

INNOVATIVE STRATEGIES FOR OPTIMIZING AIRPORT REVENUE STREAMS USING AI

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Abstract

This article explores how the airport revenue streams can be optimized using artificial intelligence (AI). It explores some of the most innovative strategies, explaining how the dual revenue model of airports – consisting of aeronautical and non-aeronautical revenues – can unlock opportunities for airports' growth using predictive analysis for passenger flow, personalized retail offering, resource allocation and operational enhancements, while considering both regional and passenger traffic variables. Case studies show successful implementation of AI at airports such as London Heathrow and Singapore Changi. The article underscores the importance of a balanced, cost-effective approach to integrating AI, ensuring sustainable revenue growth while addressing operational constraints. While AI offers transformative potential, the authors of this article find that there are significant challenges to the implementation and use of AI, particularly for smaller airports, with barriers stemming from high implementation costs and skill shortages. This makes AI a powerful and very useful tool that requires a thorough cost-benefit analysis prior to implementing at airports with a traffic of less than 1,5 million passengers per year, or in some parts of the developing world.

Keywords: airport revenues optimization, aeronautical revenues, non-aeronautical revenues, AI in airports

JEL Classification: C61, C63, D24, L93, O33, R42

1. Introduction

Airports are gateways to the local, regional, and national economy. They drive economic growth at local, regional, and national levels by enhancing connectivity and market access (Tveter, 2017). Existing literature explores to great length the positive impact of airports to the economy, so we will not insist here on this relationship that has been repeatedly proven across the literature and across the various regions of the world, from Europe to the United States and from Asia to Latin America (Button, K. et al 2010, Pot, F. et al 2022,

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Cristureanu, C. et al 2007, Gibbons, F. et al 2019, McGraw, M.J. 2017, Serebrisky, T. 2011).

Yet airports are businesses in their own right. As such, and irrespective of their ownership – private, public, or public-private partnerships – airports rely on healthy streams of revenues to cover the operating costs and to generate profit. The size of the airport is an important factor in evaluating the profitability of the airport. This is because, as expected, the economies of scale show that the larger the airport, the higher the revenues generated, and the more profitable they are.

2. Airport revenues, profitability and AI impact

Whereas there is no established scale to link the profitability of airports to the number of passengers processed, the empirical experience of the authors of this study, backed by the findings of the European Commission (Oxera, 2024), shows that any airport with a traffic below one million passengers per year will struggle to cover their operating costs and to ensure a healthy development/upgrade of the infrastructure. This is explained *inter alia* by the significant fixed costs that must be covered, including personnel, maintenance, and utilities and not even considering the investments required to develop or upgrade the existing infrastructure.

The authors of the present study note that, although there are several papers that cover the relationship between the number of passengers of an airport and its profitability, they date back several years to 2002 or 2010. We did not provide an explanation as to why this is the case since it falls outside the scope of the current paper; however, we did not want to miss pointing out the finding. Another important observation is that the studies cover European airports, making them hardly generic enough to extrapolate the results to the world level. Even so, within Europe itself the results vary considerably, such as shown by Doganis and Thompson (1975), which found that British airports required an even higher number of passengers to break even.

First-hand consulting experience with airports in Africa and Latin-America shows that at a traffic level of 750,000 passengers per year, airports struggle to break even – least to have the funding available from own sources to make meaningful investments in brownfield infrastructure, namely to upgrade existing terminals, taxiways, and runways. Where such investments were made, they resulted in increases in airport charges, which are loathed by airlines and make air transport even more expensive for passengers.

If we were to find a common denominator, we would find that an airport is expected to become profitable anywhere between one million and 1.5 million passengers. This means that, as airports approach 2 million passengers, the revenues will increase enough to cover the fixed costs, with the additional income allowing both for investments/upgrades and for profit and keeping a

balanced level of charges to airlines and fees to the passengers. The ACI-commissioned Oxera study of 2024 provides additional evidence in this regard.

Considering the critical role of passenger traffic in determining airport profitability, it emerges that revenue generation is the key for sustainable airport operations. However, the number of passengers alone cannot explain the financial health of airports. Instead, one should consider how airports diversify their revenue streams. From aeronautical charges tied directly to airline operations to non-aeronautical income derived from retail, parking, and other commercial activities, airports must strike a balance between these sources to ensure financial resilience.

In the next section, we provide a comprehensive overview of airport revenue streams to explain how airports navigate the challenges to cover their operational costs, fund infrastructure developments, and maintaining competitive pricing for airlines, while generating profit as any other business undertaking.

2.1. Overview of airport revenue streams

Before delving into how AI could help airports harvest the utmost from existing data to increase their profitability, we should present first the types of revenues concerned. Airport revenues consist of aeronautical revenues, non-aeronautical revenues, and non-operating revenues.

Aeronautical revenues include any income generated by aircraft using the airport facilities, such as for landing, parking or using air bridges. Aeronautical revenues are usually dependent upon the maximum take-off weight of the aircraft.

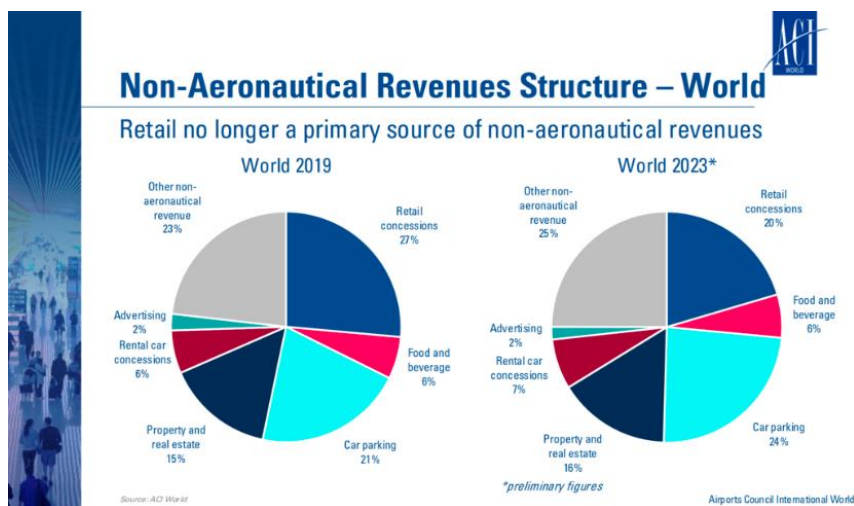
Non-aeronautical revenues on the other hand include income from leasing commercial real estate for retail shops, restaurants, and other businesses operating on the airport premises, from advertising as well as from car parking.

Non-operating revenues include revenues not directly related to the airport's core activities, such as investment income (investments in stocks, bonds, or other financial instruments), grants from government agencies or non-profit organizations, donations, or other sources such as asset sales, insurance or legal settlements. Noting that non-operating revenues may account for a significant amount at large airport, we will focus our discussion on aeronautical and non-aeronautical revenues.

According to Airports Council International World (ACI World), at the global level, aeronautical revenues accounted for 53% of the airport revenues in 2023, similarly to the 54% level in 2019, which is the baseline prior to the pandemic. At the same time, the aeronautical revenues slightly declined by 3 percentage points during the same period, while the non-operating revenues saw a steep increase by 67%, from 6% in 2019 to 10% in 2023.

When discussing about airport revenues in general but especially about non-aeronautical revenues, we should note that significant variations exist between the different regions of the world in terms of the contribution of each non-aeronautical revenue component to the total. Table no.1 below shows the evolution of the primary sources of non-aeronautical revenues in 2023 compared to 2019, while Table no.2 shows the significant variations across the regions of the world by revenue source.

Table no.1 Non-aeronautical revenues by source and region



Source: *Airports Council International* (2023).

Table no.2 Non-aeronautical revenues by source and region

Non-Aeronautical Revenue by Source								
Region	Retail concession	Car parking	Rental car concession	Property income/rent	Advertising	Food & Beverage	Other*	Subsidies & Grants
Africa	33%	15%	6%	22%	7%	1%	13%	3%
APAC	40%	5%	2%	18%	4%	2%	28%	1%
Europe	24%	16%	2%	14%	3%	3%	33%	5%
LAC	38%	6%	3%	7%	4%	5%	36%	1%
North America	8%	26%	11%	10%	1%	4%	30%	10%
WORLDWIDE	22%	16%	5%	14%	3%	4%	30%	6%

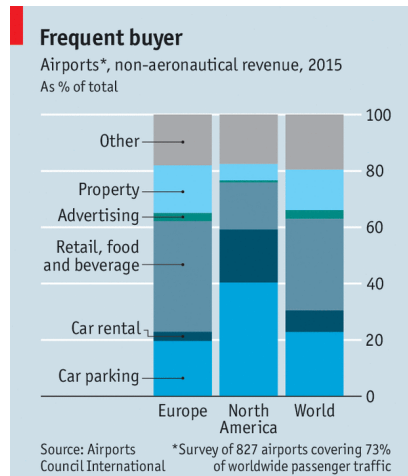
* Other revenue asset divestment, fuel concession, interest, security, utility charges, service provisions, ground transport

Source: *Moodie Davitt Report* (2009).

Table no.3 illustrates the sources of non-aeronautical revenues by region. Corroborating the information in Table no.3 with that in Table no.2, we obtain a clear indication as to the evolution of each source of non-aeronautical revenue over a 15-year period. Thus, we notice, inter alia, that car parking revenues

went up 250% in 8 years, up from 16% in 2009 and accounting for 40% of the non-aeronautical revenues at airports in North America, versus 20% in Europe and about 22% the world average.

Table no.3 Airports' non-aeronautical revenue as a % of Total



Source: *The Economist* (2017).

We referred above to how airport revenue streams are linked to the strategies airports may adopt. These strategies may be of diversification or of specialization.

Strategies of diversification are aiming to develop the non-aeronautical activities, to improve the airport's balance sheet. The most common strategy of diversification is the development of commercial activities by increasing the commercial areas for shops, restaurants, car rentals, etc., at the airport and the development of services to airport passengers, independent from the airlines (lounges, paid wireless internet access). For mid-sized or large airports, the strategies of diversification include developing consultancy or management services, know-how that is provided at a cost to smaller airports, and investments in other airports or other economic sectors.

Strategies of specialization are generally used to develop the aeronautical activity of the airport thanks to capacity increase (terminal and/or runway), commercial policies to airlines and promotion of the airport and its region. For small and medium-size airports, the development of low-cost terminals is a new trend in strategies of specialization, especially if strong competition with other airports or high-speed rail, whereas for large airports it is to maximize the infrastructure efficiency and to develop intermodality – integrating aviation, rail, and other modes of transportation to create seamless travel experiences (International Airport Review).

Lately, the trends in revenue generation include an increased focus on non-aeronautical revenues and on data transformation. As aeronautical charges face pressure from airlines and regulators to remain competitive, airports are increasingly leveraging non-aeronautical revenue streams. On the other hand, airports are adopting digital technologies to enhance operational efficiency and revenue generation. Tools such as passenger flow analytics, personalized marketing, and data-driven decision-making are becoming more widespread – though rather expensive to integrate and deploy, despite the advantages they bring.

2.2. The role of AI in airport revenue optimization

Experts around the world consider the use of technologies in all fields to be a great help to today's society. Artificial intelligence refers to the ability to mimic human intelligence in machines that are designed to perform tasks that typically require human intelligence. Although the concept of AI has been around since the 1950s, it is only in the last decade that humanity has taken technology to a more significant level of knowledge. This was due to the following three factors: the advanced ability to collect and store large amounts of data; the vast increase in computing power; and the development of powerful algorithms.

Other sectors, such as telecommunications and healthcare, have already integrated AI to some extent into their daily activities. Now, we are seeing airports doing the same to improve safety, efficiency, and decision-making processes in various sections of the aviation industry (Malaviya, 2024).

Artificial intelligence (AI) and machine learning (ML) have a significant impact on airport operations, contributing to their optimization and efficiency. A notable example is the study "Neural Airport Ground Handling", which addresses aircraft ground handling (AGH), essential for the efficiency of airport management and aviation economics. The authors (WU et al, 2023) model AGH as a multi-fleet vehicle routing problem, integrating constraints such as precedence, time windows and capacity. They propose a construction framework that decomposes AGH into sub-problems and uses a neural method to build routing solutions, using attention-based neural networks and reinforcement learning. Experiments show that this approach outperforms classical methods, demonstrating efficient generalization to instances with a large number of flights and adaptability to stochastic flight arrivals.

Another example is presented by the European Aviation Safety Agency (EASA), which highlights the multiple applications of AI in aviation. AI can assist the crew in routine tasks, increasing the operational efficiency of the flight, and can predict problems such as turbulence or icing conditions, supporting pilots' decisions in conflict situations. In maintenance, AI facilitates predictive maintenance, optimizing maintenance programs and preventing

failures. AI also contributes to optimizing flight paths, reducing carbon emissions, and supports air traffic management by analyzing weather data and traffic configurations, improving efficiency and reducing delays.

The integration of AI and ML in airport operations is revolutionizing the aviation industry, offering advanced solutions for the complex challenges of airport management and flight operations. In recent years, AI systems have been used or experimented with in several airports around the world, we have selected and looked into the ones below, where there is a positive impact on passengers and a direct link to the airport:

1. Facial recognition systems for security and check-in. Used to authenticate the identity of passengers at security points, at boarding and during the check-in process, facial recognition has a positive impact stemming from reduces waiting time, increases security through more accurate checks, and the elimination of the need for physical documents at certain stages.

2. Chatbots and virtual assistants. AI-powered digital assistants answer passengers' questions about flights, boarding gates, delays and other useful information. As a positive impact, they provide 24/7 support, reducing traveler stress and allow passengers to get quick answers through apps or kiosks.

3. Passenger flow management systems. AI analyzes real-time data from cameras and sensors to manage crowds and redirect passenger flows. The positive impact stems from reduced congestion in key areas (security, boarding gates) and reduced waiting time at checkpoints.

4. Smart baggage systems make use of AI in baggage tracking and handling, including smart tagging and RFID and camera monitoring. The positive impact is that they reduce baggage loss or delays and allow passengers to track their baggage in real time.

5. Trip planning apps. Looking from a more holistic perspective, in this case AI algorithms help passengers plan their trips by optimizing connecting routes, flight times, and costs. This results in a smoother travel experience and as reduced risk of missing connecting flights.

6. Terminal guides and assistants. In this area, AI-powered robots provide information about terminals, boarding gates, restaurants, or other services available at the airport, enabling friendly and personalized interactions and a quick guidance, especially in large and busy airports.

7. Delay prediction and schedule optimization. Analyzing weather conditions, air traffic and other data, AI predicts flight delays and optimizes flight schedules. Thus, passengers are informed in advance, reducing uncertainty with connection management being improved and unnecessary waiting being reduced.

Salis' (2021) study "Towards the internet of behaviors in airports with a fog-to-cloud approach" presents the development of an Android application that uses the concept of proximity marketing to assist airport travel. The application

provides personalized recommendations and vouchers based on traveler preferences, using machine learning and a fog-to-cloud approach. The system provides benefits to both travelers and airport planners, including heat maps that highlight infrastructure bottlenecks and suggest necessary interventions; and in the study "Neural networks trained with Wi-Fi traces to predict airport passenger behavior" the authors explore the use of neural networks to predict passenger behavior inside airport terminals.

These studies highlight how AI-based technologies can be implemented in airports to improve the passenger experience through personalized assistance and behavior prediction, thus contributing to streamlining operations and increasing the passenger experience, making it faster, safer, and more enjoyable.

2.3. AI-driven strategies for revenue optimization

As highlighted by Gündüz (2023), AI applications at airports cover areas such as flight delays, operations (including baggage handling), and security, to which we can easily add safety and commercial aspects. We would also like to stress that while one may easily think of passenger operations, cargo operations must not overlook. This is because, although less "visible", cargo may well represent a significant chunk of the revenues at some airports, depending on the respective business model and the specific economic environment.

Regarding passenger applications, AI-driven analytics can be used to understand passenger preferences and behaviors based on travel patterns, demographic data, and spending habits.

As such, AI-enabled analysis may enhance passenger facilitation by computing passenger flow management to reduce bottlenecks across the passenger journey throughout the airport. We should note that this journey starts when the passenger arrives at the airport and ends when the passenger is on board the aircraft awaiting the take-off.

By successfully resolving the facilitation aspects, passengers will not only be happier with the level of service of the airport but will be spending more time in retail and dining areas, which will then be used for an increased retail outreach to passengers and an increase in sales to passengers. Analyzing passenger movement patterns through predictive analytics help also determine optimal store placements and layouts to maximize visibility and sales potential.

Thus, by facilitating the access of passengers to shops and restaurants, the airport would not only boost its tenants' sales and customer satisfaction but enable the airport tenants to tailor retail offers to passengers that would have more time to enjoy in the stores – hence spend more money there, too. Such a circular win-win-win (airport-passengers-airport tenants) is a rare case where every stakeholder stands to win without incurring any negative impact, however slim.

At the same time, for passenger that do not benefit from lounge access by virtue of their frequent flyer status with an airline, airports may develop a paid-for-access, airport-run lounge, that would increase their offer to passengers and the non-aeronautical revenues. Yet again, passengers will need to have the time first, to be able to spend it subsequently at the lounge.

We note that retail and concessionaires at the airport would benefit significantly from the use of AI, by analyzing sales data to identify trends and optimize product offerings in retail outlets, see how demographics and travel trends affect the business to increase the average transaction values. However, since these actions are taken by tenants and not the airport per se, such analysis falls outside the realm of the airport, and we will stop here the discussion about this area.

From an operational efficiency perspective, always in support of the revenue growth, AI could be used for resource allocation optimization. Thus, AI can enhance gate management, baggage handling, and other operational areas, ensuring smoother passenger experiences, which can lead to increased spending. In addition to the improved passenger experience, the optimized operations, particularly automating maintenance schedules and optimizing resource allocation such as staffing levels at peak times would benefit the airlines, which should notice a higher level of service and a decrease of delays due to airport operational or infrastructure reasons.

AI-powered advertising platforms may enable targeted campaigns on digital screens, based on passenger profiles, flight destinations, and real-time passenger traffic data. This would maximize advertising inventory, and real-time adjustments ensure higher revenue from advertising partners.

At the end of the day, one of AI's most powerful uses at the airport stems from assisting the management with strategic decision-making as well as with scenario planning and forecasting. AI models could enable quick and informed decisions and simulate revenue impacts of external factors, such as changes in passenger traffic, economic conditions, or different schemes for airline charges.

These benefits are tangible and significant. Yet, for all the benefits mentioned above, the caveat is that many times, and especially at smaller airports, there is a lack of personnel and there is not enough trained personnel available to start with. Smaller airports, especially outside Europe or North America lack the powerful IT systems and the know-how to set up, deploy, and operate the necessary equipment and software that would enable the important AI benefits.

Before engaging in an AI transformative process, it is important to balance the benefits from using AI with the on the ground situation, which may not always require a full implementation of AI-generated processes or optimizations. The cost involved, which we will cover in the next section of the paper, may prove prohibitive or outweigh the benefits, whether operational or

commercial, since the capacity of the airport may simply not permit the airport to develop much in the current environment. Therefore, there should be a cost-benefit analysis performed to evaluate whether the costs outweigh the benefits, especially for airports with below 2 million passengers per year.

2.4. Case studies and real-world applications

The use of artificial intelligence for airports and airlines has gone viral in recent years, especially after the pandemic that hit this field deeply, so there are more airports that use AI and which have many benefits, in this sense the study "Aircraft Landing Time Prediction with Deep Learning on Trajectory Images" explores the use of artificial intelligence (AI) at Changi Airport in Singapore to predict aircraft landing times. The authors of the study collected the data during November 2022 using ADS-B data, so that the sequencing of aircraft upon landing is carried out after a very efficient time management. The proposed method is based on deep learning, using images of flight paths to predict the landing times of aircraft entering the airspace of the terminal area. The trajectories of all aircraft in flight within a specific time interval were transformed into images, where the trajectory of the target aircraft is highlighted. These images contained a variety of information, including aircraft position, speed, direction, and traffic flows, enabling the use of advanced convolutional neural networks to model landing times.

Additional data, such as aircraft type and weather conditions, are integrated to improve the accuracy of predictions. Implementation of this method resulted in a significant reduction in the mean absolute error in landing time predictions, from 82.23 seconds to 43.96 seconds. This level of accuracy, with an average accuracy of 96.1% and 79.4% of errors being low 60 seconds, highlights the potential of using AI in optimizing air traffic management.

Applying this technology means greater operational efficiency, reduced delays, and enhanced passenger satisfaction. This study highlights the benefits of adopting AI-based solutions in airports, demonstrating how more accurate landing time predictions can optimize aircraft sequencing and air traffic management (Huang & all. 2023).

Another notable example of AI impact analysis is the study by Xiaojia Guo, Yael Grushka-Cockayne and Bert De Reyck, titled "London Heathrow Airport Uses Real-Time Analytics for Improving Operations" (2020). The authors explore the implementation of a machine learning-based system to predict passenger connection times at Heathrow Airport. The main goal was to improve operational efficiency and passenger experience by connection time prediction – using real-time data to predict which passengers are likely to miss their connecting flights, allowing staff to take proactive measures such as rerouting or assisting passengers; and passenger flow optimization –

aggregating estimates of passenger arrivals at different points in the airport to adjust staffing levels and reduce congestion at checkpoints and security.

The implementation of this airport system has led to an increased operational efficiency – reducing delays caused by passengers missing connections and optimizing the use of airport resources; and an improved passenger experience – reducing waiting times and congestion, providing a more pleasant travel experience.

This study highlights how the use of real-time analytics and machine learning can transform airport operations, providing benefits for both passengers and airlines.

As lessons learned and key takeaways, we can highlight that integrating artificial intelligence (AI) technologies into airports offers valuable lessons on transforming operations, improving customer experience, and optimizing resources.

Here are some of the most important lessons that may translate into useful practices:

1. Increased operational efficiency: AI can quickly and accurately analyze large volumes of data to optimize complex processes, reducing operational costs and increasing efficiency. It does so by providing an optimal allocation of resources (staff, boarding gates, aircraft) and providing the airport with a delay prediction in (virtually) real time.

2. Improved passenger experience: AI can personalize and automate interactions with passengers, providing them with faster and more convenient services, thus reducing their stress, providing shorter wait times and an overall more enjoyable travel experience. Some examples include automated check-in systems and personalized notifications about flights and connections.

3. Faster and better-informed decisions: AI algorithms can provide real-time data-driven recommendations, helping airports make fast and well-informed decisions, improving their financial and operational performance. Examples include demand analysis to adjust aeronautical and non-aeronautical charges and predicting staffing needs based on passenger flows.

4. Sustainability and reducing environmental impact: AI can help reduce emissions and use resources more efficiently, in compliance with environmental standards and trends, and creating a more positive image for the public.

5. Improved security: facial recognition and behavioral analysis technologies can enhance security in airports and on-board aircraft. Though managed by security service on the airport and not the airport operator directly, such measures do increase passengers and staff safety, making security controls more efficient.

6. Flexibility and adaptability to change: AI helps companies be more agile and respond faster to unexpected changes. This can happen for instance in

the case of crisis management, such as flight disruptions caused by adverse weather, when resources can be adjusted according to fluctuations in demand, thus increasing resilience and reducing losses in unpredictable situations for the airport.

7. The importance of collaboration between people and technology: while not airport-specific, successful use of AI does not mean completely replacing the human factor but creating an effective partnership between people and technology. This increases employee trust and competence, and the staff can use the data generated by AI to make better-informed decisions.

8. The need for ethics and data protection: AI implementation must comply with rules on confidentiality and ethical use of passenger data, including GDPR regulations in Europe for biometric data. Ethics require transparency on how personal data is used to create a relationship of trust with passengers and to avoid legal issues.

The integration of AI into airlines and airports demonstrates that technology can transform the aviation industry, providing efficient, safe and sustainable solutions. The fundamental lesson is that the success of these innovations depends on responsible and ethical implementation, which maximizes the benefits for passengers, companies and the environment.

3. Conclusion

Incorporating artificial intelligence (AI) into the management of both aeronautical and non-aeronautical revenues can greatly improve operational efficiency and create new opportunities for increasing airport revenues, as an airport's profitability is strongly tied to its passenger volume, with a threshold of approximately one to 1.5 million passengers per year necessary to cover operational costs, generate profits, and support infrastructure investments.

To ensure financial stability, airports must balance their revenue sources, combining income from aeronautical services (like airline operations) with non-aeronautical revenues (such as retail and parking). Non-aeronautical revenue contributions differ globally, with varying proportions of income derived from sources like parking, illustrating the regional diversity in airport commercial strategies.

AI can increase airport revenue by optimizing operations, improving passenger satisfaction, and enhancing retail and concession strategies. It also enables targeted advertising and predictive analytics, maximizing sales and helping airports allocate resources more effectively.

AI technologies like facial recognition, virtual assistants, and passenger flow management systems significantly improve the airport experience by minimizing wait times, enhancing security, offering personalized services, and efficiently managing passenger movement throughout the airport.

Although AI offers numerous benefits, smaller airports may struggle with limitations like insufficient trained staff, outdated IT systems, and high initial costs. A thorough cost-benefit analysis is crucial before implementing AI, particularly for airports with fewer than 2 million passengers annually. Also, AI assists airport management by providing valuable data-driven insights, helping forecast potential revenue changes, and simulating different operational scenarios. However, AI implementation must be carefully weighed against the airport's resources and capabilities, especially for smaller airports where the costs may outweigh the potential advantages.

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