefits of this modern system of technologies, analyzes the practicability and its limitations. The system operates in different airport fields, but all these technological supports are based on IT and a well-trained workforce. First, the connectivity, and then, the integration of this system is the dimension which provide seamless, faster and accurate processing for the whole journey, also in different destinations.

A critical aspect of this transformation is the legal context; therefore, examining the legal frameworks, regulations and compliance issues surrounding the use of smart technologies in airports is crucial. The legal viewpoint concerns aspects such as privacy laws, data protection and international rules, thus, the authors render a comprehensive overview of the legal landscape.

In conclusion, the article will compare these findings, offering insight into how smart technologies reshape airport facilitation and security control. It will underscore the balance between embracing technological advancements, urging integrations between the available state-of-the-art technologies (Collins, 2024) and addressing the associated challenges and legal implications, paving the way for the regulation of airport operations in a more efficient, secure and passenger-friendly future.

2. Airport facilitation and security controls

2.1. ICAO Annex 9 and 17 requirements

The Chicago Convention (1944), also known as the Convention on International Civil Aviation (ICAO Doc 7300, 2006), is the landmark treaty establishing the framework for the regulation of the international civil aviation industry. The Chicago Convention established the International Civil Aviation Organization (ICAO), a specialized agency of the United Nations, in order to oversee and regulate activities in civil aviation worldwide. This was the foundation of international cooperation in civil aviation. As air travel expanded globally, a need for standardized regulations arose to ensure safety, security, efficiency and environmental protection. Therefore, ICAO's most important strategic objectives are safety (as a number one priority), furthermore, security/facilitation and environmental protection. In order to address this need, ICAO developed a series of technical Annexes, which contain Standards and Recommended Practices (SARPs) covering civil aviation safety and security. The Standard is a specification, which stipulates a minimum requirement, therefore, its content cannot be emptied out or implemented with less obligations. The Recommended Practice is also a specification, the uniform observance of which by the Member States is recognised as practicable and desirable, but conformity thereto is not mandatory (Sipos, 2024). SARPs adopted by the Council of ICAO are designated as 19 separate Annexes (e.g., Annex 14 on Aerodromes) to the Convention. The Annexes of at least 4000 pages contain more than 12,000 Standards. It is the elementary interest and

obligation of the contracting States to incorporate the SARPs rules set forth under the Annexes encompassing all major areas of civil aviation into their national law.

Annex 9 to the Convention on Facilitations and Annex 17 to the Convention on Aviation Security cover the basic regulatory framework; therefore, analyzing these from the viewpoint of smart technology used at airports and in the industry is necessary. Facilitation and security are the major strategic objectives of ICAO, and are mentioned together, in one group. This shows that these areas are very closely related to each other. They go "hand in hand," thus, if we minimize the facilitations, the security risk will increase immediately. If accidents or incidents occur, the investigation is always supported by facilitation. Aviation security is definitely a sensitive area, although its effect is global, it consists primarily of tasks of protection to be handled on a national level. The rules of security constitute a closed system excluding access to the inherent confidential information for those not concerned. Unlawful acts encompass all acts or attempts committed by a person endangering the safety of international civil aviation. Such acts include unlawful seizure, sabotage, taking hostages, violent intrusion (on board, at the airport, or in the area of an air navigation facility) and the deposit of weapons, dangerous tools or material for the commission of crime. Furthermore, what frequently occur are threats of bomb attacks, the communication of misleading, false information, or, the refusal to cooperate with the ground staff at the airport or with the crew during the flight. However, security and facilitation may only be effective if these two certainly important areas cooperate continually and support each other unconditionally.

2.2. Airport facilitation

Annex 9 to the Convention on Facilitations (ICAO, 2022) focuses on airport facilitation, including immigration, customs, health and security procedures to facilitate the efficient movement of passengers, baggage and cargo through airports. It has implications for airport facilitation, including immigration and customs procedures and it provides guidelines to facilitate the movement of passengers, baggage and cargo across international borders. The Annex outlines Standards for delivering health services at airports, including medical facilities, quarantine measures and health screening procedures to protect public health and prevent the spread of infectious diseases in line with the World Health Organization's (WHO) regulations (Annex 9, Chapter 8).

Annex 9 sets forth provisions for security measures related to passenger and baggage screening, access control and security checks to ensure the safety and security of airport operations. The Annex covers passenger services such as check-in, boarding, baggage handling, electronic processing of clearance procedures and the communication of information to enhance the overall passenger experience and facilitate smooth movement through airports. Annex 9 also addresses airport infrastructure and facilities requirements, including terminal design, signage, seating areas, transportation opportunities [e.g., taxi flow, in the future air taxis, (Xiaobing et al., 2022)] and amenities to support efficient airport operations and passenger facilitation.

Overall, Annex 9 is crucial in promoting efficient airport facilitation for

immigration, customs, health, security and passenger services at airports worldwide. The passenger is required to travel with valid and secured documentation and needs to cooperate with the airport authorities (e.g., customs, security, health-related or narcotics control etc.). Therefore, compliance with Annex 9 is a key requirement for airports to ensure the smooth flow of passengers (provide smooth accessibility for the elderly and disabled persons), all kinds of goods and baggage, while maintaining the necessary safety, security and public health checks.

2.3. Airport security control

Aviation security is a system of capabilities, due to which the performers of the industry can provide effective and competent protection to aircraft on the surface or in the air, to the passengers and crew on board the aircraft or on the grounds of airports, to the ground-staff and third persons on the surface vis-à-vis unlawful acts threatening their security (Sipos, 2024). Annex 17 to the Convention on Aviation Security – Safeguarding International Civil Aviation Against Acts of Unlawful Interference (ICAO, 2022), addresses specifically this field of the industry, providing SARPs to prevent acts of unlawful interference with civil aviation, such as terrorism or sabotage. It stipulates measures for airport, aircraft, cargo, mail and other goods security, and for the screening of passengers and baggage, crew and ground personnel. Its implications for airport security control include outlining specific security measures that airports need to implement to prevent acts of unlawful interference with civil aviation. These measures include access control [prevent weapons, explosives or any relevant dangerous devices (Annex 9, Chapter 4, 4.2, 2022)], passenger, baggage, cargo screening and surveillance systems. These measures include using metal detectors, X-ray machines, explosive detection systems, and other screening technologies.

Annex 17 requires airports to provide security training and awareness programmes for airport staff, security personnel and other stakeholders involved in aviation security. This ensures that personnel are adequately trained to identify and respond to security threats effectively. The Annex emphasizes the importance of coordination and cooperation among airports, airlines, law enforcement agencies and other relevant authorities to enhance the effectiveness of security measures and exchange information on potential security threats. Annex 17 also mandates developing and implementing security contingency plans to respond to security incidents, emergencies, and acts of unlawful interference with civil aviation. These plans include procedures for crisis management, communication and coordination of response efforts. In smart airports such plan is mandatory, if the system, for example, fails, is cyberattacked, or manipulated, or the energy system breaks down, to which the risk manager needs to react immediately, provide resources (energy, maintenance, workforce etc.) and make prompt decisions in collaboration with the police, national services, other airport authorities and industry stakeholders.

In a nutshell, Annex 17 plays a critical role in ensuring the safety and security of airport operations. No doubt, the smart airport system advances airport security. Compliance with Annex 17 helps airports mitigate security risks, protect passengers and crew, ground personnel and the general public, furthermore, infrastructure

(aircraft), and maintain the integrity of the aviation system on national and international levels [such as Airports Council International – Europe (ACI-Europe), International Air Transport Association – Europe (IATA-Europe), European Regions Airline Association (ERA), European Business Aviation Association (EBAA), and the European Cockpit Association (ECA)].

2.4. Current status

This scene of airport operations presents several significant challenges. These significantly contribute to determining the need to adopt smart technologies, which is supported by the adoption of Annex 9 and Annex 17 requirements in airport facilitation and security control. The appreciation of such technological integrations requires some level of familiarization with these challenges. One of them is "congestion and long waiting times." The increase in global air travel has resulted in crowded airports, which have, therefore, sustained extreme congestion [according to optimistic forecasts, the air passenger traffic is about to double to over 10 billion annually by 2050 (ATAG, 2021)]. Therefore, the need for smart airports is essential. The automated check-in points, security checks and baggage collection are a minimum standard application in our days. This leads to longer waiting times for passengers both arriving and departing from flights, which may be a source of passenger irritation or missed planes for others. Additionally, this increased demand puts extra pressure on airport facilities and resources themselves, as a more skilled workforce is needed to cope with the increased density.

Another major challenge faced by global airports is "security threats and vulnerabilities." In an era when security threats are getting rapidly sophisticated, starting from the terrorism to digital warfare, airports are at the center of constant pressure on the safety of passenger life. This requires screening contraband items, vigilance on suspicious demeanor and cybersecurity. The key to rapid industrial development is the safe and secure environment of travel. Therefore, it is always a challenge how to safeguard the required level of protection while maintaining smooth passenger flow and the highest level of passenger experience. Surely, there is a high demand for improved passenger experience. Modern passengers today do not just want to get from Point A to B safely, but they need a smooth, quick, and enjoyable travel experience. This includes quick check-ins, minimal waiting times, self-explanatory guidance and individual services, which ensure hassle-free movement and customized experience throughout the passenger journey. These expectations are more or less unmet in conventional airport procedures, generally characterized by manual interventions and lengthy procedures.

Operational inefficiencies (such as system failure, lack of installation or training etc.) are considered to be one of the significant challenges to global airports. Most airports still operate on outdated technological systems that do not comply with the currently increasing volume and complexity of airport operations. Such inefficiencies manifest themselves in various forms, from scheduling delays and mismanagement of resources to the lack of real-time data, which can be used to make effective decisions (e.g., sensitive traffic operations data linked to aircraft movements or passengers' data linked to biometric recognition). Such inefficiencies increase the operational costs and

severely affect the service quality, which causes dynamic operational challenges (for example, if the technical system of self-check-in breaks down, this requires urgently more workforce to serve the huge number of passengers, baggage or goods).

In recent years, environmental concerns have drawn increasingly more attention. Airports are extremely energy-intensive. Therefore, they need to introduce a wide range of sustainable and energy-saving measures to ensure the comfortable and fast movement of passengers and aircraft within the airport. The airports also come under mounting pressure to make a difference in the protection of the environment. The following concerns are currently of high priority: the carbon footprint, environmental noise pollution, water, air quality and waste management. Environmental sustainability with increased operational efficiency is becoming increasingly harder to achieve. The efforts to hire, train and retain highly qualified professional workforce remain constant challenges, especially in the areas of security and customer service.

Technological disparities in service quality and security standards between airports are also a significant area of concern. While some airports are technologically advanced, others tend to lag behind, given financial constraints or lack of expertise.

In conclusion, all these issues make airports face an array of complex challenges that call for revisiting the traditional approaches used in airport facilitation and security control. The rise of the integration of smart technologies as a pivotal solution to combat these multi-dimensional challenges focuses on increasing efficiency, enhancing security measures and passenger experience, and on easing operational and environmental concerns.

3. Smart solutions and services at airports

In many airports, the present technology is based on Radio Frequency Identification (RFID). This system supports the operational achievements in the area of baggage tractors and tracking, baggage screening, secured area access control, food and merchandise monitoring, parking access management, etc. Smart Baggage Handling (SBH), for example, is a central area of technological integration at airports. They use Radio Frequency Identification (RFID) technology and applications of advanced tracking for baggage handling. Such innovative systems increase the accurate sorting of baggage, reduce the risks of lost or misrouted baggage, and ensure that even passengers can track their baggage in real-time through applications.

Nowadays, the industry has increasingly adopted new “smart” technologies in response to the growing demand for more efficient, secure and passenger-centric airport services. These technologies are literally changing the face of the game at the airport.

1) The following support passengers from check-in to boarding:
    - Automated gates and security checkpoint [with Automated Tray Retrieval System (ATRS)];
    - Self-check-in [Common Usage Self-Service (CUSS)];
    - Self-baggage drop-off systems [Self Baggage Drop (SBD) including automated baggage scanning and weighing] [At Dubai International Airport, 32 self-service bag drop machines and 16 check-in kiosks can be controlled completely by personal mobile devices without touching the screens;

thereby providing a safe and convenient airport experience (Emirates Airlines Media Centre, 2021)];

- Automation of immigration (passport control) processes (At Dubai International Airport, the passport control procedures take approx. 15 seconds without human intervention);
- Facial recognition (face and iris recognition) to identify passengers at automated gates and various checkpoints;
- Digital guidance and wayfinding support [At London Heathrow (LHR) Terminal 5, two autonomous robots (called Bill) have guided the passengers since 2020 (British Airways Media Centre, 2019)];
- Health monitoring and alert systems (to prevent outbreaks of infectious diseases and pandemics) such as measuring body temperature with heat cameras. [See, the Communicable diseases which have affected civil aviation worldwide: e.g., Serious Acute Respiratory Syndrome (SARS-CoV coronavirus) 2003; Highly Pathogenic Avian Influenza (bird flu) (H5N1) 2005; Swine Influenza Virus (SIV) (H1N1) 2009; Middle Eastern Respiratory Syndrome (MERS-CoV coronavirus) 2012; Novel virus of the Avian Influenza (H7N9) 2013; Western-African Ebola-Virus (EVD) 2014; Zika Virus 2016; Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) 2019 (Sipos, 2021)];

2) The following support the airports' operational staff and management:
   - Intelligent Cleaning systems (smart recycling bins, intelligent waste management etc.);
   - Autonomous Vehicles (AV) systems in airport areas;
   - Autonomous Mobile Robots (AMRs) for inspection, maintenance and repair (use for remote maintenance activity and equipment monitoring tasks);
   - Rostering and optimization of the movements of air carriers, ground handling and maintenance services, operational staff and even mass transportation within terminals [supported by the Global Positioning System (GPS)] (Heritage, 2021).
3) The evolution of the application of smart technologies at airports can be well identified (**Figure 1**):

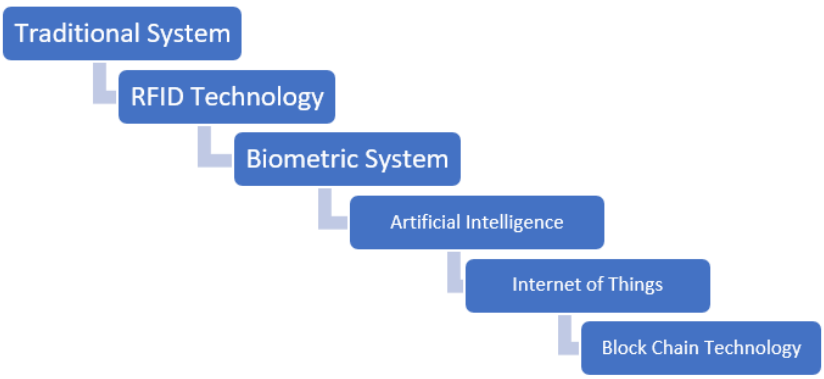

Figure 1. Evolution of smart technologies at airports.

Biometric system: Several areas of smart technologies are becoming critical at

airports, such as Biometric Verification Systems (BVSs). Biometric systems are gaining popularity at airports to verify identity. This includes facial recognition technologies similar to the existing passport technologies for passengers' check-in, security checks and boarding. This helps to improve security along with the proper identification of passengers and diminishes time otherwise taken to produce traditional boarding passes and identity documents, making boarding faster. Behind this technology, the Transportation Security Officers (TSOs) verify the passenger's ID data, flight status, position and also any other person's movement (operational staff, ground personnel) in the area of the airport. It seems as if the TSOs were not present, as there is no human interaction with the people at the airport, but they carefully monitor, follow the whole process from their offices. The implementation of this system requires on the one hand, special training for operational staff, on the other hand, an adequate contingency plan in the case of system failure, and a regulatory procedural background is a must.

Artificial intelligence (AI): Another central area for potential technological integration is security and operations aided by AI. As it is well-known, AI can play a vital role in boosting security and aiding operations. For example, data from security cameras can be analyzed to identify the suspicious movements of people or dropped baggage through AI-based algorithms. This system is capable of blocking unauthorized individuals from reaching the critical infrastructure and can make a distinction between "bad" and "good" persons in terms of access and legitimacy. In passenger screening, AI enhances the recognition of banned goods in baggage and reduces human error while doing this faster. Automated check-in and boarding procedures are also getting wide acceptance at global airports. Self-service kiosks whereby the passengers can check-in, as well as automated boarding gates have already been installed at many airports. Such systems help decrease the length of procedures, they result in lower waiting times for passengers, and, in general, allow the traveler to handle their documents as well as boarding processes with lesser dependence on staff.

Internet of Things (IoT): IoT is getting wide acceptance in airport operations nowadays. IoT devices and sensor technology are increasingly used to monitor anything from environmental controls (such as lighting and temperature) to tracking equipment and vehicles on the tarmac, also to collecting data on the current condition of the aircraft. This technology contributes to the capacity to use resources most optimally with operational speed. Predictive Maintenance Analytics (PMAs) and Crowd Management Analytics (CMAs) are also very helpful in improving airport facilitation. Advanced analytics predict equipment needs in maintaining and managing crowd flow within the airport. The passenger's data analysis, including their movement through the terminal, allows optimal workforce and other resource allocation. The IoT must be implemented at all airports as this is one of the cutting-edge tools to organize and control the seamless flow and movement of passengers or any other persons who are staying at the airport (for various reasons using the infrastructure of the airport such as restaurants, shopping and business centers, post office, restrooms, etc.). It can be used to identify and disperse these people. It also helps to organize the workforce as there are different operational periods every day when more people use the airport facilities. If the passenger numbers increase, more

workforce is needed to support the operations (every 1000 additional passengers at the airport require a minimum of 20 more operational staff).

Block chain technology: This technology, at this stage does not enhance airport security but plays a vital role, for example, in aircraft management and maintenance as provides a secure record of the aircraft or engine maintenance and repair status, underwrites the spare parts and other components information, and records all critical information.

These smart technological applications in aviation benefit not only all airport operations efficiently and safely, but also passengers, since they ensure a comfortable journey with less disruptions and stress. For example, smart technologies guarantee the required level of protection, while maintaining a smooth passenger flow (advanced passenger information (API) system, smooth identity and security checks) and the highest level of passenger experience (data criterion, less delays, calm and comfortable procedures from home till arriving at the next destination). These all promote the good reputation of the airport, which is valuable for all parties.

3.1. Improvement of airport facilities and security control with the support of smart technologies

The introduction of smart technologies has made tangible progress in airport facilities and security control. Smart technologies have helped to enhance security sophistication at the airport. Sophisticated surveillance systems, AI-enabled threat detection (e.g., supplying information to make profiles, identifying the blacklisted passenger), and biometrics have definitely increased the existing level of security. The technologies will enable the identification of higher levels of security threats more accurately and efficiently, which ensures greater safety for those travelling. For example, AI-based systems can handle large amounts of data from diverse sources for a relatively short period to identify prospective safety failures. Smart technologies help to improve operational efficiency at airports vis-à-vis time-consuming outdated applications. Smart technologies replace manual operations in almost all airport processes, leading to tremendous operational and financial efficiencies. Right from automated check-ins and boarding, through baggage screening systems, which are intelligent or AI for scheduling resource management in minimizing bottlenecks and passengers flowing with their baggage. This kind of effectiveness will not only reduce the cost of operation but also increase the capacity of airports, which handle high amounts of passengers as well as flights.

Smart technologies also ensure improved passenger experience. Using technologies, including mobile boarding passes, biometric verification and real-time baggage tracking have dramatically improved the passenger experience. Through these technologies, passengers are now provided with greater convenience and ease regarding travelling, reduced waiting time, they also have more control and access to information and to the airline lounge (as the system can identify the frequent-flyer passengers), which relatively ease stress associated with travel. Smart technologies also support sustainability enhancements.

Namely, smart technologies raise the sustainability of all airport operations to a new level. This entails efficient use of resources (energy and water), facilitating

improved waste management as well as bringing about a reduction in carbon footprints associated with airport operations. For instance, smart lighting, Heating, Ventilation, and Air Conditioning (HVAC) systems adjust automatically, with reference to actual occupancy levels, which reduces energy consumption. Airports also provide improved and enhanced emergency and crisis management with the support of smart technology. In addition, using smart technologies in airports improves the capacity to handle emergencies and crises. Applications providing real-time analysis of data and communication facilities assist rapid decision-making and efficient management of resources in an emergency environment, thereby ensuring higher security and safety for passengers and operational staff.

3.2. Advantages, challenges and limitations of smart technology implementation at airports

The use of smart technologies at airports includes a range of advantages and disadvantages, each affecting varied sections of airport functions as well as passenger experiences.

The authors interviewed Dr Sultan Al Shamsi, Director of Quality Assurance at Sharjah International Airport (SHJ), who shared his views about the advantages and limitations of these systems. According to him, in the smart system implementation, the main challenges are effective training, technology, regulations and risk management (with a comprehensive contingency plan).

3.2.1. Advantages

There are huge numbers of advantages provided by the new facilitation environment. The most important one is the efficient operational environment and enhanced security measures. The smart technology reduces the need for human presence (the operational staff will be present but in the control rooms), which means there will be less human error and crowds in the terminal. Self-check-in and biometric passports are automatized, so passengers can embark the aircraft (smart gates) without meeting operational staff. This will provide more environmentally-friendly and sustainable surroundings (e.g., not all employees will need to travel to the airport).

Smart technologies automate routine tasks that require human intervention in processes, including check-in, security checks and baggage handling. Through automation, operational smoothness is ensured, drastically reducing waiting time at different service nodes, positively affecting capacity utilization. With AI-based security tools and enhanced surveillance systems, threats can be detected more aptly and effectively. Unauthorized persons cannot enter the Terminal, also those who are hanging around for more than 5–7 h at the airport will be identified. The biometric verification systems add up to an extra level of security, which prevents identity theft and unauthorized use.

Cost savings and revenue generation are other advantages (**Figure 2**). Despite the high installation costs of smart technologies, in the long run, such technologies could result in drastically lower operational expenditures similar to turnaround operations. Secondly, delightful passenger experiences translate into augmented revenues as contented passengers spend more willingly within airport facilities, evaluating their value-for-money experience. On top of that, smart technologies improve the flying

experience as well. Travelers experience shorter waiting times with an improved level of convenience through accessing several other aspects of their travel. This is because, with the employment of different technologies like mobile boarding passes, real-time information on flights, personalized communication tools, smart baggage reclaim areas, travelers receive the most current information on time and other essential details they need while travelling.

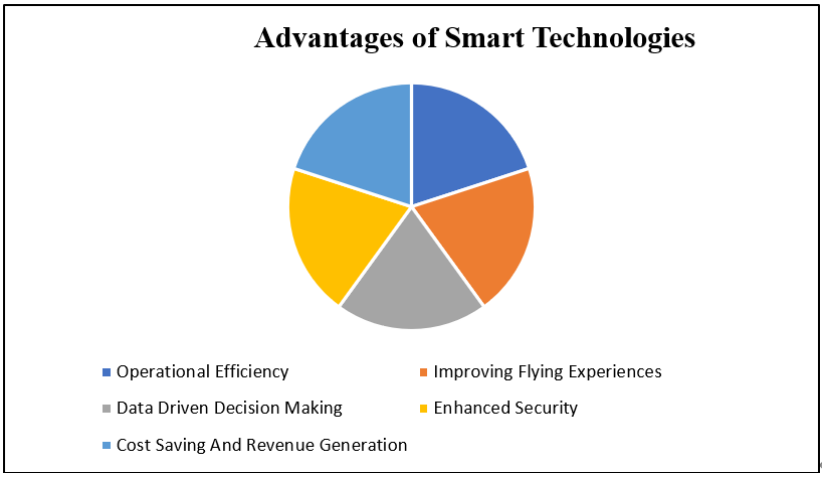

Figure 2. Advantages of smart technologies.

Data-driven decision-making is data-rich, while analytics-driven decisions on airport management are better-informed. Such data can be used to allocate resources more efficiently, schedule better, or even consult what development or services are to be provided whenever.

3.2.2. Challenges

One of the main challenges is privacy threats: using biometric data and too much surveillance threaten passengers' privacy. Airports need to ensure that they follow the rules for protecting the data and particulars of passengers properly. Also, there is a high concern about the costly implementation: in most cases, installing smart technologies may be costly, particularly for smaller airports. Accordingly, high implementation costs include capital outlays as well as long-term low maintenance and upgrade costs.

Data need to be used for authorized goals and civil aviation purposes, since on the one hand, this access needs to be limited, on the other hand, such access needs to be legally protected. Therefore, the national civil aviation authority in the security programme needs to identify the critical information and communications technology systems (ICAO Annex 17, 2022, Chapter 4, 4.9).

These data need to be protected by law. The procedure needs to protect the privacy and data of the concerned individuals via the Passenger Name Record (PNR) and the Advanced Passenger Information (API) systems (ICAO Annex 17, 2022, Chapter 9, A-B). Data-sharing does not mean jeopardizing the human rights of the passengers, operational staff or ground personnel [e.g., during the 100% X-ray full-body screening, the sensitive areas of the human body need to be covered. Nevertheless, the use of the full-body scan at airports does not cause unnecessary delays for the passengers since shoes and clothes do not need to be taken off, while

the examined persons are affected by such extent of radiation to which they are exposed during flight at cruising altitude within 10–15 min (Sipos, 2024).

Technology dependence and vulnerabilities are of concern as they are evolving so fast. With the increasing automation of various airport processes, over-dependence on technology can create vulnerabilities, mainly if the systems fail or are subject to cyber-attacks. Better contingency (backup) plans need to be framed by risk management for the occurrence of such crises (e.g., cyberattack, data manipulation, or just simple system breakdown), along with better protection of cybersecurity on an emergency basis. These technological inventions, tools and devices need to be utilized by professional workforce. Automating processes may either entail the loss of jobs or require the retraining of the workforce. Care has to be taken to manage such transitions in such a manner that not only does the work need to be carried out efficiently, but this change should not affect staff morale, either.

Using virtual metaverse visualizations and simulations by ground personnel (e.g., maintenance, repair and overhaul staff) to identify and solve problems, streamlines the process of performing aircraft upkeep and repairs. Computer-based learning systems are slowly eradicating the time-consuming manual labor, which allows for better and more efficient maintenance practices (Jiang et al., 2023). Additionally, the new "Metaverse" technology, which has lots of benefits in the aviation industry, enables real-time data and surveillance of aircraft, operational staff and belongings. This improves airline and airport services. The approach improves the entire client experience by reducing downtime, performing real-time decision-making and increasing efficiency (Alshamsi and Sipos, 2024).

These can all raise the issue of the complexity of proper integration. This means that integrating new technologies with the systems already in function is complex. Colleagues find problems while working on integrated technologies, and there might also be compatibility issues. The workforce also requires training in a change of systems; to which they have to adapt.

3.2.3. Limitations

As beneficial as being realized, integrating smart technologies in air transport also comes with its limitations, which must be well thought-over and managed.

First of all, technological limitations and reliability issues are in the focus. Not all smart technologies can be perfect. Problems like system reliability, the accuracy of biometric systems, or the efficacy of AI algorithms can raise issues. Furthermore, keeping pace with the rapidly developing technology to avoid obsolescence is another significant issue.

Moreover, financial and human factors are essential to manage. Implementing state-of-the-art technologies may be significantly hindered by costs. It is not only the capital investment in technology that is high but also the costs of maintenance, update, and training, among others. Many airports, especially second-tier airports cannot afford it, they lag behind due to financial incapacity. The implementation of new technologies also poses different human factors as barriers. Operational staff may be scared of the lack of job security or the process of learning to work with the new systems, whereas passengers are likely to be worried about privacy issues and the inability to use new technologies.

Standardization and interoperability are the most significant challenges posed by the new systems, which may not work with the currently existing technologies and processes. Furthermore, standardization in data sharing and biometric recognition may be required in order to ensure that different airports and airlines can work together without malfunction and serve them effectively and efficiently. This cooperation needs to be supported by regulation and clear compliance achievements. Different international and national regulations always emerge as very challenging to airports, especially in issues related to data protection and privacy.

Nowadays, the most significant task from the technical and regulatory viewpoint is minimizing cybersecurity risks. "The aviation industry remains a prime target for terrorist organizations that are seeking a visible, damaging impact on significant public infrastructure. These terrorist groups have primarily used the Internet for planning, collecting intelligence, recruitment, financing, and advertisement" information (Cohen, 2010). Airport digitization and interconnectivity eliminate threats from cyber sources. An airtight cybersecurity posture needs to be maintained to ensure that the data and processes are not compromised.

These limitations on smart technologies also indicate the necessity for a balanced and judicious approach to implementing them within airports. A proper set of steps should be taken so that such limitations are reasonably overcome, and the full potential from the appropriate adoption of smart technologies can be leveraged within air terminals.

However, there is a lack of regulatory requirements, which impedes unity in this area. Currently, there are no international, legally binding treaties or procedural requirements to regulate interstate relations in cyberspace.

Given the importance of cyber-technologies to the operational integrity of the aviation industry, the sector has relied on the guidelines and procedures of a non-governmental organization, to wit, the International Air Transport Association (IATA) [e.g., IATA Compilation of Cyber Security Regulations, Standards, and Guidance Applicable to Civil Aviation (2020); IATA developed its IOSA Standards and Recommended Practices (ISARPs) for Cybersecurity, Safety, Security and Airworthiness (CSSA)].

4. Legal perspectives

The regulatory perspective presents a clear challenge. Technology is always ahead of law, which has not only disadvantages. The legislator can frame suitable and reliable regulations in the knowledge of how the new technology works and serves the society. Some guidelines and procedural provisions already prevail, but regulations need to be more international to unify rules in this area.

The legal framework surrounding the adoption of smart technologies at airports is multi-layered, addressing compliance and ethical concerns, with a significant focus on the Standards established by ICAO. One important legal implication of smart technologies is data protection and privacy laws. Incorporating biometric data processing and other smart technologies at airports raises profound privacy concerns. Compliance with various data protection regulations, like the General Data Protection Regulation (GDPR) [Regulation (EU) 2016/679] in Europe, is essential. These laws

set forth stringent requirements for collecting, using, and storing personal data, emphasizing the need to safeguard passenger information sufficiently. It is also necessary to ensure compliance with ICAO Standards. ICAO is instrumental in defining global norms for aviation safety, security, and efficiency. Airports integrating smart technologies must conform to ICAO's SARPs, including those specified under ICAO's Annex 17, which stipulates security standards in order to protect international civil aviation from unlawful acts [ICAO Doc 8973 Aviation Security Manual (Restricted), 2022]. The provisions of Annex 17 "shall not preclude the application of national legislation with regard to aviation security measures or other necessary controls" (ICAO Annex 9, 2022, General Principles).

Cybersecurity regulations [e.g., Regulation (EU, Euratom) 2023/2841] also play a vital role in the adoption of smart technologies (Scott, 2019). The digital transformation of airports requires strict adherence to cybersecurity regulations to prevent unauthorized data breaches and cyber-attacks, ensuring the resilience of operational systems. ICAO provides guidelines to establish comprehensive cyber defense strategies for airports. Adopting smart technologies is essential to ensure ethical considerations in technology use. The deployment of surveillance technologies and the handling of personal data raise ethical concerns, including transparency in data use and upholding passengers' rights to privacy. The adoption of any new technology or innovation should facilitate interoperability and standardization.

To maintain the integrity of global aviation operations, ICAO stresses the need for the interoperability of smart technologies across different airports and airlines. This ensures seamless integration into the international aviation infrastructure, adhering to universal standards for efficiency and compatibility. Any technological change or improvement and introducing novel technologies require the obtainment of "regulatory approvals and certifications" (processes by which new technologies or systems are assessed, approved and certified to ensure that they conform to regulatory and safety standards), the confirmation of adherence to established safety and operational criteria. This can involve intricate processes involving various regulatory entities. As a global industry, air transport necessitates international collaboration and coordination. ICAO advocates a collaborative international approach in aviation, which is particularly relevant when implementing smart technologies in airports. The implementation of a unified technology adoption strategy requires coordination among diverse global stakeholders, including air carriers, other airports, and governmental agencies. The adoption of any new technology should be based on legal liability and responsibility. Legal obligations and accountability are associated with the deployment and operation of smart technologies in airports, including liability for potential technological failures or security breaches.

From a liability viewpoint, it should be highlighted that, on an international level, there have been no uniform liability rules for damages caused by aviation industrial performers such as international airports, aircraft manufacturers, air navigation service providers (ANSPs), maintenance, repair and overhaul companies (MROs), the ground handling service providers, the travel and transport service providers (agents), civil aviation authorities (CAAs) etc. (Sipos, 2024). An international liability regime exists only for air carriers, regulated by the Warsaw Convention (1929) and its amendments (so-called Warsaw System, Sipos, 2019); furthermore, the "new" Montreal

Convention (1999) for the Unification of Certain Rules Relating to International Carriage by Air (ICAO Doc 9740, Montreal, 1999). For example, in the case of product liability or security issues and any other legal disputes related to these areas, the national statutes and legislation are applicable. In addition, the Montreal Convention (which replaced the Warsaw System and prevails over any other rules that apply to international carriage by air) has no provision for smart technology in airports or liability arising from related activities. Based on this, the Montreal Convention (1999) for this field is not applicable; therefore, the national laws prevail (Sipos, 2021).

Airports need to assume the legal intricacies related to liability and accountability, particularly in scenarios involving technological failures or security lapses. It is imperative to manage these risks to ensure the seamless functioning of smart technologies. This legal landscape underscores the importance of a meticulous, well-considered legal approach to integrating smart technologies in airports on the national level, balancing innovation with legal, ethical and operational imperatives.

5. Conclusion

In conclusion, implementing smart technologies in airports is a critical step towards addressing the current challenges in airport facilitation and security control. While the benefits of these technologies are significant, it is equally important to acknowledge and manage the associated drawbacks and limitations. A balanced approach, focusing on technological innovation, operational efficiency, passenger satisfaction as well as compliance with local and international legal requirements is essential for integrating these technologies successfully. As airports continue to develop and adapt to these smart solutions, they pave the way for a more secure, efficient and passenger-friendly future in air travel.

The smart airport is an autonomous solution. It requires high financial investment to put into service the state-of-the-art technology, but the benefits highlighted in this paper speak for themselves. In addition, these advantages are not only operational, but at the same time financial. Cost savings can be identified through better operations planning and efficiency. The authors' purpose was the introduction of the technological and operational developments of Smart Airports in compliance with the relevant legal challenges.

The importance of this technology is that it can be more efficient if the systems are connected and create a simplified system. Smart technology needs to be integrated. The "smart" system integration is the next step to be taken not only at one airport but in accordance with other national airports. On an international level, the integration is not feasible as security data and information are very sensitive and complicated, as well as foreign airports operate in different jurisdictions, furthermore, smart technology is not available for all (mainly for financial reasons), in addition, facilitation levels are diverse in different airports and depend on many factors. Such integration is based on unified and harmonized regulations, and the main concern is the lack of the regulatory background. The relevant ICAO 9 and 17 Annexes contain Standards and Recommended Practices in general, which means that the legislator on the national level needs to regulate this newly emerged area from operational,

technological and human rights points of view. The ICAO Annexes need to be revised by the ICAO Council to comply with these newly emerged, more advanced and prevalent smart technologies.

All airports are different, although they all follow the ICAO SARPs and other international/national regulations, therefore, their operational and technological models are compatible. These differences can be harmonized by the uniform smart airport system. Some airlines operate under global alliances, to wit, they keep their brand and business model but cooperate to provide a seamless travel experience for their passengers. The airports can cooperate closely to operate more efficiently. However, if the airport is not smart, this may result in bad travel experience.

The Smart Airport system impacts all industry performers and persons, operating or staying at the airport, therefore, each entity needs to cooperate with one another, not only on a national but also on an international level. For this complex collaboration, relevant institutions with jurisdiction and competence need to exist. Institutional support is essential to guarantee adequate protection and rights for all parties concerned.

The future is clear: less human interaction and more automation. The safety, security and economic benefits together with operational/management advantages, are visible, but technology provides much more. These new technologies serve the interests of the travelling general public and the business community, the sustainable environment, the quality of life, and last but not least, the passengers with special needs who can also enjoy a seamless travel experience during the whole journey.

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