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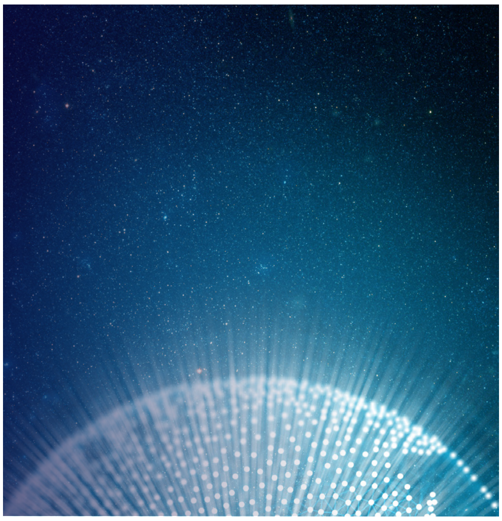
Anticipate, Innovate, Transform

Resilience in the Aviation Industry

CONTENT



RESILIENCE IN THE AVIATION INDUSTRY

BY JIM MILLER AND SABINE REIM, GUEST EDITORS

During the peak of the COVID-19 crisis, government-mandated air travel restrictions, bans, and quarantine measures resulted in unprecedented disruption and financial loss in the aviation industry. Today — despite worker shortages, high fuel costs, airfare increases, and sustained schedule disruptions — air travel demand is returning to pre-pandemic levels, and the industry is returning to a state of profitability.

However, a return to profitability will not protect the industry from the next disruptive event. Instead, implementing integrated resilience measures across the aviation ecosystem will be critical to ensuring long-term economic viability. Emerging technologies, regulations, and changes in demand can serve as cornerstones, putting pressure on industry players to become active participants in creating a more integrated operating model.

As uncertainties linger around recovery profiles, the economic outlook, and supply chain stresses, industry stakeholders seek to de-risk their operations and deliver greater robustness. They are also working on artificial intelligence (AI) and sustainability initiatives that will be transformative for the industry.

Approaches to change have not been even and will continue to cause discrepancies between players, both within and across subsectors. This will have a significant effect on competitiveness between airlines, airports, and nations as hubs. There is a clear need for a collaborative approach to ensure a level of consistency and cooperation between players to deliver long-term success for the industry and, thus, consumers.

The pace of change requires stakeholders to take a "clean slate" approach in an industry that has historically relied on incremental adjustments. Legacy systems, fragmented regulation, and volatile profitability will not make this journey easy, but it is now widely recognized that fundamental change across the value chain is critical to companies' survival — as well as an opportunity to thrive.

This issue of *Amplify* explores the first steps being taken by various aviation industry players. Their efforts are laying the groundwork for future attempts to deliver a more efficient, resilient, adaptable, and sustainable industry.

IN THIS ISSUE

In our first article, Fabian Steinmann offers concrete suggestions for improving the air transport industry's resilience. Steinmann says to achieve resilience in operations, air transport operations should simultaneously upgrade system design, system preparedness, system response, and system change. System-design improvements include increasing capacity buffers, so a single runway disruption doesn't ripple through a network, as has been the case in the UK. System preparedness involves deploying additional resources in the case of large events or strikes, proactively reducing flights before large storms, and improving connections between air transport companies and weather forecast providers. System change requires reviewing lessons learned from disruptions while considering proactive measures — always remembering that improvements in one area of the network may cause issues in other areas.

> **ON THE GROUND, A COMBINATION OF AI, IOT, AND ML IS REDUCING TURNAROUND TIMES, STREAMLINING GATE ASSIGNMENTS TO REDUCE TAXI TIMES, AND EVEN REDUCING FOOD WASTE**

Next, Cutter Expert Curt Hall looks at how AI, cloud computing, big data, machine learning (ML), computer vision, and Internet of Things (IoT) are being leveraged to combat disruptive forces such as pandemic-caused economic uncertainty, growing public awareness of climate change, and rising fuel prices. Hall describes which airlines are using which technologies for what purpose, such as shifting to cloud applications to help them scale and deploying AI to increase fuel efficiency and solve crew-staffing problems. Predictive analytics are helping airlines with weather forecasts, flight operations (reducing speed or altitude to lower fuel costs), and aircraft selection. On the ground, a combination of AI, IoT, and ML is reducing turnaround times, streamlining gate assignments to reduce taxi times, and even reducing food waste.

Following Hall's piece, David Hart and Andrew Cunningham address economic-regulation risks. The authors delve into the distinct approaches recently taken by the UK Civil Aviation Authority (CAA) and the Irish Aviation Authority (IAA). CAA allocated an additional amount of money that airlines would pay back over a long period to offset the economic damage from the pandemic to Heathrow Airport Limited. IAA reacted in real time, suspending many regulations at Dublin Airport and ensuring monetary support would be forthcoming from the national government. Both airports have recovered well from the pandemic-caused downturn, and the authors say one's view of the pandemic (was it a one-off? a predictor of large future shocks?) affects any final conclusion on which approach was the right one.

Our fourth article, authored by a group from the National Renewable Energy Laboratory, presents a roadmap for creating a more sustainable aviation ecosystem. The authors first explain the interdependencies in the ecosystem, including between infrastructure, communications and technology, energy justice, energy solutions, human systems, and transportation networks. They then look at solutions such as sustainable aviation fuel, hydrogen-based fuels, and electric propulsion systems. The authors conclude by describing the benefits of taking a holistic approach in which industry, federal, and state entities collaborate to help the aviation industry reach its decarbonization goal.

OF PARTICULAR INTEREST IS THE POTENTIAL FOR PLAYERS TO COME TOGETHER TO CREATE A MORE INTEGRATED OPERATING MODEL

Finally, repeated *Amplify* contributor Ralph Menzano posits that airports can be viewed as microcosms of cities and, as such, offer important lessons to public sector entities around the world. Specifically, emulating the strategies used by airports during the pandemic could help municipalities and others become more resilient. Airport leaders moved quickly to shut down terminals and gates, adjust flight schedules and staffing, and change parking systems — then pivoted to delivering vaccines and medical supplies rather than passengers. Leaders also made sure they were ready to resume expansion plans and hit revised passenger targets as soon as restrictions eased. Menzano points to strategies and technologies other public sector entities could benefit from, including sustainable programs (airports are adopting electric vehicles to transport passengers and luggage and deploying goat herds to maintain dense scrub vegetation), virtual assistants to help customers navigate complex websites, and personnel programs that simultaneously promote equity and diversity.

We will closely watch the strategies and technologies being used by major players and others as they work to boost the airline industry's resilience. Of particular interest is the potential for players to come together to create a more integrated operating model that helps the industry more easily weather the next disruptive event.

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A HOLISTIC APPROACH TO RESILIENCE FOR AIR TRANSPORT INDUSTRY

Author

Fabian Steinmann

Interconnected systems and networks are defining features of modern society in an increasingly complex world. They influence one another in unpredictable ways, and disruptions have the potential to create significant ripple effects. We see this in air transport operations, which rely on a complex, interconnected network of technologies, processes, and people. Industry experts are acknowledging this complexity and recognizing the need for a more resilient approach.

Resilient systems adapt to changing circumstances quickly and effectively, but they require effective communication, cooperation, coordination, and collective action from stakeholders. Neglecting these elements results in fragmented efforts, hindering the system's ability to respond cohesively to disruptions. Conversely, paying attention to interorganizational dynamics promotes cohesive responses, helping systems adapt and thrive in the face of changing circumstances.

During a recent discussion on resilient and sustainable infrastructure, Northeastern University Professor and Founding Director of the Global Resilience Institute Stephen Flynn remarked: "There is no point being an island of resilience in a sea of fragility."[1] In air transport, that translates to the fact that airlines can no longer focus solely on their own operations; successfully transporting people from A to B requires coordination between multiple parties. Security staff, ground handlers, air traffic control, and public transport companies that get passengers to and from terminals play a vital part and have the potential to slow down (or break) the entire operation.

Clearly, we must take a more holistic view. This approach requires strengthening interorganizational interfaces; analyzing bottlenecks; and focusing on improving resilience before, during, and after a disruptive event.[2]

4 ELEMENTS OF OPERATIONAL RESILIENCE

Achieving operational resilience involves practices and conditions that span four overarching elements: system design, system preparedness, system response, and system change. These elements work in unison to provide a comprehensive perspective on air transport resilience.

1. SYSTEM DESIGN

System design focuses on the setup of an operation and the amount of excess capacity incorporated into the network as a buffer. The larger the buffer, the better a network copes with natural operation deviations and unexpected disruptions.[3]

Augmenting buffer capacity enhances the potential for a resilient operation, but it can adversely affect network efficiency. Those responsible for the network must manage this trade-off.[4] A good first step is to quantify maximum network utilization to create a benchmark for estimating remaining headroom.

For example, in 2017, the UK Civil Aviation Authority (CAA) conducted a review investigating the trade-off between level of punctuality and increase in flight movement.[5] It concluded that runway usage at the six major UK airports had continuously increased, causing congestion. With little buffer capacity left, the network had become so brittle that diversion issues at one airport quickly affected the entire network.

The report found that no new ground infrastructure was planned for in the coming years and predicted that, with the projected increase in flight movements, the issue of limited buffer capacity would be amplified. Report authors said it would be essential to collectively work on the network's resilience to maintain a high level of safety and meet consumer interest. Prior to that point, no shared obligations existed to tackle the resilience of the UK air transport system.

A cross-industry working group was formed and, today, the major UK-based airlines, airports, air traffic control service provider, the regulator, and other aviation stakeholders are part of the Industry Resilience Group (IRG).[6] IRG's main objective is to work on improved situational awareness through information exchange and better data collaboration.

The CAA report focused on constrained airspace and runway capacity. But as passenger numbers increased and operations ramped up during the summer of 2022, other bottlenecks that could significantly impact overall performance, such as the security clearance process, became apparent.[7] Achieving resilience across the network requires a holistic approach that takes into account various processes and interorganizational interfaces.

More reviews of critical network parts provide better visibility into the true remaining buffer capacity and help stakeholders make more targeted investment decisions. For example, Ryanair invested a substantial amount of money in ground-handling equipment at its main UK hub, Stansted Airport, as quick turnaround times are a key part of its operation.[8] Note that investments do not necessarily always need to involve physical infrastructure; they could include better use of available data or increased/enhanced training.

Another critical part of system design is establishing a consistent audit system. Internal processes, stakeholder interfaces, and the environment continue to change and impact the operation and its embedded buffer capacity. Changes in operations or external environment can affect risk profiles, and audits help leaders evaluate whether or not existing barriers are sufficient to mitigate emerging threats, helping to stabilize operations.

2. SYSTEM PREPAREDNESS

Anticipating possible disruptions is critical to enhancing resilience.[9] Close monitoring of available data is important, and a network must be able to translate early, weak signals of danger into potential safety concerns. For instance, the UK's main air navigation service provider, NATS, compiles a list of special occasions that could impact operations. This includes state visits and sporting events with the potential to create additional stress to the network.[10] This type of added demand requires additional buffer capacity, such as increasing the number of air traffic control officers on duty.

Another practical example of successful mitigation occurred around Christmas 2022. On 7 December, the UK Border Force declared a plan to go on strike from 23 December to 26 December and again from 28 December to 31 December — extremely busy travel periods. A reduction in flight schedules would have caused massive economic loss for airlines and airports, ultimately affecting thousands of people. Instead, the UK government decided that army personnel would be trained and put in place to screen passengers to limit the effects of the walkout on passenger flights.[11]

Of course, deploying additional resources is not always an option. In those cases, proactively reducing performance output can be a good option, especially in situations where demand for resources outweighs available supply. For example, airlines might choose to cancel flights 24 or 48 hours in advance of a severe weather event. This circumvents the need for airlines to cancel numerous flights on the day of the storm, which tends to result in large numbers of diversions, thousands of passengers stranded at airports, and crews and aircraft left out of position for the next day's operations.

Proactively reducing flights results in more stable operations compared to planning a full flight program and reacting tactically to issues on the day. It can also be cost-effective to make deeper cuts than strictly necessary to ensure a fresh start the following day, rather than having disruptions affect operations for days. Willingness to proactively sacrifice parts of the operation for the greater good can strengthen operational resilience.

IRG is working to reinforce the connection between the UK's weather forecast provider and air transport stakeholders to ensure that operational planning is based on up-to-date, accurate data. This helps ensure that an appropriate number of flights are cancelled in response to expected weather conditions.

3. SYSTEM RESPONSE

This element of resilience combines emergency management, business continuity, disaster recovery, and several other reactive management concepts. Early detection of a disturbance helps networks contain the damage and stop the failure from spreading. In an increasingly interconnected world, organizations should establish effective communication channels to promptly inform the network and minimize operational impacts. Lack of communication can impede timely situational awareness, creating a barrier to system resilience.

Preestablished response plans are often put in place for events or threats that occur with relative frequency. The efficiency of this response hinges on the design principles described above, including redundant systems, buffer capacity, and other measures. These can minimize the impact of disruptions to network operations.

As stated in the CAA report, the network was at risk of being overwhelmed if an airport closure occurred due to increased runway use. This posed a threat because diversions could not be managed at other airports without significantly impacting operations. Therefore, in a collaborative effort, IRG produced a mass-diversion protocol for a single runway closure at any UK airport. The protocol contains a list of pre-allocated slots at several UK airports that provide air traffic control officers with an overview of the available buffer capacity at individual airports so they can efficiently distribute diverted aircraft.

For some events, no exact preplanned response is available, especially when events are so severe that internal resources of individual organizations are overwhelmed and additional resources are required. The response to these types of events usually involves multiple stakeholders, requiring an effective governance structure for communication and coordination.[12]

Local resilience forums in the UK can provide airports with the necessary additional resources to handle such events. The forums are multiagency partnerships comprising the National Health Service, local authorities, emergency services, and other stakeholders that airports wish to include.[13] Efficient resource management and a coordinated approach among multiple stakeholders in a dynamic situation require an effective governance structure. Regular training exercises can enhance interface capabilities, promote familiarity among staff working with other entities, and generate a shared understanding of workflow.

> **EARLY DETECTION OF A DISTURBANCE HELPS NETWORKS CONTAIN THE DAMAGE AND STOP THE FAILURE FROM SPREADING**

Following severe events, the priority is to recover rapidly to an acceptable level of performance. This aspect of resilience, often referred to as "bouncing back," emphasizes achieving a high repair rate and restoring functions promptly to reach pre-disruption performance levels.

The pandemic illustrated that some events do not permit an immediate recovery, necessitating instead a focus on survivability. During such events, the focus shifts toward survival, and organizations may adopt an emergency configuration. The pandemic provided multiple examples of this: London's Heathrow Airport closed entire terminals to save costs, and airlines converted passenger aircraft into cargo planes, helping to transport essential goods around the world and creating a vital source of airline income.[14,15]

During these unprecedented occurrences, networks undergo a re-synchronization process, dramatically altering dynamics. This creates the need to reevaluate and possibly reconfigure vital connections and interfaces, emphasizing the need for an adaptable governance framework to facilitate secure and smooth adaptations during a crisis.

4. SYSTEM CHANGE

The last element of resilience involves "bouncing forward." After recovering from a disruption, networks should seize the opportunity to review the incident and pinpoint lessons learned. This introspective process involves both contemplating potential improvements and recognizing the positive aspects, ensuring the preservation of effective practices for future events.[16]

Network enhancements aren't restricted to learning from past events; they can stem from proactive measures. It is essential to note that apparent improvements in one area of the network may inadvertently produce side effects in other parts, potentially compromising the network's stability.

Before introducing modifications, it is essential to perform risk assessments and network analyses to detect possible repercussions, and communicating these adaptations throughout the network is crucial. The UK Airspace Change Organising Group (ACOG) is a good example of this type of change; it aims to strengthen the resilience of the UK airspace in the long term.[17] The UK's airspace design was created in the 1950s and 1960s, and although the design has evolved and new airways have been added, traces of the relatively simple original design can still be seen in today's complex UK airspace structure.[18]

With the number of flights expected to rise in the near future, the UK government acknowledges a need to update and redesign the country's airspace in its Airspace Modernisation Strategy.[19] Of course, such a significant transformation presents its own set of challenges. ACOG is responsible for identifying the benefits, disadvantages, and trade-offs, while ensuring effective communication with all relevant stakeholders. Although some of these changes are several years off, networks should consider them now, as implementing these changes may require considerable time. Achieving long-term adaptability is a crucial element of resilience.

CONCLUSION

Resilience is a multifaceted concept, involving system design, system preparedness, system response, and system change. Various tools and principles are available for each of those elements to support organizations and networks as they strive to become more resilient. There are multiple forums working to establish a more holistic view on the concept of resilience and promote the interorganizational element. Achieving resilience is a team effort, so organizations need to come together to work on strengthening resilience across the network.

REFERENCES

1. "Resilient and Sustainable Infrastructure." Council on Foreign Relations, 9 March 2022.

2. Pettersen, Kenneth A., and Paul R. Schulman. "Drift, Adaptation, Resilience and Reliability: Toward an Empirical Clarification." *Safety Science*, Vol. 117, August 2019.

3. Woods, David D. "Resilience and the Ability to Anticipate." In *Resilience Engineering in Practice: A Guidebook*, edited by Erik Hollnagel, et al. CRC Press, 2010.

4. Madni, Azad M., and Scott Jackson. "Towards a Conceptual Framework for Resilience Engineering." *IEEE Systems Journal*, Vol. 3, No. 2, April 2009.

5. "CAP1515: Operating Resilience of the UK's Aviation Infrastructure and the Consumer Interest." UK Civil Aviation Authority (CAA), 7 July 2017.

[6] "Report of the Voluntary Industry Resilience Group." UK Civil Aviation Authority (CAA), December 2017.

[7] Dollimore, Laurence. "No End in Sight to Holiday Nightmare: Airlines 'Resign Themselves to Summer of Chaos' and Heathrow Boss Warns of 18 Months of Misery — As Passengers Face More Mayhem Today with Huge Queues and Bag Collection in 'Disarray.'" *Daily Mail*, 8 June 2022.

[8] Burns, Justin. "Blue Handling Creation at London Stansted Already Paying Off for Ryanair." Airline Routes & Ground Services (ARGS), 11 September 2019.

[9] Dolif, Giovanni, et al. "Resilience and Brittleness in the ALERTA RIO System: A Field Study About the Decision-Making of Forecasters." *Natural Hazard*s, Vol. 65, October 2012.

[10] Howard-Allen, Wendy. "Planning for a Busy Summer." NATS blog, 23 May 2019.

[11] Syal, Rajeev. "Uniformed Soldiers to Cover for Striking UK Border Force Staff." *The Guardian*, 29 November 2022.

[12] Naderpajouh, Nader, et al. "Engineering Meets Institutions: An Interdisciplinary Approach to the Management of Resilience." *Environment Systems and Decisions*, Vol. 38, August 2018.

[13] Civil Contingencies Secretariat. "The Role of Local Resilience Forums: A Reference Document." UK Cabinet Office, July 2013.

[14] Fox, Alison. "Inside Heathrow's Precautions Against Coronavirus." *Travel & Leisure*, 4 May 2020.

[15] Horton, Will. "British Airways Removing Seats on 777s for COVID-19 Cargo While Air France Keeps Cabin Installed." *Forbes*, 10 May 2020.

[16] Hollnagel, Erik. "Resilience Engineering and the Built Environment." *Building Research & Information*, Vol. 42, No. 2, December 2013.

[17] "CAP2156C: Airspace Change Masterplan — Future Opportunities to Express Views." UK Civil Aviation Authority (CAA), 15 December 2022.

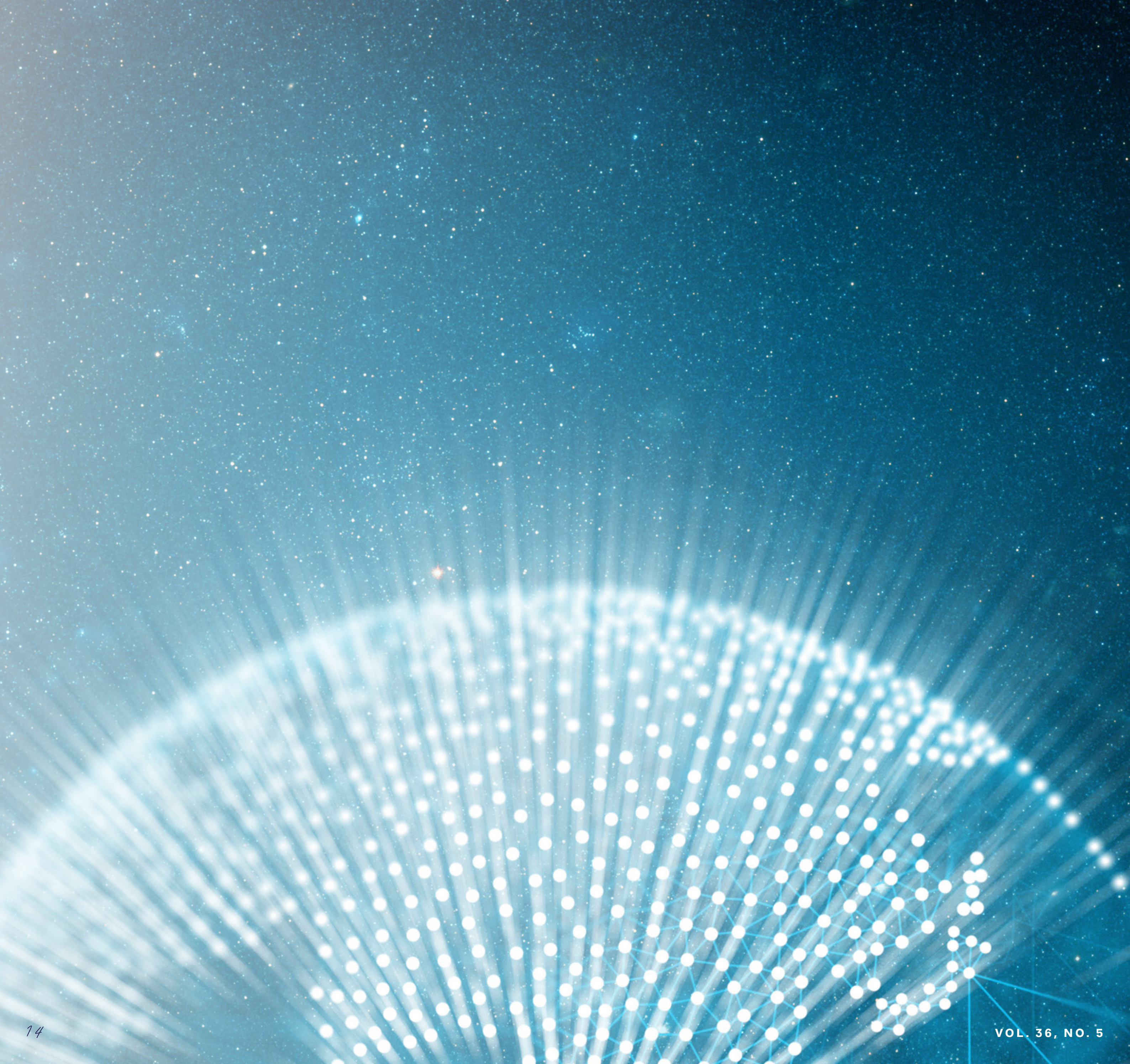
[18] Rolfe, Martin. "History Shows Why Modernising UK Airspace Is So Vital." NATS, accessed May 2023.

[19] "CAP1711: Airspace Modernisation Strategy 2023–2040, Part 1: Strategic Objectives and Enablers." UK Civil Aviation Authority (CAA), 23 January 2023.

About the author

Fabian Steinmann is a Lecturer in Organizational Resilience and Change at Cranfield School of Management, UK. His research focuses on resilience in the aviation and maritime industry. Dr. Steinmann regularly attends meetings of the UK Industry Resilience Group, a collaboration between airlines, airports, air traffic control, and regulator. With the aviation industry's interest in resilience increasing, his research area has proven to be topical and applicable to many disciplines and sectors. Dr. Steinmann was an invited speaker at the *2022 IAPH World Ports Conference* in Vancouver, Canada, where he shared his thoughts on resilience. His PhD thesis provided empirical evidence of where and how features of resilience are already being used in the UK air transport industry and also highlighted opportunities for organizations and networks to implement the concept of resilience. Dr. Steinmann earned a bachelor's degree in aerospace, aeronautical, and astronautical engineering from the University of Stuttgart, Germany, and a PhD in air transportation resilience from Cranfield University, UK. He can be reached at f.steinmann@cranfield.ac.uk.

DIGITALLY TRANSFORMING AIRLINES TO STAY COMPETITIVE IN TURBULENT TIMES



Author

Curt Hall

The airline industry is grappling with a number of disruptive forces: an economic hangover from the pandemic, uncertainty about fuel availability and costs, and growing public awareness of climate change and the impact that air travel has on global warming. Like other travel-related industries, the airline industry was largely unprepared for the pandemic. It was forced to take drastic measures to keep operating in a highly unpredictable environment that disrupted flight operations worldwide, trashed bottom lines, and left a sour taste in the mouths of countless customers.

Today, the cost of aviation fuel remains one of the most unpredictable issues facing the industry, uncertainty that's exacerbated by the war in Ukraine and ongoing troubles in the Middle East.[1] The industry is also under increasing pressure to reduce its carbon footprint and other climate impacts from governments, shareholders, grassroots initiatives, and green-conscious consumers inspired by celebrity climate activists like Greta Thunberg, who has challenged consumers to consider their participation in air travel through "flight shaming."[2]

Airlines are preparing for future disruptions by digitally transforming aircraft operations and other commercial activities to make them more resilient and competitive in the face of current and future threats. This includes investing in artificial intelligence (AI) and supporting technologies, specifically cloud computing, big data, machine learning (ML) and other advanced analytics, computer vision, and the Internet of Things (IoT).

> **AIRLINES ARE PREPARING FOR FUTURE DISRUPTIONS BY DIGITALLY TRANSFORMING AIRCRAFT OPERATIONS**

This article examines how airlines are striving to remain competitive and respond to threats in turbulent times by applying AI, cloud, and analytics technologies in two main areas:

1. Flight operations, such as flight planning/routing and crew planning/scheduling
2. Ground operations, such as gate assignments, maintenance, and other aircraft turnaround operations

MASS MOVEMENT TO THE CLOUD

Airlines are increasingly moving their IT operations to the cloud to alleviate issues associated with modernizing their legacy systems and to leverage the dynamic scaling capabilities of cloud architectures and applications. This includes more efficiently implementing new applications that can take advantage of AI, IoT, ML, mobile, and other emerging technologies. Over the past few years, many major airlines have announced partnerships or undertaken important projects with leading cloud-platform providers:

- **American Airlines.** Microsoft Azure is the preferred cloud platform for this airline's digital transformation efforts. This includes migrating its strategic operational workloads (data warehousing and legacy applications) into a single operations hub running on Azure, which the airline sees as essential to increasing the efficiency of its operations and meeting its sustainability goals.[3]

- **Delta Airlines.** Delta is using Amazon Web Services (AWS) as its main cloud provider, including its digital business transformation efforts and developing secure infrastructure that will support more data-driven insights. Delta is training employees on AWS to increase cloud adoption and further the development of client-facing and internal applications.[4]
- **Lufthansa Airlines.** Although it's using several cloud providers (AWS, Microsoft Azure, and Google), Lufthansa has made Google a strategic partner in optimizing its airline operations. This includes combining previously disparate systems and data sources into a unified platform using Google's cloud infrastructure and ML capabilities.[5]
- **Scandinavian Airlines.** This airline is using Microsoft Azure to lower infrastructure costs and gain agility for its development teams, including Azure data center services and ML tools to build predictive models to support its operations.[6]
- **Southwest Airlines.** Southwest is using AWS, its preferred provider, to carry out a large-scale modernization of its data architecture using a cloud data warehouse. The airline plans to deliver cloud-based analytics to data scientists, analysts, and business users across all of its operations.[7]
- **Swiss International Airlines.** This airline has a broad partnership with Google to use cloud technology, including AI. It has developed a flight-operations platform that integrates data from various operating units to make the airline more efficient and sustainable.[8]
- **United Airlines.** United uses AWS as its preferred cloud provider, including supporting its digital innovation initiatives with cloud-based ML, IoT, analytics, data management, computing, storage, and security services.[9]

Note that many of the AI applications discussed in this article were developed and deployed on commercial cloud platforms.

AI APPLICATIONS FOR FLIGHT OPERATIONS

Flight operations involve a range of activities necessary for the safe and efficient operation of aircraft. Table 1 provides an overview of AI applications in use or under development by airlines for flight operations. These applications do not represent all those deployed or in development, but they are a good cross-section of the types of applications airlines are developing and the technologies they are using.

According to the information provided in Table 1, airlines are applying AI to support flight operations in two main areas:

1. Flight planning, such as assisting planners in developing more optimized and fuel-efficient routes
2. Crew planning and scheduling, such as helping airlines solve crew-staffing problems

In general, airlines are implementing AI applications with the goal of applying prediction, analysis, and forecasting capabilities to add flexibility and resiliency to their operations (including more efficient utilization of aircraft and support services and the ability to recover quickly and efficiently from disruptions) and to support their customer experience (CX) and sustainability initiatives.

The major airlines are also implementing comprehensive applications designed to facilitate AI-based scenario planning for a range of flight operations. For example, the software could offer suggestions to planners on optimizing flight schedules based on changing weather forecasts or predicted airspace congestion.

Increasingly, airlines are implementing AI applications that can consider multiple factors (e.g., impact on sustainability, resiliency, and CX) when generating decisions or offering advice. Additionally, because they are designed to support multiple airline hub operations, these applications can employ big data analytics and ML to integrate and analyze data sourced from various operational systems.

AIRLINE	APPLICATION/DESCRIPTION
Air New Zealand	Uses AI for aircraft routing, including fuel-optimization planning for long-haul flights; this generates more fuel-efficient flight plans, including recommendations on avoiding headwinds to eliminate unplanned fuel stops due to inclement weather; application can recommend changes in aircraft speed/altitude to optimize fuel efficiency (e.g., to take advantage of tailwinds).
Alaska Airlines	Uses Airspace Intelligence's route-mapping tool to suggest flight routes based on ML analyses of real-time weather and air traffic patterns, helping dispatchers create flight plans less prone to revision; benefits include more predictable flight operations and arrival times (including better CX), reduced fuel consumption, more cost-effective operations, and reduced CO2 footprint; after a six-month pilot, Alaska Airlines reduced its fuel use by 480,000 gallons and trimmed nearly 4,600 tons of CO2 emissions.
American Airlines	Uses a hub-efficiency analytics application running on Azure Cloud Services; application uses cloud storage, analytics, and ML to integrate and analyze data, such as routing, weather, aircraft load factors, customer connecting flight information, gate availability, and runway availability.
British Airways	Testing an ML analytics system that examines flight plans using real-time data from the Global Air Traffic Control database and suggests faster routes; this optimizes aircraft flight times, reduces delays, and saves on fuel.
Garuda Indonesia	Deployed CAE Crew Planning and CAE Crew Management to automate and digitize its aircraft crew management operations; applications use AI/ML resource planning tools to optimize crew schedules, forecast crew resources, ensure safety standards compliance, and support fast recovery from disruptions.
Lufthansa Airlines	Partnered with Google to develop Operations Decision Support Suite planning tool that integrates data from Lufthansa's core systems; software uses data on aircraft rotation, passenger management, crew management, and technical fleet management to optimize flight operations, including more efficient aircraft use; also uses a Google Cloud application designed to reduce CO2 emissions via efficient aircraft usage, AI-enabled scenario planning, and ML analysis of weather patterns and aircraft fuel efficiency gained through optimized routing.
Southwest Airlines	Moved its data warehouses and analytics to AWS (Amazon Redshift); uses AWS storage, containers, ML (Amazon SageMaker), and services to optimize operational applications that support flight operations and gate assignments.
Swiss International Airlines	Developed a new operations platform on Google Cloud that uses data from various units and processes within the airline (e.g., passenger itineraries, aircraft assignments, crew rostering, and aircraft maintenance) to propose optimum scenarios for keeping flight operations as stable and efficient as possible; uses Google Cloud forecasting models to predict wind/weather patterns for route planning/fuel optimization.
United Airlines	Implementing a company-wide analytics and ML program running on AWS and developing cloud applications and services that can scale efficiently to meet demand, helping to optimize flight scheduling and other aircraft operations; uses IoT and Amazon SageMaker ML tools to predict irregular operations and respond faster to potential delays.

Table 1. AI airline applications for flight operations — flight planning/routing/fuel optimization/aircraft utilization/crew scheduling/sustainability/recovery

For example, Lufthansa is experimenting with Google's Vertex AI Forecast service to better predict the Bise wind, which blows from the northeast to southwest in Switzerland and can have a major impact on flight schedules. Google says the service can accurately predict the Bise hours in advance with a more than 40% relative improvement in accuracy over Lufthansa's internal heuristics.[10]

FLIGHT PLANNING, ROUTING & FUEL OPTIMIZATION

Most major airlines are using some form of AI to optimize their aircraft flight-planning and routing operations. Goals include reduced flight times, fewer unscheduled interruptions, and better fuel consumption (allowing aircraft to fly longer routes without having to land and refuel).

These goals both improve the CX and reduce CO2 emissions, supporting airline sustainability efforts. The ability to conduct longer flights also helps airlines meet growth initiatives, giving them the ability to fly to new destinations and/or service new markets.

ADVANCED WEATHER MODELING

Airlines are also focused on improving their weather modeling. This includes applying predictive analytics and other ML techniques to develop applications that not only support more accurate weather forecasts but also recommend changes in aircraft flight operations (e.g., reduced speed, altitude) to optimize fuel use and shorten flight times.

Several airlines are turning to AI experts at major cloud providers to assist their efforts. Lufthansa and Swiss International are both working with Google to build predictive analytics for advanced weather modeling, and other airline flight operations using BigQuery and Vertex AI.

AIRCRAFT UTILIZATION/ FLIGHT ROTATION

Flight rotation management (FRM) is the process of selecting the aircraft best suited for a particular flight, and it's key to optimizing flight operations and decreasing fuel consumption.

Aircraft selection is a complex problem that must take into account aircraft availability, capacity, range, fuel consumption, weather, and maintenance schedules. Consequently, airlines have made FRM a key target for applying AI. Several airlines are experimenting with AI as a tool to improve FRM, including Lufthansa.[11]

CREW SCHEDULING

Airlines are upgrading their crew management capabilities to optimize flight operations and improve their ability to respond to staffing problems. To meet their needs, vendors of commercial airline solutions are building AI and analytics into their tools. For example, CAE (a Canadian manufacturer of simulation technologies) has added ML to its crew-planning/crew management resource-planning tools to improve crew-resource forecasting and help airlines recover faster from disruptions (e.g., a storm that results in large numbers of crew members not being able to get to their assignments).

AI IN GROUND OPERATIONS

Airline ground operations include aircraft gate scheduling and assignment and the many other activities and processes required to maintain and prepare an aircraft for flight. Table 2 provides an overview of AI applications currently in use or under development by airlines for ground operations.

Table 2 describes applications in which airlines are combining AI with IoT, predictive analytics and other ML techniques, mobile, and machine vision technologies to perform aircraft maintenance (including predictive maintenance) and to optimize their gate-scheduling and various other aircraft-turnaround activities.

The efficiency with which ground operations are conducted can have a huge impact on airline flight operations. Consequently, airlines are intensely focused on applying AI to ground operations as a way to improve overall operational efficiency, reduce turnaround times, and streamline gate assignments to eliminate confusion and reduce the need for lengthy taxis.

AIRLINE	APPLICATION/DESCRIPTION
Alaska Airlines	Deployed Aermetric's cloud-based maintenance and logistics hub platform; uses IoT, big data, and ML to provide near-real-time analytics for inter-fleet health monitoring, including chronic issue identification and predictive maintenance for smart aircraft fleet management; this increases aircraft availability while providing substantial savings in reduced unplanned maintenance.
American Airlines	Uses intelligent gating application at DFW airport; analyzes data in real time, including routing and runway information, to automatically assign the nearest-available gate to arriving aircraft; this has reduced manual gate assignment workload and taxi times by about 10 hours per day; also uses mobile app ConnectMe, which lets maintenance personnel, ground crew, pilots, flight attendants, and gate agents collaborate to increase on-time departures and accelerate aircraft turnaround times.
British Airways	Uses Assaia ApronAI smart video system to record every moment from when an aircraft arrives at the airport to its departure; this helps turnaround teams monitor numerous tasks (e.g., fueling, cleaning, baggage handling, catering, loading, and unloading), alerting them to issues that could delay departure; also uses ML to adjust volume of fresh food loaded onto individual flights to help meet customer demand while minimizing waste.
Greater Toronto Airports Authority	Deployed Assaia ApronAI smart video system to optimize operations at Toronto Pearson International Airport's 106 gates; system monitors aircraft turnaround processes in real time, capturing and analyzing data used to highlight and address inefficiencies and provide accurate estimates of timeliness to increase gate availability, improve on-time performance, and provide accurate information to passengers.
Lufthansa CityLine	Uses a smart video system to monitor aircraft turnaround and reduce flight delays; developed by zeroG (part of Lufthansa Systems) and based on Microsoft Azure Video Analyzer (Azure Stack Edge service); provides auto-generated, near-real-time data of what happens during aircraft turnaround, including safety-related information; video streams are processed on the edge and remain on-premise; extracted data can be integrated with existing customer back-end systems directly or via cloud; system automatically blurs out people working around aircraft and apron from video material and does not store personnel-related data.
Scandinavian Airlines	Uses ML application running on Microsoft Azure Cloud to predict correct quantity of fresh food to be loaded onto flights; system improves customer satisfaction and reduces food waste by 45%.
Swiss International Airlines	Trialing an AI-based video system to automate passenger count process during flight boarding; goal is to ease crew workload; data recorded will be used solely for passenger count and will not involve facial recognition; recordings will be processed in full compliance with strict European (GDPR) and Swiss (FADP) data-protection provisions and then deleted.

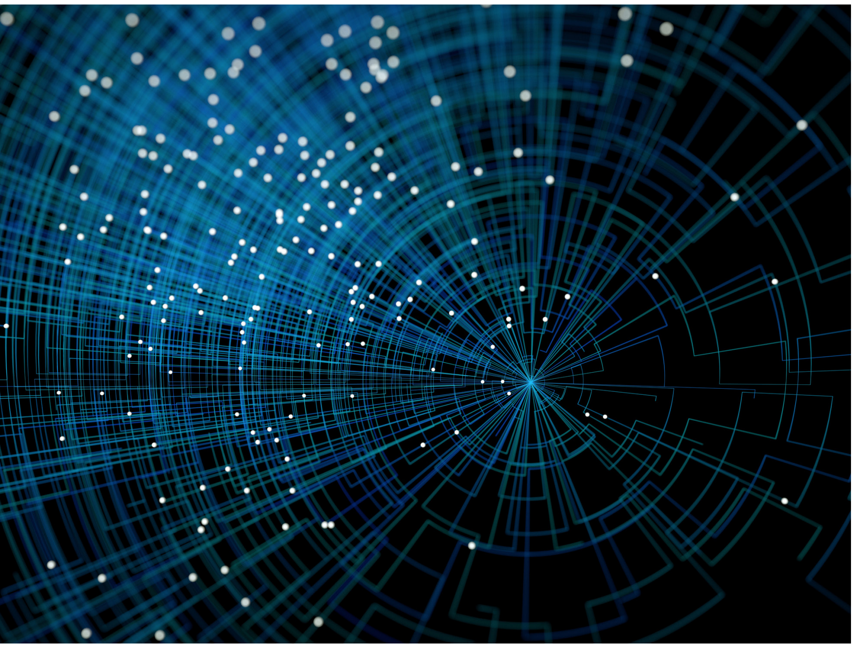
Table 2. AI airline applications for ground operations — aircraft gate assignment/maintenance and turnaround

These goals are also essential to reducing fuel usage, which would lower costs and reduce CO2 emissions (helping airlines meet their net-zero goals). The ability to maintain on-time departure and arrival schedules also has a positive effect on passenger satisfaction and can help airlines comply with regulations.

INTELLIGENT GATE ASSIGNMENT

Gate assignment is complex. It must take into account walking distances for passengers (including transfers), baggage-handling distances, connecting flight schedules, aircraft/gate-size compatibility, gate availability, time restrictions on an aircraft remaining at a gate, and taxi distances.[12] Airlines first started using rule-based AI systems in the late 1980s to automate gate assignments. Today, many are applying updated ML and AI techniques to optimize gate assignment.

American Airlines operates an intelligent gating system at its largest hub, Dallas Fort Worth International Airport (DFW), where it has 136 gates. The cloud-based application combines ML and analytics to conduct real-time analysis on routing and runway information to assign the nearest-available gate to arriving aircraft. American says the application reduces aircraft taxi times, saving the airline thousands of gallons of jet fuel each year. The application's decision-making also factors in connecting customer information, allowing extra time for passengers to catch their next flight.[13]



Previously, gating decisions for American aircraft at DFW required more manual involvement from gate planners. The new application can analyze multiple data points simultaneously for hundreds of daily arrivals, shaving more than a minute of taxi time per flight. This adds up to 10 hours of reduced taxi time per day, lower fuel usage, and reduced CO2 emissions.

MAINTENANCE & AIRCRAFT TURNAROUND

Aircraft turnaround involves considerably more than gate scheduling. Upon gating, an aircraft must be deplaned, refueled, cleaned, catered, safety-checked, and boarded. Every second a plane remains on the ground can result in lost revenue, and a variety of advanced tools are being used or considered by airlines.[14]

COMPUTER VISION

Smart camera systems are being deployed to monitor and analyze turnaround processes. The data can be used to improve multiple aircraft-preparation processes, including gate assignments, alerting, delay prediction, safety compliance, and sustainability. British Airways, Lufthansa, Swiss International, and the Greater Toronto Airports Authority are all using (or plan to deploy) such applications to replace manual, error-prone processes that require collecting data from various maintenance units.

These systems apply ML to video imagery acquired from cameras deployed in various scenarios. For example, Assaia ApronAI analyzes captured images to determine the exact time each turnaround process starts and ends, tracking whether or not each task was being performed on time.[15] Analysis is performed in real time to show what is happening on the apron (the area around the parked aircraft), allowing planners, gate schedulers, mechanics, and other ground-support staff to better understand the current situation as it is developing. To ease performance demands, smart cameras typically perform processing on edge or near-the-edge devices (i.e., cameras). This also ensures the system complies with the General Data Protection Regulation (GDPR), California Consumer Privacy Act, and other data-protection and privacy regulations.

PREDICTIVE ANALYTICS FOR FRESH FOOD OPTIMIZATION

Airlines are using ML to more accurately predict the volume of food loaded preflight onto an aircraft. Goals include less food waste, lower costs, and improved customer satisfaction. British Airlines and Scandinavia Airlines are using or testing such systems.

COMBINING AI, ANALYTICS & MOBILE TO SPEED AIRCRAFT TURNAROUND

Airlines are implementing mobile apps that allow maintenance personnel, ground crews, pilots, flight attendants, and gate agents to collaborate to ensure that flights depart on time. These apps give ground personnel access to the information they need to prepare the aircraft before departure (which typically resides across different systems) on their phones, replacing unwieldy desktops and laptops. For example, American has deployed ConnectMe, a Microsoft Power App that team members can access from any mobile device.

> **WE EXPECT TO SEE AIRLINES CONTINUE TO DEVELOP COMPREHENSIVE APPLICATIONS**

CONCLUSION

The airline industry has turned to AI to digitally transform airline operations to remain competitive and better respond to current issues and future threats.

As highlighted in this article, most airlines are focused on applying AI to optimize key flight and ground operations but appear open to experimenting with the technology across a broad range of applications. (A number of the applications covered in this article are fairly new developments or are in testing or pilot stages.) Many airlines are also using AI to support their additional strategic goals of providing a better CX and to achieve their sustainability initiatives.

To get around the limitations imposed by their existing legacy architectures, airlines have embraced a cloud-first approach. In addition to using the cloud's dynamic scalability to support rapid application development and deployment, airlines are increasingly leveraging the expertise of the major cloud providers' AI gurus and data scientists to help them implement cutting-edge applications that combine AI with analytics, IoT, machine vision, and mobile. A key trend to note is the increasing use of machine vision in smart cameras deployed to support aircraft maintenance and turnaround operations (beyond their widespread use in airport security scenarios).

Going forward, we expect to see airlines continue to develop comprehensive applications that not only facilitate scenario planning for a range of flight and ground operations, but also factor considerations like sustainability, resiliency, and CX into the decision-making process.

REFERENCES

1 "Top 8 Challenges for the Aviation Industry in the Post-COVID 19 Era." Global Market Insights, 21 December 2022.

2 Cummins, Nicholas. "Greta Thunberg Is Making People Rethink Air Travel: The Flight Shaming Movement." Simple Flying, 3 October 2019.

3 "American Airlines and Microsoft Partnership Takes Flight to Create a Smoother Travel Experience for Customers and Better Technology Tools for Team Members." Microsoft News Center, 18 May 2022.

4 "AWS Selected as Delta's Preferred Cloud Provider." Amazon Press Center, 13 July 2022.

5 "Google Cloud Lands Agreement with Lufthansa Group to Support Optimization of Its Airline Operations." Cision PR Newswire, 20 January 2020.

[6] "Scandinavian Airlines Reduces Loyalty Program Fraud with Microsoft Azure Machine Learning." Microsoft, 13 May 2020.

[7] "AWS Selected as Southwest Airlines Preferred Cloud Provider." Amazon Press Center, 8 March 2023.

[8] "SWISS Takes Off with Google Cloud to Make Its Flight Operations More Efficient and Sustainable." SWISS Newsroom, 28 April 2022.

[9] "AWS Named United Airlines Preferred Cloud Provider." Amazon Press Center, 30 November 2021.

[10] Nawalgaria, Anant. "Lufthansa Increases On-Time Flights by Wind Forecasting with Google Cloud ML." *Google Cloud Blog*, 28 September 2022.

[11] Talbott, Chris. "The Future of Sustainable Flying Is Data-Driven for Lufthansa Group." *Google Cloud Blog*, 12 October 2022.

[12] Haghani, Ali, and Min-Ching Chen. "Optimizing Gate Assignments at Airport Terminals." *Transportation Research Part A: Policy and Practice*, Vol. 32, No. 6, August 1998.

[13] Microsoft News Center (see 3).

[14] Ciesluk, Karol. "Turnaround Time: Why It's Important and How Airlines Can Speed It Up." Simple Flying, 21 June 2020.

[15] "Marubeni to Contribute Through AI Analysis and Process Visualization in Efficiency of Understaffed Ground Handling, Improving the On-Time Performance and Enabling More Slots." Assaia/WING Aviation Press Co., 9 August 2022.

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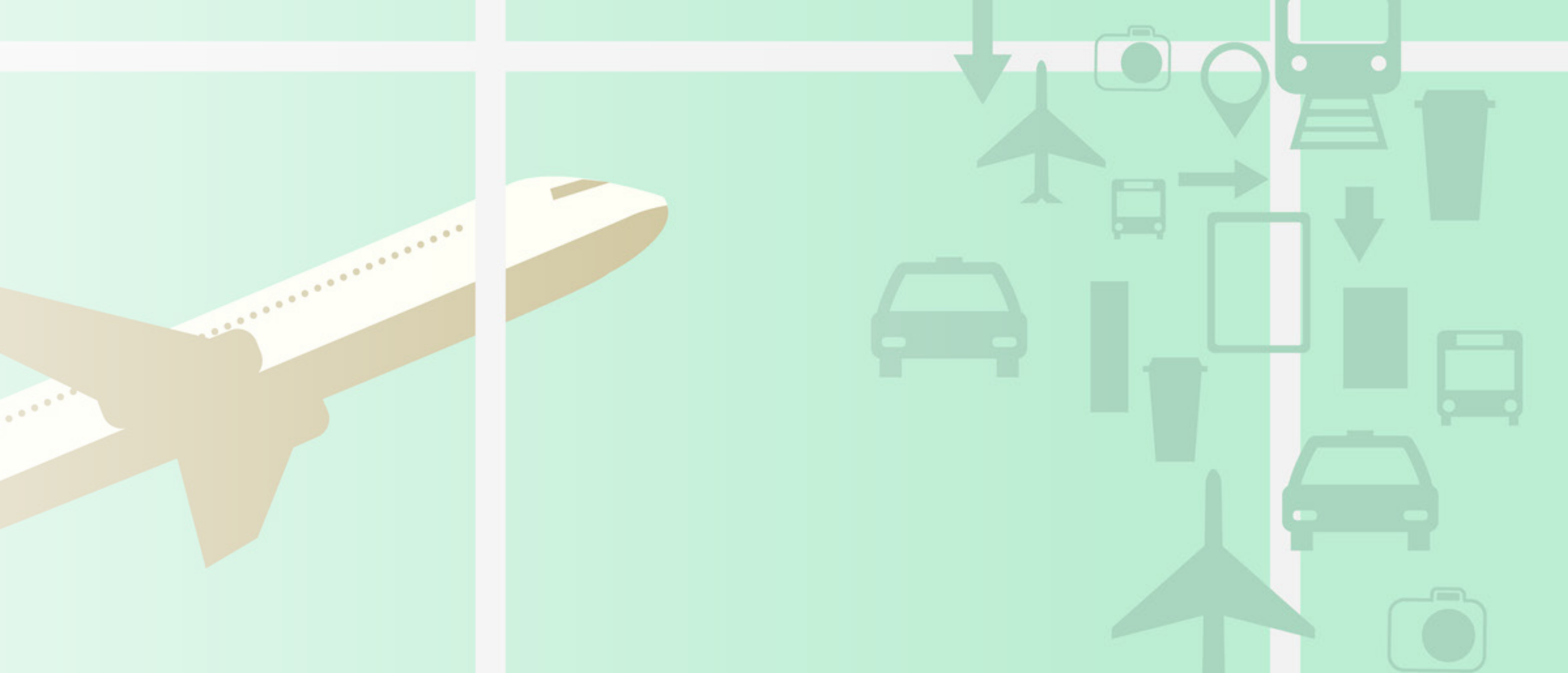
Curt Hall is a Cutter Expert and a member of Arthur D. Little's AMP open consulting network. He has extensive experience as an IT analyst covering technology and application development trends, markets, software, and services. Mr. Hall's expertise includes artificial intelligence (AI), machine learning (ML), intelligent process automation (IPA), natural language processing (NLP) and conversational computing, blockchain for business, and customer experience (CX) management He also focuses on the Internet of Things, including platforms, architectures, and use cases; big data platforms and use cases; and business intelligence (BI), predictive modeling, and other analytic practices. Mr. Hall's research also includes mobile and social technologies in the enterprise as well as mobile BI and collaboration. He has conducted extensive research on how all these technologies are being applied to develop new advisory, decision support, customer engagement, and other enterprise applications.

Mr. Hall is a frequent contributor to Cutter's Technology and Sustainability research deliverables as well as *Amplify*. He served as Editor of numerous Cutter journals, including *Intelligent Software Strategies, Data Management Strategies*, and *Business Intelligence Advisor*. His recent studies examining the enterprise adoption of key emerging technologies and practices delivered four series of in-depth, survey-based Cutter Consortium research: "AI & Machine Learning in the Enterprise," "Blockchain Rising," "CX Management in the Enterprise," and "IPA in the Enterprise. Mr. Hall also coauthored, with Cutter Senior Consultant Paul Harmon, *Intelligent Software Systems Development: An IS Manager's Guide* and contributed to James Martin and James Odell's *Object-Oriented Methods: Pragmatic Considerations*. His work has appeared in various technical journals and IT publications, including as a contributing author to PricewaterhouseCoopers Technology Forecast Yearbooks. Mr. Hall can be reached at experts@cutter.com.



HOW RISKY ARE ECONOMICALLY REGULATED AIRPORTS POST-COVID?

Authors

David Hart and Andrew Cunningham

The only way to avoid risk is to do nothing. And even that carries the risk of nothing getting done. To be active is to bear risk. To be productive is to bear risk. Some risk can be expected from past experience and mitigated, and some risk can be anticipated with less precision and best-effort contingency plans put in place. But risk cannot be removed from life or business practice.

Each year in the UK, nearly 6,000 people are hurt by their trousers and another 10,000 by their socks and tights — to the extent that they need hospital treatment. Our trousers and tights are not out to get us, but risk exists. Nor do most of us consider how to mitigate the risk posed by getting dressed. The associated risk has not occurred for us — at least not beyond the extent to which our response of grabbing the side of the bed hasn't mitigated it.

In business, investors and infrastructure operators make risk assessments moment to moment based on historical information, likely future events, and/or ways in which risk can be expected to materialize. A great deal of management time goes into reducing or managing the extent of anticipated risk and likely impacts. The cost of mitigating this risk and establishing contingency plans is well thought through and broken down into costs and possible market responses.

Typically, economic regulators deal with risk through the weighted average cost of capital (WACC) they assign to a regulated company for the period of the price control. The WACC considers "normal" risk for equity and credit investors, then makes adjustments based on how risky the regulated business is relative to a benchmark. For example, regulated water companies tend to have a lower WACC than airports because they are deemed less risky. Regulated airports generally have higher levels of demand risk than regulated water companies.

At one level, the economics of risk are simple: the riskier a business is, the higher the return an investor will require to put their money into that business. But things get complex very quickly when we start to think about just how risky a business is and who should pay for that risk.

> **A GREAT DEAL OF MANAGEMENT TIME GOES INTO REDUCING OR MANAGING THE EXTENT OF ANTICIPATED RISK AND LIKELY IMPACT**

The answer, of course, is that the consumer pays — but how? Regulators only have two choices. One option is for the regulated company to bear the risk, in which case we see a higher WACC and higher charges. Alternately, the consumer bears the risk (e.g., by the regulator "insuring" the business against certain events), in which case charges may be lower, at least until the risk crystalizes.

The general idea with respect to airport regulation is that if you can reduce the risk borne by the regulated airport, it will be less expensive and better for consumers. That opens up another contentious area — the risk is still being borne and paid for, just not by the regulated business. However, our interest here is not in the mechanics of risk in general, but in how regulators can deal with unanticipated shocks.

DEALING WITH SHOCKS AT DUBLIN & HEATHROW AIRPORTS PRE-COVID

Shocks happen, and when they do, they tend to affect passenger volumes at airports. Heathrow Airport Limited (HAL) is the business that owns and operates Heathrow Airport, and when it was putting forward its business case for the next price control on airport charges back in 2014, it specifically considered the issue of demand shocks. More precisely, it looked at how negative shocks like volcanic ash, avian flu, and 9/11 affected passenger volumes through the airport.

One can argue about whether short-term shocks lead to an overall loss of demand or just a demand shift (i.e., people still fly but on another day) and whether events like the Olympics (which was expected to boost tourism to the UK in 2012) lead to an overall decline or increase in passengers. One could also argue that the extent of the impact of a demand shock (e.g., from unexpected snowfall) might turn on how efficient the airport's response is to the shock.

However, we know for certain that shocks occur, and when they do, they can have an adverse effect on demand. The UK Civil Aviation Authority's (CAA) approach, broadly, was to take this shock data, make a few adjustments, and argue that while you can't tell exactly when a shock will hit, they tend to happen every X years and have an average effect on demand. CAA divides one by the other to come up with an average annual figure that is applied to the passenger forecast to offset volumes.

CAA argues that it is not double counting to include both the WACC increase for risk and the shock factor, as they account for different situations. According to CAA, the risk uplift in the WACC should only contain the risk that the CAA accommodation in the passenger forecast is wrong and so should be smaller. However, as CAA has never stated what the WACC uplift was, it's impossible to say what effect the shock factor had on the WACC.

In contrast, the Irish Aviation Authority (IAA) price-control settlements for Dublin do not include explicit shock uplifts in the WACC or an adverse shock generator in the passenger forecasts. Rather, IAA relies on the more traditional method of allowing the market to add in the cost of the risk of shocks and assumes that is what has happened when it makes its WACC decision.

WHAT HAPPENED DURING COVID?

The difference between the COVID-19 pandemic and previous shocks is that it lasted much longer and its effects were much more significant. Consequently, it is reasonable to assume that mechanisms designed to deal with lesser shocks might be overwhelmed. Indeed, the responses by the two regulators were different, but each was consistent with their original positions on factoring in shocks.

CAA's position was that shocks were already accounted for in the settlement, so all that needed to be done was to make HAL whole because the pandemic's impact was so much larger than anticipated. CAA faced a decision on how to do this. It could either allocate an additional amount to the OPEX settlement (so-called fast money, as the airlines would have had to pay back over a short period) or allocate an additional amount on the regulated asset base (so-called slow money, as the airlines would pay the money back over a much longer period through funding the depreciation of the regulated asset base). Given the state of the airline industry at the time, CAA chose the slow money approach. One can argue about the amount repaid, but in essence it was making HAL whole following an unexpectedly large shock.

In Dublin, the strategy was different. Rather than a "truing up" like at Heathrow, IAA and the Irish government reacted in real time. IAA suspended portions of the settlement (CAPEX triggers and service-quality targets were suspended), and there was support from the national government. IAA estimates these packages of support were worth some €220 million to the airport operator over two years.

In addition to responding differently to the pandemic, the regulators took different approaches to their most recent price-control announcements. CAA put in place a significant framework to account for shocks like the pandemic. This included the retention by the CAA of the adverse shock generator (which it calls the "Shock Factor") and the traffic risk sharing (TRS) mechanism.

In essence, the Shock Factor is an overlay of a percentage decrease in the forecast of passengers determined by CAA for a regulatory period. CAA describes the result of applying the Shock Factor as a risk-weighted forecast of passenger numbers. It does this to take into account the impact on passenger numbers of both the frequency and likely impact of noneconomic shocks for a regulatory period. For the current regulatory period, a Shock Factor value of 0.87% was applied by CAA to its passenger-numbers forecast to result in a prediction that has been adjusted down by 0.87% to take into account the prospective impact of shocks on the outturn of passenger numbers for HAL.

TRS reflects variations of traffic volume outturns from what was forecast, and from what was the basis of airport charges, through adjustments to the regulatory asset base (RAB). If passenger numbers were well below the forecast, for example, there would be a CAA-approved increase in value of the RAB. This would result in future increased charges to depreciate the increased RAB and/or an amount of charges being paid by users.

At a detailed level, CAA has implemented two "bands" based on the extent of prospective passenger volume variations from what was forecast and was the basis for the price cap established by CAA. First, there is a band designed to take account of passenger variation volumes of up to 10%. CAA has decided that within this band, 50% of traffic-related airport charges risk would be shared with airlines and the passengers that fly with them. Second, CAA established another band for volume outturns of more than 10% from what was forecast. CAA states that where variations are more than 10%, 105% of traffic-related airport charges risk would be shared with users.[1]

By comparison, IAA has not seen the need to dramatically change the architecture of its price control. There are no bands to take account of variations in passenger numbers from what was forecast and no adverse shock-adjustment factors. For IAA, it is essentially business as normal.

HOW ROBUST ARE THE AIRPORTS?

To determine robustness, we must first establish some context. Both airports use hub models, pooling passenger demand from a wider range of destinations than point-to-point airports. Healthy hub airports tend to be more resilient to adverse economic shocks than point-to-point airports.

In 2017, CAA commissioned a comparison of Heathrow with a number of other airports, looking at EBITDA as a measure of financial performance and passenger volumes as a measure of demand. The study showed that when looked at in terms of EBITDA per passenger, Heathrow performs well against its comparator group and is outperformed only by Hong Kong and Seoul. Further analysis shows that Heathrow's EBITDA performance was in the top two or three comparator airports and that over the 2011–2015 period, Heathrow's performance was improving.

The same study also included data for Dublin Airport, but was not specifically designed to assess Dublin's performance against a comparator group. While Dublin's financial performance was solid, Heathrow consistently outperformed it, and Dublin's performance was consistently toward the bottom end of the comparator group.

	2017	2018	2019	2020	2021	2022
HEATHROW						
EBITDA adjusted (£m)	1,752	1,792	1,828	270	384	1,684
Passenger volumes (m)	78	80.1	80.9	22.1	19.4	61.6
DUBLIN						
EBITDA (€m)	254	273	276	-2.1	25.4	249*
Passenger volumes (m)	29.6	31.5	32.9	7.4	8.5	30.3*

*Dublin Airport data not available for 2022, so group data is reported.

Table 1. A comparison of EBITDA and passenger volumes at Heathrow and Dublin Airports (source: regulatory account annual submissions to CAA and IAA)

When the pandemic hit, both airports were profitable and had passenger volumes near capacity (see Table 1). The effect of the pandemic on EBITDA and passenger volumes was dramatic and seems to have lasted for two years (2020 and 2021). It's interesting to note that Heathrow still reported a strongly positive EBITDA and that Dublin remained broadly profitable (although it recorded a small negative EBITDA of -€2 million in 2020 before recovering in 2021).

The strong recovery in 2022 is also interesting. Heathrow EBITDA and passenger volumes improved by 338% and 218%, respectively. At Dublin, the numbers were 880% and 256% (although this is slightly misleading as Table 1 compares Dublin Airport 2021 performance with group performance for 2022).

There is some debate between the two airports and their airlines about the speed of the recovery and its likely path. What we can say for certain is that recovery has been rapid, financial performance is improving, and even the most pessimistic forecasts suggest a return to pre-pandemic traffic numbers by 2025. Consequently, we can conclude that both airports are relatively resilient.

WHO WAS RIGHT?

Dublin and Heathrow airports aren't directly comparable. Although they are both hubs, there are notable differences. Heathrow is a major hub, one of the world's busiest and strategically important globally. Dublin is a secondary hub that's experiencing strong growth and is well placed to gain business in the lucrative transatlantic market. Their ownership structures, debt-to-equity ratio, and ambitions are all different. What matters is whether the regulatory interventions are appropriate and support their development.

Both airports were relatively near to capacity pre-pandemic, were relatively robust during it, and have now experienced strong traffic recovery.

Airport investors need certainty to invest. Of less certainty is the rate of return they will demand. The offering from IAA is a straight RAB environment that is effectively underwritten with support from the regulator and the government if the shock is severe enough to warrant it. Such an approach is flexible and agile, and the regulatory compliance costs are low. IAA and the Irish government have demonstrated that they will be accommodating should this type of shock hit again.

The downside is the amount of trust this approach relies on. Investors must trust that a future regulator will be sympathetic and supportive in the event of another pandemic-type shock. If they believe that to be the case, all is good; if they don't, some risk will be priced in, and costs at Dublin Airport will rise.

Conversely, CAA has fettered the discretion of the future CAA by creating a regulatory superstructure that determines how it would react. The plus side is certainty for investors. The downside is the regulatory cost and the risk that the dead bands are incorrectly set, alongside any gaming or unanticipated behavior that goes with any regulatory decision.

Essentially, any final conclusion turns on how one views the pandemic. If one sees it as a one-off in terms of the size and scale of the shock that was properly dealt with at the time, a big regulatory structure isn't needed. This is especially true if the markets trust the regulator to do the right thing.

Alternatively, if one thinks the pandemic marked a change and that shocks are likely to become larger, longer-lasting, and unpredictable to the point that they overwhelm existing regulatory arrangements, a CAA-type approach is wise. This is especially true if prices are particularly sensitive to the WACC or the regulator is not fully trusted by the markets.

Although it is too early to say whether we are now in a world where pandemic shocks will be common, it does appear that recovery has been rapid and strong for these two airports and the airlines that fly from them. If the COVID-19 pandemic was a one-off, it should be readily accommodated within existing regulatory structures, and there is no need for the additional regulatory superstructure adopted by the CAA.

The truth is, both regulators are gambling: IAA on its credibility and the COVID event being a one-off, CAA on the world having changed and markets needing it to fetter its discretion. Unless we see another COVID-type event, IAA's gamble seems the one more likely to pay off.

REFERENCE

[1] "Final and Initial Proposals for H7 Price Control." UK Civil Aviation Authority (CAA), accessed May 2023.

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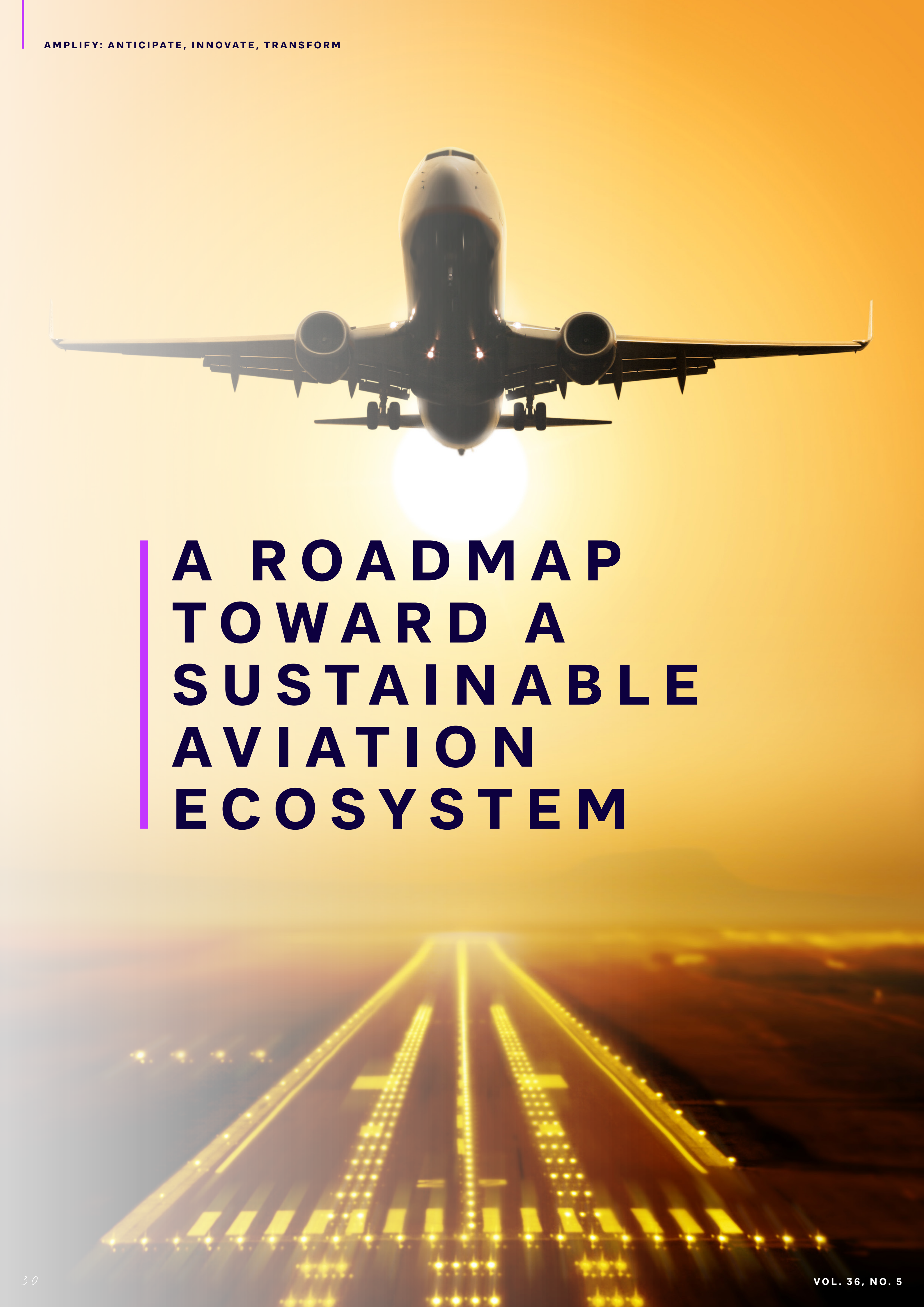
David Hart is Professor of Teaching and Professional Practice at Queen Mary University of London (QMUL), UK. He is a globally recognized expert in the economic regulation of airports, leading regulation review of UK airports, helping draft the UK Civil Aviation Act, and designing much of the current regulatory regime for Heathrow Airport. Prof. Hart has held leadership roles in eight airport price controls in the UK and abroad and has advised airlines, regulators, and governments on economic regulation. He was among the key architects of the framework of airport service quality regulation at Heathrow and has provided substantial input into each revision of the framework over the last two regulatory reviews. Prof. Hart is an expert in the design of regulatory models and incentive structures to deliver the aims of governments and regulators and has advised the UK government on governance models deployed by economic regulators. He designed the current regime for the treatment of CAPEX at Heathrow, was a key figure in the design of the governance models for Q6 and H7 Heathrow price controls, and recently led a governance review for a UK regulator. Prof. Hart earned a master of arts from the Universities of Cambridge and Warwick, UK, and a master of science degree from QMUL. He can be reached at david@claritylimited.co.uk.

Andrew Cunningham has been working in the airport and airline industry for more than 25 years. In the past two decades, he has held senior leadership roles in seven economic regulation reviews in the UK. Six of these have been for airports and one in the water industry. In each review, Mr. Cunningham has considered the issues to implementation of the settlement by the regulator. In particular, he has substantial experience regarding service quality needs of passengers in the context of regulated airports and seeking to promote the interests of consumers within the often-competing aspirations of stakeholders. Prior to his work in air transport, Mr. Cunningham was Head of Regulation and Business Performance for a water utility company. His experience in the water industry complements his air transport experience. Mr. Cunningham earned a master of arts in air transport management from Cranfield University, UK, and a master of science degree in theology from the University of Chester, UK. He is also a fellow of the Royal Aeronautical Society. He can be reached acunningham@tmaconsulting.co.uk.



A ROADMAP TOWARD A SUSTAINABLE AVIATION ECOSYSTEM

Authors

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Around the world, entities of all sizes seek to modernize the aviation industry by optimizing routes, increasing aircraft efficiency, and reducing fossil fuel dependence. The industry is balancing strong passenger and cargo demand, safety, and the need for decarbonization.[1] Globally, aviation accounts for about 1 gigaton of greenhouse gas (GHG) emissions per year (approximately 2% of global emissions in 2019) and is poised to increase.[2]

The industry is committed to achieving decarbonization by continuing energy-efficiency efforts and introducing sustainable fuels and new types of aircraft. Currently, the focus is on fuels for flight operations and, to a lesser extent, low- to zero-emission ground operations.[3] Most recently, multiple alternative-propulsion systems and fuels have been proposed, including electrified and hydrogen-fueled aircraft.

Meeting US and international 2050 goals for sustainable aviation fuel (SAF) will require drastic, rapid improvements in carbon reduction and advancements in current technologies or introduction of new ones.[4] Deep decarbonization (gradual elimination of carbon-emitting fuels) of the industry is now critical; strong evidence links climate change with increased CO2 levels in the upper atmosphere and other aviation-induced factors.[5] CO2 and non-CO2 aircraft emissions exacerbate climate change; impacts vary with the altitude at which they are emitted.[6] Non-CO2 impacts from aircraft include nitrogen oxides, contrail cirrus, water vapor, aerosol sulfate, and soot emissions that, combined with CO2, create a positive radiative-forcing effect that causes warming.[7]

Airports and ground operations contribute about 10% of aviation GHG emissions, often with disproportionate impacts on surrounding lower- and middle-income communities.[8] Many airports have committed to decarbonization and transformation of their operations as they prepare to serve a more diverse aircraft portfolio.[9] Figure 1 shows the sources of GHG emissions spanning fuels, aircraft, and infrastructure operations.

The complexity and interdependencies required to safely move passengers and goods across transportation modes will continue to increase, generating the need for innovative technologies and integrated solutions. Adding to the complexity is aviation's extremely high safety standards, global scale, and current market evolution.

Near term, SAF is a priority solution. Meeting industry goals of carbon neutrality requires advancing the state of SAF production, decarbonization, and deployment while advancing new technologies and logistics.

> **DEEP DECARBONIZATION OF THE INDUSTRY IS NOW CRITICAL**

Supporting technologies include alternative energy carriers, propulsion systems, and infrastructure. Alternative energy sources, including hydrogen and electricity, could add benefits such as noise reduction, localized emissions reduction, decreases in ongoing maintenance, and higher viability for autonomous aircraft routes due to the inherent benefit of simpler aircraft systems. New aerial vehicle designs, propulsion requirements, uses, and automation drive complexity while offering new value.

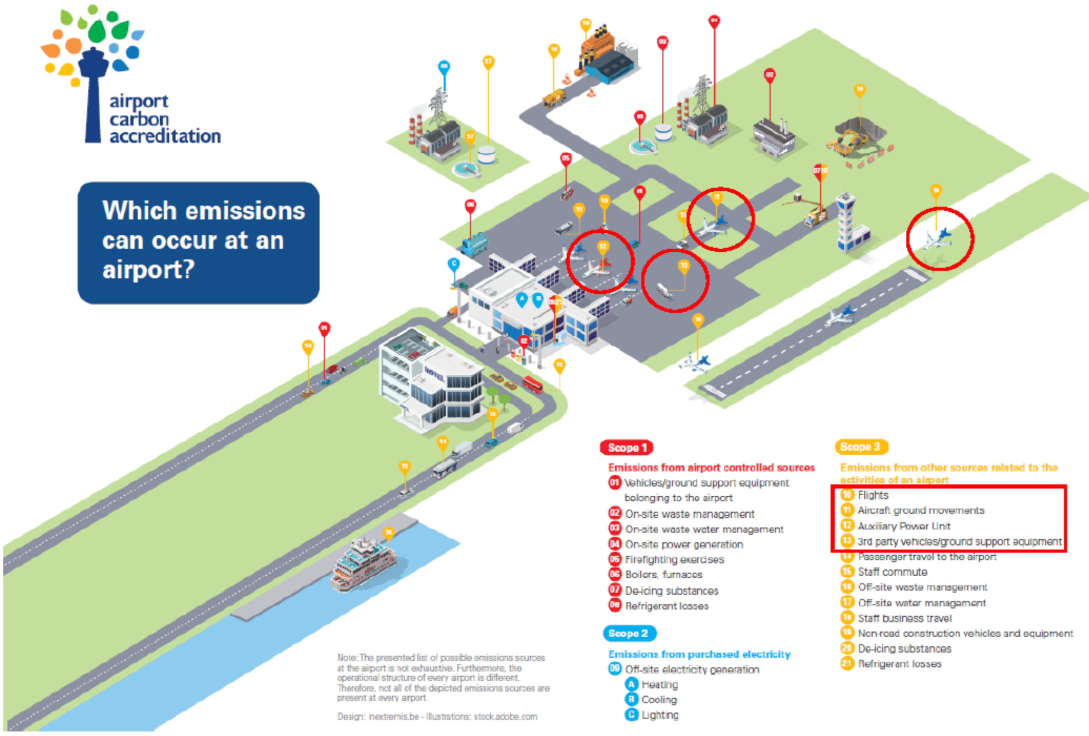

Figure 1. Carbon sources from aviation ecosystems (source: Airport Carbon Accreditation)

Since its inception at Kitty Hawk, North Carolina, USA, the aviation industry has evolved into a safe, reliable system that continues to improve en route and aircraft efficiency in a complex system that balances safety, economics, available infrastructure, and technology advancements. As major energy users, transportation systems play a key role in many communities, whether from energy transport, noise, emissions, or mobility connectivity.

Deep decarbonization of the aviation sector thus requires contributions from environmental, economic, human, operational, and energy perspectives. Opportunities to improve efficiency and lower emissions can benefit from a holistic view that strengthens existing initiatives — potentially unlocking unforeseen opportunities and overcoming constraints.

Focusing on any one set or even related sets of systems for transformation in the aviation industry addresses only part of the challenge. As aviation operations diversify to include electrified options, hydrogen, SAF, and other low-carbon fuels, the interdependencies between support systems will require holistic assessments and multiple solution sets to achieve full decarbonization.

Integrated system analyses can lead to well-coordinated approaches prior to implementation. The ability to develop and de-risk solutions for global implementation will allow impacted stakeholders (e.g., regulatory agencies, airport authorities, manufacturers, cities/towns, financial institutions, the public) to choose implementation pathways at an appropriate pace and scale.

UNDERSTANDING THE AVIATION ECOSYSTEM

Figure 2 shows the interdependencies across the aviation industry. Each set of systems (communications/technology, energy justice, energy solutions, human systems, and transportation networks) comprises multiple subsystems, highlighting the degree of connectivity in this industry and thus the need to approach solutions holistically. Each subsystem influences other subsystems and supports the critical infrastructure of aviation-based operations.

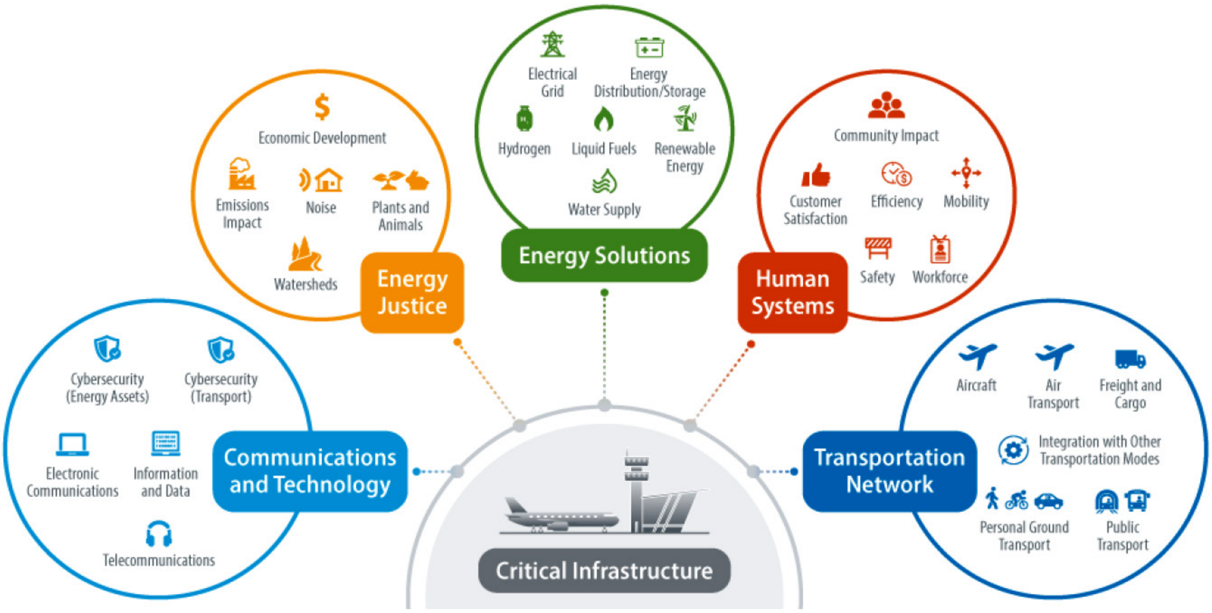

Figure 2. Interdependencies in the aviation industry (source: National Renewable Energy Laboratory)

For example, low- and no-carbon solutions have the potential to improve efficiencies, innovate solutions, and address local and global issues, including improving energy justice by influencing jobs, emissions, noise, or other factors. Physical, electrical, and cyber resilience are paramount for communications/technology to support the transportation of fuels, passengers, and goods. Human systems demand the highest safety factors throughout the three pillars of fuels, airport ecosystems, and aircraft while recognizing related needs of the transportation market driven by customer experience, accessibility to transportation, and community impact of established or emerging transportation amenities.

TRANSFORMING THE AVIATION ECOSYSTEM

Decarbonizing the aviation industry will require steady, transformational growth. Efforts are already underway and growing, with commitments from industry coalitions such as the US Federal Aviation Administration (FAA), International Civil Aviation Organization (ICAO), International Air Transport Association (IATA), and others to reduce CO2, other emissions, and environmental impacts.

For example, ICAO's global coalition for sustainable aviation includes companies like Airbus and Archer that are pursuing zero-emission aircraft and universities like Cranfield University, UK, and the Eindhoven University of Technology, the Netherlands, that are researching novel fuels.[10] The coalition includes 47 partners dedicated to sustainable aviation.

Major efforts are focused on SAF, and leading airports are evaluating ways to both modernize and decarbonize, targeting net-zero operations by 2050 or sooner.[11] To meet these goals and create financially viable low-carbon solutions at unprecedented speed and scale, public and private stakeholders have expressed the need to collaborate. They recognize that new approaches will be needed to bring these solutions to fruition, including a coordinated research, development, demonstration, and deployment (RDD&D) focus.

Figure 3 shows the three major pillars of the aviation ecosystem: energy carriers (fuels), airport ecosystems, and aircraft. Categorizing the numerous interconnections, subsystems, and energy-related influences is key to ensuring prioritization of the largest, most influential decarbonization pathways while minimizing unintended consequences to adjacent activities and communities.

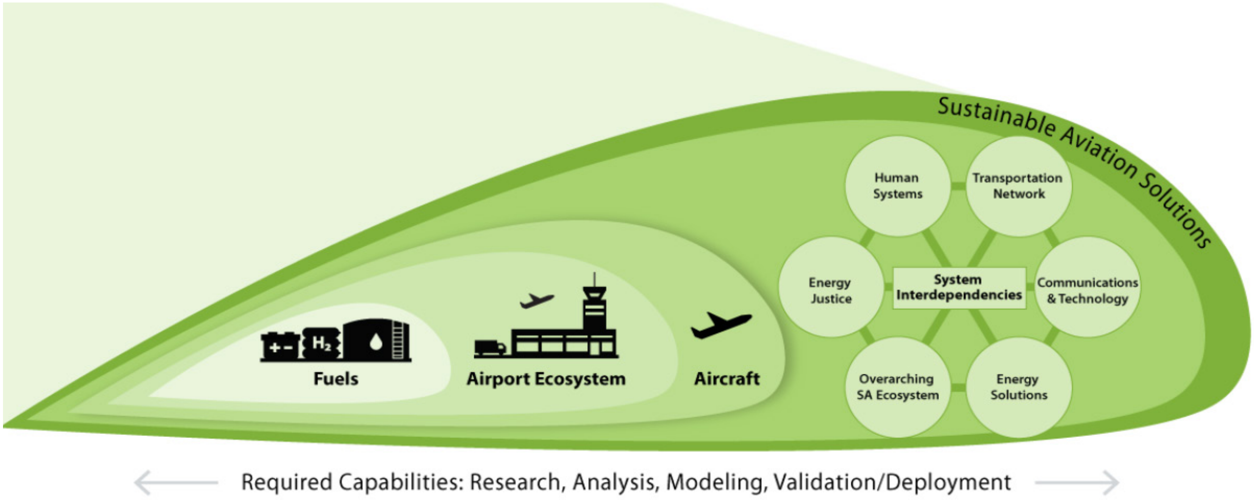

Figure 3. Sustainable aviation solutions (source: National Renewable Energy Laboratory)

SAF

Traditionally, aviation fuels have been petroleum-derived liquids that are delivered to airport storage facilities. Decarbonized solutions for future fuels include SAFs (including electrofuels, aka "e-fuels"), hydrogen, and electricity.[12] Each alternative has challenges related to production, distribution, and storage.

SAF requires multilayered development and validation along the feedstock supply (e.g., cooking oil), pretreatment, intermediate stream production, technology validation, refiner, distribution, and customer value chain. Numerous feedstock pathways must be scaled up to address the global use of local resources and the volume required to meet global demand. Turning feedstocks into liquid fuel requires physical collection, contaminant processing, and chemical manipulation, so refiners need significant technical, environmental, and economic reassurances to successfully scale up operations.

Streamlined ASTM certification processes and other initiatives have contributed to significant airline offtake agreements and the US federal government's SAF Grand Challenge, which aims to have 35 billion gallons of SAF in place in the US by 2050.[13] Companion efforts by the FAA focus on improving aircraft efficiency and quantifying various elements to reduce emissions and increase aircraft operations efficiency under programs such as Continuous Lower Energy, Emissions, and Noise (CLEEN)[14] and ASCENT (Aviation Sustainability Center).[15]

Despite numerous challenges, SAFs have the potential to decrease carbon emissions from air travel. SAF is simpler and faster to implement than other solutions, giving experts time to develop zero-emission solutions for the long term. Because SAFs still emit GHGs (and global aviation fuel use is on track to double from 106 billion gallons in 2019 to 230 billion gallons in 2050), more carbon-neutral forms of SAF should be a part of the solution to decarbonize aviation.[16]

HYDROGEN-BASED FUELS

Hydrogen gives aviators the ability to refuel at rates equivalent to fossil fuels. It may also lower engine-noise levels; reduce or eliminate carbon emissions; and leverage infrastructure across ground, marine, and air transportation and industrial networks.[17]

Hydrogen refueling rates are comparable to Jet A refueling rates, with the National Renewable Energy Laboratory (NREL) recently making significant progress on rapid delivery to vehicles. In April 2022, NREL demonstrated an average mass flow rate of 14 kg/min (21-kg/min peak), similar to those used by heavy-duty vehicles. A kilogram of hydrogen has approximately the same amount of energy as a gallon of jet fuel. Pairing localized renewable energy generation with hydrogen can lead to energy-storage and grid-stabilization capabilities that support transportation needs.

Distance traveled depends on decreasing weight within the system; currently, hydrogen offers longer distances than battery-fueled electric aircraft. However, the technology needs improvements to reach the operational capabilities of traditional fossil fuels due to hydrogen's lower volumetric energy density in both gaseous and liquid form.[18] Estimates show that hydrogen combustion could reduce aviation's climate impact to a degree similar to SAFs.[19]

Hydrogen economics, infrastructure, and storage on the aircraft present significant challenges for the two pathways currently under development: direct combustion and hydrogen fuel cell–generated electricity. Efforts are underway to mitigate these issues. Airbus announced that hydrogen-fueled propulsion systems would be at the heart of a new generation of zero-emissions commercial aircraft.[20] The first is a turboprop-driven aircraft capable of carrying around 100 passengers about 1,000 nautical miles. United Airlines and Alaska Airlines have announced investments in hydrogen-based aircraft with ZeroAvia for the type of 70-seat aircraft pervasive in regional travel.[21] In 2012, the US Army launched 16 fleet vehicles powered by hydrogen fuel cells in the US state of Hawaii, fueled by hydrogen stations on Oahu, Hawaii.[22]

The cost of hydrogen is high compared to other sustainable energy sources. To address that challenge, in June 2021, the US Department of Energy announced the Hydrogen Shot initiative, which aims to reduce the price of 1 kg of hydrogen to US $1 in one decade.[23] Another key challenge involves the emissions intensity of current hydrogen fuel production. The most economic method uses steam methane reforming of natural gas. For hydrogen to be an effective contributor to the decarbonization of the aviation industry, whether as a direct energy carrier or a feedstock for liquid fuels, production processes like clean electrolyzers and carbon-capture technologies must become more cost-effective.

ELECTRIC FLIGHT

Electrified propulsion provides a significant opportunity to decarbonize travel for trips under 500 miles, but there are a range of emerging technologies and propulsion types. Electric vertical takeoff and landing (eVTOL), alternative-propulsion conventional takeoff and landing, and larger short-haul aircraft are being pursued by various commercial ventures. Potential benefits include reduced noise, maintenance, and emissions; use of existing energy infrastructure (although improvements may be necessary); and opportunities for local electrical generation and storage.

> **THE COST OF HYDROGEN IS HIGH COMPARED TO OTHER SUSTAINABLE ENERGY SOURCES**

At least seven manufacturers are in the FAA-certification process. Several others are actively developing propulsion systems, forming airline partnerships, and seeking certification through ICAO-approved pathways. Multiple manufacturers have completed test flights, and initial deployments have begun in flight-training operations and short-distance seaplane services using retrofitted aircraft. Benefits such as efficiency gains, lower operating costs, and the potential to use existing general aviation airports (or expanded vertiport locations) make this technology appealing to underserved markets and subsidized routes such as the US federal Essential Air Service market.

It will take years before this approach achieves mass certification, builds the necessary support infrastructure, and gains passenger confidence. Nonetheless, battery electric vertical takeoff and landing capabilities were more established than hydrogen options as of 2022, based on aircraft known to be in the FAA-certification process. This is particularly the case with the general aviation sector, which accounts for more than 90% of registered civil aircraft in the US and where shorter-haul flights are more common.[24]

CONCLUSION

Proper assessment of aviation decarbonization opportunities will require research on: (1) interdependencies with other industries and (2) their social, economic, and environmental impacts. These include energy generation, transmission and distribution planning, ground transportation and other intermodal logistics, industrial and manufacturing needs, community energy and transportation planning from rural to urban locations, autonomous energy systems to facilitate incorporation of grid edge technology, and energy/environmental justice.

Multiple US federal agencies are addressing components of this system while seeking additional collaboration aimed at decarbonizing aviation at a system level in a resilient, sustainable manner. Industry, federal, and state collaborations are necessary for the aviation industry and related interdependent systems to reach their decarbonization goal. Such a holistic approach would highlight other benefits of the global aviation ecosystem moving toward decarbonization:

- Mobility options are anticipated to accelerate with the commercialization of electric and hydrogen-based aviation. Rapid intercity-to-regional transportation, point-to-point, or rural-to-urban flight options may offer better coordination for intermodal connections and provide new, lower-cost options for commerce.
- Emission, contrails, and other environmental pollutants will be reduced should greater volumes of decarbonized fuels integrate into the aviation industry.
- Cyber measures leveraged from energy-sector efforts are available to increase the security and safety of new aviation options.
- As more airports adopt onsite renewable electricity generation and energy storage, resilience of the energy supply and ability to meet demand may offer enhanced benefits for both aviation and local community energy needs.
- Carbon-negative SAFs or e-fuels would assist with environmental efforts.
- Lower-cost mobility and freight/package delivery costs could provide an economic boom to the US and the world.

The decarbonization challenge is formidable. Airports, bases, and vertiports are complex, interdependent systems that are rapidly changing in their energy types, use cases, and demand models. However, advanced research and analysis on an aircraft's energy components such as batteries, power electronics, and hydrogen components (including fuel tank and material composites) could accelerate new mobility applications, and holistic RDD&D could maximize impact and accelerate decarbonization across the industry.

This is an excerpt of a larger technical report from the National Renewable Energy Laboratory (NREL). Access the full report or visit the NREL website to explore ongoing sustainable aviation research.

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REFERENCES

[1] Teter, Jacob, et al. "Aviation." International Energy Agency (IEA), September 2022.

[2] Bouckaert, Stéphanie, et al. "Net Zero by 2050: A Roadmap for the Global Energy Sector." International Energy Agency (IEA), May 2021.

[3] Teter et al. (see 1).

[4] Teter et al. (see 1).

[5] Grobler, Carla, et al. "Marginal Climate and Air Quality Costs of Aviation Emissions." *Environmental Research Letters*, Vol. 14, No. 11, November 2019.

[6] Matthes, Sigrun, et al. "Mitigation of Non-CO2 Aviation's Climate Impact by Changing Cruise Altitudes." *Aerospace*, Vol. 8, No. 2, January 2021.

[7] Grobler et al. (see 5).

[8] Wolfe, Philip J., et al. "Near-Airport Distribution of the Environmental Costs of Aviation." *Transport Policy*, Vol. 34, July 2014.

[9] Greer, Fiona, Jasenka Rakas, and Arpad Horvath. "Airports and Environmental Sustainability: A Comprehensive Review." *Environmental Research Letters*, Vol. 15, No. 10, October 2020.

[10] "ICAO Partners on the Global Coalition for Sustainable Aviation." International Civil Aviation Organization (ICAO), accessed May 2023.

[11] Teter et al. (see 1).

[12] E-fuels are low-carbon or carbon-neutral fuels containing hydrogen and CO2 produced using electricity and a carbon source; see: Ramirez, Adrian, S. Mani Sarathy, and Jorge Gascon. "CO2 Derived E-Fuels: Research Trends, Misconceptions, and Future Directions." *Trends in Chemistry*, Vol. 2, No. 9, September 2020.

[13] "Sustainable Aviation Fuel Grand Challenge." Biomass Research & Development (BR&D), accessed May 2022.

[14] "Continuous Lower Energy, Emissions, and Noise (CLEEN) Program." US Federal Aviation Administration (FAA), accessed May 2023.

[15] "Project by Topic." The Aviation Sustainability Center (ASCENT), accessed May 2023.

[16] Holladay, Johnathan, Zia Abdullah, and Joshua Heyne. "Sustainable Aviation Fuel: Review of Technical Pathways." US Department of Energy, Office of Scientific and Technical Information, 9 September 2020.

[17] Fuel Cells and Hydrogen 2 Joint Undertaking. "Hydrogen-Powered Aviation: A Fact-Based Study of Hydrogen Technology, Economics, and Climate Impact by 2050." Publications Office of the European Union, 2020.

[18] Sharpe, Jessica E., et al. "Modelling the Potential of Adsorbed Hydrogen for Use in Aviation." *Microporous and Mesoporous Materials*, Vol. 209, June 2015.

[19] Fuel Cells and Hydrogen 2 Joint Undertaking (see 17).

[20] "The ZEROe Demonstrator Has Arrived." Airbus, 22 February 2022.

[21] "Alaska Airlines and ZeroAvia Developing World's Largest Zero-Emission Aircraft." Press release, Cision PR Newswire, 1 May 2023.

[22] Garland, Nancy L., Dimitrios C. Papageorgopoulos, and Joseph M. Stanford. "Hydrogen and Fuel Cell Technology: Progress, Challenges, and Future Directions." *Energy Procedia*, Vol. 28, 2012.

[23] Hydrogen and Fuel Cell Technologies Office. "Hydrogen Shot." US Department of Energy, Office of Energy Efficiency & Renewable Energy, accessed May 2022.

[24] "State of General Aviation 2019." Aircraft Owners and Pilots Association (AOPA), accessed May 2023.

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WHAT PUBLIC SECTOR ENTITIES CAN LEARN FROM AIRPORT INNOVATION DURING THE PANDEMIC

Author

Ralph Menzano

Airports are microcosms of cities. In the early 2000s, the term "aerotropolis" was coined: a metropolitan subregion with infrastructure, land use, and economic activity centered around an airport. Like cities, airports usually have defined utilities, roadways/streets, commercial regulations, and special construction permits.

Airports often have their own particular accounting needs (somewhat like retail entities), utilities, asset management requirements, personnel requirements, and management hierarchy. Some US airports (like those in San Francisco, Philadelphia, Atlanta, Denver, and Chicago) have a city/county government hierarchy; others (like those in New York City, Los Angeles, Dallas, Toronto, and Orlando) operate as their own authority. In aviation circles, it's usually accepted that all airports, regardless of management model, should run at a surplus — bringing in more revenue than their expenses. Because airports are considered public sector entities, we use the term "surplus" rather than "profit."

What is less known is that the surplus is generated by non-aeronautical activities (concessions, car rental, parking, hotels, advertising, and other property uses), rather than aeronautical revenues. At larger airports, in my experience, revenues for these commercially oriented activities can account for 70% or more of total revenue, with aviation revenue (e.g., airline fees) accounting for around 30%. In a sense, airports are like urban or suburban shopping districts that happen to have an aviation component.

In 2019, enplaned passenger numbers (one key performance indicator) peaked, and airport success stories proliferated. It seemed as though just about every airport had new gates, a new terminal, new concessions, or some other renovation in progress, including Orlando International Airport's Terminal C[1] and New York's LaGuardia Airport's billion-dollar renovation.[2]

In 2020, airport economic development and the industry's basic business model were severely challenged by the pandemic. Associations like the Airport Council International, the American Association of Airport Executives, the International Civil Aviation Organization, and the International Air Transport Association (IATA) and their member airlines, airports, and affiliated vendors pivoted to address the precipitous drop in air travel. Through interviews with individuals with deep airport knowledge, this article strives to answer the following:

- How were airport economic models able to flex during the pandemic?
- Is there a success story that can serve as a model for other airports and other public sector entities for future resilience?
- How has the push toward sustainability affected airport management, and how might it drive the public sector in the future?
- What technology investments can be made for long-term operational efficiencies? How will airports of the future be able to exert more control over their campuses through autonomous electrified vehicles and sustainable aviation?
- How can the industry take advantage of artificial intelligence and analytics going forward?

REMARKABLE REBOUND

Both US and international enplaned passenger statistics have shown a consistent climb out of the hole caused by the pandemic (see Table 1).

Note that although the 2023 estimates are my calculations, they are rooted in expert predictions that passenger numbers will soon return to 2019 levels. Willie Walsh, Director General of IATA, says that by the end of 2023, most regions will reach or exceed pre-pandemic demand levels.[3] According to IATA, international air travel continues its recovery (albeit below the US's recovery slope), despite the fact that domestic markets are still strongly dependent on COVID-19 policies and pandemic-related developments. Generally, the recovery in international air travel has been strong, but Asia-Pacific still lags, following a prolonged shutdown and only more recent market reopenings, especially in some of the largest markets.[4]

Airports were abruptly impacted by the pandemic, but there was a certain confidence about maintaining a level of service, the necessity of air travel in our lives, and a post-pandemic rebound. IATA's Annual Review 2022 put it this way:

> Looking back at the pandemic, we can point to our service with pride ... airlines kept the world connected. Airlines kept vital supply lanes open to deliver lifesaving vaccines and medical supplies. And they operated to the highest levels of safety throughout. Over and over, the aviation workforce rose to the occasion. In fact, the importance of aviation was made absolutely clear by the pandemic restrictions. People recognized that their quality of life deteriorated and economies suffered.[5]

Most organizations experiencing a 60% drop-off in customers, as airports did in 2020, would have simply ceased operations. Airports were able to survive through a combination of adjustments that demonstrated their resilience. For example, they quickly made changes corresponding to airline flight schedules, including staffing, gate and terminal openings/closures, parking systems, and concession management. Some airports even continued their expansion plans, and Orlando Airport's belief in the need for its new terminal was validated. "Orlando International Airport saw nearly 10 million more passengers in 2022 than the year before," says Kevin Thibault, CEO of the Greater Orlando Aviation Authority. "These numbers validate our strong belief that Terminal C was more than needed to meet projected demand. By continuing to build during the pandemic, we are now well positioned for the future growth and economic expansion of the Central Florida region."[6]

Reconfiguring many administration aspects allowed airports to stay open while other businesses closed. In essence, airports were able to tread water until travel restrictions were eased and they could revert to business as usual. Assistance from the US government is helping with the recovery, including the Investment in the Infrastructure and Jobs Act (IIJA), which contains US $15 billion for airport infrastructure funding.[7] Money from IIJA can be invested in runways, taxiways, safety, and sustainability projects, as well as terminal, airport-transit connections, and roadway projects.

Enplaned passengers (in millions)

YEAR	US	PERCENT CHANGE	WORLDWIDE	PERCENT CHANGE
2019	927	3.9%	4,543	3.8%
2020	388	-58.2%	1,807	-60.2%
2021	658	69.8%	2,185	20.9%
2022	853	29.5%	3,781	73%
2023*	937	9.01%	4,594	17.71%

*Author estimates

Table 1. Steady growth in US and international passengers following the pandemic (sources: US Office of the Assistant Secretary for Aviation and International Affairs, Statista, US Federal Aviation Administration, US Bureau of Transportation Statistics, World Bank, International Air Transport Association, International Civil Aviation Association)

A SUCCESS STORY

Airports followed the historic downturn with a consistent recovery, overcoming difficulties like fuel price increases, personnel shortages (pilots, crews, and support staff), and a demand for travel that sometimes outpaced flight supply. Not to mention that much of the world continues to experience pandemic-related reduced flight schedules as well as a general recession, lockdowns in China, and a war in Ukraine.

To get a firsthand view into how airports were able to survive the downturn, rebound, and move forward, we spoke with Phillip Washington, CEO of Denver International Airport, which currently ranks third in the world in enplaned passengers.

Denver International Airport had a quicker recovery than many other airports because it's less reliant on international and leisure travelers, Washington told us. The airport experienced declines in surplus, but airline revenues were roughly the same.

Interestingly, recovery was not the only objective for Denver. Washington and his team created a strategic plan called "Vision 100" that set targets for handling 100 million enplaned passengers in five to eight years (the airport was designed for 50 million).[8] Government funding in the hundreds of millions of dollars is part of the plan, but there's more to it. The plan also aims to:

- **Empower people.** Encourage internal employees and vendors of all sizes to be innovative. To this end, the airport has established a Center of Equity and Excellence in Aviation (CEEA) that aims to tackle the workforce issues facing all transportation sectors and create a starting point for innovation. CEEA is focused on three key areas: a business development training academy, career pathways, and a research and innovation lab.
- **Improve capital program management.** Grow the infrastructure by being efficient and proper stewards of governmental grants allocated to the airport while interacting with the agencies within the City and County of Denver.
- **Improve asset management.** Ensure that all assets are maintained to achieve their economic lifespan, adhere to preventive maintenance schedules, and ensure safety for employees and passengers alike. Within this pillar, there is a major component of enhancing the customer experience and another aimed at greenhouse emissions mitigation.
- **Expand global connections.** The airport has formed a connection with Ethiopia that coincides with the US having the largest diaspora community of Ethiopians in the world (approximately 500,000). Growth in air cargo and domestic flights are also part of this pillar.

INTERESTINGLY, RECOVERY WAS NOT THE ONLY OBJECTIVE FOR DENVER

Washington told us he wants to examine how airports can identify technology trends and look for applications that can be quickly adopted by airport staff to propel them, as a team, to become a leading authority. One potential area is using predictive analytics, especially in the third pillar (asset management), where early warnings can mitigate or eliminate reactive maintenance. Decreasing outages of all kinds is a clear goal of any customer-facing enterprise, airports among them.

IMPROVING SUSTAINABILITY & TESTING TECHNOLOGY

The aviation industry continually strives to do better with regard to sustainability. IATA members (airlines and airports) have resolved to achieve net-zero carbon emissions by 2050.[9] Airports like Denver International see value in having connected autonomous vehicles handle the 24/7/365 routes for ever-present hotel and rental car shuttles. In fact, because of their route monotony, airport shuttles are better candidates for autonomy than vehicles with even slight route variations. In addition to being autonomous, airport shuttles could be electrified to provide a cost-effective, eco-friendly customer experience. Denver International Airport is going even further with the planned construction of a consolidated rental car facility that should reduce the number of shuttles transporting customers to and from rental car parking lots and terminals for more sustainable operations.

When it comes to general technological transformation, airports are excellent proving grounds. Potential pilots include smart parking, chatbots (for the type of virtual assistance increasingly seen in the retail industry), sustainable fuels, cybersecurity, customer experience, and private networks.

The latter could enhance a number of applications like airport operational systems (gate and terminal management), customer-facing systems (flight information displays, baggage-handling systems), and tenant-facing systems (concession, car rental, hotel, and airline). Additionally, the large amounts of data contained in an airport's Internet of Things could be facilitated by a fast, highly secure, reliable communications backbone using a private 4G or 5G network.

Many airports are trying to solve traffic congestion exacerbated by the ride-share renaissance. Some airports have four or more lanes going around the airport that are now reduced to two due to drop-offs and pickups in the two lanes closest to the curb. High-occupancy vehicle lanes are one answer; automatic tolling for single-occupancy vehicles is another possibility.[10]

Of course, Denver is not the only airport with innovative sustainability solutions. The Chicago Department of Aviation's (CDA) O'Hare Airport has used goats and other grazing animals to maintain dense scrub vegetation on its property. The grazing sites are outside the airfield fence, including hilly areas along Willow-Higgins Creek that are difficult to maintain with traditional landscaping equipment. The program helps CDA achieve many economic, operational, and environmental benefits, including:[11]

- Providing a more efficient way of removing vegetation along steep embankments and rocky areas that are difficult to maintain with traditional mowing
- Reducing habitat for wildlife that may be hazardous to airport operations
- Reducing soil erosion and rutting from the use of heavy equipment
- Reducing air pollution from gasoline-powered equipment
- Reducing landscaping waste sent to landfills and air pollution from trucks hauling the waste
- Clearing weeds and invasive species without the use of herbicides
- Allowing US Department of Agriculture research on the effectiveness of the grazing herd on vegetation removal and wildlife changes resulting from grazing

CAPITALIZING ON RESILIENCY & EXPANDING THE AIRPORT MODEL

Airports have become public sector stars. They are models of strategic resiliency, confidence, and positive attitude, often running more like a commercial enterprise than a public agency. They quickly recovered from recent socioeconomic downturns, demonstrating to public sector entities like cities, counties, and states how to run at a surplus and ignite economic development.

Denver International Airport, a clear model for the industry, is the economic engine for its metropolitan region, generating $33 billion a year, employing nearly 30,000 employees, and supporting nearly 260,000 jobs.[12] Rather than rest on its accomplishments, it is planning to double its capacity, an achievement that would positively impact the region.

Beyond sheer economics, applying the guiding principles of Denver's Vision 100 (below) to public sector entities nationwide could yield a level of resilience, confidence, and positivity for all:[13]

1. **"Sustainability and resiliency.** Our goal is to become the greenest airport in the world while ensuring that our actions and decisions foster a healthy and resilient organization.
2. **Equity, diversity, inclusion, and accessibility.** We are better when everyone is at the table and when we respect and listen to all viewpoints.
3. **Operational excellence.** We maintain focus on ensuring efficient and effective operations while collaborating with our partners to identify and address challenges and review our experiences, implementing improvements based on learning.
4. **Enhancing the customer experience.** This is our core business. We will work closely with our stakeholders to meet and exceed the needs and desires of our travelers."

Other public sector entities could benefit from the airport model by:

- Creating programs like CEEA to simultaneously promote equity and diversity
- Enhancing communication infrastructure to promote telehealth, remote education, and telework
- Promoting the citizen experience by deploying virtual assistants to help users navigate complex websites
- Adopting and developing sustainability ideas like landscaping herds
- Adopting electric and autonomous vehicles to mitigate traffic and reduce pollution

We can conclude lessons learned from airports can and should be extrapolated and redeployed into larger public sector settings. They have validated many innovations and proven to be valuable, controllable test sites.

REFERENCES

[1] Orlando International Airport Press. "Orlando International Airport Breaks 50 Million Passenger Mark for 2022." Greater Orlando Aviation Authority, 3 February 2023.

[2] "A Whole New LGA Nears Completion." A Whole New LGA, accessed June 2023.

[3] "IATA Annual Review 2022." International Air Transport Association (IATA), accessed May 2023.

[4] Karp, Aaron. "ACI Warns Asia-Pacific's Airports Remain in Financial Distress." Aviation Week Network, 12 April 2023.

[5] International Air Transport Association (IATA) (see 3).

[6] Orlando International Airport Press (see 1).

[7] "Bipartisan Infrastructure Law — Airport Infrastructure." US Federal Aviation Administration (FAA), accessed May 2023.

[8] Murray, Jon. "Denver International Airport Ranks Third in the World — Again — for Passenger Traffic." *The Denver Post*, 6 April 2023.

[9] "Major Projects: Vision 100." Denver International Airport, accessed May 2023.

[10] IATA (see 3).

[11] Menzano, Ralph. "Smartphone Toll Systems: Boost Revenue, Enable Congestion Control & Promote High-Occupancy Commuting." *Amplify*, Vol. 35, No. 8, 2022.

[12] "Grazing Herd." O'Hare & Midway International Airports, accessed May 2023.

[13] Denver International Airport (see 9).

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