The Evolution of Wayfinding Within Airports

Bonnie Powell, Stanley E. Young, and Andrew Duvall

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5400-83211
December 2023

The Evolution of Wayfinding Within Airports

Bonnie Powell, Stanley E. Young, and Andrew Duvall

National Renewable Energy Laboratory

Suggested Citation
Powell, Bonnie, Stanley E. Young, and Andrew Duvall. 2023. *The Evolution of Wayfinding Within Airports*. Golden, CO: National Renewable Energy Laboratory. Technical Report NREL/TP-5400-83211. https://www.nrel.gov/docs/fy24osti/83211.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5400-83211
December 2023

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

Acknowledgments

This report was made possible through support provided by Dallas Fort Worth International Airport (DFW), and through the U.S. Department of Energy's Technology Integration Program Technologist in Communities effort. The authors thank the DFW team for their input and support.

List of Acronyms

AR	augmented reality
BLE	Bluetooth low energy
CVG	Cincinnati/Northern Kentucky International Airport
DFW	Dallas Fort Worth International Airport
DIA	Denver International Airport
FAA	Federal Aviation Administration
SITA	Société Internationale de Télécommunications Aéronautiques
UWB	ultra-wideband

Executive Summary

The process of navigating within airports has evolved over the years, with various technologies emerging to complement static signage. Historically, wayfinding began with static signage and airport staff members providing personal guidance, before progressing into digital signs, interactive kiosks, and displays. In recent years, wayfinding has continued along its digital path using mobile applications, indoor positioning technology, and even robot guides. With ever-larger airport facilities and a growing number of travelers, the future of wayfinding will likely be heavily linked to further digital developments such as facial recognition, augmented-reality technology, and autonomous vehicle navigation. This report delves into the history of interior wayfinding in airports, its present state, and the anticipated future. Key wayfinding technologies are discussed in detail, with an emphasis on emerging smartphone applications. Other considerations such as traveler stress, legal issues, pandemic safety, and language barriers are included. A wayfinding framework is proposed, with static wayfinding technologies serving as the base upon which dynamic and personalized digital technologies are built. In this framework, electronic wayfinding technologies do not replace—but rather augment—traditional methods. These technologies can be integrated into existing wayfinding systems for a seamless traveler experience.

Table of Contents

List of Figures

1 Introduction

Wayfinding within airports is of key importance for airport customers, employees, and stakeholders. Interior navigation has environmental, health, and safety impacts, as well as economic impacts such as increasing spending and reducing traveler stress. In addition, studies have found that wayfinding has a large impact on passenger satisfaction at airports. For example, a Thai study identified seven areas travelers found important for airport service quality (Chonsalasin, Jomnonkwao, and Ratanavaraha 2021). Security was the most heavily weighted, followed by check-in and wayfinding. Navigating security screening has been an added challenge for airports post-9/11. Within wayfinding, the ease of finding directions inside airport terminals was found to be the most important element.

Innovative and intuitive wayfinding solutions are therefore a top priority for customer satisfaction, with over 50% of airlines having implemented or planned wayfinding initiatives by 2024 according to the Société Internationale de Télécommunications Aéronautiques' (SITA's) *2021 Air Transport IT Insights* report (SITA 2021). There also may be opportunities for wayfinding upgrades to be funded by the recent Infrastructure Investment and Jobs Act. The act has $25 billion allotted to airport and air traffic control projects, including $1 billion in competitive grants for airport terminal and control tower modernization (Yang 2022).

2 Wayfinding Approaches

This report outlines 10 categories of wayfinding technologies for airport terminal navigation based on a review of existing literature, companies, and products. The impacts of various considerations including legal considerations, traveler stress, and language barriers on these technologies are discussed. A layering framework for effective wayfinding strategies is proposed based on the review of technologies and airport wayfinding practices.

Although the report focuses on wayfinding within terminals, airport wayfinding begins with the airport's website, online maps such as Google Maps or Apple Maps, and entrance to the physical airport. An airport's website sets the stage for separate facilities and how they are referred to—including through names, numbers, colors, and standard lettering. The website may also mention navigation information and the interconnectedness of facilities (such as pedestrian bridges or shuttles between terminals). On the way to the airport, airport access roads and signage are a traveler's first physical introduction to airport wayfinding, although virtual interactions through online maps often precede physical infrastructure. Pictograms, colors, lettering, and the use of digital signs can orient the traveler before they step foot inside.

Interior airport wayfinding has evolved to incorporate new technologies. Airports began with simple tools such as static signage and staffed information desks. The digital era ushered in electronic displays appropriate for ever-changing information (such as flight status), as well as interactive maps and kiosks for self-check-in and navigation. Further digital technologies such as mobile applications and robot guides have been used in recent years. Figure 1 shows a sampling of wayfinding technologies over time. These technologies are further discussed in the following sections.

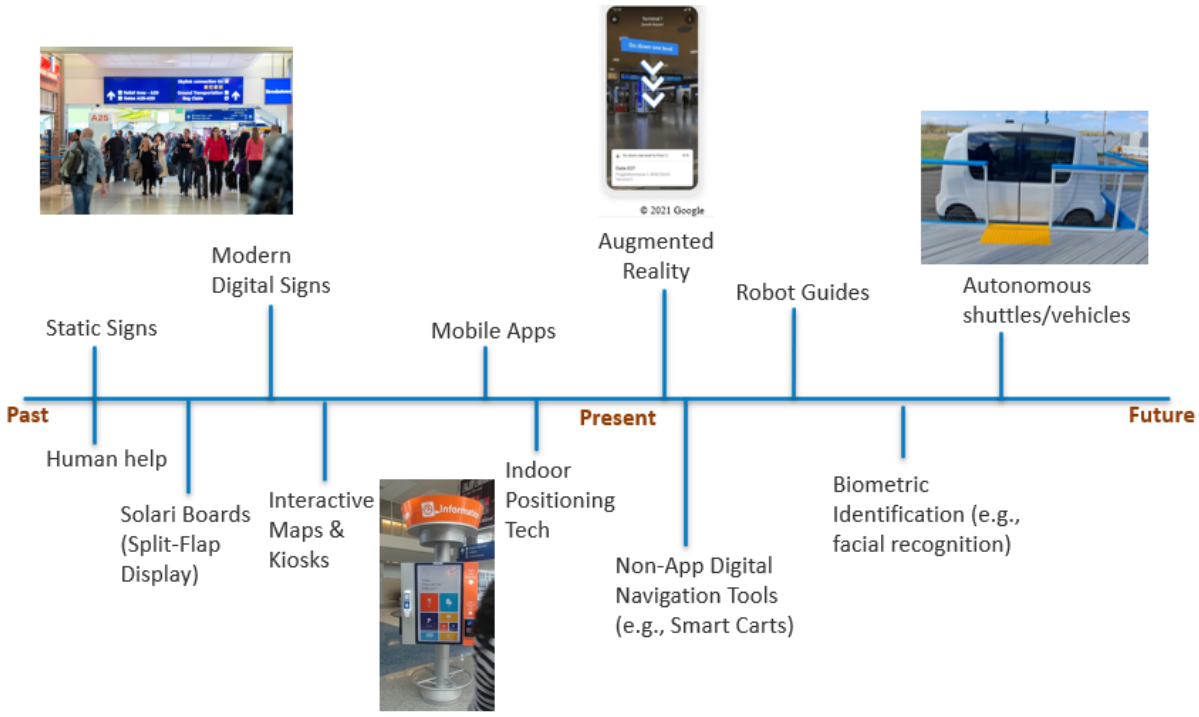

Figure 1. A sampling of wayfinding technologies. The technologies on the right-hand side have not yet been widely adopted.

2.1 Static and Digital Signs

Static signs are still present in airports today and are key long-term fixtures. Signs can lead to an airport having a holistic feel. Dark signs with light-colored text are becoming popular at airports internationally (Figure 2) (Nehl and Schlaich 2021). Although digital signs are now the norm for information that often changes such as flight or baggage status and pandemic protocols, static signs providing directions to parking lots, restrooms, and check-in desks are still pervasive and popular. Digital signs are becoming "smarter" and more connected to different systems, such as mobile applications, or equipped with additional technology such as facial recognition. These developments are discussed further in Sections 2.5 and 2.8. Digital signs can have multiple purposes, such as advertising and conveying changing public health guidelines (e.g., mask mandates during the COVID-19 pandemic).

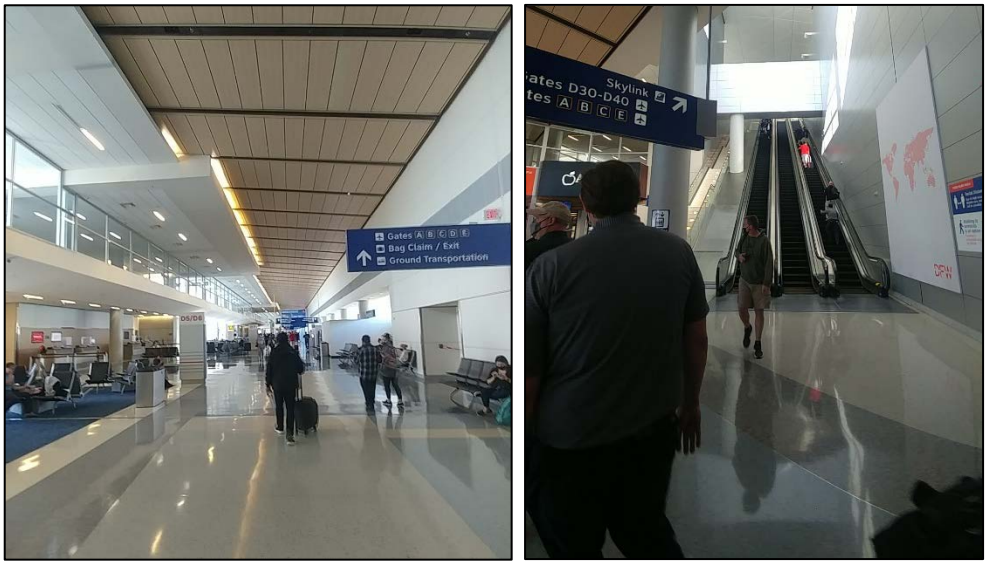

Figure 2. Static signs with dark backgrounds and light-colored text at Dallas Fort Worth International Airport (DFW).

Photos taken by Stanley E. Young on Nov. 1, 2021

In the United States, the Federal Aviation Administration (FAA) publishes airport design and engineering standards, including standards for signs on airport runways and taxiways. The FAA also provides guidelines (not standards) for signage within terminals. The last *Airport Signing and Graphics* guidelines were published in 2013 (FAA 2013). Issues such as up (or down) arrows conveying to either go straight ahead or go up (or down) a level are discussed in these guidelines, with associated recommendations. For example, the FAA guidelines recommend an up arrow be used in "the vast majority" of situations conveying a traveler to go straight ahead (FAA 2013). However, the guidelines note that the use of specific arrows is dependent on the situation. In 2011, the Airport Cooperative Research Program published *ACRP Report 52: Wayfinding and Signing Guidelines for Airport Terminals and Landside* (Harding et al. 2011). This report, sponsored by FAA and published by the Transportation Research Board, includes discussion on a holistic wayfinding strategy. Internationally, the International Organization for Standardization has a technical committee responsible for standardizing airport pictograms, but these are also only recommendations, and some airports choose to use their own (Nehl and Schlaich 2021). There are also multiple considerations for designing signs with colorblind travelers in mind.

The language(s) used on signs is another key consideration. Many airports use English as either the primary or secondary language on signs along with the local language (Figure 3). Determining which languages to include on signs, and standardizing that choice across the airport, has large implications for travelers.

Figure 3. Signs with two languages, directing to Taiwan Taoyuan International Airport (left) and inside Madrid-Barajas Airport (right).

Photos from Unsplash: https://unsplash.com/photos/ea2DjFQJgkY, https://unsplash.com/photos/1cpiF66YKZU

2.2 Interactive Displays

As digital technology advanced, interactive digital displays emerged. Digitally displayed maps and kiosks allow for user input and cater to the person using the machine, such as the one at DFW shown in Figure 4. These have allowed for more personalized information, querying of flight and gate information on the fly, and a faster check-in process. However, interactive displays require a traveler to stop and physically interact with a piece of equipment, and typically only one person can use the equipment at a time.

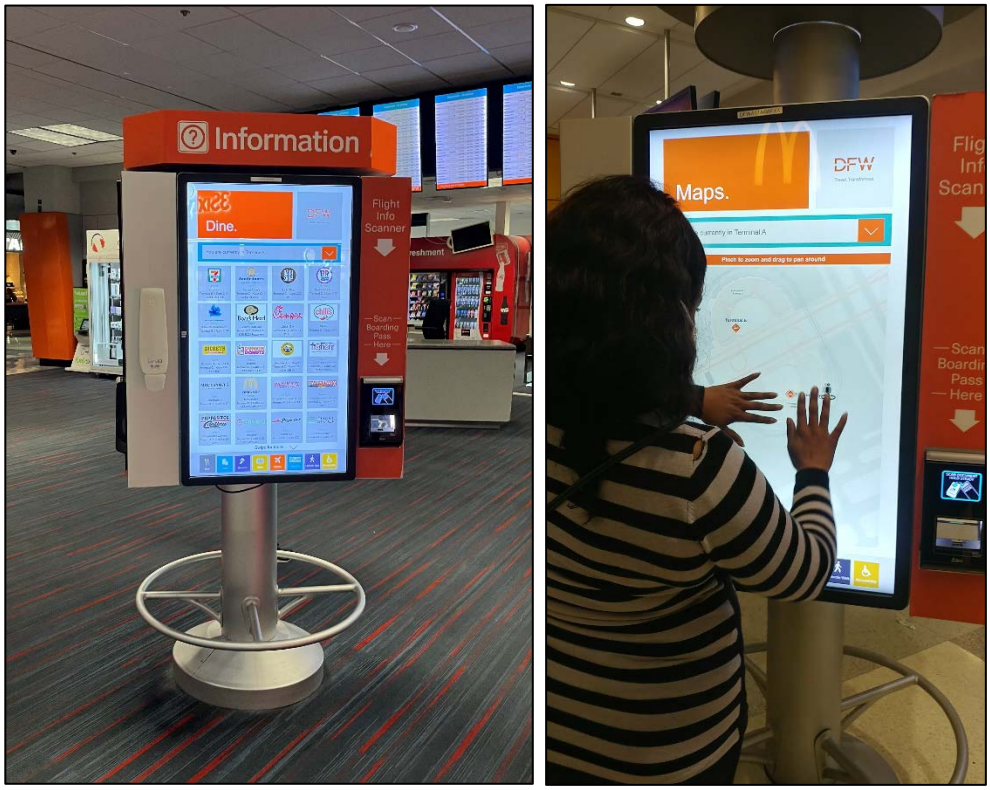

Figure 4. Information kiosk with an interactive map at DFW. The user scans their boarding pass to get personalized directions.

Photos taken May 27, 2023, by Bonnie Powell (left), and Nov. 1, 2021, by Stanley E. Young (right).

2.3 Floor-Based Navigation

Utilizing the floor of an airport to assist with wayfinding can be beneficial for multiple types of travelers and situations. For example, an embedded route on the ground can assist vision-impaired travelers. Graphics and pictograms on the floor can help those with a lower field of vision such as wheelchair users or the elderly. Lastly, laser projections onto the ground could help guide travelers toward certain corridors and may catch the attention of travelers looking at their smartphones. Multiple companies currently sell safety sign projection systems, with the advantage of the "signs" not becoming faded or dirty over time (Image Projection 2022). A similar projection system could be used for indoor airport wayfinding—these systems could be easily changed based on the passenger makeup and time of day (e.g., using different languages or changing placement). A field study at Rotterdam The Hague Airport found that the contrast between the color of the ground and the digital projection, as well as animating the projection, were key considerations to attract traveler attention (Figure 5) (Tezcan and Hiemstra-van Mastrigt 2019). There are also opportunities for more creative laser projection solutions. For example, one company sells portable laser projectors that can be used to project directions on the ground in front of a bicycle (LaserCube 2023).

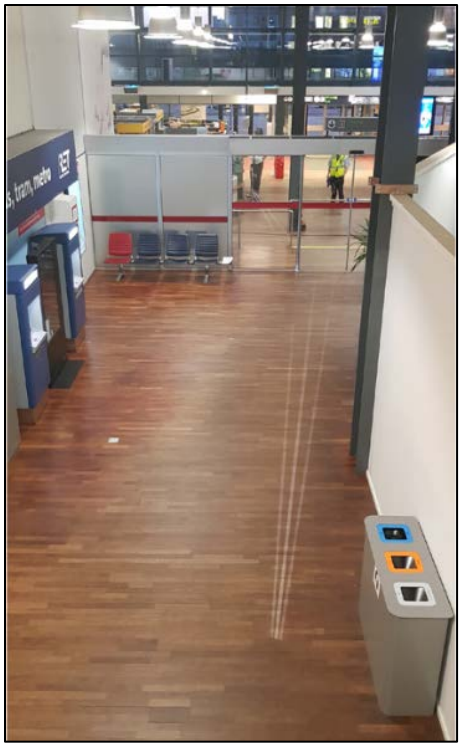

Figure 5. Projection at Rotterdam The Hague Airport directing travelers toward the exit as part of a field study conducted by Tezcan and Hiemstra-van Mastrigt (2019)

2.4 Employee-Provided Guidance

Information desks have generally become less staffed at airports over time, in some cases replaced with help text lines and mobile apps. There is still staff assistance available, but on a more limited basis. Denver International Airport (DIA) is piloting a "Meet & Assist" service program where a customer requests in advance a staff member to guide them through the airport (DIA 2022). Such programs are usually paid, and prices vary greatly between airports. Another newer option is customer service kiosks with the capability to speak with an off-site staff member live but virtually. Munich Airport has such kiosks and has historically prioritized customer service using airport staff (Future Travel Experience 2014). DIA has a live chat feature available and call/text options from a personal device (Figure 6). Malpensa Airport in Italy has a "virtual desk reception system"—an interactive screen that virtually connects you to a live staff member (Milan Airports 2015). Generally, employee-provided guidance programs are minimized due to cost and other issues related to staffing. However, airports commonly have volunteer ambassadors throughout the airport that assist with wayfinding. As language translation via smartphones and other electronic means continues to mature, the need for dedicated customer interaction staff for wayfinding continues to decline.

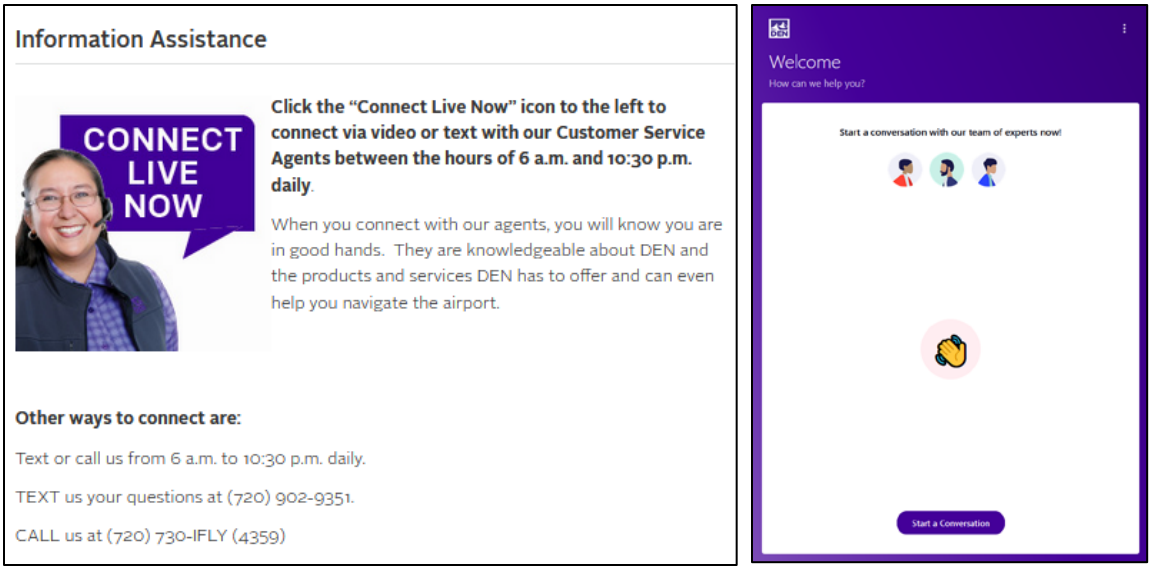

Figure 6. A screenshot from DIA's information assistance webpage: https://www.flydenver.com/traveler_services/information-assistance

In addition, although many airports still have traditional, staffed information booths—with either volunteers or paid employees—airport facilities staff have noticed generational differences based on who approaches these staffed stations, according to an employee at Cincinnati/Northern Kentucky International Airport (CVG) (B. Cobb, personal communication, March 20, 2023). These anecdotal observations show that older generations tend to approach staffed booths far more often than younger generations. In many cases, there is a role reversal where airport staff approach people of younger generations when they appear noticeably lost (as opposed to the traveler approaching the booth).

2.5 Mobile Applications and Augmented Reality

There is a plethora of mobile applications related to airport wayfinding. Most of these apps focus on only a few pieces of the airport experience. Some integrate multiple aspects (beyond just wayfinding) such as ordering food to your gate and navigating via an interactive map. There are relatively few examples that touch on most parts of the customer airport experience including traveling to the airport, storing boarding passes, estimating wait times or security clearance times, paying for parking, and displaying pertinent security information, interior map navigation, etc. There may be opportunity for applications to extend their services or combine with one another to become an "all-in-one" app for the full airport experience.

There is great competition for a customer's attention, including the ever-present barrier of motivating a customer to download a new mobile application. Travelers may be more likely to use an app they already have downloaded and use often—such as Google Maps or Apple Maps. These big players have moved beyond exterior navigation and have begun pilots into interior building navigation, as well as integrating access to the goods and services found within, similar to how such apps have developed for external (roadway) navigation. Augmented reality (AR), where a mobile device displays layers on top of a visual of the surrounding environment, is also being developed for wayfinding purposes. AR is an enhancement of a mobile app with arrows,

text, and other visuals to help the user find their desired location, as shown in Figure 7. Multiple companies, including Google, are developing AR wayfinding solutions.

Figure 7. Screenshot from Google Maps Indoor Live View AR directions in John F. Kennedy International Airport Terminal 4 in New York City.

Screenshot taken by Bonnie Powell on Nov. 22, 2023

2.5.1 Airport and Airline Apps

Many airports and airlines have their own smartphone applications that include wayfinding capabilities. Although most airline apps allow customers to book and track flights and view boarding passes, wayfinding features vary between apps. The terminal maps for Delta, United, and American Airlines are very similar, although each airline only has terminal maps for a limited set of airports (the ones that they operate in). These airlines also have turn-by-turn directions available for their airports (Figure 8). If the entered destination is on the other side of security, these directions include estimates for time it will take to go through security if you have TSA PreCheck, CLEAR, or neither. American Airlines' app also has a feature to preorder food from restaurants, with the capability of having food delivered to your gate. Budget airlines such as Frontier and Spirit do not have airports maps.

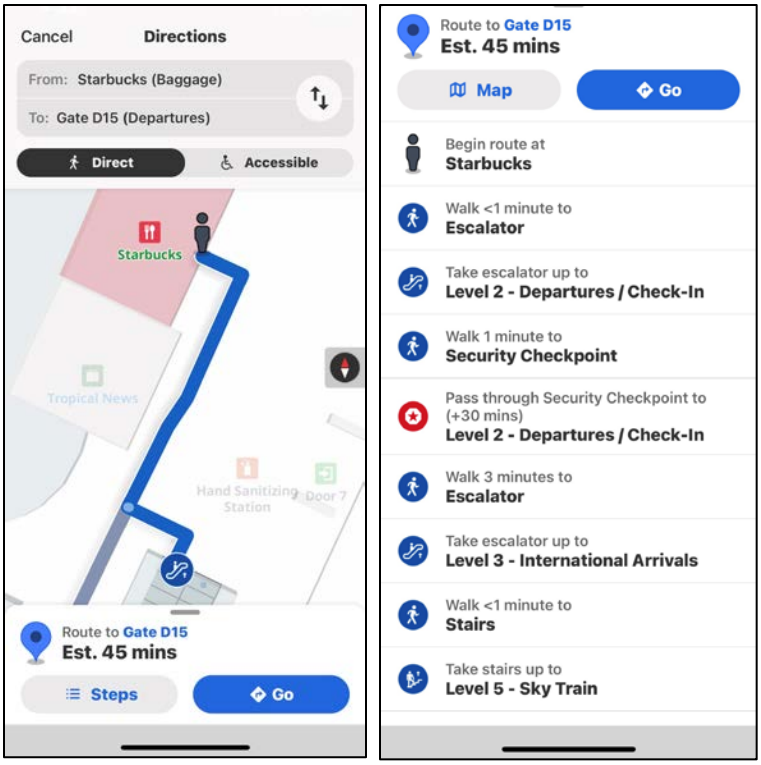

Figure 8. Screenshots of the American Airlines app turn-by-turn directions for Miami Airport

Many airports also have their own app. Some, such as DIA, have an airport map with directions in an interface nearly identical to airline apps. In addition, some airport apps use more recent technology that utilizes Bluetooth low-energy (BLE) beacons to identify a user's location for more targeted content. For example, San Francisco International Airport piloted an app in 2014 using indoor positioning technology to help visually impaired travelers (Lowensohn 2014). DFW's app allows users to preorder meals and has interactive maps. Copenhagen Airport's app has a shopping directory and the location of key points of interest, as well as flight tracking and reservation and payment options for parking (CHP 2023); this app was the first to use AR directions indoors. AR apps are discussed in Section 2.5.3. In the United States, airports often have difficulty acquiring regular users for their apps. Travelers typically prefer airline apps for their airline of choice.

2.5.2 Third-Party Apps

Google Maps and Apple Maps dominate the outdoor navigation industry. Both apps have been adding features for indoor wayfinding in recent years. Many airport businesses and gates are labeled in both Google Maps and Apple Maps traditional mapping platforms, as shown in Figure 9. Each app has a directory that allows you to sort by category such as food, shops, and gates.

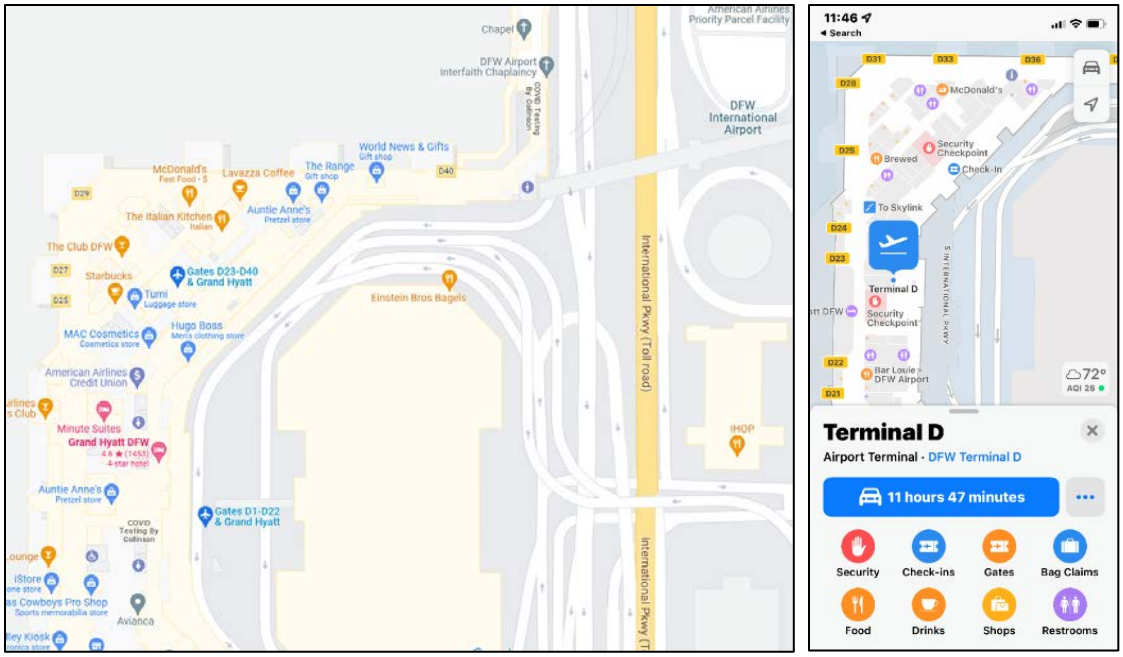

Figure 9. DFW Terminal D interior on Google Maps (left) and Apple Maps (right).

Source: © 2022 Google, map data; © 2022 Apple, map data

Some airports and airlines work in partnership with other private companies to develop smartphone apps and deploy indoor positioning technology. For example, Pointr specializes in indoor maps and navigation and has partnered with airports and airlines (Pointr 2022). Pointr and other companies are working on similar indoor navigation solutions as Google, with AR apps that display directions on a smartphone screen. Their methods differ and are further described in Section 2.6.

Smartphone apps also seem to be moving in the direction of being a "one-stop shop" for multiple customer needs during travel. Delta's website describes their app as a resource "to support you during your travel journey," including booking flights, navigating the airport, and tracking bags (Delta 2023). Other third-party apps such as TripIt (owned by Concur) and Wanderlog have tried to break into the market by integrating lodging, airport parking, flight status, and airport navigation into a single app. Companies such as Expedia and Tripadvisor also have travel planning features that integrate multiple pieces of the travel experience. In March 2023, Uber announced that they will be adding "airport guides" to the app to help customers navigate to the rideshare pickup area at select airports (Bastone 2023). These will include step-by-step directions in addition to walking time estimates. Various apps exist targeting just one piece of the travel journey—such as the MyTSA app, which shows estimated wait times and approved items for passage through security. Overall, most apps only focus on a few pieces of the travel experience, even those that claim to be all-in-one.

2.5.3 AR Apps

Indoor Google Maps (also referred to as Google Indoor Live View) launched in March 2021, with airports being one of its primary applications (Google 2022). The three other applications are indoor malls, stadiums, and transit stations. Indoor Google Maps uses a mobile phone's camera and compares the image to a database of images from the facility to assess the traveler's

position and orientation (i.e., which direction the traveler is facing). The app displays directions on the screen superimposed on the camera image (referred to as AR), as shown in Figure 10. In April 2021, Zurich Airport partnered with Google Maps and became the first airport to offer Indoor Live View (Business Traveller India 2021). This type of navigation is currently only available in select locations. For example, Indoor Google Maps became available at John F. Kennedy International Airport in New York (Terminal 4) in September 2023 (Metropolitan Airport News 2023). Copenhagen Airport was the first airport to test and offer AR for indoor navigation in 2011 through the CPH Airport App, in partnership with SITA (Future Travel Experience 2011).

Apple Maps also has indoor maps for select airports and malls, but these do not have AR features. Apple works directly with the owner or operator of the facility to enable the feature (Apple 2023). However, Apple partners with third-party companies such as Dent Reality and YAP, who have products with AR indoor maps. AR features are available for outdoor walking directions directly in Apple Maps.

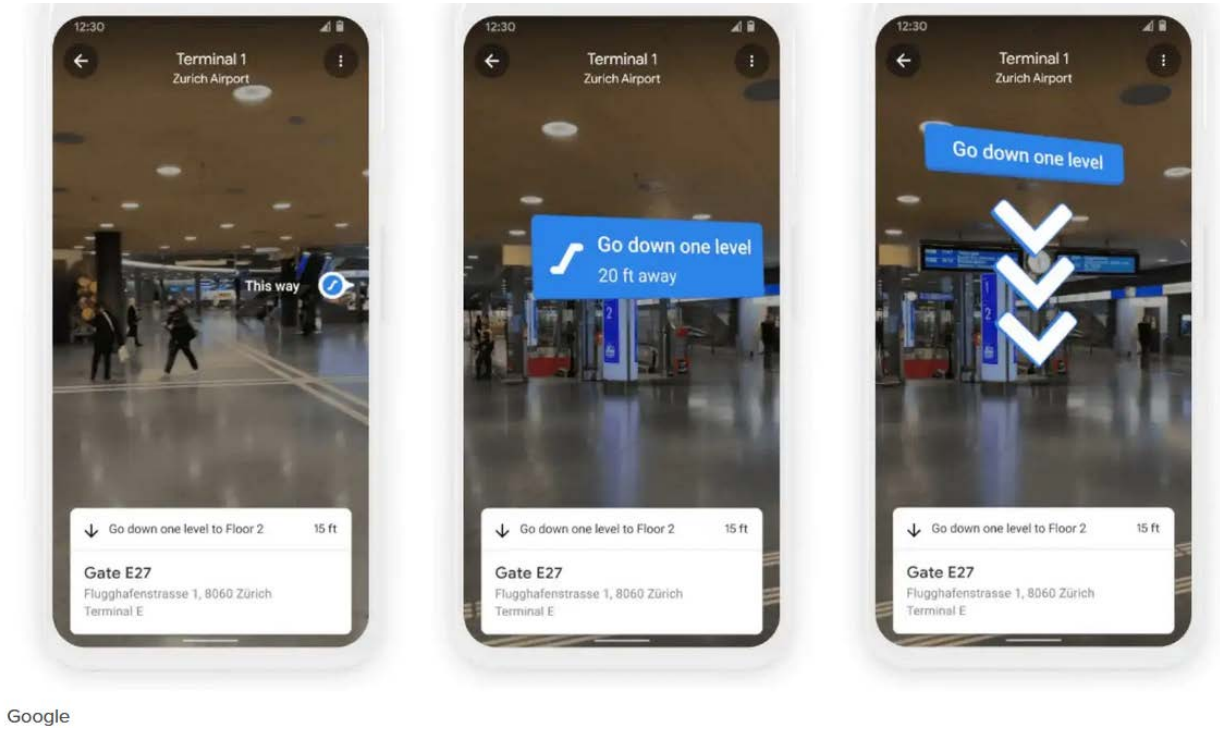

Figure 10. Indoor Google Maps directions using AR.

Source: Loyola (2021); © 2021 Google

There are multiple other companies developing AR wayfinding applications, some in partnership with airports. Gatwick Airport in England created a mobile app with AR wayfinding capabilities using 2,000 navigation beacons (see Section 2.6), among other features (Bose 2019). The technology in this area is evolving quickly, and new features are coming out often. There may be opportunities for airports and/or airlines to partner with companies to rapidly develop and deploy indoor wayfinding technology.

2.5.4 App Challenges

A mobile app is an attractive option for airports, airlines, and other businesses alike due to the ability to push new updates, respond quickly to a dynamically changing environment, and utilize a technology that is already in the pockets of most travelers. However, relying on mobile apps also presents certain challenges. These include leaving out travelers who do not have (or cannot easily operate) a smartphone or have certain disabilities impacting their use of mobile apps, conflicting interests between commercialized recommendations and other concerns, conflicting information between the mobile app and built environment, and difficulty balancing while holding a smartphone and other items while navigating.

According to Pew Research Center, approximately 85% of U.S. adults own a smartphone (although 97% own either a smartphone or cell phone) as of 2021 (Pew Research Center 2021). This varies by age demographic, with only 61% of U.S. adults aged 65 or older owning a smartphone, although this percentage has increased over time (Pew Research Center 2021). In addition, mobile apps in the United States are required to comply with the Americans with Disabilities Act (ADA). Many mobile apps also follow the Web Content Accessibility Guidelines. These guidelines include text alternatives for non-text content, captions for audio content, not using color as the only way of conveying information, keyboard accessibility, and limited flashing to avoid inducing seizures, among other recommendations (W3C WAI 2023). Following these guidelines can make a mobile app accessible to more users, potentially enabling indoor wayfinding using a mobile app for travelers with disabilities. However, although most travelers use mobile apps, they are not currently an accessible option for all.

In addition, during the stress of navigating an airport and balancing heavy luggage and family members, having to pull out a phone (and hold it up, in the case of AR features) may not be an attractive option. Apps can be very useful for travel to an airport—a task already accomplished using smartphone navigation assistance in most cases—and stationary tasks such as scanning a boarding pass. In order to address challenges such as needing to hold a mobile device, apps and other similar technologies can be layered on top of other wayfinding technologies. The base layer can be static signage for static information, supplemented by digital signs for changing information, and lastly advanced technologies such as mobile apps for more personalized information. This framework is further discussed in Section 4.

Mobile apps also present concerns that, while not limited to apps, may be more prevalent for this specific wayfinding technology. For example, mobile apps may direct travelers to certain destinations based on commercial interests that may not be the traveler's preference or meet other goals such as environmental considerations. Another challenge facing mobile phone wayfinding solutions is the potential conflict between what a smartphone is showing and what the traveler is seeing in the physical environment. This can cause the traveler to become disoriented and unsure whether to trust a physical sign or the directions on their phone. Reliable and seamless integration between physical and digital directions is key to avoid this issue. Although neither of these issues are limited to mobile app wayfinding (e.g., static signs can also be biased in directing passengers based on commercial interests and can contain outdated information), these challenges may be more apparent in the case of mobile apps.

2.6 Indoor Positioning Technology

Electronic location referencing remains a major barrier indoors, and its advancement is crucially linked to the development of smartphone navigation apps. Whereas GPS technology has revolutionized outdoor navigation, no parallel technology has emerged to aid indoor navigation. It remains a challenge for smartphones to know the precise location of an indoor user, as well as their trajectory (speed and direction) of travel. However, there are a few approaches. As previously mentioned, Google utilizes scene matching of a smartphone digital camera against a database of existing building photos to locate the traveler. Such a process requires large resources, and its widespread adoption remains to be seen.

A more prevalent method is using BLE beacons. This method requires small, battery-powered devices to be installed throughout a facility. A BLE-enabled device (such as a modern smartphone or tablet) senses the beacon when it passes within a certain distance of it. The strength of the Bluetooth signal is used to determine the user's location. BLE beacons are used by many applications (such as the previously mentioned company Pointr) but must be deployed strategically throughout the environment and cataloged, and the information must be made available to the smartphone applications. Access to beacon data can be contentious as well as mutually beneficial. There can be competition between airports, airlines, and third-party app developers for access to these data. In 2014, SITA, an air transport information technology company, set up a common-use beacon registry to promote the use of beacons and reduce associated costs (SITA 2022). The registry allows multiple stakeholders (including airlines, airports, and third parties) to share beacon data. This registry could be in an airport's interest if they want an app developer to be able to use the airport's existing beacon infrastructure, reusing already deployed infrastructure—as well as policy enactments that mandate shared use of such technology. According to SITA's *2021 Air Transport IT Insights* report, 83% of airports are planning major Internet of Things (IoT) initiatives by 2024, including deploying "beacons or sensors powering wayfinding solutions as well as personalized messages regarding facilities, baggage, and more" (SITA 2021).

Although BLE beacons are the most prevalent type of beacons used for indoor navigation applications, another beacon technology has emerged in recent years with similar functionality. Ultra-wideband (UWB) beacons are also small, battery-powered devices that can be installed throughout a facility. Similar to BLE, UWB also operates through a UWB-enabled device that senses the beacon when it passes by. However, UWB uses time-of-flight and time-difference-of-arrival positioning methodologies to triangulate a user's position (both using radio signals) rather than the strength of a Bluetooth signal (Slamich 2023). In addition, UWB beacons have a higher range than BLE beacons (approximately 300 meters and 100 meters, respectively) and therefore require fewer beacons to be deployed in a facility (Slamich 2023). UWB beacons are also more accurate than BLE at identifying a user's location (on the order of centimeters versus meters), although BLE beacons have proven to be accurate enough for effective indoor navigation applications (Slamich 2023). Lastly, while Bluetooth is standard on modern smartphones, UWB is a newer technology and was introduced into smartphones beginning in 2019 (e.g., iPhone 11 onwards). Therefore, some travelers may not yet have a UWB-enabled device. In practice, UWB is more commonly used for locating devices or objects (e.g., Apple AirTags) than for indoor navigation, likely due to their high location accuracy.

Indoor positioning technology also has multiple uses beyond wayfinding, including:

- **Marketing.** For example, the technology could track how long someone spends in a store or push coupons to the cellphone of a person walking by a shop (Pichler 2019).
- **Tracking employees.** Live employee locations can be used for safety, security, and maintenance purposes. Airport employees often experience long commutes—including time spent navigating within an airport—and wayfinding technologies could help reduce commute time to job locations. However, privacy and employee–employer relationships should be considered.
- **Tracking passengers.** Passenger tracking using sensors can be used to optimize traffic flow through certain parts of the airport (Xovis 2023). The technology can forecast wait times, identify when and where lines are forming, and estimate the occupancy of a space (such as a gate). This information could change airport operations in close to real time, impacting where passengers need to move next.
- **Connecting to transit.** Passenger transitions from planes to the airport and internal and external transit can utilize indoor positioning technology to ensure transitions are smooth and efficient.

Until a standards-based method provides ubiquitous indoor positioning (similar to GPS outdoors), indoor wayfinding applications will likely lag behind outdoor wayfinding applications in terms of ease of use and full functionality.

2.7 Non-App Digital Navigation Tools

Creative tools for turn-by-turn directions are emerging, moving beyond apps. For example, live turn-by-turn directions were recently integrated into airport carts in San Diego International Airport (Rozario 2022). The free smart carts work as traditional luggage-carrying carts, but include screens that allow the user to get directions to their gate, restaurants, shops, etc. The display shows personalized flight status information and includes advertisements. Combining wayfinding needs with other passenger experiences such as carrying luggage could be an impactful pairing.

Hologram technology is being considered at airports such as CVG to improve wayfinding. At CVG, a 3D hologram is planned to guide travelers in the correct direction when they exit an escalator. Various innovative technologies are being developed to aid people with navigation, and digital solutions will continue to emerge.

Finally, virtual tours have emerged to familiarize travelers with an airport before they arrive. For example, CVG developed a "360 virtual tour" using Google Maps, which can be used with virtual reality gear and is available on the CVG website (CVG 2023). Users can navigate the virtual area at their own pace. Among other airports, Cairo International Airport and Chicago O'Hare International Airport also have virtual tour options on their websites (Cairo Airport Company 2023; Chicago O'Hare International Airport 2023). Digital twins of airports can be used to enhance these virtual tours with 3D scans of a space.

2.8 Biometric Technology

Another technology that can be used for personalized content is facial recognition and other biometrics. Although currently used by some airport security already, facial technology could

become more prevalent in the future for broader purposes such as providing personalized shopping suggestions and wayfinding directions to the customer's specific gate. However, there are concerns about privacy and higher inaccuracies among certain groups (such as those with darker skin, women, and older adults) in facial recognition technology (Zoufal et al. 2021; Singer and Metz 2019). According to SITA's *2021 Air Transport IT Insights* report, 45% of airports are planning major biometric ID management programs by 2024 (SITA 2021).

As one example, Delta Air Lines has launched multiple technologies in a handful of U.S. airports as part of a larger initiative for airports to be designed for "walking speed" and hands-free navigation leveraging biometrics (Ausband 2022). These include Delta's Digital ID and Parallel Reality technologies.

Delta's Digital ID technology uses facial recognition as a means of replacing physical forms of identification. Digital ID can be used in partnership with Delta's more creative endeavor, Parallel Reality, which Delta announced that launch of in 2020. Parallel Reality aims to display personalized information on a digital screen to multiple passengers at the same time (Delta 2022). This technology would allow for information such as flight status and gate directions to be displayed in the passenger's preferred language on a single screen for nearly 100 passengers simultaneously. Developed in partnership with Misapplied Sciences, a beta experience at Detroit Metropolitan Airport launched in June 2022. Users scan their boarding pass or activate facial recognition at a nearby kiosk if enrolled in Digital ID through the Fly Delta app. The goal is for biometrics such as facial recognition technology to take away the need for customers to scan a boarding pass.

Figure 11. Delta's Parallel Reality experience under construction at Detroit Metropolitan Airport.

Photo taken by C. Alexander Hirst on June 15, 2022

Not all of Delta's technology and infrastructure upgrades as part of their "walking speed" airport initiative involve biometric technology. For example, in 2022, Delta opened new terminals in Los Angeles International Airport and LaGuardia Airport with multiple infrastructure upgrades, including a 250-foot "LED digital backwall" in a terminal check-in area in Los Angeles with dynamic wayfinding information (in English and Spanish) (Ausband 2022).

Prague Airport, as another example, is also experimenting with customized signs. In December 2019, digital signs were deployed displaying information in six languages, with those languages changing throughout the day based on the passenger makeup (Prague Airport 2019).

2.9 Robot Guides

Japanese airports were among the first in the world to use robot guides to assist passengers in wayfinding, beginning in 2016. These robots were planned to greet visitors at Haneda Airport near Tokyo for the 2020 Olympic Games. However, rollout was delayed due to the COVID-19 pandemic. The robots were intended to help passengers navigate and for security (Business Standard 2020). Japan is also experimenting with developing autonomous vehicles, such as those used to shuttle passengers in the delayed 2020 Olympic Games (Murray 2021). Wayfinding to such services will likely be important, especially because autonomous travel is less familiar to the public (Nehl and Schlaich 2021).

Robot guides have also been deployed beyond Japan. In 2018, passenger-guiding robots were unveiled in Incheon International Airport in South Korea (Future Travel Experience 2020). The social robot "Aerobot," with a rolling base, two movable arms, and a head, was also piloted in Istanbul Sabiha Gokcen International Airport in early 2021 (Malaysia Airports 2021). Aerobot uses artificial intelligence and profiling capabilities to provide passengers with personalized information such as directions. It can also lead travelers to their destination and display congestion levels of different spaces in the airport. Heathrow Airport in London has robots named "Bill," which can also guide passengers to certain destinations and provide flight information via a screen (Hornyak 2020).

The COVID-19 pandemic has led to an even greater interest in robots and autonomous vehicles due to their ability for contactless assistance and cleaning capabilities. For example, robots have been used for cleaning and disinfecting purposes in airports such as Singapore Changi Airport, Zurich Airport, and CVG (Nehl and Schlaich 2021; Marsh 2023).

3 Other Considerations

3.1 Autonomous Vehicles

Airports are becoming increasingly interested in autonomy, from autonomous wheelchairs to passenger shuttles and air taxis. These emerging technologies have implications for airport wayfinding, as they require navigation to the new mode of transportation itself, but can also take out the need for a traveler to navigate at all once they are boarded.

There are multiple companies launching autonomous wheelchairs that navigate through the airport without a wheelchair attendant. Autonomous wheelchairs are already in use at Tokyo International Airport, and a pilot with Amsterdam Airport Schiphol is in progress as of February

2023 (Future Travel Experience 2023). These wheelchairs may be more convenient for travelers with reduced mobility. Travelers have also been known to request wheelchairs at airports for wayfinding reasons rather than mobility requirements. If someone does not know the language, has speech or hearing impairments, or has a cognitive disability, a wheelchair attendant pushing them to their destination can be invaluable.

There are also companies developing autonomous shuttles that move more than one passenger at a time—often up to 12. These autonomous vehicles can be fixed-route, on-demand, or a combination, and can operate in dedicated lanes or among regular traffic. The shuttles can be used in multiple contexts in addition to airports, such as within cities, campuses, small communities, or warehouses.

Urban electric vertical takeoff and landing (eVTOL) aircraft and their associated vertiports have also received greater funding recently. UK startup Urban-Air Port is planning to build 200 vertiports globally (SmartCitiesWorld 2022). Australia's Skyportz is planning to turn less-utilized airport parking garages into vertiports (Borrás 2022). As additional transportation modes are added, passenger wayfinding practices to new services become even more critical. Questions such as how passengers will navigate to their urban taxi and what systems will work together (and how) will need to be addressed.

3.2 Legal Considerations

There are various legal considerations regarding privacy in modern wayfinding and sharing data. Such considerations include compliance with privacy laws, as well as public opinion related to data collection and sharing. Collected data can include location (such as from beacons), frequent flyer information, and even health data such as temperature to identify if someone may have COVID-19 (Zoufal et al. 2021). Sharing or disclosing not only traditional personally identifiable information but also travel and mobility patterns of individuals (both customers and employees) could potentially fuel public distrust of new wayfinding technologies and even an airport more generally. There are also potential tensions between airlines, airports, and third-party app developers that are vying to cater to the same customer market. For example, American Airlines recently sued The Points Guy over the use of their frequent flyer data (Lyons 2022).

3.3 Traveler Stress

The need to navigate through large, busy, complex airport facilities, often while under time duress, can contribute to stress. Improved wayfinding technologies can help mitigate some of these challenges and reduce the stress that travelers experience. This section outlines some of the ways in which airports have been working to reduce traveler stress.

There has been increased interest in calm, quiet spaces located within airports to ease the stress of traveling and serve various traveler needs. Some of this interest has likely been accelerated by the COVID-19 pandemic, which introduced additional stressors to the airport experience. In U.S. airports, existing quiet spaces range from sensory rooms intended for customers who are sensitive to stimuli (Seattle-Tacoma Airport) to outdoor terraces (Pittsburgh International Airport) and meditation rooms (Houston's George Bush Intercontinental Airport) (Puckett 2022). Private rooms such as the Escape Pods at Syracuse Hancock International Airport (Figure 12)

equipped with a desk and chair are ideal for privacy and taking business calls. Many airports also have nursing rooms. Such spaces vary in terms of payment structures.

Figure 12. Escape Pod at Syracuse Hancock International Airport.

Photo taken by Bonnie Powell on Jan. 8, 2023

International airports have traditionally led the way in creating pleasant, low-stress spaces for travelers. For example, Singapore Changi Airport has won awards for its spectacular garden spaces, including walking trails and waterfalls that have become a tourist attraction even to those who are not flying (Green 2019; Nehl and Schlaich 2021). DIA has multiple outdoor decks with lounge chairs and fire pits (Figure 13). These spaces have been used to enhance the travel experience for current passengers, but also to inspire additional travel and retail purchases. Traveler stress should be considered and integrated into the wayfinding experience, such as directing passengers to designated calm zones.

Figure 13. View of the outdoor deck at the western end of Concourse B in DIA.

Photo taken by Bonnie Powell on Feb. 6, 2023

In addition to calm zones, easing the stress of the wayfinding process itself is important to consider. Certain groups in particular may benefit from targeted wayfinding upgrades. Most literature is aimed at general airport wayfinding, but passengers with disabilities or families with young children have different requirements and needs. For example, wayfinding techniques specific to wheelchair users and their line of sight should be considered. The number of air passengers who use wheelchairs is projected to increase due to the aging of the population, so such investments would be timely (Qing, Sun, and Reneker 2020).

4 Discussion

The field of airport wayfinding is rapidly changing, and the need for better wayfinding continues to increase with the diversification of modes and various services available at the airport. As digitization advances and big data are harnessed, airports need to carefully consider what technologies they choose to use. Mobile applications are a popular topic, including their integration with indoor positioning technology. However, there are challenges with advanced digital technologies in addition to clear benefits. Too many push notifications can overwhelm travelers (referred to as notification fatigue), and passengers can become confused and irritated when digital tools constantly change. Indoor positioning technology is still developing, and no equivalent to GPS has emerged for indoor navigation in terms of full functionality and adoption across industries.

To address such issues and ensure the effectiveness of wayfinding in airports, the authors recommend a layering framework consisting of three layers of information: static, dynamic, and personalized (Figure 14). Electronic wayfinding technologies do not replace—but rather

augment and complement—traditional methods. A well-designed airport with clear static signage is the foundation upon which digital wayfinding technologies are built. Even as technology progresses, fundamentals of static signage will remain the base for information that does not change (such as exits, gates, and other spatial information). This will be augmented with digital displays for conveying dynamic information. Newer technologies, either through smartphone apps, robots, or interactive kiosks, seek to customize or personalize the information to the traveler. All three layers of information (static, dynamic, and personalized) can be integrated into existing wayfinding systems for a seamless traveler experience. Human behavior responding to various wayfinding technologies should be studied throughout the research process and prior to the deployment of technologies through partnerships with social scientists.

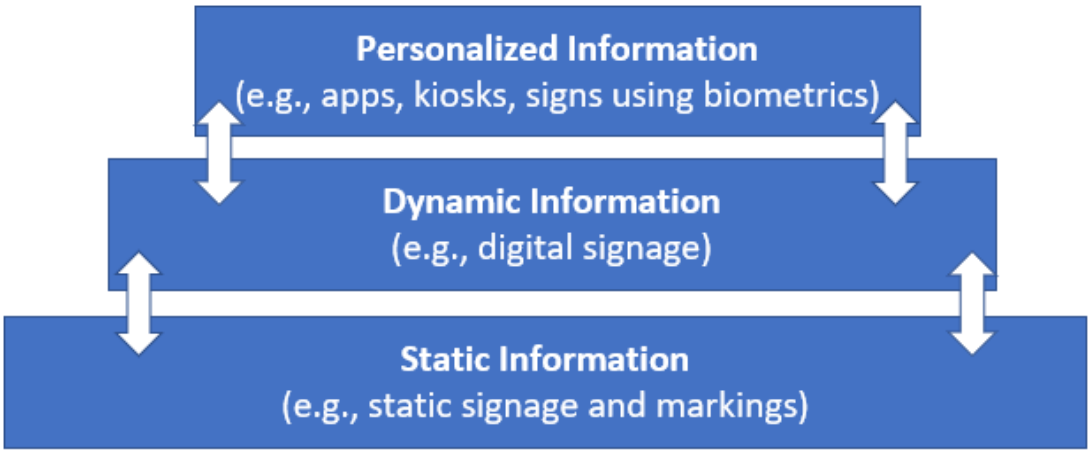

Figure 14. Layering framework outlining example wayfinding technologies for static, dynamic, and personalized information

This layering of wayfinding information is analogous to roadway wayfinding, where static signage is the base upon which digital signs for dynamic information (such as construction road closures) and navigation apps supplement. However, at an airport, the visual appearance of these multiple technologies can be integrated through the use of standard pictograms and colors to create a streamlined traveler experience and a local identity for the airport. In order to effectively provide this integration, wayfinding consulting firms advocate for a holistic airport wayfinding strategy (Mijksenaar 2023). *ACRP Report 52* outlines three key principles for an airport wayfinding strategy: continuity, connectivity, and consistency (Harding et al. 2011). There are also opportunities for powerful partnerships across industries to strengthen the wayfinding experience, as interior airport navigation spans many different sectors.

5 Conclusion

Airport terminal wayfinding has evolved over time, moving from static signage and employee help desks to digital kiosks and biometric signs. These technologies and their history are important for an airport to understand in order to create a seamless travel experience for their customers. In recent years, innovative digital wayfinding technologies have increased in popularity, including AR apps and robot guides. These trends are important to study, but the building blocks of wayfinding should not be abandoned. As airport facilities continue to increase in size and complexity, and as the total number of air travelers continues to rise, the development

and refinement of wayfinding technologies and practices will become ever more critical. Wayfinding is central to the performance of airport operations, and among the most immediate in how traveler experiences are shaped. This report proposes a theoretical layering framework with static information as the base upon which dynamic and personalized information is built. Through integration of these layers with standardized graphics and colors, an airport's wayfinding strategy can provide a sense of both identity and direction.

References

Apple. 2023. "Indoor Maps in Apple Maps." Accessed July 10, 2023. https://register.apple.com/resources/indoor/program/indoor_maps#indoor-maps-in-apple-maps.

Ausband, A. 2022. "How Delta is designing airports built for 'walking speed.'" *Delta News Hub*, Aug. 31, 2022. https://news.delta.com/how-delta-designing-airports-built-walking-speed.

Bastone, N. 2023. "Uber launches airport guides to help cut pickup confusion." *Axios*, March 7, 2023. https://www.axios.com/local/san-francisco/2023/03/07/uber-launches-airport-guides-san-francisco.

Borrás, Jo. 2022. "Skyportz signs agreement with airport parking company to build 400 eVTOL vertiports." *Electrek*, Jan. 19, 2022. https://electrek.co/2022/01/19/skyportz-signs-agreement-with-airport-parking-company-to-build-400-evtol-vertiports/.

Bose, Y. 2019. "Best of Beacons: Gatwick Airport leverages 2,000 Beacons for Indoor Navigation and more." *Beaconstac,* April 24, 2019. https://blog.beaconstac.com/2017/06/best-of-beacons-gatwick-airport-leverages-2000-beacons-for-indoor-navigation-and-more/.

Business Standard. 2020. "2020 Olympic: Robots to greet, guide visitors at Haneda Airport." March 6, 2020. https://www.business-standard.com/article/news-ani/2020-olympic-robots-to-greet-guide-visitors-at-haneda-airport-120030600685_1.html.

Business Traveller India. 2021. "Zurich Airport teams up with Google Maps." April 6, 2021. https://www.businesstraveller.com/business-travel/2021/04/06/zurich-airport-teams-up-with-google-maps/.

Cairo Airport Company. 2023. "Virtual Tour at the Cairo Airport." Accessed July 12, 2023. https://www.cairo-airport.com/en-us/Airport/Virtual-Tour.

Chicago O'Hare International Airport. 2023. "Map." Accessed July 12, 2023. https://www.flychicago.com/ohare/map/pages/default.aspx.

Chonsalasin, D., S. Jomnonkwao, and V. Ratanavaraha. 2021. "Measurement model of passengers' expectations of airport service quality." *International Journal of Transportation Science and Technology* 10 (4): 342–352. https://doi.org/10.1016/j.ijtst.2020.11.001.

CHP. 2023. "CHP Airport App." Accessed July 10, 2023. https://www.cph.dk/en/customer-service/app.

CVG. 2023. "360 Virtual Tour of Cincinnati/Northern Kentucky International Airport." Accessed July 10, 2023. https://www.cvgairport.com/terminal/360.

Delta. 2022. "Groundbreaking PARALLEL REALITY™ technology coming to Delta's Detroit hub." Accessed December 2023. https://news.delta.com/groundbreaking-parallel-realitytm-technology-coming-deltas-detroit-hub-0.

Delta. 2023. “The Fly Delta App.” Accessed December 2023. https://www.delta.com/us/en/delta-digital/mobile.

Denver International Airport (DIA). 2022. “DEN Meet & Assist Services.” Accessed March 2022.https://www.flydenver.com/sites/default/files/concierge/den_Meet_Assist_Terms_Conditions.pdf.

Federal Aviation Administration (FAA). 2013. *AC 150/5360-12F – Airport Signing and Graphics.* Washington, D.C.: FAA. https://www.faa.gov/airports/resources/advisory_circulars/index.cfm/go/document.information/documentID/1022248.

Future Travel Experience. 2011. “Copenhagen embraces mobile technology with Augmented Reality app.” March 2011. https://www.futuretravelexperience.com/2011/03/copenhagen-embraces-mobile-technology-with-augmented-reality-app/.

Future Travel Experience. 2014. “Munich Airport enhancing the passenger experience with ‘something new and something old fashioned.’” May 2014. https://www.futuretravelexperience.com/2014/05/munich-airport-enhancing-passenger-experience-something-new-something-old-fashioned/.

Future Travel Experience. 2020. “Incheon Airport presses ahead with AI, biometrics and big data plans amid global COVID-19 pandemic.” May 2020. https://www.futuretravelexperience.com/2020/05/incheon-airport-presses-ahead-ai-biometrics-big-data/.

Future Travel Experience. 2023. “Amsterdam Airport Schiphol tests autonomous mobility vehicles with Axxicom Airport Caddy.” Feb. 2023. https://www.futuretravelexperience.com/2023/02/amsterdam-airport-schiphol-tests-autonomous-mobility-vehicles-with-axxicom-airport-caddy/.

Google. 2022. “Go Inside with Indoor Maps.” Accessed March 2022. https://www.google.com/maps/about/partners/indoormaps/.

Green, J. 2019. “Singapore’s New Garden Airport.” *The Dirt*, April 8, 2019. https://dirt.asla.org/2019/04/08/singapores-new-garden-airport/.

Harding, J. R., M. Elizer Jr., J. Alderman, M. J. Frankel, S. T. Chrysler, C. M. Poe, L. L. Higgins, et al. 2011. *ACRP Report 52: Wayfinding and Signing Guidelines for Airport Terminals and Landside*. Washington, D.C.: Transportation Research Board of the National Academies. https://crp.trb.org/acrpwebresource2/acrp-report-52-wayfinding-and-signing-guidelines-for-airport-terminals-and-landside/.

Hornyak, T. 2020. “Meet the robots that may be coming to an airport near you.” *CNBC Tech Drivers*, Jan. 11, 2020. https://www.cnbc.com/2020/01/10/meet-the-robots-that-may-be-coming-to-an-airport-near-you.html.

Image Projection. 2022. “Safety Signage for Facilities & Warehouses.” Accessed March 2022. https://safety.uselight.com/discover/?gclid=Cj0KCQjw29CRBhCUARIsAOboZbJawsi0AmXieNHgxCk3WTAvgo8Ld-rzydCczTnpIEQMLduUblFo-c8aAmYqEALw_wcB.

LaserCube. 2023. “World’s First Portable Laser Show.” Accessed July 10, 2023. https://www.laseros.com/.

Lowensohn, J. 2014. “San Francisco Airport testing beacon system for blind travelers.” *The Verge*, July 31, 2014. https://www.theverge.com/2014/7/31/5956265/san-francisco-airport-testing-beacon-system-for-blind-travelers.

Loyola, R. 2021. “Google Maps can now give you directions inside a mall or airport.” *Macworld*, March 30, 2021. https://www.macworld.com/article/342049/google-maps-can-now-give-you-directions-inside-a-mall-or-airport.html.

Lyons, K. 2022. “American Airlines suing The Points Guy over app that syncs frequent flyer data.” *The Verge*, Jan. 21, 2022. https://www.theverge.com/2022/1/21/22895317/american-airlines-the-points-guy-app-frequent-flyer-copyright.

Malaysia Airports. 2021. “Social Robots Introduced As Part of Airports 4.0 Initiative.” Feb. 23, 2021. https://www.malaysiaairports.com.my/media-centre/news/social-robots-introduced-part-airports-40-initiative.

Marsh, C. 2023. “Airports Turn to Autonomous Cleaning Robots to Maintain Cleanliness.” *AviationPros.com*, April 17, 2023. https://www.aviationpros.com/airports/airport-technology/operations/article/53029139/how-to-use-autonomous-cleaning-robots-in-an-airport-environment.

Metropolitan Airport News. 2023. “JFKIAT Teams Up With Google Maps to Launch Indoor Live View at JFK Terminal 4.” Sept. 25, 2023. https://metroairportnews.com/jfkiat-teams-up-with-google-maps-to-launch-indoor-live-view-at-jfk-terminal-4/.

Mijksenaar. 2023. “Approach: How we do it.” Accessed July 10, 2023. https://www.mijksenaar.com/approach/.

Milan Airports. 2015. “Virtual Desk reception system. Malpensa Airport.” YouTube video, 0:46. https://www.youtube.com/watch?v=xqOph1PSLyU.

Murray, L. 2021. “Meet the robots of the Tokyo Olympics.” *E&T: Engineering and Technology*, June 15, 2021. https://eandt.theiet.org/content/articles/2021/06/meet-the-robots-of-the-tokyo-olympics/.

Nehl, Heike, and Sibylle Schlaich. 2021. *Airport Wayfinding*. Salenstein, Switzerland: Niggli Verlag.

Pew Research Center. 2021. “Mobile Fact Sheet.” April 7, 2021. https://www.pewresearch.org/internet/fact-sheet/mobile/.

Pichler, S. 2019. “Indoor Positioning Use Cases for Airports.” *ArcGIS Blog*, July 16, 2019. https://www.esri.com/arcgis-blog/products/arcgis-indoors/real-time/indoor-positioning-use-cases-for-airports/.

Pointr. 2022. “Pointr – Deep Location® Company.” Accessed March 2022. https://www.pointr.tech/.

Prague Airport. 2019. “Prague Airport is Introducing Digital Signage, Passenger Information Is Provided in Six Languages.” Press release, Aug. 12, 2019. https://www.prg.aero/en/Prague-Airport-Is-Introducing-Digital-Signage.

Puckett, J. 2022. “Airports Are Creating Inclusive Quiet Spaces Where All Travelers Can Find Calm.” *Condé Nast Traveler*, Jan. 25, 2022. https://www.cntraveler.com/story/airports-are-creating-inclusive-quiet-spaces-where-all-travelers-can-find-calm.

Qing, Z., C. Sun, and J. Reneker. 2020. “Evaluation of Airport Wayfinding Accessibility with the Use of a Wheelchair Simulator.” *Transportation Research Record* 2675 (4). https://doi.org/10.1177/0361198120980445.

Rozario, K. 2022. “Smart Carts That Take You To The Best Deals At The Airport.” *Forbes*, Jan. 21, 2022. https://www.forbes.com/sites/kevinrozario/2022/01/21/smart-carts-that-take-you-to-the-best-deals-at-the-airport/?sh=21e01bc06724.

Singer, N., and C. Metz. 2019. “Many Facial-Recognition Systems Are Biased, Says U.S. Study.” *The New York Times*, Dec. 19, 2019. https://www.nytimes.com/2019/12/19/technology/facial-recognition-bias.html.

SITA. 2021. *2021 Air Transport IT Insights.* Geneva, Switzerland: SITA. https://www.sita.aero/globalassets/docs/surveys--reports/2021-air-transport-it-insights.pdf.

SITA. 2022. “Beacons API.” Accessed March 2022. https://www.developer.aero/api-catalog/beacons-overview.

Slamich, M. 2023. “Bluetooth vs Ultra-Wideband (UWB): which is best for indoor location system?” Pointr, May 4, 2023. https://www.pointr.tech/blog/bluetooth-vs-ultra-wideband-which-technology-to-use-for-indoor-location.

SmartCitiesWorld. 2022. “UK start-up plans to build 200 vertiports across the globe.” Jan. 25, 2022. https://www.smartcitiesworld.net/air-travel/uk-start-up-plans-to-build-200-vertiports-across-the-globe-7349.

Tezcan, P., and S. Hiemstra-van Mastrigt. 2019. “The Effect of Light Projections for Wayfinding Purposes within an Airport Context.” *The Journal of Navigation* 72 (5): 1200–1216. https://doi.org/10.1017/S0373463319000092.

World Wide Web Consortium Web Accessibility Initiative (W3C WAI). 2023. “How to Meet WCAG (Quick Reference).” Updated Nov. 12, 2023. https://www.w3.org/WAI/WCAG22/quickref/?versions=2.1.

Xovis. 2023. “Accurately Manage Passenger Flow at Airports.” Accessed July 12, 2023. https://www.xovis.com/solutions/airport.

Yang, Rachel Y. 2022. *Infrastructure Investment and Jobs Act (IIJA) and Airport Funding*. Washington, D.C.: Congressional Research Service. https://crsreports.congress.gov/product/pdf/IN/IN11864.

Zoufal, D. R., S. Cusson, D. J. Larsen, T. Person, D. Hantman, and E. A. Maliszewski. 2021. *ACRP LRD 42: Legal Implications of Data Collection at Airports*. Washington, D.C.: Transportation Research Board. https://doi.org/10.17226/26207.