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Indoor Airport Wayfinding for Blind and Visually Impaired Travelers

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16. Abstract

By conservative estimates, more than 4 million Americans have impaired vision, with the prevalence rising as the population ages. Wayfinding in complex public spaces, such as airport terminals, poses a major challenge for this group and adversely affects their mobility and quality of life.

Wayfinding refers to the ability to find one’s way to a desired destination. In an airport, critical wayfinding tasks include finding and passing through security, reaching a departure gate, traveling between gates to make a connecting flight, finding the baggage claim and ground transportation (taxi, bus, or rail), and finding relief stations for service animals. These wayfinding tasks must often be accomplished under time pressure. Other important wayfinding tasks include finding bathrooms, restaurants, and ticketing kiosks.

This project had three objectives: (1) to describe the demographics and wide range of visual impairment and wayfinding needs within the target population; (2) to explore challenges and solutions related to specific factors affecting airport wayfinding by visually impaired people; and (3) to develop three types of recommendations for enhancing accessibility of airport terminals: those having a broad consensus and which can be implemented in the near future, those requiring consultation with stakeholders for which alternative solutions need discussion, and those requiring technical research and development.

This technical note identifies best practices and recommendations for potentially viable solutions. This technical note is also intended to encourage discussion and raise questions for a broad audience including Federal Aviation Administration staff, airport administration, airline staff, people with interests in accessible transportation systems, vision rehabilitation specialists, visually impaired travelers, and members of the general public with an interest in accessibility.

Ultimately, solutions could be found through collaboration and consensus among stakeholders. Improved wayfinding and other forms of accessibility within airports require communication and shared responsibility of two major groups—those providing airport services and the users of those services.

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The team members all have expertise in topics related to wayfinding by blind and visually impaired pedestrians. Collectively, the team members themselves cover the full range from fully sighted to totally blind, and all have substantial national and international air travel experience.

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*Dr. Bosco Tjan died tragically and unexpectedly on December 2, 2016, just days before final publication of this document. He was a professor at the University of Southern California (USC) and co-director of USC Dornsife's Cognitive Neuroimaging Center. He was widely respected as an insightful and generous colleague, an outstanding teacher, a prolific researcher, and an exceptional collaborator across the university and at other institutions. He was as eager to share and apply the results of his research as he was to teach graduate students and postdoctoral fellows. We would like to pay special recognition to Dr. Tjan's contribution to this important study.

TABLE OF CONTENTS

LIST OF ACRONYMS

ADA	Americans with Disabilities Act
app	Application
BVI	Blind and Visually Impaired
ESRI	Environmental Systems Research Institute
FAA	Federal Aviation Administration
GIS	Geographic information system
GPS	Global positioning system
iOS	iPhone® Operating System
IR	Infrared
LOS	Level of service
MSP	Minneapolis-St. Paul International Airport
NIBS	National Institute of Building Sciences
O&M	Orientation and mobility
PA	Public address
POI	Point of interest
SITA	Société Internationale de Télécommunications Aéronautiques
SFO	San Francisco International Airport
TSA	Transportation Security Administration
U.S.	United States

EXECUTIVE SUMMARY

By conservative estimates, more than 4 million Americans have impaired vision, with the prevalence rising as the population ages. Wayfinding in complex public spaces, such as airport terminals, poses a major challenge for this group and adversely affects their mobility and quality of life.

Wayfinding refers to the ability to find one's way to a desired destination. In an airport, critical wayfinding tasks include finding and passing through security, reaching a departure gate, traveling between gates to make a connecting flight, finding the baggage claim and ground transportation (taxi, bus, or rail), and finding the relief stations for service animals. These wayfinding tasks must often be accomplished under time pressure. Other important wayfinding tasks include finding bathrooms, restaurants, and ticketing kiosks.

Air travel has become increasingly important as part of mainstream life in the United States and abroad. Many travelers have disabilities, including people with visual impairment ranging from those who are blind and who rely exclusively on nonvisual methods for wayfinding to those with mild, low vision, who rely on visual cues for wayfinding. For convenience, this technical note refers to this group of travelers collectively as blind and visually impaired (BVI). However, it should be noted that needs and requirements sometimes differ for those who are blind and rely on nonvisual solutions, and those who have low vision and often rely on visual cues. When this distinction is relevant, the authors of this technical note will refer specifically to travelers who are "blind" or travelers who have "low vision." Enhancing airport accessibility for the diverse BVI population requires a multifaceted approach. This technical note contains recommendations for ways to enhance airport wayfinding for BVI travelers.

The project had three objectives: (1) to describe the demographics and wide range of visual impairment and wayfinding needs within the target population; (2) to explore challenges and solutions related to specific factors affecting airport wayfinding by visually impaired people. These factors include acoustic and visual design, signage and maps, language-related concerns, assistive technology, and evaluation methods; and (3) to develop three types of recommendations for enhancing accessibility of airport terminals: those having a broad consensus and which can be implemented in the near future, those requiring consultation with stakeholders for which alternative solutions need discussion, and those requiring technical research and development.

This technical note identifies best practices and recommendations for potentially viable solutions. The technical note is also intended to encourage discussion and raise questions for a broad audience including Federal Aviation Administration staff, airport administration, airline staff, people with interests in accessible transportation systems, vision rehabilitation specialists, BVI travelers, and members of the general public with an interest in accessibility.

Ultimately, solutions could be found through collaboration and consensus among stakeholders. Improved wayfinding and other forms of accessibility within airports require communication and shared responsibility of two major groups—those providing airport services and the users of those services.

The recommendations discussed within this technical note cover six topics: (1) diversity of the target population; (2) acoustic, tactile, and visual design; (3) signage and maps; (4) language-related concerns; (5) assistive technology, and (6) evaluation methods for terminal accessibility.

INTRODUCTION

Air travel has become increasingly important as part of mainstream life in the United States (U.S.) and abroad. Many travelers have disabilities, including people with visual impairment ranging from those who are blind and rely exclusively on nonvisual wayfinding methods to those with mild, low vision, who rely on visual wayfinding cues. Enhancing airport accessibility for the diverse blind and visually impaired (BVI) population requires a multifaceted approach.

Wayfinding refers to the ability to find one's way to a desired destination. In an airport, critical wayfinding tasks include finding and passing through security, reaching a departure gate, traveling between gates to make a connecting flight, finding the baggage claim and ground transportation (taxi, bus, or rail), and finding the relief stations for service animals. These wayfinding tasks must often be accomplished under time pressure. Other important wayfinding tasks include finding bathrooms, restaurants, and ticketing kiosks.

In 2015, the Federal Aviation Administration (FAA) Airport Safety Research and Development Section, in conjunction with the Office of Airport Safety and Standards Airport Engineering Division, issued a research grant to the University of Minnesota to examine the challenges faced by BVI travelers with respect to wayfinding within airport terminals, and what reasonable steps can be taken to remedy those challenges.

Recommendations discussed within this technical note cover six topics: (1) diversity of the target population; (2) acoustic, tactile, and visual design: (3) signage and maps; (4) language-related concerns; (5) assistive technology; and (6) evaluation methods for terminal accessibility.

PURPOSE AND OBJECTIVES.

The objectives of this research project were as follows:

- Describe the demographics and wide range of visual impairment and wayfinding needs within the target population.

- Explore challenges and solutions related to specific factors affecting airport wayfinding by BVI travelers. These factors include acoustic and visual design, signage and maps, language-related concerns, assistive technology, and evaluation methods.

- Develop three types of recommendations for enhancing accessibility of airport terminals: those having a broad consensus and which can be implemented in the near future; those requiring consultation with stakeholders for which alternative solutions need discussion; and those requiring technical research and development.

The purpose of this technical note is to identify best practices and recommend potentially viable solutions. This technical note is also intended to encourage discussion and raise questions for a broad audience including FAA staff, airport administration, airline staff, people with interests in accessible transportation systems, vision rehabilitation specialists, BVI travelers, and members of the general public with an interest in accessibility.

DISCUSSION OF TOPIC AREAS

TOPIC 1—DIVERSITY OF THE TARGET POPULATION.

DEMOGRAPHICS. According to a recent analysis [1], in 2015, there were 4.24 million BVI individuals over the age of 40 years in the U.S., with the number projected to double by 2050. These estimates used a criterion of best-corrected acuity in the better eye worse than 20/40. These numbers can be considered lower bounds because they do not include BVI individuals under the age of 40 or people whose acuity is poorer than 20/40 because of inadequate refractive correction.

The population of BVI travelers is diverse. BVI includes a wide range of vision conditions from totally blind to mild, low vision. Low vision refers to any form of chronic visual impairment (exclusive of total blindness) that affects everyday function. Note that the definition of low vision is more inclusive than the statutory definition of legal blindness, which is defined in the U.S. as a corrected visual acuity in the better eye of no more than 20/200, or a visual field of no more than 20 degrees.

Low vision can manifest as a reduction of three major aspects of vision: (1) acuity loss (reduced vision for small details such as text); (2) reduced contrast sensitivity (difficulty seeing boundaries between objects and their backgrounds or difficulty seeing contours such as the edge of steps); and (3) visual-field loss (either loss of central vision or loss of peripheral vision). In addition, vision impairment can include sensitivity to glare, difficulty adapting to lighting changes, reduced depth perception, and color vision challenges. All these issues can adversely impact visually guided wayfinding in airports. In addition, people who are blind or who have the most severe forms of low vision must rely on nonvisual strategies for wayfinding. In general, people with impaired vision make greater use of auditory and tactile information when independently wayfinding. Together, these considerations mean that strategies for improving airport wayfinding by the diverse population with visual impairment should consider multisensory solutions involving visual, auditory, and tactile perception.

The majority of visually impaired people are over 65 years of age because the primary causes of visual impairment are age-related eye diseases, with the most common being macular degeneration, glaucoma, cataract, diabetic retinopathy, and optic-nerve disease. In addition to older adults, many younger people, including children, also have visual impairments. An appreciation of BVI travel must consider this broad age distribution of people.

The specific wayfinding difficulties of the BVI traveler and the potential solutions for their challenges depend on multiple factors, including the nature and extent of vision loss, the level of mobility skill and rehabilitation training, and personal attitudes about independence or the desirability of seeking assistance. It is a challenge for airports and airlines to accommodate these diverse wayfinding needs of the BVI population.

By improving wayfinding, BVI travelers would have the dual benefits of extending greater independence, and reducing costs and demand for assistance from airport and airline personnel.

Strategies for enhancing airport wayfinding for BVI travelers could benefit a large and diverse group of people. In the spirit of universal design, these improvements can enhance wayfinding by the traveling public as a whole. The United Nations defines universal design as "the design of products, environments, programmes and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design." [2] Universal design "shall not exclude assistive devices for particular groups of persons with disabilities where this is needed." [2] A list of universal design principles is available at the Center for Universal Design at North Carolina State University website [3].

WAYFINDING SCENARIOS. Recommendations about accessibility should consider the variation in size and complexity of airports as well as the variations in the number and training of airport personnel.

The most common wayfinding challenges faced by BVI travelers are much the same as those faced by the general public; however, the challenges must often be performed without the ability to read signs or easily grasp the layout of large, open areas in airports. Imagine, for example, traveling any of the following routes with little or no visual input:

- From curbside, to check in, to the Transportation Security Administration (TSA) security check point, to departure gate
- From arrival gate to baggage claim to ground transport
- From arrival gate to another gate for a connecting flight
- From anywhere to a bathroom, restaurant or food vendor, and then to a departure gate

BVI travelers with service animals, face the additional challenge of first finding a service animal relief area and then a gate or other destination. This is particularly troublesome if the BVI traveler requires leaving and re-entering the secured area of the airport.

Currently, airports address these challenges with a wheelchair assistant or other helper who walks with the BVI traveler. Some transfers within secured areas of the airport are accomplished by electric cart. A common challenge is that arrangements for such assistance are often unreliable, and these meet-and-assist requests frequently get lost or are not provided in a timely manner.

A fundamental and recurring challenge is the need to find reliable methods for connecting a BVI traveler with the necessary source of assistance. Current methods of connecting BVI travelers with human guides are generally ad hoc and sometimes unavailable during off hours or crowded times.

A particularly pressing issue is the case of a BVI traveler who needs to make a tight airline connection and must arrange ahead for a reliable meet-and-assist request.

There is a need for developing a single point of contact for seeking assistance at a particular airport. Establishing a single point of contact would require coordination between airport personnel and the resident airlines. Information about this point of contact needs to be made readily available to BVI travelers as well as airport staff. Potential solutions might involve a special phone number or smartphone application (app).

One possible model is the Airport Customer Assistance Program at Toronto Pearson International Airport. This program includes a phone contact where BVI travelers can arrange ahead for a sighted guide to meet them at the arrival gate or at a curbside check-in.

Even when assistance from a guide is available, there is sometimes inadequate follow-through. Two examples illustrate common challenges:

- When electric carts are used for transport, BVI travelers may be dropped off at one location without certainty of further assistance to complete the journey. Use of an electric cart also makes it difficult for BVI travelers to take food stops or bathroom breaks.

- Challenges occur in complex airports where the guide's responsibility for assisting BVI travelers changes from place to place. This is particularly challenging at airports where a terminal change involves a bus connection; the guide frequently will not accompany the passenger between terminals. The BVI traveler may exit the bus to encounter a noisy and confusing drop-off zone outside of the terminal building. There is a need to ensure that human assistance for a BVI traveler gets the traveler all the way to the destination within the airport. When complex transfers are required (e.g., between terminals), the BVI traveler has the responsibility of notifying the airline in advance of the issue. But given such notification, a reliable system needs to be in place to provide assistance all the way to the destination.

<u>SERVICE ANIMALS</u>. A particular concern of some BVI travelers is facilitating access to relief stations for service animals. How do BVI travelers with service animals get to and from relief stations quickly? Relief stations should be located so that it is practical for the BVI traveler and service animal to visit the relief station between tightly scheduled flights. To meet this requirement, it is likely that large airports would need multiple relief stations. Since exiting and re-entering security is typically time consuming, it is desirable to locate relief stations within the secured zone of the airport.

Information about the location of the relief station should be readily available to the BVI traveler and also to airport personnel who may be providing assistance. This information should include estimates of time and distance. For example, a database could be constructed listing the walking distances and average walking times from each gate to the nearest relief station. A BVI traveler making a connection might learn, for example, that it will take approximately 10 minutes from the arrival gate to the relief station and 7 minutes from the relief station to the departure gate

<u>ATTITUDES AND PREFERENCES FOR INDEPENDENT WAYFINDING</u>. It is suggested that airport personnel who provide assistance to BVI travelers have some training in guiding people with visual impairment. An example of this training is the Disability Awareness Training program at San Francisco International Airport, which includes a video and a manual [4]. This

training could distinguish the needs of people with vision disabilities from people with other disabilities, including those who require wheelchairs. Airport guides—variously termed passenger service agents, wheelchair agents, wheelchair pushers, etc.—are often inadequately trained in assisting BVI travelers who do not need nor wish to ride in a wheelchair. This inadequacy can lead to confusion, friction, or even humiliation [5].

It is important for airport and airline staff to understand the wide range of preferences and mobility skills in the BVI population. Many BVI travelers will need the assistance of a human guide. It is important to recognize that the BVI traveler's preferences or skills should not be assumed by the airport guide but rather asked of the BVI traveler. Ideally, airport design would also be conducive to independent wayfinding by a BVI traveler with good mobility skills, and the preference for the traveler to proceed independently. This need for independent wayfinding applies for both blind and low-vision travelers. Regardless of the assistance available or the characteristics of the airport, some BVI travelers may wish to function independently without assistance, and it is important to respect their wishes.

Some BVI travelers may be unfamiliar with or unable to use smartphone-based or other assistive mobile technology for wayfinding. In such cases, the BVI traveler may be reliant on airline or airport personnel for assistance.

<u>TOPIC 2—ACOUSTIC, TACTILE, AND VISUAL DESIGN</u>.

<u>MULTISENSORY DESIGN</u>. Using universal design helps the mainstream sighted population as well as those with varying levels of visual impairment. It is important for universal designers to address issues of visual accessibility for BVI travelers, while also accommodating the multisensory experience of people who are blind.

While it is obvious how stairs present barriers to people in wheelchairs, and it is easy to appreciate how lever handles on doors are more accessible for people with severe arthritis or other impairments affecting hand grip, it is less evident how the sensory environment (visual, auditory, and tactile) can create barriers for the BVI population. These barriers can take the form of anxiety, confusion, insecurity, and disorientation. These factors can limit one's confidence and independence as well as present safety risks and dangers. Lack of awareness of these barriers in the airport terminal design process can easily result in environments that hamper functioning of all people but especially those with vision impairment. It is common to focus on visual aesthetics in the design of interior spaces, but it is critical to realize the significant role the design of interior environments has on visual comfort and accessibility.

Accessible visual design can maximize functionality for people with low vision as they move within an environment. For example, an environment with key features designed with high levels of visual contrast is much safer and more navigable for people with low vision than an environment with low-contrast features. Reflections and glare can reduce visual capabilities, whereas high levels of evenly distributed diffused light can maximize or maintain visual function within the space. Extreme fluctuations in light levels while moving from place to place cause challenges for many senior citizens and others whose eyes take longer to adapt. These challenges can significantly reduce visual function.

On the other hand, people with little or no visual function rely on tactile and auditory cues for mobility and interpretation of the environment. For example, blind pedestrians rely on the sense of touch whether experienced through the grip of a cane as it contacts the floor or through the soles of shoes contacting the ground. Material changes on the ground can be used for orientation and wayfinding clues when transitioning from one area to another or to indicate veering from a desired path.

Blind pedestrians also rely heavily on auditory cues to follow and adjust to sounds of people and their luggage moving through the concourse, to locate or avoid restaurants and cafes, or use the sounds of plumbing fixtures to help determine the location of restrooms. Additionally, many independent BVI travelers use echolocation to understand spatial orientation, to locate objects within space, and even to explore and understand the surrounding architectural form. Echolocation is the use of self-generated sounds (tongue clicks, finger snaps, claps, and cane taps) to probe the environment. Some blind pedestrians are able to gather information about the properties and layout of objects in space from the returning echoes. For a review of capabilities and characteristics of human echolocation, see Kolarik et al. [6].

The sense of smell also can help the BVI traveler to navigate, e.g., updating one's position and orientation with respect to a bakery or restaurant. Without sight, the BVI traveler relies heavily on multisensory perceptions to navigate safely, confidently, and independently through the terminal environment. Design guidelines and awareness that take multisensory factors into account can greatly improve the effectiveness of independent BVI travel.

This section recommends some basic design guidelines to benefit BVI travelers in airport terminals. These design guidelines will also benefit all travelers through increased clarity and comfort within unfamiliar places and hectic situations typically experienced in airports.

<u>SURFACE CHARACTERISTICS AND TRAVEL PATHS</u>. Attention to the visual, tactile, and auditory properties of travel paths and other surfaces can enhance airport accessibility and wayfinding by BVI travelers.

Hard surfaces provide better acoustic information, e.g., cane echoes, presence or absence of pedestrian footfalls, and sounds from roller bags.

Hard surfaces are recommended in travel paths, while carpeting is recommended for seating areas, such as airport gates. The boundary between the hard surface and the carpeting can provide a tactile cue, and also a visual cue, assuming good light-dark contrast.

If hard surfaces are consistently used for travel paths, it is recommended that they be kept clear of stationary obstructions. If kiosks, sales/vending areas, pedestal mounts, temporary retail signs, or other moveable elements are intended to extend into the concourse area, flex borders could be used. Islands with contrasting flooring against the general flooring field would limit and demark the maximum extent of the allowable encroachment area. The contrast could be both tactile and visual. For example, tactile contrast could be implemented with tile or terrazzo versus carpet, or polished stone tile versus honed tile with tighter module and beveled edges. Visual contrast is best defined by a large light-dark difference.

Ceiling height can also affect auditory characteristics of a space and provide cues for wayfinding. For example, seating and other ancillary areas could have lower ceiling heights with higher levels of acoustic absorption to dampen sound. Concourse areas could have higher ceilings with less acoustic dampening to create acoustic contrast between concourse walking areas and the more passive zones.

One specific challenge for BVI travelers is locating the service desks at gates. For example, the traveler may successfully navigate the concourse to reach the approximate gate area, but have difficulty in locating the service desk. There is a need for developing cues for easy, nonvisual access to gate service desks. At a minimum, it can be helpful to have gate podium areas that incorporate high visual contrast in color and finish as well as accent lighting and some acoustic difference from the general seating areas.

The development of new mobile wayfinding technologies has the potential to facilitate nonvisual location of service desks. Additional research is recommended to study and determine the efficacy of the new technologies in such situations. If the results are not favorable, consideration could be given to conducting research and development of additional technology components that could trigger suitable audible alerts on demand to assist the BVI traveler to more effectively locate and approach the podium at gates.

Another strategy often considered to address the wayfinding needs of the BVI traveler is the use of tactile guide strips. Tactile guide strips are similar in design and construction to hazardous warning strips that are required by accessibility regulations to delineate passage between safe and hazardous areas, e.g., the edge of a subway platform. Rather than providing warnings, tactile guide strips are intended to provide a wayfinding function and are placed along designated paths on the floor. The BVI traveler can follow the guide strip from one key location to another. The benefits of this technology are debated. In complex environments, such as airports, it is not clear how the paths should be laid out and how this information would be conveyed to unfamiliar BVI travelers. Such a traveler, encountering a guide strip might not know where the path leads or terminates. Moreover, the rough texture of the guide strips can have the unintended consequence of creating tripping or slip risks, can topple luggage carts and roller boards and can create uncomfortable vibrations for people using wheelchairs. While some BVI travelers advocate for tactile guide strips, others perceive them to be stigmatizing and contribute little or no benefit. Given these uncertainties, the use of tactile guide strips in airports is not recommended at this time. Future research may clarify their benefits for BVI travelers as well as mitigate their hazards for others.

<u>CLARITY OF PUBLIC ADDRESS ANNOUNCEMENTS</u>. All airport travelers rely heavily on public address (PA) announcements. These announcements are particularly significant for the BVI traveler who may not be able to see and read critical announcements on flight status displays at the gate and elsewhere. The acoustic quality of PA announcements is also obviously critical to people with hearing loss.

The intelligibility of PA announcements depends on many elements ranging from the environmental condition, the specifics of the infrastructure, and the sound system used. One of the most critical elements affecting the clarity is to minimize background noise at the source. It is suggested that announcements be made from a quiet environment, ideally in a voice-over quality booth. While this may be possible for terminal-wide announcements from a centralized location, it would not be viable for localized announcements within the individual gate areas. Nevertheless, design of the podium areas from which announcements are made could help minimize the likelihood of background noise and include a high-quality directional microphone.

Additionally, it is recommended that the cables and the loud speakers for the PA system be of high quality, and the cables need to be shielded. Finally, the loudspeaker system and interior acoustics of the terminal need to be integrally designed for best acoustic clarity. This requires a coordinated design effort where reverberation qualities of the terminal are considered when specifying the type, location, and orientation of PA loudspeakers. Efforts could be made to target reverberation times in the terminal in range of 1.5 to 2.5 seconds, which will also help with overall loudness during high-activity periods. Loudspeakers with higher degrees of pattern control are needed for more reverberant spaces. Integrated models of room acoustics and loudspeaker simulators could be built to calculate and map intelligibility on the occupied areas of the floor base on loudspeaker specifications, while taking reverberant level, late acoustic reflections, and background noise into account. This same process and level of care and specificity could be required for systems that are to be developed through design/build procurement systems. PA system integration design should never be made on generalized assumptions of room acoustics.

<u>ESCALATORS AND MOVING WALKWAYS</u>. Escalators and moving walkways are critical elements for wayfinding in large airport terminals, but they can be difficult for the BVI traveler to locate and use. In both cases, the challenge is finding the start and safely distinguishing an entrance from an exit. This is especially challenging with improved technology, which is typically quieter. Once found, the process of confirming the direction of travel for an escalator or moving walkway can be very risky especially when luggage is in tow.

There is a precedent in Japan for audible beacons at the entry ports of escalators and moving walkways to assist the BVI traveler, but there is currently no precedent for such in the U.S. The development of new, mobile, wayfinding technologies has the potential to improve upon this challenge. Additional research could study and determine the efficacy of the new technologies in such situations. If the results are not favorable, consideration could be given to conducting research and development of additional technology components that could trigger suitable audible alerts on demand to assist the BVI traveler to more effectively and safely approach the entry port of the escalator.

There is precedence in the U.S., however, for audible announcements in moving walkways when approaching termination; but there is tremendous variation and inconsistency of how these warnings are implemented, even within the same concourse. The researchers' review of this feature in airports revealed numerous installations that were confusing, misleading, and unhelpful. For best results, the following recommendations are suggested.

- Make announcements from speakers built into the moving walkway system at the terminus.

- Point and focus speakers toward the approaching pedestrian.

- Do not locate speakers in ceilings and especially not in remote locations. It is critical that the announcement be localized at the termination of the moving walkway.

- Whenever possible, incorporate motion sensors to detect approaching pedestrians to activate announcements so the announcement triggers only when there is an approaching pedestrian.

- Provide ambient noise sensors to adjust the volume of the announcements to compensate automatically for environmental noise levels.

While the researchers recommend well-designed audible warnings at the ends of moving walkways, they do not advocate the use of audible alerts at the end of escalators. There are multiple cues that do an excellent job of alerting the BVI traveler of the presence of the pending termination, such as (1) the treads level out, which can be easily perceived by placing one foot and/or the cane on the next tread (up or down) and (2) the handrails curve to level out on approach to the landing. So all it takes is one hand gripping or abutting the rubber grip to anticipate the termination. Even service animal users can sense the leveling out, as the dog shifts around when the treads level out beneath their paws.

<u>VISUAL DESIGN</u>. A building's visual accessibility affects the mobility of low-vision users of the space. Visual accessibility can be defined as the use of vision to travel efficiently and safely through an environment, to perceive the spatial layout of key features in the environment, and to keep track of one's location in the environment [7]. Design can improve visual accessibility in two main ways: by enhancing the visibility of key features including obstacles and hazards, and by providing visual cues for effective wayfinding through the space.

Key general issues relevant to accessible design for low vision include the following.

<u>Luminance Contrast</u>. The light-dark difference between objects and their backgrounds, or between distinct surface regions, should be high. A chair with dark upholstery on a dark carpet is hard to see. Carpeting that continues from a flat surface down steps or a ramp makes the steps or ramp hard to see. Differences in chromaticity (e.g., green versus red) can sometimes be helpful for people with low vision, but are not as reliable as differences in luminance contrast (e.g., light-dark contrast). This is because some people with low vision have deficiencies of color vision.

In addition to the recommendation for visual contrast between flooring for travel paths and other areas mentioned above, the researchers recommend designs with good visual contrast between horizontal surfaces (flooring) and vertical surfaces (baseboard or wall). Such contrast cues facilitate judgments of the size and shape of the space, help to mark the boundaries of the space, and help to highlight cues for the presence of ramps and stairs within the space.

It is important to use high-visibility contrasting strips at top and bottom treads of stair runs and ramps in accordance with Americans with Disabilities Act (ADA) design standards and other governing (state and local) codes. It is recommended that stair treads and risers have contrasting color. If the treads and risers have the same color, high-visibility contrast strips could be used at each stair tread nosing.

Glass partitions or doors are particularly hazardous for people with low vision. If the glass is necessary, consider including high-contrast visual features to signal their presence.

Overall Light Levels and Transitions in Lighting. Proper lighting is important for the general population. Transitions in overall lighting from a bright area to a dimly lit area, or vice versa, can be particularly challenging for people with low vision for two reasons: (1) aging and/or the eye condition may extend the time for adaptation to the changed light level; and (2) for low-vision pedestrians with reduced contrast sensitivity, the change in lighting may make some lower-contrast features fall below the threshold for visibility.

Glare. There are two types of glare: (1) veiling glare, a reduction of target contrast due to the superposition of light from a bright external source and (2) disability glare, a reduction of acuity or contrast sensitivity due to physiological processes within the visual system. Both types of glare can cause challenges for people with low vision. Bright sources of directional lighting, such as sunny windows, are particularly challenging. If key features of a space, such as a step or other obstacle, must be located in a region with glare, special care needs be taken to visually highlight the feature. Properly arranged lighting is required so travelers need not face directly into it along common travel paths. Seating could include options not facing windows. Also, recall that lighting characteristics of a space with outdoor lighting exposure can vary dramatically based on time of day, year, and weather.

If direct lighting is used to highlight obstacles or other features, care could be taken to occlude the light source from direct viewing by pedestrians on travel paths.

The National Institute of Building Sciences (NIBS) [8] issued a report on guidelines for enhancing architectural design for people with low vision. This report has many detailed recommendations to guide designers of public spaces. For example, the report recommends sizes and colors of bollards and barriers in pedestrian pathways to contrast with backgrounds. The report also contains many detailed recommendations concerning windows, glazing, and methods for controlling glare.

INFORMATION DISPLAYS AND SIGNAGE. Flight status monitors are often difficult or inaccessible for people with low vision, and certainly inaccessible to people who are blind. The most obvious solution is to deliver the relevant information in more customizable form (visual or auditory) on a traveler's mobile device.

When intended to be accessible for BVI travelers, it is recommended to place information displays or signage within "kissable" access; that is, place them approachable for close-up viewing at no more than average head height. The displays and signage could also be located away from glare sources.

It is suggested to ensure that all signs required by code (including in restrooms) have a background field color that contrasts with the wall. This will ensure that the signage will be noticed by people with low vision. For example, if a wall is light in color, a sign with a dark background and white lettering would be desirable. For the same reason, it is also recommended to avoid locating required signage on glass walls or sidelights.

TOPIC 3—SIGNAGE AND MAPS.

BACKGROUND. Airport terminals provide special challenges to BVI travelers for a variety of reasons. Terminals are typically large buildings with multiple functional areas that require the traveler to navigate along loosely defined, generally unfamiliar routes. The presence of large open spaces, vertical separation of levels, crowded areas, and ambient noise, together with the normal stress and time constraints of getting to a gate or making a connection, add further challenges for BVI travelers. Wayfinding supports, such as signage, tactile cues, and a variety of maps can play a critical role in minimizing wayfinding errors, frustrations, delays, and the need for individual assistance. These aids, if accessible to BVI travelers, can also greatly increase independence, a sense of safety, confidence, and wellbeing.

The most inclusive and broadly applicable approach is to combine architectural features, such as differentiated floor finishing, with accessible signage and maps to provide wayfinding support at all key areas of the airport. One solution is to provide designated paths, such as tactile guide strips on the floor or specialized information points, for BVI travelers. However, this approach, which has been adopted internationally in limited cases, has not been fully assessed, embraced, or required within the U.S., and it is not recommended at this time. The preferred solution is to adopt universal design principles, where the same primary paths and information sources are designed to simultaneously support the needs of a broad range of end users. A good example of universal design is the use of signs with large, high-contrast fonts. This design not only allows easier access by BVI travelers, it also benefits many older adults with mild vision deficits and fully sighted travelers in finding and reading the signs at a greater distance.

CRITICAL SIGNAGE CONSIDERATIONS. Airport terminals are divided into functional zones that define the overall sequence of activities for a departing or arriving passenger. Wayfinding assistance can be similarly elaborated based on using a hierarchical system of signage design. Primary signs are the largest, and they direct travelers to the primary functional zones within a terminal (e.g., ticketing/check-in, baggage claim, gates, and concessions). Secondary signs direct travelers to more specific functions within the primary functional zones (e.g., specific gate numbers, baggage claim carousel numbers, airline names, or specific ground transportation). Tertiary signs identify support spaces or services within the terminal (e.g., restrooms, information desks, and service animal relief areas). By dividing the terminal into functional zones, desired travel routes can be defined as a series of linked waypoints, and wayfinding can be provided to assist with the journey using consistent and standardized signage. For this to work, however, the signs must be accessible to BVI travelers, which is often not the case. People with no (or very limited) usable vision will not be able to use traditional signs and will need some electronic form of a sign or point of interest (POI) in an electronic map or app (discussed more in the Nonvisual Access to Signage section). BVI travelers with usable vision may be able to use signs, but there are some important factors that should be considered. For instance, signs must be highly visible and placed in consistent locations in the terminal where travelers know to look. They must be well-lit, be in nonglare locations (a challenge for many concourses), and incorporate large, high-contrast information content.

The 2015 design guidelines from the Low Vision Design Committee of the NIBS provide detailed recommendations on signage for wayfinding. Briefly, the committee recommends: (1) placing wayfinding signs such that they are able to be read from at least 2 m away perpendicular to the direction of travel; (2) using nonglare, high-contrast, white-on-black text; and (3) using a font size of at least 22 mm high and not less than 1% of the distance at which the sign is to be read. The committee also recommends minimizing any reliance on color, as BVI people often have deficient color vision, and suggests avoiding multiple colors or flashing messages [8].

<u>NONVISUAL ACCESS TO SIGNAGE</u>. There have been several efforts to make signage accessible to BVI travelers through senses other than vision (see reference 9 for a review). Talking Signs®, for example, actively transmit speech signals via an infrared (IR) signal to receivers carried by BVI travelers. Computer vision software has been developed to extract and read signs in the environment. Signage may also be tagged by computer reader patterns to aid machine detection and identification. Unfortunately, none of these approaches has gained broad application.

A technology that has proven extremely helpful for both sighted and BVI travelers is the growing use of audible information indicators, such as elevators that speak the floor number, and audible warnings, such as those indicating the beginning or end of moving walkways. This information is an excellent example of universal design, as it not only helps BVI people but also anybody who may be distracted by their cell phone or by maneuvering their luggage. In addition, this type of auditory warning acts as an excellent nonvisual orientation cue for BVI travelers, as it allows for easy detection and pinpointing of where the beginning of a moving walkway or escalator is located—information that is otherwise often hard to perceive without vision. When possible, airports are encouraged to adopt more of these auditory cues. Self-voicing messages can also be used as auditory landmarks, helping to guide BVI travelers to a key decision point or specific location, such as a gate, bathroom, etc. In this way, the auditory information serves as an environmental beacon that can help orient the user to the desired location. This information could be based on a timer, an environmental sensor, or even linked to a navigation app and triggered by the traveler such that the connected device only sounds when it is in range.

Another approach that is gaining in popularity in large buildings and airports is the use of digital beacons, such as the iBeacon™. Instead of hearing the auditory information coming from the environment, these devices work using Bluetooth® low-energy proximity sensing to provide text-to-speech location information to the user's cell phone. Using a network of iBeacons can provide an indoor positioning system, similar in function to use of global positioning systems (GPS).

There are other nonvisual signage and mapping technologies, including a myriad of digital beacon and sensor-based solutions, narrative and tactile maps, navigation apps such as BlindSquare [10] and other multimodal navigation interfaces that are in various stages of development. While there is currently no one unified solution for providing accessible wayfinding support through airports, there are many viable possibilities, and the ultimate solution will likely piggyback several different technologies. Projects involving small-to-midscale testing of different technologies in several airports would be instrumental in developing a unified system.

CRITICAL MAP INFORMATION. Because of the diverse nature of the BVI population, there is no one wayfinding support that serves all people. However, maps are excellent aids for a person to know where they are in the terminal, where they want to go, or for them to get an idea of the global layout of the airport or concourse. Along with indicating current location and global spatial cues, maps could also provide information about elevators, escalators, assistance desks, and other POIs. Large-print, high-contrast visual maps posted in the airport at expected locations (e.g., next to an information desk or at a major intersection) will likely best serve travelers who are elderly or have low vision, as these maps are most easily localized and legible in a cluttered visual environment. Providing audio messages or narrative information, triggered by user interaction, could also be helpful as a redundant channel. BVI travelers require audio, narrative, or tactile supports, and maps downloadable to a personal device. In general, using multimodal interfaces will support the most people and often have unintended benefits. For example, an auditory beacon indicating the end of a moving walkway is an important cue for warning BVI people and also benefits people who are texting while walking or otherwise not paying attention. Likewise, augmenting a visual map with verbal narrative descriptions of the space or route not only benefits BVI travelers but also is useful to many sighted people who prefer hearing directions rather than reading a map.

DIGITAL MAP INTERFACES. In addition to a fixed map posted in an airport, maps downloadable to a personal device (e.g., a smartphone) that integrate a database of wayfinding information could allow real-time wayfinding support. These maps could also be linked to a network of iBeacons or other positioning devices and connect to an accessible app using a multimodal interface. Such a system would likely have the most impact and support the greatest number of people. These systems allow step-by-step route directions that can be selected by travelers according to their individual needs and preferences. The systems also allow prejourney route planning and exploration, i.e., allowing the user to learn the layout by a virtual walk through the space in advance of physically being there. This prejourney virtual tour has the benefit of allowing the BVI traveler to explore and learn the airport off-line in a safe and low-stress manner. A virtual tour also facilitates the development of a cognitive map that can aid navigation once the traveler arrives at the airport. Essential to BVI travelers would be the ability to select customized routes that include orienting information such as changes in slope and texture, acoustic cues, highly visible landmarks, and directions to the closest service animal relief area from each gate.

COMMERCIAL INDOOR MAPPING EFFORTS. Commercial potential has motivated various efforts on gathering and/or mapping indoor commercial and public spaces. Most major commercial and open-source map services now include some coverage of indoor spaces. Examples of these companies and their services are Google (indoor Google Maps), Microsoft (Bing Venue Maps), HERE (WeGo venue maps), Apple (Maps, Indoor Survey app), and OpenStreetMap Foundation (OpenStreetMap). Some of these services, notably Google Maps and OpenStreetMap, also allow users to add to their map databases by importing floor plans in the form of images or manual tagging. Devices for mapping indoor spaces for the purpose of generating indoor maps and virtual reality spatial rendering have become available (e.g., the

Trimble Indoor Mobile Mapping Solution by Trimble Inc.). The researchers recommend taking advantage of, or otherwise adding to, these commercial mapping efforts in airports. The resulting databases can then be made available to third-party app developers, including those developing apps for BVI travelers.

TOPIC 4—LANGUAGE-RELATED CONCERNS.

BACKGROUND. Spatial language refers to the use of clear and unambiguous verbal descriptions that support route guidance and wayfinding. It can also be used to describe key environmental attributes, such as the distance or direction of landmarks with respect to the listener, to describe the arrangement of objects, such as chairs or benches for seating, or to describe the configuration of a layout, such as the global shape of an airport terminal. Spatial language is a useful technique for conveying information to BVI travelers in unfamiliar environments because it is natural and intuitive to most people. Another advantage of this mode of information transfer is that verbal descriptions can be provided in real time from a human assistant or a mobile wayfinding app, or as a fixed message from an auditory beacon or narrative map, e.g., a verbal description of a space that includes both route and configurational information. Language-based information is generally inexpensive to author and implement in existing technologies and importantly, it does not require the user to learn a new interface to be effective, as is the case with many other information access solutions.

Another key benefit of verbal descriptions is that they can be provided in many languages, meaning that the same system can support the diversity of people that pass through the airport. To the extent that stereotypical instructions involving a small, well-defined set of terms can be developed, it is possible to create multilingual representations e.g., English, Spanish, and Chinese. If using a wayfinding app, the descriptions could be user selectable and generated using the embedded text-to-speech engine and language libraries of the smartphone device.

IMPORTANT LANGUAGE CONSIDERATIONS. Spatial language has its limitations. Most importantly, unless the description is carefully structured, the terminology can be vague and unclear. For instance, when trying to find a gate, one blind traveler was told that "it is over there." When this ambiguous description was met with confusion, the traveler was invited to "sit on those yellow chairs and the cart will pick you up." This example illustrates how language itself is not sufficient to convey meaningful information. The description must reference landmarks or other features that are unambiguously known by the BVI traveler, or specify actions or directions that are also unambiguous. Using such language can pose a challenge for airport personnel and information content producers who are likely unfamiliar with best practices for conveying effective spatial descriptions.

Although there are no specific standards for producing spatial language descriptions, research from the wayfinding literature and techniques from the orientation and mobility (O&M) field provide some simple guidelines that can be used when conveying nonvisual information using spatial language. The first rule of thumb is to use consistent terminology and to provide descriptions in a structured manner. For instance, it is helpful to give spatial instructions in terms of first providing the direction to face and then the distance to walk. For example, the phrase "turn left and walk 20 feet" allows the traveler to first know where they should orient and then the distance they will travel. Providing geometric descriptions at intersections instead of just giving the route directions is preferable. For instance, when giving route information, telling the BVI traveler that they are "at a four-way junction and should turn left" is preferable than simply instructing them to "turn left," as the latter does not provide any useful information about the spatial structure of the environment. The advantage of providing even basic geometric information in a verbal description is that it helps promote an understanding of the global configuration of the space in memory, which is called a cognitive map. The ability to build up an accurate cognitive map is particularly important for BVI travelers in large, complex, and noisy environments such as airports where nonvisual sensing is sometimes inaccurate. Thus, the ability for a BVI traveler to match auditory or tactile cues in the environment with their cognitive map is an important characteristic of effective nonvisual wayfinding behavior [11].

The frame of reference used in verbal descriptions is also important. O&M training emphasizes the importance of using both absolute (allocentric) and relative (egocentric) terminology. Absolute terminology, such as north, south, east, or west, is useful as it can provide orientation or describe a specific location independent of the user's current position. For example, if a BVI traveler was trying to get to a nearby cafe, an instruction telling them that it is "at the northeast corner of the food court" provides an unambiguous, fixed spatial reference. Importantly, this description conveys the destination using language that is independent of their immediate location, meaning that they could use the same information in a meaningful way to get to the coffee kiosk from anywhere in the food court. By contrast, while egocentric terminology is often more intuitive, such as "the coffee kiosk is ahead and to the left," this description is only relevant if both the user's current position and orientation are known. The best approach is to provide both absolute and egocentric terminology in the same description, which allows the traveler to integrate their current position and orientation into a global frame of reference. An example of this approach is: "you are facing north at a four-way intersection. Terminal A extends ahead and behind you, and Terminal B extends to your left and right." This type of verbal description logic has been shown to be extremely effective for nonvisual learning and wayfinding in large buildings [12].

Spatial language is not just about giving route directions. It is also extremely effective for describing the layout of features in the immediate environment. Several guidelines are essential to consider when using this medium to describe the direction of objects or landmarks around the BVI traveler. In these scenarios, O&M professionals often use clock face directions to describe the surrounding environment, e.g., "the TSA checkpoint is at 10 o'clock in 50 feet." Descriptions that are spatially contiguous are more easily comprehended and lead to a better mental representation than those that describe discrete spatial regions of the surrounding environment. The most effective way to verbally depict a scene is to describe the landmarks surrounding the user in a circular fashion versus describing the left side from near to far, then the right side from near to far [13]. For instance, if a BVI traveler was entering a gate area, it is preferred to say "a seating area is from 8 to 10 o'clock, a laptop charging station is at 11 o'clock, the check-in desk is at 12 o'clock, gate 34 is at 1 o'clock, and another seating area is at 3 o'clock," than to say "a seating area is from 8 to 10 o'clock, a laptop charging station is at 11 o'clock, another seating area is at 3 o'clock, gate 34 is at 1 o'clock, and the check-in desk is at 12 o'clock." This guideline has relevance for how narrative maps and other spatial description systems should be developed.

Finally, although language is a symbolic medium of information exchange, it does not directly specify spatial cues, which must be cognitively interpreted to be meaningful. For instance, being told that "the escalator is to your right in 3 meters," is only meaningful if you distinguish left from right and have a good understanding of metric units. By contrast, perceiving the direction and distance of the escalator via visual, auditory, or tactile sensing is done effortlessly without conscious thought. Unlike language, these perceptual modalities directly access spatial information. The result of cognitive interpretation is that processing spatial language descriptions requires more time and additional cognitive load than the same spatial information conveyed perceptually [14]. This distinction is particularly relevant for the development of nonvisual wayfinding supports in high-stress, attention-demanding, and spatially confusing environments such as airports. In such environments, it is preferable to augment purely language-based displays with those that convey spatial information from perceptual modalities, such as spatialized audio or tactile maps. In summary, providing BVI travelers with perceptual information about their environment is beneficial as it increases the bandwidth of nonvisual flow of spatial information that can be specified compared to language-only interfaces.

SUGGESTIONS FOR USING SPATIAL LANGUAGE. As described in the previous sections, there are many benefits for using language to support wayfinding in an airport setting, either in isolation or as part of a larger wayfinding system. Although there is some guidance from the literature and current O&M practices, the lack of clear standards for language-based interfaces and for the development of assistive technology can be a deterrent for facilities wanting to make their property accessible. A useful approach before commencing the development or implementation of a new BVI wayfinding system is to leverage as much knowledge as possible from existing technology. Coupling new technology to existing applications is also generally beneficial to the BVI traveler. For instance, it can be burdensome for BVI travelers to learn multiple interfaces with different styles of information content and delivery across multiple accessibility platforms. The more a new system can adopt existing approaches to information access, the more readily it will be accepted and used effectively. With respect to spatial language interfaces, there are some established commercial solutions for outdoor navigation that could be referenced when developing extensions to indoor spaces. For example, the Sendero Group's line of GPS products [15] has over 15 years of experience providing accessible, speech-based route guidance and POI descriptions to BVI travelers. Likewise, the BlindSquare app [10], based on the robust Foursquare® and OpenStreetMap engines, is a popular accessible outdoor navigation system for mobile platforms. These systems provide a robust description logic that, if extended indoors, would be familiar to many BVI users. This familiarity reduces the learning curve and improves user efficiency when interacting with the device. If airport personnel or app developers follow the informal guidelines described earlier in this section and leverage core terminology from existing commercial devices, the likelihood of a new indoor wayfinding system to succeed and have significant functional utility will be greatly improved.

COMBINING AUDIO AND TACTILE CUES FOR DISPLAYING SPATIAL INFORMATION. This section briefly discusses the merits of multimodal interfaces and how other modalities can be an excellent complement to spatial language. More information on hardware implementation is discussed in the Topic 5–Assistive Technology section. Although spatial language when used alone can be confusing to clearly and unambiguously describe complex routes or environments (e.g., airport layouts), there are often significant benefits in combining nonvisual modalities to convey this information. One promising approach is to combine language and audio output with touch and vibrotactile cues on an interactive map that can be deployed to the BVI traveler's smartphone. The key advantage of this approach is that the BVI traveler can use both real-time spatial language descriptions to provide relevant semantic information about their surroundings and real-time haptic information to obtain spatial information about nearby landmarks or the airport layout. Such a system requires a mechanism to provide real-time positioning, but its advantage is that it can be implemented on devices that many BVI users already own. The system uses either the Apple® iPhone® Operating System (iOS) or the Google Android™ platform that employs many universal design parameters in the native interface, thereby reducing development costs of the wayfinding app.

Spatialized audio interface is another approach that has proven effective for supporting BVI wayfinding. With this technology, the users hear the distance and direction of objects around them in three-dimensional space. For instance, rather than being told that "the ticket counter is at 1 o'clock in 10 feet," the user would simply hear the words "ticket counter" coming from that location in space. Spatialized audio, like vision, is based on the relation of head orientation during movement, so as the users turn their head, the location of where they hear the message updates correspondingly. Spatialized audio has been implemented in various systems, such as the Personal Guidance System developed by Loomis and colleagues, and it has proven extremely effective for supporting BVI navigation and spatial learning [16]. A significant challenge for spatialized audio-based systems is that they require tracking of the head, which necessitates expensive external hardware to be worn by the user. In addition, these interfaces rely on binaural/stereo audio, meaning that the user must wear headphones and possess good binaural hearing. This may cause challenges due to masking of ambient sounds in the environment that BVI travelers rely on for orientation. The magnified sound level of busy airports may also complicate hearing and interpretation of the spatialized audio information. One solution to the masking issue is for the user to wear bone-conducting headphones, as these do not mask other environmental sounds. These headphones may also be useful in noisy environments, as the signal uses vibration through the facial bones to transmit information. This means that this delivery system may be more perceptible in loud environments than ear buds or circumaural headphones.

In summary, there are several approaches to combining audio or vibrotactile information with verbal descriptions (e.g., synthetic speech or braille) for conveying direction and distance information or for depicting spatial arrangement and layout. It is likely that development of any robust, nonvisual wayfinding system to be used in airports would employ several of these technologies. This is a domain that is worthy of future research.

<u>TRAINING OF PERSONNEL</u>. One of the biggest recurring challenges for training airport, airline, and travelers' assistance personnel is in the proper way of guiding BVI travelers. Success in this domain starts with fostering an increased understanding of the range of vision conditions and an awareness of different attitudes toward assistance. One articulate BVI traveler commented on recurring experiences with untrained airport personnel, "I often felt like a second-class citizen." This is a difficult issue to address, given the turnover of personnel. The challenge is an argument for development of assistive technology with good interface design which, to some extent, can supplant untrained human escorts. In this spirit, spatial language is a good

foundation from which to build a wayfinding assistance system as it can be conveyed live by airline or airport personnel, via output from smartphone apps, via recorded audio, or from braille or large print.

Another simple yet effective training technique for people producing verbal descriptions and spatial language interfaces is the mental navigation test. This is an informal evaluation technique that allows designers, employees, or anybody creating nonvisual content to benchmark verbal instructions, language-based interfaces, or verbal protocols that will be delivered to BVI travelers. With this test, the designers close their eyes and imagine that they are following the verbal information provided. Self-reflective questions are informative for the designer to evaluate the efficacy of the content they created. For instance: Does the terminology make sense? Could I reach the goal or perform the task based solely on the information content provided? What confusion or mistakes might occur based on this information? How could the verbal descriptions, instructions, or nonvisual cues be modified to be more useful or understandable? Considering such questions allows the content designer to put themselves in the head of the potential BVI user, providing a sense of first-hand awareness that is difficult to achieve as an objective third-party developer. Employing this informal technique of reflective insight, coupled with adherence to the above guidelines, could simplify the process of verbal content creation by airport, airline, and travelers' assistance personnel while also providing BVI travelers with intuitive, meaningful, and usable wayfinding support.

While the researchers have highlighted some informal techniques to improve awareness and training, there is a need for more research on the development of instructional training modules aimed at eliminating the challenges described in this section. A promising approach in advancing this effort is likely to employ an interactive system that allows people to use a dictionary of core spatial terminology and instructions that can be applied to many common travel scenarios, user needs, and information requests. Once established, such a system could provide a standardized training protocol that could be delivered to all personnel and applied to any new technology-design projects in an efficient and consistent manner. The result could yield cost savings in the number of man hours required for meet-and-assist requests, reduce the resources spent on training, and minimize the number of complaints received by frustrated BVI travelers owing to well-meaning but uninformed airport, airline, and travelers' assistance staff.

TOPIC 5—ASSISTIVE TECHNOLOGY.

BACKGROUND. Modern technology presents opportunities for the development of assistive devices to help BVI travelers in airports. As with assistive technology in general, the development of cost-effective devices often means piggybacking on mainstream technologies. It is necessary for the look and feel of assistive technology across airports to be uniform so that solutions and user experiences will be clear and uncomplicated. Sophistication in the use of technology varies widely across the BVI population. A solution that may work for some advanced users may not be effective for many other BVI travelers.

In this section, the researchers discuss the novel use of technology including app-based wayfinding, accessible formats for map data, and the use of auditory beacons.

APP-BASED WAYFINDING. There is active development of navigation apps on mobile devices (iOS and Android) specially designed for BVI users. There is potential for adaptation of these apps, or development of new apps, for airport wayfinding.

Key elements of wayfinding apps for BVI users include the following:

- Location sensing of the pedestrian and determination of heading. It is important that accuracy and reliability be sufficient to locate airport gates, bathrooms, restaurants, baggage carousels, ticketing kiosks, and exits to ground transportation. A quantitative criterion for location accuracy might be precision to within the length of a long cane, roughly 6 feet (2 meters).

- Heading refers to the facing direction of the user. Detection of heading is essential in order to give egocentric directions relative to the user, such as "ahead 20 feet" or "30 degrees ahead and to the right."

SPECIFICATION OF NEARBY POIs (INCLUDING DIRECTION AND DISTANCE). BVI travelers need basic information such as the number of the gate they are passing, locations of nearby restaurants, location of nearby elevators, etc. The availability of this kind of information requires access to a database of functionally salient locations within the airport. Such geographic information system (GIS) databases are being developed for commercial use in airports. For examples of products, see Société Internationale de Télécommunications Aéronautiques (SITA) [17] and Environmental Systems Research Institute (ESRI) [18].

Routing Instructions to Remote Destinations. A necessary attribute of a wayfinding app is to guide the user from the current location to a destination. Similar to many car navigation apps, this guidance is typically performed by navigating the user from one waypoint to the next. An app needs to be flexible enough to recognize if the user deviates from the prescribed route and to generate corrective instructions if necessary.

User Interface. Wayfinding apps for BVI travelers need to convey spatial information to the user in an accessible format. Potential formats could include computer speech or other acoustic coding; braille output or other tactile coding; high-contrast, large-print graphics for people with low vision; or some combination of these. The interface needs to be ergonomically simple, quick to use, and robust in the context of crowds and noise. Often, the interface will use spatial language.

Several smartphone apps have been developed and successfully used for GPS-based wayfinding outdoors by BVI people. These apps include Ariadne GPS [19], Seeing Eye GPS™ [20], and BlindSquare [10]. When indoors and away from windows, GPS signals are not reliable, nor do they provide adequate spatial resolution for finding key locations such as bathrooms, baggage carousels, or departure gates.

While the challenge of developing fully functional, nonvisual, indoor wayfinding technology remains to be solved [21 and 22], the researchers believe there is evidence that current technology can be used for BVI wayfinding in airports. A prototype indoor navigation aid for BVI travelers was implemented in Terminal 2 at San Francisco International Airport (SFO). The prototype used approximately 300 Bluetooth iBeacons whose signals could be used by an iPhone app to locate the pedestrian with an accuracy of about 5 meters [23]. This demonstration project was initiated by the San Francisco mayor's Startup- in Residence program, and involved collaboration between SFO, the LightHouse for the Blind and Visually Impaired in San Francisco, and the company indoo.rs®, Inc.

The authors of this technical note observed a demonstration of this system during a visit to SFO Terminal 2 on September 25, 2015. The BVI user who demonstrated the system interacted with it using an iPhone app accessible via VoiceOver, the iOS built-in synthetic speech software. The BVI user was able to query the phone for POIs including stores, restaurants, and gates, and follow wayfinding instructions to reach a destination. The app also provided the BVI user with arrival and departure information for Terminal 2 flights. One issue with speech-based wayfinding apps can be environmental noise, which makes the synthetic speech difficult to hear. BVI users will often resort to the use of an earphone, but this was not a practical solution for our group demonstration.

Based on this demonstration and discussions with SFO airport staff and a representative from the LightHouse, the researchers believe that the feasibility of a useful app-based wayfinding system for BVI travelers has been demonstrated. To extend this demonstration beyond one terminal at one airport, the researchers suggest encouraging conditions that enable BVI-oriented apps developers to access location-sensing hardware and GIS databases in all airports where these technologies exist. (The number of such airports is expected to rise rapidly.) The researchers conceive of conditions in which

- one or more software companies develop algorithms for location sensing based on Bluetooth beacons or other technology. A notable effort is the development of an open standard for audio-based navigation by the London-based company, Wayfindr [24].

- the airport personnel maintains and either leases or sells a database of functionally significant POIs and their locations in the airport.

- a third party develops an app, which can use this airport database and the navigation/location algorithms to provide helpful wayfinding information to BVI travelers.

A GIS system in which BVI-oriented wayfinding app developers can extend their applications to navigation within airports is preferable. The researchers recommend standards requiring that airport GIS databases include relevant information for BVI travelers, such as locations of service animal relief stations, and that the databases and navigation/location software output be in a generic format that is amenable for use in BVI apps. The researchers suggest a format that is general enough to capture data from a wide range of airports and present the data in an accessible format on a smartphone. An additional goal would be the seamless integration of navigation based on GPS for outdoors and iBeacons, ultra-wideband signals, video mapping, or other technologies for indoors. Such systems could benefit from user input of shared POIs.

ACCESSIBLE MAP INFORMATION. Map information can be presented as auditory verbal messages. An example is the use of Talking Signs® Remote Infrared Audible Signage (http://www.geog.ucsb.edu/~marstonj/DIS/CH2_4.html) to provide information about the immediate environment. The Talking Signs continuously transmit messages encoded as IR signals, which are picked up and decoded by the pedestrian's handheld receiver and converted to audio speech [25]. The fixed messages generated by Talking Signs are not designed to provide wayfinding information between arbitrary locations in a complex space.

A more recent development is the ClickAndGo Wayfinding system of narrative maps [26]. The advantage of the ClickandGo narrative mapping service is that the maps (comprised of verbal descriptions and high-contrast print and symbols) are designed by O&M professionals and customized to each facility. Because they are designed explicitly for BVI users, each map contains wayfinding information that would not be present on traditional maps, e.g., descriptions of changes in floor texture, salient sounds, or other nonvisual landmarks, as well as detailed verbal descriptions of key routes and layout geometry. When combined with a beacon system, the maps also allow for real-time positioning. ClickandGo is a commercial service with a proven track record, including contracts to provide narrative maps in transportation venues such as the Washington Metropolitan Area Transit Authority and the New York City Department of Transportation. Use of such a system in airports would be a natural extension to other transportation hubs and would support the goal of having a consistent and seamless interface available to BVI travelers.

With the increasing importance of graphical communication in our society, some research has focused on development of new tactile, vibrotactile, and haptic methods for conveying graphical information including in maps. For a review of the pros and cons of some of these approaches, see O'Modhrain et al. [27].

There are several relatively straightforward technologies for preparing tactile maps, including the use of braille embossers. One limitation of tactile maps is that the density of graphical information is typically low compared with corresponding visual maps. This means that a tactile map of a large and complex space, such as an airport, would either be very large or contain only a small subset of the information in a printed map of the same physical size. In principle, however, tactile maps of selected portions of an airport (e.g., from a specific gate to baggage claim) could be made available to BVI passengers prior to travel either in hard copy or as downloads to a braille embosser. Research is needed to determine the practical value and limitations of hardcopy tactile maps for airport wayfinding.

Vibro-audio maps, discussed earlier, represent another promising wayfinding solution for use in airports. Key advantages of this interface are that the maps are based on commercially available smartphones that many BVI people already own; incorporate multimodal information including haptics, audio, and gestures; and can use existing data sources to provide BVI travelers with either real-time information (assuming a positioning system such as iBeacons, or can be used in an offline prejourney mode).

AUDITORY BEACONS. The BVI traveler often relies on the sense of sound to locate targeted elements within an indoor environment. For instance, to exit a restaurant or store, it is common to listen for the sound of traffic to determine the location of an exit. To find a bathroom while walking through a terminal concourse, one may hear the sound of hand dryers or flushing plumbing fixtures to localize the door to the bathroom, and check the accessible sign for gender before entering. Other elements, however, can be difficult to locate. In familiar places, it is possible to learn and remember the relative positioning of key elements in the space, that is, to create a cognitive map of the space. But memorization is not feasible for unfamiliar environments such as rarely visited airport terminals.

Although few common examples of auditory beacons exist in the U.S., an exception is the Audible Pedestrian Signal that has a slow, ticking sound or periodic beep that comes from the push-pad adjacent to a crosswalk. The signal pitch and interval changes when it is time to cross. The real significance is that it always ticks so that a BVI pedestrian can locate the start of the crosswalk. There are few, if any, other audible beacons used on a national or consistent basis in the U.S. other than ADA requirements for audible signals announcing the arrival of an elevator cab or a signal as the elevator cab passes a floor level. In Japan, however, auditory beacons are commonly present to help BVI pedestrians locate turnstiles in transit facilities and escalators in public spaces. These devices are becoming more common in Israel, Europe, and Australia. The resistance to audible beacons in the U.S. is due to the perceived noise pollution they produce.

Development of on-demand audible beacons, however, has the potential of solving the noise pollution concern while providing wayfinding benefits for BVI pedestrians. In these systems, audible beacons are activated only when they are needed. The systems rely on a personal mobile device (e.g., a smartphone) to send a low-energy signal out to a receiver that activates the audible signal. The receiver generates a recognizable sound or audible message to indicate its identity and location. Examples of this type of auditory beacon are the products developed and sold by the French company, EO Guidage [28].

On-demand audible beacons of this kind could be particularly useful in airport terminals to find locations such as the entry port of an escalator or the podium at the nearby departure gate. In both cases, the BVI traveler needs to be in the general area but then must successfully navigate the final 6 to 8 feet. This homing process can be treacherous when luggage is in tow when mistakenly attempting to enter the exit portal of an escalator or moving walkway. Finding the podium at a gate is less physically treacherous but can be more socially awkward when trying to find a broad opening in the seating area, i.e., clear of legs, feet, and bags, to find the podium.

New emerging indoor wayfinding mobile apps may address these and other related concerns. As technology of this kind emerges, BVI user groups could evaluate their efficacy in airport terminals. If the technology is deficient in this context, the researchers recommend research and development of related add-on technologies that could enable audible beacons on demand for select critical locations and features in airports. A critical challenge that will need to be resolved is the creation of automatic volume level control to contend with ambient noise fluctuations.

<u>TOPIC 6—EVALUATION METHODS FOR TERMINAL ACCESSIBILITY</u>.

<u>EXISTING METHODS AND CHALLENGE</u>. Having a reliable and repeatable method for assessing terminal accessibility is essential for identifying challenging areas, tracking improvements, and prioritizing resource allocation.

Existing methods (e.g., FAA Airport Disability Compliance Program) often focus on compliance review and complaint resolution. While adherence to established standards is a key element for maintaining effective accessibility, compliance-based assessments are of limited use for evaluating new approaches, standards, or technologies. Furthermore, in-depth studies of terminal accessibility have often been descriptive and policy-oriented [29], making comparisons between studies difficult if not impossible.

Terminal wayfinding [30 and 31] and airport level of service assessment [32-34] are well-established areas of research fields. The core methodologies developed in these fields are applicable to the assessment of airport accessibility by BVI or other disabled travelers. However, the researchers are unaware of any such applications.

<u>DATA ON BVI TRAVELERS</u>. Ideally, a comprehensive assessment of terminal accessibility would start with existing data on BVI passengers. These include demographic data of air travelers as well as incident reports and complaints as collected by the airlines and airport operators. The latter are not generally available to researchers. Lack of data collection standards and reporting requirements contribute to the lack of data.

A major U.S. international airport provided the researchers with records documenting accessibility-related complaints from travelers. Most of these complaints involved cart service and parking but not accessibility issues within the terminal (although there were a few reported issues related to service animal relief areas). This airport also has a Travelers Assistance program, which is distinct from the national organization called Travelers Aid® International, Inc. Their mandate includes many types of assistance in addition to helping people with disabilities. However, the organization does not keep data on the number of people with disabilities they served.

Mandating data reporting can be costly to the operators and may not be a viable policy. On the other hand, an established and effective data collection standard could be beneficial to all stakeholders. Such a standard could improve the relevance of the data for evaluating terminal accessibility, enabling cross-facilities comparison and longitudinal tracking, and encouraging data sharing. In particular, a standard approach for rating airport level of service and wayfinding could be adopted specifically for evaluating terminal accessibility by BVI travelers and other travelers with special needs.

<u>DATA ON SPECIFIC NEEDS FOR BVI TRAVELERS</u>. There have been first-person accounts of BVI traveler experiences in airports [5 and 35], but a surprising lack of systematic studies on the needs of BVI airport travelers from the perspective of BVI travelers themselves. While regulations and guidelines for BVI accessibility have often been developed with inputs from advocacy groups, the extent to which such inputs addressed the general needs is unclear. Moreover, there is no systematic data set for assessing any unmet needs after the implementation of recommended guidelines.

A survey administered to BVI travelers for assessing difficulties and needs for airport wayfinding would provide highly valuable data. Such a survey would document (1) the general routine a BVI traveler takes to navigate a given (familiar and unfamiliar) airport terminal from curb to gate, (2) the common challenges the BVI traveler faces during an uneventful routine, (3) the modes of failure the BVI traveler often encounters, and (4) the typical resolution for these failure modes. De-identified raw data from such a survey could be made available to researchers up on request, while summary data could be widely disseminated.

CROWD-SOURCED EVALUATIONS. There are crowd-sourced reviews (e.g., Yelp®) of major U.S. airports. While the large majority of the reviews are from able-body travelers, it is possible to search through these reviews for issues specifically related to BVI travelers. However, the number of relevant search results is likely to be very low. For example, searches performed by the researcher on Yelp for Los Angeles International Airport (LAX) using key words "vision," "visual," "disable," "impair," and "blind" resulted in 6 hits (out of 3988 reviews) that were related to accessibility with disabilities, but none specially related to BVI travelers. A similar search of Minneapolis-St. Paul International Airport (MSP) resulted in 3 hits (out of 1014 reviews) concerning accessibility and none of them specifically related to BVI travelers.

To collect crowd-sourced data on terminal accessibility, it seems necessary to build a dedicated website or app to gather ratings and reviews of airports from BVI travelers. This could be a part of the survey study discussed in the previous section. Such a review feature could also be incorporated into the wayfinding apps discussed in the Assistive Technology section.

OBJECTIVE RATINGS OF TERMINAL ACCESSIBILITY. Having a standard rating system for assessing terminal accessibility for BVI and other travelers with special needs could be highly beneficial. Such a standard could enable comparisons across studies, airport terminals, time periods, and implementations. Such a rating system, which does not currently exist, could be established by using existing systems for scoring airport level of service (LOS) [33] and wayfinding [31]. These existing systems can be adjusted so that the measurements can be performed from the perspective of BVI travelers. For example, terminal accessibility for BVI travelers can be measured in terms of LOS based on waiting time, processing time, walking time, walking distance, level changes, orientation/information, and space availability for passengers [36]. Quantitative metrics for terminal wayfinding, such as visibility index [37], can be also adapted specifically for BVI travelers (e.g., by redefining "visibility" in terms of a BVI traveler's aided ability for orienting).

A consensus list of key criteria for airport BVI accessibility could be developed. Measurements based on such a standard rating system could be used to establish objective performance standards. A cumulative index, taking into account the relative importance of the itemized scores to BVI travelers, could be created to provide an overall score of BVI accessibility for individual airports.

An initial formal survey of BVI accessibility using such a standard rating system could kick-start a process of continuous assessments performed by the airports and/or major BVI advocacy groups. Ratings could also be solicited from individual BVI travelers, although such self-initiated sampling is often biased and needs to be statistically adjusted to be representative.

SUMMARY OF RECOMMENDATIONS

RECOMMENDATIONS.

Recommendations for enhancing BVI accessibility at airport terminals were established based on the six topic areas discussed in previous sections of this technical note. The recommendations generally fell into three categories: (1) recommendations having a broad consensus and which can be implemented in the near future; (2) those requiring consultation with stakeholders for which alternative solutions need discussion; and (3) those requiring technical research and development. The recommendations for each topic area are summarized below.

TOPIC 1—DIVERSITY OF THE TARGET POPULATION.

- There is a need for BVI travelers to have a reliable single point of contact at an airport for seeking wayfinding assistance.

- Guided assistance needs to ensure follow-through to the traveler's destination within the airport.

- The researchers recommend locating relief stations for service animals within the secured zones of an airport. Also, situate the relief stations so they are practical for a BVI traveler and service animal to visit it between tightly scheduled flights. Information about the location of relief stations, including estimated walking time from gates or other key locations, needs to be readily available to both travelers and airport staff.

- As part of training in disability awareness, it is recommended that airport and airline staff be trained in dealing with BVI travelers. The staff could also learn that there is a wide range of preferences for assistance and mobility skills in the BVI population.

TOPIC 2—ACOUSTIC, TACTILE, AND VISUAL DESIGN.

- The researchers recommend terminal finish color and material palettes to incorporate hard surfaces for primary concourse circulation areas juxtaposed with carpet (or other softer and more acoustic dampening material) of highly visible luminance contrast (i.e., light-dark contrast) for peripheral seating, lounge, and retail areas.

- At the terminus of all moving walkways, incorporate integral speakers within the side curb base for audible alerts for the termination of the moving walkway.

- Study and determine the efficacy of emerging indoor wayfinding mobile apps to locate critical elements such as the entry port of escalators (versus exit port) and service podiums at gates. As necessary, explore potentially related technological add-ons for audible beacons for enhanced localization on demand.

- Design architectural components of importance with features having high-luminance contrast, especially steps and ramps, glass doors, signage, critical service desks, and obstacles in travel paths.

- For glare mitigation, locate flight status displays away from glare sources and provide seating in gate areas facing away from windows.

- The researchers recommend compliance, to the greatest extent possible, with the 2015 report on guidelines for enhancing architectural design for low vision issued by The NIBS [8].

<u>TOPIC 3—SIGNAGE AND MAPS</u>.

- Build all navigational supports around universal design principles in order to benefit the greatest number of people and to provide the most economical path for ensuring robust airport accessibility. For example, use signs with large, high-contrast fonts and maps with clear, simple, and high-contrast graphics.

- When considering sign placement, adopt a hierarchical system of signage that provides wayfinding assistance along routes between functional zones of the airport or to specific regions or destinations within those zones.

- Place highly visible signs in consistent locations in the terminal. Signs need to be well-lit, situated in nonglare locations, and incorporate large, high-contrast information content.

- Using multimodal information (vision, auditory, or touch) for signs and maps would support the broadest range of BVI travelers and could also yield unintended benefits for sighted travelers as well.

- Digital maps combining multiple types of indoor localization technologies and multisensory outputs in a wayfinding app are likely to have the most impact for BVI travelers.

<u>TOPIC 4—LANGUAGE-RELATED CONCERNS</u>.

- Research is needed to establish a description logic that pertains to the unique challenges of navigating in airports. This work could integrate existing knowledge about spatial language and BVI navigation with cutting-edge spatialized audio or haptic technologies in order to provide BVI travelers with a consolidated system that conveys as much nonvisual information about their surroundings as possible.

- Use consistent terminology and provide both absolute (north-south) and relative (left-right or clockface directions) in the description.

- Use a standard description logic that gives both direction and distance information.

- Support cognitive map development by using geometric information describing object arrangement or spatial layout.

- Use of spatialized audio and touch-based interfaces are preferable to language-only descriptions as perceptual information requires less cognitive load to process and allows increased bandwidth of spatial information flow.

- Leverage knowledge from accepted, commercially available information access solutions in the development of new wayfinding systems and speech-based interfaces.

- Recommend that content providers try to imagine using the information they are creating without vision to assess its clarity and usefulness.

- Use multimodal information when possible as this has the greatest potential to convey meaningful information to the greatest number of people.

TOPIC 5—ASSISTIVE TECHNOLOGY.

- Continue development of indoor wayfinding technology accessible via smartphone apps for use by BVI travelers in airports. Where possible, have these apps include multimodal information access (visual, auditory, and tactile).

- One wayfinding technology goal could be seamless integration with wayfinding software used for other modes of transportation (bus, rail) and also GPS-based software for outdoor navigation.

- Adopt open-source standards for location sensing in airports to facilitate use in wayfinding apps for BVI travelers.

- Design airport GIS databases to include relevant information for BVI travelers, including the location of service animal relief stations.

- Conduct research to evaluate the value and practicality of providing tactile maps of airports for BVI travelers.

- Engage BVI user groups in the study of the efficacy of on-demand auditory wayfinding technology especially regarding safe and effective approach to escalators, moving walkways, restrooms, and podium locations at departure gates. If results are not satisfactory, conduct further research and development of on-demand audible beacons as an added component for an integrated system.

TOPIC 6—EVALUATION METHODS FOR TERMINAL ACCESSIBILITY.

- Collect accessibility-related incident reports from airport operators on a voluntary basis to identify the common challenges faced by BVI travelers.

- Use results from incident reports to design and conduct a formal web- and app-based survey of BVI travelers to identify routine methods of terminal/gate navigation, common and specific challenges, and a list of desirable improvements

- Upon compilation of results from the incident reports and the survey, develop a standard objective BVI accessibility rating system by adapting established methods used in assessing airport level of service and terminal wayfinding.

- Collect data using the standardized system of 3 and iterate.

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