
# Improving Intelligibility of Airport Terminal Public Address Systems (2017)

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AIRPORT COOPERATIVE RESEARCH PROGRAM

## ACRP RESEARCH REPORT 175

# Improving Intelligibility of Airport Terminal Public Address Systems

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Emeryville, CA

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2017

## AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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Richard Carman, PhD, PE, was the principal investigator. The primary editor and author was Deborah Jue. Other authors of this report are Gary Glickman of Wilson Ihrig; Joel Lewitz; Chips Davis; Adam Parkes, David Watts, and Karen Jackson of CCD; and Lee Glenn and Rick Lee of HKS. CSA provided valuable assistance with the field measurements. Joel Lewitz and Chips Davis provided important practical insight and knowledge regarding the design, installation, and commissioning of public address (PA) systems. CCD developed and conducted the pilot passenger study and prepared the human factors chapter based on their experience and research. HKS brought the architect's lens to help develop the practical design issues. We would also like to thank Silas Bensing of Wilson Ihrig for his detailed attention to the field data analyses and Herb Singleton of CSA for his insight during this project.

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- City of San Antonio/SAAS
- Corpus Christi International Airport
- Dallas/Fort Worth International Airport
- Denver International Airport
- Fairbanks International Airport
- Fort Wayne International Airport
- Los Angeles World Airports
- Maryland Aviation Administration
- Maryland Aviation Administration (BWI)
- McCarran International Airport
- Metropolitan Airports Commission
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- Nantucket Memorial Airport
- Oakland International Airport
- Philadelphia International Airport
- Pittsburgh International Airport
- Portland International Airport
- Prince George Airport Authority
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- San Diego County Regional Airport
- San Francisco International Airport
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# FOREWORD

By Theresia H. Schatz
Staff Officer
Transportation Research Board

*ACRP Research Report 175: Improving Intelligibility of Airport Terminal Public Address Systems* provides design guidelines to improve public address speech intelligibility for passenger-processing interfaces for all types and sizes of airport terminal environments. These guidelines are intended to be used by airport operators and design consultants.

The guidelines include (1) a summary of data on public address systems, terminal finishes (e.g., walls, floors and ceilings) and background noise levels in a variety of airport terminals, (2) identification of acoustical shortcomings and the results of impacts on existing public address systems; and options for enhancing intelligibility in existing airport terminals as well as ensuring intelligibility in new terminal designs.

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Audible announcements in airport terminals are often hard to understand. Given that the airport terminal environment is dynamic, the speech intelligibility of public address systems can decline and people can find it hard to understand announcements due to background noise and/or poor system design. Understanding announcements is even harder for (1) hearing-impaired travelers, (2) people for whom English is not their native language, and (3) distracted travelers. Poor intelligibility in public address systems degrades the efficacy of fire alarm notifications and other public service and emergency announcements that are critical in airport terminals.

The report reflects empirical research on existing acoustical conditions in airport terminals and demonstrates how terminal architecture and the design of public address systems within terminals affect intelligibility of announcements.

Under ACRP Project 07-14, research was conducted by a team of specialists led by Wilson Ihrig. The design guidelines were developed through field measurements at airports as well as an online questionnaire to collect information from the airport industry (airlines, airports, and consultants) to review how the industry understands factors related to speech intelligibility. A passenger survey was also developed to gain insight on ways airports can conduct their own research on human factors specific to their airports.

# CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

# Improving Intelligibility of Airport Terminal Public Address Systems

*ACRP Research Report 175: Improving Intelligibility of Airport Terminal Public Address Systems* presents guidelines developed to help airports and their consultants design, procure, install, operate, and maintain PA systems adequate for both communication and safety. The report also addresses training needs for personnel involved with PA systems. Although many of the acoustical concepts are well-studied and readily applied from other public spaces, such as transportation hubs (for example, subway stations and railway terminals) and shopping centers, the challenges and elements at airports (for example, room shapes, ambient noise sources, multiple languages, security concerns, multiple operators, and schedules) combine to form a unique environment.

The research team conducted a literature review, took field measurements at airports, administered an online questionnaire to assess industry perceptions on this topic, and developed a pilot passenger survey on how airports can conduct their own research on human factors issues specific to their airports. The research team developed the questionnaire to collect information from the airport industry on how the industry understands factors involved in speech intelligibility and whether respondents consider intelligibility a widespread problem. Given that the passenger experience may differ from that of staff and crew in the airport and to understand how data might be collected from passengers, the pilot passenger survey was conducted at one airport.

Many airports seek professional design services for new projects and extensive renovation projects; the importance of parameters such as room volume and shape, surface finishes, and noise control is not always clear during the design process. PA systems are sometimes updated or replaced without awareness that room acoustics and ambient noise conditions are vital to the success of a PA system. The guidelines in this report clarify how design can establish conditions for satisfactory PA system performance and how a PA system can be optimized for best performance, given actual acoustical conditions.

Following are the main guidelines for improving speech intelligibility:

- Use a Speech Transmission Index (STI) 0.60 performance target to compensate for the typical difference in the ambient condition between performance testing and normal operations.
- Ensure that acoustically absorptive treatment is adequate (nominally 15% to 25% of surface area)—proper reverberation time is critical to speech intelligibility.
- For spaces with ceiling heights higher than 24 feet, get professional input for acoustics and PA system design; ceiling-mounted loudspeakers are generally discouraged for these types of spaces.
- Ensure that the PA system provides at least 10 to 15 dB signal-to-noise ratio (SNR) in the presence of typical daytime ambient noise conditions.
- Prepare announcements so as to take advantage of human response to broadcast information.
- Require commissioning to verify and optimize the PA system prior to sign-off or acceptance.

CHAPTER 1

# Introduction

## 1.1 Background

Air travel is a common experience for millions of people around the world. When navigating an airport, each traveler brings his or her own prior experience and expectations to the journey. These experiences reflect a broad spectrum—from the first-time flyer to the million-mile, business traveler. On arrival at the airport, an airline passenger normally follows a basic routine of checking in, passing through security, and finding the boarding gate. This routine may include eating and shopping. At the other end of the flight, those with checked luggage must find their baggage carousel and wait for baggage to arrive.

Travelers' experiences at airports can be pleasant or not, depending on many factors, including obtaining flight, gate, and boarding information, which may be fluid. A passenger's journey from curbside to boarding is often assisted by announcements from the airport's PA system. Although only a few announcements are relevant to any one passenger at a time, it is these announcement that matter most to those for whom they are intended and can have consequences if such announcements are not heard and understood. Whether an announcement is understood depends on human factors as well as physical factors and sometimes how they interact.

Ways of communicating information to air travelers have improved with the use of electronic screens presenting relevant travel information. These screens are known as flight information display systems (FIDS) and wayfinding signs. Smartphone applications have become another way to convey information to travelers. However, audible communication through the PA system is still the primary means of conveying information, and, for travelers with hearing impairments and travelers whose first language is not English, the need for high speech intelligibility is particularly acute. Public service announcements made during an emergency are extremely important. In the event of a fire or a security threat, airport passengers must be made aware of and understand safety and/or evacuation instructions.

Clarity of announcements can make a difference in whether or not a traveler hears and understands flight and gate information that is important to them or is irrelevant and can thus be ignored. Broadcasting a message does not guarantee it has been understood. A necessary condition for understanding a message is that it be intelligible, which, in this context, means it was audible and sufficiently clear to be comprehensible. As travelers can attest, not all PA announcements are intelligible.

These guidelines, which are intended for use by airport managers and technical staff, present (1) information on speech intelligibility, (2) guidance to use during the design process in order to improve the likelihood of intelligibility, and (3) guidance on operation policies to improve intelligibility (a) through training programs for those airport and airline employees who routinely make public announcements via the PA system and (b) for using recorded messages that are clear and intelligible.

## 1.2 Current Need for Guidelines

Air travelers experience various airport environments—from large atriums to smaller gate hold areas—often with significantly different levels of passenger activity in each. The wide array of sizes and shapes of terminal areas and range of background noise present challenges for airport designers when it comes to ensuring announcements will be intelligible. Being aware of design challenges and how to approach and solve them can help increase the chances of success.

A clear understanding of what physical factors affect intelligibility is essential to designing better airport terminals and the PA systems that serve them. It has been said that acoustics is the forgotten dimension in architectural design. The technology necessary to design and construct a terminal space in which the acoustics and amplified sound system achieve the appropriate goal is readily available, but not always incorporated. Even with the best design, inadequate implementation can affect the outcome and should be given careful consideration from conceptual design through final commissioning, lest the best of designs be compromised. Intelligibility is also affected by human factors related to passengers' attention and expectations, thus adding another layer of complexity.

The research included a literature review, an industry survey of airports and airlines, and extensive acoustical measurements in numerous terminal spaces at airports both large and small. To obtain passengers' perspectives on intelligibility, a small pilot study of airport terminal public address systems was conducted at one airport. The primary goal of the research was to develop a basis for a comprehensive and practical set of guidelines for use in (1) designing new airport terminals and in renovating existing terminals and (2) guiding airport management.

An online search of relevant literature and an industry survey concluded that no comprehensive set of intelligibility guidelines for airport PA systems exists. A small percentage of the surveyed airports do apply limited, acoustical criteria when designing or renovating facilities. Guidelines are needed that present the concepts of good design and their implementation in a manner that can be understood by technical professionals and by airport decisionmakers and within the airline industry in general. The guidelines herein are intended to address these needs.

## 1.3 Previous Studies

The research included a review of domestic and international literature on intelligibility studies in airports related to the quantitative and human factor aspects of the subject. This review was accomplished through online search engines using appropriate search terms to focus on relevant studies. The literature review sought to identify existing resources that would be useful for evaluating the factors (physical and human) that affect PA system announcement intelligibility in airports. The review produced few documents on the topic specifically relating to airports. A similar result was encountered in searching for literature on human factors. However, studies for other public transportation facilities (for example, transit) offer some guidance on PA system announcement intelligibility relevant to airports.

Although rail transit and railway stations are dissimilar to airports, they share similar acoustical challenges. These similarities make general lessons learned in the design of new rail stations and the renovation of existing stations applicable to airports. Given that the investigation into the existing research on airport acoustics produced little information, the acoustical design lessons learned from transit stations are helpful to consider. Architectural design in rail stations often includes spacious, reverberant spaces such as can be found in older railway stations (for example, New York's Pennsylvania Station and Grand Central Terminal and Washington, D.C.'s Union Station). Recently these stations have undergone renovation, which has included efforts to improve the intelligibility of the PA system and controlling reverberation in large arrivals halls with high ceilings so as to overcome some of the existing challenges.

Another similarity between rail stations and airports is the large volume of passengers that pass through them—such volumes result in higher levels of background noise and create a need for durable and easily maintainable room surfaces (both floors and walls). With maintenance in mind, surfaces that are easiest to maintain are generally hard and smooth, which makes such surfaces acoustically reflective and results in more reverberation. Similar to larger transit stations, airports have a wide variety of spaces with different sizes and shapes that must be accommodated and that serve different purposes. The public address system in transit stations, although used somewhat less than in airports, serves the same purpose to communicate schedule and departure information to passengers.

### 1.3.1 Acoustics and Speech Intelligibility

The physical parameters that affect speech intelligibility include the speech intelligibility (SI) evaluation method, hearing acuity and perception issues, and architectural acoustic conditions (e.g., reverberation time, diffusion and obstructions, background noise, PA system design, and announcement quality).

The literature review uncovered few documents on acoustics and speech intelligibility specifically relating to airports. Five physical factors affect speech intelligibility: (1) room volume and shape, (2) reflection and echoes, (3) reverberation, (4) architectural design, and (5) PA system design and announcement quality. These factors are discussed in greater depth in Chapter 4.

### 1.3.2 The Human Factor

Although the literature review found few documents on human factors concerning airports, the review did produce useful information about speech intelligibility relevant to human factors. Usually, the intelligibility of an announcement is considered in terms of such features as pitch, tone, and loudness. However, the human factor in the equation is often overlooked. Many factors can impede attention to hearing, understanding, and attending to a message. Some factors are influenced by context and location (such as the number and variety of competing auditory stimuli within a particular environment), but many factors may be seen as a result of the attention and perception of the individual person. Chapter 5 provides guidance on addressing these factors and discusses the following key topics:

- Attention and perception
- Message content
- Message cuing

## 1.4 Organization of Guidelines

The guidelines present material to help nontechnical and the technical users understand the physical and human factors affecting intelligibility. Important concepts are illustrated and design details that can be applied are discussed. This information serves as a basis for appreciating the key points of a good design and the steps that can be followed to implement one.

The guidelines are organized into chapters. Chapter 1 presents background. Survey findings on the industry's perception of this issue are presented in Chapter 2. Chapter 3 discusses speech intelligibility, provides background and information on how it is measured, and lists relevant codes and standards. Chapter 4 presents material on concepts and physical factors affecting intelligibility, including acoustics, architectural design, and PA system design. Chapters 5 through 7 provide guidelines for good design and implementation. Chapter 5 addresses human factors and how humans respond to messages and auditory input in an airport environment

This information is of particular importance.

This indicates information related to design.

This indicates information related to implementation.

***Figure 1-1. Icons used.***

and ways to improve messages and announcement practice. Chapter 6 presents information on architectural design and includes guidance on how to improve room acoustics and the ambient environment. Chapter 7 presents guidance on PA systems, including information on electronics and equipment, loudspeaker configuration (layout and proximity), loudspeaker quality, and appropriate types of loudspeakers for different circumstances (e.g., high ceilings and large atriums). Chapters 8 and 9 present information and guidelines on the PA system bid and installation process, and the commissioning of the PA system, respectively, followed by chapters on announcements (Chapter 10) and operations, maintenance, and training (Chapter 11). Chapter 12 includes decision tools and examples to follow. Chapter 13 suggests ideas for future research.

Icons, as presented in Figure 1-1, are used throughout the report.

## 1.5 How To Use These Guidelines

Figure 1-2 illustrates the basic relationships among topics discussed in this report. The material starts with an introduction and foundational information in Chapters 1 through 5. These chapters support the relevant guidance for design in Chapters 6 and 7, which are followed by guidance relevant to procuring and executing design (in Chapters 8 and 9) and operation (in Chapters 10 and 11).

The guidelines have been structured with the expectation that most users will focus on Chapters 6 and 7, using Chapters 2 through 5 for background. Much of the discussion in Chapters 6

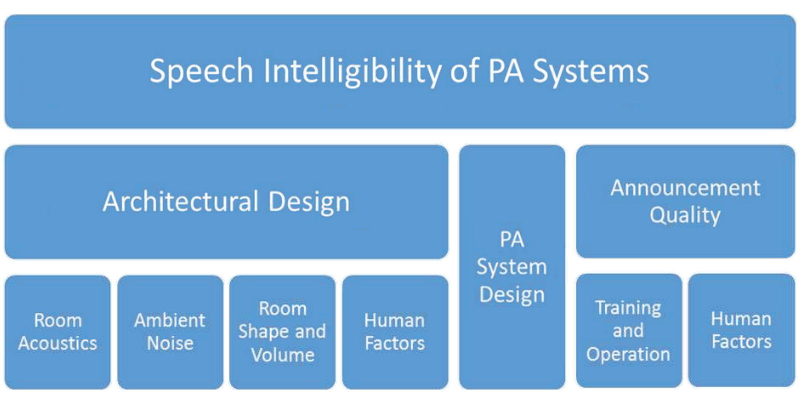



***Figure 1-2. The relationships among various speech intelligibility topics.***

**Table 1-1. Project timing chart for physical factors that affect PA system speech intelligibility.**

| Physical Factor | Project Timing | Primary Discipline | Related Disciplines |
|---|---|---|---|
| Room shape/volume | Conceptual or schematic design | Architect | Owner, structural engineer |
| Reflections/echoes | Design development | Architect | Acoustical consultant |
| Reverberation | Design development | Architect | Architectural finishes consultant, acoustical consultant |
| Ambient noise | Design development and/or construction documents | Architect | Mechanical engineer, acoustical consultant |
| PA system | Design development and/or construction documents | Audiovisual (A/V) designer | Architect, acoustical consultant |
| Commissioning | Substantial completion | A/V commissioning agent | Airport operations staff |
| Announcements | Training and operations | Airport operations staff | A/V commissioning agent |

and 7 is intended for standalone consumption, so there is some duplication, given that users may not have fully read and digested the background information. Chapters 8 through 11 are much shorter than Chapters 6 and 7, so they rely more on references to previous chapters. Supplementary material is presented in the appendices. The References section lists all references used throughout the document, including those used only in the appendices.

Different users will review this material at different phases of the project. Table 1-1 outlines when key issues can be affected by design. The basic priorities for speech intelligibility of public address systems are as follows:

- Primary:
  - Control reverberation
  - PA system design appropriate to the architectural and acoustical environment
- Secondary:
  - Reduce ambient noise
  - Implement PA system optimization and commissioning
- Tertiary: Proper training and instruction for announcements and microphone technique

CHAPTER 2

# Industry and Passenger Perspectives

## 2.1 Introduction

To assess how various stakeholders perceive intelligibility of PA announcements in airport terminals, the research team developed a questionnaire about respondent understanding of the factors involved in speech intelligibility and whether respondents believe speech intelligibility is a widespread problem. Given that respondents may not be familiar with specific terminology, many questions included multiple-choice answers to guide the responses and lend consistency. In many cases, respondents also could choose to provide additional comments or select "other" as a response.

The questionnaire targeted airline industry people who have a role in the operation of the airports about communications transmitted over the PA system (i.e., managers, facilities personnel, passenger services, IT and security, and related consultants and vendors). These results are only a sample of the industry—with only 66 responses, these results have a 10% margin of error to achieve a 90% confidence level for a population of about 400 airports and 100 airlines. All survey respondents were asked some of the same questions, and those common questions and answers are summarized in the next section.

To understand how data might be collected from passengers, a pilot passenger survey was conducted at one airport. This effort sought to determine the feasibility of such a survey, as well as whether this type of survey could be conducted on a larger scale and how reliable and meaningful the data would be.

## 2.2 Overall Industry Perspectives

A total of 66 individuals responded to the online survey. These individuals represented 38 airports, 5 airlines, and 21 consultants, vendors, and trade representatives. The median years of experience in the industry across all respondents was 25 years. There were five questions about PA systems in common for all respondents, and the results are summarized in Table 2-1.

The following figures illustrate the questions with multiple options, and, for some questions, the other minor responses and gradations in response.

For the questions in Figures 2-1 and 2-2, many respondents gave no response or were unable to respond to the questions.

The question in Figure 2-3 allowed multiple selections, and the Other category was selected by 11% of the respondents. The additional factors offered under Other included microphone selection, user training, poor acoustical design, poor commissioning, gate areas in close proximity, number of announcements.

**Table 2-1. Industry survey, primary findings.**

| Question | Primary Response(s) | Other Substantial Responses |
|---|---|---|
| Are poor PA systems a widespread problem? | 55% agree | 35% no response*<br>10% disagree |
| Should PA systems be improved? | 46% agree | 27% no response*<br>24% disagree |
| What negatively affects the speech intelligibility of PA systems (multi-select)? | Room acoustics (68%)<br>Background noise (67%) | PA electronics/design (45%)<br>PA layout (48%)<br>Announcement quality (50%) |
| Areas where the PA system could be improved (multi-select)? | Gate areas (64%)<br>Concourse (68%) | Departures (41%)<br>Ticketing (41%)<br>Baggage claim (45%)<br>Curbside areas (47%) |
| Source of information (multi-select)? | Personal observation and experience (95%) | Discussions with other facilities (55%)<br>Discussions with airlines staff (44%)<br>Customer feedback (24%) |

* These respondents did not have the opportunity to answer these questions.

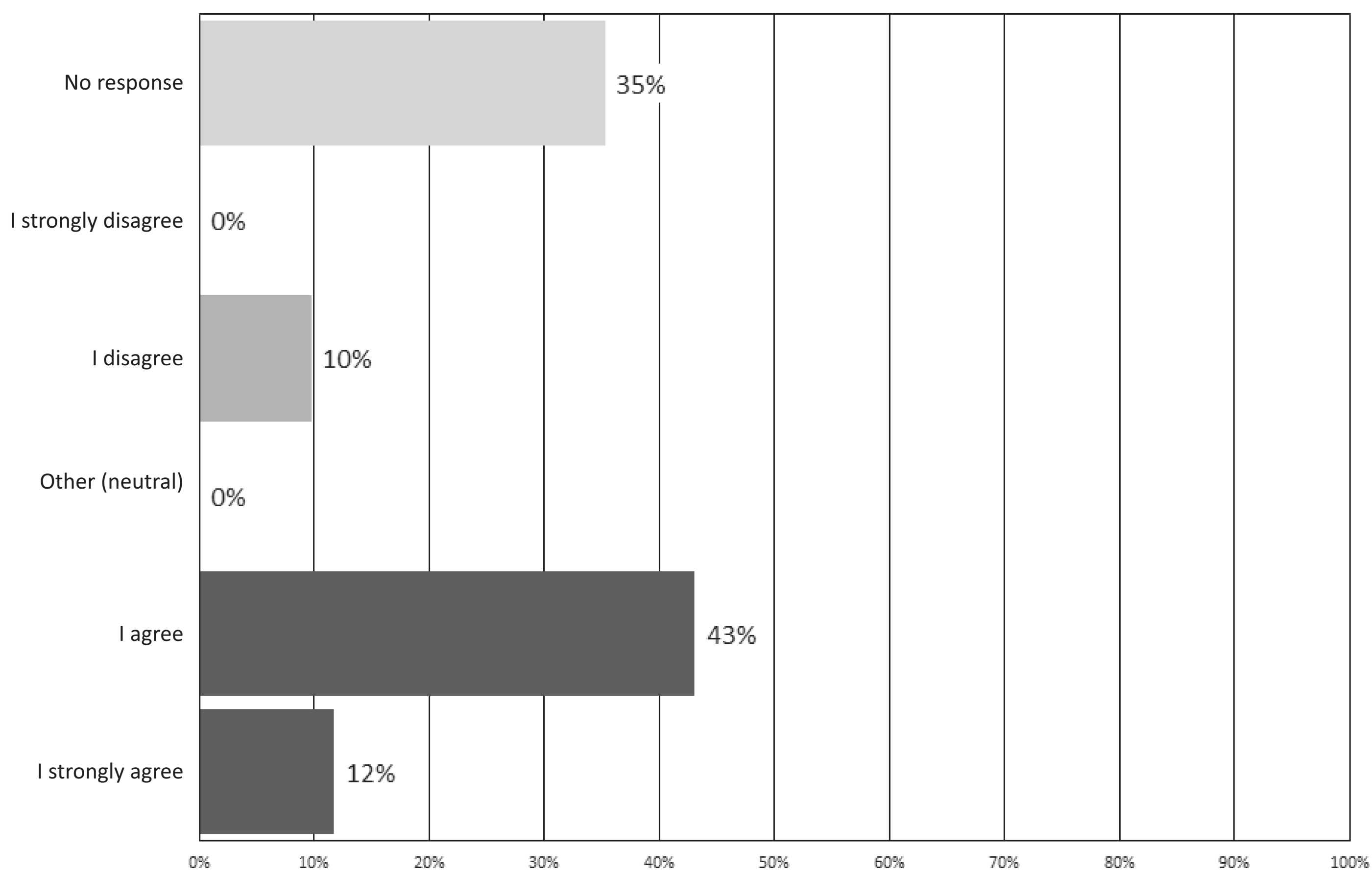



***Figure 2-1. Question: Are poor PA systems a widespread problem? (66 respondents)***

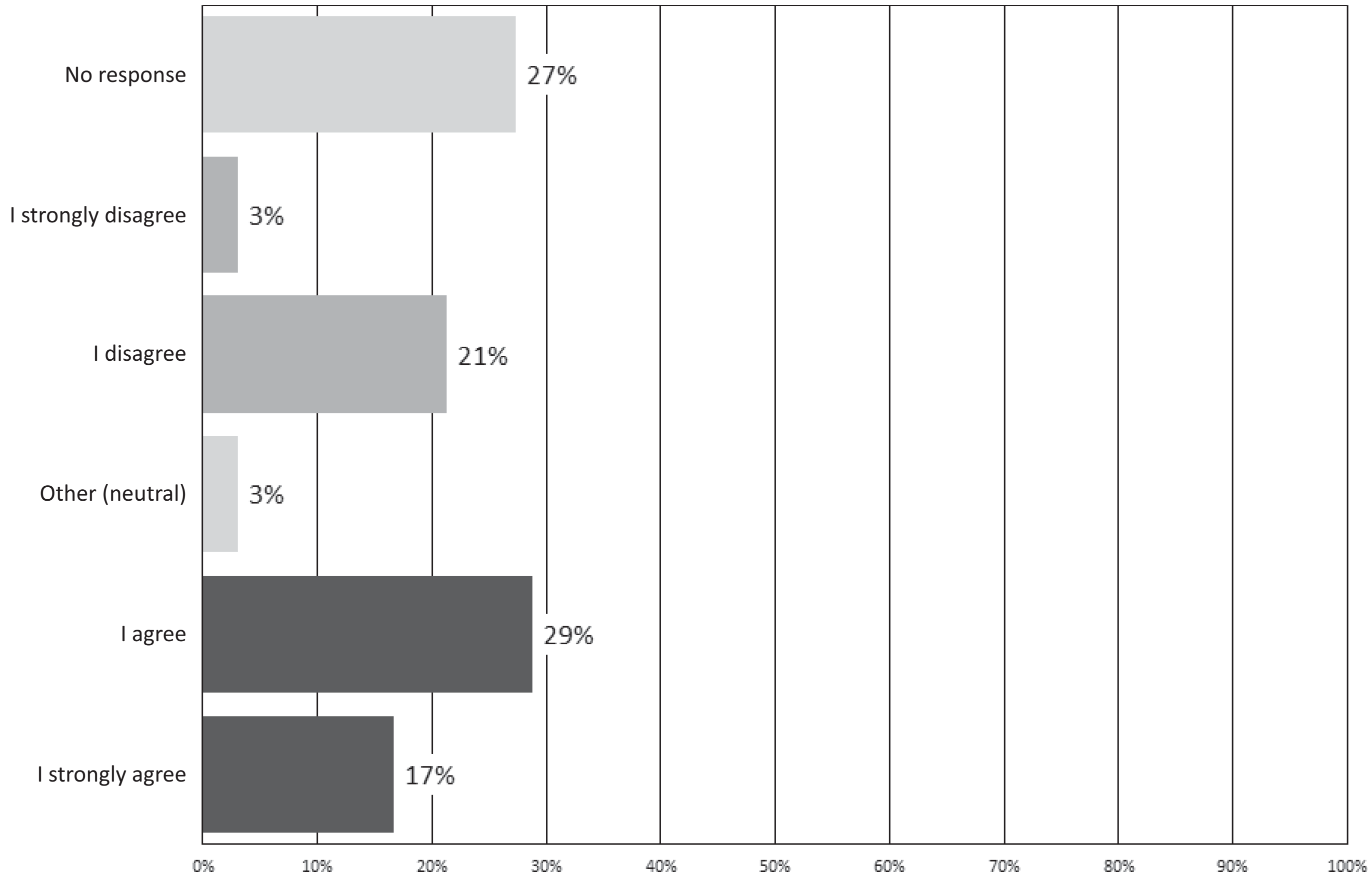



***Figure 2-2. Question: Should PA systems be improved? (66 respondents)***

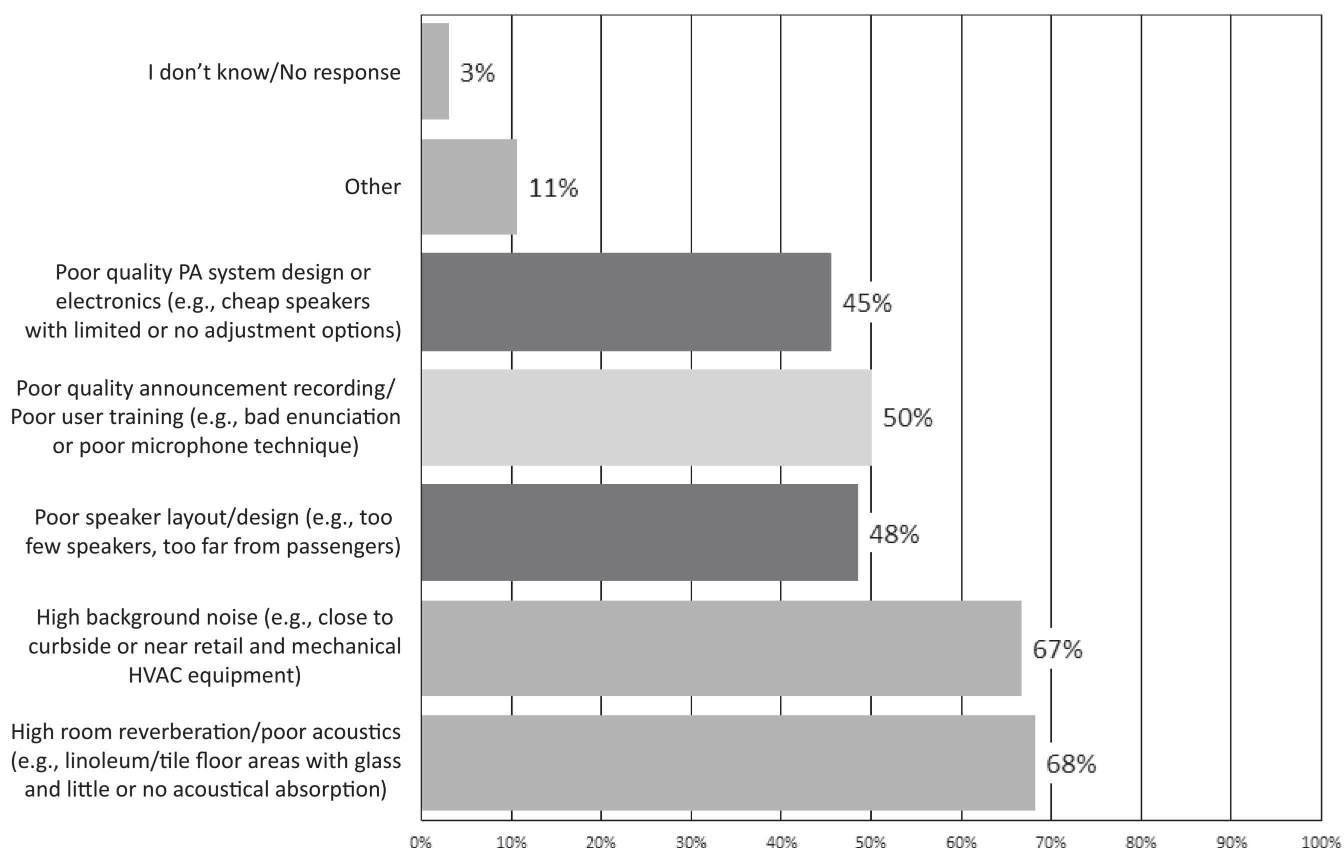



***Figure 2-3. Question: What negatively affects the speech intelligibility of PA systems? (66 respondents)***

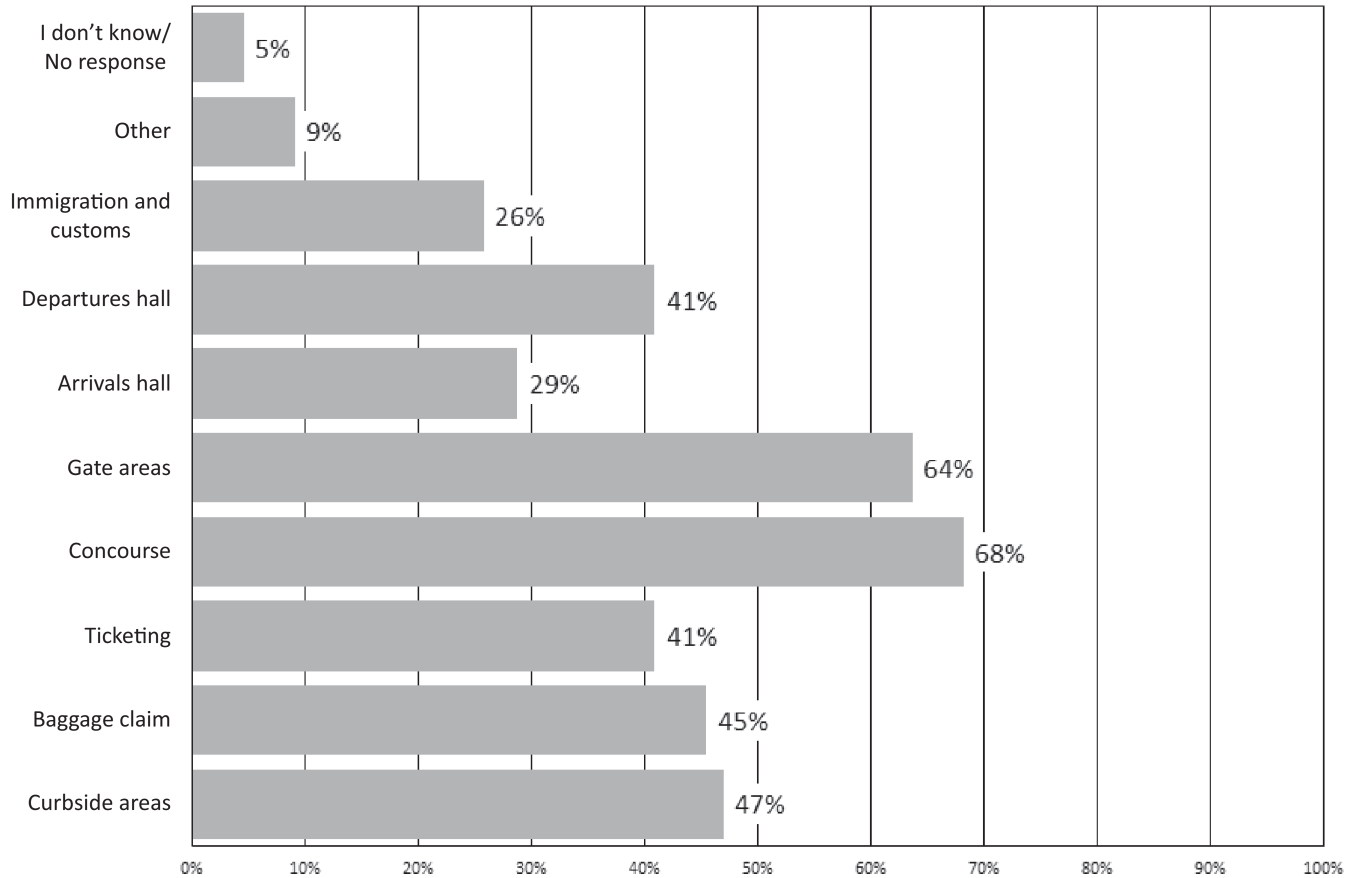



***Figure 2-4. Question: In what areas could the PA system benefit from improvements? (66 respondents)***

The question in Figure 2-4 allowed multiple selections, and the Other category was selected by 9% of the respondents. The additional factors offered under Other included restrooms and concession areas, back of house, highly reverberant areas with hard surfaces, and separate/remote rental car customer service areas.

The question in Figure 2-5 allowed multiple selections, and the Other category was selected by 6% of the respondents. The additional sources of information offered under Other included passenger feedback, building tenants, and previous experience in IT management.

## 2.3 Airports and Airport-Based Staff

### 2.3.1 Summary

Airports from across the United States and Canada provided input to this research (see Figure 2-6). The responses received from two Canadian airports were consistent with the results from the U.S. airports. Of the 66 total responses, 38 airports are represented by 46 respondents. Table 2-2 and Figures 2-7 through Figure 2-12 summarize the results.

### 2.3.2 Detailed Results

For the information in Figure 2-7, in addition to Spanish, French and Chinese, the Other languages were German and Japanese. Some respondents used this field to indicate that they only use non-English languages as needed (e.g., for specific flights).

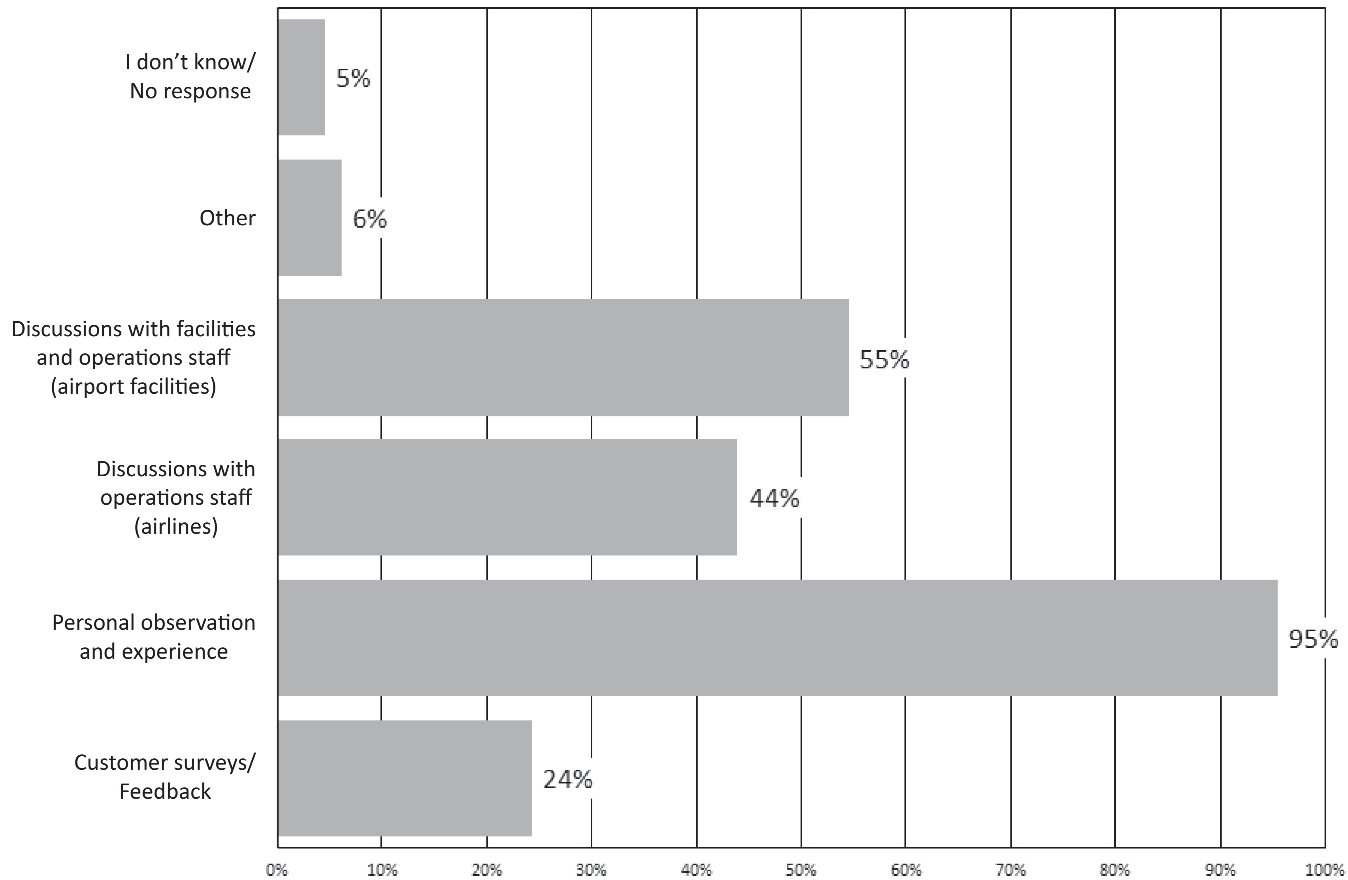



***Figure 2-5. Question: What informs your understanding of this issue? (66 respondents)***


***Figure 2-6. Questionnaire responses, geographic distribution—United States.***

**Table 2-2. Industry survey, responses from airport-based staff.**

| Question | Popular Response | Other Substantial Responses |
|---|---|---|
| What type of service? | 71% domestic and international | 29% domestic only |
| Non-English announcements | 66% no or none | 34% yes |
| Non-English languages* (multi-select) | Spanish (34%) | French (11%)<br>Chinese (5%) |
| Non-English options* (multi-select) | Prerecorded or automated (39%) | Language specialists (29%) |
| Announcement quality controls | | |
| PA system design criteria** | 75% no/no response | 25% yes |
| Acoustical design criteria** | 84% no/no response | 16% yes |
| Speech intelligibility design criteria** | 93% no/no response | 7% yes |
| Positive factors | Good speaker layout design (72%)<br>Good system design or electronics (61%) | Low background noise (43%)<br>Good room acoustics (43%)<br>Good announcements/ recording quality (39%) |
| Negative factors | High background noise (58%) | Poor PA design (45%)<br>Poor room acoustics (50%)<br>Poor PA equipment (50%)<br>Poor announcements/ recording quality (42%) |
| Areas at your airport that are generally good | Gate areas (71%) | Baggage claim (53%)<br>Ticketing (50%)<br>Concourse (50%) |
| Areas at your airport that are poor | Curbside (39%) | Ticketing (34%)<br>Departures halls (29%) |

* These responses are only for those airports providing non-English announcements.
** The remaining respondents either responded “Unknown” or gave no response.

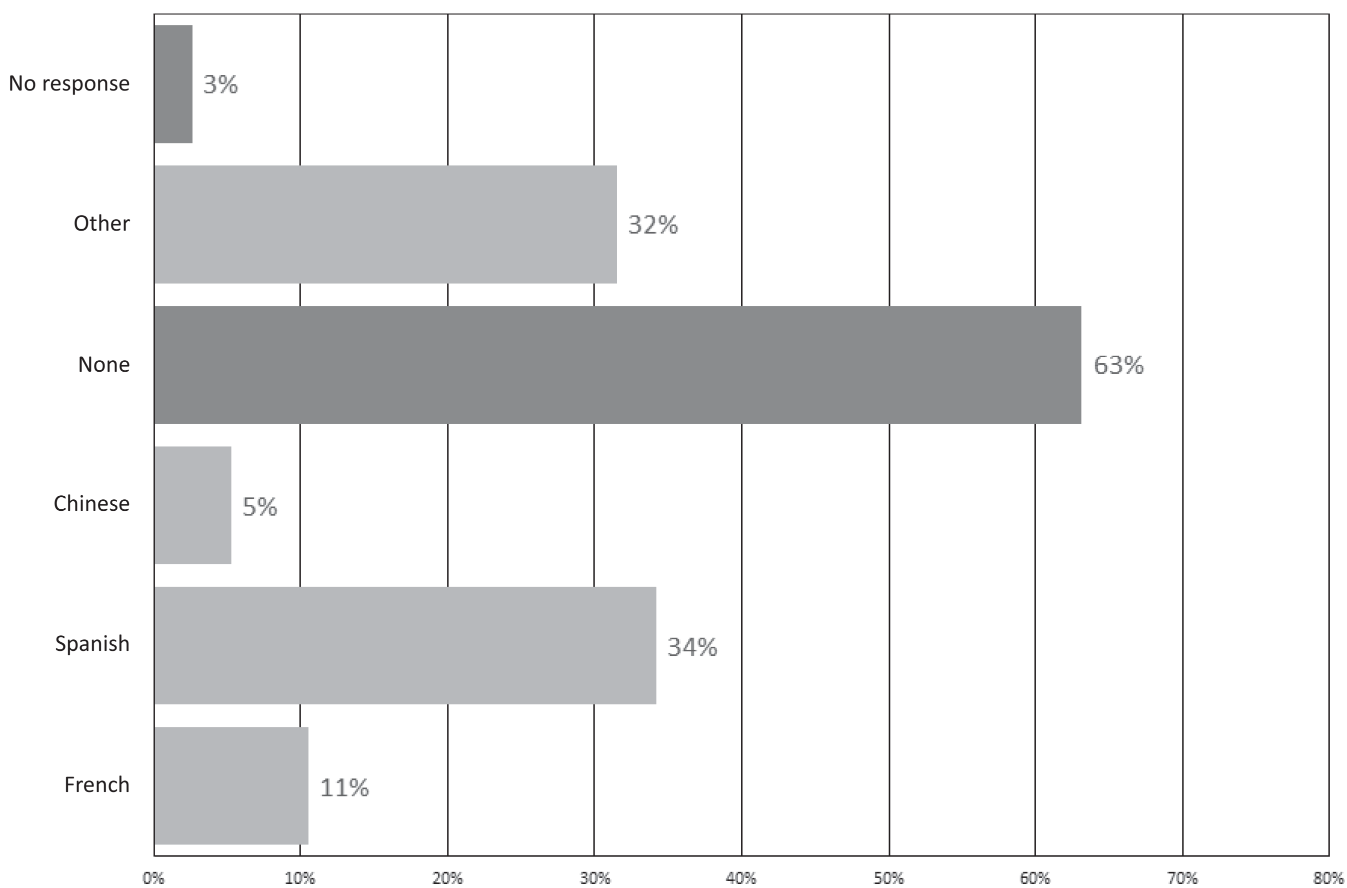



*Figure 2-7. Question: Which languages other than English are used for standard message announcements? (38 airports represented)*

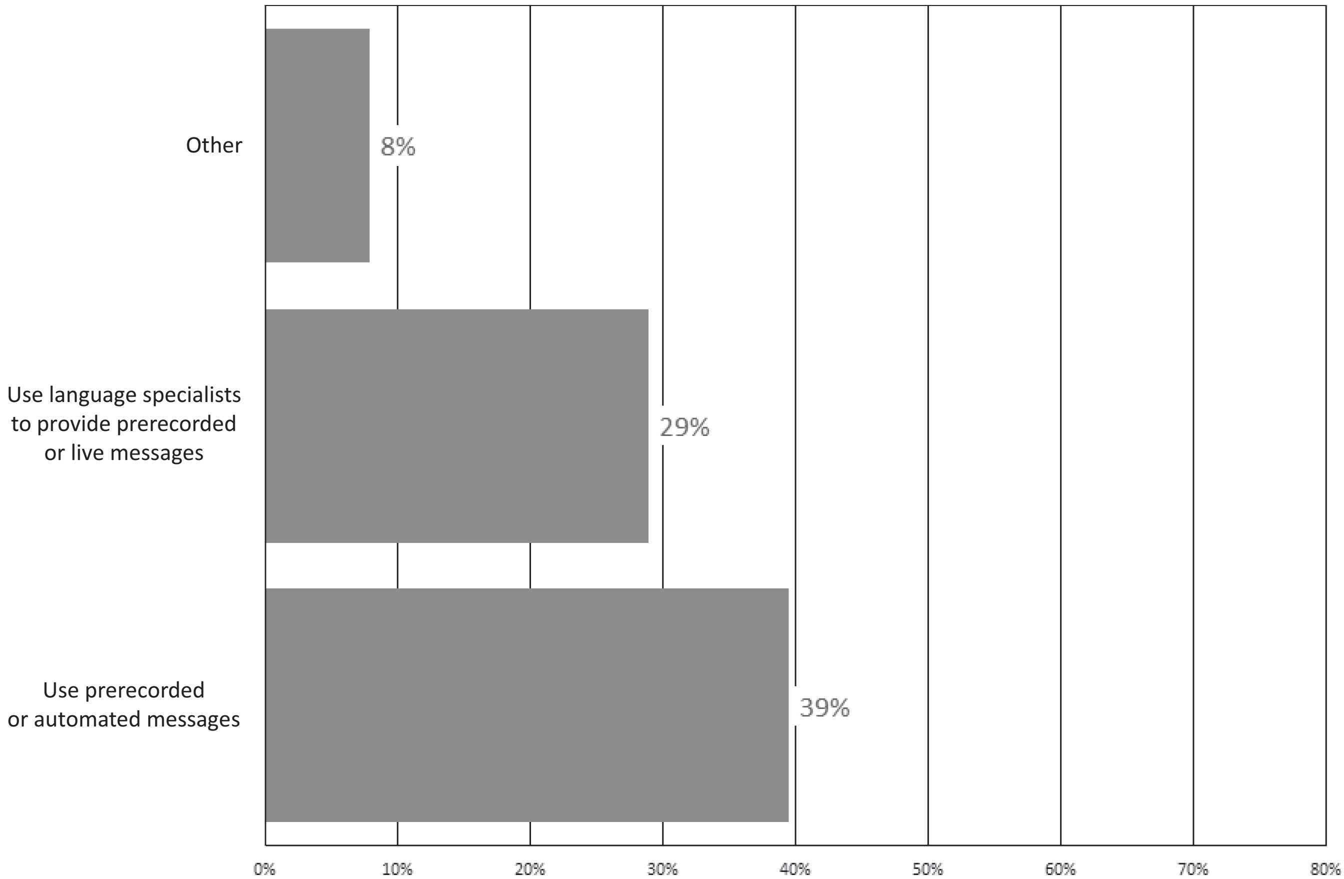



***Figure 2-8. Options for non-English announcements. (23 responses)***

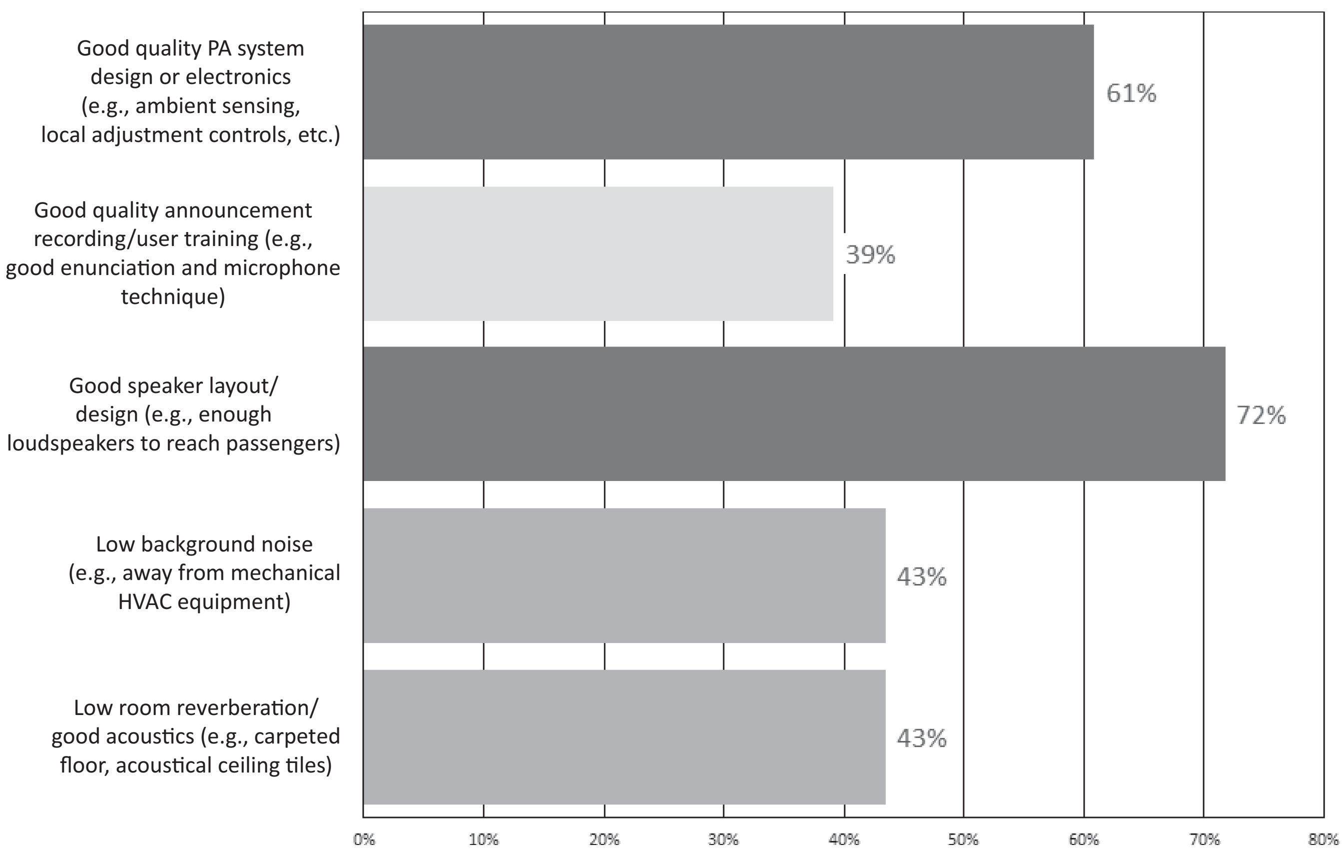



***Figure 2-9. Question for airport-based respondents only: What are positive factors for PA system speech intelligibility? (38 airports represented)***

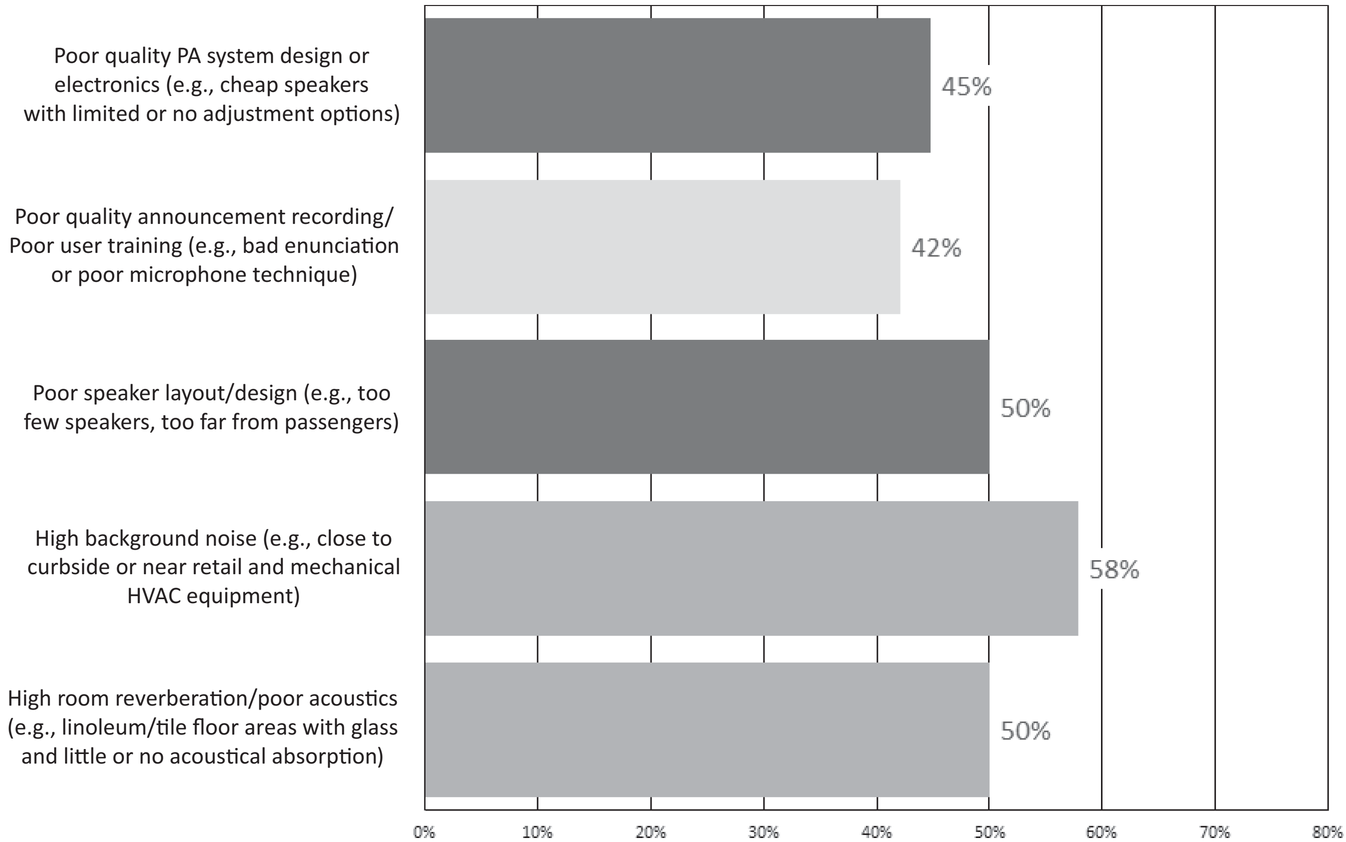



***Figure 2-10. Question: At your airport, what are negative factors for PA system speech intelligibility? (38 airports represented)***

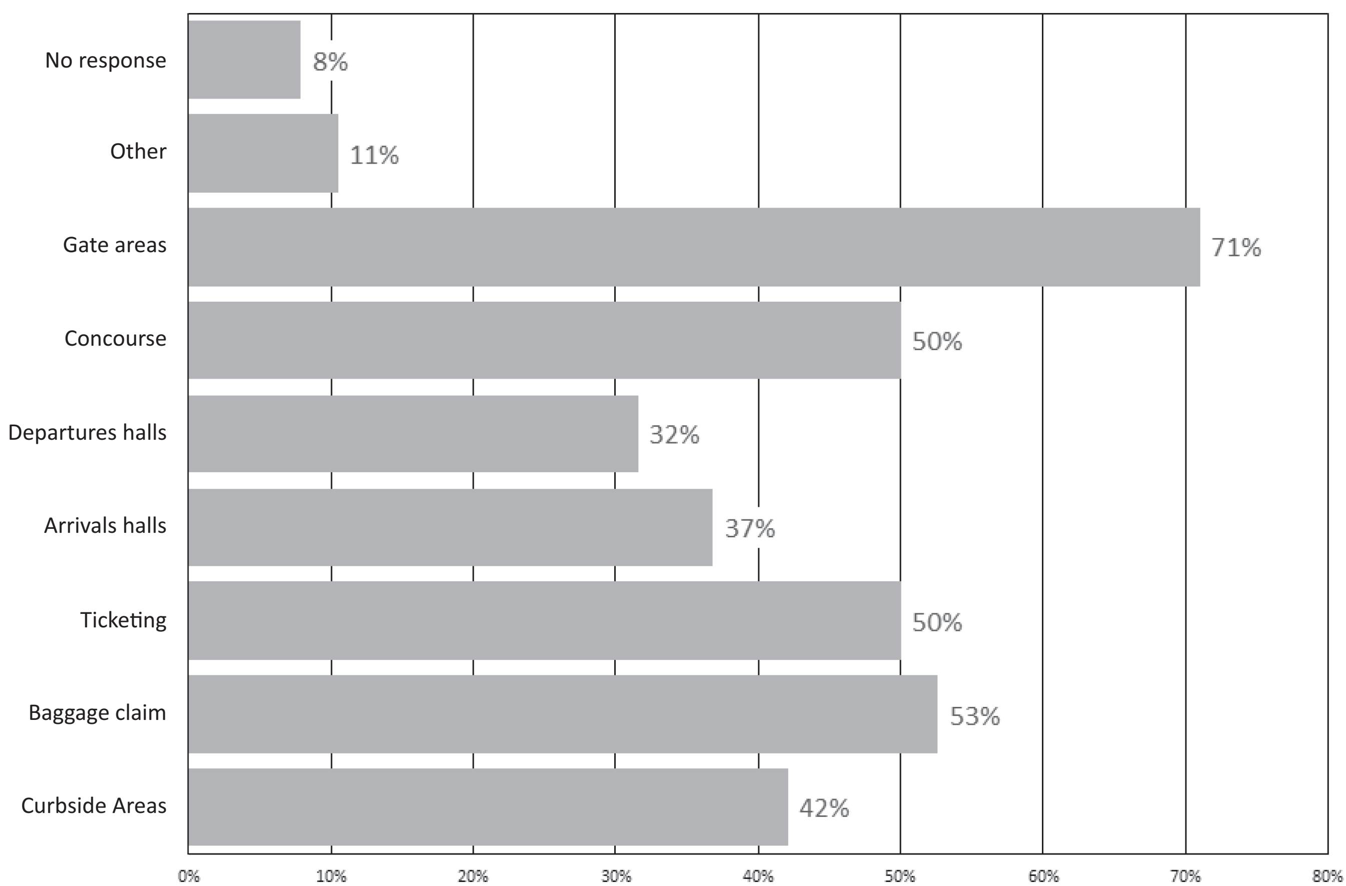



***Figure 2-11. Question: At your airport, what areas are good? (38 airports represented)***

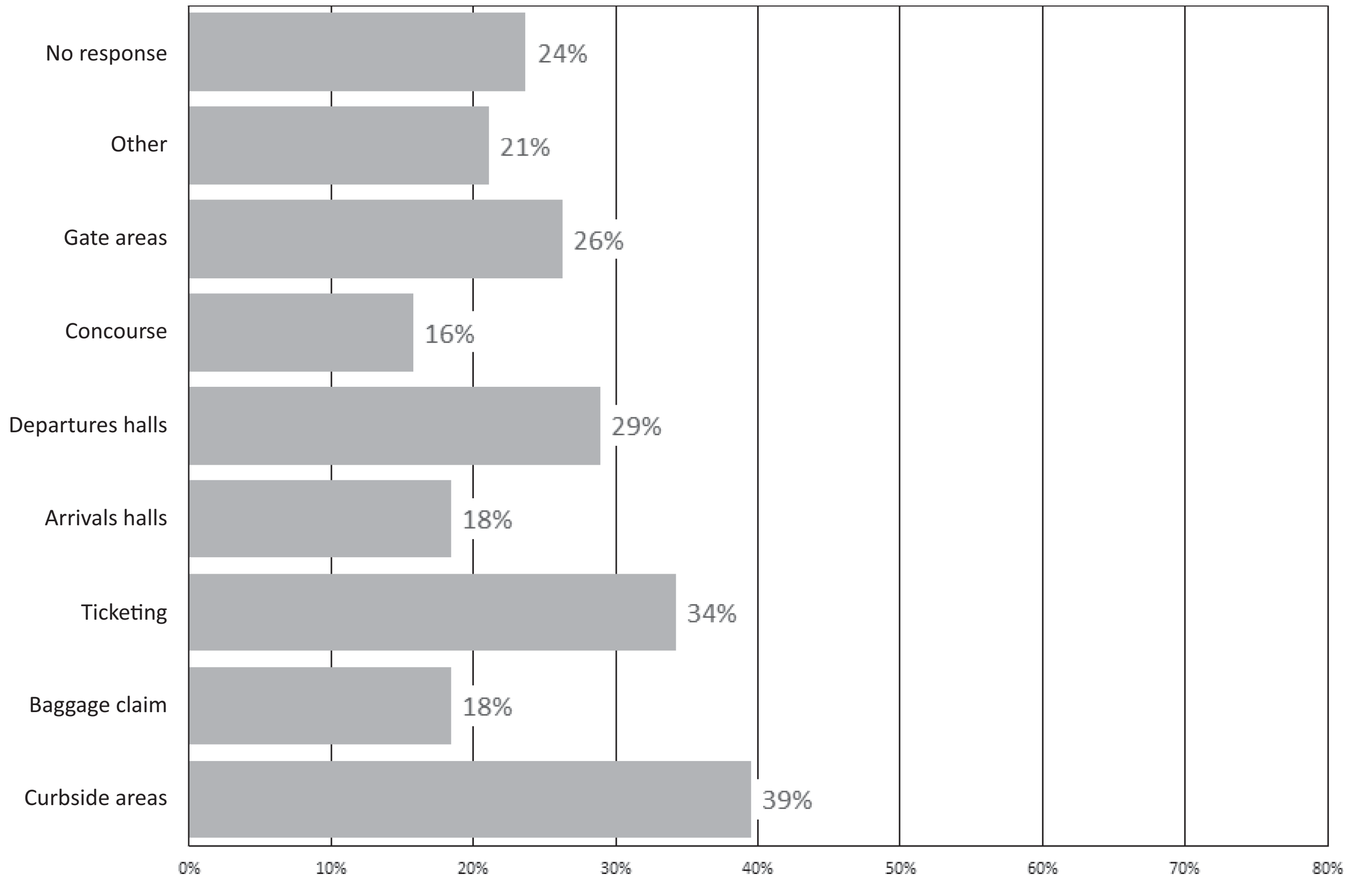



***Figure 2-12. Question: At your airport, what areas are poor? (38 airports represented)***

For the information in Figure 2-8, of those 14 airports providing non-English language announcements, the Other techniques to control the quality of these announcements included handled by Public Affairs, professional recordings of customer-service–approved text, reviewed by IT department, professionally produced and reviewed by system engineer, and reviewed and approved by airport director and marketing manager.

Some of the questions were refocused to the specific environment at each terminal where airport-based–staff work (Figures 2-9 through 2-12).

## 2.4 Airlines

Of the 66 total respondents, 13 were affiliated with airlines or the airline industry, including 6 from 2 major U.S. passenger carriers, and 3 from other, smaller air carriers.

## 2.5 Consultants

Of the 66 total respondents, 12 were consultants for design and planning firms, and 6 were vendors/installers representing 3 firms, including 1 major vendor of PA systems and 2 firms that provide installation or integration of PA systems.

## 2.6 Passengers

A passenger survey was tested at one of the airports to determine the feasibility of such a survey, whether this type of survey could be conducted on a larger scale, and how reliable and meaningful the data would be. The data obtained from the test survey was useful in obtaining feedback from passengers. Speech intelligibility measurements were also conducted in the areas where the passenger surveys were conducted.

The aim of the passenger survey was to gain understanding and insight into how passengers hear, understand, and perceive different kinds of PA announcements when traveling through different airport touchpoints. The passenger survey was developed to focus on human factors, and, in asking passengers what they have heard and what issues they have encountered with PA announcements, endeavored to gain a passenger's perspective of PA intelligibility that could be used to inform the acoustical study. (See Chapter 5 for further discussion on Human Factors and their role in this topic.)

The passenger survey involved engaging directly with airport passengers to obtain their views on PA announcements in general, how they hear those PA announcements, what content they listen to/perceive, what issues they have encountered, and what factors may affect their ability to perceive announcements correctly. A total of 76 passengers were surveyed using trained ergonomists with experience in survey design and collection. A copy of the survey questions and result summary is included in Appendix B.

A total of 43 passengers were aware of an announcement just prior to the survey. Of these, four indicated that the announcement was muffled or unintelligible. Of the remaining respondents who heard enough to understand the announcement:

- Fewer than 10% felt that the announcement was relevant to their journey.
- About 18% did not understand the content or meaning of the message.
- Reasons cited for not hearing the message well included high background noise, poor sound quality (echoes/distortion), message spoken too quickly, announcement volume too low, outside noise, message not spoken clearly enough, and audio clutter/multiple messages.

## 2.7 Conclusions

The major conclusions from the industry survey are as follows:

- Although 55% agreed that poor speech intelligibility from airport PA systems is a widespread problem, only 46% agreed that existing PA systems require improvement.
- Across all industry responses, most respondents indicated that high background noise and room acoustics were the most important negative factors on speech intelligibility of PA system announcements, with other factors relating to the design of the PA, electronics, and layout receiving responses from 45% to 48% of the respondents, and poor-quality announcements receiving 50%.
- Airport-based staff were relatively even in their expectations of what hinders speech intelligibility of PA system announcements, with high background noise receiving 50% of the responses.
- Gate areas and concourses received the most votes for areas of the airport that could be improved, although airport and airport-based staff generally thought that the gate areas in their own airports are satisfactory. This dichotomy is likely because gate areas are the places where passengers are most anxious about announcements related to boarding, delays, upgrades, and so forth and these are considerations that airport staff do not have.
- Most opinions reflected personal experience or interaction with passengers or airport staff. Nearly one-quarter of the respondents had information from passengers.
- Of the airports surveyed, almost three-quarters provide international service.
- More than one-third of the airports broadcast standard announcements in a non-English language, and some technique or process is used to control the content or quality of the announcements.

- Of the airports surveyed, one-quarter of the airports were aware of specific PA system design criteria.
- Most of the airport-based staff believe that PA system design or installation is one of the most important factors for speech intelligibility, with room acoustics and background noise following announcement quality.

Major conclusions from the pilot passenger survey are as follows:

- The questionnaire results can vary widely across airports and different areas of the airport; for example, passengers in the gate area tend to be more aware of announcements than those in other areas of the airport.
- Passengers have different needs based on the phase of their journey (see Chapter 5 re human factors).
- Many passengers rely on sources of information other than PA system announcements. This may be true for various reasons, one of which could be that they are most likely not to understand the PA announcements.
- Based on the results obtained, the questionnaire used for the passenger survey is a useful starting point for airports to develop and implement their own questionnaires.

CHAPTER 3

# Speech Intelligibility

## 3.1 Introduction

Although the acoustical requirements for airports are much less demanding than they are for other large public spaces (such as concert halls), the same design tools are available to deliver acoustical success in airports as well. A concert hall is an acoustical success when attention to the details of the acoustical environment results in a high quality of sound. An airport is an acoustical success when passengers can hear and understand announcements that are relevant to them. The attention paid to acoustics in airports has often not been as focused as it could be on important parameters for speech intelligibility, and airport planners have often not taken full advantage of the tools available to them. Some airports have favorable acoustics and an intelligible PA system, but in other airports, intelligibility could be improved.

Audibility (the fact that sound can be heard) does not necessarily result in intelligibility. International Electrotechnical Commission (IEC) Standard 60268 defines intelligibility as "a measure of the proportion of the content of a speech message that can correctly be understood." The speech signal can be degraded in some ways, thus limiting the transfer of information content.

A loud PA signal can be unintelligible if the space is too reverberant. Reverberation is the persistence of sound in a space, and a highly reverberant space is one with hard surfaces and little acoustical absorption. The result is sound that continually reflects around the space, rather than being absorbed quickly at the room surfaces; sound lingers (slowly decays) and masks successive sounds. To achieve good speech intelligibility, the sound of each word must decay rapidly; otherwise, successive words will be muddied by the lingering sound.

A high level of background noise can also interfere with intelligibility by masking the spoken sound unless the spoken sound is sufficiently amplified above the background noise. A good example of this is the so-called "cafe effect" in which many people in a group are talking at the same time, forcing all speakers to raise their voices to be understood, in turn making it even harder for everyone to be understood. A related phenomenon is called the "Lombard effect," in which speakers modify their normal speech pattern to adjust for an increase in ambient noise. In this case, speakers automatically and subconsciously raise their voices, increase pitch, and improve articulation, resulting in improved intelligibility.

## 3.2 Background

The scientific aspects of speech intelligibility have been studied for many decades. Early tests would either have listeners assign a numerical value or a subjective term to rate how well they could understand a speaker, or they would have listeners document what words or sentences they heard (or thought they heard), so that by experiment an objective number and percentage accuracy could be determined. One of the early methods of the second test was a subjective test called the "monosyllabic word intelligibility" test, which used spoken words and a group of listeners to test for intelligibility by measuring the number of words correctly identified. A truly objective method for measuring intelligibility without listeners became available 43 years ago with the introduction of the Speech Transmission Index (STI).

The physical parameters that affect speech intelligibility include the method of speech intelligibility evaluation; hearing acuity and perception issues; architectural acoustical conditions such as reverberation time, diffusion, and obstructions; background noise; the design of the PA system itself; and announcement quality.

The literature review uncovered few documents on this topic specifically relating to airports. Relevant findings are summarized below.

**Speech intelligibility and special populations**

- Older passengers benefit from airport spaces with higher STI than those designed for the average passenger (Kim and Soeta 2013; Morimoto, Sato, and Kobayashi 2004; Sato, Morimoto, and Wada 2012). The specific reasons were not controlled, and there may be factors other than hearing impairment for this population.
- Hearing-impaired passengers benefit from airport spaces with higher STI than those designed for non-hearing-impaired passengers (Festen and Plomp 1990).
- When one language is the only or primary language for announcements, non-native language listeners also benefit from airport spaces that provide a higher STI than those designed for native language listeners (Tachibana 2013, S. J. van Wijngaarden 2001, and van Wijngaarden et al. 2004).

**Reverberation time**

- Long reverberation time greater than 1 second is problematic for speech intelligibility (Kim and Soeta 2013, Tachibana 2013).
- Speech intelligibility for hearing-impaired and non-native language listeners is most sensitive to long reverberation time (van Wijngaarden et al. 2004, Yokoyama and Tachibana 2013).

**Background noise**

- A good target for announcement levels is a signal-to-noise ratio (SNR) of 10 to 15 dB (Morimoto, Sato, and Kobayashi 2004).
- At higher SNR in noisy environments, too much signal can degrade speech intelligibility (Morimoto, Sato, and Kobayashi 2004).
- Background noise conditions have a disproportionate effect on people with hearing impairment and non-native language listeners, and such listeners benefit from a higher SNR (Festen and Plomp 1990, Tachibana 2013).

The reader may also be interested in *ACRP Report 157: Improving The Airport Customer Experience* (Boudreau 2016) and ACRP Project 07-13, "Enhancing Wayfinding for Aging Travelers and Persons with Disabilities."

## 3.3 Qualitative Measures of Intelligibility

The scientific aspect of speech intelligibility has been studied for over 70 years. Qualitative or—more accurately—subjective measures of speech intelligibility were the initial assessments developed; one such measure is a scale rating the quality of intelligibility. The disadvantage of qualitative tests is primarily one of resources—although a recording can be used to generate the test words and sentences, many listeners are recruited to give their assessment. Another disadvantage is that each listener may have language skills or physical conditions that color his or her ability to offer an unbiased result. Such qualitative test results can be difficult to repeat. One advantage of qualitative measures is that they are useful for understanding issues such as native language or non-native language comprehension and particular sound combinations related to specific languages.

## 3.4 Signal-to-Noise Ratio

The signal-to-noise ratio (SNR) is a measure of how clearly a signal can be heard above noise, and it is a critical factor for speech intelligibility. SNR is defined as the ratio of the information (or signal) over the interference (noise). Given that sound and noise (unwanted sound) are commonly measured as sound pressure levels (SPLs) using decibels (dB), the ratio of the sound pressures can be equally expressed as the difference in decibels. Industry practice thus uses SNR to quantify the difference between the PA system sound level and the background noise level (e.g., heating, ventilation, and air conditioning noise). On a more basic level, SNR can be viewed as the effect of any unwanted sound that degrades intelligibility, such as sound lingering from announcements due to excessive reverberation.

Early research into an objective measure of speech intelligibility focused on the correlation between good SNR values and speech comprehension.

**Industry practice supports the use of 10 to 15 dB SNR, but a minimum design goal of 10 dB SNR may be adequate, if other positive factors are in place.** Figure 3-1 shows the measured SNR at each of the 46 airport spaces measured during unoccupied conditions. The average SNR

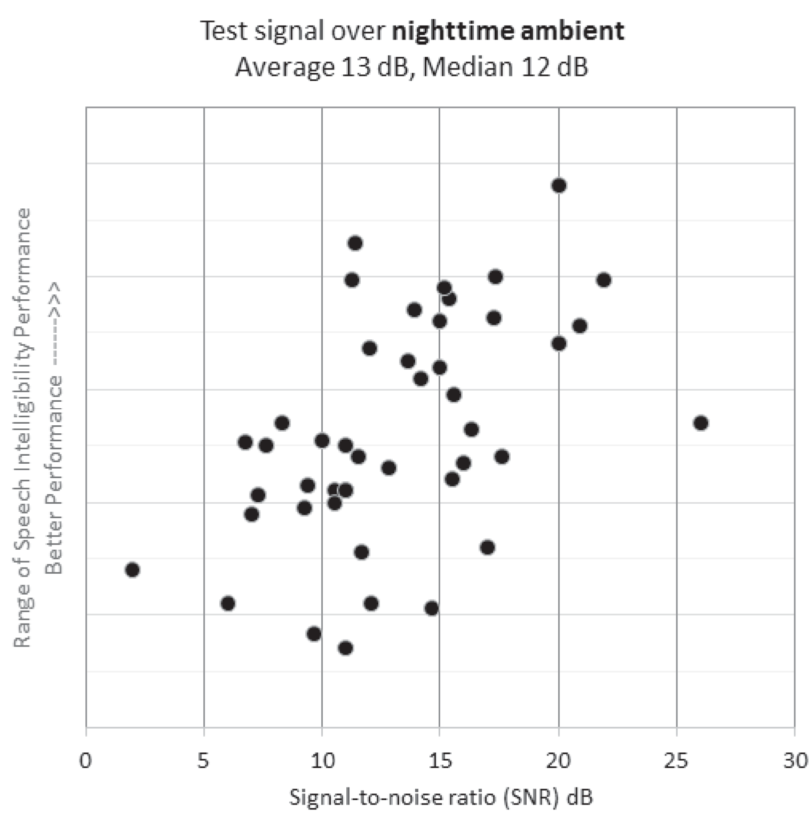



***Figure 3-1. SNR field measured in 46 airport spaces.***

was 13 dBA. The main point to understand here is that the preponderance of spaces had an SNR greater than 10 dB.

## 3.5 Quantitative Measures of Intelligibility

### 3.5.1 Speech Transmission Index

The most widely accepted quantitative measure of intelligibility is the Speech Transmission Index (STI), which is defined in IEC 60268-16:2011, *Objective Rating of Speech Intelligibility by Speech Transmission Index.*

STI values range from 0 to 1, with numbers close to 1 achieving high levels of intelligibility, yet even an STI value of 1.00 is no guarantee that the speech quality heard will be perceived as perfect. This quantitative measurement method relies on comparing a known signal broadcast through the loudspeaker with the sound measured at the receiver (e.g., height of the human ear); the test signal covers the frequency range of human speech with a specific sequence of periodic (repeating) signals.

The early research on STI also produced qualitative ratings ranging from "bad" to "excellent" for various ranges of STI values; given that these qualitative ratings are no longer included in IEC 60268, they are not included here.

Codes and application standards typically recommend a minimum STI of 0.45 or 0.50. IEC 60268, Annex G, for example, suggests that an STI 0.50 rating is an appropriate "target value for VA (voice address) systems." The distinction between a VA system and a PA system is that the VA system might be used for emergency or internal use—not for general purpose public messages and announcements. Table 3-1 excerpts information from Annex G of IEC 60268 and includes language about STI value acceptability contained in Annex G. As discussed in Section 3.8, to reach the design target during daytime operations, it will often be necessary to address the fact that daytime ambient conditions are higher than nighttime operations.

### 3.5.2 Speech Transmission Index for PA Systems

The development of instruments to measure STI more efficiently led to the development of the Rapid Speech Transmission Index ("the RASTI method") in 1979. When RASTI was applied to PA systems, however, shortcomings in the method became apparent. To make it practical to measure of the intelligibility of PA systems, Jan Verhave and Herman Steeneken, using extensive

**Table 3-1. Examples of STI qualification bands and typical applications.**

| STI Range | Typical Uses | Comments from IEC 60268 |
|---|---|---|
| 0.66–0.75 | Theaters, courts, assistive listening systems, classrooms, concert halls | High speech intelligibility |
| 0.62–0.65 | | Good speech intelligibility |
| 0.58–0.61 | Concert halls, modern churches | High-quality PA systems |
| 0.46–0.53 | Public spaces, cathedrals | Acceptable for voice address (target 0.50) |
| 0.42–0.45 | Difficult (challenging) spaces | |
| 0.00–0.41 | | Not suitable for PA systems |
| Source: IEC 60268 | | |

22 Improving Intelligibility of Airport Terminal Public Address Systems

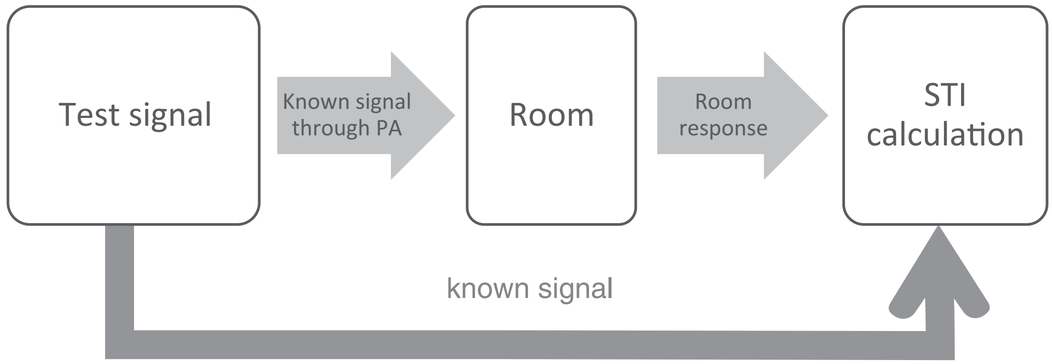



***Figure 3-2. Sound transmission index calculation process.***

research, developed the STI-for-PA method. United States and international standards exist to define specific measurements for speech intelligibility. Standards also exist for rating the effect of noise on intelligibility. In 1992, a convenient and efficient means of measuring speech intelligibility for PA systems, the Speech Transmission Index for PA (STIPA), was introduced. STIPA has come into wide use in the last decade and is an easy means of measuring the STI performance of a PA system in an existing space with background noise (see Figure 3-2).

Figure 3-3 shows the STI values from Figure 3-1 in relation to the SNR condition. The STI values measured at all 46 facilities during nighttime or quiet off-hour operations are plotted

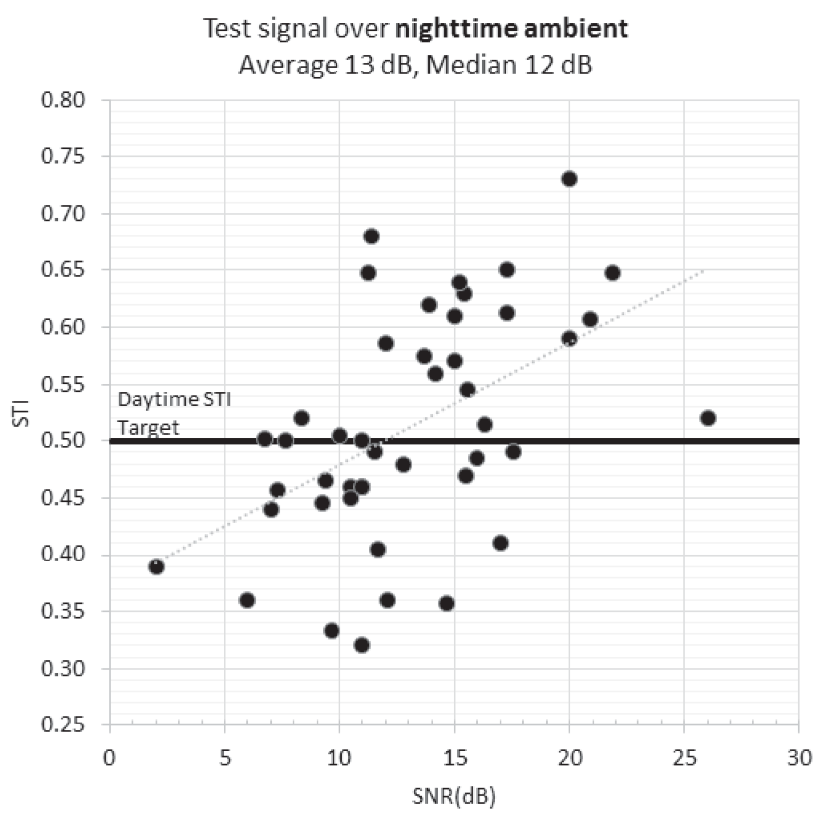



***Figure 3-3. STI plotted against SNR, field measured in 46 airport spaces.***

against the SNR. **The average STI value over all of these measurement locations was 0.51, which addresses the feasibility and practicality of achieving STI performance in conformance with the IEC 60268 VA target of 0.50. There is a general trend of improved STI performance with greater signal-over-ambient conditions. Although the average over all 46 measurement spaces was 13 dB SNR, the achievement of an SNR greater than 10 dB does not automatically result in high STI performance (see Figure 3-3) and other factors are important as well (see Chapter 4).** For areas with STI 0.50 or better, the average was 15 dBA, but these STI results were not absolutely fixed to the SNR value.

Almost 25% of the spaces measured STI 0.60 or better, and the average SNR was 16 dBA. The highest SNR was not a predictor of high STI performance. Thus, the guidance target is 10–15 dB SNR, in line with the spaces that provided STI 0.50 or better.

According to IEC 60268, a 3 dB change in the SNR should result in a 0.10 change in the STI. This is true for a single environment where the only change is the level, but across the 46 field measurements, each with different reverberant conditions and with different frequency characteristics, a 3 dB change in the SNR resulted in a much smaller STI change—about 0.03 points.

## 3.6 Code Requirements

The National Fire Protection Association (NFPA) has developed NFPA 72, Annex D (NFPA 2016), which addresses speech intelligibility in specific detail. Although the contents of Annex D are not mandatory, many public agencies use it as a basis of testing for adequate intelligibility. Annex D includes a specific test protocol for voice communication systems, a list of references, terminology definitions, discussion of STI and STIPA, issues having to do with background noise, and acceptability criteria. Annex D describes a clear approach for measuring intelligibility in an existing building and is directly applicable to airport facilities. NFPA 72 also specifies recommended acceptance criteria of 0.50 STI; values as low as 0.45 are acceptable as long as the average performance is 0.50. Annex D also mentions the importance of the design process for new buildings, including that hand calculations are sometimes adequate, but that more complex designs are "frequently better and more cost-effectively analyzed using readily available computer-based design programs." (See Section 7.12 for guidance on practical considerations for combining life safety systems with the general announcement PA system.)

## 3.7 Other Considerations

### 3.7.1 Non-native Language Listeners

Annex H of IEC 60268-16:2011 indicates that the SNR should be increased by 4 to 5 dBA to provide the same quality of speech intelligibility for non-native listeners; a 3 dBA SNR increase corresponds to a 0.10 improvement in the STI. Given that the guidelines focus on United States airports, the main focus of the discussion of non-native listeners will be on international travelers and on gate announcements and other announcements made in English; however, airports in some regions will want to take this into account for their populations as well.

Annex H, Table H.1, indicates that, **for non-native listeners, the target STI should be increased by 0.05 to 0.36 above the target goal for native listeners**. Table 3-2 is adapted from Annex H, Table H.1, and illustrates the different target adjustments based on language fluency. Table 3-2 also includes some qualitative ratings in association with each STI target value. **Practically speaking, it can be challenging to achieve an STI greater than 0.70 in an airport environment, so a cap on the total adjustment to the target goal should be considered.**

**Table 3-2. Adjusted intelligibility qualification tables relative to standard STI values for nonnative listeners.**

| STI Label Category | Standard STI | Nonnative Listeners Category I *Experienced, daily nonnative language use* | Nonnative Listeners Category II *Intermediate experience and level of nonnative language use* | Nonnative Listeners Category III *New learner and/or infrequent nonnative language use* |
|---|---|---|---|---|
| Bad–poor | 0.30 | 0.33 | 0.38 | 0.44 |
| Poor–fair | 0.45 | 0.50 | 0.60 | 0.74 |
| Fair–good (3) | 0.50 | 0.55 | 0.68 | 0.86 |
| Fair–good | 0.60 | 0.68 | 0.86 | Not achievable |
| Good–excellent | 0.75 | 0.86 | Not achievable | Not achievable |

Adapted from IEC 60268

Note 1. For details on STI label categories, refer to ISO 9921

Example: To achieve an intelligibility equivalent to an STI of 0.45 for a nonnative Category II listener, the transmission system needs to achieve a performance of 0.60.

Note 2. For intermediate values between the stated standard STI, interpolation should be used to estimate the adjusted STI.

Note 3. The nonnative category adjustments have been interpolated from the values in Annex H.

### 3.7.2 Hearing Impairment, Age-Related Hearing Loss, and ADA Considerations

Annex I of IEC 60268-16:2011 provides information on methods to adjust STI targets based on age and general assumptions about hearing impairment. The SNR should be increased by 4.5 dBA to provide the same quality of speech intelligibility for someone with a 20 dB hearing loss defined against the pure-tone average (PTA) hearing level. A 3 dBA SNR increase corresponds to a 0.10 improvement in the STI. The STI is not reliable for all types of hearing impairment, and other researchers use subject-based listening tests or other speech intelligibility methods to predict performance. Age-related hearing loss, however, can be directly adjusted. Table 3-3 is adapted from Annex I and presents these adjusted STI values, showing that the **STI should be raised by 0.12 to 0.21 points to account for hearing impairment. As mentioned in Section 3.7.1, a cap on the total STI adjustments should be considered**.

Passengers with hearing impairments and using conventional hearing aids can benefit from a PA system with a higher SNR setting. However, many airport environments can be noisy, and

**Table 3-3. Adjusted intelligibility qualification tables relative to standard STI values for listeners over age 60 with hearing loss.**

| STI Label Category | Standard STI | Older listener *PTA=15 dB* | Older listener *PTA=20 dB* | Older listener *PTA=30 dB* |
|---|---|---|---|---|
| Bad–poor | 0.30 | 0.42 | 0.47 | 0.51 |
| Poor–fair | 0.45 | 0.57 | 0.62 | 0.66 |
| Fair–good (3) | 0.50 | 0.62 | 0.67 | 0.71 |
| Fair–good | 0.60 | 0.72 | Not achievable | Not achievable |
| Good–excellent | 0.75 | Not achievable | Not achievable | Not achievable |

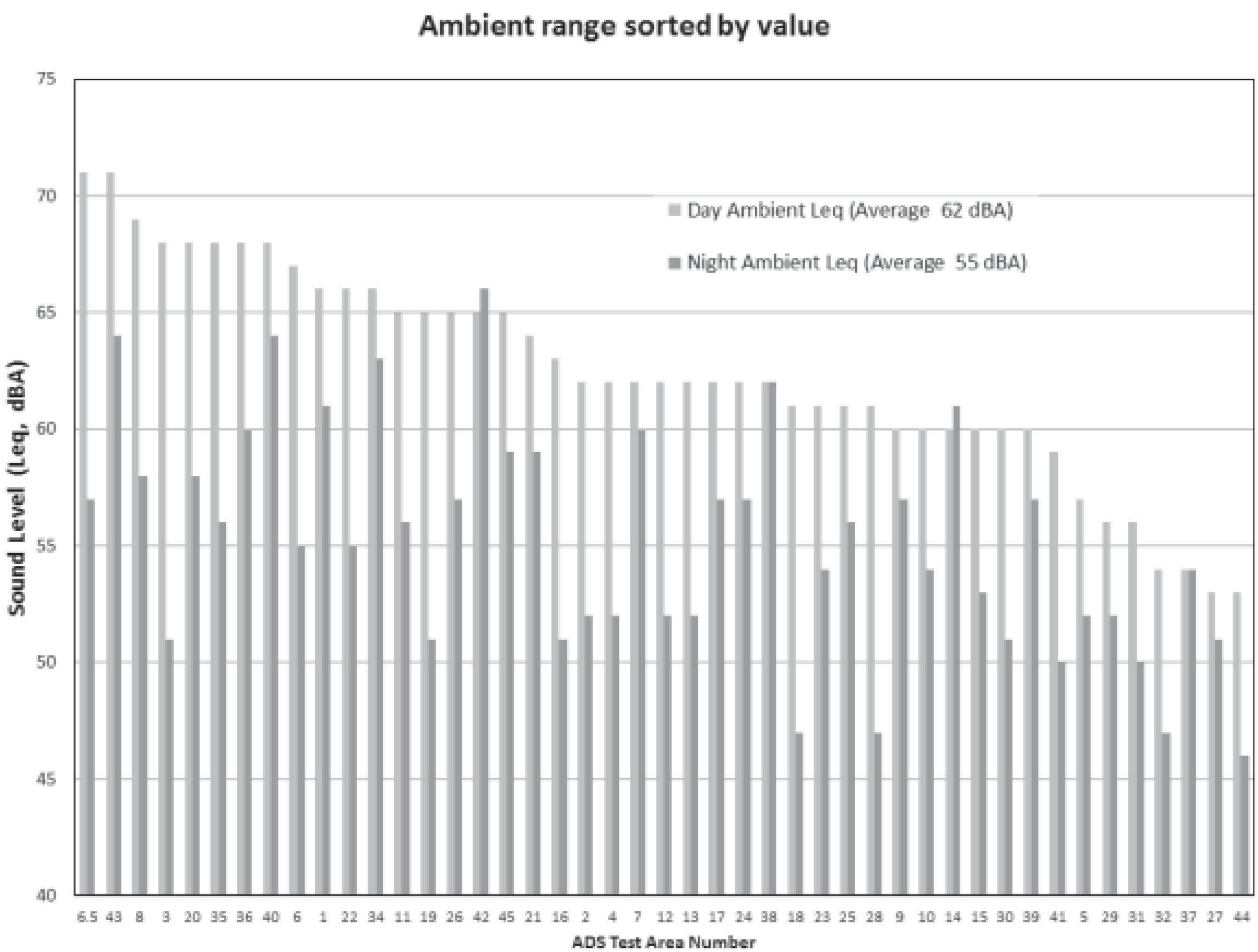
Note 1. For details on STI label categories, refer to ISO 9921.
Note 2. Standard STI values assume that listeners have a PTA between 0 and 5 dB.
Note 3. These values have been derived from the values in Annex I.
PTA = Pure-tone average hearing level.

given that noise is also amplified by hearing aids, it is not surprising that people with hearing aids opt to turn them down, relying more often on visual displays instead.

Per the ADA (ADA Standards 2010), in each assembly area where audible communication is integral to the use of the space, an assistive listening system shall be provided. In Chapter 7, additional information is provided for integrating audio-frequency induction loops into the PA system. These induction loops are essentially a loop of cable or an array of loops placed around a room or a building to generate a magnetic field that can be picked up by compatible devices such as modern hearing aids.

## 3.8 Effect of Ambient Noise on STI

Given that speech intelligibility and the STI are influenced by the SNR, the ambient noise conditions that affect the SNR also affect the STI. Figure 3-4 summarizes the range of ambient conditions measured, with the average daytime condition being 62 dBA and the average nighttime condition being 55 dBA over all 45 spaces where the ambient condition was measured.




Note: STI was measured at 46 spaces, but the ambient conditions were measured at only 45 spaces. No ambient conditions were measured at ADS 33.

***Figure 3-4. Ambient noise levels measured in 45 of the 46 different airport locations.***

**Table 3-4. Calculated daytime equivalent STI (wet) based on nighttime STI (dry) and daytime ambient conditions.**

| ADS | Use | Measured STI (dry) | Calculated STI (wet) | Difference | Nighttime ambient (dBA) | Nighttime SNR (dBA) | Daytime ambient (dBA) |
|---|---|---|---|---|---|---|---|
| 3 | TSA | 0.61 | 0.43 | -0.18 | 51 | 11 | 65 |
| 4 | Concessions | 0.65 | 0.51 | -0.14 | 52 | 22 | 62 |
| 5 | Gates | 0.68 | 0.43 | -0.25 | 52 | 11 | 57 |
| 6.5 | Concessions | 0.41 | 0.15 | -0.26 | 57 | 11 | 71 |
| 16 | Ticketing | 0.61 | 0.53 | -0.08 | 51 | 21 | 63 |
| 18 | Baggage | 0.73 | 0.46 | -0.27 | 47 | 20 | 61 |
| 19 | Baggage | 0.63 | 0.45 | -0.18 | 51 | 15 | 63 |
| 20 | Gates | 0.65 | 0.49 | -0.16 | 58 | 11 | 65 |
| 21 | Concourse | 0.49 | 0.35 | -0.14 | 59 | 12 | 64 |
| 22 | Ticketing | 0.52 | 0.23 | -0.29 | 55 | 8 | 66 |
| 35 | TSA | 0.45 | 0.18 | -0.27 | 56 | 11 | 68 |
| 43 | Curbside | 0.39 | 0.14 | -0.25 | 64 | 2 | 71 |
| 45 | Baggage | 0.61 | 0.50 | -0.11 | 59 | 15 | 71 |
| | | | | Average -0.20 | | | |

Measured daytime ambient conditions were on average 7 dBA higher than the nighttime conditions. Section 4.5 presents more discussion on ambient noise, and Section 6.6 presents guidance on controlling these sources.

It can be difficult to conduct the STIPA test during daytime operations for some reasons, including interference between the test and operational PA announcements, annoyance of traveling passengers, and the potential variability of ambient conditions during daytime operations. Thus, it is important to understand how the STI that is experienced during daytime operations may differ from the STI results obtained during nighttime conditions. The nighttime STI is measured during "dry" conditions, and the in situ daytime STI is measured or calculated during the "wet" condition. Since the SNR during the dry condition is often much greater than 10 dB, the expected STI under wet conditions can often be calculated by adding the daytime or wet ambient to the dry STI measurement result.

The expected change in the STI is about –0.20 points. Thus, a dry STI measurement of 0.70 can be expected to result in a daytime effective performance of approximately 0.50 under average conditions. Factors other than the A-weighted ambient sound levels may affect this difference; in particular, since the STI is frequency-dependent, a smaller change (perhaps –0.15 to –0.10) may occur between the dry and wet values, if the daytime ambient conditions can be controlled to maximize the SNR.

Ambient noise-sensing systems are becoming more widespread, and they typically provide about 5 to 8 dB additional SNR. An SNR increase of 3 dB can provide a 0.10-point improvement in the STI, but it is also important to know that ambient noise-sensing systems cannot overcome extremely challenging conditions under reverberant or high ambient noise conditions. More details are provided in Chapter 7.

## 3.9 Guidance Targets

### 3.9.1 Design

- **SNR: 15 dBA or better (preferred) in daytime ambient conditions; 10 dBA minimum. This is influenced during architectural design to control the ambient conditions and during PA system design and installation.**

- Design STI:
  - Daytime (wet): 0.50. This is the minimum target per NFPA 72, Annex D.
  - Nighttime (dry): Performance testing and commissioning are done outside normal operating hours. Design for a target STI = 0.60 to 0.70. Specific target value will depend on site-specific conditions. Based on the typical difference between daytime and nighttime ambient conditions, the following can be considered:
    - 0.60 for a PA system replacement. Without improving the acoustical environment; it may not be possible to achieve much more.
    - 0.65 based on the project's ability to control or lower the reverberation time and ambient noise and support the PA system.
    - 0.70 for new terminal or renovation; many options are available to provide a satisfactory acoustical environment to support the PA system.
  - The design STI can be applied terminal- or project-wide or different spaces can be assigned different STI values.
  - See Equation 3-1 to determine nighttime (dry) design goal.
- Human factors (HF): Add 0.03 to 0.10 points to compensate for challenges that specific passenger populations such as the following may have:
  - International travelers and non-native language listeners
  - Passengers with disabilities such as hearing impairment

Also be aware of other site-specific considerations for which compensation is required.

*Equation 3-1. Guidance STI formula during design.*

$$\text{Dry Design STI} = [0.60 \text{ to } 0.70] + \text{HF}$$

### 3.9.2 Performance and Commissioning

The STI performance is typically measured during ambient conditions that are lower than conditions during normal daytime operations, and the correction for daytime ambient conditions can be approximately -0.20 STI point. If desired, one can develop the performance STI requirement by reducing the design STI by 0.10 to account for an ambient noise-sensing system.

- Performance STI: This is the value shown in the specifications. It can be applied terminal- or project-wide or different spaces can be assigned different STI values. See Equation 3-2 to determine nighttime (dry) performance goal.
- Ambient noise microphone adjustment (AN): This is an adjustment to allow for ambient noise-sensing in the PA system. The overall performance STI can be reduced by 0.10 point.

*Equation 3-2. Guidance STI formula to implement in specifications.*

$$\text{Dry Performance STI} = \text{Design STI} - \text{AN}$$

CHAPTER 4

# Physical Factors Affecting PA Intelligibility

## 4.1 General Acoustical Principles

This chapter presents and discusses the acoustical principles that affect the speech intelligibility of PA systems in enclosed spaces such as airport terminals. To present background information to understand these principles, this section introduces the basic concepts of acoustics, including how sound is measured. The general design principle for room acoustics is to provide a diffuse sound field in which strong echoes are not present and the reverberant field is more dominant than the direct sound from individual sound sources.

As illustrated in Figure 4-1, six physical factors interact with one another to affect speech intelligibility. Volume and shape directly influence the reverberation and reflections and echoes in a space. In turn, reverberation and reflections and echoes influence the ambient noise. Announcement quality is an important and often overlooked factor that is influenced by PA system design. PA system design is influenced by reverberation, reflections and echoes, and ambient noise.

## 4.2 Spatial Considerations—Volume and Shape

Room volume and shape strongly influence the basic acoustical properties of each space. The important factors in this regard are overall size and shape, the orientation of room surfaces, and how reflective or acoustically absorptive the room surfaces are. Volume and reverberation time are related, and the room shape can create strong reflections, resulting in echoes that can degrade intelligibility.

Building type and space programming generally dictate overall room volume and shape. More control and flexibility are generally feasible for ceiling heights, shape of ceilings, and design of interiors. Conventional rectangular shapes and flat surfaces are generally straightforward to control acoustically, but curved surfaces, which are challenging, are discussed further in Section 4.4.

Ceiling height is a key factor in acoustical design and PA design. Consider the following basic height groupings:

- “Low” ceiling height: less than 13 feet
- “Medium” ceiling height: 13 to 24 feet
- “High” ceiling height: >24 feet

Table 4-1 shows the number of spaces encountered during the acoustic field studies for each of the basic ceiling height groupings. The average ceiling height for all of the spaces tested was 24 feet.

Figure 4-2 shows the measured STI plotted against the median ceiling height with the dashed lines showing the divisions between the low, medium, and high ceiling groupings indicated above. Despite some outliers, the general trend indicates a decrease in the STI with increasing

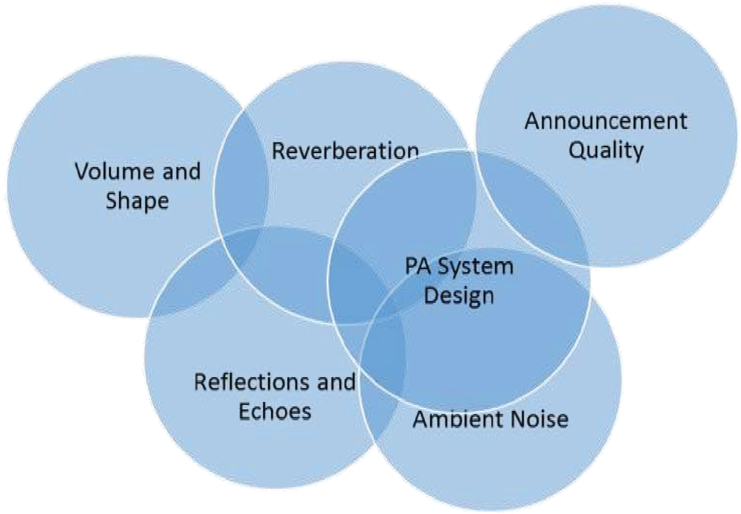



***Figure 4-1. The six physical factors that affect PA system speech intelligibility.***

**Table 4-1. Categorization of field study locations by ceiling height.**

| Number of Test Spaces for Each Ceiling Height Grouping | | |
|---|---|---|
| Low<br><13 feet | Medium<br>13 to 24 feet | High<br>>24 feet |
| 12 spaces | 19 spaces | 15 spaces |

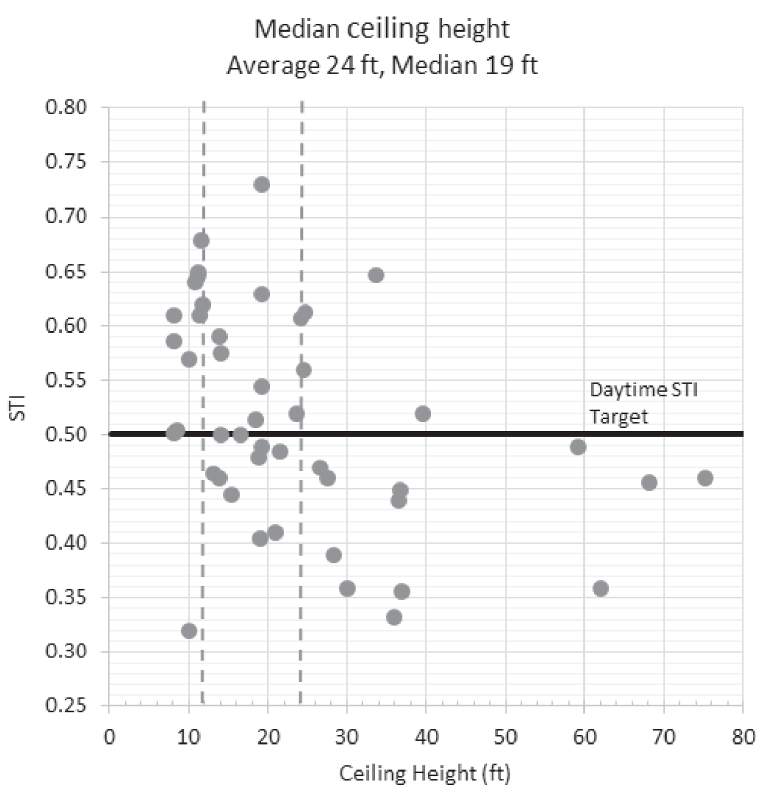



***Figure 4-2. STI plotted against median ceiling height. STI target 0.50 for daytime ambient conditions.***

ceiling height. For STI 0.60 or better, the average ceiling height was 16 feet with a range of 8 to 34 feet. For STI 0.50 or better, the average ceiling height was 17 feet with a range of 8 to 40 feet. **This data demonstrates that, for most ceilings less than 10 feet high, an STI of 0.50 should be achievable, whereas when ceiling height is greater than 10 feet, it is more challenging to achieve an STI of 0.50, even though most test results indicate that an STI of 0.50 is achievable up to 24 feet. The data indicate that where ceilings are over 24 feet high, it is very challenging to achieve an STI of 0.50.**

## 4.3 Reverberation

Reverberation refers to the persistence of sound in an enclosed space due to reflections. Some reverberation is inevitable and actually necessary, but excessive reverberation can be detrimental to intelligibility. Reverberation is measured as the decay of sound with time. The commonly used measure of sound decay is the $RT_{60}$. The $RT_{60}$ is defined as the time (in seconds) it takes for sound, after it is stopped in an enclosed space, to decay by 60 dB. Figure 4-3 graphs reverberation time.

The basic formula for $RT_{60}$, as shown in Equation 3, is a function of *volume* and *effective acoustical absorption*. Various other formulas are used to calculate reverberation time, and all of these formulas address nominal geometry and acoustical absorption conditions. However, this formula, developed by Wallace Clement Sabine, was the first and is still useful for general guidance. Given that the $RT_{60}$ is proportional to volume, the larger the volume, the higher the reverberation time for a fixed amount of absorption. In larger spaces, the sound strikes the surfaces (where it would be absorbed) less frequently, reducing the decay time and thereby increasing the reverberation time. Given that volume and surface area do not increase in the same proportion, as spaces increase in volume, there is proportionally less surface area to treat, and to achieve the same reverberation time, more surface area needs to be treated or else the surface area needs to be treated with more effective absorptive material.

The Sabine formula assumes uniform distribution of absorption for a "live" room. Several other algorithms are in common use. One of these, the Eyring formula, assumes uniform distribution for a "dead" room—that is, a room with a very high level of acoustical absorption; this is not typically applicable to airport spaces. The Fitzroy formula has a distinct advantage in that it evaluates the three axes of a room individually (i.e., north–south, east–west, floor–ceiling) and then combines these to determine the overall contribution. The Arau-Puchades method is similar to the Fitzroy

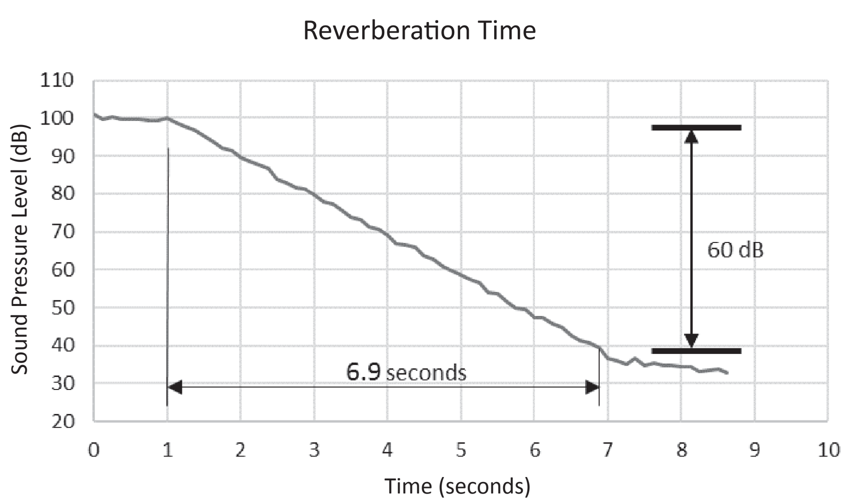



***Figure 4-3. Reverberation time ($RT_{60}$).***

formula in that three axes are analyzed; however, it uses a different variation for combining them. Either of the latter two methods are attractive for design studies because they allow one to isolate particular room surface pairs and study design changes. The acoustical absorption of air starts to come into play at frequencies of 2,000 Hz and higher and may be necessary for complex spaces where the reverberation time is difficult to control, because it can be factored into design calculations in addition to the room finishes.

Reverberation time is the differences in the sound-absorbing characteristics of common room finishes.

***Equation 4-1. $RT_{60}$ (Sabine formula).***

$$RT_{60}\,(\text{seconds}) = 0.049\ V/A$$

$V$ = room volume ($ft^3$)
$A$ = effective acoustical absorption (sabins) = $[S_1\alpha_1 + S_2\alpha_2 + S_3\alpha_3 + \cdots\cdots + S_n\alpha_n]$
$S$ = surface area ($ft^2$)
$\alpha$ = average absorption coefficient of surface material

The larger the volume of the space, the more surface area must be covered with acoustical absorption to maintain the $RT_{60}$ within an acceptable range. The acoustical absorption in the space is the total absorption provided by the interior room finishes. In some cases, an entire surface may be an opening into the adjacent space (e.g., the dividing plane between a low-ceiling gate hold area and the adjacent higher ceiling walkway. The absorption is calculated by multiplying the surface area of interior room finishes by their respective absorption coefficient and summing the total absorption in the room (expressed in sabins).

When reverberation time is *not* controlled, the following can result:

- The persistence of reverberant sound in the space has a masking effect on later-occurring sounds.
- In the case of announcements, the masking effect results in overlapping speech syllables, which can sound garbled and unintelligible to the listener.
- Reverberation has the undesired effect of increasing room ambient noise (since the reverberant noise tends to build up more in spaces with longer reverberation times).
- Higher ambient noise degrades the SNR of the announcement level, which further undermines the intelligibility of announcements.

***Caution:* Spaces with high reverberation cannot simply be "compensated for" by boosting the signal level of announcements. In fact, this can have the opposite effect and further degrade speech intelligibility by exciting more of the reverberant field. Refer to the discussion on SNR in Section 3.4 and the discussion on designing PA systems in large reverberant spaces in Section 7.8.**

Reverberation time is frequency-dependent. Typically, it is evaluated over the audible frequency range with particular attention to the behavior at 500 Hz and 2,000 Hz, which are important frequencies with respect to speech intelligibility. Low-frequency reverberation can also be an important factor in airport spaces and needs to be considered when determining how the PA system should be equalized (see Section 8.4.4). A sample $RT_{60}$ chart is shown in Figure 4-4, comparing a well-controlled baggage claim area with a poorly controlled concourse area. In Figure 4-4, the high ambient noise levels and the limitations of the airport PA systems did not allow a full 60 dB test. This is a common issue, and, in these cases, the initial trend is extended to estimate the reverberation time, as shown in the figure.

As mentioned in Chapter 1, few previous studies were found in the literature review specific to airports, although some researchers have investigated large public spaces and various measures

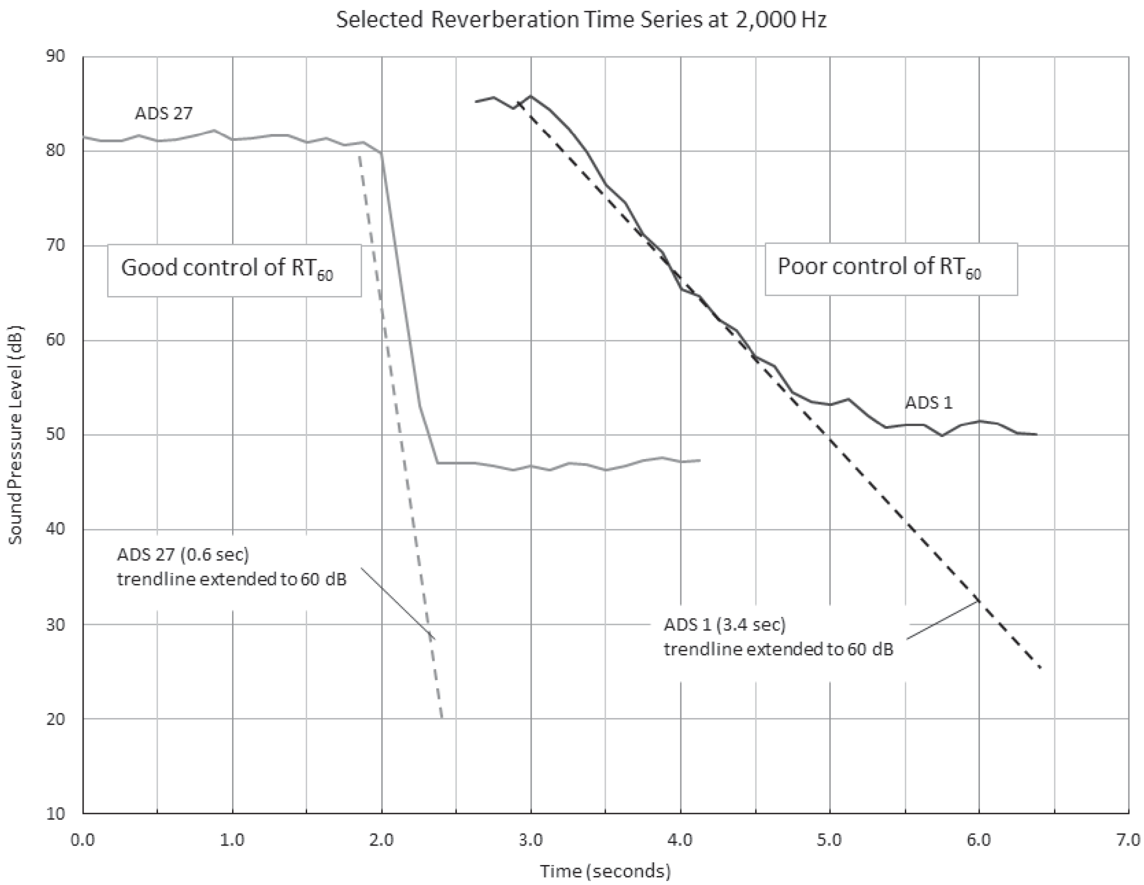



***Figure 4-4. Comparison of reverberation time measurements.***

of intelligibility. Studies indicate that speech intelligibility is strongly correlated to reverberation time, and, although successful examples have been identified in the literature with reverberation times up to 2.4 seconds, reducing the reverberation time below 1.9 seconds showed the strongest effect on increasing STI.

The results of the acoustic field studies confirm how critical it is to control reverberation time for speech intelligibility in the design of airport terminal spaces. In fact, other than good PA system design, an adequate reverberation time and low ambient noise levels are the two most important parameters for achieving good intelligibility. Passengers with visual impairment also rely on the acoustic characteristics of spaces to orient themselves within those spaces, so a total reduction of reverberant conditions would not be helpful for those passengers. Table 4-2 compares the measured reverberation times as a function of terminal space type.

Figure 4-5 presents all of the reverberation time data at 2,000 Hz from 45 spaces at 6 airports grouped by ceiling height. The strong association between $RT_{60}$ and STI is evident with the STI dropping off substantially with increased reverberation time. Of all the case studies, only a few achieved STI 0.50 intelligibility with reverberation over 2.0 seconds. Most industry survey respondents (69%) judged high reverberation to be one of the most important factors hindering passengers' ability to understand PA announcements.

Based on all of the field measurements, the average reverberation time at 2,000 Hz measured 1.6 seconds. In many cases, spaces with reverberation times less than 1.6 seconds were also near or better than the STI 0.50 target. Good acoustical practice would provide lower reverberation

**Table 4-2. Measured reverberation times grouped by terminal space.**

| | $RT_{60}$ (2,000 Hz) | | |
|---|---|---|---|
| | Average | Low | High |
| **Arrivals** | 2.0 | 1.6 | 2.3 |
| **Baggage** | 1.5 | 0.6 | 2.8 |
| **Concourse** | 1.8 | 0.8 | 3.4 |
| **Food court** | 1.9 | 1.1 | 3.0 |
| **Gates** | 1.3 | 0.7 | 3.5 |
| **Ticketing** | 1.6 | 0.6 | 2.9 |
| **TSA** | 1.4 | 1.0 | 2.1 |
| **All spaces** | 1.6 | 0.6 | 3.4 |
| **All adequate spaces (STI 0.50 or greater)** | 1.1 | 0.6 | 2.9 |

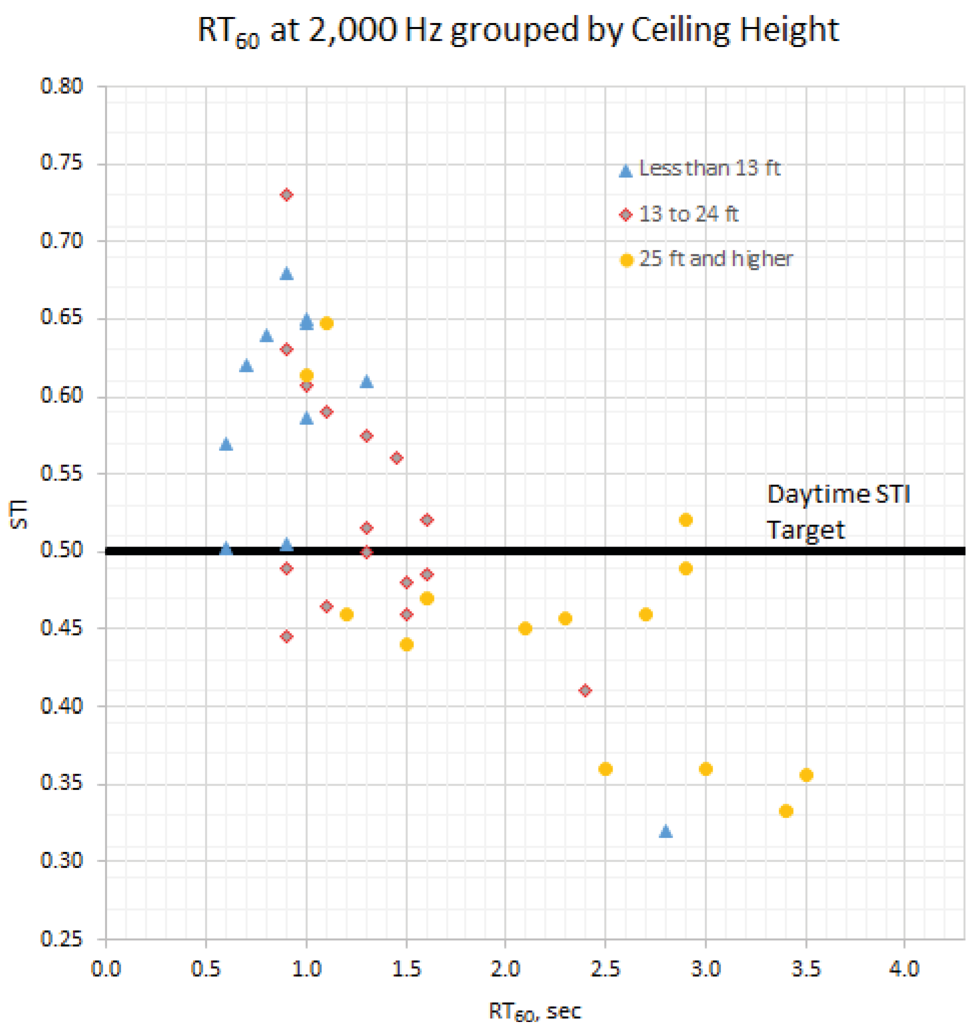



***Figure 4-5. STI plotted against reverberation time, grouped by ceiling height.***

time, depending on the space and what is feasible given the size of the space. For more information, see Chapter 6.

**The average reverberation time for spaces with STI 0.50 or better was 1.1 second or less, while the average reverberation time for spaces with STI greater than or equal to 0.60 was 1.0 second or less. Thus, while $RT_{60}$ is strongly tied to STI performance, the nominal guidance target is in the range of 1.1 to 1.5 seconds, preferably less. Figure 4-6 illustrates the typical surface area required to achieve an $RT_{60}$ of 1.5 seconds or less, expressed as a percentage of total surface area. Guidance is set for 1.5 seconds—slightly lower than the field measurement results and more in line with best practice for acoustics.**

### 4.3.1 Acoustical Finishes

Reverberation can be controlled through the use of acoustically absorptive room surface finishes, which can be more or less effective, depending on their inherent qualities. In an airport terminal environment, surface finishes that are desirable for aesthetics and maintenance are not always those with the best acoustical properties. Finding the appropriate materials and mix of those materials can be a challenge when working to develop a design that adequately controls reverberation. However, various acoustical products exist, with an increasing number of products available on the market that not only provide necessary control of reverberation but that can also be used to enhance spaces visually. Section 6.3 provides more information on designing acoustical finishes, the range of products that can be used, and what to look for when reviewing acoustical product data.

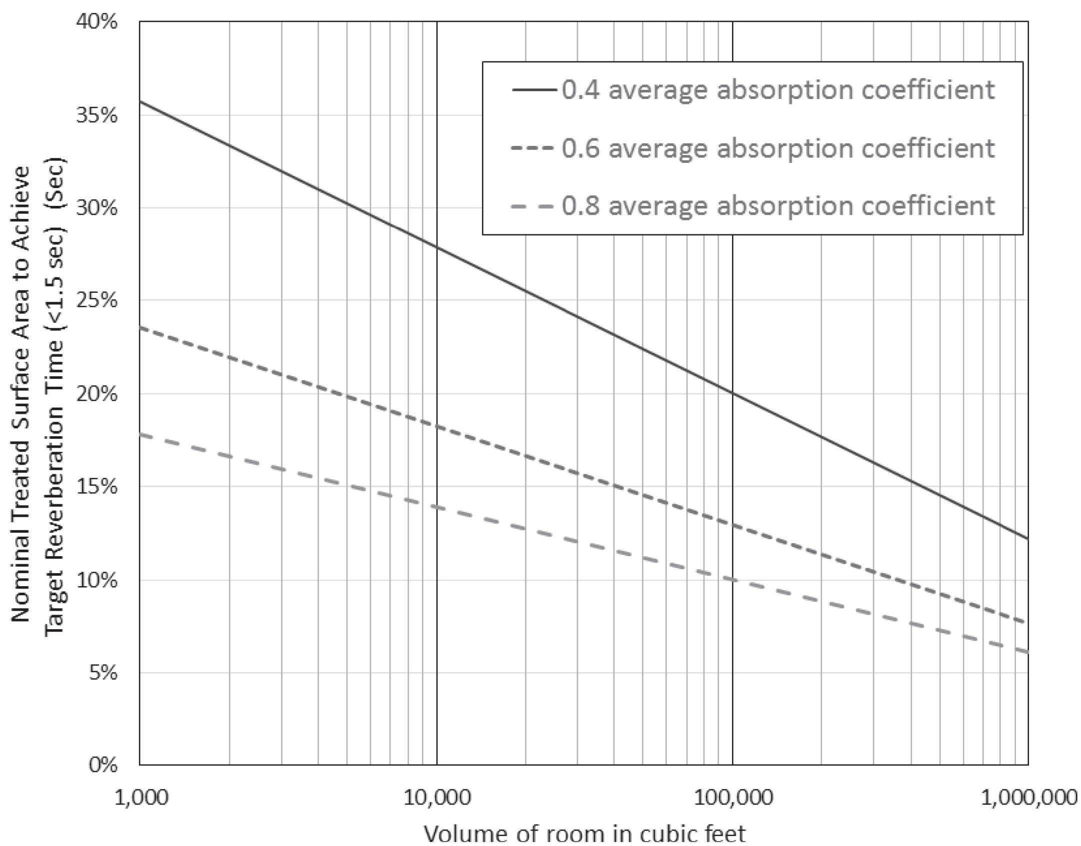



***Figure 4-6. Nominal percentage surface area necessary to achieve $RT_{60}$ less than 1.5 seconds.***

There is a trade-off during design when deciding which materials to use and how much to use, depending on how absorptive they are. For instance, some materials are quite absorptive (e.g., 1-in.-thick acoustical panels) and could require less surface area application than a less absorptive material (e.g., ½-in. think suspended acoustical tile). However, there is a limit to how effective a minimal amount of treatment will be, even if it is inherently absorptive. In general, it is better to use more material over a broader area than highly absorptive material over a small area. The Sabine formula (Equation 4-1) is based on an assumption of nearly uniform absorption coverage. As coverage becomes more localized (that is, nonuniform), other equations must be used to calculate $RT_{60}$. See Section 6.10 for more information on modeling.

### 4.3.2 Passengers

Clothing worn by passengers absorbs sound. When determining how much reverberation will exist, the average number of travelers in a space needs to be taken into account as well as the fact that the number is constantly varying. Appendix E provides acoustical absorption data for people and comparison with acoustical absorption for standard finishes.

## 4.4 Sound Reflections and Strong Echoes

A diffuse field is one where the reflected sound from all surfaces is higher than the direct sound from any one source. As good room acoustics design strives to provide a diffuse sound field, unwanted sound reflections and focusing can cause discernible echoes and adversely affect spaces, even when reverberation time is adequately controlled. A concave surface can focus sound, unless it has been treated with an appropriate acoustically absorptive material. Sound reflections are perceived as echoes when reflected sound arrives about 50 to 100 milliseconds after the original sound. For illustration, consider that sound (which travels at a speed of 1,120 feet per second) would take about 50 milliseconds to reflect from a surface about 30 feet away and about 100 milliseconds to reflect from a surface about 55 feet away.

Echoes should be avoided where possible with proper PA design and architectural design. The degree to which the echo will be disturbing to listeners is a function of the echo level (the strength of the echo relative to the direct sound) and the delay time. Psychoacoustic research experiments have investigated disturbance due to discrete echoes in specific reverberation conditions. Sounds separated by 80 milliseconds are perceived as separate events, and thus, for adequate speech intelligibility, the delay should be significantly less than 80 milliseconds; industry practice shows that a delay less than or equal to 40 milliseconds is ideal. The longer the delay, the lower the echo must be relative to the direct sound.

Some surfaces, such as those with a concave shape, have a focusing effect on incident sound that can lead to acoustical "hotspots" in a room that reduce intelligibility. Convex surfaces, on the other hand, can have a diffusive effect on incident sound and help to spread sound in a space. Certain shapes can have particularly strong focusing effects depending on the geometry. Shapes to avoid include any sort of concave curved wall or ceiling such as a dome, arch, oval, or rotunda, unless an adequate amount of acoustical absorption is provided to offset these focusing effects.

"Flutter echo" refers to a distinct sound reflection pattern that may occur in the presence of large flat or parallel surfaces. This might be noticed in a large hallway where sound from a hand clap, for example, reflects repeatedly off the walls or between parallel planes of acoustically hard ceiling and floor. The sound can be observed to "return" several times before it dies out. This effect can be controlled by acoustically treating one or more of the surfaces. An alternative is to slope one of the parallel surfaces (e.g., one of the walls or the ceiling) at a 1:11 slope.

## 4.5 Ambient and Background Noise

One of the main goals in speech intelligibility is to increase the signal-to-noise ratio (SNR). The ambient noise can compromise intelligibility by decreasing the SNR. In an airport environment, background noise is the steady noise that does not vary much during the day. Ambient noise is the all-encompassing noise at any moment, including the background noise and transient noise. There are many sources of background noise in an airport terminal. They can be steady or constant noises, but many are time-varying or transient noises. It is important to think about how to account for this difference when considering SNR.

Not surprisingly, in the industry survey, background noise was considered one of the most important factors negatively affecting passenger ability to understand PA announcements. Both this factor and reverberation time were cited as negative factors, indicating that background noise and reverberation time are recognized as influencers of speech intelligibility. This has been borne out with measurements as discussed in Section 3.8.

### 4.5.1 Steady Noises

Examples of steady noises are airport terminal HVAC systems and escalators. These noises are relatively easy to account for in design and can be controlled so that they do not significantly impair intelligibility. For exterior curbside locations, the ambient noise is also caused by automotive traffic in the airport or on nearby busy roadways.

### 4.5.2 Transient Noises

Transient noises are intermittent and thus, during design, are more challenging to account for due to their continually varying nature. Examples of transient noise sources include occupant activity such as people talking and moving about, television monitors, airplane activity, and roadway traffic.

### 4.5.3 Ambient Noise Measurements (Interior Sources)

Table 4-3 summarizes ambient noise data obtained from the field studies, organized by type of space. When the results for spaces meeting the target STI value of 0.50 are compared with

**Table 4-3. Summary of interior ambient noise data by terminal area.**

| Terminal Area | Ambient Noise Levels (dBA)—Daytime | | | Ambient Noise Levels (dBA)—Nighttime | | |
|---|---|---|---|---|---|---|
| | Average | Low | High | Average | Low | High |
| **Concourse and food court** | 64 | 62 | 71 | 57 | 52 | 63 |
| **Arrivals hall and gates** | 60 | 51 | 67 | 54 | 47 | 61 |
| **Baggage and curbside** | 62 | 53 | 71 | 55 | 46 | 64 |
| **Ticketing and TSA** | 63 | 56 | 68 | 55 | 51 | 66 |
| **Average of all spaces** | 62 | 51 | 71 | 55 | 46 | 66 |
| **Average of adequate spaces (spaces with STI 0.50 or greater)** | 61 | 53 | 71 | 54 | 46 | 63 |

Samples were short snapshots of the particular time that the space was accessed. To the extent possible, these values represent the typical conditions without nearby PA announcements or nearby transient noises.

the entire group of measurements, the nighttime and daytime measurement results are not significantly different—only 1 dBA different for the average values. Furthermore, there is a small but consistent difference in measurements between some of the terminal areas. Concourse and food court areas not only had the highest average values for daytime and nighttime, the low value (background) was also substantially higher for that category—6 to 11 dBA higher during the daytime and 1 to 6 dBA higher during the nighttime. This makes sense, given that the food court areas in general tended to have the highest ambient noise levels.

The average daytime ambient noise level for all adequate spaces (where the dry condition speech intelligibility measured STI 0.50 or better) was 61 dBA, just slightly less than the 62 dBA average for all spaces.

Perhaps a more useful grouping of the data considers only the ambient level, irrespective of the terminal use. Some airports were inherently quieter than others, so averaging across "quiet" and "noisy" gate areas made it difficult to capture the difference. By separating the ambient measurements by level, a clearer characterization was identified with the four groups shown in Table 4-4. **The two noisy groupings had a higher $RT_{60}$; the longer reverberation time directly increases the ambient environment about 1 dBA.** The octave band spectra for each of these four groups are provided in Appendix I.

### 4.5.4 Ambient Noise Measurements (Exterior Sources)

Control of exterior noise should be addressed by providing building facade elements in the design of the base building that adequately attenuate noise (see Section 6.6.9). Jet noise is an example of a transient noise that can be intrusive to the acoustical environment of interior spaces. Proper glazing can provide sufficient attenuation of jet noise. The acoustical metrics that describe noise attenuation of exterior shell elements such as glazing are the Outdoor-Indoor Transmission Class (OITC) and the Sound Transmission Class (STC).

During the field study, measurements were performed in an unoccupied gate with airplanes taking off on a runway next to the terminal. Average noise from jets ranged from 59 to 62 dBA, with maximum noise levels of 63 to 68 dBA. Given that higher frequencies are attenuated more than lower frequencies, the potential for jet noise to degrade STI is not as high as one might expect. Figure 4-7 compares interior noise from several jets taking off with the interior ambient noise level of 55 dBA.

**With a design target of 59 dBA for ambient noise levels during the day, it would be helpful to improve the building shell design to provide an additional 3 to 9 dBA noise reduction. This could require an OITC 40 rating for terminal buildings exposed to loud runway noise. It may be necessary to increase the building sound insulation target near runways to achieve the target 59 dBA ambient conditions.**

**Table 4-4. Airport ambient conditions, grouped by sound level and spectral characteristic.**

| Ambient Character | Average Ambient Level (dBA) | Average STI | Average $RT_{60}$ at 2,000 Hz |
|---|---|---|---|
| Daytime noisy | 65 | 0.51 | 1.8 |
| Daytime quiet | 59 | 0.51 | 1.4 |
| Nighttime noisy | 59 | 0.50 | 1.8 |
| Nighttime quiet | 51 | 0.52 | 1.4 |

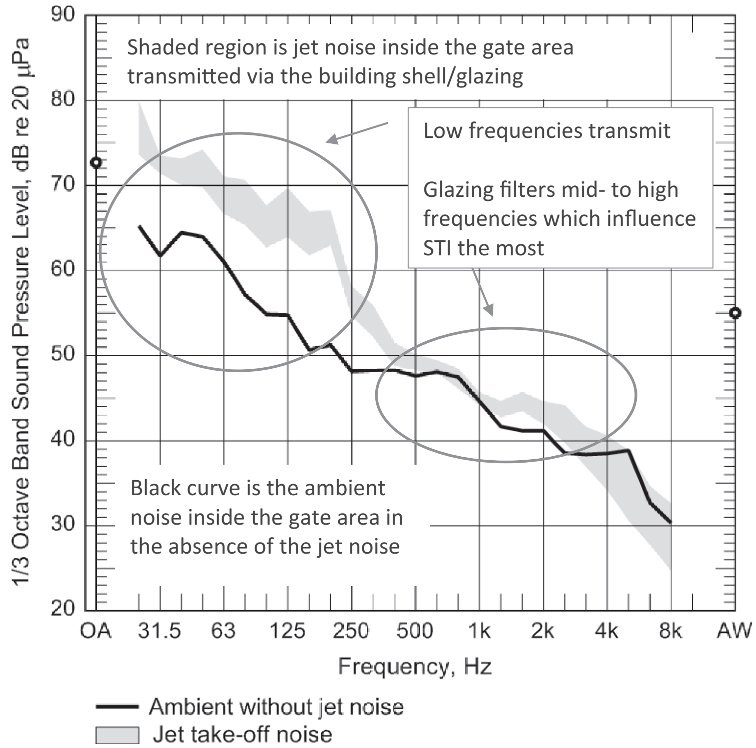



***Figure 4-7. Noise measured in unoccupied gate area during jet take-offs on runway adjacent to terminal building.***

## 4.6 PA System Design

One of the concepts underlying speech intelligibility is the SNR—how does the PA system provide adequate signal to compensate for the ambient noise environment? The two primary physical factors that affect the SNR and the speech intelligibility of PA systems are reverberation time and ambient noise. If the ambient noise level is high, the PA system design and settings must be able to furnish the 10 to 15 dB SNR. If the reverberation time is overly long, it is difficult to reduce the ambient noise, and also the passenger's ability to distinguish and understand the content of the message is decreased. A major goal in PA intelligibility is to implement a PA sound system that reproduces sound without distortion and at a level sufficiently above the background noise level. (See Chapter 7 for detailed information on which aspects of PA system design are related to speech intelligibility.)

## 4.7 Announcement Quality

In particularly challenging environments, announcement quality is even more important. To take full advantage of good room acoustics, a well-designed sound system, and low background noise, the prerecorded announcements need to be of high quality. The industry standard for live announcements must also be considered—currently the quality of live announcements varies depending on the training and speaking ability of the person making them. (Chapter 5 presents more detailed observations and suggestions on live speaking and automated and artificial voice messaging systems. Chapter 10 addresses announcement content and composition. Chapter 11 includes guidance about training.)

## 4.8 Guidance Targets

Given that SNR is one of the underlying concepts for speech intelligibility, PA systems must furnish adequate signal to compensate for the ambient noise environment. Guidance values are as follows:

- **Design for $RT_{60}$ 1.1 to 1.5 seconds at 500 to 2,000 Hz to support adequate speech intelligibility of the PA system.**
- **Design for daytime and nighttime ambient noise levels 59 dBA or less with noise control techniques to maintain low ambient noise conditions and maximize PA system SNR.**
- **Aim for median ceiling height less than 16 feet if ceiling-mounted speakers are desired. This should be generally straightforward to achieve adequate performance without the need for substantial input from design professionals in acoustics or PA system design. Ceiling heights greater than 24 feet are not good candidates for ceiling-mounted speakers.**
- **Consider the necessary building sound insulation to achieve the target 59 dBA ambient conditions near runways.**

CHAPTER 5

# Human Factors Affecting PA System Intelligibility

## 5.1 Introduction

Although the PA system design and acoustical environment may be optimally designed, the human factor ultimately determines whether a PA announcement is heard, understood, and acted on. This chapter considers what human factors may influence attention, perception, and effective listening to PA announcements. Effective listening is assumed here to be where the passenger has heard, understood, and can act on the information given in a public announcement message. Beyond speech intelligibility, which requires that the message has been heard and (nominally) understood, effective listening carries with it the element of the human factor.

## 5.2 Psychology of PA Announcement Intelligibility: Attention and Perception

This section discusses attention and perception and how they affect whether people will hear and understand PA announcements.

Research shows that auditory attention can be conducted in two ways: "bottom-up" or "top-down" processing.

- **Bottom-up processing** begins with the stimulus, and the stimulus influences what listeners perceive. For example, listeners may start with no preconceived idea of what they are hearing and the stimulus itself influences their perception of what they are hearing. Bottom-up processing is stimulus-driven and the perception of the message itself directs the listeners' cognitive awareness of what they are hearing. In PA terms, the message content influences what the listener perceives of the message.
- **Top-down processing** uses the listeners' personal experiences and knowledge, individual expectations, and current goals to influence perception. With top-down processing, listeners use what they know in order to perceive what they are attending to. Top-down processing is also goal driven, which can be either voluntary or task-dependent. In PA terms, the listeners themselves influence how they process and understand the message.

From a theoretical perspective in an airport environment:

> An *experienced passenger* is likely to be using top-down processing to actively seek information from auditory messages and will have expectations regarding the information and format of those messages based on past experiences. It can be assumed that the experienced passenger would be an effective listener, actively seeking the information from the message and able to perceive, through past experience, what is required from them and to act accordingly. Frequent passengers employing top-down processing would know what they are searching for and employ a template-based search (Fritz et al. 1994).

However, simple real-world observations from a passenger pilot study suggest that, contrary to the theory that experienced passengers will be more active listeners, these passengers actually tend to “tune out” the PA messages—for example, frequently using headphones to isolate themselves from exterior messages. This behavior changed in the gate area, where they actively listened for information directly relevant to their journeys—for example, listening for when their allocated seat row or boarding group could board the plane. This suggests that they were only actively listening at points in their journeys when they knew information would be provided about actions they needed to take—particularly information that might not be available through other channels. (A high proportion of business passengers interviewed in the airport passenger survey noted that they looked for updates and flight details on their mobile devices using airline apps and texts; these would offer information about gate numbers, delays, etc., but would not give boarding instructions.)

Let’s return to the theory of bottom-up information processing and apply it to an airport environment:

> A novice, infrequent or *inexperienced passenger* is likely to process information in a bottom-up way. Inexperienced passengers having no expectation of the flight information messages would employ bottom-up processing, seeking information from the PA message and identifying salient points in the message in order to understand it. The processing of the salient points could almost be considered as highlighting certain features in comparison to their neighbors, for example destination names, times, etc. which stand out as salient within a message. The research suggests that novice passengers may not be actively listening and so will be more likely to employ bottom-up processing (Fritz et al. 1994).

Real-world observations from the pilot study support the theory that inexperienced passengers are not actively listening at all points in their journey through the airport. Inexperienced passengers stated that they were often distracted by other activities in shops and food outlets and so were unlikely to be paying attention to PA announcements. However, at key points in their journeys, they actively sought information—such as immediately after leaving the security screening area and in the departure hall or gate areas as their departure time neared. Because of the multiple auditory and visual stimuli encountered in an airport, the inexperienced passenger was no more likely than the experienced passenger to be actively listening for PA messages. **Use key words such as flight destinations as salient points at the beginning of the announcement to draw passenger attention to PA messages.**

An important concept in processing information is the notion of passengers being “primed” to listen for a message. Research in attention and perception suggests that even relaxed participants who are not considered to be actively listening, but are pre-primed with the expectation of a message, will on some level be “ready to attend” to the message (Cherry 1953). Prepriming may be helpful in getting passengers to be more attentive to PA messages. For example, if check-in agents were to regularly instruct passengers to “listen for PA messages,” this could increase the priming effect. (This instruction could also be incorporated into self-service check-in machines as a closing message on the screen.)

A version of priming can also be achieved by repeating PA messages (Labiale 1990). The first PA message serves as a primer to attract attention to the message, and a repeat of the message immediately or shortly after allows passengers to process the information. It is best to play the messages consecutively within a short space of time, as repeating a message after a long delay may result in passengers missing the content of the message a second time. **Play or announce important messages twice consecutively to ensure that nonattentive listeners can focus on the PA message and then process the information presented within it.**

### 5.2.1 Passenger Attention/Distraction

Human attention is limited. It is impossible for us to attend to the multitude of stimuli assailing our senses on a minute-by-minute basis and so our brain is continually making decisions at a subconscious level as to which stimuli to attend to and which to disregard. The “subconscious” is the part of the mind that one is not fully aware of at a given moment but that is influencing one’s feelings and actions in that moment. The subconscious awareness of messages is completely separate from a conscious decision made by a passenger concerning which messages to "choose" to pay attention to. Thus, our subconscious is processing data that our sensory receptors are constantly collecting about visual, auditory, and haptic stimuli. (Haptic stimuli are any form of stimulation involving touch.)

The literature provides many studies to support the limited attention of humans, suggesting that we have a limited processing pool and that we, therefore, tend to focus our attention on one area to the exclusion of attention to another (Spence and Santangelo 2010). This is known as "selective attention" and is found to be especially evident when a person is presented with a competing task; for example, when someone is focusing on checking in, he or she cannot focus on announcements being made.

With regard to airport messages, several competing stimuli may cause messages to be missed in such a complex environment. Passengers are notably less aware of auditory messages in areas like ticketing or check-in. Passengers focusing on checking in may subconsciously tune out other stimuli to deal with the task at hand. In the pilot study, when passengers were surveyed at a busy airport check-in area, they were often found to be genuinely unaware that any PA messages had been played in the preceding 10 minutes.

Passengers also *choose* not to listen to announcements, or "tune them out." Passengers may tune out messages for multiple reasons—they may be chatting, concentrating on work, shopping, eating or drinking, or reading. In general, passengers tune out when they believe that they do not require any information or when they believe that they have access to adequate information via other channels (e.g., an airline app on a smartphone). Passengers are less likely to tune out in the gate areas; in the pilot study, passengers were noted to be more actively listening for when to board—information that they would be unable to access via their personal technology or on FIDS.

Research also suggests how to increase the strength of the message when there are competing stimuli in the environment by making information directly relevant to the task required and removing messages that are not directly required, or relevant, to that area (Cherry 1953). For example, while at the check-in counter, passengers fail to hear security messages and often tune out messages they perceive to be relevant to other parts of the airport but not to them. **Although it is understood that some PA messages are mandatory, general guidance would be to remove messages that are not directly relevant to a given airport location and to tailor relevant messages to the tasks required of passengers in that location.**

### 5.2.2 Barriers to Attention and Perception

Some psychological factors can be barriers to effective listening—stress and anxiety may be associated with the airport experience and an impending flight, or they may be stresses and anxieties particular to an individual, the individual's previous experience of the airport, and/or his or her own personality.

#### *Stress and Arousal*

Psychological research tells us that stress and increased arousal hinder the amount of auditory information that can be processed. The greater the level of stress or arousal, the more limited the attentional resources there are to focus on other things (Ericksen and St. James 1986). It is difficult to predict the factor by which the level of attention to auditory features reduces under stress, because levels of stress and an individual's reaction to stress are subjective.

Stress in the airport environment may be especially acute, with evidence showing that the environment can induce depression, extreme anxiety, or panic attacks in vulnerable individuals (Bor 2007). Stress may be experienced by an individual for various reasons: time pressure, fear of flying, discomfort in crowds, and business or personal pressures related to the trip or not related to the trip. Cultural background, gender, age, and language skills may mediate how passengers deal with stress during traveling.

Regardless of the reasons, the effect of stress on attention is the same—a narrowing of focus and reduced attentiveness to external stimuli such as auditory PA announcements. Thus, stress may be a strong determining factor in how well messages are attended to. Levels of stress experienced can vary by individual. For example, for a passenger who is anxious about flying, levels of stress may be high on check-in, drop a little after security on reaching the gate hold area where attention may be diverted by nearby food and shopping, and then rise again when boarding begins. In another example, a bereaved passenger flying to a family funeral may have a constant level of stress throughout the journey through the airport. **At key points in the passenger journey (where PA announcements include instructions requiring action or a response from the passenger), concise, simple, targeted messages are needed to capture potentially limited passenger attention.**

**To draw attention and enhance message understanding**

- **Keep messages simple**
- **Use a "hook" or key word to draw attention**
- **Use key words such as a flight destination, rather than a flight number, to draw attention**

### *Bias and Expectation*

Confirmation bias is a strong psychological phenomenon that may lead to a passenger misinterpreting an auditory message (Fritz et al. 1994). Once an individual has formed a theory, hypothesis, or idea based on experience, research suggests it will take more than a single instance of contradicting information for that individual to alter his or her opinion. Our biases are stronger than our understanding of processes. Numerous studies in psychology illustrate that people (1) fail to attend to information that contradicts their expectations or (2) actively disregard contradictory information.

Confirmation bias may be an issue, for example, for the regular traveler who is used to consistently using the same gate for a particular flight. Because of this bias, the traveler may fail to properly attend to an auditory message when it is presented (for example, if the traveler is expecting to hear "Gate 6" when the announcement to proceed to the gate is called, he or she may assume the announcement said "6" when it did not).

If presented with two conflicting pieces of information, a passenger may revert to the information that he or she feels most comfortable with, for example, the original information they received face to face from the check-in agent. Information given face to face is generally given greater precedence over information given by other means, such as PA announcements. **Encourage check-in agents to urge passengers to listen for auditory messages in case of changes. Where messages provide information that represents a change to previously provided or expected information (e.g., a gate change), this fact should be clearly stated and be reiterated across other channels such as the FIDS. For example, it would be useful to have the FIDS screens display text information that is aligned with the updates presented in the auditory messages.**

**Research suggests that, if important auditory messages are repeated consecutively, with only a short break between messages, passengers can focus attention on the message on its first play and process the information it provides on the second play.** This allows time for individuals to focus, recognize the information, reconcile that information with their understanding, and process the information to understand what action is required. This is also particularly useful for non-native listeners who require a longer time to process auditory information that is not in their native language (Zhang et al. 2005).

**Play important messages twice consecutively to allow passengers to hear, process, and act on information that they have been given. Clearly state if information presented is a change to information previously given (e.g., a gate change).**

### *Limited Attention*

Research suggests that the passenger's level of attention always affects whether announcements are processed and acted on or not. For example, a passenger with a long transfer time or a delay may simply "switch off" and fail to process any auditory messages (Umera-Okeke 2008). The passenger's motivation to listen to a message strongly affects how much of a message is attended to and/or processed. The length of time a transfer passenger may have to wait can affect attention span. A passenger with a long transfer time may assume that auditory messages are not immediately relevant and may tune out. A parallel example in a work environment would be a light workload, leading to lapses in attention; in the airport environment, long periods of waiting with little to do can lead a passenger to daydream, exhibit low levels of attention, or be diverted by other things (e.g., a tablet, computer, or personal music device) with the resulting likelihood that the passenger will miss announcements (Mense, Debney and Druce 2006).

This tendency to switch off also applies to passengers with limited processing ability, although research suggests that someone with limited processing ability is particularly susceptible to the "cocktail party effect" and so will be more receptive to a message that contains his or her name in it (Cherry 1953). **Although a message using a passenger's name is useful where there is a need to directly address a particular passenger, this is not feasible for general flight announcements. Simple messages requiring little in the way of processing are preferable.**

**To summarize, for some passengers, PA announcements are not as effective as a message delivery service, no matter how the message is manipulated. Thus, PA announcements should not be considered as a single source of information and should always be used in conjunction with other information sources, such as FIDS.**

### *Task Interference*

Passengers are often distracted from hearing announcements by tasks they are engaged in, such as conversations, ordering food and drinks, or interacting with their phones or tablets. However, passengers may choose to receive updates on their smartphones and so may have less need to hear announcements.

## 5.3 Message Content of Announcements

**Messages should be kept short, concise, and to the point (Miller 1956). Research and observations suggest that including an introductory preamble, for example, "Flying Airways welcomes you to Terminal 6 today and would like to . . ." may result in passengers "tuning out" a message before the core information has even been delivered. Keep conversational, chatty PA messages to a minimum.**

### 5.3.1 Relevance

Passengers' attention can be drawn to a message by information that is directly relevant to them, even when they are not paying attention to announcements in general. The most effective way to draw attention is the passenger's name (Cherry 1953). **Airports already make calls for passengers to go to gates using specific passenger names when a flight is closing and those passengers are still expected at the gate. In this instance, the name should be used first to attract attention, and then the name should be repeated; the whole message should be simple, directly and immediately relevant, concise, to the point, and without introduction. Figure 5-1 illustrates this approach.**

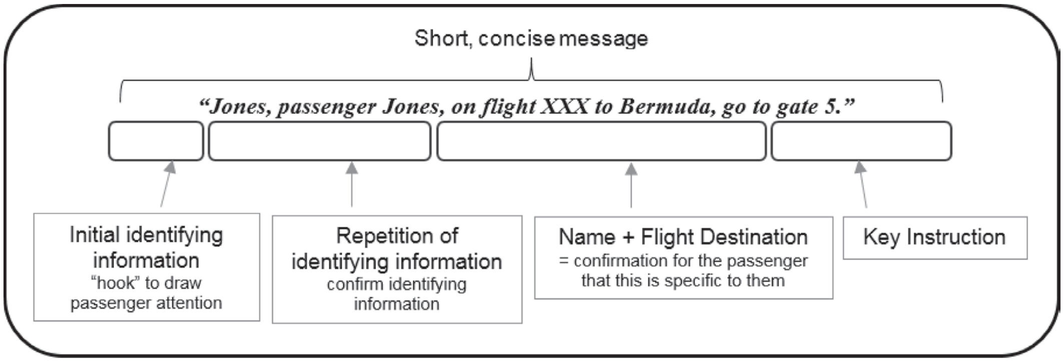



*Figure 5-1. Guidance for message format.*

## 5.3.2 Repetition

Repeat key identifying information within a single message. Although passengers' attention may be drawn by initial recognition of a key name or phrase, travellers may not immediately process or understand the initial stimulus that has drawn their attention. The ability to process message information varies widely across the general population and even across passenger types—frequent travelers will be more attuned to relevant messages and process information quickly, while novice travelers may require more time to process messages. Because passengers' attention varies, repetition of the key identifying information (passenger name in the case of specific passenger information or flight destination) is advised so as to reach most passengers. This key identifying information can be used to focus on task- or location-relevant messages by using specific "hook" words to capture attention.

With a good understanding of what captures people's attention, it is possible to create auditory messages that will capture even the attention of people primarily focused on visual information. For example, passengers reading a FID board can still have their attention drawn to an auditory announcement by the right key word or phrase.

The key words and the relevance of the message are particularly important here (Iwamiya et al. 2004). It is not sufficient to simply remove sensory clutter such as background music or to use other sound-reducing techniques in the environment; the message must capture the passenger's attention.

**Higher level information such as flight destinations is particularly salient for the passenger and makes for very effective key words for gaining passenger attention. Passengers approached during the pilot study were readily able to state their destination but frequently had to refer to their tickets or documentation when asked their flight numbers. It is also logical to assume that, for the average traveler, a destination is easier to remember than a seemingly random collection of numbers and letters. Flight destinations are ideal key words that can be used to get passenger attention, for example: "Denver, Denver, Flight XY123 to Denver, now boarding at Gate 4."**

## 5.3.3 Message Content: Types of Speech

### *Conversational vs. Clear Speech, Synthesized vs. Natural Speech*

Conversational speech is much harder to process and understand because there are no breaks between words. The breaks that we believe we hear between words are actually imposed by our perceptual system. Conversational speech, if written as it were spoken, would have no spaces between words and they would literally run into each other (as in "Rowsonetotenboardingnow").

In fact, if a word were extracted from a sentence of conversational speech, it might not be as easily recognized as it would be when heard in isolation.

**PA announcements given in the gate areas are frequently rushed and presented in a conversational rather than a "clear speech" style, making differentiation among words difficult (Payton, Uchanski and Braida 1994). In the presentation style called "clear speech," the speaker speaks each word individually, verbally highlighting the spaces between the words using hard consonant sounds at the ends of words. Because meaningful, grammatically correct, and clearly spoken (as opposed to conversational style) sentences are better understood across a wider audience, providing training in this type of speech presentation to those staff making announcements in the gate areas would be especially helpful. Clear speech is consistent with the principles of universal design.**

The benefits of using clear speech have also been shown to increase as noise levels increase.

Relative to live voice or recorded voice announcements (natural voice), synthesized voice requires additional time for comprehension as listeners adjust to the synthesized voice; thus, for a given message, the comprehension and speech intelligibility of a text-to-speech (TTS) announcement is reduced compared to natural voice (Tsimhoni, Green and Lai 2001, Venkatagiri 2003). Studies suggest that the following techniques are useful:

- **Using a slightly higher TTS signal level compared to natural voice announcements.**
- **Repeating the important TTS message to allow passengers to adjust to the synthesized voice.**
- **Minimizing use of TTS messages in areas where conditions challenging to speech intelligibility are present (e.g., highly reverberant space and/or high percentage of non-native language listeners).**

### 5.3.4 Message Content: Non-native Language Listeners

Non-native listeners find clearly spoken sentence style easier to understand than conversational style because they can identify individual words (Zhang et al. 2005).

**Familiarity with the semantic structure of the words in an announcement helps in recall and processing of the auditory message. This is particularly relevant for passengers who are from other countries and so may particularly benefit from hearing key words relevant to the flight information in a language familiar to them. For example, using the destination name as the key word, if you were playing a flight announcement for Rome, Italy, you would make an additional flight announcement using the Italian names, "Roma, Italia." Where it is relevant to reach a high proportion of non-native listeners, key words in the language of the flight destination or carrier are particularly useful.**

**PA announcements in gate areas are often spoken quickly, making it particularly difficult for non-native listeners to understand. Repeating a message after a very short delay allows time for non-native listeners to process what they are hearing and understand its meaning. The delay must be brief: if the delay between the original and the repeated message is too long, passengers may have returned to conversations, phones, tablets, or other distractions and fail to catch the entire message again. The first message is to draw the passenger's attention, while the second message gives the passenger time to process and understand the information.**

## 5.4 Message Delivery: Gender

Early human factors research into male versus female voices when attempting to command listeners' attention was related to aircraft warning systems and was specific to aircrew. This research found that the female voice was more authoritative and better at getting aircrew to do what they needed to do, and so, although male voices are now sometimes used for systems such as ground proximity warnings and traffic collision avoidance, female voices dominate the realm of aircraft warning systems. The early studies documented greater physical response markers (such as heart rate) to messages spoken by females than males and a faster response rate to instructions. More recent research also suggests that female speakers are more intelligible than male speakers (Amano-Kusumoto and Hosom 2011, Alm and Behne 2015).

In some contexts, male speakers may be just as clear and effective as female speakers; also, male speakers may be more effective for certain listeners because those listeners prefer listening to a male voice. Satellite navigation systems, for example, offer a choice of male and female voices to cater to personal preferences.

However, research overall indicates that the female voice is more intelligible than the male voice for audio messages. This may be because female speakers tend to have larger vowel spacing and more precise timing and spaces between words and sentences. Although attentiveness to an announcer's voice may be influenced by personal preferences, studies show that where intelligibility is an issue—such as where there is a high proportion of non-native speakers—a female voice is preferable.

**Diction and timing are important considerations for all speakers making announcements; the female voice can provide better intelligibility for audio messages and can be more efficacious for specific types of announcements (e.g., announcements in the international terminal and text-to-speech announcements).**

### *Background Noise and Auditory Clutter*

TVs are often in food court and gate areas (see Figure 5-2). TV audio volumes are often set to a relatively low level so that the volume does not carry too far from the immediate areas they are sited in. However, these sources of additional auditory output are not linked to the PA system and so will continue to play during PA announcements. For some passengers, this source of noise may be a distraction or may interfere with the audibility of the announcements and cause the passengers to have difficulty hearing targeted auditory messages (Potter and Choi 2006). If it is not possible for this competing auditory channel to be linked to the PA system and paused during airport announcements, then it is important to ensure that the volume and clarity of the PA system in these areas can override such competing auditory streams.

Background music is also sometimes played in food court areas; if the music and announcements are broadcast over the same loudspeaker system, it is helpful to pause the music before PA

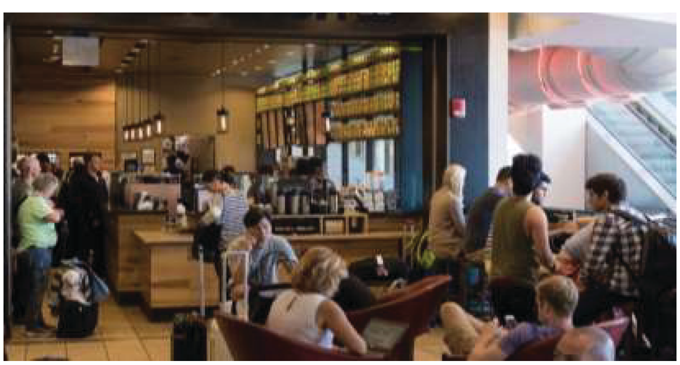


Photo Credit: CCD

***Figure 5-2. Cafe environment where auditory clutter, such as background music or TV may be present.***

announcements so that the announcements can be heard, processed, and understood. However, if both systems use different loudspeakers, then it may be difficult to integrate the two systems.

**Reduce all unnecessary background noise. Where possible, ensure that all electronic sources of background sound are paused when a PA announcement is played so that the background sounds do not compete with the auditory message.**

### *Gate Areas and Auditory Clutter*

Gate areas can become busy at the beginning of a flight's boarding process immediately prior to a flight's departure. Some passengers (often business travelers) tend to stand and wait in the gate area entrance nearest to the desk and the boarding entrance. In this location, on the boundary between the gate area and the adjacent corridor, gate area announcements are often muffled and sometimes difficult to hear. Frequently, gate announcements from adjacent gates clash or overlap, making both announcements difficult to hear and understand. Gate agents are often focused on getting the flights that they are responsible for boarded and may not be aware that an adjacent gate's agent is already mid-announcement. This often leads to announcements at adjacent gates being made in parallel (overlapping); consequently, there is poor clarity of individual messages within the gate area, which makes it difficult for passengers to distinguish the content of the message that is relevant to them. **Gate agents should ensure that their messages are played or spoken in isolation and that messages do not overlap with neighboring gate PA messages.**

Gate areas often have the greatest variations in clarity of message because announcements are frequently made by individual gate staff, rather than being prerecorded, standardized announcements. Passengers frequently say that PA announcements in these areas are muffled, are not spoken clearly enough, or are spoken too quickly. The gate agent may be on the tenth flight of the shift and so be inclined to run through a repeated announcement quickly; however, gate agents should be prompted to remember that, **for passengers seeking information about an imminent departure, each announcement is an important announcement. PA announcements should be spoken clearly and at a measured pace.**

## 5.5 Message Cuing

### *Cuing and the "Absence" of Background Noise*

Passenger attention can also be drawn by the sudden absence of stimuli if there recently was stimuli (Cherry 1953). For example, if an airport plays background music, a break in the music will cue an announcement. Although a passenger may be paying explicit attention to reading the information on a display board, a passenger cannot completely exclude auditory input, suggesting that, at some level, the passenger's mind is attending to it implicitly. **Breaks in background noise should immediately precede an auditory message and be short enough for passengers to notice the absence of such noise and draw their attention to the auditory output and without being so long that the passenger's attention is again lost.**

### *Cuing Tones*

Limited research in the field of complex auditory perception makes it difficult to categorically define how complex sounds—such as conversational speech—are affected by preceding and following sounds. Studies are frequently conducted in locations that are not representative of the complex environments presented by airports and often test single tones in isolation without background noise (Lotto and Holt 2011). In the absence of direct, real-world research, the following guidance is provided. This guidance can be applied to any complex environment so as to have the greatest chance of gaining listener attention.

**Where cuing tones are used**

- **Use short familiar tones**
- **Associate tones to specific types of announcements**
- **For gate areas in close proximity, do not overlap messages—especially not messages with tones**
- **Precede all emergency messages with a meaningful alarm sound or tone**
- **Combine alarms/tones with voice instructions**

## 5.6 Passenger Journey Maps and Passenger Information Needs

A passenger journey map is used to describe a passenger's experience of traveling through an airport (journey), with key locations in the journey identified as touchpoints. For each touchpoint, the passenger's activities, thoughts, and interaction with the airport are analyzed. These passenger journey maps cover the following:

- Passenger goals—what the passenger needs to accomplish at that stage of the journey
- Passenger perspectives—insights into passenger thoughts and emotions
- Airport information sources—the different information sources (e.g., PA, FIDS, and signs) the passenger uses to inform journey decisions
- Passenger attention to PA announcements—the likely level of attention the passenger is giving to PA announcements at that point of the journey and potential influences on their attention
- Insights—observations and insights into the passenger journey and aspects of the journey that can affect a passenger's likelihood of hearing and understanding PA announcements

To offer some context and passenger-specific detail, passenger journey maps have been developed for three different passenger personas:

- **The family—parent(s) traveling with children, who typically fly together once or twice a year to go on vacation. The parents are reasonably confident flyers but may be traveling through an airport they have never been to before. They have particular needs, requirements, and distractions because they are traveling with young children. See Figure 5-3.**
- **The high-tech business traveler—a frequent traveler who takes multiple flights each month and is experienced in traveling through airports and in the requirements of the processes. The high-tech business traveler uses airline/airport apps to stay informed when traveling. See Figure 5-4.**
- **The elderly infrequent traveler—has traveled through airports before, but does not travel frequently (once every few years). The elderly infrequent traveler's recollection of the airport process and what needs to be done at each stage is not always clear, and the whole experience of air travel and crowds in an airport is at times overwhelming. See Figure 5-5.**

The personas and passenger journey maps have been informed by the literature review, the pilot passenger study at a major North American airport, and the observations of human factors experts.

## 5.7 The Experience of Passengers with Impairments in Hearing and Sight

### 5.7.1 Passengers who Have Hearing Impairments and/or Are Older

**Passengers who have hearing impairments and older passengers (who may or may not have hearing impairments) benefit from implementation of all the previously noted guidance: keep it simple, use key word hooks to draw attention, and highlight pertinent information. People**

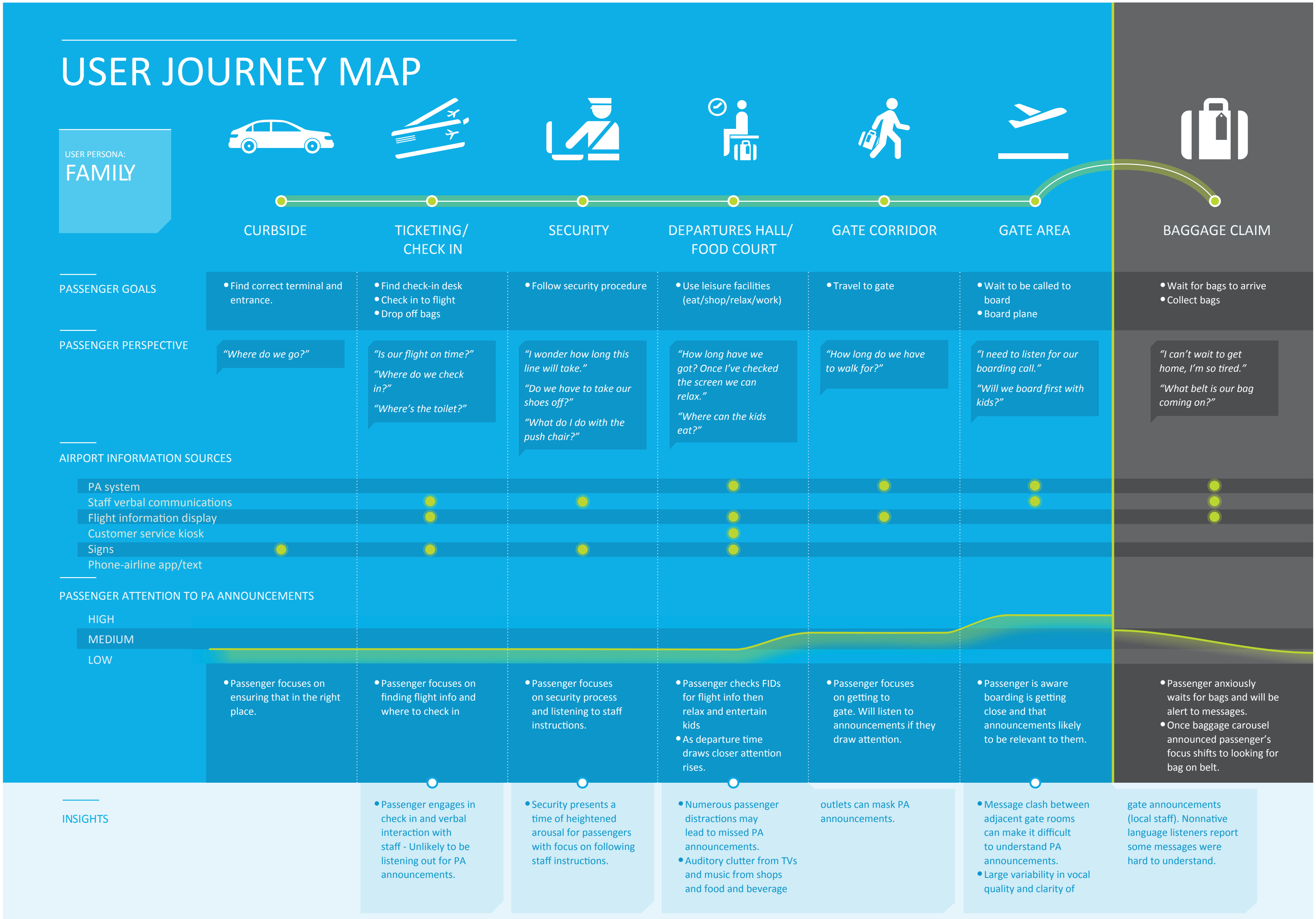



*Figure 5-3. User journey map—family.*

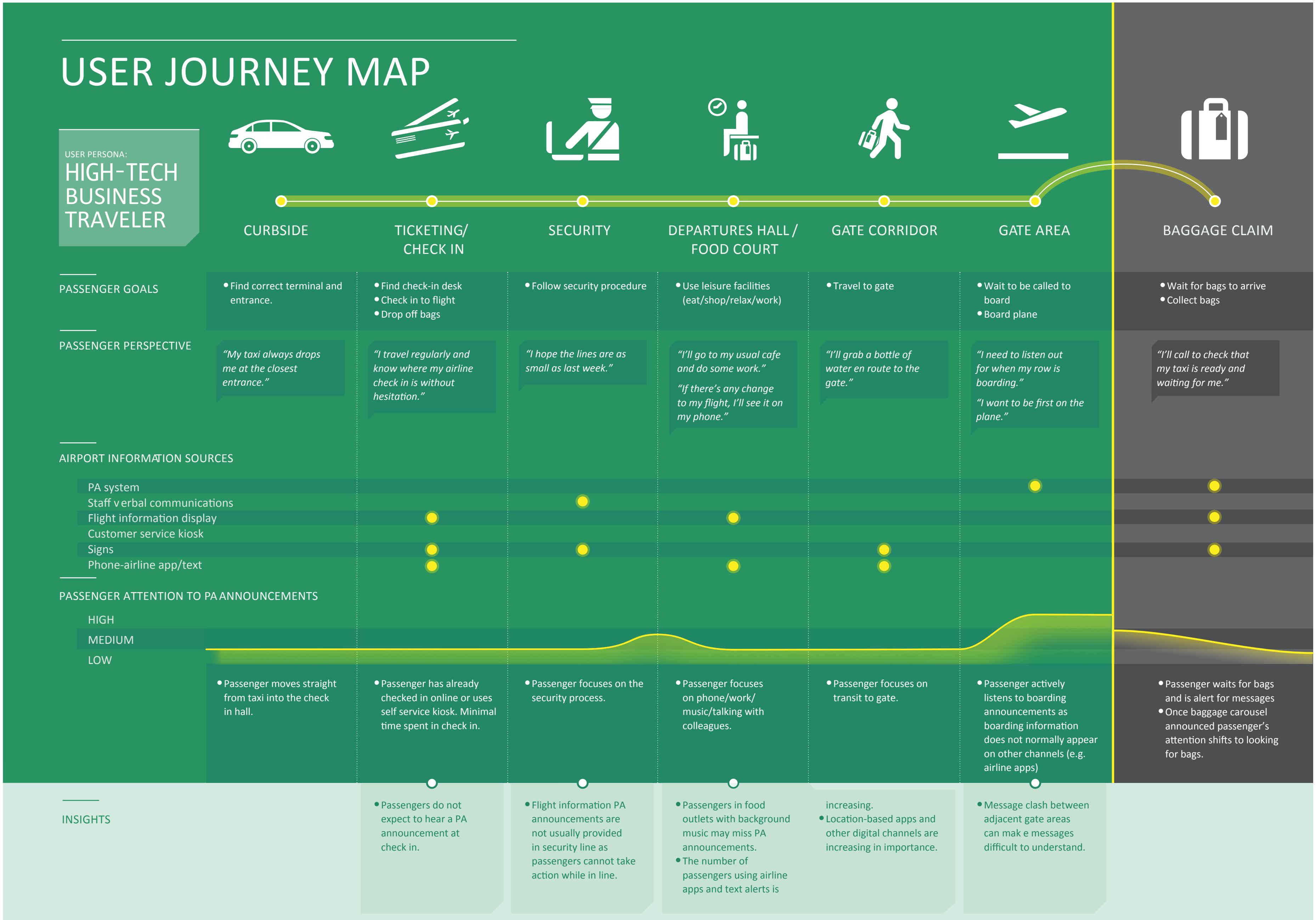



*Figure 5-4. User journey map—high tech business traveler.*

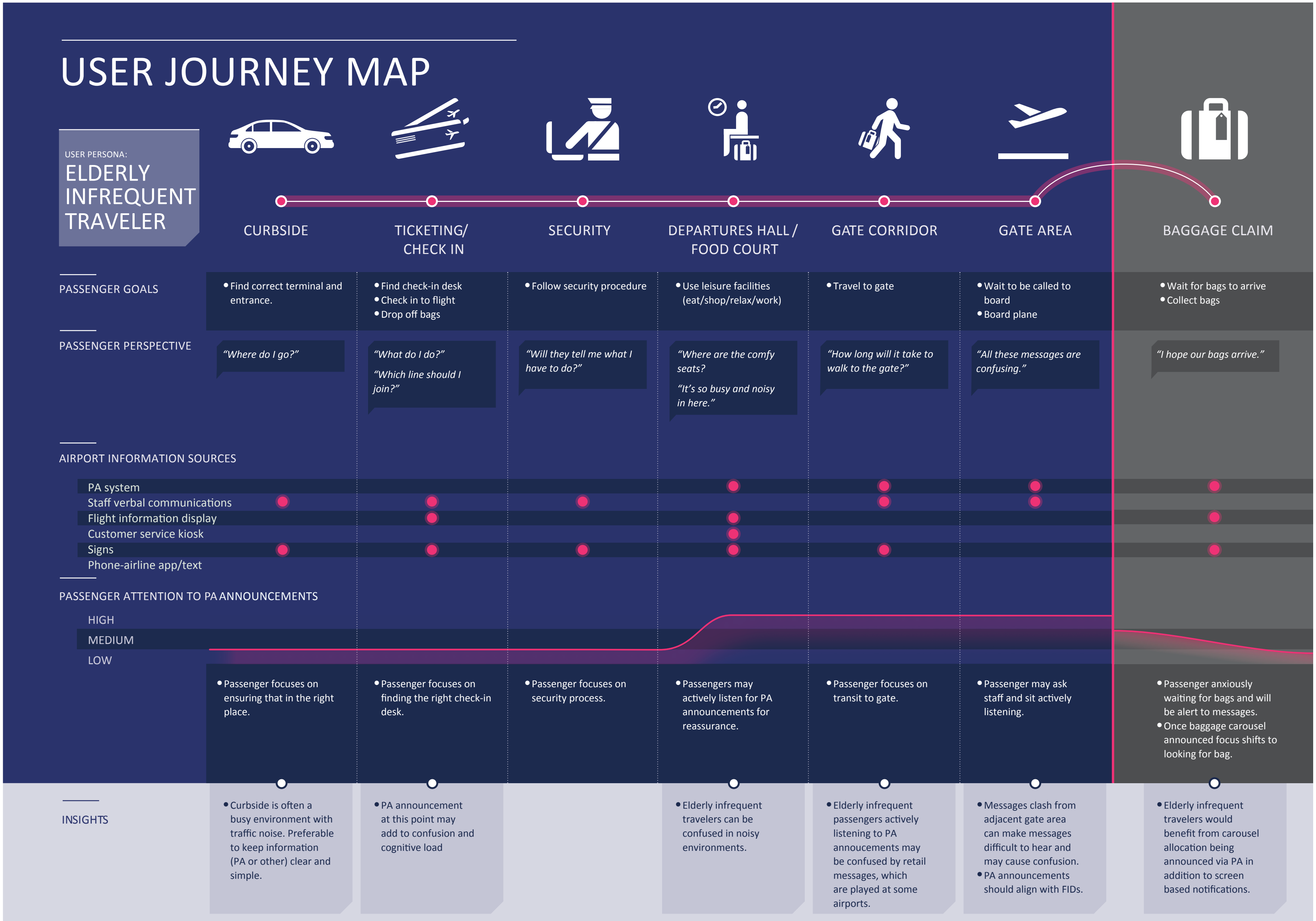



*Figure 5-5. User journey map—elderly infrequent traveler.*

**with hearing impairment also have challenges processing consonant sounds. Consonant intensity increases as part of clear speech and so clear speech could be seen to benefit older listeners (and listeners with hearing impairments) as well as improving general intelligibility for non-hearing-impaired listeners. Clear speech is consistent with the principles of universal design.**

The literature review notes that there is a lack of human factors and behavioral research into the use of induction loops and assistive devices in airports and public spaces. As such, general human factors guidance is presented, rather than specific research-backed findings.

Where induction loops or other systems are installed to help passengers with hearing impairments, the airport must find ways to communicate the provision effectively and clearly to the passengers. Possible methods include

- Informing passengers of the hearing loop provision in advance of their visit (e.g., via the website or booking service) and
- Making passengers aware of the hearing loop provision on their arrival to the airport, so they can use it if they require it, and informing passengers where they can go to get assistance if needed.

**Passengers need to be aware of the zones or areas where the induction loops or other systems are installed *and* where they are not installed, so that they can plan accordingly and not rely on the service in an area that has no hearing loop provision. When available, engage passengers having hearing impairments at every opportunity—at booking, at check-in, and through signage—to make them aware that a hearing loop is available.**

Unlike other assistive listening systems (such as FM or infrared), loop systems are easy to use, with hearing aids that use telecoils (T-coils). As of 1989, all hearing aids sold in the United States are equipped with T-coils (FCC 2015). These hearing aids are typically equipped with a switch (T or MT setting) that enables the T-coil to pick up PA announcements broadcast over a loop that can encircle a room.

An increasing number of passengers use smartphone airline apps and text services that provide them with personal flight-specific updates; these may affect hearing-impaired passengers' uptake of use of hearing induction loop systems for flight announcements, and it is expected that some passengers with hearing impairments will forego using the hearing induction loop systems and instead rely on these apps/services. In light of this, airport planners must remain open to adapting to future technologies and to implementing the most usable and effective methods of ensuring that all passengers are made aware of announcements in a timely manner.

### 5.7.2 Passengers with Visual Impairments

Passengers with visual impairments have a stronger need to recognize whether an auditory signal is pertinent to them and to be able to understand any information given by that message. Some research has shown that such passengers find that many PA messages are too long and contain unnecessary information such as welcome greetings and polite expressions (Iwamiya, et al. 2004).

**The previous guidance on the need to draw attention to key information and keep the messages short and to the point is even more relevant for passengers with visual impairments. Keep it simple—remove unnecessary greetings and polite expressions.**

## 5.8 Interplay between Flight Information Displays and PA Announcements

Passengers typically check their flight information on the flight information display systems (FIDS) on arriving at check-in and then again once they've gone through security. They check whether the flight is on time and what gate it is departing from. Passengers observed and interviewed in airports do not report seeking flight information from PA messages in the check-in area or in the security screening area.

Once through security, an increasing number of passengers use smartphone apps and/or text updates from their airlines for flight information; these passengers state that they feel comfortable that they will be informed via these channels should there be any update, delay, or gate change.

Passengers have been seen referring to the FIDS in the departure hall and gate areas; within these two areas, when passengers' focus is on flight information, it is possible that their attention could be drawn to PA announcements using destination- or name-specific "hooks." It has also been observed that, on hearing a PA announcement that directly affects his or her flight, a passenger is likely to check the flight details on the nearest FIDS.

Passengers actively seek information from PA announcements in the gate lounge and gate corridor areas when they are seeking information about when to board their flight, because their apps and the FIDS do not display this information.

**Given the many ways passengers can now receive information about the status of their flights, consistency of information across the different information channels, particularly FIDS and PA systems, is critically important to support passenger confidence and avoid confusion and undue stress.**

## 5.9 Guidance

The following guidance has been introduced and discussed in this chapter:

### 5.9.1 Attention and Perception and Message Content

- **Clearly state if information presented is a *change* to information previously given.**
- **Keep messages simple and concise.**
- **Speak announcements clearly and at a measured pace.**
- **Play or announce important messages twice consecutively.**
- **Minimize audio clutter.**
- **Consider using a female voice for specific types of announcements where certain factors challenge listeners and reduce attention or intelligibility (e.g., international terminal, text-to-speech).**
- **Present flight information—in particular, updates—consistently across PA announcements and FIDS to avoid conflicts and confusion.**

### 5.9.2 Message Cuing

- **Precede each announcement with a notable break in background music to draw attention to and furnish a cue for the announcement.**
- **Precede announcements with short, familiar tones, particularly for emergency messages.**
- **Associate tones with specific types of announcements.**
- **For gate areas in close proximity, do not overlap messages, especially messages with tones.**

CHAPTER 6

# Architectural Design

This chapter focuses on the architectural design aspects of an airport and how these aspects should be addressed during the different phases of design to better ensure that the acoustical environment in which a PA system functions is conducive to intelligibility. (Key acoustical concepts touched on here were discussed in more detail in Chapter 4.) The aspects of the PA system design and how they interact with the architectural design are discussed briefly. Chapter 7 provides a more detailed discussion of the various elements of PA system design.

An airport consists of various spaces, each having different functional requirements and often requiring different aesthetic approaches to achieve a satisfactory environment that is pleasing to airport passengers. Some airport spaces are conventional and, therefore, less challenging from an acoustical standpoint and less demanding of PA system design. In more conventional spaces—for example, concourses—PA system designers should be able to achieve very good intelligibility, without a lot of effort, using standard acoustical finishes and typical loudspeaker grids. Other spaces—for example, large atriums—are typically extremely challenging, and their special requirements—such as specialized loudspeakers—must be identified early in the design process, because the solutions available at the end of the design process may be limited or unsatisfactory. This chapter's guidance will help designers identify when a space can be considered more or less "conventional" and when a space needs special attention (along with what kind of attention might be required).

## 6.1 Key Concepts and Design Principles

Six physical factors affect announcement intelligibility in an airport:

1. Room volume and shape,
2. Amount of reverberation,
3. Reflections and strong echoes,
4. Ambient and background noise,
5. PA system configuration and quality, and
6. Quality of the announcement.

Of these, the first three factors (i.e., spatial characteristics, reverberation, and reflections and echoes) can be controlled through the architectural design process. The fourth factor (ambient and background noise) can be controlled to some degree—or at least influenced by—architectural and mechanical design. The fifth factor (PA system configuration and quality) can be controlled during the design and installation phases. The success of the built system depends on how well each of these five factors are understood and how well a proper design is implemented. The sixth factor can be controlled, to some degree, by the airport and the airlines through staff training. Figure 6-1 illustrates how these factors relate to one another.

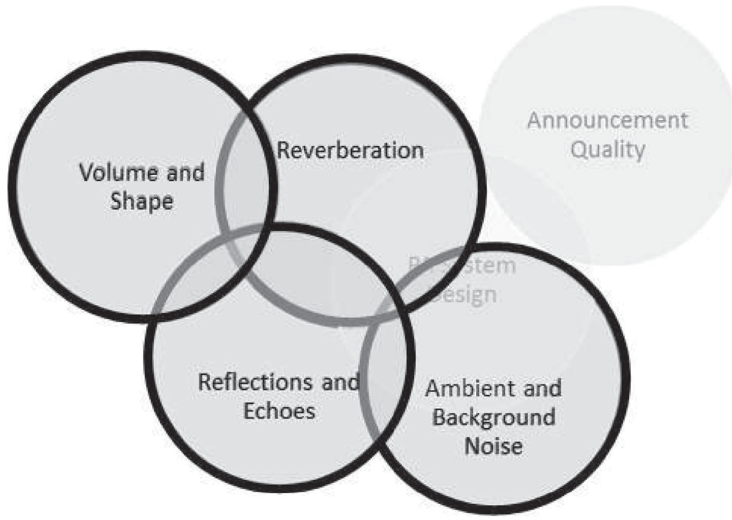



*Figure 6-1. The four physical factors that can be directly influenced by architectural design.*

### 6.1.1 Design Phases

Typical architectural design follows a general progression from conceptual development to detailed construction drawings and specifications. Most building projects are divided into design phases as illustrated in Figure 6-2.

Within the various design phases, guidelines for analyzing factors that affect speech intelligibility of PA systems are as follows:

- Conceptual design:
  - Determine the interior volume shape and character, including ceiling heights and overall visual characteristics. These will influence a room's acoustical response.
  - Flag challenging spaces (i.e., spaces with large volumes and high ceilings) for further attention in schematic design.
  - For challenging spaces, identify the general issues involved and ascertain if acoustical and/or PA system approaches could address these issues once the design is more specific.
- Schematic design:
  - For conventional spaces, standard loudspeaker configurations and typical wall, ceiling, and floor finishes are usually available and adequate. These spaces need no special attention until design development.
  - Give more attention to the more challenging spaces flagged in conceptual design to confirm that, during design development, workable acoustical and PA system solutions will be available.
  - Identify whether acoustical modeling will be necessary to properly design challenging spaces in design development.
  - Set STI goals for all spaces and identify the implications for design.
- Design development:
  - Conventional spaces: Determine room surface finishes (e.g., ceiling, walls, and floor) based on prior experience. Confirm that reverberation times will fall within normal bounds amenable to standard PA system design. Develop loudspeaker distribution and determine whether special types of loudspeakers are needed or whether ceiling-mounted cone loudspeakers in a grid pattern will be sufficient.

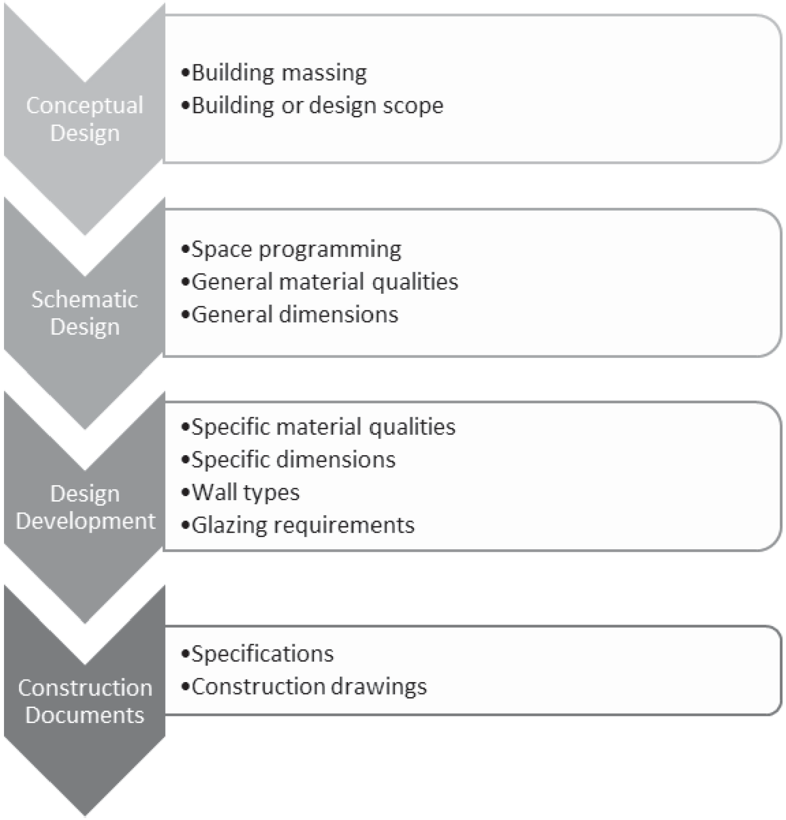



***Figure 6-2. Typical design phases.***

- Nonconventional spaces: For spaces that are large and/or have high ceilings, consider 3D acoustical modeling to more accurately evaluate the spatial acoustics and to determine optimal design tradeoffs between acoustical treatments of room surfaces and loudspeaker types and distribution.
- Construction documents:
  - Incorporate product details into drawings, specifications, and other procurement documents, including performance-based requirements and specifications.
  - Finalize the qualifications requirements for PA system installation and commissioning.
  - Refer to Chapter 8 for specifics on PA system procurement.

A basic background knowledge of the factors that affect intelligibility (see Chapters 3 and 4) can help in putting the above into practice. The STI design target would typically be established in conceptual design. As presented earlier in Chapter 3, the minimum guidance for speech intelligibility at airports is achievement of a daytime STI of 0.50, which is consistent with the NFPA 72, Annex D, guidance. However, given that STI performance is typically measured during evening or nighttime conditions, the corresponding nighttime STI target is 0.60. From this point on, only the nighttime target STI is presented.

### 6.1.2 Summary of Architectural and Mechanical Factors

Table 6-1 summarizes the three key architectural factors and one mechanical factor and these are discussed in the following sections. (For detailed discussion about the main factors that affect intelligibility and principles for obtaining good intelligibility, refer to Chapter 4.)

**Table 6-1. Physical factors that affect PA system speech intelligibility that can be influenced by architectural design.**

| Factor | Challenging conditions for speech intelligibility of PA Systems | Guidance |
|---|---|---|
| Room volume and shape | High ceilings > 24 feet | Use wall-mounted or linear array speakers as ceiling-mounted loudspeakers may not be effective |
| | Long dimensions | Provide acoustical absorption |
| | Concave surfaces | Use computer modeling |
| Reflections and echoes | Hard finishes at the end of long dimension spaces | Provide acoustical absorption |
| Reverberation | Acoustical finishes | Provide target amount of acoustical finishes (see Figure 4-6)<br>Use computer modeling |
| Ambient noise | Noise source placement | Use adequate buffer distances or enclosures for noisy sources |
| | Noise control | Control HVAC equipment noise<br>Reduce reverberation at noisy areas<br>Implement adequate building sound isolation from nearby runway<br>(See Section 6.7) |
| PA system design | High ceilings > 24 feet | Consider using wall- or tower-mounted loudspeakers |

## 6.2 Room Volume and Shape

A room with a high ceiling (greater than 24 feet) is a challenging space to design for adequate speech intelligibility. In general, the larger the volume, the greater the distance between reflecting surfaces. This, in turn, affects reflections and echoes. For instance, rooms with a length greater than 5 or 6 times the width have more noticeable echoes. Figure 6-3 illustrates such a space.

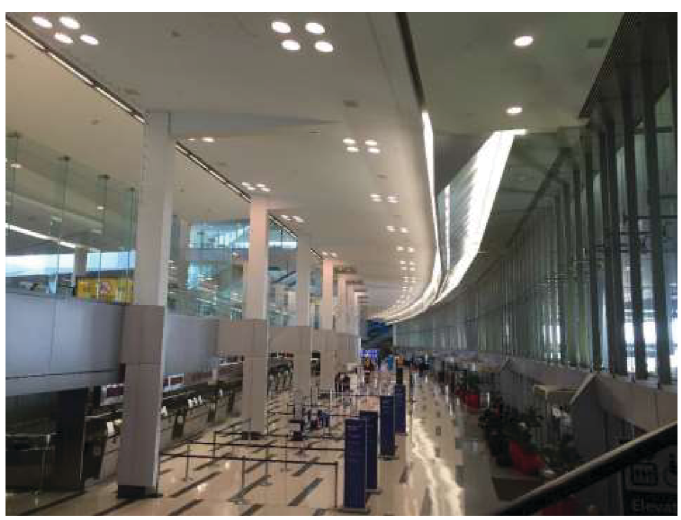


*Figure 6-3. Ticketing hall with various shapes and surfaces.*

A general design principle for good room acoustics is to provide a diffuse sound field. Concave ceilings focus sound at specific points, rather than scattering sound more uniformly. Large parallel or flat room surfaces that are acoustically untreated can result in echoes. Carpeted floors and acoustically treated ceilings are useful for acoustics.

Long volumes, such as concourses, can also present acoustical challenges, if strong reflections are allowed to propagate along the long dimension, thereby contributing to long reverberation time ($RT_{60}$) or causing late echoes that are perceived as separate events.

During the schematic design phase, the general shape and volume of individual terminal spaces are determined based on multiple design factors (such as program goals, design goals, expressive aspirations, budget, sustainability, constructability, and schedule). Given the generous programmatic size required for many terminal functions—such as ticketing, retail sales, and movement of passengers through concourses—terminal spaces frequently require significant volume to achieve proportional balance and visual connectivity. Other programmed spaces such as security and hold rooms require more moderately scaled spaces consistent with their floor area and purpose. Coexisting within the same building, these programmatic areas present distinct acoustical challenges based on size, volume, and sectional characteristics.

Parallel, flat surfaces with little or no absorption can cause flutter echoes that can impede speech intelligibility. To break up flutter echoes, it can be helpful to slope one of the parallel surfaces (e.g., one of the walls or the ceiling) at a 1:11 slope. Another technique for reducing flutter echoes is to use acoustically absorptive finishes on one surface; this technique is discussed later in this chapter.

Although many room shape challenges can be overcome with acoustical treatment, concave surfaces, especially ceilings, can be particularly challenging. These surfaces set up focusing patterns that are counter to a diffuse sound field and cause problems for PA system design. Concave surfaces must be acoustically treated to minimize these problems.

## 6.3 Acoustical Finishes

When sound reflects off several surfaces, each reflection combines to enhance the sound. This effect is experienced as reverberation, except for strong echoes. The measure of a room's reverberation characteristic is its reverberation time ($RT_{60}$). For many airport public spaces where speech communication is an important consideration, an adequate design goal for airports is an $RT_{60}$ of 1.1 to 1.5 seconds.

Some reflection is necessary for communication in larger rooms. However, too many reflections extend the reverberation time and create challenges for achieving adequate speech intelligibility of PA systems. A large, "acoustically hard" surface in a space can create a strong reflection, and if the surface is a sufficient distance from the main area where speech communication is occurring, the reflection is heard as a separate event, or an echo. For airport environments, these strong, late reflections are not normally encountered.

Hard-finished surfaces (such as non-carpeted floors, wall tiles, wood and metal panels, and gypsum board) all contribute to strong reflections. It is important to achieve balance with surfaces: reflections are required to achieve a diffuse sound field, but strong reflections can be distracting or cause difficulties with PA system operation.

Acoustically absorptive surfaces generally need to be applied over 6% to 35% of a room's surfaces (e.g., floor, walls, and ceiling) to adequately reduce overall reflections and to eliminate or minimize hot spots—areas overexposed to reflections—that interfere with adequate speech


***Figure 6-4. Gate hold area with acoustical ceiling tile and carpet.***

intelligibility of PA systems. The amount of coverage required is dependent on the total volume and the type of acoustical treatment. (Figure 6-4 illustrates this concept.)

Acoustical absorption coefficients of various typical room surface finishes are listed in Appendix E to provide context in which to understand the relative effectiveness of different finishes as sound-absorbing materials. The noise reduction coefficient (NRC) is a single number rating that describes the absorptive properties over a range of frequencies important to speech. A value of 1.0 indicates 100% absorption while a value of 0.0 indicates 100% reflection. As discussed in Chapter 4, the amount of treated surface area and the effectiveness of that treatment in a space has an indirect relationship to the reverberation time—as the acoustical absorption increases, the reverberation time decreases. **Treating a nominal 15% to 25% of surfaces may be necessary to achieve a reverberation time in the range of 1.1 to 1.5 seconds or less for volumes up to 10,000 cubic feet, and 6% to 28% may be necessary for larger volumes.**

The distribution of these finishes can be important. The basic guidance in this document assumes a generally uniform application of absorption throughout all surfaces. Thus, the reverberation time calculation for a space where only the ceiling has been treated with acoustical absorption may be different from a calculation with the same amount of acoustical absorption uniformly applied over all surfaces (e.g., ceiling, walls, and floor). **For complex or large spaces, or for challenging designs, it may be essential to enlist the services of an acoustical consultant. For simple configurations, uniform distribution of the acoustical material across all surfaces is ideal.**

### 6.3.1 Ceilings

Many ceiling finish options are available for airports, including

- Acoustically absorptive perforated panels
- Gypsum board
- Acoustically absorptive cementitious panels
- Acoustically absorptive spray-applied plaster
- Acoustical ceiling tiles (ACT)
- Stretched fabric, which is used as a finish to cover acoustical absorption for complex ceiling shapes

The NRC value of these materials typically ranges from 0.40 to 0.90. When ceiling and floor are both flat, a strong echo can occur between the two, which is counter to providing adequate speech intelligibility of PA systems. To reduce the strong echo, it may be adequate to treat (either the floor or the ceiling). Treating both surfaces distributes the absorption and thus allows more flexibility with ceiling finish selection. Sloping the ceiling is another option, as discussed in Section 6.2.

### 6.3.2 Walls

Similar to the relationship between ceilings and floors described above, if opposing walls are flat, strong echoes can occur, and use of acoustical panels or similar treatments may be one way to improve the room acoustics. In some areas, such as a series of gate hold rooms with a low ceiling—less than 12 feet high—the long space between the parallel "end" walls is broken up with furniture or other large objects that also reduce the flutter effect. However, in a space with acoustically hard floors and ceilings, the wall surfaces and furniture offer the only remaining option for controlling reverberant sound.

### 6.3.3 Floors

It is critical to address terminal building circulation zones, given the hard floor surfaces in these areas. In some areas of the airport, carpet is an option (e.g., in gate hold rooms). The main circulation areas are typically finished with an easy-to-maintain and durable surface (e.g., terrazzo tile or sealed concrete).

If carpet is installed, it is either glue-down carpet tiles or wall-to-wall carpeting. For cleaning and maintenance reasons, the carpet tends to be low pile or outdoor grade, which provides only 0.30 NRC. When ceiling and floor are both flat, a strong echo can occur between the two, which is counter to providing adequate speech intelligibility of PA systems. Two reasons to consider using a carpet are as follows:

- All passengers traverse the floor, and passengers generate more background noise on a hard floor surface.
- Where there is a dramatic ceiling design, it may be difficult to integrate an adequate acoustically absorptive treatment using hard floor surfaces.

## 6.4 Acoustical Considerations by Terminal Functional Area

Various terminal areas serve different functions. Consequently, the architectural and acoustical considerations are different for each area. The needs of the PA system also vary, depending on the function. This section discusses areas describing physical challenges and how the function of space affects PA announcements. These spaces are divided into two types: exterior and interior. Airport exterior spaces are often limited to curbside areas (arrivals and departures). Interior spaces include ticketing, TSA security checkpoints, gates areas, concessions, baggage claim, and arrivals and departures halls. Table 6-2 summarizes the design elements relevant to interior spaces.

The only exterior space at airports where PA systems are used is the curbside area. Table 6-3 summarizes the two design challenges relevant to this space.

## 6.5 Concept of Acoustically Distinguishable Space (ADS)

Terminal spaces served by the PA system can vary in size and shape from relatively small (<5000 cubic feet) to very large (>>500,000 cubic feet) to very long (length >5 times width). A useful concept to keep in mind when identifying these spaces is the concept of an acoustically distinguishable space (ADS), which is defined in NFPA 72 as a space that is "distinguished from

**Table 6-2. Summary of design considerations for interior spaces.**

| Challenge/Condition | Thresholds | Guidance |
|---|---|---|
| Ceiling height | Moderate >13 feet | Be aware of increased challenges for speech intelligibility beyond basic PA system design |
| | High >24 feet | Consider wall-mounted or column array loudspeakers as ceiling-mounted loudspeakers might not be viable;<br>Use design professionals for acoustics and PA system design |
| Reverberation time | 1.1 to 1.5 seconds | Treat 15 to 35% SA for <10,000 square feet;<br>Treat 6 to 28% SA for >10,000 square feet |
| Ambient noise | Moderate >59 dBA | Apply acoustical treatment and noise controls |
| | High ≥65 dBA | Use design professionals for acoustics and A/V consultant for PA system design |
| Strong echoes | Large reflective surfaces more than 100 feet away from an ADS | Use acoustical absorption if required to minimize echo |
| | Large parallel surfaces | Use acoustical absorption on one surface or taper one surface 1:11 |
| Concave surfaces | Any | Use acoustical absorption on the concave surface<br>Consider wall-mounted or column array loudspeakers |
| PA loudspeaker placement | High ceiling >24 feet | Consider wall-mounted or column array loudspeakers<br>Use design professionals for acoustics and PA system design |

SA: surface area

other spaces due to acoustical, environmental or use characteristics, such as reverberation time and ambient sound pressure level." ADS is a subjective concept, in part based on understanding the physical factors at play; there are no hard and fast rules in defining an actual ADS. Figure 6-5 illustrates how an ADS might be determined.

A building has boundaries defined by the exterior shell (such as walls, windows, doors, and roof). Many rooms also have clear boundaries, defined by walls and a door. In airports, there also are well-defined rooms and well-defined spaces; in many cases, the definition of the space might be based on a boundary where there is no wall. The concept of ADS is general: a space that measures 12 ft high by 100 ft long by 50 ft wide is probably acoustically similar to an adjacent space measuring 10 ft high by 80 ft long by 55 ft wide. The addition or lack of acoustical absorption from one space to another (e.g., carpet in a gate hold area and tile in the lobby) can be enough to distinguish the two as separate ADSs. Commonalities can be found in gate hold areas, baggage claim areas, ticketing halls, gate counters, and concession areas, which have similar reverberant and ambient sound conditions. Figure 6-6 shows such a space.

**Table 6-3. Summary of design considerations for exterior spaces.**

| Challenge | Thresholds | Guidance |
|---|---|---|
| Ambient noise | High ≥65 dBA | Select horns or column array loudspeakers |
| Reverberation time at lower levels | 1.1 to 1.5 seconds | <10,000 square feet treat 15 to 35% SA<br>>10,000 square feet treat 6 to 28% SA |

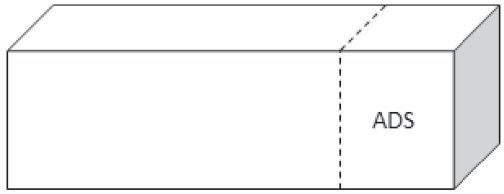



*Figure 6-5. Schematic illustration of an ADS.*

A series of spaces, such as gate hold rooms, could be considered one ADS because they share the same ceiling height and width, furnishings, and other acoustical characteristics (exceptions may be gate areas that have different environmental conditions—for example, one or more areas are closer to a restaurant or bar or near noisy HVAC equipment). The concourse or walkway next to these gate hold areas, on the other hand, would probably constitute a different ADS, given a higher ceiling, an acoustically hard floor finish, and a different PA system layout. Figure 6-7 shows such a space.

## 6.6 Ambient and Background Noise Considerations for Interior Spaces

PA announcement levels are typically set to be about 72 dBA at the height of a typical standing passenger. To meet the guidance target (10 to 15 dBA SNR), the background noise level should be 59 dBA, because this is essential for adequate speech intelligibility of PA systems. Ambient noise-sensing microphones can help adjust the PA signal to account for increases in ambient noise conditions; if an ambient noise-sensing system will be specified for the PA system, it will only be necessary to design for the typical, ongoing environment. Other basic guidance for controlling ambient noise sources includes providing

- Adequate buffer distances or enclosures for mechanical equipment, escalators, concessions areas, and similar noise sources.
- Adequate isolation at gate areas from exterior noise coming from passenger boarding bridges.

*Figure 6-6. Ticketing hall—long, low room.*

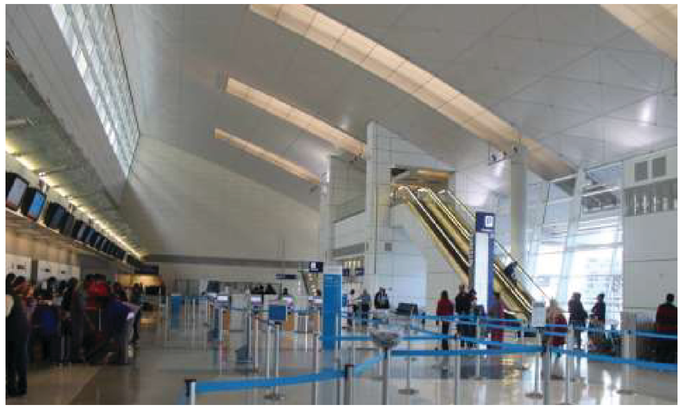


*Figure 6-7. Ticketing hall with high, sloping ceiling.*

### 6.6.1 Mechanical Equipment

Background noise caused by mechanical equipment is generally the easiest type of noise to control. The most common examples of noise-generating mechanical equipment in terminals are the HVAC system (the base building system and tenant improvements), escalators, moving walkways, elevators, baggage carousels, baggage conveyors, and concessions refrigeration equipment. **To achieve target quiet ambient noise levels of 59 dBA or less, the HVAC system itself must typically be designed for 50 to 55 dBA or less.** Noise criteria (NC) level guidance is adapted from ASHRAE (ASHRAE 2011), where NC 40 is used for lobbies and corridors. NC 45 typically corresponds to a 50 to 53 dBA background sound level; in a space where HVAC equipment is the dominant noise source, the equipment defines the quiet ambient sound level. Table 6-4 provides guidance about industry practice for controlling this type of equipment.

### 6.6.2 Airport Passengers

The sound generated by passengers contributes to the ambient noise. The main challenge from an acoustical design standpoint is the variability of this noise level due to the constantly changing number of passengers present at any one time and changes in their levels of activity. A hard floor reinforces the sounds that passengers make when walking and rolling luggage along the floor. Highly reverberant room conditions also strengthen the sound of passenger voices. A room with high reverberation tends to encourage people to talk louder, because the din makes people feel

**Table 6-4. Typical design goals for HVAC and mechanical equipment in public spaces.**

| Space | Design Goal | Typical Sound Level Equivalent | Comment |
|---|---|---|---|
| Concourse and circulation | NC 45 | 50 to 53 dBA | Consider vibration isolation for the fans and ductwork |
| Baggage claim | NC 45 to 50 | 50 to 58 dBA | Strive for NC 45 if possible |
| Arrivals and ticketing | NC 45 | 50 to 53 dBA | Consider vibration isolation for the fans and ductwork |
| Hold rooms/lounges | NC 40 | 45 to 48 dBA | Use vibration isolation for the fans and ductwork |
| Moving walkways, baggage claim belts | NC 60 at a 3-foot distance from motors and noise sources | 65 to 68 dBA | Provide a higher level of acoustical absorption in the 8-to-12-foot area nearest the source to control the reverberant sound |

they must speak more loudly or yell to be heard. Three basic options to mitigate these issues are (1) design of walls or structures to contain or limit noise from passengers, (2) establishment of a buffer distance between noisy passenger spaces (e.g., a sports bar) and noise-sensitive areas (e.g., a gate hold area), and (3) use of acoustical absorption to reduce reverberant buildup.

Events at U.S. airports in August 2016 underscore the importance of controlling ambient noise. In two separate events, at two different airports, unidentified loud noises inside the terminal led to speculation that guns were fired. In the first case, the noise was caused by cheering from people watching the Olympic Games. In the second case, an unidentified noise was mistakenly linked to gunfire. In both cases, the confusion caused concern and panic.

### 6.6.3 Airport TV Monitors

TV monitors are in many places in airports, particularly gate hold areas and concessions courts. Some airports have chosen to silence TVs and use closed captioning, while other airports have chosen to play TV audio at a low level. However, in some of these cases, the volume of the TV audio is high enough to interfere with PA system announcements. (This situation can be particularly frustrating when it appears that no one is actually watching or listening to the TV broadcast.) These televisions are usually not interlocked or interfaced with the PA system, so when announcements are made, the speech intelligibility of the PA system is reduced because the TV audio interferes with it.

Placement of TVs requires coordination with the tenant/operator to minimize intrusion in passenger areas and maximize the speech intelligibility of the PA system.

### 6.6.4 Competing PA Announcements

Simultaneous announcements made in adjacent spaces are another source of competing noise for individual announcements. Typically, airport PA systems are designed to keep this from happening by interlocking announcements so that two gate agents cannot make announcements in the same zone at the same time. Sometimes the issue is that the loudspeakers from two different zones are too close together (see Figure 6-8). The resolution of these problems is largely in the scope of PA system design and PA system operations and training. **During the architectural design process, it may be possible to increase the acoustical isolation between close spaces using furniture or a high level of acoustical absorption (e.g., NRC >0.8, ~25% coverage).**

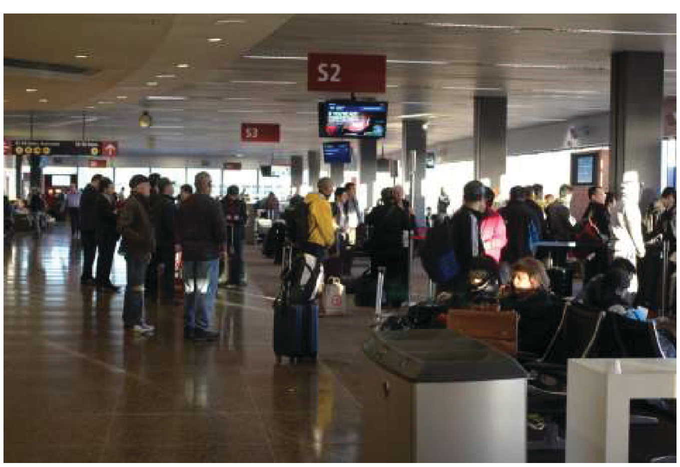



***Figure 6-8. Adjacent gate waiting areas.***

### 6.6.5 Background Music

Most airports avoid playing background music; however, some airports play music in certain areas and/or under certain circumstances. Typically, background music is linked to the PA system, so that the music is paused or muted during PA system announcements. If this is not the case, the speech intelligibility of the PA system is reduced, because the background music interferes with PA announcements as discussed in Chapter 5.

In attempts to improve passenger experience, some airports have introduced live music in selected areas. Programs can range from a quiet soloist to a full band (e.g., eight-piece band or combo). PA announcements in these areas can be affected by competition from the performance. **Thoughtful design can limit the zone of influence of such events—for example, by including barriers or walls to minimize the noise impact of the performance on adjacent public areas and ensuring a high level of acoustical absorption (e.g., NRC >0.8, ~25% coverage) in the performance area, as well as addressing the particular requirements of the PA system in such circumstances.**

### 6.6.6 Passenger Boarding Bridges

Sound from passenger boarding bridges is generally not a significant factor in PA system intelligibility, and most boarding bridges do not have loudspeakers. However, it may be useful to consider how to minimize jet engine noise transfer into the gate area via the bridge, because this noise increases the background noise and affects the intelligibility of announcements in the gate area. Adding a high level of acoustical absorption to the 8-to-12-foot area immediately next to the bridge access door can help contain noise in that immediate area.

In an emergency, airports have processes to direct passengers off the boarding bridge and so do not have to rely on PA announcements in the passenger boarding bridges.

### 6.6.7 Electric Passenger Transport Carts

Electric transport carts are generally quiet relative to other sources of background noise. Furthermore, the little noise they generate is only momentary in any one location. The reverse backup alarm is highly audible, for obvious reasons, but these alarms are seldom used near gate hold areas and hence probably are not a major source of noise. At facilities that have higher-than-average use of these carts, airport spaces should be designed to avoid the need for backup maneuvers (e.g., by increasing corridor width to allow for vehicle-turning radius).

### 6.6.8 Interterminal Automated People Movers (APMs)

Larger airports often have APM systems running between terminal buildings. These systems can either be outdoors or underground. In some airports, the APM is within the concourse of the terminal building. Shuttle vehicles themselves generate noise, but the platform waiting areas typically have automated doors that close when the shuttle enters and leaves the station. These doors tend to minimize the shuttle vehicle-generated noise (e.g., vehicle HVAC) heard by waiting passengers.

### 6.6.9 Aircraft Noise at the Terminal

At some airports, noise from small jet and propeller airplanes approaching the terminal, as well as more distant noise from airplanes taking off or landing on runways, is not sufficiently addressed by the terminal building shell (this is particularly true for small plane operations on

*Figure 6-9. Food concession area.*

the tarmac when the exit doors are open during passenger embarkation and debarkation). If the exterior shell is not adequate to control such noise sources, exterior noise can greatly affect the ambient noise conditions in the airport and influence PA system speech intelligibility (e.g., in gate hold areas).

**Nominal OITC 40/STC 55 for walls and windows in a terminal building next to a runway may be needed in order to reduce this aircraft noise, which has been documented to reach 65 to 70 dBA inside a modern airport.**

### 6.6.10 Concession Areas

Retail kiosks may have their own audio systems that contribute to background noise, although the music from such systems would typically be localized to the immediate vicinity of the kiosks. The base building design can consider the added noise sources for planned areas.

Food courts can be a source of background noise, depending on how fully occupied they are. In addition, the flooring in food court areas is normally acoustically hard for ease of maintenance, and the ceiling height may be moderate or high (see Figure 6-9). The most effective ways to minimize the effects of food court noise on the speech intelligibility of PA systems are to

- **Apply as much acoustical absorption as possible, so that the noise is not enhanced more than necessary.**
- **Select furniture that minimizes unnecessary noise from chairs scraping on the floor.**

## 6.7 Ambient and Background Noise Considerations for Exterior Spaces

Motor vehicle noise at the curbside is likely to be a substantial contributor to the ambient noise level at the curbside, particularly if the roadway is partially enclosed, in which case the noise would reflect from overhead roadway decks and terminal exteriors and, in some cases, nearby parking structures. Ambient noise levels in these areas can easily be higher than announcement levels. Therefore, vehicle noise needs to be considered in the design of the curbside area (see Figure 6-10).

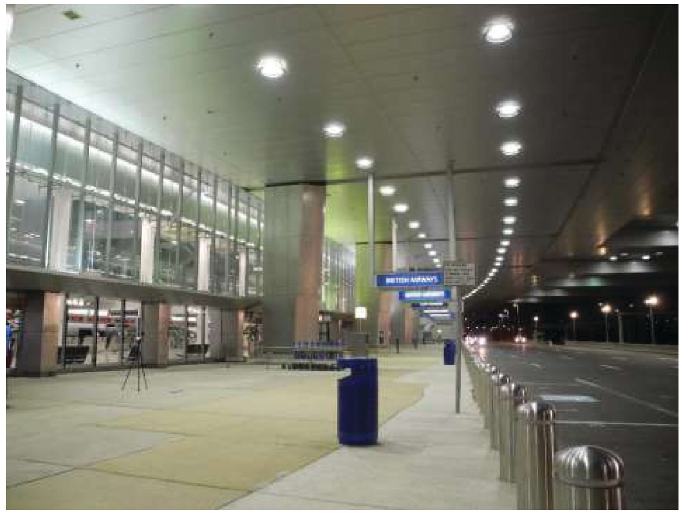


***Figure 6-10. Curbside area with deep overhang and a high ceiling.***

To support a successful PA system design, it is essential to reduce reflection conditions in the curbside area; in semi-enclosed conditions, it may be necessary to consider reverberation. This typically entails the use of cementitious or other exterior-grade acoustically absorptive treatment to the exterior finish and possibly to the underside of roadway decks or similar hard surfaces above the curbside area.

## 6.8 Airport Size Considerations

Although larger airports tend to have more acoustically complex spaces and are more heavily traveled, many terminal spaces (e.g., gate hold rooms, restrooms, and TSA security checkpoints) are similar, regardless of the size of the airport; consequently, the design challenges are similar. From the standpoint of speech intelligibility for PA systems, design considerations are the same for all spaces, regardless of airport size.

## 6.9 Sustainability Considerations

Many resources offer information about sustainable design as it relates to architectural finishes and materials. Many eco-friendly acoustical products are available that use recycled materials and materials with low off-gassing. Renovation projects may require replacement of a considerable quantity of wallboard, metal, wiring, and electronics; some amount of this can be recycled. Many organizations have addressed the management of sustainable materials in architectural projects. The EPA provides procurement guidelines for construction products (see https://www.epa.gov/smm/comprehensive-procurement-guidelines-construction-products). Chapter 7 provides information about electronics and sustainability.

## 6.10 Computer Modeling Software for Acoustical Design

This section discusses the benefits and limitations of computer programs that can be used to model the acoustic environment of common, as well as unusual, terminal spaces. With such modeling tools, it is possible to quantitatively determine speech intelligibility in the presence of background noise for several representative locations (i.e., ADSs) within an enclosed terminal space, thus optimizing loudspeaker type, configuration, and placement. Several commercially available software packages include both acoustical design and PA system design to estimate the speech intelligibility of the combined designs. Chapter 7 presents more information about necessary program features.

In general, with the guidance presented in this chapter, simple spaces with ceiling heights of 12 feet and lower could be designed for the target speech intelligibility [STI 0.50 for daytime (wet) conditions], and ceiling heights up to 24 feet could be adequately addressed with best-practice guidance, although an outside acoustical consultant would be helpful in identifying challenging conditions. Design of complex spaces and spaces with ceiling heights greater than 24 feet would benefit from an acoustical consultant who can evaluate basic speech intelligibility using various room acoustics computer packages that include a simple PA system module.

The key properties of any 3-D software package are as follows:

- A ray-tracing algorithm, which is essential to model a complex space (because it may be important to know the specific placement of acoustical treatment);
- The ability to calculate the STI from the PA system, including the capability to model loudspeakers in the ceilings, on the walls, and in linear arrays;
- The ability to calculate the $RT_{60}$ (for complex spaces, the program should include several different algorithms, including those developed by Sabine, Fitzroy, and Arau-Puchades); and
- The option to factor air absorption into design calculations in addition to the room finishes—this is useful for complex spaces where the reverberation time is difficult to control.

A computer model is only one of the tools in the PA designer's toolkit—computer models are not a substitute for the PA designer's skill and experience. A PA system designer must use professional judgment when determining how to apply a computer model and how to interpret the results of the modeling to predict PA system performance.

CHAPTER 7

# Public Address System Design

## 7.1 Introduction

PA system design involves many factors, including not only the electronic components of that system, but also the space in which loudspeakers will be installed. This chapter provides (1) an overview of PA system design for the lay reader and (2) an understanding of the site-specific issues encountered at airports. The purpose of a PA system in an airport is to broadcast information, paging, announcements, and emergency messages to a large audience, including travelers, airport employees, TSA and other security employees, and emergency response personnel. The announcements can be live, digitally stored, text-to-voice, or prerecorded. The goal of a good PA design is intelligibility of messages under various conditions. Appendix G provides a detailed description of PA system components.

Sound coverage furnished by loudspeakers is typically grouped in predefined zones within which there are multiple loudspeakers. A zone can be defined by several factors—function, size, acoustical environment, and location (e.g., airside, landside, and TSA). The PA system should be able to address individual zones or multiple zones and broadcast locally generated live announcements such as at baggage or gate areas. The primary objective of the PA system is to deliver this information with adequate levels of intelligibility.

The biggest challenge facing an airport PA system designer is to develop a system that can broadcast the announcements (signal) at an adequate level above the ambient noise environment (noise); thus, the system requires a high signal-to-noise ratio (SNR). The loudspeaker selection (including size, sensitivity, directional characteristics, location, orientation, and quantity) plays an important role in maximizing SNR. The primary goals of loudspeakers are to focus sound directly to the listeners' ears, while minimizing sound energy projected onto walls, ceilings and other acoustically reflective surfaces. This must be done within the context of budget, aesthetics, availability of loudspeaker mounting points, and the acoustics of the space in which speakers are installed.

Assuming the acoustical design of the terminal space in which a PA system is installed does not compromise the system's function, the design of the PA system is crucial to the ultimate intelligibility of announcements. (Refer to Chapter 4 for discussion on the physical factors and Chapter 6 for discussion on architectural design.)

## 7.2 Terminology and Components

### 7.2.1 Terminology

The following terms are used to understand and define a PA system. A well-designed system should provide the following:

- **Intelligibility.** The goal is to achieve easy comprehension of the spoken word.
- **Stability.** The announcements broadcast over the PA system should be free of feedback and spurious pick-up. Feedback—the endless cycling of loudspeaker output back into the

microphone input—is the result of improper loudspeaker location and insufficient electronic gain control. Pick-up of unwanted outside signals can be caused by an aging system or poor installation. In the case of poor installation, the audio signal cables act as an antenna to pick up and amplify signals from outside the PA system. This can be resolved by using proper grounding and shielding techniques and minimizing cable loops that promote electromagnetic induction of signals into the system.

- **Clarity.** Freedom from distortion or noise. Distortion mixed with noise hinders speech intelligibility, especially under low SNR conditions.
- **Linearity.** The PA system's output at the listening position should vary in direct proportion to the sound source. A linear system provides high-quality reproduction (fidelity) of the input sound. A system that does not do this is nonlinear.
- **Naturalness.** The PA system should sound balanced and natural. Given that a PA system is primarily a means for broadcasting the spoken word, the range of frequencies important to understanding speech (nominally 200 to 4,000 Hz) will be present without some frequencies being predominant or lacking.
- **Adequate sound level.** The amplitude of the sound signal is a measure of loudness and is usually measured in decibels (dB) of sound pressure level (SPL). The PA system should be loud enough to be heard in the area served without being objectionably loud.
- **Uniform sound coverage.** In the region served by each loudspeaker zone, the entire area should receive evenly distributed sound levels. Neither hot spots where sound is noticeably higher, nor dead zones where sound is absent are desirable. Ideally, the uniformity is about ± 1 dB.
- **Adequate ratio of direct-to-indirect sound.** Direct sound travels from the loudspeaker directly to the listener's ears. Indirect sound is reflected off one or more surfaces before it reaches the listener. Too much indirect sound interferes with the clear understanding of speech. Echo and reverberation are examples of indirect sound that can compromise intelligibility.
- **Adequate SNR.** The PA system sound level must be sufficiently above the ambient noise level to achieve intelligibility. Ambient noise sources include HVAC systems, aircraft operations, human activity, concession mechanical equipment, TVs, escalators, and people movers.

### 7.2.2 Components

Specification of appropriate component products is an essential part of design for intelligibility. *Sound Reinforcement Engineering* (Ahnert and Steffen 2000), *Advanced System Gain Structure* (McGregor 1999), *Sound System Engineering* (Davis and Patronis 2014), and *Handbook for Sound Engineers* (Ballou 2012) are good resources. The PA system components that affect intelligibility include the microphones, headend electronics, and loudspeakers (see Figure 7-1). All of these components are subject to bandwidth distortion, which can diminish intelligibility in the presence of noise.

Any component in the signal path—from input to loudspeaker—can introduce distortion in the form of nonlinearity between input and output. Generally, purely electronic components (such as headend electronics and power amplifiers) maintain the best one-to-one relationship between input and output. Components introducing the greatest nonlinearity are usually electromechanical transducers (such as microphones and loudspeakers). Professionally prepared

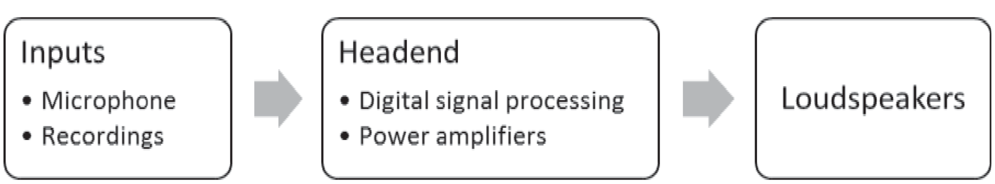



*Figure 7-1. Typical PA system signal path.*

prerecorded announcements will have adequate sound level and be free from noise and distortion. Loudspeaker selection is critical in PA system design because variation in output over a loudspeaker's frequency range introduces distortion, which diminishes intelligibility, particularly in the presence of noise. Thus, when specifying equipment, it is important to use high-quality, commercial-grade components for the loudspeaker and microphones. Consumer-grade or home hi-fi components have no place in airport PA systems.

Components within a PA system must be properly matched to ensure that their impedance and signal levels are matched to the other components in the system. In simple terms, a device's impedance is its opposition to current flow between components. Proper impedance-matching maximizes power transfer between components. Mismatched impedance makes this power transfer inefficient and will introduce signal loss as the sound signal moves from one mismatched component to the next. Signal loss then increases the likelihood of a poor signal and distortion at the loudspeaker due to poor signal level and poor gain settings. In modern PA systems, impedance matching is less of a problem because inputs are typically actively balanced. When all components are obtained from one manufacturer, it is more likely that the individual components are properly matched.

The PA system should be correctly configured at every stage of its operation. Overdriving inputs with a signal that is too strong can cause output clipping, which will introduce distortion and diminish intelligibility. Clipping is a type of waveform distortion that occurs when the signal is cut or "clipped" because the device has reached the limit of its ability to transmit the full signal power. Clipping in the digital signal processor (DSP) can occur when the signal is driven beyond its digital capability to perform the signal processing functions easily. Clipping can also occur when the amplifier is overdriven beyond its maximum capability, causing the signal broadcast through the loudspeaker to no longer match the original input. This can also cause permanent damage to the loudspeakers. For example, when a microphone is abruptly turned off or disconnected, a crunchy, static-like chirp is heard at the loudspeaker; this chirp can cause the loudspeaker cone to break.

## 7.3 Microphones

**The microphone converts acoustic signals to electrical signals. In airport PA systems, the acoustic signal is the human voice. Quality microphones are rugged and robust with a smooth, linear response, typically ± 72 dB, in the speech frequency range between 200 Hz and 4,000 Hz.**

Two types of microphones are used in airport PA systems: omnidirectional and unidirectional. The unidirectional microphone is most sensitive to sound arriving from one particular direction and is less sensitive at other directions. This gives the unidirectional microphone a higher gain-to-feedback ratio, which maximizes performance and intelligibility. A cardioid microphone is an example of a unidirectional microphone and has a heart-shaped response about its main axis (see Figure 7-2). This pick-up pattern is the most sensitive at 0 degrees (on-axis) and is least sensitive at 180 degrees (off-axis). Independent of microphone selection, feedback rejection can also be improved with proper loudspeaker placement at the microphone location. If the design can avoid loudspeakers above the microphone location, omnidirectional microphones can be used.

The omnidirectional microphone has a lower gain-to-feedback ratio, which is undesirable, but the following desirable attributes explain its common use in airport PA systems:

- Lower distortion.
- Smoother off-axis coloration.

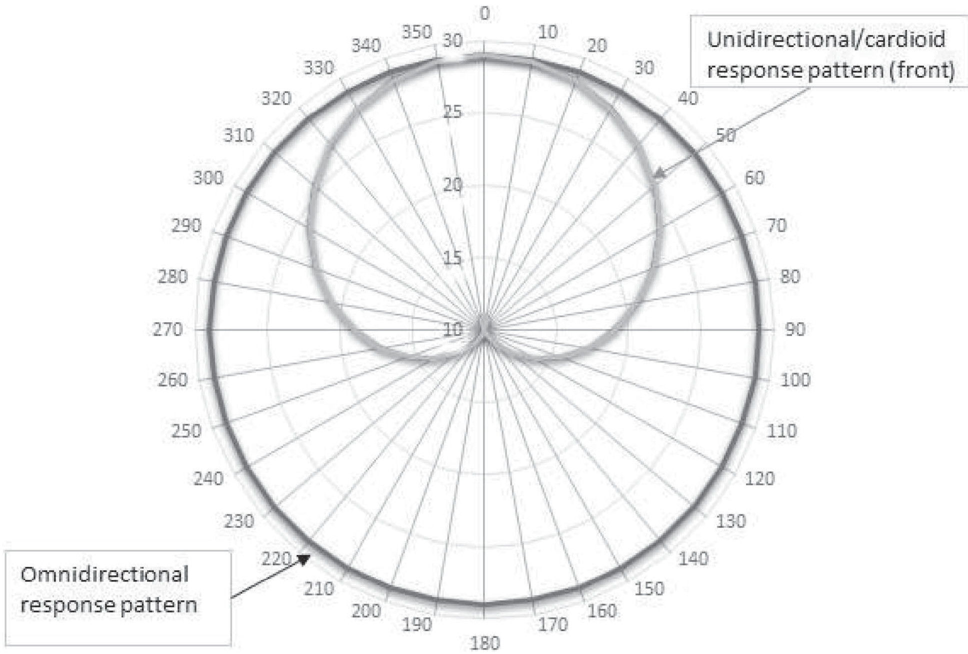



*Figure 7-2. Polar response pattern.*

- Simpler training. Less microphone technique training is required, because there is no proximity effect in omnidirectional microphones. A common, but ineffective, microphone technique is to speak with the microphone right up to the speaker's lips, which disproportionately increases the low-frequency (bass) response of the microphone—this can then cause the microphone signal to overload or distort, or, in the case of automatic gain systems, the microphone gain is lowered in response to the strong bass response.

Airport paging microphones have a "push-to-talk" feature which keeps the microphone muted until the talker is ready to make an announcement. A good push-to-talk microphone has a reliable, high-quality, long-lasting switch. The button is mounted on the microphone or on the paging station, depending on the type of microphone used.

### 7.3.1 Handheld Microphones

Handheld microphones are used in airport PA systems because they are convenient for users. Such microphones are particularly useful to improve intelligibility for live announcements in noisy, reverberant environments (e.g., baggage claim or gate areas). Handheld microphones are found at wall- or desk-mounted paging stations where the microphones are conveniently located and readily accessible to gate and baggage agents. Handheld microphones should have a frequency response designed for voice communications.

The limiting factors that affect paging microphone performance are microphone sensitivity and frequency response. The microphone output should match the DSP input in level and impedance to maintain good signal quality. Handheld microphones typically have a clip or hook for mounting to the wall station. One manufacturer offers a microphone with a magnet to hold the microphone on the wall station. Besides serving as the microphone input, the paging stations also have a keypad for access control and routing. The pushbutton on the side of the microphone activates it and engages the PA system. Figure 7-3 shows a push-to-talk microphone.

Photo Credit: J. Lewitz

***Figure 7-3. Push-to-talk microphone.***

### 7.3.2 Other Paging Microphone Types

Desktop (gooseneck) paging microphones, which are similar to handheld microphones in performance and function, are used where podium or desk stations are more convenient for paging or where vertical surfaces for the handheld microphone mounting plates are not available. The desktop and gooseneck microphones also have pushbuttons, typically on the base or paging station, to activate the microphone and engage the PA system. Figure 7-4 shows a desktop paging microphone.

Photo Credit: Wikimedia Commons

***Figure 7-4. Desktop paging microphone.***

## 7.4 Headend Electronics

Headend electronics are components that constitute the "brains" of the PA system. Headend equipment constitutes the control center where most of the functional aspects of the PA system are established and stored. The main components of the headend electronics are the digital signal processor (DSP) and the power amplifiers. This equipment is typically rack mounted in a telecom or server room.

In a large airport, the headend may be in a central location, feeding audio signals to audio power amplifiers in satellite equipment rooms to minimize loudspeaker line power loss. Long loudspeaker lines waste amplifier power and are costly. Typically, loudspeaker line loss should be kept under 0.5 dB. A 3 dB loss would represent a loss of half the power over the length of the line, so loudspeaker line loss is an important design consideration. **Loudspeaker line loss is determined primarily by the impedance of the connected loudspeaker load, the length of cable, and the cable size. Line loss can be compensated for by using larger gauge (AWG) cables, but this is also a cost consideration. Shortening the loudspeaker lines by remotely locating the amplifiers, if possible, is the most cost-effective strategy. Minimize loudspeaker line power loss. This can be done through specification and layout.**

An important part of the headend DSP is the processing of the information from the ambient-noise-sensing microphones. Some systems include ambient-noise-sensing microphones to measure the noise environment in each zone. The DSP in the headend uses that information to temporarily add gain to the loudspeaker input signal when the ambient noise levels increase.

### 7.4.1 Digital Signal Processor

The digital signal processor (DSP) makes changes to audio signals. The functions of the DSP include

- Pre-amplification
- Compression
- Limiting
- Equalization
- Delay
- Combining
- Routing
- Switching
- Gain staging

The DSP is used to select, combine, route, filter and otherwise process audio signals (including basic functions of calibration, level-setting, delay, and equalization) before amplification.

**Device latency is the time it takes to transmit the digital signal through the DSP, including the A/D (analog to digital) and D/A conversion. Device latency should be considered in the PA system design and product selection. Excessive audio delay anywhere in the PA system hinders intelligibility, but can be controlled through specification and component selection.**

More detailed explanations of each DSP function are available in other sources such as *Sound Reinforcement Engineering* (Ahnert and Steffen 2000), *Advanced System Gain Structure* (McGregor 1999), and *Handbook for Sound Engineers* (Ballou 2012). Key operations that relate to speech intelligibility are included here:

#### *Pre-amplification*

During pre-amplification low-level microphone signals to be processed by the DSP are amplified. This stage electronically amplifies a very weak signal (for example from a microphone or pick-up) and transmits it to the DSP. Balanced gain structure—starting with the pre-amplification stage and throughout the entire PA system including the DSP—is important to optimize speech intelligibility.

### *Compressors and Limiters*

**The compressor, a component of the DSP, narrows the difference between the softest and loudest sounds passing through the PA system. The compressor does this by compressing the dynamic range of the audio signal, thereby essentially reducing the volume of loud sounds and amplifying quiet sounds. Large swings or extreme peaks in the PA signal level are detrimental to intelligibility. If the PA is too loud that can be annoying or distracting, but if it is too soft, the intelligibility would be lost in the ambient noise. Such issues can be controlled through specification, component design and PA system optimization.**

A limiter is a compressor with a high compression ratio and a fast attack time. The attack time determines how quickly the compressor's gain reduction reacts to changes in the input signal level. A limiter is intended to "limit" peak levels in the audio signal. Compression is sometimes built into the paging microphone circuitry.

### *Equalization (EQ)*

Equalization increases or decreases the level of different frequencies in the PA signal. Equalization is performed by digital electronic equalizers within the DSP component. A basic type of equalization is the bass/treble control in a home stereo system. In the DSP, the equalizer performs more complex frequency-response adjustments to tailor the frequency response of the PA system to improve sound quality and intelligibility. Examples of EQ use for speech intelligibility would be to emphasize and smooth the frequencies useful for understanding speech or to compensate for frequency-response anomalies in the loudspeakers or room response. Different equalization is necessary for different signal sources and zones such as loudspeaker zones, local announcements, prerecorded announcements, and background music.

### *Audio Delay*

In some situations, it is necessary to delay an audio signal in time to synchronize arrival of signals between loudspeakers at different distances from a listener. Sound travels at a fixed rate of speed. **Speech intelligibility is affected if one loudspeaker broadcasts a signal sooner than a later arriving signal that has to travel from across a large room. Audio delay can be necessary to synchronize arrival of signals between loudspeakers and improve speech intelligibility.** The need for audio delay can be identified during design and optimized during installation/commissioning.

### *Combining, Routing, and Switching*

Combining, routing, and switching signals includes collecting signals from different sources, directing them to desired zones, and switching between sound sources. This process is done in the DSP on direction from the users. For example, the curbside message "active loading and unloading only" is routed to the power amplifiers serving the curbside loudspeakers in the DSP. Another example is when an emergency page is to be broadcast; a signal from security would switch from normal paging announcements to the emergency message.

### *Gain Staging*

Gain structure is an important software control function within the DSP and affects overall intelligibility. Gain stages are the points in the signal chain where level adjustments are made. This is important for system calibration which sets overall PA system sound levels. **Noise and distortion can occur if levels are not properly balanced in the DSP. Gain staging and structure are established during PA system design.**

*Audio Power Amplifiers*

The role of the audio power amplifier is to amplify the low-power signals from the DSP to a level suitable for driving the loudspeakers. This step is where the signal levels are matched. The power amplifiers should be sized for the wattage necessary to drive the loudspeakers to the required sound levels. When the power amplifiers are undersized or overdriven, clipping and other distortion occurs, which hinder intelligibility and can damage the loudspeakers. **Audio power amplifiers should be appropriately sized to avoid distortion in the signal and degradation of speech intelligibility. The system should be engineered to furnish a minimum 3 dB of headroom at maximum power amplifier output.**

### 7.4.2 Ambient-Noise-Sensing System

Ambient noise conditions influence speech intelligibility and the STI. One technique to offset the effect of varying daytime ambient conditions is to use an ambient-noise-sensing system that can boost the PA signal 4 to 6 dB during periods of higher-than-normal ambient conditions.

When planning implementation of ambient-noise-sensing microphones in the PA system, consider the following:

- Commissioning gain adjustments are typically made during low to moderate ambient conditions (quiet daytime periods during operations)
- STI tests are typically conducted during low ambient conditions (nighttime or after operation hours)
  - These quiet daytime conditions are expected to be the same or slightly higher than the nighttime ambient noise conditions during which the STI tests are done.
  - Based on calculations made on the ADS measurements and laboratory tests, on average, the daytime STI can be 0.20 lower than the STI measured during nighttime conditions.
- Ambient noise microphones can help offset some of this reduction, given that they are typically programmed to increase the announcement signal as the daytime ambient noise level increases.
- Practically speaking, there is a limit to what the ambient-noise-sensing system can achieve. Issues such as feedback and distortion typically limit the gain that the ambient-noise-sensing system can provide. A nominal 4 to 6 dB boost can often be implemented.

## 7.5 Loudspeaker Type Selection

Although there are many types of loudspeakers, Table 7-1 lists types commonly used at airports. The type of loudspeaker selected for a particular space depends on the use for which it is normally intended and for which it was designed. Some types of loudspeakers function well as a distributed system, whereas others are intended to cover a large space with a few loudspeakers.

### 7.5.1 Cone Loudspeakers

Distributed ceiling-mounted cone loudspeakers are preferred in mid-to-low-ceiling areas (less than 24 feet). Cone loudspeakers provide the most uniform sound coverage if the proper loudspeaker density is maintained. A good rule of thumb is to space the loudspeakers at a distance equivalent to the floor-to-ceiling height. Uniform sound coverage contributes to good intelligibility by maintaining uniform PA sound levels in the listening plane. The listening plane is an imaginary horizontal surface located at the listener's ear height.

Distributed loudspeakers in a low-ceiling space can be operated at lower audio power levels. This improves intelligibility, especially in reverberant spaces. Distributed ceiling-mounted

**Table 7-1. Loudspeaker types and beneficial configurations.**

| Loudspeaker Type | Configuration | Comment |
| --- | --- | --- |
| Ceiling-mounted | Distributed on ceilings | Mid-to-low ceilings; not suitable for concave ceilings |
| Passive column array | Distributed on walls or columns | Easy to reach longer distance (high ceiling, long throw) |
| Steerable column array | Distributed on walls or columns | Easy to reach longer distance (high ceiling, long throw), ability to "steer" coverage to the desired listening area. |
| Wall-mounted (multiple components in a single box or enclosure) | Distributed on vertical surface | Similar to passive column array, but with limited sound coverage pattern control |
| Omnidirectional/spherical | Do not use | Basic properties run counter to speech intelligibility needs at airports |

loudspeakers in high ceiling spaces are less desirable because they have to be operated at higher sound levels. This does not automatically result in better speech intelligibility. If too few loudspeakers are spaced too far apart, uniformity of sound coverage and intelligibility are diminished.

Spaces where the floor and the ceiling are both acoustically hard and reflective are problematic for distributed ceiling-mounted loudspeaker systems. Aside from the problem of reverberant buildup, the reflections between the two reflective parallel surfaces reduce intelligibility. In this case, carpeted floor or acoustical ceiling treatment should be considered so that at least one of the two opposing parallel surfaces is absorptive.

Acoustically treated flat ceilings are most appropriate for ceiling-mounted cone loudspeakers. Avoid ceiling-mounted loudspeakers in concave ceilings that are not acoustically treated. Concave ceilings exacerbate the multi-focusing effect of the sound energy and greatly reduce intelligibility. Focusing of sound would be an acoustical anomaly that would result in nonuniform sound coverage. Acoustically treating the surface will diminish the focusing effect by reducing the reflections off the surface.

Cone loudspeakers with a coaxial construction are necessary to optimize clarity and intelligibility. Loudspeakers with a single-cone construction cannot faithfully reproduce the broad band of frequencies required. Loudspeakers with a dual-cone construction use separate transducers for the low and high frequencies. Each transducer is uniquely designed for the frequencies to be reproduced. The separate cones are coaxially mounted in a single frame to synchronize arrival of sound from each cone where the frequencies cross over from low to high. Figure 7-5 shows examples of ceiling-mounted cone speakers.

### 7.5.2 Passive Column-Array Loudspeakers

Passive column-array loudspeakers are very useful in large areas with high ceilings, areas where the speaker must reach an area quite far away (long throws), and so forth. Passive column arrays use small individual loudspeakers vertically stacked so as to interact with one another to maximize sound coverage in the horizontal plane and narrow the coverage in the vertical plane. Figure 7-6 shows an example of a passive column array loudspeaker sound field distribution. This enables the loudspeaker to maximize sound coverage in the listener plane and minimize sound coming from reflecting surfaces, thus improving intelligibility, especially in reverberant

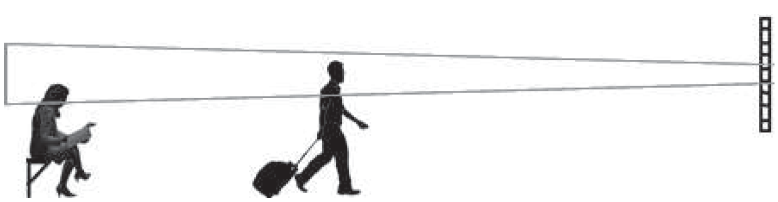
Photo Credit: Wilson Ihrig

***Figure 7-5. Examples of ceiling-mounted cone speakers.***

spaces. The columns are mounted at a low level so that the plane of sound coverage corresponds to the listener's ear height. Also, the horizontal energy distributions are fairly wide.

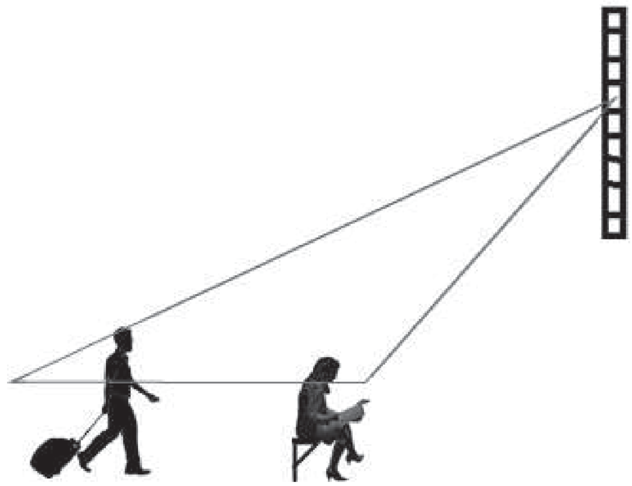
### 7.5.3 Steerable Column-Array Loudspeakers

Steerable column-array loudspeakers have the same attributes as passive column-array loudspeakers, except that the loudspeakers in the array have individual microprocessor controls to allow the coverage to be actively or electronically "steered" to direct the sound coverage toward the listeners. Maximizing direct sound (i.e., the sound that comes directly from the loudspeaker to the listener) improves intelligibility. Defining the coverage pattern to the areas where the listeners will be seated or standing is useful when the space is very large and reverberant. The sound energy is directed away from walls, windows, and similar surfaces. Unwanted reflections excite the reverberant field and diminish intelligibility. Steerable column arrays can be mounted high on a wall or column and vertically flat against the wall because the coverage can be electronically steered down to the listeners. Figure 7-7 shows an example of array steering.



Source: Wilson Ihrig

***Figure 7-6. Example of passive column array loudspeaker sound field distribution.***



Source: Wilson Ihrig

*Figure 7-7. Example of array steering.*

Steerable column arrays have less sound attenuation over a defined distance than standard box or passive column-array systems. This is a result of microprocessor control of the individual loudspeakers in the column and their interaction with each other. Fewer steerable-column arrays are needed to uniformly cover a large area. Figure 7-8 shows an example of steerable-column array loudspeakers.

### 7.5.4 Horn Loudspeakers

A horn loudspeaker uses an acoustic horn to increase the overall efficiency of the driving element. Because horn loudspeakers are not as directional as passive column arrays or steerable column arrays, horn loudspeakers are not as desirable indoors in large spaces. Their weather resistance makes them more suitable for curbside applications. Their high efficiency also

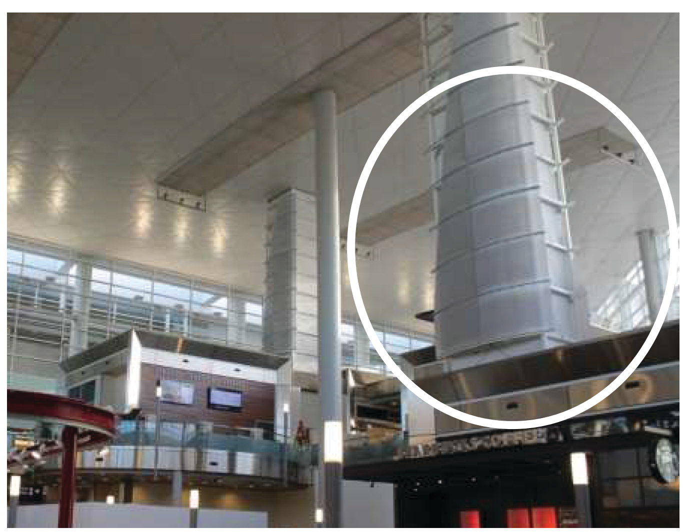


Photo Credit: Wilson Ihrig

***Figure 7-8. Example of steerable column array loudspeakers*** **(circled*****).***

Photo Credit: Wilson Ihrig

***Figure 7-9. Examples of horn loudspeaker.***

supports the higher sound levels required in noisy outdoor areas such as at curbside. Figure 7-9 shows examples of horn loudspeakers

### 7.5.5 Undesirable Loudspeaker Applications

In a large space, wall-mounted nondirectional loudspeakers (e.g., cone loudspeakers in a box) provide poorer uniformity of sound coverage than distributed column loudspeakers. Optimizing uniformity of sound coverage improves intelligibility.

Omnidirectional or spherical loudspeakers should be avoided because they work against the concept of maximizing the ratio of direct-to reverberant sound to maximize intelligibility. By its very nature, an omnidirectional loudspeaker delivers excessive sound energy to the reverberant field, thus diminishing intelligibility.

## 7.6 Loudspeaker Layout

The design of a loudspeaker layout is somewhat determined by the type of loudspeaker that will best serve the space. The loudspeaker selection is typically based on the physical layout of the space. As noted above for microphones, feedback rejection can also be improved with proper loudspeaker placement at the microphone location. If loudspeakers can be avoided above the microphone position in the design, omnidirectional microphones can be used. The physical loudspeaker spacing can also be determined based on the kind of loudspeaker that might be required. Not all loudspeakers are designed to serve a broad range of acoustical environments. The acoustical environment and physical dimensions of the space will dictate what loudspeaker type is best, where the loudspeakers are mounted, how many loudspeakers are needed, and what type of loudspeaker layout configuration will be used.

**In a low-ceiling space, the distributed ceiling-mounted loudspeakers need to be close together to furnish uniform sound coverage and avoid "hot spots." The number of loudspeakers and the spacing density is a function of the sound pattern broadcast by the individual loudspeakers. A loudspeaker with narrow angle of coverage will require more loudspeakers.**

**In a high-ceiling space, the challenges are different, because a loudspeaker that is too far from the listener will not have an adequate ratio of direct-to-indirect sound; the listener will not be able to understand announcements over the ambient noise. This is a case where a different type of loudspeaker must be considered.**

### 7.6.1 Loudspeaker Zones

An important part of the design process is to identify "zones" where sound coverage is desired (e.g., ticketing, concourses, gates, and baggage areas). The DSP is programmed to route specific PA signals from specific paging stations to the power amplifiers serving the loudspeakers in a desired zone of coverage.

**Part of the design process is to identify an acoustically distinguishable space (ADS) where the acoustics and physical characteristics of the space are fairly uniform.** An ADS is distinguished from other spaces due to acoustical, environmental, or use characteristics (e.g., reverberation time and ambient or background sound level). Intelligibility will be maintained when PA system design elements, including sound level, equalization and loudspeaker type, location and orientation are consistent and tailored to each ADS.

### 7.6.2 Spatial Considerations

For a well-defined space, where wall-to-wall distances and floor-to-ceiling distances are not great, the challenges are fewer. All spaces, regardless of size, require a sufficient amount of acoustical treatment on room surfaces to provide adequate absorption of reverberant sound.

**For very large spaces, the types of available loudspeakers that will function properly and produce acceptable intelligibility are limited. In large spaces, installing the loudspeakers closer to the passengers is advisable. This installation is done with wall- or column-mounted loudspeakers with high directional capabilities to concentrate the sound on the listeners.**

### 7.6.3 Audio Delay

**Design should avoid overlapping sound coverage from loudspeakers. For instance, when a listener hears sound from two separate loudspeakers spaced more than about 40 feet apart, the delayed arrival of sound from the more distant loudspeakers creates an artificial echo, which will reduce intelligibility. In some cases, an electronic audio delay unit in the DSP can be used to synchronize arrival of sound in zones of overlapping coverage from loudspeakers spaced more than 40 feet apart. Loudspeakers must be grouped into different zones.**

### 7.6.4 Loudspeaker Grid: Distribution

Two types of distributed loudspeaker systems are found in airports:

- Distributed ceiling-mounted loudspeakers pointing down. Typically, these
  - Are found in spaces with low or medium ceiling heights (i.e., less than 24 feet)
  - Are on ceilings less than 24 feet high; the spacing is nominally equal to the ceiling height
  - Use cone loudspeakers (so called because of the "cone" loudspeaker diaphragm and conical coverage pattern)
- Distributed wall- or column-mounted loudspeakers. Typically, these
  - Are found in high ceiling spaces and highly reverberant environments
  - Use loudspeaker column arrays (so called because of their construction using loudspeakers vertically stacked in a column)

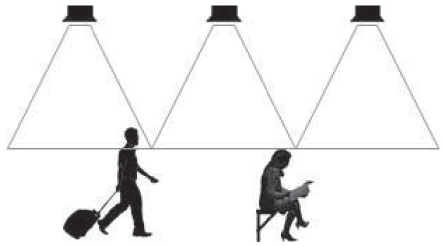


***Figure 7-10. Example of loudspeaker coverage.***

Where a distributed loudspeaker system can be used, the loudspeaker grid (i.e., loudspeaker spacing in the grid) depends on several characteristics, including

- Ceiling height
- Loudspeaker directivity
- Loudspeaker sensitivity
- Distance from any one loudspeaker to a listener
- Acoustical conditions, including reverberation and noise

From an intelligibility standpoint, the main goal of selecting a loudspeaker distribution pattern is to minimize the distance from a loudspeaker to a listener's ear, regardless of where a person stands. Such a distribution will allow for more uniform coverage. Figure 7-10 shows an example of loudspeaker coverage. The distance between the loudspeaker and the listener will determine the configuration of the loudspeaker installation. From a cost standpoint, it is necessary to optimize the number of loudspeakers while designing for acoustically acceptable coverage. The type of loudspeaker selected will determine the distribution of loudspeakers.

**If the ceiling height is less than 24 feet, the distributed ceiling-mounted loudspeaker spacing is the same as the ceiling height. For ceilings higher than 24 feet, ceiling-mounted loudspeakers create a challenge for adequate speech intelligibility, so in this case, use distributed wall- or column-mounted loudspeakers.**

### 7.6.5 Point Source Distribution

In some cases (e.g., physical restrictions such as available mounting points or the size and shape of the space), a single point source may be the best way to provide the most uniform sound coverage. A point source is a single loudspeaker or cluster of loudspeakers projecting sound to a large space such as an atrium, large concession area, or arrivals hall.

## 7.7 Loudspeaker Quality

The quality of a loudspeaker refers to its ability to reproduce sound, either from a recording or a live announcement, that is as close to the original sound as possible. Use only robust, professional-quality, reliable, loudspeakers. Loudspeakers can introduce distortions into the PA system, which can make it difficult to optimize the system for suitable speech intelligibility. The goal is to minimize the need to compensate electronically for poor frequency response or other quality deficiencies such as loudspeaker sensitivity. A low-quality loudspeaker often has low sensitivity, which then needs more amplifier power to achieve a specified sound level. This is costly, inefficient, and counterproductive to sustainability. See Appendix G for an example of the relevant excerpts of specification for loudspeakers.

Quality loudspeakers have an overall response of typically ± 5 dB over a broadband operating range between 70 Hz and 15,000 Hz with a smooth, linear response, typically ± 2 dB, in the speech frequency range between 200 Hz and 4,000 Hz. Coaxial construction, adequate magnet weight (10 oz. or more for the low-frequency reproducer), and high sensitivity (95 dB at 1 watt, 1 meter) are all attributes of a quality loudspeaker.

Specify quality loudspeakers:

- **Adequate magnet weight (10 oz. or more)**
- **Overall ± 5 dB over the range of 70 Hz to 15,000 Hz**
- **Smooth, linear response (± 2 dB) over 200 Hz to 4,000 Hz**
- **Coaxial construction**
- **High sensitivity (95 dB at 1 watt, 1 meter)**

## 7.8 Loudspeaker Terminal Location Considerations

PA system design considerations primarily depend on two factors: ceiling heights and acoustical conditions. At airports, these two factors are consistently the same at some terminal locations; however, many spaces are highly variable. Loudspeaker selection should be appropriate for specific terminal functional areas. Table 7-2 summarizes guidance for selecting loudspeakers and designing layout specific to areas within the terminal. Relevant acoustical factors (ordered by terminal functional area) follow:

- **Ticketing.** Ticketing areas can have high ceilings and can be reverberant and noisy due to passenger activity. Column array-type loudspeakers should be considered to maximize SNR.
- **TSA security checkpoint.** These areas are particularly noisy because of the number of passengers brought together in a small area. Consider increasing the density of the loudspeakers to provide increased sound coverage and intelligibility.
- **Long corridors.** These corridors tend to be quieter than other circulation areas, unless noise from people movers is excessive. Low-ceiling areas typically use distributed ceiling-mounted loudspeakers.
- **Gate hold areas.** Gate areas typically have low ceilings and carpeted floors for which distributed ceiling-mounted loudspeakers will suffice. Increase loudspeaker density in gate areas affected by outside jet noise and in areas where there are overlapping zones of loudspeaker coverage. Avoid TV audio interfering with the PA announcements.
- **Concessions.** Retail and food courts are usually noisy from passenger activity and mechanical noise from concession refrigeration and other mechanical equipment. High ceiling spaces should use column or array loudspeakers to maximize SNR.
- **Large circulation areas.** Acoustically large spaces, such as arrivals and departures halls, are typically noisy and reverberant. Avoid distributed ceiling-mounted loudspeakers in high ceiling spaces. Use column or array loudspeakers to maximize SNR.
- **Baggage claim.** Many of these areas have low ceilings, but carousel noise is a problem. Maintain adequate sound level and distributed ceiling-mounted loudspeaker density.
- **Curbside.** These areas are often extremely noisy because of traffic. The almost constant drone of cars and buses is difficult to overcome especially if loudspeakers are too far apart. Outdoor conditions may dictate weather-resistant horn loudspeakers.
- **Restrooms.** Restrooms are usually small volume spaces that are often quiet and can be easily covered by a minimum number of ceiling-mounted loudspeakers.
- **Customs/immigration.** This area typically has a low ambient profile, with important PA announcements in several languages. Maximize SNR with dense loudspeaker coverage, typically closely spaced ceiling-mounted loudspeakers.

**Table 7-2. Guidance summary for PA system design.**

| | Physical Factor Challenges | | | |
|---|---|---|---|---|
| **Condition/Challenge** | **Reverb.** | **Reflections and Echoes** | **Ambient Noise** | **Guidance** |
| Ceiling height <24 feet | | X | | Ceiling-mounted loudspeakers; loudspeaker spacing comparable to ceiling height |
| Ceiling height >24 feet | X | X | | Loudspeaker spacing less than ceiling height |
| Ceiling height >>24 feet | X | X | | Use wall-mounted or column array; special attention during optimization/commissioning |
| Concave ceiling | | X | | Avoid ceiling-mounted loudspeakers unless the ceiling has high performing acoustical tile |
| Exterior spaces | | X | X | Exterior spaces typically require durable loudspeaker materials, typically found in horn loudspeakers |
| Few hard surfaces (<15% surface area) | | | | No special design requirements |
| Moderate hard surfaces (<40% surface area) | X | X | | Loudspeaker spacing less than ceiling height; special attention during optimization/commissioning |
| Many hard surfaces (>40% surface area) | X | X | X | Loudspeaker spacing less than ceiling height; special attention during optimization/commissioning; use wall-mounted or steerable column array |
| Busy, active areas | | | X | Loudspeaker spacing less than ceiling height |
| Multiple gate areas in the same ADS | | X | | Loudspeaker spacing within each zone less than ceiling height; >40 feet spacing between loudspeakers for each gate |
| Mechanical equipment in public spaces | | | X | Loudspeaker spacing less than ceiling height; use higher PA signal level |
| HVAC equipment above public spaces | | | X | Loudspeaker spacing less than ceiling height; use higher PA signal level |
| Areas with TVs | | | X | Loudspeaker spacing less than ceiling height |
| Areas with intrusion from exterior jet noise | | | X | Loudspeaker spacing less than ceiling height; use higher PA signal level |
| Small volume space <<5000 cubic feet | | | | No special design requirements |
| Very large volume space >>500,000 cubic feet | X | X | | Use wall- or column-mounted loudspeakers with high directional capabilities; special attention during optimization/commissioning |

## 7.9 System Interfaces

Level balancing is in the interface between live and prerecorded announcements. Specifically, no matter what the origin of the page, the sound level must be consistent and adequate at the listening location. All sources must be prepared, tested, and adjusted to maintain consistent level into and out of the DSP to maintain consistent levels of intelligibility. The various announcements must be clear and distortion free. Typical sources include

- AODB (airport operational database)
- FIDS (flight information display system)

- PBX (phone system for paging)
- Mobile phones (for messaging to phones or smart devices)
- Text-to-voice
- Gate microphones
- Emergency announcements
- Call-in recordings (within the airport or from exterior calls)

## 7.10 Computer Modeling for PA System Design

Software modeling brings value to the design process. Programs are available to create a 3-D model of the airport terminal and the PA system within each space. The physical space is built in the computer, surface treatments are added, and then the loudspeaker devices are entered. From this, the program evaluates the acoustics of the space and derives expected PA system parameters. This allows virtual modeling and pretesting and enables design issues to be addressed early in the process. Software modeling can help guide installation and limit costly design changes. Intelligibility can be predicted because the same computer model is used for both the acoustical design and the PA system design. The power of the model lies in the ability to quickly evaluate options based on the performance results.

The following questions should be considered when selecting software modeling for PA system design:

- What is the processing power and speed of the software?
- How easy is it to construct the physical space in the computer model?
  - Is there a built-in drawing module?
  - Can it be integrated with third-party CAD programs?
- How easy is it to place loudspeaker devices in the model?
- Can SPL, STI, Reverberation Time and Uniformity be derived from the model?
- Is there a large database of loudspeaker devices available for the model?
- Is there a database of acoustical materials available?

Some software programs are simplified for use in mass notification types of projects. Computer modeling is necessary to predetermine the performance expectations for the PA system design.

As discussed in Chapter 6, many commercially available packages can evaluate the room acoustics and calculate the STI from the PA system (STIPA). However, these are not all comprehensive packages for PA system design given that they typically only model the output of the loudspeakers, not the complete PA system component design. For a simple or moderately complex room, a basic PA system design program that uses simplified characteristics of the room acoustics (e.g., percentage surface area treated) may be sufficient. For complex spaces, however, a software package that can import the room acoustics model would be useful. In these cases, the designers should anticipate this and prepare for this hand-off during construction document design.

## 7.11 Considerations for Renovation Projects

Renovation projects can take the form of partial or complete replacement of the PA system. If it is desired to keep the existing loudspeakers, a complete loudspeaker system survey is required to verify that all loudspeakers are operational and have adequate power-handling capacity. Existing loudspeakers could be several decades old, in which case it would be prudent to examine them, including a listening test to assess potential deterioration

Reusing existing loudspeakers presupposes that the zoning and coverage of the existing system is adequate. Loudspeaker lines must be checked for continuity. Most of the existing loudspeakers can be used with a new or updated digital headend with very good results. Inspect all loudspeakers and address previous connection issues. All renovation projects will benefit from recommissioning of the system (see Chapter 9).

## 7.12 Considerations for Combining Emergency and Non-Emergency Announcements

It may be desirable to use the PA system loudspeakers as part of the airport's Emergency Alert System (EAS). This can be done, subject to local code requirements. If the PA system will be used for major mass evacuation, certain equipment conditions may be required (e.g., UL-rated loudspeakers and end-of-line monitoring and programming input logic to control priorities). Per NFPA 72, existing PA systems can be used as part of an EAS following a formal risk assessment and with approval of the authority having jurisdiction (AHJ).

PA systems can be used for emergency announcements, as long as the PA system meets the code requirements for emergency use, including

- Meeting objective, measurable intelligibility criteria
- Supervised lines and other reliability code requirements
- Emergency power backup

A combined system would require a way to switch to the emergency announcement source while muting the non-emergency announcements. This can be done digitally in the DSP. Some jurisdictions require an analog relay to avoid DSP programming changes (even with software password protection) or failures, which could disrupt the switchover.

## 7.13 Sustainability and PA Systems

The EPA provides information on the sustainable management of the following electronics and lifecycle stages (EPA 2016):

- **Raw materials** acquisition and manufacturing.
- **Purchase and use.** Covers both "first use" and "second use." First use indicates use by the original purchaser of the product, and second use indicates when the first user no longer uses the electronic product and sells or gives the product to another person.
- **Storage.** Concerned with how long users store products when they have finished using them, thus affecting when a product is ready for end-of-life management.
- **End-of-life management.** Products at their end-of-life are managed by one of two practices:
  - Collected for recycling. May be subsequently reused, refurbished, or recycled for materials recovery.
  - Disposed of primarily in landfills. Combustible components may be collected and sent to waste-to-energy incinerators.

On their website (epa.gov/smm-electronics), the EPA indicates that sustainable electronics management includes the following steps:

- **Buy green.** Purchase new equipment designed with environmentally preferable attributes. The EPA website includes a list of ways to buy greener electronics.
- **Power consumption.** The power amplifiers and headend electronics have the highest power requirements. The amplifiers are typically multichannel units with outputs ranging from 200 watts to 600 watts per channel. Using multichannel units minimizes materials compared to separate single-channel units. Use Energy Star-rated equipment, or review information at energystar.gov to evaluate equipment energy use.

- **Sourcing of materials.** Although many of the materials for the enclosures and electronics can be widely sourced, all audio electronics require some small amount of rare metals, and some permanent magnets in loudspeakers may also use rare metals such as neodymium.
- **Carbon footprint.** Many of the manufacturing facilities for the circuit boards and parts within PA system components are outside of the United States. Some of the component-level manufacturers are in the United States, but most of them are off shore. Thus, there are transportation costs involved in every level of the component chain.
- **Reuse and donate electronics.** Lengthening the service life of electronics to keep them out of the waste stream is preferable to recycling. Headend electronics have few moving parts and can be donated to non-profit organizations and schools to upgrade their PA systems. Loudspeakers can be similarly reused or donated, although the loudspeaker cones can experience wear or aging that affect performance after a long period of performance or operation in harsh environmental conditions.
- **Recycle electronics.** Electronics recycling (e-cycling) allows for the recovery of the rare metals from the electronics. To ensure responsible e-cycling, e-cycling businesses should be certified by a third-party program. The EPA has more information on responsible and sustainable e-cycling.

## 7.14 Induction Loops for Assisted Listening

For people with hearing loss to receive the same passenger information and emergency messages that other travelers would expect to hear, an assistive listening system is necessary. Because it is not practical to hand out personal receivers at the airport, an induction loop system is used to transmit an audio signal directly into a hearing aid via a magnetic field. This greatly reduces background noise, competing sounds, reverberation, and other acoustic distortions that reduce clarity of sound. The loop requires signal conditioning for the broadcast information signal, and the signal in the loop, in turn, induces a signal in a telecoil (T-coil) receiver, such as most modern hearing aids. Perimeter loops are the simplest kind of hearing loop with the area to be served surrounded by a copper cable embedded in the floor which is connected to an output amplifier. Multiple loops serve individual areas of the airport (e.g., gates and baggage claim). Loops can also be installed at point-of-sale or service counters. The feed for the system is a separate output from the DSP. Installation and equipment standards are included in IEC 60118-4.

CHAPTER 8

# Construction Phase

## 8.1 Construction Review for Room Acoustics

As with many aspects of construction, some components of the architectural finishes that affect PA system speech intelligibility will require close and careful inspection during installation, but other components may only require a general review of construction practices or spot checks to document general conformance with the specifications. Ultimately, a properly designed and installed PA system within a suitably designed acoustic space can be fine-tuned during commissioning.

Any acoustical treatments for spaces should be reviewed for proper submittals and installation. Examples of important elements and potential problems applicable to any acoustical project follow:

- **Vibration-isolated ceilings and walls.** Some ceilings and walls may require vibration isolation to provide noise control for noisy or vibrating equipment and maintain low ambient noise conditions. Proper selection and installation of isolators or resilient channels is crucial. Springs are often incorrectly sized, with a "bigger is better" mentality that results in a stiff spring that provides little or no vibration benefit. Ceilings must be held off the walls (and caulked if necessary for fire and/or sound isolation). Soffits, suspended lights, wall-mounted brackets and other items need to be designed and coordinated to avoid short-circuiting the ceiling or wall isolation.
- **Sloped ceilings or walls.** These elements may be incorporated to minimize flutter echoes or other reflections that interfere with speech intelligibility.
- **Acoustical ceilings and acoustically absorptive surfaces.** These provide specific and important amounts of absorption. In general, more absorption than specified can be beneficial because it tends to reduce the reverberation time—too little can undermine speech intelligibility goals. Proper distribution is also important—most materials should be uniformly spread across the available surfaces.

## 8.2 PA System Bid Process

The specifications for the PA system and associated acoustical materials related to architectural finishes and sound isolation elements will have the appropriate information related to performance and treatment areas. Specific to the PA system, the specification will have the following information:

- Equipment electrical and power requirements
- Computer language requirements
- Equipment compatibility information with existing systems
- Interface integration requirements

- **Acoustical performance requirements**
  - **PA sound levels at listener positions**
  - **Off-axis sound levels**
  - **PA sound level uniformity**
  - **STI performance**
- Loudspeaker specifications
- Loudspeaker spacing and placement (when crucial or unusual)
- Environmental conditions
  - Temperature, humidity, etc.
  - Nominal targeted room acoustics design goals (e.g., reverberation time)
  - Nominal targeted daytime ambient noise conditions design goals
  - Nominal room dimensions and finish treatments
- Measurement method (by reference or described)

Other features that can be considered include system design and components that support built-in PA system component health monitoring and which include effective built-in test capability. See Appendix G for sample text related to speech intelligibility.

## 8.3 PA System Installation

### 8.3.1 Submittals

During the project construction phase, the architectural finishes and PA system installation need to be coordinated with the base building schedule as well as with any other cabling installations for electrical, Ethernet/IT, security, and other A/V systems.

Typically shop drawings and product information cut-sheets will be prepared by the drywall, ceiling, or finish subcontractor or PA system installer (integrator) and submitted for review. The general contractor or airport representative must have personnel with knowledge and ability to review and comment on those submittals. The PA system installer should provide an Operations Manual that covers, at a minimum, how to make PA-system-level changes and how to operate the paging stations. Guidance and background information to understand the PA system information is provided by others, for instance in *Audiovisual Best Practices* (Cape and Smith 2005).

### 8.3.2 Shop Tests

Each component must be tested and verified that it meets the requirements, whether it be a performance test for power capacity or a simple verification that the correct part has been obtained and installed. Best practices (Cape and Smith 2005) call for all equipment to be shop tested. An owner's representative can be present during these tests:

- Proper function of the equipment
- Shop mock-up of system
- Loading and testing of all software
- Preset adjustments

### 8.3.3 Onsite Testing

Best practices call for preliminary testing to be performed before system commissioning to determine if the system is substantially complete and proper connections have been made. These tests can include

- Powering on all equipment and verifying the functions of all components
- Verifying signal paths for all field-terminated wiring

- Configuring and testing the functionality of the PA system
- Balancing the PA system components
- Configuring basic PA announcement settings
- Configuring basic zone EQ settings
- Verifying any communications services that are integrated with the PA system (e.g., telephone, Ethernet, fire, and others)
- Checking loudspeaker polarity
- Verifying loudspeaker line impedance
- Checking hum and noise level
- Verifying acoustical and electrical frequency response
- Verifying signal-to-noise ratio (SNR)

Document initial tests and adjustments, including numerical values of relevant equipment settings, for reference during the system acceptance testing.

## 8.4 Site Reviews and Inspections

The three tests presented in the following subsections (8.4.1 through 8.4.3) are also done during commissioning to verify operation and optimize the system, but it is generally expected that installers will have performed the basic preliminary work to demonstrate for themselves that they have installed the system correctly.

### 8.4.1 Balancing the System

Balancing the system means that all inputs and outputs to the headend of the PA system are at the same or comparable levels. Once the PA system outputs are balanced (equal) at all zones, the overall PA system sound level can be set for each input so that there are no obvious fluctuations in level between different inputs or interfaces. There are three elements of the PA system, and each element can require adjustments for the system to function properly:

- **Input signal.** Each audio input is considered, along with the native input level and conditioning or gain required. An equalized reference curve and relative levels for each input source is matched for all loudspeaker zones so that all inputs are generally presenting same signal level to the headend and loudspeakers. Gain adjustments at the input signal allow the system to maximize the SNR. It is good practice to have separate controls for level adjustments and equalization for each of the inputs. At airports, these inputs and system interfaces are typically as follows:
  - AODB (airport operational database)
  - FIDS (flight information display system)
  - PBX (phone system for paging)
  - Mobile phones (for messaging to phones or smart devices)
  - Text-to-voice
  - Gate microphones
  - Emergency announcements
  - Call-in recordings
- **Amplifier (headend) gain settings.** These gain settings typically start off at the neutral setting to maximize the signal-to-noise ratio (SNR). Each element of the PA system can inject noise native to the electronics of each element. Although this kind of noise has, in recent years, typically been reduced because of improvements to the electronic components, it is still best practice to hold gain adjustments to a minimum at the headend. All gain settings should be set to avoid distortion. Proper gain structure should be optimized throughout the system to

minimize noise and signal distortion. Usually distortion is caused by overdriving the microphone preamplifier (e.g., the headend gain is too high). Normally, an input attenuator (pad) is implemented at the headend amplifier to reduce the level at this point, which allows the level control to be provided at the second gain stage. (For more details, see McGregor 1999.)

- **Zone gain settings.** Given that each ADS has slightly different acoustical properties and background conditions, adjustments at individual loudspeaker zones may be necessary during commissioning and optimization.

### 8.4.2 Setting PA Announcement Levels

The overall sound pressure levels in each loudspeaker zone should be around 72 to 78 dBA at the nominal listening height (3 to 5 feet above the floor) or as indicated in the specifications.

### 8.4.3 Loudspeaker Zone Frequency Response Equalization

The level from the microphone in each loudspeaker zone is the first area that is checked and adjusted before starting frequency equalization or any other adjustments for that zone. Typical tasks to equalize each loudspeaker zone are as follows:

- **Document the background.** Measure and document the background (or quiet ambient) noise level (dBA) and the frequency spectrum in one-third octave bands from 125 Hz to 6,300 Hz.
- **Measure the Initial EQ.** Broadcast a pink noise (equal level in each one-third octave frequency band) signal through the loudspeakers. As needed, make level adjustments to the pink noise signal so that the measured broadcast signal is approximately 10 dB above the background level in each frequency band from 125 to 6,300 Hz. Adjust the equalization to attenuate sharply the PA system frequency response below 125 Hz at approximately 6 to 12 dB per octave. Roll off (attenuate) the frequency response above 6,300 Hz at 6 dB per octave. This attenuation filters out frequencies that are not important for speech intelligibility.
- **Adjust the Zone EQ.** Play pink noise through the loudspeakers in each zone, set the EQ level, and spatially equalize for that ADS area.
  - Set the live announcement level.
  - Talk into the microphone (live announcement) and measure the sound pressure level in that loudspeaker zone. The level should be measured on-axis with the loudspeaker. Confirm that the microphone gain has been set so that the measured sound pressure level falls between 72 and 78 dBA, depending on the acoustical conditions and specification requirements. These levels should be maintained throughout the zone.
  - After the live announcement level has been set up, play pink noise through the microphone via “talk-box” at the same level as the reference level announcement.
  - Adjust the frequency band equalizer so that the spatially averaged sound is a nominal match for pink noise; however, note that it is not usually advisable to increase the gain for any individual one-third octave band by more than 2 dB.
- **Readjust the sound pressure level.** After frequency equalization, the loudspeaker zone overall sound pressure levels will typically require adjustment to reset back to the reference level. Sound pressure level variations around the entire loudspeaker zone should be noted at this time.
- **Troubleshoot as needed.** Refer to Section 9.4.5, which presents troubleshooting tips.

CHAPTER 9

# Commissioning Public Address Systems

## 9.1 Introduction

This chapter presents the post-construction process (referred to as commissioning) for the PA system. Important steps in this process involve tuning, balancing, and other adjustments that can affect speech intelligibility. Many of the concepts discussed elsewhere in *ACRP Research Report 175* are brought to bear during commissioning.

**For PA systems, it is important to have verification that the system is performing as designed and to optimize the system for its intended use within the framework of the built system; this process is known as commissioning. Commissioning is not intended to relieve the PA system vendor/installer of responsibility for providing a system that meets the project's specifications and other requirements. Commissioning offers an opportunity to fine-tune the system electronically within the constraints imposed by both the acoustics of the space and the electronic response of the PA equipment in the as-built condition.**

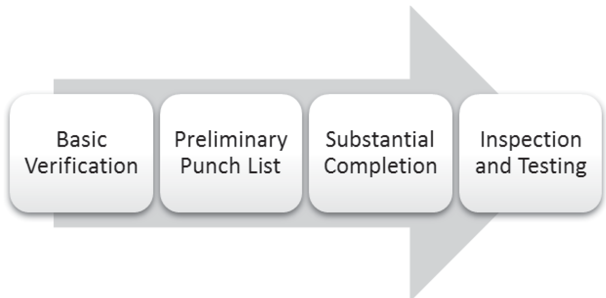
The vendor/installer should conduct testing (as discussed in Chapter 8), but an outside party also should review and test the installed system as part of a commissioning process. Key reasons to have the commissioning performed by an independent party include

- A separate task and budget will not be affected by potential cost overruns during installation.
- Although the vendor/installer and commissioning agent both have knowledge of the PA system electronics, a qualified and experienced commissioning agent also should have experience in acoustics and speech intelligibility in particular.
- A third party (other than the installer) can be part of an impartial quality assurance process to uncover and resolve problems such as those involving wiring or inadequate labeling and/or documentation.

The qualifications for the commissioning agent include familiarity with and experience in the following:

- Operation and design of PA systems in airports and similar large public interior spaces
- Optimization and testing of PA sound systems
- Room acoustics principles and acoustical measurements
- Speech intelligibility and STIPA measurement procedures

Given that many of the key terms and concepts for commissioning are like those for Installation in Section 8.3, only issues specific to commissioning PA systems at airports are discussed in the following sections.




Source: Adapted from Cape and Smith (2005)

***Figure 9-1. Steps in commissioning a PA system.***

## 9.2 Overview

Four steps have been identified in the overall process for PA system commissioning, as shown in Figure 9-1 (Cape and Smith 2005):

1. Prepare for commissioning. This includes basic verification of the system function, which may be included in the installation contract.
2. Generate a preliminary punch list, which forms the basis for substantial completion, and may be included in the installation contract. Items such as workmanship, installation delays, and equipment failure can be identified at this step.
3. Establish substantial completion. Once the items on the preliminary punch list have been completed, the system is ready for the commissioning agent to evaluate and optimize the system.
4. Inspect and test the system by the commissioning agent.

## 9.3 Key Concepts

### 9.3.1 Verification

Verification occurs during the Basic Verification step and inspection and testing and confirms that the PA system meets the intent of design specifications contained in the contract documents (Cape and Smith 2005). The quantifiable elements include items that can be objectively verified (e.g., the number of electrical components, power ratings, and frequency response characteristics). Verification also encompasses review of the software, firmware, and hardware settings that affect the overall system performance such that the system provides the intended function of broadcasting live and recorded announcements over the PA system. Often the installer has performed a basic verification with appropriate tests to demonstrate and substantiate to their satisfaction that they have achieved the contractual obligations as part of the installation process (see Section 8.3).

Specific verification tasks include

- Verifying and optimizing audio signal paths throughout the system
- Verifying that control systems and user interfaces are operating correctly and efficiently and providing the required functionality
- Completing all programming of audio devices and verifying their functionality
- Verifying that all contractual obligations have been met, including the complete system installation and provision of documentation

### 9.3.2 Optimization

Optimization occurs during inspection and testing and is project specific, requiring the commissioning agent to be familiar with the operation of PA systems in large public spaces and the evaluation of speech intelligibility, optimizing and sound system testing. Although PA systems at shopping centers and transportation stations have elements that are sometimes similar to airports (e.g., large volume/high ceiling rooms, elongated spaces, and high ambient noise levels), airports are unique in terms of security for airside and landside procedures. The diversity of public spaces within an airport and the nature of the secure environment and PA system announcements at airports are different from those of other large public spaces. The PA system technical staff, be they airport personnel or installer/operators, will have access to the secure login and control of the software for tuning and level adjustments, while the commissioning agent will advise PA system technical staff as to adjustments to be made during commissioning. These adjustments set the proper sound levels and equalization (frequency tuning the system), taking into account the acoustical conditions of each acoustically distinguishable space (ADS).

## 9.4 Inspection and Testing

The three tests presented in the following subsections (9.4.1 through 9.4.3) were developed more fully in Chapter 8 because the basic preliminary work is expected to be completed by the installer. Commissioning and optimization adjustments are discussed below.

### 9.4.1 Balancing the System

As was discussed in Chapter 7, there are three elements of the PA system, and each element can require adjustments for the system to function properly

- **Input signal.** It is good practice that the timbre and the levels for each input are as equal as possible in terms of natural sound and sound level.
- **Amplifier (headend) gain settings.** Proper gain structure should be optimized throughout the system to minimize noise and signal distortion.
- **Zone gain and equalization settings.** Given that each ADS can have different acoustical properties and background conditions, adjustments at individual loudspeaker zones are necessary. Zones that are similar, with comparable acoustical and loudspeaker layouts, can have their settings copied and pasted to each area. However, all levels and STI measurements must be documented.

### 9.4.2 Setting PA Announcement Levels

In addition to the information in Chapter 8, spatial averaging should be used for all equalization procedures. ASTM E336-16 includes a method for determining space-averaged levels by using fixed microphones or manually scanned microphones—use this method unless a more current method is developed specifically for use in STIPA measurements. A single microphone placement for analyzing and equalization is not recommended. The actual sound pressure level in a particular loudspeaker zone will depend on the background noise and acoustical conditions. After every adjustment of equalization, limiting, compressing, and/or microphone automatic gain control/level-setting, zone levels must be rechecked and adjusted. Each software module (e.g., local zone input, "all-call" inputs, and recorded messages) should be checked for the gain structure appropriate to each zone. Level-setting is important for consistency of PA announcements and speech intelligibility throughout the airport.

### 9.4.3 Loudspeaker Zone Equalization

In addition to the steps listed in Chapter 8, consider that loudspeaker zone equalization settings are typically adjusted for good speech intelligibility. As discussed in Chapter 7, a natural-sounding system is desirable; this often requires some adjustment to the natural frequency response of the loudspeaker. High-end frequencies (e.g., 2,000 Hz and higher) should not sound harsh, and low-end frequencies (e.g., 125 Hz and lower) can be flat or turned down because the PA system is not being optimized for music quality. Furthermore, excessive low-frequency content through the PA system can reduce speech intelligibility. Overall, the goal is that reproduction should result in a natural sound.

Zones that have very reverberant spaces, or where the ambient noise level is higher than other zones, may require further reduction of the low frequencies and limited amplification of the mid- and high-frequency bands (e.g., 500 Hz; 1,000 Hz; and 2,000 to 3,000 Hz). However, this can cause problems with the loudspeaker output recursively being picked up by the microphones (feedback) if the loudspeakers are close to the announcement microphone location. Loudspeakers installed above microphone locations may need to be set at a lower tap (level). Within the headend software, the "Ring Mode Equalizing" setting or feedback suppression should be activated, and the level and equalization settings should be rechecked and adjusted for all microphone inputs to that loudspeaker zone. Ring mode feedback equalization is possible on all DSPs using narrow-band parametric equalizers.

In some cases, it may be necessary to induce feedback to test the ring mode control or to test if ring mode should be implemented. If the gain settings are somewhat unstable, cupping the microphone with the hands and moving the microphone around will produce feedback. Raising the gain slightly can also induce feedback for a borderline system. Use very high Q parametric filters (i.e., filters with narrow bandwidth) to reduce the feedback at each of the problem areas. However, if ring mode control is being used, it is not advisable to "over EQ" the system, because this can cause the broadcast signal to sound unnatural. Usually three narrow-band parametric equalizers are enough to fix the problems of gain before feedback. As with any adjustments, after these adjustments are made, the zone gain must be set back to the reference level.

### 9.4.4 Measuring and Reporting STI

After the PA system has been initially balanced, equalized, and optimized, the speech intelligibility performance can be tested. If the STI performance does not meet the performance requirement, additional adjustments and optimization of the PA system may be necessary. The specific procedures for measuring STI are being developed by the industry to clarify procedures not defined in IEC 60268-16. ANSI is working with the industry trade group, InfoComm International®, to establish a standard for measuring STI values. Various measurement methods and practices will be standardized, including microphone height and how to obtain a spatial average in each ADS. Following is an annotated list of the basic steps required; these steps typically are conducted during nighttime or after airline flight operations to avoid interference with airline operations and disturbance to passengers.

1. **Measure the quiet ambient noise.** This is the condition without the STIPA signal. This can be measured at a single location representing a passenger's ear or spatially averaged between the typical passenger's seated and standing positions.
2. **Document announcement sound level.** During nighttime hours, observe and document the nominal announcement sound level broadcast through the balanced and equalized system in each ADS. Typically, this is measured at several locations or obtained as a spatially averaged

$L_{eq}$. Document the level of each announcement source: standard recorded announcements and live announcements (e.g., gate announcements, fire department, paging, and text-to-speech). With this lower ambient noise condition, ambient-noise-sensing systems should have no effect on the PA signal.

3. **Play the STIPA test signal.** Broadcast the signal through the PA system via a
   a. waveform audio (WAV) file uploaded to the system server,
   b. direct input at the headend or at the gate microphone input, and/or
   c. live announcer simulator (talk-box) at the gate agent push-to-talk microphone.

   In all cases, the gain settings for the input signal should be adjusted so that the level of the STIPA signal matches the target signal level for the normal inputs fed through each of the above input sources (i.e., server, headend, or talk box). For example, if the signal level from recorded announcements is specified or designed for a nominal 75 dBA level at 5 feet above the floor, at any off-axis position from any loudspeaker, then the STIPA signal played through the PA system should generate a nominal 75 dBA level at the same locations.
4. **Measure the STIPA signal.** The test instrument automatically determines the measurement period. This is typically between 15 and 20 seconds, depending on the measurement instrument used. There can be no apparent extraneous noise during the measurement period (i.e., when the instrument is sampling the STIPA signal). For instance, if someone sneezes or slams a door during a measurement, the measurement should be discarded and a new one started. The measurement instrument will automatically determine if a sample is invalid. In this case, the instrument allows you to discard that test and repeat it. Good practice dictates that an average of at least three tests should be made at each measurement position. The instrument typically reports each individual test result as well as the average of all the samples at one position before the technician resets the meter for the next test position.
   a. Position the test microphone off-axis from any loudspeaker with the microphone at a nominal height 3 to 5 feet above the floor and no closer than 3 feet to any loudspeaker or flat surface.
   b. Conduct a stationary measurement at several locations within the ADS. An arithmetic average of all STI values measured in one ADS can be made if a single STI value is needed for that ADS.
5. **Document results.** Document these initial results in a memo and note whether or not the STI results are in conformance with contractual and code requirements.
6. **Optimize and document.** If necessary, make additional adjustments to the gain or equalization settings to compensate for the root causes of the nonconforming performance (e.g., background noise and room acoustics) and repeat the STI tests. It may be necessary to recommend physical changes to the installation, such as adding or upgrading loudspeakers. However, nonconforming areas, systems, and acoustical problems are usually documented during evaluation of existing systems. New systems should have been designed for proper coverage and acoustical conditions. Headend upgrades should have had tests during evaluation to document any requirements for additional loudspeakers and acoustical treatments. Some design software allows the user to adjust loudspeaker types and locations for proper coverage and tap settings for SPL mapping within a space. Document these adjustments.

Section 12.2.2 offers two examples that demonstrate how optimization and commissioning would improve the speech intelligibility of two different spaces. When the reverberation time is high, optimization would be helpful. Although use of high-performing acoustical ceiling tiles helps control reverberation time, there is still room for improvement.

### 9.4.5 Troubleshooting the Speech Intelligibility of the PA System Installation

The following can be considered if the STI result is lower than the target goal:

**Signal level:** The nominal gain setting for the input may be need to be adjusted higher. Determine whether the paging system microphone level or the prerecorded input levels need adjusting or additional equalization. Other issues with zone gain may bear investigating.

**Uniformity:**

- If the loudspeaker spacing has not been optimized to achieve a consistent level (e.g., ± 1 dBA) throughout the zone, the overall zone signal level may require increasing to achieve the target STI result.
- Poor uniformity and localized problems with dead zones or areas with less signal coverage may be due to individual loudspeakers or overall loudspeaker selection or layout.

**Ambient noise:**

- High background noise levels (e.g., from mechanical equipment, passenger activities, televisions, or food court refrigeration units) may also require higher overall zone levels.
- This condition is typically outside the control of the PA system installer/commissioner; however, the localized condition at a particular ADS might be noisier than others. This fact is worth documenting and discussing with the AHJ to determine if it is possible to reduce the ambient noise.

**Ambient-noise-sensing system:** Verify that this system is working properly. These are typically set to provide up to about 5 dB gain for ambient noise levels higher (louder) than the quiet nighttime environment observed during installation and commissioning. Gain-sensing settings must be tested for feedback problems. In the software, raise the gain to the highest-level set in the noise-sensing module and test for feedback.

**Equalization:**

- In adverse acoustical conditions, it may be necessary to attenuate the lower frequencies up to the 650 Hz band. Adding a low shelf filter to attenuate low frequencies with a 6 or 12 dB attenuation per octave slope can reduce the low-frequency content in the room and reduce the masking effect that such low frequencies and adverse reverberation can cause, both of which can reduce speech intelligibility.
- The higher frequencies (1,000 to 4,000 Hz) can have a strong effect on speech intelligibility, because the consonant sounds (/s/, /k/, /ch/, /t/, etc.) have strong components in this frequency range. Adjusting the EQ to boost the higher frequencies could be helpful.

**Reverberant conditions:**

- These conditions are typically outside the control of the PA system installer/commissioner; however, the localized condition at a particular ADS might have more acoustically hard or challenging conditions than others. This fact is worth documenting and discussing with the AHJ to determine if it is possible to reduce the reverberant environment.
- Highly reverberant areas can benefit from a low shelf filter with a cut off frequency of 650 Hz to attenuate lower frequencies to help reduce the effects of low frequencies, reverberation, and masking.
- Wall locations and higher directivity loudspeakers can improve the situation. Sound should only be directed to the areas of occupied passengers or personal for communication.

### 9.4.6 Considerations for Combination Emergency and Non-Emergency Systems

Subject to local code requirements, the fire marshal can require tests of the emergency fire/mass evacuation cut-over system, which will require fire/emergency announcements and possibly STI measurements to evaluate adherence to Annex D of NFPA72 (NFPA 2016). If the PA system will be used for major mass evacuation, certain conditions may be required (e.g., UL-rated loudspeakers, end-of-line monitoring, and programming input logic to control priorities). The fire/emergency input to the PA system should be measured to document the STI. See Chapter 7 for additional information.

## 9.5 Final Checkout and Verification

It is good practice to walk through the airport while it is in full operation. Listening to the different zones at peak travel hours is important to obtain a subjective confirmation that everything is functioning properly. During this final step, there is often some minor adjustment required for some zones. This procedure will permit the commissioning agent to aurally verify the levels, proper operation, and intelligibility of all zones.

CHAPTER 10

# Public Address System Announcements

## 10.1 Introduction

Guidance developed in Chapter 5 and based on human factors is presented here to improve how passengers respond to and understand PA announcements. The basic guidance consists of the following points:

1. **Use key words, or "hooks" at the beginning of the announcement to draw passenger attention to PA messages.**
2. **Clearly state if information presented is a *change* to that previously given**
3. **Keep messages simple and concise.**
4. **Announcements should be spoken clearly and at a measured pace.**
5. **Play or announce important messages twice consecutively.**
6. **Minimize audio clutter.**
7. **Consider using the female voice for specific types of announcements where factors challenge listeners and reduce attention or intelligibility (e.g., international terminal, text-to-speech).**
8. **Flight information, and in particular updates, should be presented consistently across PA announcements and FIDS to avoid conflicts and confusion.**

## 10.2 Announcement Content

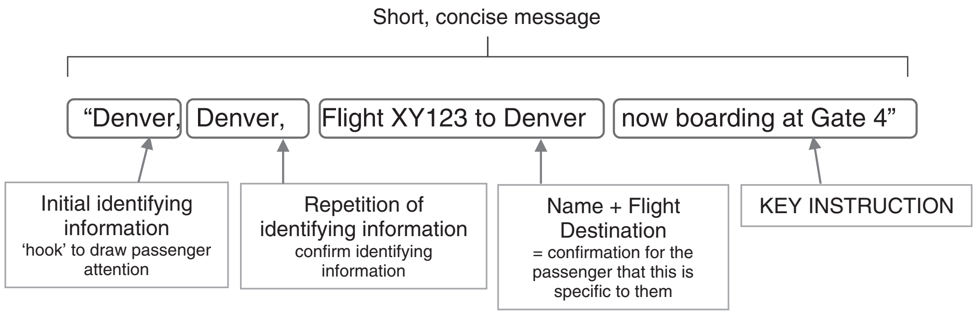
### 10.2.1 Recording Quality

- CD recording quality
- Low background noise (e.g., 35 dBA or lower)
- High-quality microphone and gain structure to eliminate distortion in the recording (see Chapter 7)

### 10.2.2 Announcement Information

- Use key words, or "hooks," such as flight destinations, at the beginning of the announcement to draw passenger attention to PA messages.
- Clearly state if information presented is a *change* to that previously given (e.g., a gate change).
- The message should be meaningful and grammatically correct.
- Keep messages simple and concise.

An example might be: "Denver, Denver, Flight XY123 to Denver now boarding at Gate 4." Figure 10-1 shows this example broken down into announcement information components.




Source: CCD

***Figure 10-1. Announcement information example.***

## 10.3 Announcement Delivery and Live Announcements

Prerecorded announcements tend to be made by professionals or staff members trained and skilled in speaking into a microphone and announcement delivery. The following apply to all announcements and should be included in basic training for all gate agents and any crew or staff likely to make an announcement under normal or emergency conditions.

- Clearly state if the instruction within the PA message is a change to previously given or expected information. For instance, "This is a gate change."
- Ensure that the message is played or spoken in isolation and does not overlap with neighboring gate announcements.
- Speak announcements clearly and at a measured pace. Do not chew gum or have similar items in the mouth.
- Keep messages short and concise. Use clear speech. Keep conversational, chatty messages to a minimum. Remove unnecessary greetings or polite expressions.
- Be aware of diction and timing. Also be aware that the female voice can provide better intelligibility of audio messages and could be more efficacious for specific types of announcements where other factors challenge listeners and reduce attention or intelligibility (e.g., international terminal, text-to-speech).

## 10.4 Automated Announcements

Because automated announcements can be tuned out as audio clutter (refer to Chapter 5 for more detailed discussion) or increase the ambient noise levels and reduce PA system SNR, care should be taken to avoid overexposing passengers and other building visitors. From an operations perspective, automated announcements mean that staffing load can be reduced or reallocated for more urgent or time-sensitive tasks, while ensuring that necessary information is provided to the public reliably with known frequency.

## 10.5 Artificial Voice Systems

For text-to-speech (TTS) or synthesized voice, the following guidance is available:

- Consider using a slightly higher TTS signal level (5 dB) compared to natural voice announcements.
- Repeat the important TTS message to allow passengers to adjust to the synthesized voice.
- Minimize use of TTS messages in areas where challenging conditions to speech intelligibility exist (e.g., highly reverberant space or high percentage of non-native language passengers.)

## 10.6 Message Cuing

Use the following to alert passengers to an impending announcement:

- Precede each announcement with a notable break in background music to draw attention to and provide a cue for the announcement.
- Precede announcements with short, familiar tones, particularly for emergency messages.
- Associate tones with specific types of announcements.
- For gate areas in close proximity, do not overlap messages, especially messages with tones.

CHAPTER 11

# Operation and Maintenance of the PA System

## 11.1 Operation of the PA System

This chapter presents operational policies and procedures that affect the speech intelligibility of PA systems in airport terminals. The installing contractor should provide an operations manual that covers how to operate the paging stations.

### 11.1.1 Employee Announcement Training

**Input from the industry and passengers reveals that training for airport staff on best practices for making announcements would be valuable. Individual airports or airlines may have specific concerns or existing practices that can be incorporated or updated. Discuss the following with airport staff:**

- **Announcement composition: Be concise and use a hook. See Chapter 10.**
- **Announcement delivery: Use clear speech technique. See Chapter 10.**
- **Microphone technique: Learn how to use a microphone properly.**
- **Announcement timing: Where overlapping announcements are possible, develop standard operating procedures for employees.**

### 11.1.2 Use of Microphones

If unidirectional microphones are used, certain precautions should be considered. Some characteristics of unidirectional microphones make them best suited to airport PA systems. Because unidirectional microphones are less sensitive to off-axis sound than omnidirectional types, the talker should speak directly into the microphone. A change in the microphone's frequency response usually gets progressively more noticeable as the arrival angle of sound increases. This is due to off-axis coloration where high frequencies tend to be lost, resulting in a "muddy," less intelligible announcement. The talker should be an inch or two away from the microphone. Speaking too closely into the microphone decreases intelligibility. This is a characteristic of unidirectional microphones, where bass response increases when the talker is too close to the microphone. Too much bass will make the announcement sound unnatural and less intelligible. For maximum intelligibility, announcers should speak slowly and clearly.

### 11.1.3 Voice Quality and Microphone Technique

A good-quality PA system will faithfully reproduce the human voice from microphone to loudspeaker. Older or existing systems with less desirable PA systems may require more effort by airport staff. Staff should

- Determine the optimal combination of microphone to mouth placement and vocal effort to achieve a sound that passengers can understand. It may be necessary to have co-workers provide feedback.

- Ensure their mouths are clear of food or other foreign objects—such obstructions make it difficult for passengers to understand announcements.
- Speak into the microphone. Some people speak from their voice box or throat, making it difficult for the microphone to pick up any signal.
- Use clear speech technique. Do not rush; speak with a measured cadence.

### 11.1.4 Competing Announcements

Some PA systems include a lock-out that prohibits simultaneous announcements from adjacent or nearby spaces. Lacking such a control, especially for existing systems where loudspeakers at the edge of a zone easily broadcast into the adjacent zone or gate hold area, it is best practice to wait until the other announcement is completed.

### 11.1.5 Zoning Announcements

Loudspeaker zoning is a useful tool in limiting announcements to areas where they are relevant. For example, limiting curbside announcements to the curbside, ticketing, and landside arrivals areas makes sense, given that gate passengers are not likely to require an announcement that their cars should not be parked at the curb.

## 11.2 Maintenance of the PA System

This section discusses maintenance best practices. A maintenance contractor or airport personnel should maintain the PA systems. The PA system installer should provide information on how to make level changes in the PA system. With older analog systems, more hands-on testing and adjusting is expected. With newer digital systems, maintenance tasks are reduced; many, if not most, digital systems monitor all aspects of the signal flow and will list problems in the fault log.

System design and components can be specified to support built-in PA system component health monitoring and to include effective built-in test capability. If these capabilities are included in the system, appropriate training and testing on these functions should be included in regular maintenance operations. More information is provided in *Sound Systems Engineering* (Davis and Patronis 2014). Tasks for airport personnel and technicians include the following:

- Frequently checking the digital system fault log and addressing problems that arise.
- Periodically checking the paging stations for broken microphones or microphone cables.
- Periodically checking paging zones for sound level anomalies by walking the zones during announcements. (Refer to the installing contractor's operations and maintenance manual for steps to making changes in the digital system.)
- Periodically checking paging zones during announcements for buzzes, rattles, or inoperative loudspeakers. Contact the installing contractor for verification and replacement.
- Documenting changes. (Keep track of any changes to the installed/commissioned settings to the DSP, EQ, and levels and retest to confirm conformance.)
- Referring to equipment manufacturers' user manuals for operational guidelines.
- Cleaning. Keep the rack-mounted equipment clean and free from dust and debris.
- Scheduling periodic visits by the installing contractor for complete end-to-end system compliance with system performance requirements.

CHAPTER 12

# Decision Tools and Examples

This chapter cross-references key tables and figures provided in the guidelines. Application examples are included here to illustrate how problems can be minimized at various steps of the design process.

## 12.1 Quick Reference for Guidance Tables and Charts

*Architectural Design Guidelines*

See Figure 4-6. Nominal percentage surface area necessary to achieve $RT_{60}$ less than 1.5 seconds
See Table 1-1. Project timing chart for physical factors that affect PA system speech intelligibility
See Table 6-1. Physical factors that affect PA system speech intelligibility that can be influenced by architectural design
See Table 6-2. Summary of design considerations for interior spaces
See Table 6-3. Summary of design considerations for exterior spaces
See Section 6.7 Ambient and Background Noise Considerations for Exterior Spaces

*Mechanical Equipment Design Guidelines*

See Table 6-4. Typical design goals for HVAC and mechanical equipment in public spaces

*PA System Design Guidelines*

See Table 7-1. Loudspeaker types and beneficial configurations
See Table 7-2. Guidance summary for PA system design

*Commissioning Tests*

See Figure 9-1. Steps in commissioning a PA system.
See Section 9.4.5 Troubleshooting the Speech Intelligibility of the PA System Installation

*Announcement Guidelines*

See Figure 10-1. Announcement information example.

## 12.2 Examples from Field Measurements

Following are nine examples taken from the research. During the field measurements, the research team “walked” each ADS to sample the one-third octave band spectrum once per second. Thus, some samples were taken on-axis under a loudspeaker and some were taken between loudspeakers. The uniformity of sound coverage can be represented graphically from this data. The data was measured using pink noise at a level necessary for good acoustical SNR. If it took

30 seconds to walk the space, for example, there are 30 curves in that ADS plot. For each example in this section, a range of values illustrating the "PA System Target Uniformity" is included. The measured uniformity printed at the top of the plot is the range of A-weighted values for all the curves in that ADS.

A "target uniformity" range is shown on each plot, centered on the average of the 1,250 Hz one-third octave band values. This target range indicates a typical frequency response optimized for speech intelligibility and natural sound, not music reproduction. The plots show frequency-specific uniformity and do not imply PA system sound level performance. These plots are useful to evaluate issues that affect speech intelligibility. Figure 12-1 shows such a plot. For each example, a sample of the ambient noise level at the time of the measurement is shown in each figure as a reference.

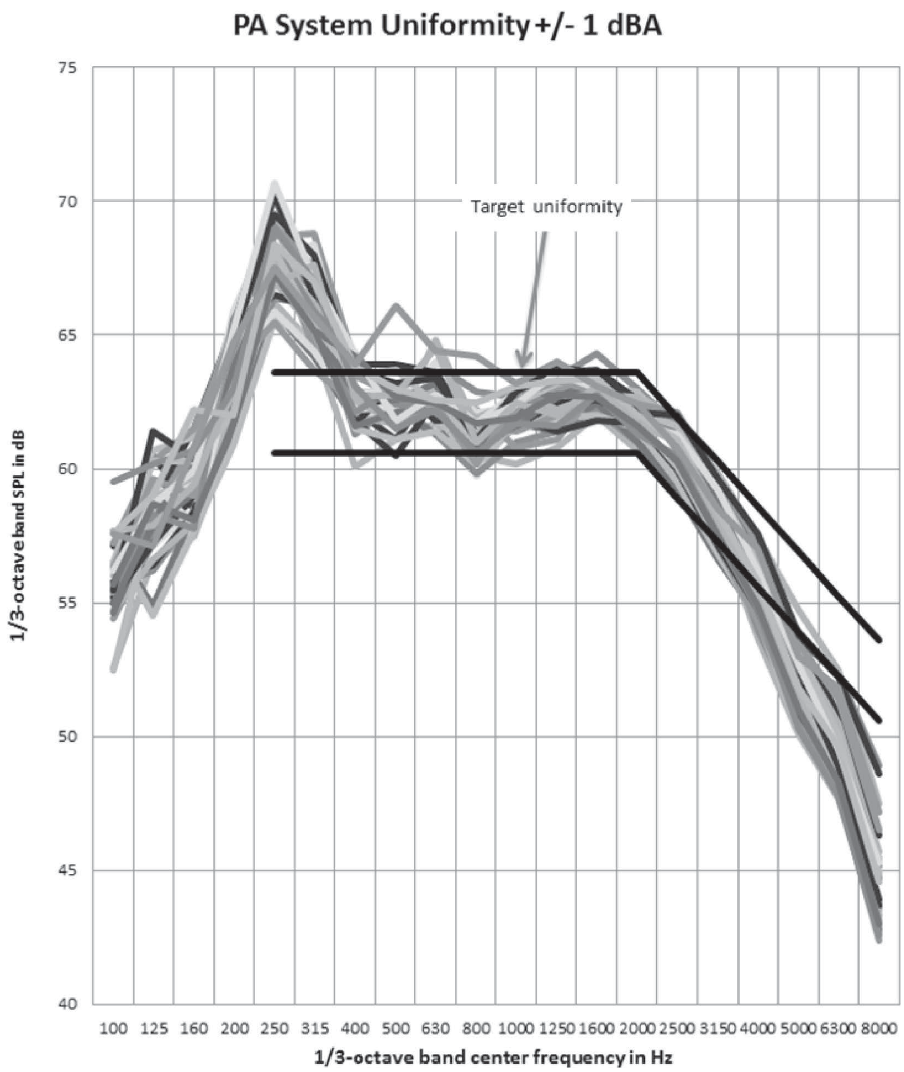



*Figure 12-1. Sample PA system uniformity graph.*

**Example 1 Design Overcomes Very Challenging Conditions to Achieve STI 0.49**

**Description: Large Concessions Space**
Year commissioned: 2005 (Upgrade to digital system in 2015)

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 64 dBA Leq |
| Announcement SPL | 72 dBA Leq |
| Nighttime ambient noise level | 59 dBA Leq |
| STI range | 0.46 to 0.49 |
| Uniformity | ± 4 dBA |
| Reverberation time ($RT_{60}$) | 2.7 sec at 500 Hz<br>2.9 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 59 feet |
| Finishes | Perforated metal ceiling, terrazzo floor, glass wall/window at perimeter |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Digital |
| Paging microphone type | Omnidirectional push talk |
| Loudspeaker type | Ceiling- and fascia-mounted loudspeakers around perimeter; steerable column array at one end (by video monitor); one frontal loudspeaker at opposite end |
| Loudspeaker spacing | 31 feet (ceiling-mounted loudspeaker spacing) |
| Ambient sensing microphones | Yes |

***SPEECH INTELLIGIBILITY DISCUSSION***

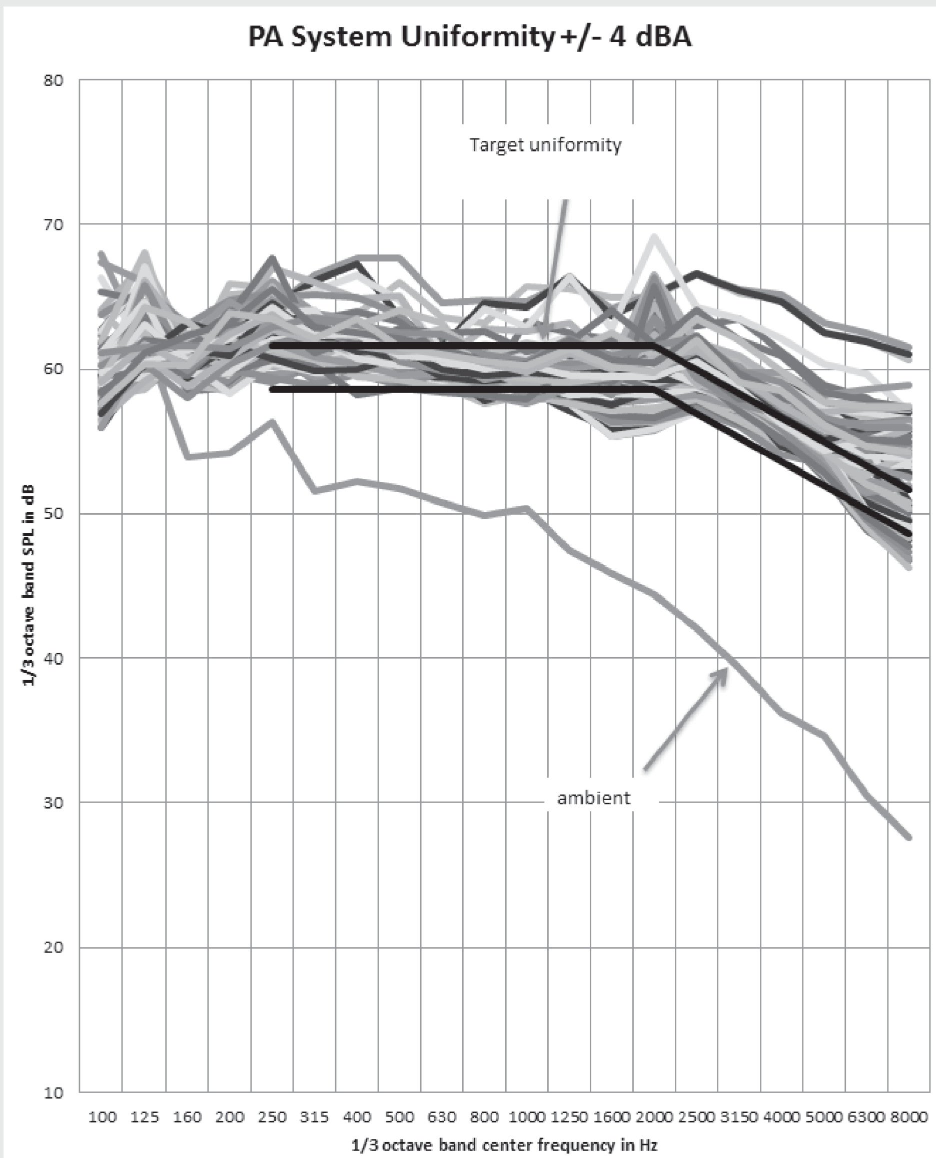
The speech intelligibility at this space could be improved, but it performs remarkably well considering the challenging factors, including:

- Room acoustics. This is a very reverberant space at > 2 seconds.
- High ambient/background noise. The nighttime ambient noise level of 59 dBA is on par with the higher range of conditions measured; likewise, the daytime ambient noise level of 64 dBA was consistent with the higher range measured at all locations. Daytime noise sources include food court activity, dishes, HVAC, and background music.
- Loudspeaker layout. The ceiling is high—well above the 24-ft guidance for ceiling-mounted loudspeakers—and the spacing was larger than 20 feet. The column array and frontal loudspeaker help improve speech intelligibility.

***WHAT CAN BE IMPROVED***

- Room acoustics: Incorporate acoustical absorption to reduce the $RT_{60}$ as close as possible to 1.5 seconds or less. This will reduce some of the daytime ambient noise and reduce noise from announcements at nearby gates. (See Chapter 6 re architectural design.)
- High ambient noise:
  - Incorporate noise control to reduce background sound from the HVAC system; NC 45 or lower. (See Chapter 6 re architectural design.)
  - Incorporate interconnect with background music to mute music during announcements. (See Chapter 5 re human factors.)
- Loudspeakers and PA system design:
  - Replace ceiling-mounted loudspeakers with more column arrays. This might not be practical for such a new system. (See Chapter 7 re PA system design.)
  - Improve PA system EQ. (See the testing and commissioning procedures discussed in Chapters 8 and 9.)
  - Improve uniformity of PA sound coverage. (See the testing and commissioning procedures discussed in Chapters 8 and 9.)

(a) Large concessions space.




(b) Measured PA system uniformity and frequency response.

**Example 2 High-Performance Ceiling Treatment Provides STI 0.65 in High Ceiling Space**

**Description: Concessions, Food Court**
Year commissioned: 2011

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 62 dBA Leq |
| Announcement SPL | 73 dBA Leq |
| Nighttime ambient noise level | 52 dBA Leq |
| STI range | 0.62 to 0.69 |
| Uniformity | ± 1 dBA |
| Reverberation time ($RT_{60}$) | 1.1 sec at 500 Hz |
| | 1.1 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 30–38 feet |
| Finishes | Terrazzo floor, acoustical ceiling tile, gypsum board interior finishes |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Digital |
| Paging microphone type | Omnidirectional push talk |
| Loudspeaker type | Ceiling-mounted loudspeakers |
| Loudspeaker spacing | 28–36 feet (ceiling-mounted loudspeaker spacing) |
| Ambient-noise-sensing microphones | Yes |

***SPEECH INTELLIGIBILITY DISCUSSION***

Excellent PA system sound coverage and high speech intelligibility, largely due to controlled reverberation. Challenging conditions include

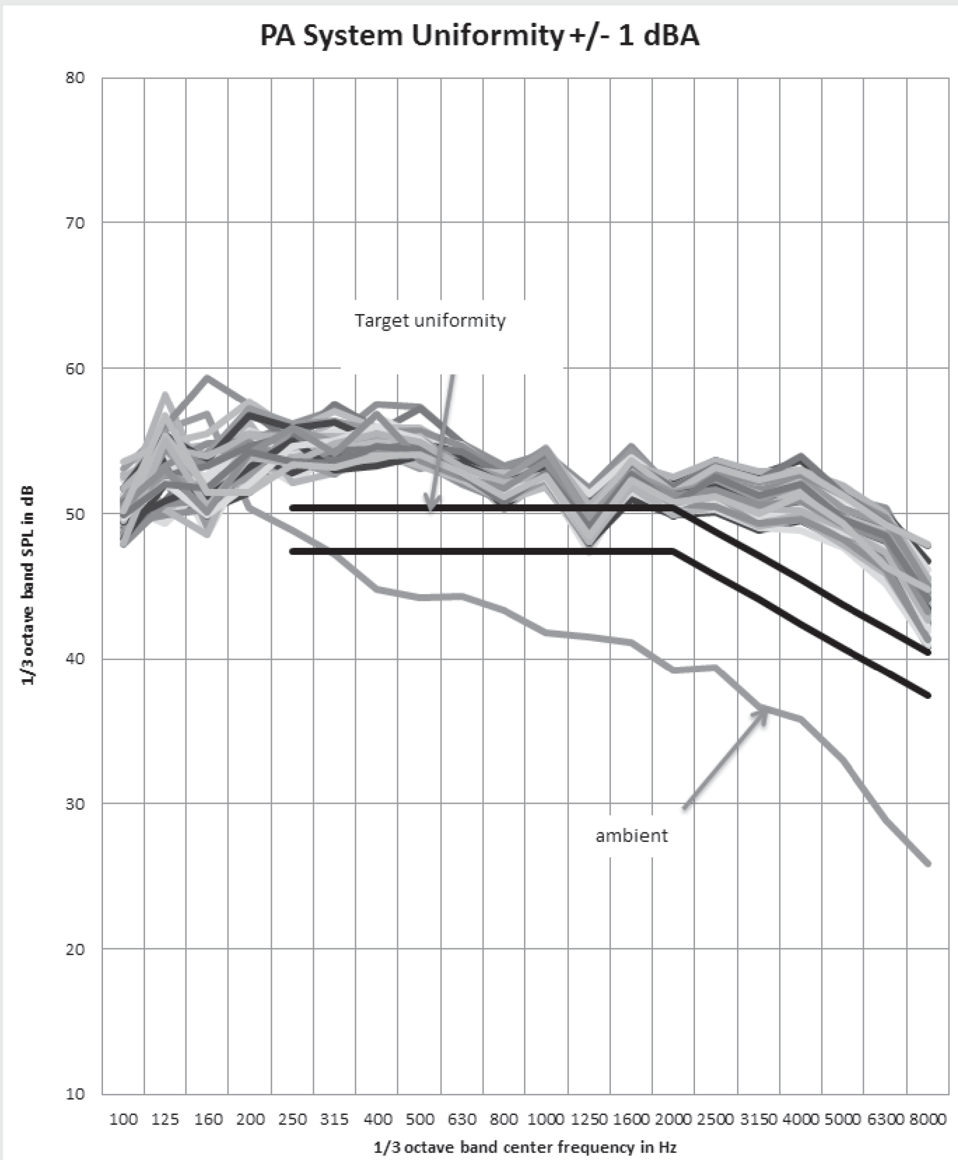
- Large-volume space with high ceiling and tile floor.
- Localized background noise from food court mechanical equipment (e.g., refrigeration equipment).
- PA system frequency response is relatively flat except for mid-low "bump" at 400 Hz that tends to mask intelligibility at higher speech frequencies.

***WHAT CAN BE IMPROVED***

- Room acoustics: none. High-NRC ceiling tiles already in use.
- High ambient noise: Incorporate noise control to reduce background sound from the HVAC system; NC 45 or lower. (See Chapter 6 re architectural design.)
- Loudspeakers and PA system design: Improve PA system EQ per testing and commissioning procedures discussed in Chapters 8 and 9.

Photo Credit: Wilson Ihrig

**(a) Concessions area.**




**(b) Measured PA system uniformity and frequency response.**

### Example 3 Average Performing ADS with Room for Improvement Achieves STC 0.49

**Description: Ticketing**
Year commissioned: 2011

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 62 dBA Leq |
| Announcement SPL | 70 dBA Leq |
| Nighttime ambient noise level | 52 dBA Leq |
| STI range | 0.47–0.52 |
| Uniformity | ± 1 dBA |
| Reverberation Time ($RT_{60}$) | 1.0 sec at 500 Hz<br>0.9 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 18–20 feet |
| Finishes | Carpeting in cue area, terrazzo floor adjacent; angled ceiling of micro-perforated metal panel with faux wood finish; glass exterior wall; gypsum board and metal panel interior; and ventilation diffusor walls. |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Digital |
| Paging microphone type | Omnidirectional push talk |
| Loudspeaker type | Ceiling-mounted loudspeakers; |
| Loudspeaker spacing | 12–17 feet (ceiling-mounted loudspeaker spacing) |
| Ambient-sensing microphones | Yes |

***SPEECH INTELLIGIBILITY DISCUSSION***

Many positive attributes in this space, including PA system uniformity, but the speech intelligibility can be improved. Challenging conditions include

- Large areas of acoustically hard surfaces.
- Background noise.
- PA system frequency response is relatively flat except for mid-low "bump" at 200 Hz that tends to mask intelligibility at higher speech frequencies.

***WHAT CAN BE IMPROVED***

- Room acoustics: None.
- High ambient noise: Incorporate noise control to reduce background sound from the HVAC system; NC 45 or lower. (See Chapter 6 re architectural design.)
- Loudspeakers and PA system design: Improve PA system EQ per testing and commissioning procedures discussed in Chapters 8 and 9.

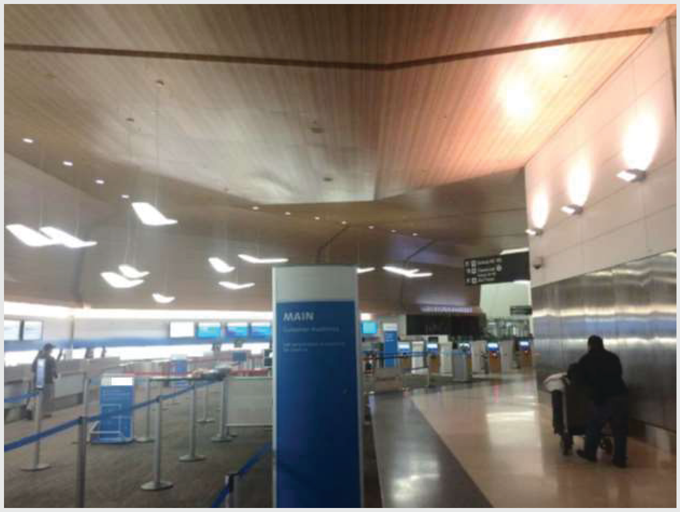
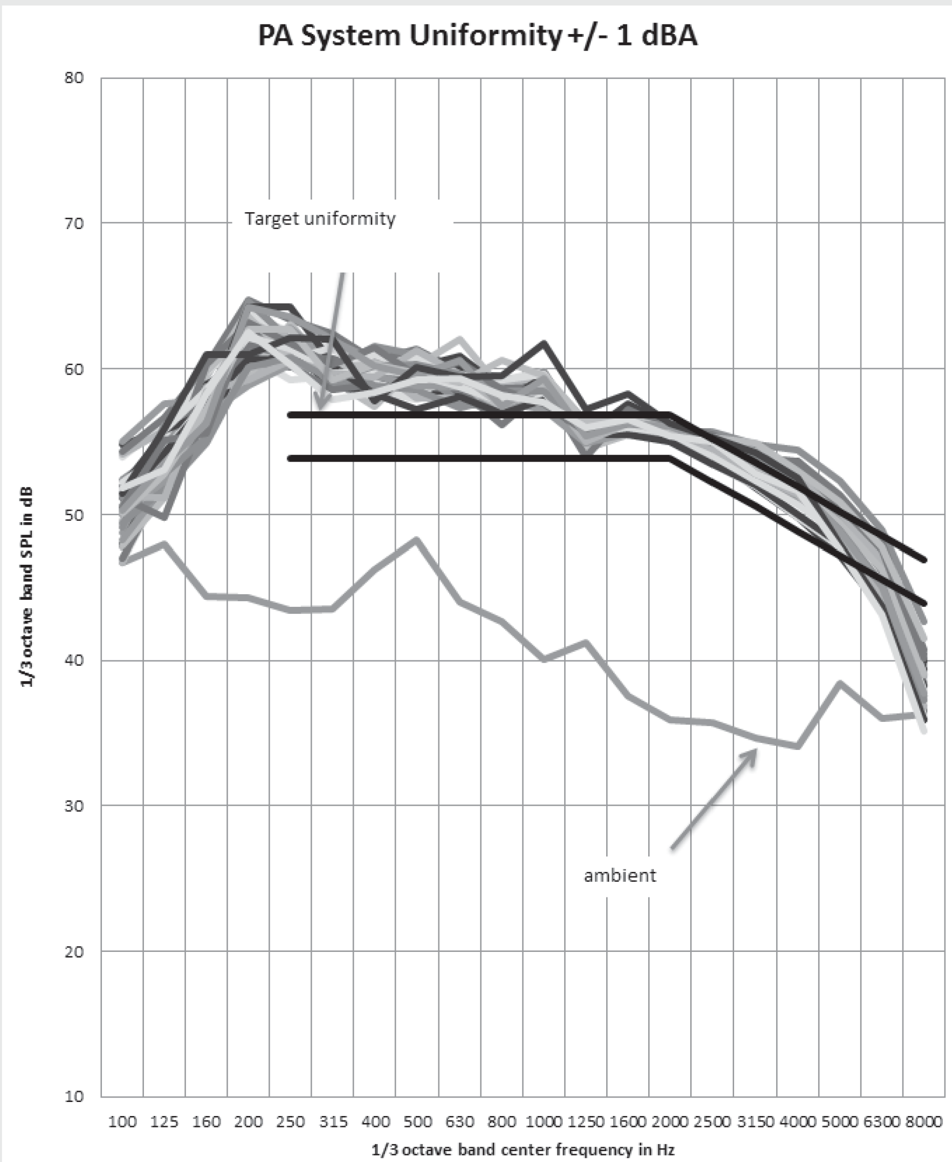



Photo Credit: Wilson Ihrig

**(a) Ticketing area.**




**(b) Measured PA system uniformity and frequency response.**

### Example 4 Low-Ceiling Space Underperforms at STI 0.32

**Description: Baggage claim area**
Year commissioned: unavailable

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 62 dBA Leq |
| Announcement SPL | 70 dBA Leq |
| Nighttime ambient noise level | 62 dBA Leq |
| STI range | 0.32 |
| Uniformity | ± 1 dBA |
| Reverberation Time ($RT_{60}$) | 2.9 sec at 500 Hz<br>2.8 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 8–13 feet |
| Finishes | Arched plaster ceiling, terrazzo floor. No acoustical treatment. |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Digital |
| Paging microphone type | N/A |
| Loudspeaker type | Ceiling mounted |
| Loudspeaker spacing | unknown |
| Ambient-noise-sensing microphones | No |

***SPEECH INTELLIGIBILITY DISCUSSION***

This space is in the same airport as the previous example. In this case, the low ceiling cannot overcome poor acoustical environment. Challenging conditions include

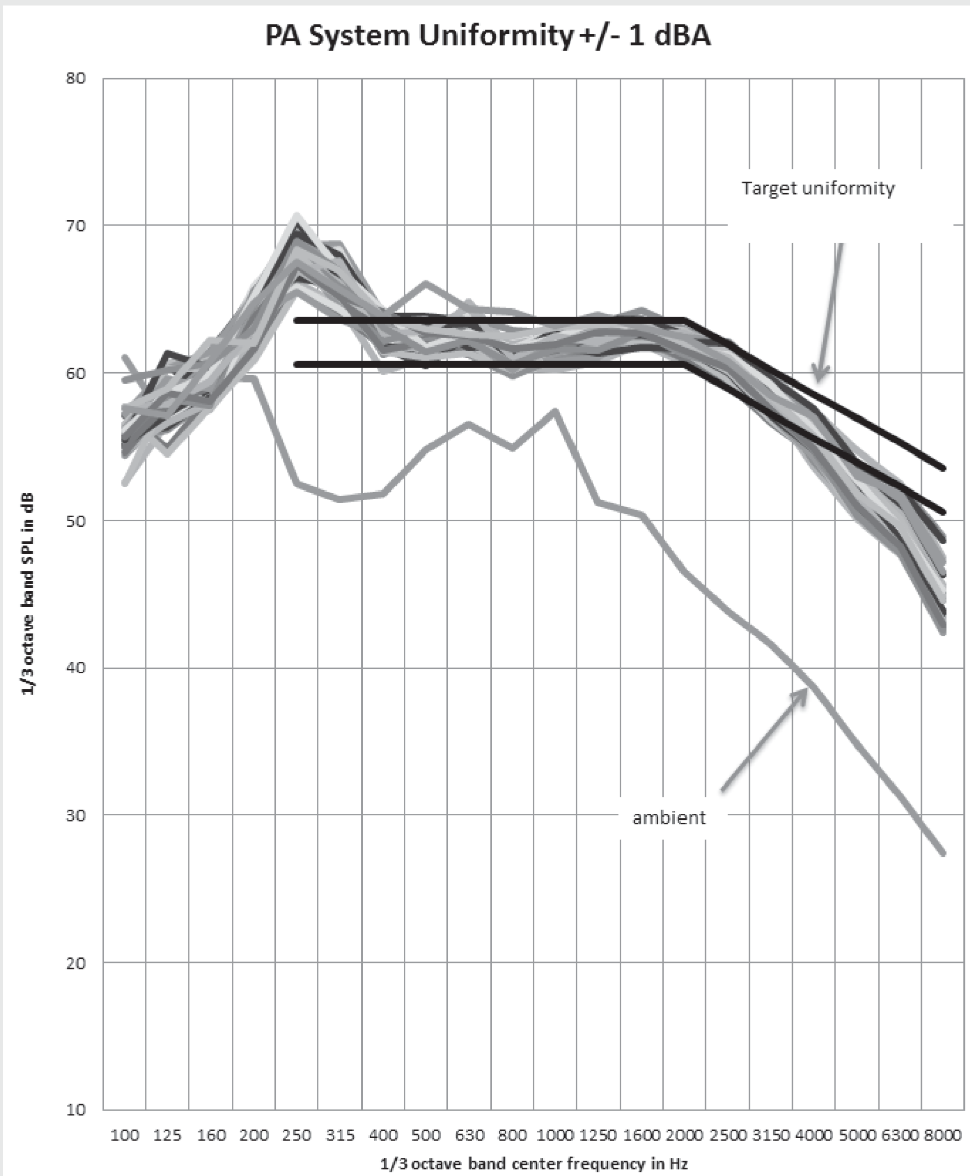
- Acoustically hard surfaces
- Long reverberation time
- Adverse reflections from the ceiling
- High ambient noise from HVAC
- PA system frequency response is not smooth, with a "bump" at 250 Hz that can distort the sound.

***WHAT CAN BE IMPROVED***

- Room acoustics: Substantial benefits to be gained from increasing the acoustical absorption to reduce the reverberation time and reduce strong reflections from the ceiling. Incorporate acoustical absorption to reduce the $RT_{60}$ as close as possible to 1.5 seconds or less. This will also reduce some of the daytime ambient noise. (See Chapter 6 re architectural design.)
- High ambient noise: Incorporate noise control to reduce background sound from the HVAC system. NC 45 or lower. (See Chapter 6 re architectural design.)
- Loudspeakers and PA system design: Improve PA system EQ per testing and commissioning procedures discussed in Chapters 8 and 9.

Photo Credit: Wilson Ihrig

**(a) Baggage claim area.**




**(b) Measured PA system uniformity and frequency response.**

### Example 5 Quiet Ambient and Basic Good Design Achieves STI 0.73 (dry)/0.46 (wet)

**Description: Baggage claim area**
Year commissioned: 2004/2008

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 61 dBA Leq |
| Announcement SPL | 67 dBA Leq |
| Nighttime ambient noise level | 47 dBA Leq |
| STI range | 0.73 |
| Uniformity | ± 2 dBA |
| Reverberation Time ($RT_{60}$) | 0.8 sec at 500 Hz |
| | 0.9 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 19 feet |
| Finishes | Terrazzo floor; metal-slat suspended ceiling; glass exterior wall. |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Digital |
| Paging microphone type | N/A |
| Loudspeaker type | wall mounted at 14.5 feet height |
| Loudspeaker spacing | 21 feet |
| Ambient sensing microphones | Yes |

***SPEECH INTELLIGIBILITY DISCUSSION***

Nighttime ambient conditions are extremely low, which partially accounts for the exemplary STI result. However, daytime conditions lower the STI to a 0.46. Challenging conditions include

- Strong reflections from glass wall
- Moderate ambient noise from HVAC
- PA system frequency response is not smooth, with strong high-frequency response which possibly contributes to the high STI
- Low announcement signal level

***WHAT CAN BE IMPROVED***

- Room acoustics: Despite low reverberation time, some benefits can be gained from reducing strong echoes off glass wall and metal slats. (See Chapter 6 re architectural design.)
- High ambient noise: Incorporate noise control to reduce background sound from the HVAC system. NC 45 or lower. (See Chapter 6 re architectural design.)
- Loudspeakers and PA system design: Improve PA system EQ per testing and commissioning procedures discussed in Chapters 8 and 9.

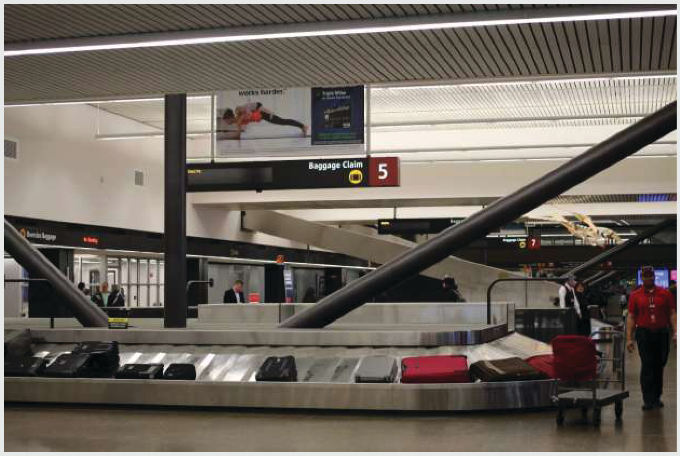
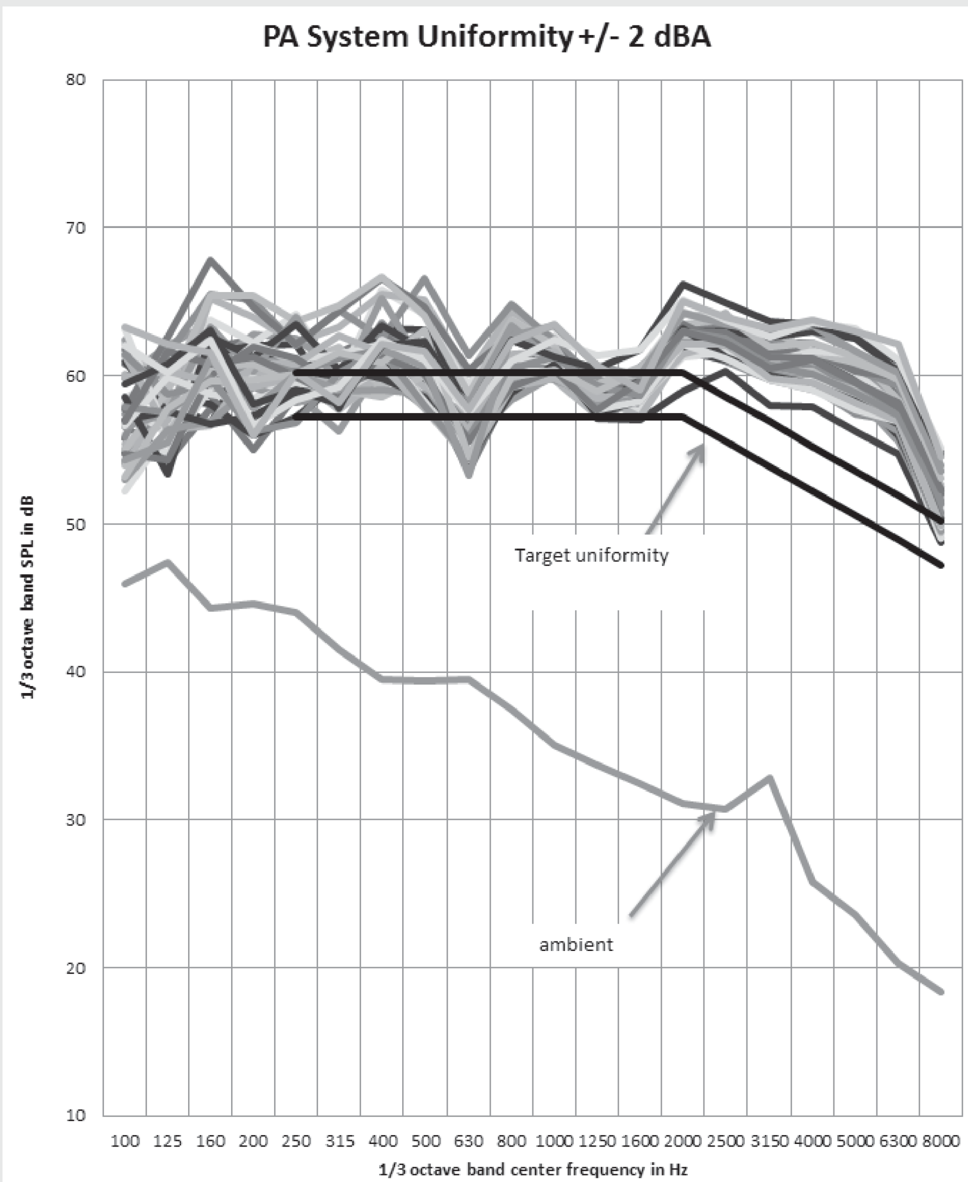



Photo credit: Wilson Ihrig

**(a) Baggage claim.**




**(b) Measured PA system uniformity and frequency response.**

**Example 6 Challenging Conditions for Large Space Achieves STI 0.56**

**Description: Large concessions space**
Year commissioned: 1953/1998

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 68 dBA Leq |
| Announcement SPL | 69 dBA Leq |
| Nighttime ambient noise level | 64 dBA Leq |
| STI range | 0.61 (low ceiling area at counters)<br>0.51 (high ceiling area at tables) |
| Uniformity | ± 3 dBA |
| Reverberation Time ($RT_{60}$) | 1.6 sec at 500 Hz<br>1.6 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 14 feet at low ceiling above food counters; 25 feet at higher ceiling above customer dining area; 35 feet at highest ceiling above customer dining area |
| Finishes | Acoustical tile suspended ceiling; tile floor; gypsum wall (though minimal wall surface area because court is open on both ends). |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Digital |
| Paging microphone type | N/A |
| Loudspeaker type | Perimeter ceiling mounted and wall mounted |
| Loudspeaker spacing | 4–8 feet |
| Ambient-noise-sensing microphones | Yes |

***SPEECH INTELLIGIBILITY DISCUSSION***

Despite ambient conditions and low announcement level, above-average speech intelligibility achieved. Challenging conditions include

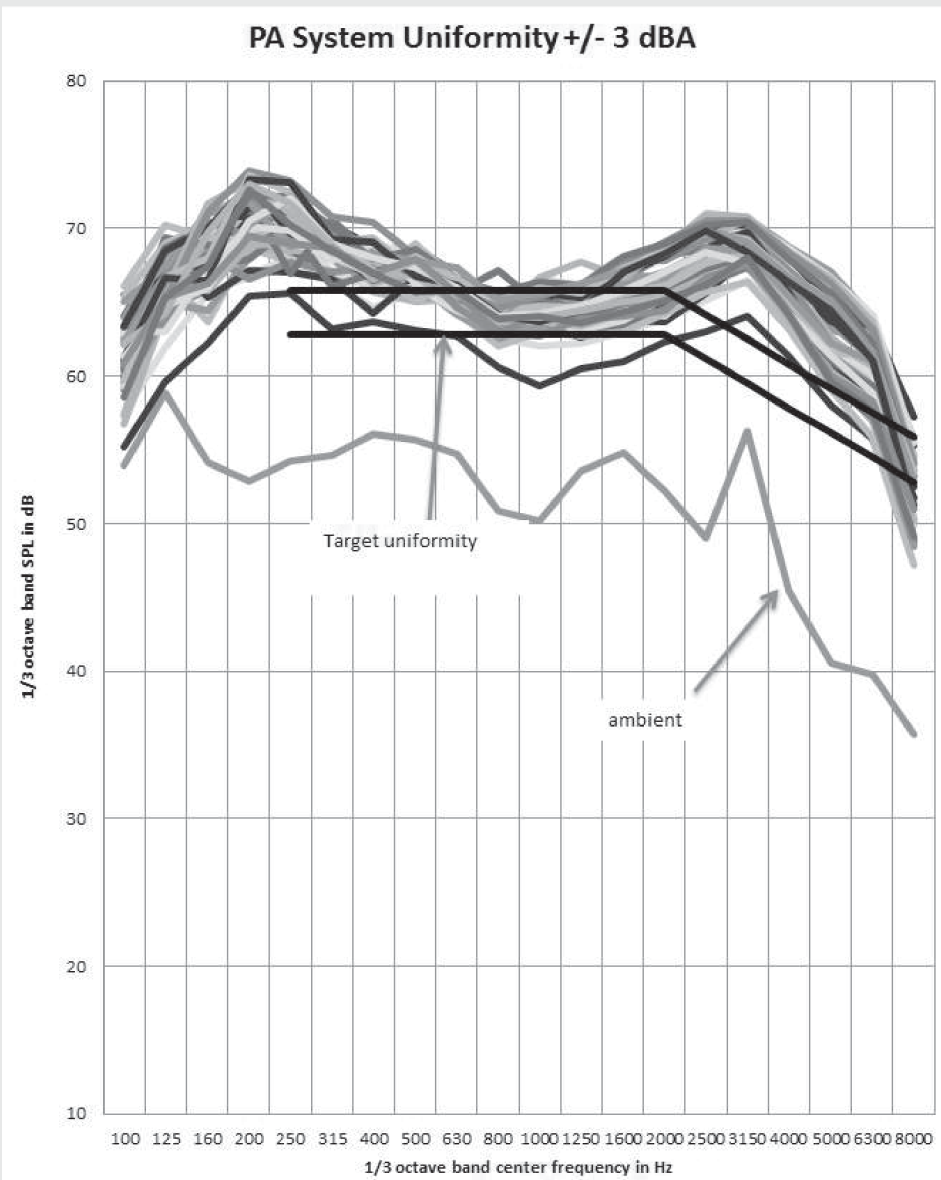
- Long reverberation time.
- High ambient noise.
- Excessive low-frequency energy tends to mask intelligibility at higher speech frequencies.
- PA system frequency response is not smooth, with a "bump" at 2,500 Hz that can distort the sound.

***WHAT CAN BE IMPROVED***

- Room acoustics: Minor benefits to be gained from increasing the acoustical absorption to reduce the reverberation time at high ceiling areas. Incorporate acoustical absorption to reduce the $RT_{60}$ to below 1.5 seconds. This will reduce some of the daytime ambient noise. (See Chapter 6 re architectural design.)
- High ambient noise: Incorporate noise control to reduce background sound from the HVAC system. NC 45 or lower. (See Chapter 6 re architectural design.)
- Loudspeakers and PA system design: Improve PA system EQ per testing and commissioning procedures discussed in Chapters 8 and 9.

Photo credit: Wilson Ihrig

**(a) Concessions area.**




**(b) Measured PA system uniformity and frequency response.**

### Example 7 Moderately Challenging Space With Room for Improvement, STI 0.46

**Description: TSA Screening Area**
Year commissioned: 2009

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 58–60 dBA Leq |
| Announcement SPL | 63 dBA Leq |
| Nighttime ambient noise level | 51 dBA Leq |
| STI range | 0.46 |
| Uniformity | ± 2 dBA |
| Reverberation Time ($RT_{60}$) | 1.3 sec at 500 Hz<br>1.2 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 28 feet |
| Finishes | Carpeted floor; hard panel ceiling; gypsum walls with large glass doors on one end. |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Unverified |
| Paging microphone type | Handheld |
| Loudspeaker type | Ceiling mounted |
| Loudspeaker spacing | 17 feet |
| Ambient sensing microphones | No |

***SPEECH INTELLIGIBILITY DISCUSSION***

This space is typical for small airports and other securely separated areas. Many aspects can be modified to provide substantial improvement. Challenging conditions include

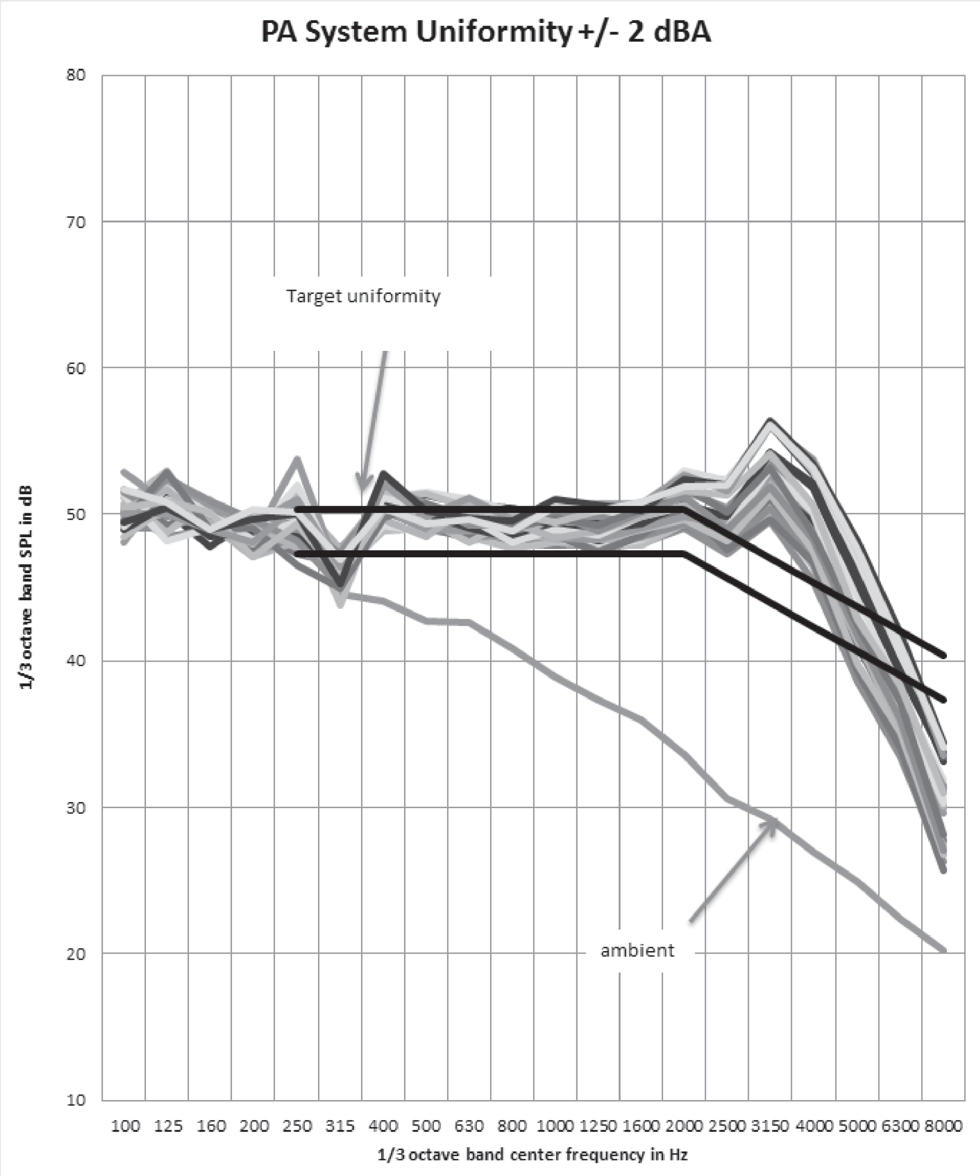
- Acoustically hard surfaces (especially ceilings and large surfaces such as walls and glass doors)
- Moderately long reverberation time
- High ambient noise from HVAC
- PA system frequency response is not smooth, with a "bump" at higher frequencies 2,000 Hz and 5,000 Hz that can distort the sound.

***WHAT CAN BE IMPROVED***

- Room acoustics: Substantial benefits to be gained from increasing the acoustical absorption to reduce strong reflections from the walls. (See Chapter 6 re architectural design.)
- High ambient noise: Incorporate noise control to reduce background sound from the HVAC system; NC 45 or lower. (See Chapter 6 re architectural design.)
- Loudspeakers and PA system design:
  - Increase announcement signal level and improve PA system EQ per testing and commissioning procedures discussed in Chapters 8 and 9.
  - Ambient sensing microphones would help offset some of the ambient noise.

Photo credit: Wilson Ihrig

**(a) Small TSA screening area.**




**(b) Measured PA system uniformity and frequency response.**

**Example 8 Highly Challenging Space With Room for Improvement, STI 0.36**

**Description: Lower Level of Gate Area**
Year commissioned: 2000

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 64–69 dBA Leq |
| Announcement SPL | 74 dBA Leq |
| Nighttime ambient noise level | 58 dBA Leq |
| STI range | 0.29–0.39 |
| Uniformity | ± 1 dBA |
| Reverberation Time ($RT_{60}$) | 2.9 sec at 500 Hz<br>3.5 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 31 to 42.5 feet |
| Finishes | Terrazzo floor, gypsum board, partial coverage with perforated metal ceiling tiles. |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Digital |
| Paging microphone type | Handheld paging |
| Loudspeaker type | Wall-mounted speaker pairs at gates to supplement original high ceiling-mounted system |
| Loudspeaker spacing | 4 speakers, 2 at each gate |
| Ambient-noise-sensing microphones | Yes |

***SPEECH INTELLIGIBILITY DISCUSSION***

This is dual level space that can be found in many airports where the end group of gates features a full height ceiling with the gates on the lower level. Many aspects can be modified to provide substantial improvement. PA system frequency response is excellent without excessive low-frequency response. The uniformity of the PA sound coverage is also excellent in this area. Challenging conditions include

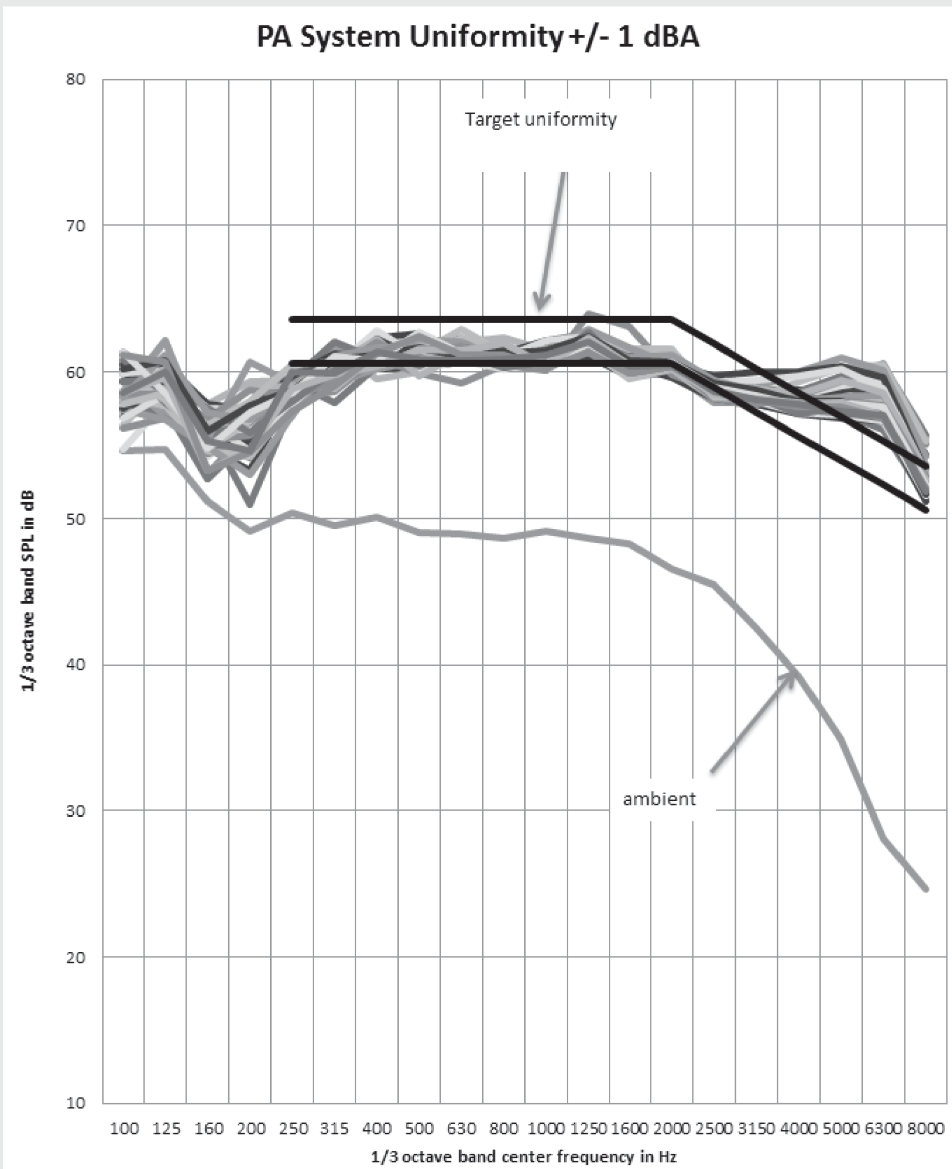
- High ceiling
- Acoustically hard surfaces (especially ceilings and large surfaces such as walls and glass doors)
- Long reverberation time
- Some ambient noise from HVAC and coupled areas at the mezzanine and upper levels

***WHAT CAN BE IMPROVED***

- Room acoustics: Substantial benefits to be gained from increasing the acoustical absorption to reduce strong reflections from the walls. (See Chapter 6 re architectural design)
- Loudspeakers and PA system design: Insufficient placement and number of speakers for these conditions; the uniformity is a measure of the reverberant sound field, but there is very little direct sound level

Photo credit: Wilson Ihrig

**(a) Lower level gate area.**




**(b) Measured PA system uniformity and frequency response.**

**Example 9 Satisfactory Ticketing Area, STI 0.61**

**Description: Ticketing near TSA**
Year commissioned: 2004/2008

***TECHNICAL DATA***

| | |
|---|---|
| Daytime ambient noise level | 63 dBA Leq |
| Announcement SPL | 67 dBA Leq |
| Nighttime ambient noise level | 51 dBA Leq |
| STI range | 0.55–0.64 |
| Uniformity | ± 2 dBA |
| Reverberation Time ($RT_{60}$) | 0.9 sec at 500 Hz<br>1.0 sec at 2,000 Hz |

***ARCHITECTURAL/ACOUSTICAL DETAILS***

| | |
|---|---|
| Ceiling height | 24 feet |
| Finishes | Terrazzo floor, suspended slat ceiling, glass exterior wall, gypsum board interior walls with acoustically reflective wood panels above ticketing counter and acoustical tile above ticketing agents. |

***PA SYSTEM DETAILS***

| | |
|---|---|
| PA system type | Digital |
| Paging microphone type | Handheld paging |
| Loudspeaker type | Left and right line arrays mounted above each main entry double door; each line array consists of four trapezoidal speakers |
| Loudspeaker spacing | 15 feet, on each side of double door |
| Ambient sensing microphones | Yes |

***SPEECH INTELLIGIBILITY DISCUSSION***

This ticketing space is providing desirable acoustics with a relatively low reverberation time, good coverage by line arrays, and clear announcements overall. Lower end of STI range measured 75 feet from entry doors in breezeway circulation space between Ticketing and TSA. PA system frequency response is good, but somewhat ragged in the mid-low ranges, which is detrimental to good intelligibility. Uniformity of PA sound coverage within this ADS is good. This space achieves most of the desired characteristics.

***WHAT CAN BE IMPROVED***

- Loudspeakers and PA system design: Mid-low range could be improved

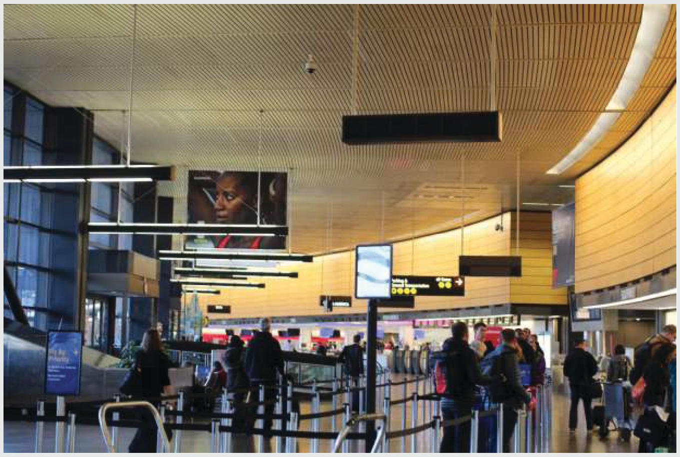
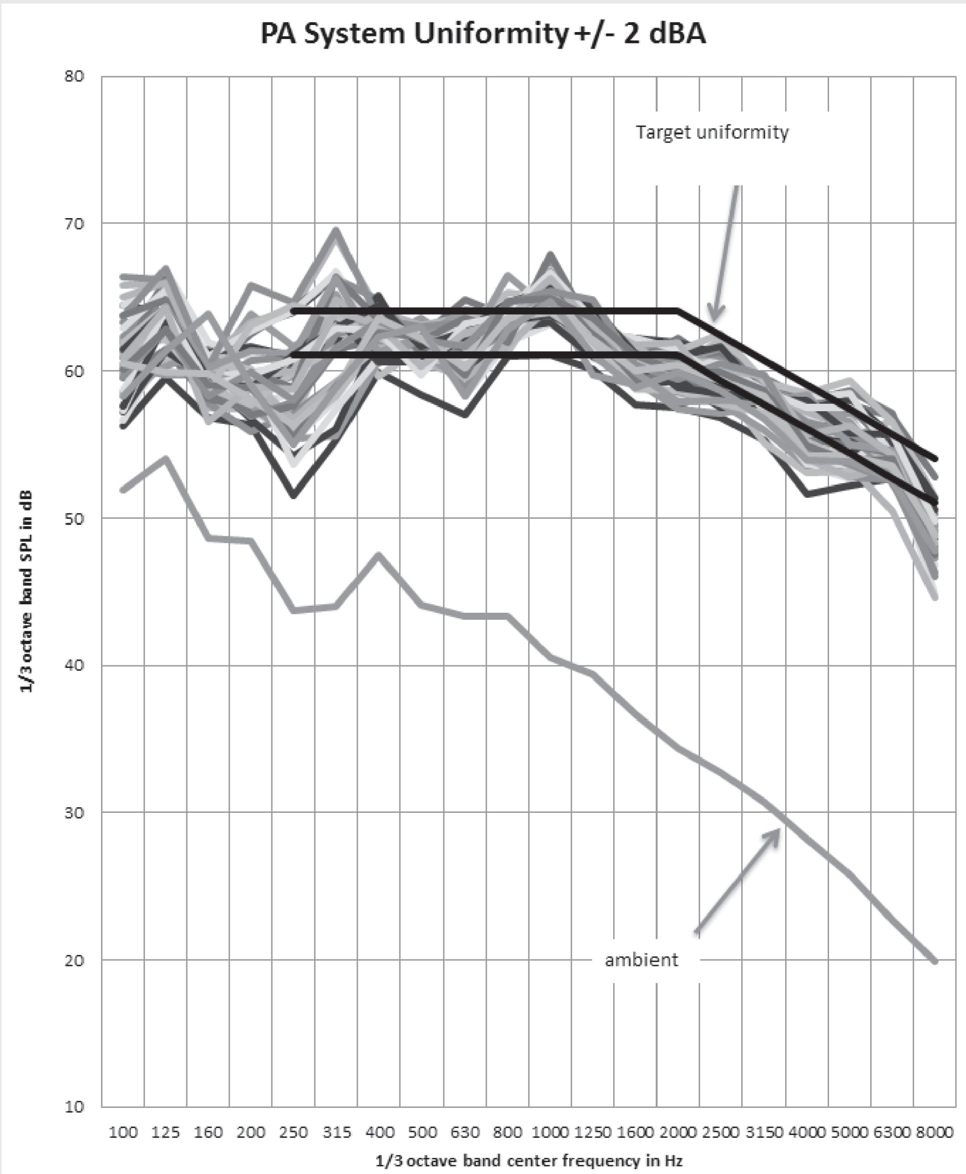


Photo credit: Wilson Ihrig

**(a) Ticketing area.**




**(b) Measured PA system uniformity and frequency response.**

CHAPTER 13

# Future Research

The following subject areas would benefit from additional research:

- In situ measurement of daytime STI tied to passenger experiences at those tested locations. This kind of test would require coordination and cooperation with airports to a deep level that requires time, access and security logistics. Such coordination and cooperation were not available for this project. Individual airports might choose to conduct such a study as part of their own data collection to develop priorities for renovation of an existing terminal.
- The pilot passenger study indicated that experienced passengers at one major U.S. airport tended to tune out PA messages; this is the opposite of the top-down processing model that expects experienced passengers will actively seek information. Additional studies would be useful to determine whether this behavior is specific to certain kinds of experienced passengers (e.g., frequent domestic business travelers), generally true across the United States, or only specific to this airport or this region.

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APPENDIX A

# Annotated Bibliography

## Acoustics and Speech Intelligibility

**Festen, Joost M., and Reiner Plomp. 1990. "Effects of Fluctuating Noise and Interfering Speech on the Speech-Reception Threshold for Impaired and Normal Hearing."** ***Journal of the Acoustical Society of America*** **88 (4): 1725–1736.**

This paper examines the effects of a high background level (80 dBA) for 20 "normal" hearing listeners and 20 hearing-impaired listeners to understand speech. The background noise is presented as a steady-state modulated noise or a single voice. The speech-reception threshold (SRT) is the sound level at which a steady-state-noise (speech) achieves a 50% score. As discussed by others (S. J. van Wijngaarden 2001), this metric can be directly used to indicate the required increase in signal-to-noise ratio (SNR) to achieve the same level of intelligibility as someone with normal hearing. Interfering modulated noise (fluctuating speech) requires an SNR increase of 4 to 6 dB over a steady-state signal; a single competing voice requires an increase of the signal of 6 to 8 dB. For hearing-impaired listeners, an additional 4 dB change is required for modulated noise and 10 dB for a competing voice. For the project, this information is useful to evaluate how to address passengers with hearing loss. For example, this information would suggest that, in an emergency or urgent condition, announcements could be raised in level by about 8 to 10 dB.

**Kang, Jian. 1998. "Scale Modeling for Improving the Speech Intelligibility from Multiple Loudspeakers in Long Enclosures by Architectural Acoustic Treatments."** ***ACUSTICA*** **(S. Herzel Verlag) 84: 689–700.**

Although this paper pre-dates new computer modeling methods that adequately evaluate long enclosures (such as an airport concourse or ticketing hall), the research and discussion of effective acoustical treatments is still relevant. In such spaces, multiple speakers are often used, and their sound fields can interact destructively to degrade the STI. The paper investigates the effectiveness of different treatments; all improved the STI, but only three provided substantial results: (1) highly absorptive treatments at the end walls (effectively extending the enclosure and preventing long-delay reflections); (2) membrane absorbers (e.g., acoustical ceilings) can be effective, but their effect can be limited by the room geometry; and (3) strategic obstructions to break the room into smaller ADSs. The other two treatments evaluated—ribbed diffusers and porous absorbers—showed small improvements. This information will be useful for architectural design guidance.

**Kim, Yong Hee, and Yoshiharu Soeta. 2013. "Effects of Reverberation and Spatial Diffuseness on the Speech Intelligibility of Public Address Sounds in Subway Platform for Young and Aged People." International Congress on Acoustics. Montreal: Acoustical Society of America.**

This paper explores *listening difficulty,* which is a relatively new subjective measure of speech intelligibility and compares those results with STI requirements. Twenty people of about 22 years average age, and 20 people of about 69 years average age were exposed to 12 simulated sound fields for different reverberant and acoustical conditions. On average, the hearing ability of the older group was almost 18 dB lower than the young group. The listening difficulty evaluation was compared to another subjective evaluation, and it was found that only listening difficulty was strongly correlated for both age groups with the STI and reverberation time. Reverberation time was shown to have a high correlation to STI. Reducing the reverberation time below 1.9 seconds showed the strongest effect on increasing STI. This information will be useful for architectural design guidance.

**Lundin, F. J. 1986. "A Study of Speech Intelligibility of a Public Address System." (*KTH Computer Science and Communication*) 27 (1).**

This paper is one of the few airport-specific studies we found, and it describes research done after the completion of the Arlanda Airport in Stockholm to compare different predictive models for speech intelligibility. One of the departure halls was modeled; it had a ceiling height of 8.7 m (28.5 ft.), with 39 ceiling speakers distributed on a staggered grid pattern at 9.2 m (30 ft). Two different signal-to-noise ratios (SNR) were used with two different background noise levels. Speech intelligibility was evaluated using the articulation index (AI), and the study pre-dates the use of STI as an objective measurement, so there is very little that can be directly applied to the current research. However, one interesting observation was that the models were better at predicting the 10 dB SNR case where the speech level was 85 dBA and the background was 75 dBA, than the case where the SNR was 20 dB and the speech level was 70 dBA and the background level was 50 dBA. While a 20 dB SNR is generally better than 10 dB SNR, it is possible that the lower signal level was inadequate for the size of the room.

**Morimoto, Masayuki, Hiroshi Sato, and Masaaki Kobayashi. 2004. "Listening Difficulty as a Subjective Measure for Evaluation of Speech Transmission Performance in Public Spaces." *Journal of the Acoustical Society of America* (Acoustical Society of America) 116 (3): 1607–1613.**

This paper evaluates the suitability of a new subjective test of "listening difficulty." Given that subjective intelligibility test results can be highly dependent on the familiarity of the words to the listeners, the authors propose a test based on familiar words to determine the "listening difficulty" under different reverberant field conditions in the laboratory. Despite its focus on subjective evaluation rather than objective measures, this paper provides recent and relevant information on the challenges of speech intelligibility in spaces with long reverberation times consistent with the typical large public spaces found in airport concourses and ticketing halls. The authors found that with a speech signal that is 15 dBA or more above the background noise (signal-to-noise ratio >15 dBA), the speech intelligibility is very high, regardless of reverberant conditions. On the other hand, listening difficulty was markedly affected by SNR and reverberant conditions. A low reverberation time of 0.5 seconds and an SNR of 15 dB provided adequate results, but, at a reverberation time of 2 seconds, the listening difficulty was ranked high, regardless of SNR. This paper provides more support for the necessity of limiting the reverberation time where possible, in particular in areas where critical announcements are made.

**Morimoto, Masayuki, Hiroshi Sato, and Megumi Wada. 2012. "Relationship Between Listening Difficulty Rating and Objective Measures in Reverberant and Noisy Sound Fields for Young Adults and Elderly Persons." *Journal of the Acoustical Society of America* (Acoustical Society of America) 131 (6): 4596–4605.**

This paper provides more results from the earlier research (Morimoto 2004), in which subjective tests about listening difficulty were performed for a group of young adults and a group of older adults. In the current paper, listening difficulty was directly compared with STI, with the result that the group of older adults required an STI increase of 0.12 points to match the results of the young adults for listening difficulty. This information is useful to evaluate how to reach passengers with hearing loss.

**Sato, Hiroshi, and Masayuki Morimoto. 2009. "Effect of Noise and Reverberation on Sound Localization of Acoustic Guide Signal for Visually Impaired Persons in Public Spaces." Ottawa: International Institute of Noise Control Engineering.**

This paper discusses ways to improve acoustic guide signals as they have been used in Japan. Such signals have been used to guide visually impaired individuals through a complex space. To our knowledge these are not yet used in the United States. If used, acoustical design and guide signal speaker design needs to consider sound localization and SNR, initial delay and reverberation energy (less so reverberation time) as the temporal pattern is important in a reverberant field.

**Smith, Howard G. 1981. "Acoustic Design Considerations for Speech Intelligibility."** ***Journal of the Audio Engineering Society*** **29 (No. 6): 408–415.**

This paper provides a good overview of the basic concepts underlying this issue, including discussion of the modulation transfer function (MTF), which was the precursor to the STI. The conundrum raised by Lundin above (Lundin 1986) about the signal-to-noise ratio (SNR) and speech intelligibility is discussed. The key issue seems to be reflections. While some researchers advocate that all reflections degrade intelligibility, Houtgast and Steeneken (1972) and Lochner and Berger (1964) indicate that some reflections are helpful. The MTF developed by Houtgast and Steeneken, which takes into account key findings from their research, shows that a high SNR creates reflections that reduce articulation (and intelligibility) and a low SNR allows for the discreet reflections that will improve articulation. This concept is important—speech intelligibility issues cannot be solved by increasing the announcement level (and increasing the SNR).

**Steeneken, Herman J. M. 2014. "Keynote Lecture: Forty Years of Speech Intelligibility Assessment (and Some History)." Proceedings of the Institute of Acoustics. Birmingham.**

This paper, a comprehensive overview of speech intelligibility by one of the pre-eminent researchers in the field, (1) provides a timeline of the development of assessment techniques since 1974, with informative comparisons of differences between the early use of subjective techniques and subjective results between different countries and (2) describes the development and standardization of objective techniques. This paper includes an excellent reference list of foundational documents in speech intelligibility. This information will be useful as supplemental reading.

**Tachibana, Hideki. 2013. "Plenary Lecture: Public Space Acoustics for Information and Safety." International Congress on Acoustics. Montreal: Acoustical Society of America.**

In this paper, Tachibana summarizes the research efforts of his group and provides information about field studies to document the ambient conditions at many large, interior, public spaces, including air terminals, railway stations, and shopping centers. The ambient sound environments in these spaces ranged from 60 to over 90 dBA. The reverberation time at five of these spaces is charted, indicating potentially challenging conditions for speech intelligibility with all spaces measuring over 1 second up to 2.4 seconds. The research group noted that one air terminal building with "excellent" acoustics measured 2.4 seconds in the middle frequency range. These ambient environments were re-broadcast in a controlled laboratory setting to evaluate the subjects' responses to these sound pressure levels: environments just over 60 dBA were considered "A little noisy," whereas environments of 70 dBA were ranked "Moderately noisy." In ranking the difficulty of speaking and listening with someone within 1 m (3 ft), environments greater than about 67 dBA were "A little disturbing," and environments over 70 dBA were "Moderately disturbing."

The research group also used subjective evaluations of PA system speech intelligibility with a mix of native language (Japanese) and non-native (mostly Asian language) subjects for different conditions of room reverberation time and background noise. With an air conditioning equipment background noise level of 65 dBA, native listeners rated the conditions "a little difficult" for reverberation time of about 4 seconds, with "fairly difficult" conditions for 5 seconds or longer. Non-native listeners had a "fairly difficult" experience with reverberation time exceeding 1 second. This information is consistent with other research and will be useful for architectural design guidance.

**van Wijngaarden, Sander J. 2001. "Intelligibility of Native and Non-Native Dutch Speech." *Speech Communication* (NH Elsevier) 35: 103–113.**

This paper, developed from van Wijngaarden's doctoral research, compares how speakers of Dutch were able to understand the language under different acoustical conditions. The non-native speakers were all Dutch-speaking Americans who had lived in the Netherlands for 1 to 3 years. Two different, subjective tests were applied, but the one that was most directly linked to objective differences was the speech reception threshold (SRT) evaluation, which provides a solid measure for the speech intelligibility of whole sentences at a speech-to-noise (SNR) ratio that corresponds to 50% understanding for short, everyday sentences; the SRT listening test with non-native speakers required an additional boost in the SNR of 3 to 4 dB compared to native speakers. The paper also includes results on the effectiveness of Dutch spoken by non-native speakers. This information is consistent with other research and will be useful for design guidance—for example, this information would suggest that in an emergency or urgent condition, announcements should be raised in level by about 3 to 4 dB for international terminals where a higher percentage of travelers are non-native speakers.

**van Wijngaarden, S. J., et al. 2004. "Using the Speech Transmission Index for Predicting Non-Native Speech Intelligibility." *Journal of the Acoustical Society of America* 115 (3): 1281–1291.**

This paper (which extends van Wijngaarden's 2001 paper to relate standard STI label categories to corresponding results for non-native speakers) presents the results for five characterizations of non-native speakers by earlier researchers, depending on the relative age at which the listener learned the test language (early or late) and the proficiency of the listener at understanding the test language (high and low). These previous studies used different subjective tests, which were corrected to the corresponding STI values. Four of these earlier tests were conducted in English and one was conducted in German. Non-native listeners' corresponding STI values for fair speech (0.45 points) ranged from 0.50 for early learners to 0.74 for late learners; low-proficiency subjects required an STI 0.60 for fair speech, while high-proficiency subjects also tested to 0.50. The paper includes (1) results of speech reception threshold (SRT) to investigate the effects of bandwidth limiting and reverberation time for non-native listeners and (2) results for Dutch spoken by non-native speakers. This information will be useful for design guidance—for example, this information would suggest that in comparison with domestic terminals, a higher STI target should be considered for international terminals where a higher percentage of travelers are non-native speakers.

**van Wijngaarden, S. J., H. J. M. Steeneken, and J. A. Verhave. 2011. "The Future Is Bright for the Speech Transmission Index; Dealing with New Challenges after Four Decades of Development." Proceedings of the Institute of Acoustics. Seattle.**

A comprehensive overview of the electronic instrumentation involved in evaluating speech intelligibility, current challenges with STI applications, and an outlook on upcoming developments. Compared with a similar overview approach by Steeneken (2014), this paper is more focused on the development of electronics and measurements standards that enable the objective assessment of SI. The paper includes a useful reference list. This information will be useful as supplemental reading.

**Yokoyama, Sakae, and Hideki Tachibana. 2008. "Study on the Acoustical Environment in Public Spaces." Shanghai: International Institute of Noise Control Engineering.**

This paper provides some of the background alluded to in Tachibana's 2013 presentation. Specifically, the airport had an acceptable background noise level (57 dBA) with high 19 m (63 ft.) ceilings and acoustical treatment on the ceilings and walls. In the observations of the researchers, the acoustical conditions were well-designed for subjective speech intelligibility. This information will be useful for evaluating the field measurements.

## Human Factors

**Alm, M., & Behne, D. 2015. "Do Gender Differences in Audio-Visual Benefit and Visual Influence in Audio-Visual Speech Perception Emerge with Age?" *Frontiers in Psychology,* 6, 1014+.**

Similar to the Amano-Kusumoto research, this study supported the findings that females are typically more intelligible speech readers than males. This information will be useful for design guidance to define ways to improve message intelligibility.

**Amano-Kusumoto, A., & Hosom, J.-P. 2011. A Review of Research on Speech Intelligibility and Correlations with Acoustic Features. Oregon Health & Science University (OHSU), Department of Biomedical Engineering. Beaverton: Center for Spoken Language Understanding (CSLU).**

This study reviewed current research on speech intelligibility. Noteworthy was that gender plays a part in intelligibility—cited were two studies in which female speakers were more intelligible than males. The researchers hypothesized that this could be because female speakers tend to have larger vowel spacing and more precise inter-segmental timing than male speakers, although it was not clear whether other factors such as frequency could have been in play here. This information will be useful for design guidance to define ways to improve message intelligibility.

**Bor, R. 2007. "Psychological Factors in Airline Passenger and Crew Behavior: A Clinical Overview." *Travel Medicine and Infectious Disease,* 5, 207–216.**

Air travel can induce considerable stress in individuals who are simply outside their natural environments and comfort zones. It has been suggested that air travel especially "can induce depression, anxiety, panic attacks or even psychosis in vulnerable individuals." This paper further suggests that cultural background, gender, and age may mediate how passengers deal with stress during traveling. For this project, this research suggests that stress may be a strong determining factor in how well messages are attended to.

**Cherry, E. C. 1953. "Some Experiments on the Recognition of Speech, with One and Two Ears." *Journal of the Acoustical Society of America,* 25(5), 975–79.**

Research in attention and perception suggests that even relaxed participants who are preprimed with an expectation of a message will, on some level, be "ready to attend" to the message. This ties in with the "Cocktail Party Effect" found by Cherry and dichotic listening tests. For instance, one may be attending to a particular conversation, but will pick up one's name in another conversation. In application to this project, the suggestion is therefore twofold: (1) even when relaxed, regular travelers will expect updates/travel information in the form of auditory announcements and so it is suggested therefore that they are more attuned to them than novice travelers; and (2) the attention of regular travelers will be drawn more to specific messages than novice travelers who may be overwhelmed with new stimuli.

**Festinger, L. 1957. *A Theory of Cognitive Dissonance.* Stanford: Stanford University Press.**

"Cognitive dissonance" occurs when an individual holds two conflicting attitudes or beliefs. The dissonance refers to the sense of discomfort felt by the individual. Festinger proposed the theory of cognitive dissonance and suggested that we all have an inner drive to hold all of our inner beliefs and attitudes in harmony and, therefore, seek to avoid or reduce disharmony. In an airport environment, this could be as simple as a passenger told at the check-in desk that they would be boarding at Gate 6 and an announcement that calls passengers to Gate 8. Unless the call to Gate 8 was announced as a specific gate change in the message, the passenger might find the two pieces of information in conflict and assume the auditory message was in error. An oral message delivered in person by an airport employee (e.g., at a check-in desk) would exert more influence over a decision-making conflict than a PA message—unless that message was announced as a change.

**Forrester, A. M. (2007). Auditory Perception and Sound as Event: Theorising Sound Imagery In Psychology. Retrieved January 21, 2016, from T[H]E [EAR] OF THE DUCK:** https://theearoftheduck.wordpress.com/2012/10/15/auditory-perception-and-sound-as-event-theorising-sound-imagery-in-psychology/

Forrester notes in his paper that speech is "sound first and 'text' second." He notes that work by Rodaway (1994) highlights a gap between sound as a "perceptual experience" and the actual recognition of the meaning of the sound. Forrester also highlights the evolutionary perspective of perceiving sound. In much the same way as we are evolutionarily pre-programmed to associate red with danger, we will react to loud, disruptive noises or noises that we have, over time, come to associate with a particular warning (e.g., we may associate sirens with fires). This evolutionary reaction will (1) precede any understanding of a message informing us that there is a fire and where we should proceed to evacuate to and (2) will serve to cue us both to pay attention to the following instructions and to the basic meaning of the following message.

**Fritz, J. B., et al. 2007. "Auditory Attention—Focusing the Searchlight on Sound." *Current Opinion in Neurobiology,* 17, 1–19.**

This research discusses how our processing for auditory attention can be bottom up or top down. Bottom-up processing begins with the stimulus and the stimulus influences what we perceive. For example, one starts with no preconceived idea of what one is hearing and the stimulus itself influences the perception of what one hears. It is data driven and the perception of the message itself directs people's cognitive awareness of what they hear. Top-down processing uses background knowledge, learning, expectations, and current goals to influence perception. Behavior and processing are influenced by expectations. With top-down processing we use what we know to understand what we are perceiving—it is goal driven (voluntary or task-dependent). In bottom-up processing, we use the auditory stimulus itself to drive our perception (sound-based salience).

Top-down processing focuses on the expected features of an auditory target. This aligns with an experienced passenger's response to flight information messages. An experienced passenger is likely to use top-down processing to seek information from auditory messages and will have expectations about the information and format of those messages based on experience. It is assumed that the experienced passenger would be an effective listener, actively seeking the information from the message and able to understand, through experience, what is required from them and how to act. Experienced passengers employing top-down processing would know what they are searching for and employ a template-based search.

Relevant to this project, inexperienced passengers, having no expectation of the flight information messages, would use bottom-up processing—they would seek information from the stimulus and identify salient points in the message in order to understand it. Bottom-up saliency is the process of identifying salient points using features extracted from the sound (e.g., names and dates) and comparing them with its neighbors. Bottom-up salient detection includes detecting parts of the auditory signal that attract people's attention in terms of contrast or characteristic features. Given that novice passengers may not be actively listening, they will be more likely to employ bottom-up processing.

**Hodoshila, N., Arai, T., & Kurisu, K. 2008. "Effects of Training, Style and Rate of Speaking on Speech Perception of Young People in Reverberation." Presented at Acoustics '08. Paris. Retrieved from www.acoustics08-paris.org**

This paper suggests a benefit to conversational speech over clear speech. The authors looked at the effects of training, style and rate on speech perception in simulated reverberant environments (to replicate conditions for spoken messages over loudspeakers in public places such as railway stations). They did not find a difference in slowed speaking rates in reverberant conditions.

In contrast to the other two similar studies, they found conversational speech had a higher correct rate than clear speech (82% compared to 78.6%). They hypothesized that this could be due to the fact that the reverberant conditions masked features of the clear speech. They noted that it was possible for the characteristics of clear speech to be varied in environments where clear speech was recorded. From this they suggested that recording a clear speech auditory message in reverberation conditions would produce a much higher correct rate (rate at which the message was correctly perceived/understood) as the speakers may adjust their style to be more intelligible in that particular environment, mimicking the Lombard Effect, where the involuntary tendency of speakers is to increase their vocal effort when speaking in loud noise to enhance the audibility of their voice. Pitch, duration of syllables, and rate are also implicated with loudness in this phenomenon.

Most research supports clear speech, and it is possible that these authors have identified a key point to clear speech – that reverberant conditions may mask some elements of it. This information will be useful for design guidance to define ways to improve message intelligibility.

**Iwamiya, S.-i., et al. 2004. "Design Specifications of Audio-guidance Systems for the Blind in Public Spaces."** ***Journal of Physiological Anthropology and Applied Human Sciences,*** **23(6), 267–271.**

These researchers gained feedback on message content of PA announcements during a study that tested an audio-guidance system for the blind in public spaces, with particular reference to travel facilities. The study was conducted at Tojinmachi Station on the Fukuoka City Subway. The blind participants noted the cognitive load involved when they had to both recognize an auditory signal and understand any information contained in any message associated with the signal while walking through an environment, a task that carried a high load by itself. For this reason, these participants believed that some PA announcements were unnecessary or overly long. For example, they considered welcome greetings and polite expressions unnecessary and stated that the messages should be short and simple and just contain the key information that the passenger requires to act on.

**Labiale, G. 1990. In-Car Road Information: Comparisons of Auditory and Visual Presentations. Proceedings of the Human Factors Society 34th Annual Meeting.**

This presentation considered different information presentation forms (visual/auditory/repeated auditory) about in-car information. Although difficult to generalize between in-car and airport environments, the study did provide support for accurate recall of auditory messages of 7 to 9 information units by a significant number of tested drivers (93.6%). Processing of auditory messages requires the retention of this information to allow time for recognition of words and comprehension to take place. This is known as Short-Term Auditory Memory and works in much the same way as short-term memory itself works. Labiale's paper provides support for "Miller's Magic Number 7 (plus or minus 2)" (Miller 1956).

**Lotto, A., & Holt, L. 2011. "Psychology of Auditory Perception."** ***Wiley Interdisciplinary Reviews: Cognitive Science,*** **2(5), 479–489.**

This paper describes that limited research in the field of complex auditory perception makes it difficult to categorically define how complex sounds–such as conversational speech–are affected by preceding and following sounds. Studies frequently focus on simple tones and signals presented in isolation. Airports are aurally complex environments to begin with, given that they have background music, machine sounds, aircraft noise, retail outlet information or music, and conversational background from traveling passengers.

**Mense, B., Debney, S., & and Druce, T. (2006). "Classroom Listening and Remembering." In** ***Ready, Set, Remember: Short-Term Auditory Memory Activities.*** **Camberwell: ACER Press.**

Motivation to listen to a message will strongly affect the amount of information understood or effectively processed from an auditory signal. Listeners may be directing their attention to other auditory inputs from mobile devices and so exhibit a lack of interest in auditory signals provided by the airport. This is similar to research by Umera-Okeke.

**Miller, G. 1956. "The Magical Number Seven, Plus Or Minus Two: Some Limits on Our Capacity for Processing Information."** ***The Psychological Review,*** **63, 81–97.**

A noted psychological theory on short-term memory states that most adults can store between 5 and 9 items in their short-term memory. This theory has been expanded to state that, if information can be grouped or chunked together, more information can be stored. The relevance of this with regard to PA announcements is support for keeping messages short and simple—5 to 9 items are ideal, a sentiment also expressed in research by others. An example of putting key information first and keeping the message short and concise follows: "Chicago, Chicago. Flight AA6754 now boarding at Gate 6."

**Moran, M. 2012. "Designing for Intelligibility vs. Audibility." Eaton, Cooper Notification Solutions. Long Branch: white paper.**

In highly reverberant spaces it may be prudent to identify areas in which intelligibility can be obtained and to highlight these locations by design features within the environment. This white paper refers to these as "rally points" and may be viewed in the same way as passengers clustering around visual information boards. This information will be useful for design guidance to define ways to resolve problems with highly reverberant spaces.

**Payton, K. L., Uchanski, R. M., & and Braida, L. D. 1994. "Intelligibility of Conversational and Clear Speech in Noise and Reverberation for Listeners with Normal and Impaired Hearing."** ***Journal of the Acoustical Society of America,*** **95(3), 1581+.**

These researchers considered the intelligibility of clear speech and conversational speech with both "normal" and hearing-impaired participants. Clear speech is defined as having a slower speaking rate, greater speech intensity and emphasis, increased emphasis on consonants compared to adjacent vowels, and increased word duration. They found that clear speech was more intelligible across participant types and across degraded listening conditions (e.g., additive noise and reverberation). It was also noted that, as noise levels increased, the difference in scores between the two types of speech also increased. This information will be useful for design guidance to define ways to improve message intelligibility.

**Potter, R., & Choi, J. 2006. "The Effects of Auditory Structural Complexity on Attitudes, Attention, Arousal, and Memory."** ***Media Psychology,*** **8, 395–419.**

Research into radio messages proposed that when structurally complex and structurally simple auditory messages were played, participants showed improved memory for the audio messages which were more structurally complex. Structurally complex for the purpose of this research paper was defined as containing multiple voice changes, sound effects, music onsets, and/or production effects, NOT making the message itself complex. Structurally complex messages resulted in more positive attitudes to messages, greater arousal (reported by galvanic skin response and cardiac monitors), greater memory for the message and larger self-reported attention. Many of these production effects would be inappropriate in the airport environment and add to auditory clutter. To translate the findings of this paper into use for airports, it is suggested that different announcers (i.e., voices) could be used for different message types: this would provide structural complexity with differing tones.

**Proctor, R. W., & Zandt, T. V. 2008. Chapter 7, "Hearing, Proprioception, and the Chemical Senses." In *Human Factors in Simple and Complex Systems* (pp. 165–185). Boca Raton: CRC Press.**

This text describes work by Miller and Isard in 1963 in which the researchers presented normal sentences (e.g., bears steal honey from the hive); semantically anomalous but grammatically correct sentences (e.g., bears shoot work on the country); and ungrammatical strings (e.g., across bears eyes work the kill), to listeners. They found the lowest recall rate for the ungrammatical strings, followed by semantically anomalous sentences. The best recall was obtained from the meaningful (normal) sentences. These results indicate that, while perception of an auditory message is helped by grammatically correct sentences, semantic context is also important. This information will be useful for design guidance to define ways to improve message understanding.

**Spence, C., & Santangelo, V. 2010. "Auditory Attention." In E. C. Plack, *Oxford Handbook of Auditory Science: Hearing* (pp. 249–270). Oxford: Oxford University Press.**

These authors note that many studies now show that people can only effectively attend to one auditory stimulus at a time. They also note that most studies are conducted in silent laboratory conditions with only one or two stimuli presented. They suggest that, in complex auditory environments, our awareness is much less than we would believe. They state that "in the absence of attention, people have no conscious awareness of most of the auditory stimuli around them." This suggests limited capacity for attention and that individuals need to focus their attention on a single object or stream within the auditory scene around them in order to process the auditory information correctly. This supports reducing other auditory distractions where possible prior to message presentation.

This text also refers to a study by Conway et al. in 2001 in which, having tested a group of participants on working memory performance, they found that a group of "low span" participants found it harder to filter out irrelevant information. Individual differences in working memory capacity were found to correlate with an individual's ability to selectively focus their auditory attention to a particular auditory stream. There was evidence to suggest that the low span participants also attended to a background irrelevant message to a better degree than the high span participants. However, it is noted that the background message contained the participant's name. It is possible that the presentation of their name caused them to focus on that message rather than the message they were asked to attend to, suggesting a degree of plasticity in their focus.

**Tavassoli, N., & and Lee, Y. 2003. "The Differential Interaction of Auditory and Visual Advertising Elements with Chinese and English." *Journal of Marketing Research,* 468–480.**

A lack of auditory distraction does not always lead to greater attention to an auditory stimulus. This paper discussed work in 1989 by Anand and Sternthal which suggested that an abundance of available cognitive resources may lead to the generation of idiosyncratic thoughts which may distract and result in less attention to the auditory message to be played. For example, when we compare this to a work environment, periods of low workload and stimulation result in lapses in attention. This could be translated in the passenger's case to periods of waiting with little to do leading to daydreaming, low levels of attention, and a likelihood of missing announcements.

**Tsimhoni, O., Green, P., & Lai, J. 2001. "Listening to Natural and Synthesized Speech while Driving: Effects on User Performance."** ***International Journal of Speech Technology,*** **4(2), 155–169.**

Comprehension of text-to-speech synthesized speech messages was compared to that for natural speech messages in a study undertaken while driving. The study found that varying driver workload did not affect comprehension, but that comprehension of synthesized speech in the text-to-speech condition was significantly worse than the natural speech information condition. This is consistent with other research and will be useful for design guidance to define ways to improve message understanding.

**Umera-Okeke, N. 2008. "Listening Effectively for Results in an ESL/EFL Classroom."** ***African Research Review,*** **1(1), 47–54.**

This researcher notes that individual listening types will always affect attention to messages. These listening types are identified in a teaching environment but may be assumed to be generalizable across individuals and, therefore, relevant to passengers. Related to the project, bored, tired, and inattentive listeners may have been subject to delays and have simply "switched off" from external information. This researcher also refers to controlling listeners and describes them as people who prefer always to talk rather than to listen. This particular type of listener may disregard external cues and messages. This information will be useful for design guidance to define ways to improve message understanding.

**Van Horn, L. 2007. "Disability Travel in the United States: Recent Research and Findings." 11th International Conference on Mobility and Transport for Elderly and Disabled Persons (TRANSED). Montreal. June 18–22,**

This study summarizes work in 2005 by the Open Doors Organization, which undertook a travel market study looking at 1,373 adults with disabilities traveling. One of their findings was that 17% of all passengers surveyed said that they had difficulty hearing announcements. While unable to ascertain the participant breakdown for this study, it is suggested that not all of the 17% may have hearing impairment. This information will be useful for design guidance to explore ways to improve message communications.

**Venkatagiri, Horabail S. 2003. "Segmental Intelligibility of Four Currently Used Text-To-Speech Synthesis Methods."** ***Journal of the Acoustical Society of America*** **113 (No. 4, Pt. 1): 2095–2104.**

It can be difficult to understand artificial voice transcription of electronically stored text, and this paper provides review and discussion of the shortcomings of text-to-speech (TTS) systems available in 2003. This paper studies intelligibility of four TTS systems compared to a control human voice under challenging signal-to-noise conditions. The paper indicates that (1) intelligibility is improved for a signal-to-noise ratio (SNR) of 5 decibels (dB) compared to 0 dB, and (2) listeners tend to process artificial voice differently, once they realize that a TTS system is being used. This information will be useful for design guidance. For example, this information could suggest that announcements with artificial voice be repeated to extend the overall duration and allow passengers to adjust to the voice delivery. This work could also imply that synthesized voice may not be suitable for international terminals.

**Yokoyama, Sakae, and Hideki Tachibana. 2013. "Subjective Experiment on Suitable Speech-Rate of Public Address Announcement in Public Spaces." International Congress on Acoustics. Montreal: Acoustical Society of America.**

This is another paper on text-to-speech (TTS), in this case evaluating the suitable speech-rate the TTS system should be set to. The research evaluates the speech rate based on subjective tests that measured listening difficulty and speech intelligibility for Japanese language words. One key finding of this research is that reverberation time is the most important factor to consider for speech

intelligibility by non-native listeners; native listeners were not much affected by reverberation time or speech rate. However, listening difficulty was affected for both native and non-native listeners when the speech rate and reverberation time were changed. This information will be useful for design guidance. For example, this work could imply that synthesized voice may not be suitable for international terminals.

**Zhang, Y., et al. 2005. "Effects of Language Experience: Neural Commitment to Language Specific Auditory Patterns." *NeuroImage,* 703–720.**

This paper discusses work by Strange in 1995 in which it is stated that speech perception is affected by an individual's language experience and that adult non-natives have difficulty in discriminating other language contrasts. Using magnetoencephalography, these researchers found that processing non-native speech required a significantly longer period of brain activation. It is suggested that this may lead to frustration and confusion if the whole message was not attended to or if the non-native speaker's attention had been drawn to the message part way through. This supports an argument for repeating auditory messages. This information will be useful for design guidance to define ways to improve message understanding.

APPENDIX B

# Pilot Passenger Survey Questions and Results Summary

## Summary of Results

- Passengers were willing to answer a short survey on airport announcements.
- Passengers were willing to answer survey questions when airside—departure lounge, food court, and gate area. This is thought to be because once they are airside, passengers are generally more relaxed and have some time available while visiting retail offerings or waiting for their flights. Passengers in these areas typically understand that they will need to listen for a PA announcement to help them with their journeys (i.e., boarding calls).
- Passengers in landside airport areas—check-in, international arrivals, and baggage claim, were less willing to answer the survey questions. This is thought to be because passengers in these areas are either keen to get through security to the departure lounge or in a rush to leave the airport and get to their onward travel/destination. It is also believed that passengers in these areas are generally less engaged with PA messages because they may not feel that such messages are important at that stage of their journey. A shortened survey question set might be better suited to these airport areas.
- Passengers typically check their flight information on the flight information display boards on arriving at check-in and once again after going through security. They check that their flight is scheduled on time and check for the gate allocation.
- An increasing number of passengers are using smartphone apps and/or text updates from their airlines and describe that they feel comfortable that they will be contacted should there be any update, delay, or gate change.
- Passenger behavior is to "tune out" from actively listening to announcements that they do not consider relevant to them. Not relevant may mean that it is a long time before their departure time, they hear a keyword in the announcement (e.g., a destination which is not theirs or is another passenger's name), and/or it is a message they have heard before and do not feel is important to them.
- Passengers stated that they felt PA announcements were most important to their journey when they are at gate areas.
- Some non-native speakers stated that PA announcements were spoken too quickly for them to understand the full message easily.
- Within the food court and some gate areas there were TVs. It was felt that the TVs were too quiet to easily listen to above the background noise, but could still be heard as muffled noise. This source of unintelligible noise may annoy some passengers.
- Background music is played in some food court areas, but was paused before PA announcements enabling the PA announcements to be heard. TV sound did not pause before the announcements.
- Gate areas in the terminal areas can get busy immediately prior to a flight departing. Some passengers (a high proportion of whom were business travelers) tended to stand and wait in

the gate area entrance nearest to the desk and boarding entrance. In this position—on the boundary between the gate area and the adjacent corridor—passengers commented that gate area announcements were muffled and sometimes difficult to hear and that on occasions the general corridor and gate announcements clashed/overlapped, thus making both announcements difficult to hear.

## Questions

**SECTION 1 – The Last 10 Minutes**

Please take a moment to consider the last 10 minutes that you have spent in this area of the airport:

1. Have you heard any PA announcements in the last 10 minutes?
   Yes – go to Q3
   No – go to Q2
2. **If you answered No to Q1.** There have been a few announcements in the last 10 minutes. We are interested to understand what causes passengers to miss airport announcements. Can I ask if there has been anything which may have distracted you from hearing them, such as the following activities? Please select any applicable answers:
   a. In a rush
   b. Airport process (check-in, security) has been distracting me
   c. In conversation
   d. The children have been noisy
   e. Reading a book
   f. Listening to music
   g. Shopping
   h. Visiting restroom
   i. Stressed
   j. Distracted
   k. Other – please describe ______________________________
   **Please go straight to Section 2.**
3. Did the PA announcement provide information that was relevant to you?
   Yes – go to Q5
   No – go to Q4
4. What made you decide that the message was not relevant to you?
   a. It was for a different flight – heard the destination
   b. It was a last call for a different passenger
   c. It was a security/safety announcement and I have heard them before
   d. Other – please describe ______________________________
5. Was the content of the message clear and easy to understand?
   Yes – message made sense
   No – I don't know what it meant
6. Could you hear every part of the PA announcement clearly?
   Yes
   No
7. **If you answered No to Q6.** What made the message difficult to hear? Please select all that apply:
   a. Announcement too quiet
   b. Concourse background noise too high
   c. Announcement had poor sound quality (echo/distortion, etc.)

d. Announcement was spoken too quickly to understand
e. Announcement was not made in my language – please state language ______________________________
f. I was distracted and did not hear it properly
g. Other – please specify ______________________________

**SECTION 2 – Your Airport Experience—Whole Journey**

For the following questions, please consider your experience for the whole of your journey traveling through the airport today:

8. Do you feel PA announcements are important to you and your journey?
   Yes
   No
9. Do you actively listen out for PA announcements when in the airport?
   Yes
   No
10. Are there any areas of the airport where you are more likely to pay attention to PA announcements?
    a. Curbside areas
    b. Ticketing/check-in
    c. Departures lounge/hall
    d. Arrivals hall
    e. Concourse/walkways
    f. Gate areas
    g. Baggage claim
    h. Other – please specify
11. Have any PA announcements been difficult to hear or decipher whilst in the airport today?
    Yes
    No
12. **If you answered Yes to Q11.** Please specify the airport location where the PA announcement was difficult to hear:
    a. Curbside areas
    b. Ticketing/check-in
    c. Departures lounge/hall
    d. Arrivals hall
    e. Concourse/walkways
    f. Gate areas
    g. Baggage claim
    h. Other – please specify ______________________________
13. Why was it difficult to hear at that location in particular?
    ______________________________
14. Have there been any points of the journey today where you needed more information to be provided by PA announcements?
    Yes – what information did you need and where? ______________________________
    No

**SECTION 3 – Generic Questions**

15. What is the purpose of your journey today?
    a. Business
    b. Leisure

16. How often do you fly?
    a. Occasionally – less than one time per year
    b. 1 flight per year
    c. 2–5 flights per year
    d. 5+ flights per year
17. How often do you visit **this** airport?
    a. Occasionally – less than **once** per year
    b. 1 flight per year
    c. 2–5 flights per year
    d. 5+ flights per year
18. Is this airport:
    a. Your origin
    b. Your destination
    c. The location of your connecting flight
19. Are you traveling alone or in a group?
    a. Alone
    b. Small group
    c. Family with children
    d. Large group – 6+
20. Do you use a device to assist with hearing? E.g., hearing aid, hearing induction loop.
    Yes
    No
21. **If you answered Yes to Q20.** Are you aware of and have you used the induction loop/FM hearing loop?

APPENDIX C

# Abbreviations, Acronyms, and Initialisms

| | |
|---|---|
| ACT | Acoustical tile |
| A/D | Analog to digital |
| ADA | Americans with Disabilities Act |
| ADS | Acoustically distinguishable space |
| AHJ | Authority having jurisdiction |
| ANN | Announce or announcement |
| ANSI | American National Standards Institute |
| AODB | Airport operational database |
| APM | Automated people mover |
| ASHRAE | Formerly known as the American Society of Heating, Refrigeration and Air-conditioning Engineers |
| ASTM | American Society for Testing Materials |
| A/V | Audiovisual |
| CCD | CCD Ergonomic and Design Consultants |
| CSA | Cross-Spectrum Acoustics, Inc. |
| D/A | Digital to analog |
| dBu | Decibel unit of measure for electrical noise |
| DSP | Digital signal processor |
| EPA | U.S. Environmental Protection Agency |
| EQ | Equalization |
| FIDS | Flight information display system |
| GBF | Gain before feedback |
| FASA | Fellow of the Acoustical Society of America |
| FAES | Fellow of the Audio Engineering Society |
| Ft. | Feet or foot |
| HF | Human factors |
| HKS | HKS Architects, Inc. |
| Hz | Hertz or once cycle per second |
| dB | Decibel |
| dBA | Decibel, A-weighted |
| HVAC | Heating, ventilation, and air conditioning |
| IEC | International Electrotechnical Commission |
| NC | Noise criteria |
| NFPA | National Fire Protection Association |
| NRC | Noise reduction coefficient |
| OITC | Outdoor/Indoor Transmission Class |
| PA | Public address |
| PE | Professional Engineer |

| | |
|---|---|
| PBX | Private branch exchange (phone server) |
| PhD | Doctorate of Philosophy |
| RASTI | Rapid speech transmission index |
| RT, $RT_{60}$ | Reverberation time |
| SA | Surface area |
| SNR | Signal-to-noise ratio |
| SPL | Sound pressure level |
| STI | Speech transmission index |
| STC | Sound transmission class |
| STIPA | Speech transmission index for PA |
| THD | Total harmonic distortion |
| TTS | Text-to-speech |
| VA | Voice address |

APPENDIX D

# Glossary

- **Ambient noise.** The prevailing general noise existing at a location or in a space, which usually consists of a composite of sounds from many sources near and far.
- **Background noise.** The general composite nonrecognizable noise from all distant sources, not including nearby sources or the source of interest. In a building or airport, background noise consists of a large number of distant noise sources.
- **Decibel (dB).** Ten times the logarithm (base 10) of a ratio. The decibel is a measure on a logarithmic scale of the magnitude of a particular quantity such as sound pressure, sound power, or sound intensity with respect to a standardized quantity.
- **Decibel, A-weighted (dBA).** The sound pressure level in decibels as measured on a sound level meter, using the internationally standardized A-weighting filter or as computed from sound spectral data to which A-weighting adjustments have been made. A-weighting de-emphasizes the low and very high frequency components of the sound in a manner similar to the response of the average human ear. A-weighted sound levels correlate well with subjective reactions of people to noise and are universally used for community noise evaluations.
- **Digital signal processor (DSP).** See Appendix F.
- **Equalization.** See Appendix F.
- **Gain before feedback (GBF).** See Appendix F.
- **Flutter echo.** This phenomenon is a distinct sound reflection pattern that may occur in the presence of large flat or parallel surfaces. For instance, a hand clap will echo repeatedly.
- **Frequency.** The number of oscillations per second of a periodic noise (or vibration) expressed in Hertz (abbreviated Hz). Frequency in Hertz is the same as cycles per second.
- **Human factors.** The study of how humans behave physically and psychologically in relation to particular environments, products, or services. Also known as ergonomics.
- **Equivalent level (Leq).** The level of a steady noise which would have the same energy as the fluctuating noise level integrated over the time period of interest. Leq is widely used as a single number descriptor of environmental noise. This energy average is not the same as the average sound pressure levels over the period of interest, but must be computed by a procedure involving summation or mathematical integration.
- **Noise reduction coefficient (NRC).** The NRC is a simple representation of the amount of sound energy absorbed on striking a particular surface. An NRC of 0 indicates perfect reflection; an NRC of 1 indicates perfect absorption.
- **Octave band and 1/3 octave band.** One octave is an interval between two sound frequencies that have a ratio of two. For example, the frequency range of 200 Hz to 400 Hz is one octave, as is the frequency range of 2000 Hz to 4000 Hz. An octave band is a frequency range that is one octave wide. A standard series of octaves is used in acoustics, and they are specified by their center frequencies. In acoustics, to increase resolution, the frequency content of a sound or vibration is often analyzed in terms of 1/3 octave bands, where each octave is divided into three ⅓ octave bands.

- **Outdoor-indoor transmission class (OITC).** OITC is a standard used for indicating the rate of transmission of sound between outdoor and indoor spaces in a structure. It is different from the STC because it uses a source noise spectrum that considers frequencies down to 80 Hz and is weighted more to lower frequencies. A single number classification, specified by the American Society for Testing and Materials (ASTM E 1332, issued 1994), that establishes the A-weighted sound level reduction provided by building facade components (i.e., walls, doors, windows, and combinations thereof), based on a reference sound spectrum that is an average of typical air, road, and rail transportation sources. The OITC is the preferred rating when exterior facade components are exposed to a noise environment dominated by transportation sources.
- **PA.** This is a system with an electronic sound amplification and distribution system which contains a microphone, amplifier, and loudspeakers, used to allow a person to address a large public area.
- **Rapid Speech Transmission Index (RASTI).** The rapid speech transmission index was developed as instrumentation evolved to measure STI more efficiently.
- **Reverberation time (RT, $RT_{60}$).** The characteristic rate at which sound decays in a room. It is a function of volume and effective acoustical absorption. Various formulas can be used to calculate reverberation time, all of these formulas address nominal geometry and acoustical absorption conditions.
- **Signal-to-noise ratio (SNR).** The signal-to-noise ratio (SNR) is a measure of how clearly a signal can be heard above noise, and it is a critical factor for speech intelligibility. SNR is defined as the ratio of the information (or signal) over the interference (noise). Given that sound and noise (unwanted sound) are commonly measured as sound pressure levels using decibels (dB), the ratio of the sound pressures can be equally expressed as the difference in decibels. Industry practice thus uses SNR to quantify the difference between the PA system sound level and the background noise level (e.g., HVAC noise). On a more basic level, SNR can be viewed as the effect of any unwanted sound that degrades intelligibility, such as sound lingering from announcements due to excessive reverberation.
- **Sound absorption coefficient ($\alpha$).** The absorption coefficient of a material is the ratio of the sound absorbed by the material to that absorbed by an equivalent area of open window. The absorption coefficient of a perfectly absorbing surface would be 1.0 while that for concrete or marble slate is approximately 0.01 (a perfect reflector would have an absorption of 0.00).
- **Sound pressure level (SPL).** The sound pressure level of sound in decibels is 20 times the logarithm to the base of 10 of the ratio of the RMS value of the sound pressure to the RMS value of a reference sound pressure. The standard reference sound pressure is 20 micro Pascals as indicated in ANSI S1.8-1969, "Preferred Reference Quantities for Acoustical Levels."
- **Speech Transmission Index (STI).** The most widely accepted quantitative measure of intelligibility is the Speech Transmission Index (STI), which is defined in IEC 60268-16:2011. STI values range from 0 to 1, with numbers close to 1 achieving high levels of intelligibility. This quantitative measurement method relies on comparing a known signal broadcast through the loudspeaker with the sound measured at the receiver (e.g., height of the human ear); the test signal covers the frequency range of human speech with a specific sequence of periodic (repeating) signals.
- **Sound Transmission Class (STC).** STC is a single number rating, specified by the American Society for Testing and Materials, which can be used to measure the sound insulation properties for comparing the sound transmission capability, in decibels, of interior building partitions for noise sources such as speech, radio, and television. STC is used extensively for rating sound insulation characteristics of building materials and products.

- **Speech Transmission Index for PA (STIPA).** When RASTI was applied to PA systems, shortcomings in the RASTI method were revealed, leading to the development of STIPA. A known signal is broadcast over the PA system, and an STI value can be determined based on what is measured. Jan Verhave and Herman Steeneken developed the STI-for-PA method based on extensive research to make it practical to measure the intelligibility of PA systems.
- **Total Harmonic Distortion (THD).** See Appendix F.
- **Voice Address (VA).** More general purpose than a PA system, a VA system might be used for emergency or internal use—not for general purpose public messages and announcements.

APPENDIX E

# Examples of Acoustical Material Properties

**Table E-1. Common sound absorption coefficients per square foot.**

| Material | 125 | 250 | 500 | 1000 | 2000 | 4000 | NRC |
|---|---|---|---|---|---|---|---|
| ½” (12 mm) suspended ACT (4 kg/m$^2$) | 0.52 | 0.45 | 0.40 | 0.41 | 0.49 | 0.57 | 0.45 |
| 1"-thick high-absorption suspended ACT (.4 lb./square feet) | 0.70 | 0.95 | 0.75 | 0.99 | 1.04 | 1.01 | 0.95 |
| 50 mm acoustical fiberglass panels | 0.59 | 0.75 | 0.63 | 0.60 | 0.39 | 0.26 | 0.60 |
| 1" fabric-covered rock wool panel | 0.27 | 0.66 | 0.109 | 10.01 | 0.87 | 0.65 | 0.90 |
| Spray-on cementitious material 1" thick | 0.18 | 0.35 | 0.64 | 0.73 | 0.73 | 0.77 | 0.60 |
| 2"-thick perforated steel deck covering fiberglass insulation | 0.10 | 0.21 | 0.79 | 0.98 | 0.95 | 0.86 | 0.75 |
| Large panes of heavy plate glass | 0.18 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 | 0.04 |
| Gypsum board on studs | 0.29 | 0.10 | 0.05 | 0.04 | 0.07 | 0.09 | 0.07 |
| Linoleum floor | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.06 |
| Terrazzo or concrete floor | 0.01 | 0.01 | 0.015 | 0.02 | 0.02 | 0.02 | 0.016 |
| Wood parquet on concrete floor | 0.04 | 0.04 | 0.07 | 0.06 | 0.06 | 0.07 | 0.06 |
| Carpet 35 oz./yd$^2$, 3/32” pile, no pad | 0.10 | 0.16 | 0.10 | 0.30 | 0.50 | 0.47 | 0.27 |
| People standing (per square feet/person) | 2.0 | 3.5 | 4.7 | 4.5 | 5.0 | 4.0 | Not app. |

ACT: acoustical tile
Source: Harris (1993) and Beranek (1986)

APPENDIX F

# PA System Glossary

For more detailed discussion of individual components and these terms, refer to other sources such as *Sound Reinforcement Engineering* (Ahnert and Steffen 2000), "Advanced System Gain Structure" (McGregor 1999), *Sound System Engineering* (Davis and Patronis 2014) and *Handbook for Sound Engineers* (Ballou 2012).

- **Adequate sound level.** The amplitude of the sound signal is a measure of loudness. It is usually measured in decibels (dB) of sound pressure level (SPL). The PA system should be loud enough to be heard in the area served without being objectionably loud.
- **Adequate ratio of direct-to-indirect sound.** Direct sound travels from the loudspeaker directly to the listener's ears. Indirect sound is reflected off one or more surfaces before it reaches the listener. Too much indirect sound interferes with the clear understanding of speech. Echo and reverberation are examples of indirect sound that can compromise intelligibility.
- **Adequate SNR.** The PA system sound level must be sufficiently louder than the ambient noise level to achieve intelligibility. Examples of ambient noise sources include HVAC systems, aircraft operations, people activity, concession mechanical equipment, TVs, escalators, and people movers.
- **Clarity.** Freedom from distortion or noise. Distortion mixed with noise impedes speech intelligibility, especially under low SNR conditions.
- **Digital signal processor (DSP).** One of the headend electronics. The DSP selects, combines, routes, filters, and otherwise processes the audio signals before the amplification stage. The DSP includes the basic functions of calibration, level-setting, delay and equalization. (See Section 7.4.1 for a summary of the key functions.
- **Directivity factor.** In general terms, most sounds emit uniformly in all directions. When a sound source is placed on a hard surface, the sound that would have traveled down is reflected from the hard surface, effectively doubling the strength of the sound source. Similarly, a sound source in a corner benefits from at least three surfaces. A directivity factor can be assigned to each of four conditions.
  - 1: free field,
  - 2: on a flat plane or surface,
  - 4: at two perpendicular planes, and
  - 8: in a corner at three perpendicular planes.
- **Equalization (EQ).** Equalization increases or decreases the level of different frequencies in the PA signal. Equalization is performed by digital electronic equalizers within the DSP component. A basic type of equalization is the bass/treble control in a home stereo system.
- **Frequency response.** All audio equipment physically responds to sound according to the frequency that it receives (microphone) or transmits (loudspeaker) or both (PA system). High-quality electronics have a flat response in their nominal operating frequency range. Quality loudspeakers have an overall response of typically (± 5 dB) over a broadband operating

range between 70 Hz and 15,000 Hz with a smooth, linear response, typically ± 2 dB, in the speech frequency range between 200 Hz and 4,000 Hz. Quality microphones are rugged and robust with a smooth, linear response, typically ± 2 dB, in the speech frequency range between 200 Hz and 4,000 Hz.

- **Gain before feedback (GBF).** This is a function of how much the microphone signal can be amplified before the system begins to "howl" or feed back into the microphone. Gain is the desired increase in power level or sound level in the audio system. Maximizing gain settings from the system and rejecting feedback improves intelligibility in the PA system when a microphone is used for live announcements. Maximizing gain settings from the system and rejecting feedback improves intelligibility in the PA system when a microphone is used for live announcements. The acoustical design of the cardioid microphone capsule minimizes the sensitivity to reflected sound and signals arriving from loudspeakers, thus improving GBF.
- **Headend.** The electronics that form the "brains" of the PA system (i.e., DSP and power amplifiers).
- **Intelligibility.** The goal is to achieve easy understanding of the spoken word.
- **Linearity.** The PA system's output at the listening position should vary in direct proportion to the sound source. A linear system provides high-quality reproduction (fidelity) of the input sound. A system that does not do this is nonlinear.
- **Naturalness.** The PA system should sound balanced and natural. Because this is primarily a means of broadcasting the spoken word, the range of frequencies important to understanding speech (nominally 200 to 4,000 Hz) will be present without some frequencies being predominant or lacking.
- **PA system uniformity.** The uniformity of sound coverage can be documented by "walking" each ADS to sample the one-third octave band spectrum once per second. Thus, some samples are taken on-axis under a loudspeaker and some are taken between loudspeakers. The uniformity can be represented graphically from this data. The data uses a pink noise input signal at a level necessary for good acoustical SNR.
- **Polar plot.** A useful way to view the directionality or uniformity of an audio transducer (microphone or loudspeaker). Polar plots are two- or three-dimensional plots showing the response in any 360-degree direction. (See Figure 7-2 for an example.)
- **Power amplifier.** The role of the audio power amplifier is to amplify the low power signals from the DSP to a level suitable for driving the loudspeakers. This is where the signal levels are matched. The power amplifiers should be sized for the wattage necessary to drive the loudspeakers to the required sound levels. When the power amplifiers are undersized or overdriven, clipping and other distortion occurs. This hinders intelligibility and can damage the loudspeakers. The system should be engineered to furnish a minimum 3 dB of headroom at maximum power amplifier output.
- **Stability.** The announcements broadcast over the PA system should be free of feedback and spurious pick-up. Feedback (i.e., the cycling of the loudspeaker output back into the microphone input) results from improper loudspeaker location and insufficient electronic gain control. Pick-up of unwanted outside signals can be caused by an aging system or poor installation. If audio signal cables act as an antenna to pick up and amplify signals from outside the PA system, using proper grounding and shielding techniques and minimizing cable loops that promote electromagnetic induction of signals into the system can resolve the situation.
- **Total Harmonic Distortion (THD).** This term, used to characterize the performance of audio and power electronics, is a measure of the linearity of the components.
- **Uniform sound coverage.** In the region served by each loudspeaker zone, the entire area should receive evenly distributed sound levels. Hot spots (i.e., where the sound is noticeably higher) and/or dead zones (i.e., where the sound is very low or absent) are to be avoided or addressed. Ideally, the uniformity of sound coverage is about ± 1 dBA.

APPENDIX G

# Sample PA System Specification Relevant to Speech

This appendix provides guidance on key elements within the PA system specification that relate to speech intelligibility.

## Design Components

1. Terminal buildings.
   The terminals are classed as an assembly occupancy and shall meet the requirements of the IBC, the International Fire Code and the National Fire Alarm and Signaling Code (NFPA 72), as adopted by the Authority. The following are identified as functional areas in the terminals:
   a. Gate hold areas
   b. Concourse
   c. Ticket halls
   d. Baggage claim
   e. Back of house
2. Airport operations center.
3. Emergency operations center.
4. Nonterminal buildings.
5. Evacuation/mass notification/public address (EVAC/MN/PA) system includes:
   a. Announcement control system hardware in terminal main communications rooms and airport operations center
   b. Backup, or lifeline, announcement control system hardware in secondary terminal main communications rooms
   c. Message servers in specified terminal main communications rooms
   d. Digital amplifier mainframes and amplifier cards in terminal communications rooms
   e. Ambient noise collectors in specified communications rooms
   f. Ambient noise sensors and associated wiring in loudspeaker zones
   g. Loudspeakers and associated wiring in PA
   h. Microphone stations and associated data cabling
   i. Rack-mounted microphone stations in specified communications rooms
   j. PA system vendor software
   k. Flight announcement system and courtesy announcement system software
   l. Other work and accessories required for a complete and operational system
6. The EVAC/MN/PA system collects, manages, and distributes high-quality audible information to specific areas throughout the terminal buildings. The system has been specifically designed to intelligibly reproduce live, prerecorded, or assembled voice messages. The system is a fully network-based digital system and analyzes the ambient sound level in specified zones to adjust the distributed sound level in the zone accordingly.

## National Fire Alarm and Signaling Code (NFPA 72)

The EVAC/MN/PA system shall be capable of performing Emergency Voice Evacuation announcements and Emergency Mass Notification messages in compliance with NFPA 72 and any changes, additions, or upgrades to the system shall be fully compliant as well.

## Programming

All hardware and software requirements for EVAC/MN/PA system functionality shall be coordinated with the Authority. This includes, but is not limited to, network connectivity, paging priorities, digital message assembly, system access, microphone paging, and paging station button functionality and screens.

## Digital Message Distribution Operation

1. Each message processed by the EVAC/MN/PA system must be intelligible at destination areas.
2. Messages must be coordinated such that dissimilar messages will not be distributed within an area at any given time. No message shall be lost because of coordination or priority preemption unless such message is no longer timely.
3. Any background music distributed over the EVAC/MN/PA system must be muted for all page messages within the area affected by the page messages. Background music should be muted during the night.
4. Priority is assigned such that the emergency paging function immediately cancels all other audio announcements or messages in the affected zones. Local paging functions have a higher priority than background music and recorded messages in the local paging zone. Recorded messages override background music in all zones.

## Digital Message Assembly

1. Standard or repetitive messages are studio-recorded voices assembled from digital audio files stored in the system audio library. Assembled messages form complete phrases capable of distribution without real-time operator input.
2. The EVAC/MN/PA system can record, store, and play back permanent messages. Message "takes" are stored in nonvolatile memory.
3. Two types of permanent messages are provided: Standard messages and Assembled messages.
4. Standard messages include:
    a. Public service announcements
    b. Regulatory announcements
    c. Other institutional messages required by the Authority
5. Standard messages are assignable to any zone or zones.
6. Assembled messages include:
    a. Flight boarding announcements
    b. Flight arrival and bag claim announcements
    c. Gate change announcements
    d. Delayed flight or cancelled flight announcements
7. Digital audio library: The digital message files shall contain CD-quality (minimum 44.1 kHz 16 bit), fixed and variable digitized message files that can be prepared by a professional announcer and supplied and arranged in data tables as follows:
    - Bag claim lookup table
    - Gate hold room lookup table
    - Fixed message table

Fixed message files may also be standalone non-assembled messages such as security messages and parking warnings.

## Performance Requirements

### *Audio Specifications*

- Frequency response ±0.5 dB at 20 Hz to 20 kHz.
- Test: Measure the electrical power output of each power amplifier at normal gain setting at 50; 1,000; and 12,000 Hz. The maximum variation in power output at these frequencies must not exceed ±0.5 dB.
- Total harmonic distortion (THD) <.05 percent at rated amplifier output 20 Hz to 20 kHz.
- Distortion test: Measure distortion at normal gain settings and rated power. Feed signals at frequencies of 50; 200; 400; 1,000; 3,000; 8,000; and 12,000 Hz into each preamp channel and measure the distortion in the power amplifier output. The maximum distortion at any frequency is 3 percent total harmonics.
- Noise referenced to input −120 dBu 20 Hz to 20 kHz.
- Signal-to-noise ratio (SNR) >90 dB.
- Maximum latency—11.9 milliseconds from communications station to power amplifiers through three network switches.

### *System Equalization*

The system shall provide for frequency response equalization for each loudspeaker zone output. Filter types shall allow notch, high pass, or low pass. Filters shall have a Q range of 0.055 to 33. Provide nine filters for each zone output.

### *Ambient Noise Analysis and Control*

The systems shall include the capability to automatically adjust the volume levels in each zone, based on changes in the ambient noise levels in those zones.

1. Each zone that includes a sensor within its boundaries shall have automatic control.
2. The system shall automatically null announcement or program material for that zone to prevent "run-away" or inaccurate volume tracking and shall provide smooth unobtrusive control.
3. Software shall allow for set up of the following parameters:
   - Automatic, slaved to an automatic channel, or fixed modes
   - Configuration of one to four sensors for control of a zone and control of multiple zones from one or more grouped sensors
   - Control of threshold, maximum gain allowed and scaling ratio.
4. Software shall provide for
   - Real-time monitoring of sensor levels
   - Program levels
   - Output levels
   - Gain changes.
5. System shall provide for automatic setup of zones using the integrated system messaging.

## System Design Requirements

### *General*

- All installations must be coordinated with the appropriate department of the Authority.
- The EVAC/MN/PA system design and all modifications shall comply with all requirements of the State and Authority.

- The EVAC/MN/PA system shall comply with the requirements of the National Fire Alarm and Signaling Code (NFPA 72), the Authority's Inspection Authorities, and the Manufacturer's instructions.
- Audio modeling using an approved simulation software is required to predict the intelligibility of the space, based on architectural features and materials interacting with loudspeakers and their placement.

### *Loudspeaker Design Requirements*

- Each physical loudspeaker/amplifier zone shall consist of a discrete contiguous space with a common function (e.g., each gate hold room, concourse circulation adjacent to each gate hold room, airline ticketing lobby, baggage claim area, security checkpoint, concessions, and operations office). Areas with different functions shall not be combined in the same physical loudspeaker/amplifier zone.
- The loudspeakers for each loudspeaker/amplifier circuit shall be consistent within the circuit.
- Loudspeaker spacing shall be based on ceiling heights and ceiling materials and the type of space the zone encompasses. Loudspeakers shall be tapped and balanced with amplifier settings so that announcements are intelligible.
- Each physical loudspeaker/amplifier zone that will have varying amounts of ambient noise shall have at least one ambient noise sensor, and zones shall be evaluated for more than one ambient noise sensor based on size. Ambient noise sensors shall be mounted such that they are closer to sources of ambient noise than to EVAC/MN/PA system loudspeakers.

## Acceptance Testing/Commissioning

### *Operational Test*

Perform an operational system test to verify conformance of the system to the Specifications. Perform tests that include originating program material distribution; page material distribution; message distribution coordination; zone distribution selection; message assembly; system supervisory, alarm, and monitoring functions; ambient noise control functionality; and paging operator workstation features. Observe sound reproduction for proper volume levels and freedom from noise. All zones affected by the project shall be included in the test.

### *Intelligibility Test*

Perform intelligibility tests in compliance with NFPA 72 Chapters 18 and 24 and the requirements of this Facility.

### *Acoustic Coverage Test*

Feed pink noise into the system using octaves centered at 4,000 and 500 Hz. Use a sound level meter, with octave band filters, to measure the level at approximately 40-foot spacing intervals in each zone. For spaces with seated audiences, the maximum permissible variation in level is ±2 dB and the levels between locations in the same zone and between locations in adjacent zones must not vary more than ±3 dB.

The documentation of tests, measurements, and adjustments performed shall include a list of personnel and the list of certified test equipment used and shall be in compliance with NFPA 72.

All information recorded from all testing shall be shown on the as-built documents.

APPENDIX H

# Sample Design Criteria Elements Relevant to Speech Intelligibility

## Acoustics

The acoustic environment within and around airport terminal buildings can affect the passenger, employee, and visitor experience. Unintelligible PA announcements increase passenger stress levels.

## Reverberation, Transmission, and Equipment Noise Criteria

The Authority encourages all project design teams to employ a building acoustics specialist to review key acoustical characteristics of spaces and building systems. This review might range from a complex calculation of reverberation time for large, complex passenger processing spaces to a simple review of a wall assembly to reduce sound transmission between adjacent spaces. The following considerations shall be addressed for each project:

- **Reverberation:** Various factors (e.g., volume, shape, and the quantity and location of sound-absorbing or sound reflecting materials) contribute to the acoustical character of a space. These factors affect the reverberation time ($RT_{60}$) of the space. Undesirable sound reflections can create an uncomfortable environment acoustically and decrease speech intelligibility. "Flutter echo" is an undesirable reflection caused by parallel reflecting surfaces.

  Consider sound-absorbing finishes to reduce reverberation time, especially at the 500 to 2,000 Hz range where speech occurs. For optimal paging system performance, reverberation time should be 1.5 seconds or less, and preferably less than 1.1 seconds for critical spaces served by PA systems. Consider appropriate surfaces for sound-absorbing materials, with regard to durability and maintainability.
- **Transmission:** Noise transmission through ceilings, walls, windows, doors, and floors between adjacent spaces shall be analyzed. Strategies such as mass loading, sound isolation, and avoiding flanking noise pathways shall be considered. Required ambient noise levels based on function of the spaces shall determine the type of construction needed. Note these criteria in the Project Definition Document and specifically note recommendations for any deviations from requirements
- **Equipment Noise:** Noise and vibration data shall be provided for equipment such as air handling units, pumps, drives, variable air volume units, fan-powered boxes, cooling towers, chillers, and baggage conveyors. Vibration isolators, acoustical liners, duct sound traps, and fan speeds shall be considered and equipment shall be acoustically isolated from adjacent spaces as noted in the preceding transmission paragraph. In addition, in public spaces, plumbing noise (specifically that from roof top rain leaders) shall be assessed and controlled, if necessary.

## Noise Criteria (NC) Recommendations

The following are design criteria targets for noise levels that shall be addressed in the initial project documentation and Basis of Project Definition Document. This is not a comprehensive list of all interior spaces in a terminal or other airport facilities. These criteria are adapted from the ASHRAE guidelines for public spaces such as corridors and lobbies (*2011 ASHRAE Handbook—HVAC Applications,* Chapter 48, Noise and Vibration Control). Designers shall recommend criteria for spaces not listed below and note them in the Project Definition Document.

- Gate hold areas/Lounges: Many people use their time in a lounge to make phone calls and, if noise levels are too low, these are easily overheard. The same applies to general conversations. Therefore, it is recommended that the noise limit of NC 40 be adopted.
- Concourses and Circulation Spaces: NC 45 is recommended.
- Baggage Claim: NC 45 to 50 is recommended.
- Arrivals and Ticketing Hall: NC 45 is recommended.
- Moving Walkways and Baggage Claim Belts: A noise limit of NC 60 at 3 feet.

## PA System Intelligibility

Speech intelligibility, a quality distinct from audibility, relates to the potential ability of listeners to understand the messages delivered (not including language and contextual factors). Audibility is only a component of intelligibility, as can be demonstrated by experiences in large, hard-finished public spaces where an announcement can be heard, but the message content cannot be distinguished.

In building terms, major factors affecting the speech intelligibility of a PA system are

- The sound level of the system relative to the background noise levels ("signal-to-noise ratio")
- The acoustic response of the space and, hence, the level of "useful" sound received directly from the loudspeakers relative to the delayed reverberant sound ("direct-to-reverberant ratio").

Despite this objective approach to understanding the salient mechanisms, speech intelligibility remains a subjective quality that will be judged differently by each listener and for different messages and/or talkers. For design purposes, some objective measures are available, including the Speech Transmission Index (STI) that is often measured using the STIPA method. STI is an index from 0.0 to 1.0, with higher numbers representing higher intelligibility. International standards relating to PA systems for emergency purposes state a typical requirement for STI of 0.5. However, the standards allow for the objective nature and for lower STI ratings in response to practical constraints.

Overhead loudspeakers probably will not be viable in areas with a floor-to-ceiling heights of more than 24 feet. Loudspeakers will probably need to be integrated into floor features (e.g., services pods and FIDS supports). This approach can provide good sound coverage and intelligibility and would enable specific loudspeaker zones to be defined by partitions. However, the relocation of large objects such as retail units could result in acoustic shadow zones being created that would need additional fill in loudspeakers. Limitations on the "throw" distance for loudspeakers dictate a minimum spacing of around 45 feet.

Note acoustical requirements in other sections of these standards.

APPENDIX I

# Summary of Field Measurement Results

**Table I-1. Summary of field measurement locations and key information.**

| ADS | ADS Type | Airport Type | Ave. STI | Median Ceiling Height | Day ANN $L_{ASmax}$ | Day Ambient $L_{eq}$ | Night Ambient $L_{eq}$ | SNR-Test | $RT_{60}$ Average at 2,000 Hz |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Concourse | Major hub | 0.33 | 35.8 | 75 | 66 | 61 | 9.6 | 3.4 |
| 2 | Ticketing | Major hub | 0.49 | 19.0 | 73 | 62 | 52 | 17.6 | 0.9 |
| 3 | TSA | Major hub | 0.61 | 24.6 | 75 | 64.5 | 51 | 17.3 | 1.0 |
| 4 | Food court | Major hub | 0.65 | 33.5 | 77 | 62 | 52 | 21.9 | 1.1 |
| 5 | Gates | Major hub | 0.68 | 11.5 | 71 | 57 | 52 | 11.4 | 0.9 |
| 6 | Ticketing | Major hub | 0.46 | 75.0 | 73 | 64.5 | 55 | 11.0 | 2.7 |
| 6.5 | Food court | Major hub | 0.41 | 18.8 | 75 | 71 | 57 | 11.7 | N/A |
| 7 | Concourse | Major hub | 0.46 | 13.8 | 74 | 62 | 60 | 10.5 | 1.5 |
| 8 | Gates | Major hub | 0.36 | 36.8 | 76 | 66.5 | 58 | 14.6 | 3.5 |
| 9 | Concourse | Major hub | 0.45 | 15.3 | 72 | 62 | 57 | 9.3 | 0.9 |
| 10 | Gates | Major hub | 0.47 | 13.0 | 72 | 60 | 54 | 9.4 | 1.1 |
| 11 | Food court | Major hub | 0.36 | 62.0 | 67 | 65 | 56 | 12.1 | 3.0 |
| 12 | Concourse | Major hub | 0.52 | 18.3 | 67 | 62 | 52 | 16.3 | 1.3 |
| 13 | Concourse | Major hub | 0.55 | 19.0 | 70 | 61.5 | 52 | 15.6 | N/A |
| 14 | Gates | Major hub | 0.50 | 14.0 | 72 | 60 | 61 | 7.7 | N/A |
| 15 | Gates | Major hub | 0.58 | 14.0 | 72 | 60 | 53 | 13.7 | 1.3 |
| 16 | Ticketing | Major hub | 0.61 | 24.0 | 69 | 63 | 51 | 20.9 | 1.0 |
| 17 | Arrivals | Major hub | 0.46 | 68.0 | 68.5 | 61 | 56.5 | 7.3 | 2.3 |
| 18 | Baggage | Major hub | 0.73 | 19.0 | 69 | 61 | 47 | 20.0 | 0.9 |
| 19 | Baggage | Major hub | 0.63 | 19.0 | 65 | 62.5 | 51 | 15.4 | 0.9 |
| 20 | Gates | Major hub | 0.65 | 11.0 | 73 | 65 | 58 | 11.3 | 1.0 |
| 21 | Concourse | Major hub | 0.49 | 59.0 | 76 | 64 | 59 | 11.5 | 2.9 |
| 22 | Ticketing | Major hub | 0.52 | 39.5 | 72 | 66 | 55 | 8.3 | 2.9 |
| 23 | Baggage | Major hub | 0.48 | 18.8 | 64 | 61 | 54 | 12.8 | 1.5 |
| 24 | Gates | Major hub | 0.62 | 11.6 | 79 | 62 | 57 | 13.9 | 0.7 |
| 25 | Gates | Major hub | 0.65 | 11.0 | 77 | 61 | 56 | 17.3 | 1.0 |
| 26 | Concourse | Major hub | 0.64 | 10.7 | 76 | 65 | 57 | 15.2 | 0.8 |
| 27 | Baggage | Regional | 0.50 | 8.1 | 70 | 53 | 51 | 6.8 | 0.6 |
| 28 | Arrivals | Regional | 0.49 | 21.3 | 66 | 51 | 47 | 16.0 | 1.6 |
| 29 | Ticketing | Regional | 0.59 | 8.0 | 71 | 56 | 52 | 12.0 | 1.0 |
| 30 | TSA | Regional | 0.46 | 27.5 | 69 | 59 | 51 | 11.0 | 1.2 |

*(continued on next page)*

**Table I-1. (Continued).**

| ADS | ADS Type | Airport Type | Ave. STI | Median Ceiling Height | Day ANN $L_{ASmax}$ | Day Ambient $L_{eq}$ | Night Ambient $L_{eq}$ | SNR-Test | $RT_{60}$ Average at 2,000 Hz |
|---|---|---|---|---|---|---|---|---|---|
| 31 | Gates | Regional | 0.51 | 8.4 | 67 | 56 | 50 | 10.0 | 0.9 |
| 32 | Gates | Regional | 0.47 | 26.5 | 67 | 54 | 47 | 15.5 | 1.6 |
| 33 | Curbside | Regional | 0.61 | 8.0 | N/A | N/A | N/A | N/A | N/A |
| 34 | Baggage | Medium hub | 0.5 | 16.4 | 76 | 66 | 63 | 11.0 | 1.3 |
| 35 | TSA | Medium hub | 0.45 | 36.6 | 72 | 68 | 56 | 10.5 | 2.1 |
| 36 | Ticketing | Medium hub | 0.44 | 36.3 | 74 | 68 | 60 | 7.0 | 1.5 |
| 37 | Baggage | Medium hub | 0.41 | 20.9 | 69 | 54 | 54 | 17.0 | 2.4 |
| 38 | Baggage | Medium hub | 0.32 | 10.0 | 73 | 62 | 62 | 11.0 | 2.8 |
| 39 | Ticketing | Medium hub | 0.57 | 10.0 | 70 | 60 | 57 | 15.0 | 0.6 |
| 40 | Food court | Major hub | 0.56 | 24.4 | 72 | 68 | 63.3 | 14.2 | 1.5 |
| 41 | Gates | Major hub | 0.59 | 13.8 | 73.5 | 59 | 50 | 20.0 | 1.1 |
| 42 | Ticketing | Major hub | 0.36 | 30.0 | 75 | 65 | 66 | 6.0 | 2.5 |
| 43 | Curbside | Major hub | 0.39 | 28.3 | 70 | 71 | 64 | 2.0 | N/A |
| 44 | Baggage | Major hub | 0.52 | 23.4 | 73 | 53 | 46 | 26.0 | 1.6 |
| 45 | Baggage | Major hub | 0.61 | 11.3 | 75.5 | 71 | 59 | 15.0 | 1.3 |
| | | | | | | | | | |
| | | Average | 0.51 | 23.6 | 72 | 62 | 55 | 13 | 1.6 |
| | | Median | 0.50 | 19.0 | 72 | 62 | 55 | 12 | 1.3 |

ADS: Acoustically distinguishable space
ANN: Announcement
N/A: Not available

**Table I-2. Average octave band spectra for measured ambient conditions.**

| Ambient Condition | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---|---|---|---|---|---|---|---|---|
| Daytime—all ADS | 62.4 | 60.5 | 59.1 | 59.4 | 56.2 | 52.9 | 47.0 | 39.5 |
| Nighttime—all ADS | 59.5 | 57.2 | 54.3 | 52.3 | 49.1 | 45.6 | 40.1 | 32.0 |
| | | | | | | | | |
| Daytime—noisy (65 dBA) | 64.7 | 64.1 | 63.5 | 63.7 | 60.0 | 57.2 | 51.9 | 44.2 |
| Daytime—quiet (59 dBA) | 61.3 | 58.6 | 56.7 | 57.1 | 54.2 | 50.6 | 44.4 | 37.0 |
| Nighttime—noisy (59 dBA) | 62.4 | 60.8 | 58.2 | 57.0 | 54.5 | 51.4 | 45.4 | 37.5 |
| Nighttime—quiet (51 dBA) | 58.0 | 55.2 | 52.0 | 49.4 | 45.7 | 41.9 | 36.6 | 28.9 |

ADS: Acoustically distinguishable space

*Abbreviations and acronyms used without definitions in TRB publications:*

| | |
|---|---|
| A4A | Airlines for America |
| AAAE | American Association of Airport Executives |
| AASHO | American Association of State Highway Officials |
| AASHTO | American Association of State Highway and Transportation Officials |
| ACI–NA | Airports Council International–North America |
| ACRP | Airport Cooperative Research Program |
| ADA | Americans with Disabilities Act |
| APTA | American Public Transportation Association |
| ASCE | American Society of Civil Engineers |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| ATA | American Trucking Associations |
| CTAA | Community Transportation Association of America |
| CTBSSP | Commercial Truck and Bus Safety Synthesis Program |
| DHS | Department of Homeland Security |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| FAA | Federal Aviation Administration |
| FAST | Fixing America's Surface Transportation Act (2015) |
| FHWA | Federal Highway Administration |
| FMCSA | Federal Motor Carrier Safety Administration |
| FRA | Federal Railroad Administration |
| FTA | Federal Transit Administration |
| HMCRP | Hazardous Materials Cooperative Research Program |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISTEA | Intermodal Surface Transportation Efficiency Act of 1991 |
| ITE | Institute of Transportation Engineers |
| MAP-21 | Moving Ahead for Progress in the 21st Century Act (2012) |
| NASA | National Aeronautics and Space Administration |
| NASAO | National Association of State Aviation Officials |
| NCFRP | National Cooperative Freight Research Program |
| NCHRP | National Cooperative Highway Research Program |
| NHTSA | National Highway Traffic Safety Administration |
| NTSB | National Transportation Safety Board |
| PHMSA | Pipeline and Hazardous Materials Safety Administration |
| RITA | Research and Innovative Technology Administration |
| SAE | Society of Automotive Engineers |
| SAFETEA-LU | Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005) |
| TCRP | Transit Cooperative Research Program |
| TDC | Transit Development Corporation |
| TEA-21 | Transportation Equity Act for the 21st Century (1998) |
| TRB | Transportation Research Board |
| TSA | Transportation Security Administration |
| U.S.DOT | United States Department of Transportation |

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