Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 6, 8611-8632
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i6.3848

Leveraging complex network theory to enhance IoT applications in airport management

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Abstract: The tremendous growth in air traffic and passengers has made airports busier than ever before. This change requires airports to become smarter, more responsive and more efficient to create a seamless airport experience. Airports are increasingly adopting a variety of digital technologies to manage and improve airport performance in terms of resource consumption, carbon emissions and overall passenger journey quality. This graduation project explores the concepts of smart airports and Internet of Things (IoT) technologies. The main objective of the project is to study specific technologies that will have a strong impact on the development of smart airports. The Internet of Things (IoT) technology forms the basis of this project as we believe it is the core technology behind smart airports. By connecting physical assets, equipment, people and applications, IoT plays a vital role in increasing operational efficiency, improving the passenger experience and creating new revenue streams for airports. The project also focuses on the role of specific digital technologies such as blockchain, biometrics, indoor positioning systems, cloud computing and big data in smart airports. The research methodology of the project is based on quantitative literature research with a focus on big data analysis, including white papers, articles, press releases, annual reports and various studies.
Keywords: *Airport, Digital transformation, Digitization, Internet of things, IoT, Cyber-security, Technology.*

1. Introduction

Technology has played a significant role in the airport industry over the past few decades. From mobile booking to self-service check-in kiosks, mobile passenger services, automated boarding gates, and automated passport kiosks equipped with advanced biometric technology, technology has revolutionized the way airports interact with passengers. Airports that are going "smart" are putting technology at the heart of their business strategies and embracing new technologies such as the Internet of Things (IoT), advanced biometric systems, big data, blockchain, cloud computing, BLE signals, and more. These technologies are playing a central role in transforming airports from Airport 3.0 to Airport 4.0. In this section, we will explore some of the specific technologies that are having a significant impact on the development of airports.

1.1. Internet of Things (IoT)

The Internet of Things (IoT) is a promising topic of economic, technological and social significance. It has the potential to drive technological, commercial and economic growth significantly over the next decade. The Internet of Things aims to enable ubiquitous communication between different objects (also called things). There is a comprehensive integration between these objects and humans. These objects become part of our lives, interacting intelligently with each other to perform daily operations and simplify human life (Evans D. 2011: 1-5). The Internet of Things can be explained from different perspectives. From a connectivity perspective, it is a connection to anyone, anytime, anywhere and anything. From a connectivity perspective, it is a global network of interconnected objects (things) that are uniquely addressed based on standard communication protocols. From a network perspective, the

History: Received: 08 November 2024; Revised: 16 November 2024; Accepted: 07 December 2024; Published: 23 December 2024
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Internet has evolved from a network in which computers are connected to each other to a network in which objects are connected to each other. Finally, from the perspective of services provided by things, this is a world in which things automatically communicate with computers and with each other (a process called machine-to-machine communication) to provide services for the benefit of humans (ILNAS, 2018: 12-15).

In general, it refers to business processes and applications that sense data, information, and content generated from the connected world through connected devices embedded in the Internet infrastructure.

While the Internet of Things (IoT) will eventually have a significant impact on customers, businesses, and society as a whole, it is still in its early stages of development. The adoption of IoT technology in various sectors such as airports, transportation systems, logistics, airlines, and air cargo can improve their current operational efficiency and interaction with consumers. The Internet of Things has an unparalleled ability to combine technology, people, processes, and culture to deliver a seamless air travel experience. It has enormous potential to fundamentally change airport business models. For example, trackers, wearables, virtual steam engines, and beacons can facilitate the passenger journey from entry to exit.

1.2. Overview of the Internet of Things

The Internet of Things (IoT) refers to the communication and interaction between uniquely addressable objects over the Internet. When we talk about the Internet of Things (IoT), we are talking about the interaction between digital and physical objects. In fact, the vision of the Internet of Things (IoT) is to connect the physical world with the digital world, and the goal is to create a new ecosystem, where smart devices can communicate with each other (M2M), direct their transmissions, adapt to their environment, self-monitor, self-control, self-improve, and ultimately play an active role in their disposal without unattended interactions (Fermisan and Fries, 2014: 20-24). The term Internet of Things is relatively new, but the idea of combining computers and the Internet to monitor and control devices has been around for decades. The term "Internet of Things" (IoT) was first proposed in 1999 by Kevin Ashton, CEO of the Massachusetts Institute of Technology (MIT) Center for Automatic Identification, a research institution in the field of radio frequency identification (RFID). Ashton uses the term "Internet of Things" to describe a system in which objects in the physical world can be connected to the Internet through sensors. He coined the term to illustrate the possibility of radio frequency identification (RFID) tags being connected to the Internet to count and track shipments without human intervention (Rain RFID, 2015). In general, the term IoT covers everything that is connected to the Internet, but it is often used to define objects that "talk" to each other. The "things" in the IoT are the everyday objects in our homes, offices, and cars. In the case of aviation, this "thing" could be anything in an airport lounge or airport that is simply connected to the Internet. Network-enabled devices that use embedded processors, sensors, and communications hardware to receive, send, and process data collected from their surroundings are part of the IoT. These smart devices, or commonly referred to as connected devices, can communicate with each other through a process called machine-to-machine (M2M) communication and take actions based on the information they receive from each other.

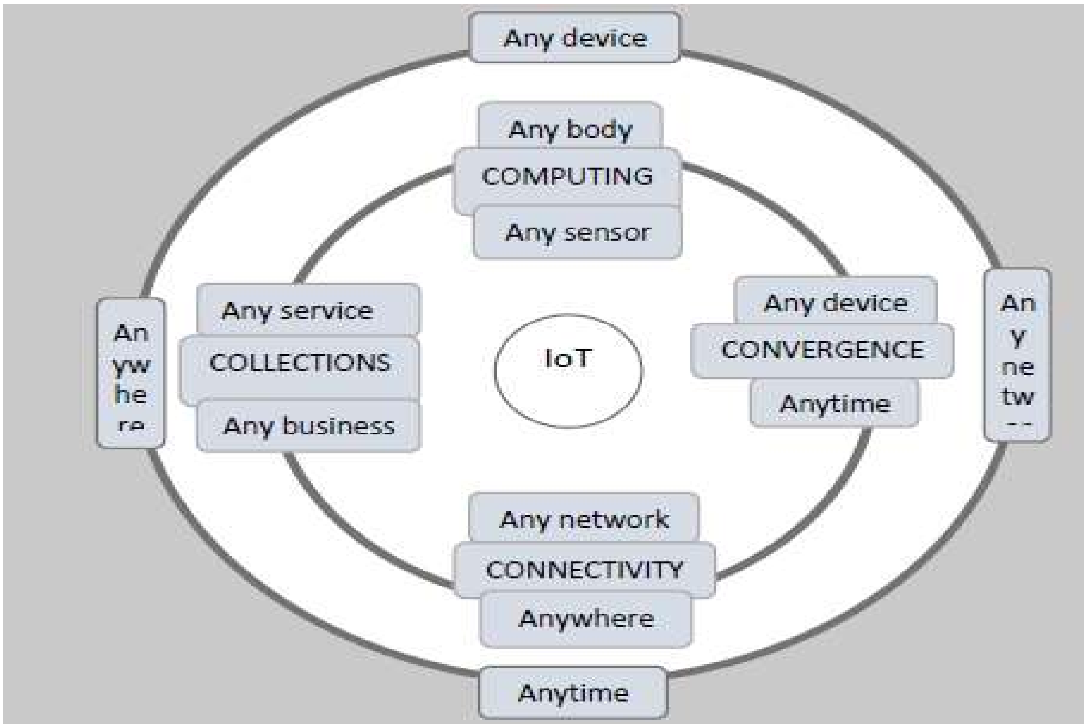

Figure 1.
The concept of the Internet of Things. A represents the globalization of technology (anytime, anywhere, any device, any network, etc.), and C represents the characteristics of the Internet of Things, such as aggregation, integration, communication, computing, etc. (ILNAS, 2018: 17).

1.3. Components of the Internet of Things

The Internet of Things consists of different components as shown in Table 1.

ISSN: 2576-8484
Vol. 8, No. 6: 8611-8632, 2024
DOI: 10.55214/25768484.v8i6.3848

Table 1.

IoT Components	Description
Sensors	Sensors have the capacity to sense the physical environment
Human	Human can act both as consumers and generators of data.
Actuators	These devices are used to manipulate the physical environment.
Physical objects	Devices(things)
Networking components	The elements of IoT are connected together by networks, using different wireless and wireline technologies, standards, and protocols to provide connectivity.
Virtual objects	Single Token ID, Digital wallet
Data storage and processing	Cloud computing can be an example of data storage and processing technology that is used for: • Processing big data and transforming it into valuable information • Building and running smart applications
Platforms	The middleware used to connect elements such as physical objects, human, and services to the IoT.

These components or devices are connected across networks through different communication technologies, such as wired (Ethernet cable) and wireless (Wi-Fi, 3G, 4G/LTE) technologies (IEC, 2016: 21-30).

1.4. Application areas of the Internet of Things

The Internet of Things (IoT) has brought a high level of technological capabilities to various consumer, commercial and industrial market segments. It is actually impossible to provide a complete and comprehensive overview of all possible applications of the Internet of Things, as the Internet of Things ultimately affects almost every aspect of human life. Application use cases exist in commercial aviation, smart airport industry, industrial services, smart cities, etc. (Table 2) (Kumar, 2016).

Edelweiss Applied Science and Technology
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Table 2.
Components of the internet of things.

Domain	Sub-domain	Example
Smart Cities	Smart Airport	Identity token management
		Automation of check- in desks, baggage collection, and security screening processes
		Asset tracking, asset Performance Management and queue management.
		Enable homeowners to optimize systems such as lighting.
	Smart Buildings/Smart home	Use intelligent sensors to detect temperature changes
		Monitoring and adjusting building systems
	Smart Transport	smarter route mapping to avoid congestion
		Connected and automated driving
		Traffic signal control system
Healthcare	Medical and Healthcare	Simultaneous reporting and monitoring of patients
		Provide care for patients in their home

1.5. IoT in Airport

It's no secret that airports as an industry rely heavily on the availability of a constant stream of data that enables smart decision-making and efficiency in day-to-day operations. Any technology that makes this possible, such as the Internet of Things, is almost always welcomed by airport management. The Internet of Things (IoT) helps airport management instantly access the information they need to improve passenger experience and efficiency operations, such as enabling staff to deal promptly and effectively with airport issues that affect passengers. This includes customer relations, maintenance and security personnel. The Internet of Things (IoT) has already had a significant impact on the airport industry, helping airport management move beyond focusing on aviation revenue alone. By connecting physical assets, equipment, people and applications, the Internet of Things plays a significant role in improving operational efficiency, enhancing the passenger experience and creating new revenue streams for airports.

However, the vision of the Internet of Things goes beyond simply generating new revenue and a better passenger experience. It has the potential to define a new vision for the airport industry as airports become increasingly smarter, aiming to bring about significant paradigm shifts in the overall airport and passenger experience (Allen. 2018; Brizzio 2018). The combination of smart airport applications and IoT-based services can create and enhance the following services:

Instant travel and smart transportation services: For example, keeping travelers informed about flight cancellations, delays, or other travel issues, airport parking availability, tracking travelers throughout their journey at the airport, and providing pre-flight travel information via Wi-Fi or GPS-enabled devices. The device provides information and route suggestions based on traffic conditions and flight status.

- Device tracking solution: Helps airport management track mobile devices to improve device availability and usage. For example, airports can use RFID technology to track wheelchairs to help reduce waiting times for arriving passengers who require wheelchair assistance.
- RFID baggage tags: Airports can use RFID tags to detect baggage within a certain range or beyond, making it easier to find lost or missing baggage and provide real-time location information to passengers.
- Fleet management: Connected vehicles enable better fleet management through sensors and devices embedded in the vehicle. Officers can continuously track the location, status, and movement of each vehicle in real time, and can identify potential vehicles.

and resolve issues before they actually impact operations. Data collected from sensors and devices can be used to develop new business models.

1.6. Leveraging Complex Network Theory to Enhance Iot Applications in Airport

Leveraging complex network theory in the context of Internet of Things (IoT) applications for airport management involves understanding and optimizing the intricate relationships and interactions among various components within an airport ecosystem. Complex network theory provides a framework for analyzing how different entities (such as sensors, devices, systems, and stakeholders) are interconnected, which can lead to improved efficiency, safety, and passenger experience.

2. Key Concepts of Complex Network Theory

1. Nodes and Edges: In a complex network, nodes represent entities (e.g., IoT devices, passengers, gates), while edges represent the relationships or interactions between them (e.g., data exchange, physical connections).

2. Network Topology: The arrangement of nodes and edges can influence the performance of the network. Understanding the topology helps identify critical nodes that, if optimized or enhanced, can significantly improve overall system performance.

3. Centrality Measures: These metrics help identify the most influential nodes in the network. For example, a sensor that monitors passenger flow may be a central node that can provide valuable data for decision-making.

4. Community Detection: This involves identifying groups of nodes that interact more frequently with each other than with those outside the group. In an airport context, this can help in understanding passenger behavior patterns and optimizing services.

2.1. Enhancing IoT Applications in Airport Management

2.1.1. Real-time Passenger Flow Management

- Example: By deploying IoT sensors throughout the airport (e.g., at check-in counters, security checkpoints, and boarding gates), data on passenger movement can be collected in real time.

Using complex network theory, airport management can analyze these data streams to identify bottlenecks and optimize staff allocation or adjust flight schedules dynamically.

Table 3.
Aircraft movements.

		Air Transport Total	Of Which Air Taxi	Positioning Flights	Local Movements
London Area Airports					
GATWICK	17,648	17,336	10	234	-
HEATHROW	36,453	36,228	13	189	-
LONDON CITY	4,254	4,182	267	30	-
LUTON	9,228	7,043	-	38	6
SOUTHEND	1,694	133	15	6	13
STANSTED	13,773	12,687	111	368	-
Total London Area Airports	83,050	77,609	416	865	19
EDMISTON LONDON HELIPORT	420	121	121	61	-

Table 4.
Trans moves by type.

		UK Operators	Other EU Operators	Other Overseas Operators
London Area Airports				
GATWICK	17,470	11,395	3,821	1,533
HEATHROW	36,742	20,661	6,739	9,183
LONDON CITY	3,991	2,538	1,168	285
LUTON	7,050	4,370	2,480	118
STANSTED	12,703	1,761	9,411	1,324
SOUTHEND	120	8	90	22
Total London Area Airports	78,076	40,733	23,709	12,465

2.2. Predictive Maintenance of Airport Infrastructure

- Example: Sensors can monitor the condition of critical infrastructure like runways, baggage handling systems, and boarding bridges. By modeling these systems as complex networks, airport operators can predict failures before they occur by analyzing patterns in the data from various sensors, thus enhancing operational efficiency and safety.

Table 5.
Air transport movements.

	EU (c)					Other International				
	Total	Scheduled		Charter		Total	Scheduled		Charter	
	EU International	All Aircaraft	Passenger Aircarft	All Aircaraft	Passenger Aircarft	Other International	All Aircaraft	Passenger Aircarft	All Aircaraft	Passenger Aircarft
London Area Airports										
GATWICK	10,913	10,455	10,455	458	458	4,644	4,387	4,387	257	257
HEATHROW	15,866	15,735	15,657	131	17	17,615	17,589	17,420	26	10
LONDON CITY	2,735	2,735	2,735	-	-	467	467	467	-	-
LUTON	4,821	4,739	4,643	82	39	1,496	1,496	1,492	-	-
STANSTED	10,084	10,007	9,666	77	76	1,751	1,733	1,357	18	13
SOUTHEND	90	90	90	-	-	30	30	30	-	-
Total London Area Airports	44,509	43,761	43,246	748	590	26,003	25,702	25,153	301	280

2.3. Enhanced Security Monitoring

- Example: Security cameras and sensors can be integrated into a complex network to monitor passenger behavior and detect anomalies. By applying network analysis techniques, airport security can identify potential threats more effectively by understanding typical patterns of movement and interactions among passengers.

Table 6.
Air pax by type and Nat of Op.

		Scheduled Services					
	Total Terminal and Transit	UK Operators		Other EU Operators		Other Overseas Operators	
	Passengers	Terminal	Transit	Terminal	Transit	Terminal	Transit
London Area Airports							
GATWICK	2,772,374	1,748,461	395	587,052	-	291,091	327
HEATHROW	5,801,997	3,101,699	-	751,873	-	1,938,042	6,364
LONDON CITY	251,844	167,830	-	61,138	-	22,876	-
LUTON	1,136,905	689,934	-	425,066	90	15,190	-
SOUTHEND	15,457	894	-	11,702	-	2,861	-
STANSTED	1,919,756	265,446	-	1,496,837	-	142,639	-
Total London Area Airports	11,898,333	5,974,264	395	3,333,668	90	2,412,699	6,691

2.4. Optimizing Resource Allocation

• Example: Analyzing the interactions between different airport services (e.g., check-in, security, customs) using complex network metrics can help determine where additional resources are needed during peak times, allowing for better staff scheduling and resource distribution.

Table 7.
Terminal and transit passengers.

	< Terminal and Transit Passengers >			<------ Terminal Passengers ------>		
	February 2024	February 2023	Percentage Change	February 2024	February 2023	Percentage Change
London Area Airports						
GATWICK	2,772,374	2,405,123	15	2,771,652	2,405,015	15
HEATHROW	5,801,997	5,200,424	12	5,795,633	5,194,577	12
LONDON CITY	251,844	226,255	11	251,844	226,255	11
LUTON	1,136,905	1,069,833	6	1,136,815	1,069,833	6
SOUTHEND	15,457	-	..	15,457	-	..
STANSTED	1,919,756	1,711,580	12	1,919,756	1,711,580	12
Total London Area Airports	11,898,333	10,613,215	12	11,891,157	10,607,260	12

2.5. Smart Baggage Tracking

- Example: IoT tags on luggage create a network of baggage movements throughout the airport. By analyzing this network, airports can optimize baggage handling processes, reduce lost luggage incidents, and improve overall passenger satisfaction.
- Integrated Transportation Systems:
- Example: Airports often serve as hubs connecting various transportation modes (taxis, buses, trains). By modeling these connections as a complex network, airports can enhance coordination among different transport services, improving the overall travel experience for passengers.

3. Indoor Positioning System (Beacon Technology)

Indoor positioning systems estimate the user's indoor location to provide the services they need. Since GPS is unreliable indoors due to the lack of visual contact with GPS satellites, indoor positioning systems (IPS) must use other methods of positioning. These include, for example, the typical consumer-grade Wi-Fi or Bluetooth Low Energy (BLE) beacons, but also ultra-wideband (UWB) or RFID-based solutions (Figure 2). With so many passengers carrying smart devices these days, beacons are the ideal way for airports to communicate with them – providing information to help them enjoy a lighter, stress-free journey, and collecting data on habits and behaviors to help airports deliver better, interactive experiences and personalized travel experiences.

Beacons also help airports and airline service providers gain the visibility and compliance they need to deliver better, faster passenger service and reduce service costs. From wheelchair assistance to station cleaning and cabin appearance, all types of support services can be improved with beacon technology.

ISSN: 2576-8484
Vol. 8, No. 6: 8611-8632, 2024
DOI: 10.55214/25768484.v8i6.3848

3.1. BLE-Beacon Technology

Bluetooth beacons transmit low-power signals that can be received by nearby Bluetooth devices, such as smartphones and tablets. Beacons themselves do not collect data. They broadcast short-range signals that can be read by Bluetooth devices near the beacon (Starling. Stephany. 2014: 2-5).

In many cases, beacons can provide mobile devices with more accurate location information than alternative technologies such as Wi-Fi, GPS, and cell tower triangulation. Importantly, beacons also work in remote areas, allowing them to be used in a variety of smart airport applications, such as displaying mobile boarding passes on smartphone screens when passengers arrive. In some cases, the mobile device may need to use a cellular or Wi-Fi connection to display relevant content, while in most cases the application can simply pull content from a local cache (Starling and Stephany, 2014: 2-5).

2.2. Airport Beaconing Implementing beacons at airports can provide a range of low-cost opportunities to communicate with passengers, such as: Passenger location: Airlines in particular, whose apps are stored on passengers' phones, will be able to integrate data from the apps to know exactly where passengers are at the airport, such as their identity, destination and class of travel, by detecting the nearest beacons. This not only helps to send relevant messages to passengers, but also helps to find them at the airport if they are late to the gate. There are many benefits to using beacon technology. Ultimately, it can help service providers communicate more actively with passengers in this area, and we will detail some of the benefits of using tracking beacons at smart airports (SITA, 2014; ACI and IATA (no date): 9-11).

Mobile boarding passes: Beacons installed at passenger touchpoints such as check-in, passport control, baggage drop, and boarding gates can be used to "pull" mobile boarding passes onto the passenger's mobile device on screen.

- Airport passenger navigation: Beacons can provide airport operators with a more reliable and cost-effective way to guide passengers through the terminal and to the correct gate. There are alternatives to indoor mapping using triangulation technologies such as cell phone signals and Wi-Fi, but when deployed correctly, BLE-based beacons can provide more accurate information and require less complex infrastructure. For example, passengers with BLE-enabled mobile devices can receive GPS locations from all nearby beacons and use the data in a mapping app to navigate the airport.
- Proximity and proximity marketing: Beacon technology can help retailers inform customers near the store about their discounts or products, or they can send welcome messages and coupons to customers' mobile devices as they enter the store.
- Baggage claim: Deploying guidance technology in baggage claim areas can provide a stress-free experience for passengers waiting for their baggage, for example, a message can be sent to arriving passengers telling them which carrier their baggage will be on and how long it will take them to wait.
- relationship between indoor positioning systems (beacon technology) and complex network theory to enhance Internet of Things applications in airport management
- Indoor positioning systems (IPS), particularly those using beacon technology, play a crucial role in enhancing Internet of Things (IoT) applications in airport management. By leveraging complex network theory, these systems can optimize various operations within an airport, improving passenger experience, operational efficiency, and safety. Here's how the relationship between beacon technology and complex network theory can manifest in airport management:
- Relationship Between Indoor Positioning Systems and Complex Network Theory

3.2. Nodes and Edges

- In an indoor positioning system, beacons (Bluetooth Low Energy devices) act as nodes that transmit signals to mobile devices carried by passengers. The connections (edges) between beacons and devices form a network that can be analyzed to understand passenger movement patterns and interactions within the airport.

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3.3. Data Collection and Analysis

- Beacons collect data on the location and movement of passengers and their devices. This data can be modeled as a complex network, where the flow of information and interactions among passengers, services, and infrastructure can be studied. This analysis helps identify trends, bottlenecks, and critical areas needing attention.

Table 8.
Domestic air pax traffic route analysis.

	Scheduled 2024	Charter 2024	Total 2024
London Area Airports			
GATWICK	207,641	206	207,847
HEATHROW	386,157	94	386,251
LONDON CITY	53,732	-	53,732
LUTON	94,483	-	94,483
STANSTED	111,243	-	111,243
Total London Area Airports	853,256	300	853,556

3.4. Centrality and Influence

- Certain beacons may serve as key points in the network (e.g., near security checkpoints or boarding gates). Using centrality measures from complex network theory, airport management can identify these influential nodes to enhance services or direct resources effectively.

3.5. Community Detection

- By analyzing the interactions among passengers through their connections to various beacons, airports can detect communities or clusters of behavior (e.g., groups of passengers traveling together). This information can be used to tailor services to specific passenger needs. | Examples of Enhancing IoT Applications in Airport Management

3.6. Real-time Navigation Assistance

- Example: Beacons placed throughout the airport can provide real-time navigation assistance to passengers via mobile apps. By analyzing the network of beacons, airports can offer personalized directions to gates, lounges, or amenities based on passenger location. Complex network analysis can help optimize beacon placement for maximum coverage and minimal signal interference.

Figure 2.
Air Transport Movements data for chart.

3.7. Crowd Management and Flow Optimization

- Example: By monitoring the density of devices connected to different beacons, airport management can assess crowd levels in real time. Complex network theory can help model passenger flow, allowing for proactive measures such as redirecting passengers to less crowded areas or increasing staff presence where needed.

3.8. Enhanced Security Protocols

- Example: Beacons can track unusual patterns of movement, such as groups lingering in restricted areas. By applying network analysis to these patterns, security teams can identify potential security threats quickly and allocate resources accordingly.'

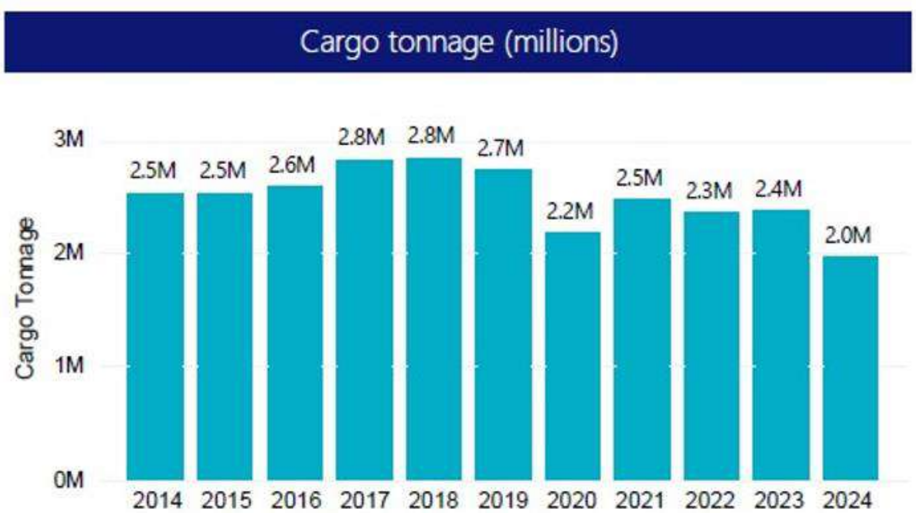

Figure 3.
Annual terminal passengers (millions) data for chart.

3.9. Personalized Marketing and Services

- Example: When passengers enter a specific area covered by beacons, they can receive tailored promotions or information about nearby shops and services. Analyzing the network of interactions between passengers and beacons helps airports understand which promotions are most effective based on passenger behavior.

3.10. Baggage Tracking and Management

- Example: Beacons attached to luggage can provide real-time tracking information as bags move through the airport. By modeling the baggage flow as a complex network, airports can optimize baggage handling processes, reduce lost luggage incidents, and enhance overall operational efficiency.

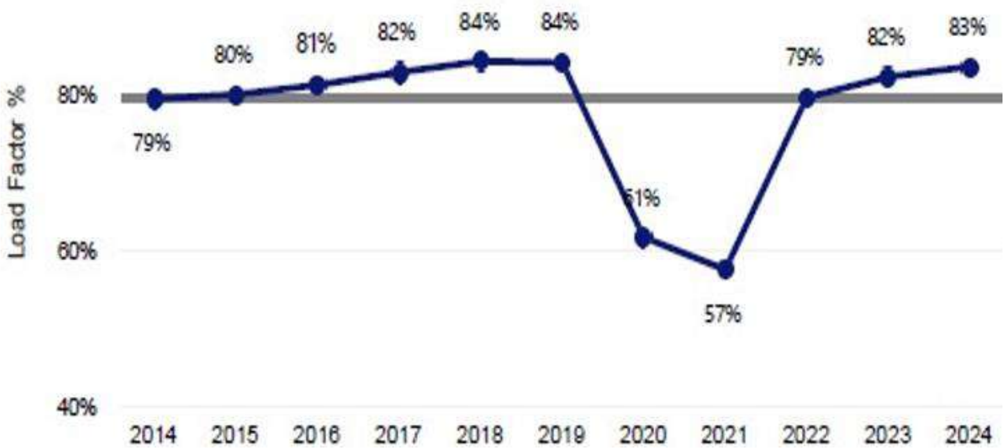

Figure 4.
Cargo Tonnage data for chart Average load factor (%).

3.11. Integration with Other IoT Devices

- Example: Beacons can interact with other IoT devices (like smart kiosks or digital signage) to provide context-aware information based on passenger location. Complex network theory can help in designing these interactions efficiently, ensuring that information is delivered at the right time and place.

Figure 5.
Average seats per flight.

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4. Biometric Technology

Multiple checkpoints operated by different stakeholders and stringent security measures make it difficult to achieve the ambition of creating a seamless passenger journey.

Biometrics is the emergence of integrated end-to-end biometric authentication solutions, including security, check-in, immigration, automated check-in and baggage drop. It has the potential to completely change the way airports identify passengers. By implementing biometric systems, smart airport operators can speed up the passenger processing process while maintaining the highest level of security. According to SITA, 77% of airports and 71% of airlines plan to implement major projects or research and development in biometric identity management within the next five years (Garcia, 2018).

Biometrics is a general technical term for verifying personal identity. Bio refers to life, and metric refers to measurement. The idea of biometrics is to find or verify an individual's identity based specifically on internal characteristics. Informatics classifies and describes biometrics as a means of identifying individuals. Biometrics are the digital analysis of biological characteristics obtained using a camera or scanner. Biometric technology is a reliable and convenient way for individuals to do this Identity verification (Jaiswal, 2011) Biometric technology, either alone or in combination with other technologies, offers tremendous opportunities for smart airports to make identity verification cheaper, more convenient, and less vulnerable to fraud. There are two types of biometrics: physical identification and behavioral identification. Physical biometrics include DNA, fingerprint, retina, hand, face, recognition, and iris, while behavioral biometrics include voice, gait, signature, and keystrokes (BioMetrica, 2018). Successful implementation of biometric technology depends on the combination of three or more of these methods to achieve very strong security.

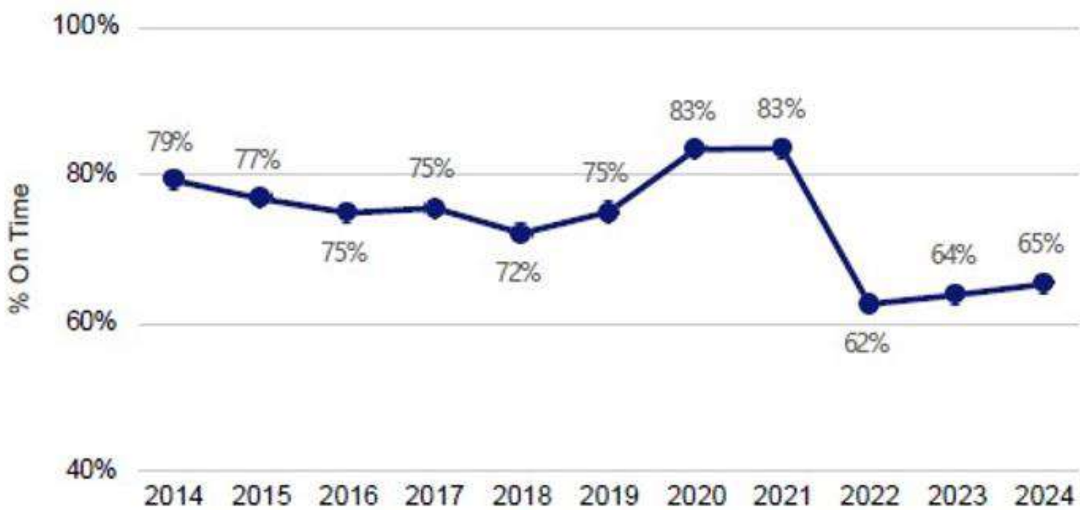

Figure 6.
Average seat per flight data for chart.

4.1. Flight punctuality trends

Percentage on time performance (percentage of flights operated within 15mins of scheduled time)

ISSN: 2576-8484
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Figure 7.
Percentage on time performance data for chart average delay minutes per flight.

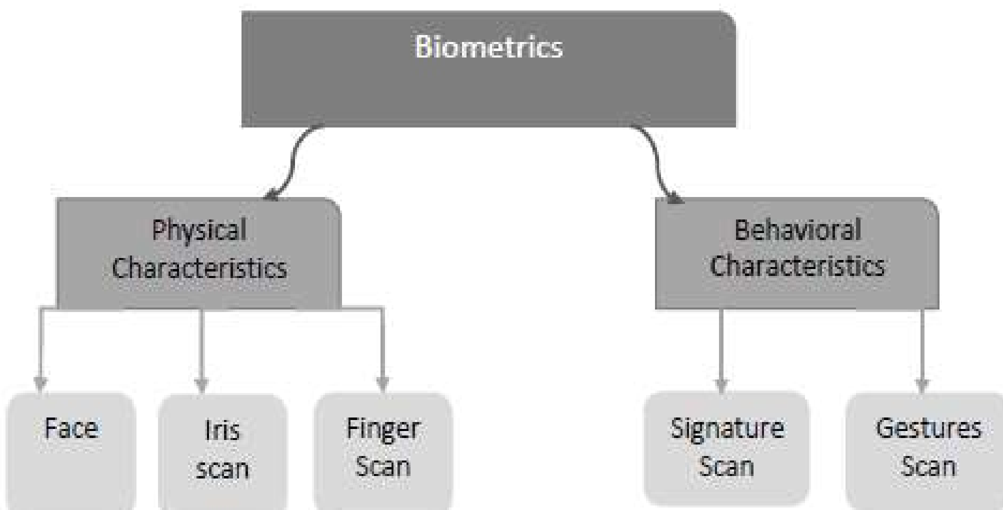

Figure 8.

4.2. Types of Biometrics Most Used at Airports

4.2.1. Iris Recognition

Iris biometrics are a highly reliable biometric system, among other physical biometric systems. They have a very low error acceptance rate. In iris recognition, the concept of pattern matching or image processing of neural networks is used to recognize a person through the iris, a thin circular structure in the eye. The goal is to identify individuals efficiently and accurately by implementing an intelligent edge detection algorithm that analyzes the random patterns seen in an individual's iris (Kak, 2010). So far, the main applications of iris biometrics technology are passport replacement (automated border crossing for aviation security, controlled access to restricted database areas, and computer login); just like fingerprints, no two irises are the same. Moreover, the patterns of the right and left eyes are different from each other.

4.2.2. Face Recognition

Face recognition is a computer application that uses a set of identification and verification data (such as a digital image or a unique video frame of that person) to automatically identify or authenticate a person. Facial recognition technology (FRT) involves analyzing individual facial features, storing these features in a database or cloud, and using them to identify those individual faces. When using a facial recognition system, the main task is to recognize and extract the individual's facial pattern. When a face is captured, the system measures specific neural mechanisms for facial perception, such as the shape of the cheekbones, the distance between the eyes, and other identifiable features. These measurements are compared to the entire image library to find the correct match. Facial recognition technology is divided into three tasks: face verification, face recognition, and queueing (Introna and Nissenbaum, 2017).

3.2.3 Fingerprint Identification

Fingerprint recognition is a reliable way to process passengers quickly and easily. Since each person has a unique fingerprint, using a fingerprint recognition system increases security as no one else can guess who they are. All fingerprint data operations are performed within a Trusted Execution Environment (TEE), ensuring the confidentiality and integrity of the code and data stored in the system's CPU (Rani and Jose, 2016). At airports, automatic fingerprint scanners are often installed at security checkpoints.

Connection between biometric technology and complex network theory to enhance Internet of Things applications in airport management Biometric technology and complex network theory can significantly enhance Internet of Things (IoT) applications in airport management by improving security, streamlining processes, and optimizing resource allocation. Here's how these two domains connect and their implications for airport operations: Connection Between Biometric Technology and Complex Network Theory

4.3. Data as Nodes and Edges

- In a biometric system, individuals are identified through unique biological traits (e.g., fingerprints, facial recognition). Each biometric data point can be considered a node in a complex network, while the relationships between different data points (e.g., an individual's travel history, interactions with various airport services) form the edges. This network can provide insights into passenger behavior and movement patterns.

4.4. Centrality and Influence

- Certain biometric data points may represent frequent travelers or individuals with specific travel patterns. By applying centrality measures from complex network theory, airports can identify key passengers whose movement significantly impacts overall airport operations, allowing for targeted services or interventions.

ISSN: 2576-8484
Vol. 8, No. 6: 8611-8632, 2024
DOI: 10.55214/25768484.v8i6.3848

Figure 9.
Average delay minutes per flight data for chart percentage of flights cancelled (within 24 hours before departure).

4.5. Community Detection

• Biometric data can help identify groups of passengers with similar travel behaviors or preferences. Analyzing these communities using complex network theory can help airports tailor services, marketing strategies, or security measures to specific passenger segments.

4.6. Dynamic Network Analysis

- Biometric systems can continuously collect data on passenger flows and interactions with airport services. By modeling this data as a dynamic network, airports can adapt their operations in real-time to optimize efficiency and enhance passenger experience. | Examples of Enhancing IoT Applications in Airport Management

4.7. Streamlined Check-in and Boarding Processes

- Example: Airports can implement biometric systems (e.g., facial recognition) for check-in and boarding. Passengers' faces are scanned as they enter the airport and when they approach the boarding gate. Using complex network theory, airports can analyze passenger flow patterns at different times and adjust staffing levels or gate assignments accordingly. This reduces wait times and enhances the overall passenger experience.

4.8. Enhanced Security Measures

- Example: Biometric identification can be integrated with security systems to monitor passenger movements in real time. By analyzing the connections between biometric data points (e.g., identifying repeat offenders or unusual travel patterns), security teams can proactively address potential threats. Complex network analysis can help identify suspicious behavior patterns among passengers, allowing for timely interventions.

4.9. Personalized Passenger Experience

- Example: Biometric data can be linked to passengers' preferences and past behaviors (e.g., preferred lounges, shopping habits). By analyzing this data as a complex network, airports can offer personalized services such as targeted promotions or notifications about relevant amenities while passengers navigate the airport. For instance, if a frequent traveler often visits a specific coffee shop, they could receive a discount offer when they pass by it.

4.10. Resource Allocation and Operational Efficiency

- Example: By analyzing biometric data on passenger flow through various airport checkpoints (security, customs, etc.), airports can optimize resource allocation. For instance, if a particular security checkpoint experiences higher traffic during certain hours, complex network analysis can help management decide when to deploy additional staff or open more lanes to reduce congestion.

4.11. Integration with Other IoT Devices

- Example: Biometric systems can be integrated with other IoT devices like smart signage or mobile apps. When a passenger's biometric data is recognized at a terminal, relevant information (e.g., flight updates, gate changes) can be automatically pushed to their mobile device or displayed on nearby screens. Analyzing the interactions between biometric recognition and these devices using complex network theory helps ensure that the right information is delivered at the right time.

5. Blockchain Technology

Blockchain technology is perhaps the most important invention after the web itself. It has been 10 years since the emergence of blockchain, but people still have a misunderstanding that Bitcoin and blockchain are the same thing, but blockchain technology is more than just Bitcoin. Today, blockchain technology is widely used in various applications, such as data management, digital identity, identity recognition and authentication, ticket booking, asset tracking, frequent flyer programs, etc.

5.1 Where did the Word Blockchain Come From? How Does it Work?

Blockchain technology began in 2008 as the infrastructure for the Bitcoin cryptocurrency and is the brainchild of Satoshi Nakamoto.

Satoshi Nakamoto is considered the most mysterious figure in the world of technology. So far, no one knows this person.

In 2008, Satoshi Nakamoto released the white paper "Bitcoin: A Peer-to-Peer Electronic Cash System", which was the first public appearance of blockchain technology. Since then, it has become a hot topic and the subject of multiple studies outside of cryptocurrencies, which were closed in the past. Blockchain is a technology that allows digital information to be stored and exchanged peer-to-peer.

Peer-to-peer network, in short, blockchain technology is a new type of internet that allows digital information to be distributed but not copied, as data is distributed across multiple separate computers rather than stored on a single server, making it fundamentally difficult to copy. A cyber-attack must be attacked simultaneously to be successful. Additionally, digital information stored in distributed ledgers is not affected by malicious changes made by single parties (Rutland, 2018).

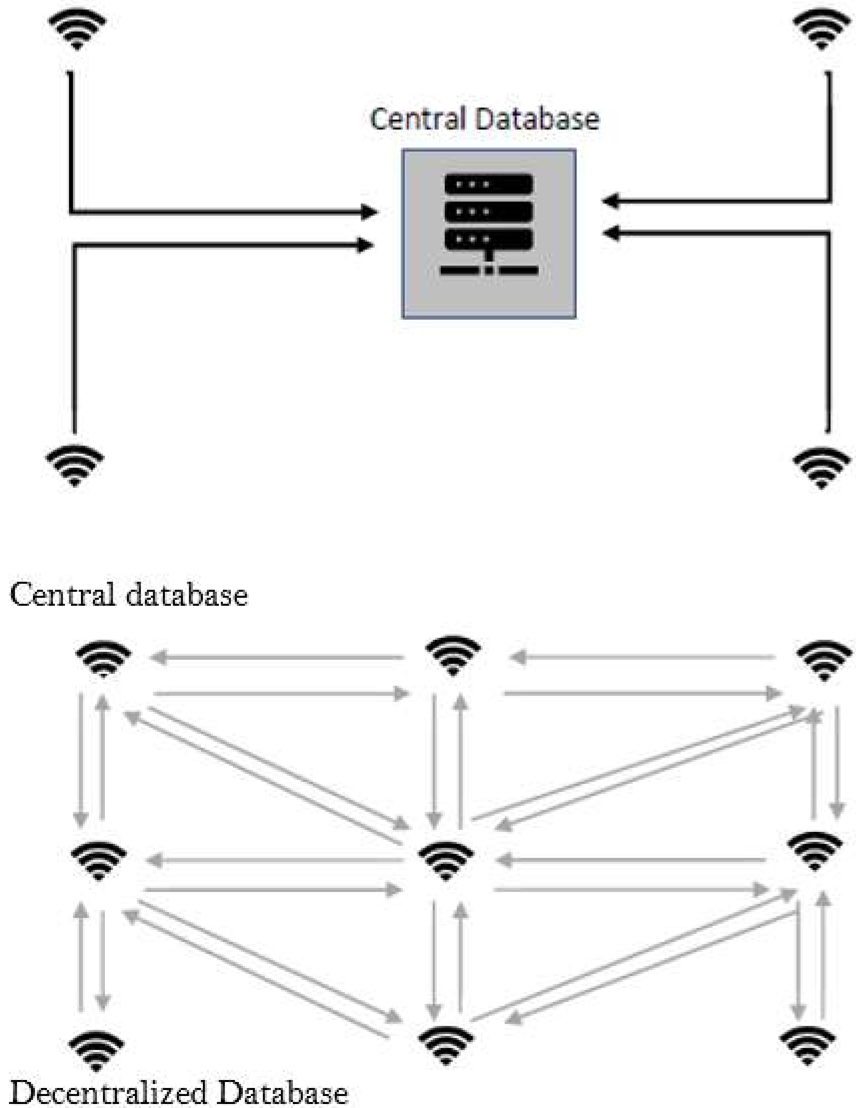

Figure 10.

5.2. Blockchain Smart Airport Domain

Integrating blockchain technology with the Internet of Things (IoT) will eliminate unnecessary intermediaries in day-to-day operations and build trust among key stakeholders. It will also help airports by providing complete transparency in various transactions. Seamless airport experience. According to the 2018 SITA Air Transport IT Insights report, 59% of airlines and 34% of airports are planning blockchain R&D initiatives by 2021 (SITA, 2018). Blockchain technology has a wide range of use cases in the smart airport industry, such as:

- Improving security and identity management at airports: Due to the decentralized nature of blockchain technology, it is highly reliable and secure, making blockchain technology ideal for improving how passengers are identified during their journey. The integration of biometrics and blockchain technology could herald a new era of identity management. It could facilitate the transnational use of biometric technology without requiring each agency to store passenger information (IATA, 2018).

- Improved baggage tracking: A decentralized ledger used by all stakeholders within the airport and between different airports will enable baggage details and owners to be automatically recorded on the blockchain. This will allow baggage information data sharing between different stakeholders to make it easier to track the status and location of baggage as it is transported and stored (IATA, 2018).

Connection between Blockchain Technology and complex network theory to enhance Internet of Things applications in airport.

The integration of blockchain technology and complex network theory can significantly enhance Internet of Things (IoT) applications in airport management by improving data security, ensuring transparency, and optimizing resource allocation. Here's how these two domains connect and their implications for airport operations:

Connection Between Blockchain Technology and Complex Network Theory

5.3. Decentralized Data Management

- Blockchain technology allows for decentralized storage and management of data across a distributed network. Each node in the blockchain can represent different IoT devices or systems within the airport, creating a robust and tamper-proof ledger of transactions and interactions. Complex network theory can help analyze the relationships and interactions between these nodes, providing insights into data flow and connectivity.

5.4. Trust and Verification

- Blockchain provides a secure and verifiable way to track transactions and data exchanges between IoT devices. In a complex network, trust is essential for effective communication between nodes. By leveraging blockchain's consensus mechanisms, airport systems can ensure that data shared among IoT devices is accurate and trustworthy, which is crucial for applications like passenger identification, luggage tracking, and security checks.

5.5. Smart Contracts

- Smart contracts on a blockchain can automate processes based on predefined conditions. In the context of complex network theory, these contracts can facilitate interactions between multiple nodes (e.g., IoT devices) in the network, enabling seamless coordination among various airport services. For example, a smart contract could automatically trigger a luggage handling process when a passenger checks in.

5.6. Data Analysis and Insights

- Complex network theory can be used to analyze the structure and behavior of the network formed by interconnected IoT devices. By applying algorithms to the data stored on the blockchain, airports can gain insights into operational efficiencies, passenger behavior, and potential bottlenecks. | Examples of Enhancing IoT Applications in Airport Management

5.7. Luggage Tracking System

- Example: Implementing a blockchain-based luggage tracking system where each piece of luggage is assigned a unique identifier stored on the blockchain. Each time the luggage is scanned at different checkpoints (check-in, security, boarding), the information is recorded on the blockchain. The complex network theory can be used to analyze the flow of luggage through various checkpoints, identifying patterns or bottlenecks in real-time. This enhances accountability and reduces lost luggage incidents.

5.8. Passenger Identity Verification

- Example: A blockchain system that securely stores passengers' biometric data (e.g., facial recognition, fingerprints) can streamline identity verification processes at different airport points (check-in, security, boarding). Using complex network theory, airports can analyze connections between passenger identities and their movements through the airport, optimizing staffing and resource allocation during peak times while ensuring privacy and data integrity.

5.9. Supply Chain Management for Airport Services

- Example: Blockchain can be used to manage the supply chain of airport services (e.g., food vendors, maintenance services) by recording transactions and inventory levels transparently. Using complex network analysis, airports can monitor relationships among suppliers, vendors, and service requests, enabling them to optimize procurement processes and reduce delays in service delivery.

5.10. Real-Time Flight Information Sharing

- Example: A blockchain-based platform that shares real-time flight information among airlines, airport authorities, and passengers can enhance communication and coordination. Complex network theory can help analyze the interactions between different stakeholders (airlines, ground services, passengers) to identify how information flows through the network and improve response times during disruptions (e.g., delays or cancellations).

5.11. Automated Maintenance Requests

- Example: IoT sensors deployed throughout the airport can monitor equipment (e.g., baggage handling systems, escalators). When a sensor detects a malfunction, it can trigger a smart contract on the blockchain to automatically notify maintenance teams. Complex network analysis can help identify patterns in equipment failures across different areas of the airport, allowing for proactive maintenance strategies.

6. Conclusion

Based on an in-depth study of current knowledge and a study of different airports where technology has reached a high degree of maturity, it is clear that new technologies, especially the Internet of Things (IoT), have an important role to play in the development of smart airports. However, solving the challenges facing airports and harnessing the power of smart airports does not only require leveraging new technologies; it is about transforming businesses in a digital environment. It is the deployment of new technologies and the integration of existing technologies, processes and services to provide a better experience for passengers and other stakeholders.

By applying complex network theory to IoT applications in airport management, stakeholders can gain deeper insights into system dynamics, enhance operational efficiency, improve safety measures, and ultimately provide a better experience for travelers. The integration of these advanced analytical techniques into airport operations represents a significant step towards smarter, more responsive airport environments. The integration of indoor positioning systems using beacon technology with complex network theory offers airports a powerful toolset for enhancing IoT applications. By understanding and optimizing the relationships between various entities within the airport ecosystem, stakeholders can improve passenger experiences, streamline operations, and enhance safety measures. This synergy not only facilitates better management practices but also positions airports to adapt to the evolving demands of modern air travel. The integration of biometric technology with complex network theory offers airports a powerful framework for enhancing IoT applications. By leveraging biometric data to create a dynamic network of passenger interactions and behaviors, airports can improve security, streamline operations, and personalize the travel experience. This synergy not only enhances operational efficiency but also positions airports to better meet the needs of modern travelers in an increasingly connected world. This article mainly focuses on explaining the role of new technologies in the development of smart airports, and when defining a smart airport, the project mainly takes into account the digital maturity of the airport, which describes the level of adoption of airport technology. By examining and reviewing the digital performance of airports that are considered very advanced and technologically mature, we found that many smart airports are small and medium-sized airports, such as the Australia and Pakistan Airport.

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