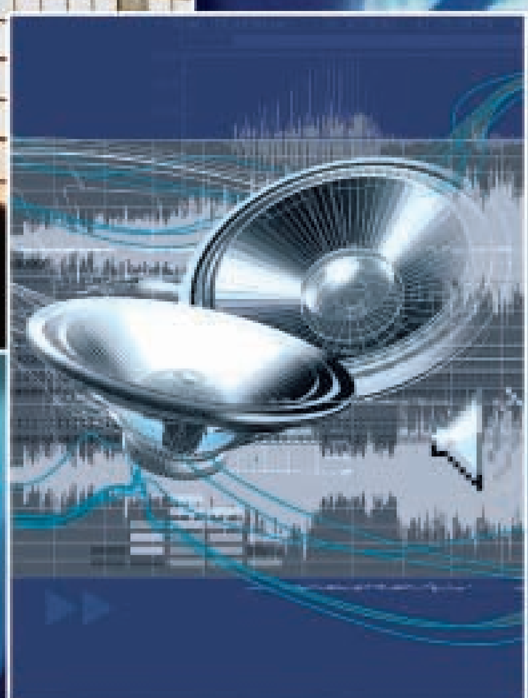
by John Haynes

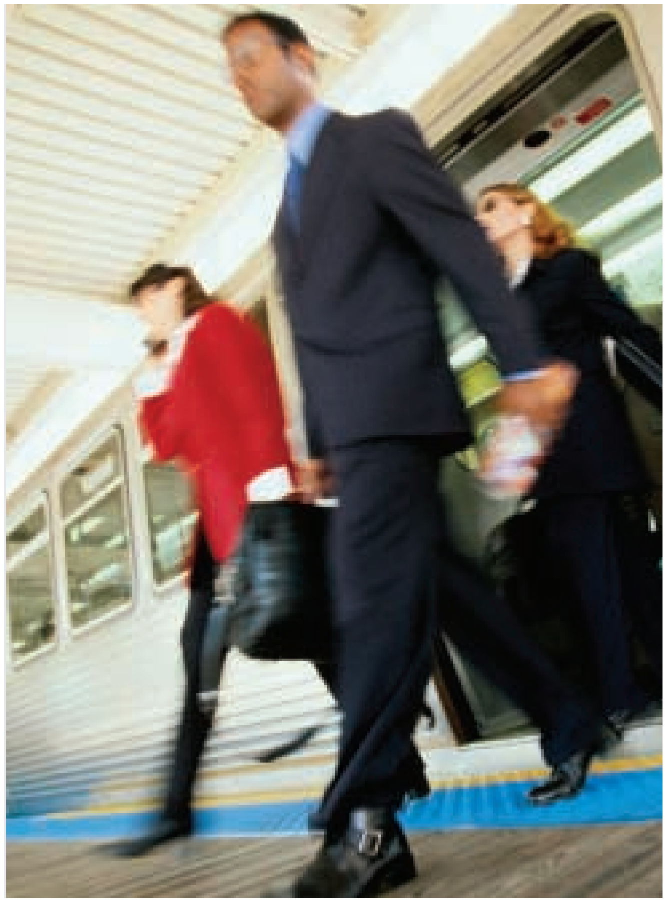
Speech Intelligibility...

New technologies enhance fire protection and life safety



A poorly designed or installed sound system can be annoying and make it difficult to hear flight arrival and departure information at an airport. It can also be aggravating, as witnessed by complaints that are regularly lodged about the audio quality at arena concerts. But the consequences can be dangerous, or even deadly, if people can't understand safety instructions from a building's emergency voice evacuation system.

Simply put, to help prevent injury and save lives, a voice system must be intelligible. The National Fire Protection Association's NFPA 72 National Fire Alarm Code now requires that emergency voice evacuation systems be intelligible to building occupants. This is not always an easy task, because many variables affect speech intelligibility, including distortion, echoes, reverberation, the level of ambient noise, and an announcement's signal-to-noise ratio.



Subway stations and transportation hubs present peculiar challenges to an audio system designer.

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Voice is generally accepted to be superior to conventional evacuation tones and bells as a means of notifying building occupants of an emergency. "People react better with emergency voice systems than without," said Merton W. Bunker, P.E., a consulting engineer with 17 years of experience in fire protection, life safety and security. "An announcement instead of just a bell gives enough information to cause a reaction."

But the fire detection and protection industry is code-driven, and existing codes only require voice systems in specific types of buildings (e.g., high-rise) and in specific occupancy classifications (e.g., places of public assembly). Even in buildings where voice systems are required, the codes still don't fully mandate testing that is extensive enough to make sure these systems provide voice intelligibility.

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Intelligibility vs. Audibility

Where conventional, non-voice evacuation tones are used, the code requires that these tones be loud enough to be audible well above the ambient background noise level. A voice message, on the other hand, is not intelligible simply because it is audible. Anyone who has stood on an underground subway platform during an announcement can attest to that.

There have been documented incidents where the inability to understand safety instructions broadcast over an emergency system has contributed to tragic deaths that might have been prevented. A system that is not audible and understandable (intelligible) may cause panic and chaos at a time when remaining calm and collected is critical. People need to know how to evacuate or react appropriately. If what they hear is "just" a fire alarm and not the message, many people think they know what to do. But what if the message is instructing them to stay put? What happens if the fire is in the stairwell normally used as a fire exit?

The September 11 terrorist attacks strongly underscored the need to clearly hear and comprehend emergency instructions during a fire, earthquake, or other perilous situation. Since 9/11, the federal government has begun implementing new requirements for mass notification throughout certain government facilities, including military bases. Beginning in fiscal 2004, mass notification is required by the U.S. Department of Defense in all new "inhabited buildings" as specified in United Facilities Criteria (UFC) 4-010-01 *(Minimum Antiterrorism*

Standards for Buildings). The new federal requirements specifically mandate the installation of intelligible voice notification systems in and around these facilities.

Recent intelligibility surveys conducted in a variety of existing, occupied buildings using handheld analyzers have shown highly mixed results. Even within a single building, voice evacuation messages are often unintelligible in areas of high ambient noise (e.g., manufacturing floors) although completely intelligible in office areas.

Questions and concerns about liability may arise as people recognize the critical role that speech intelligibility plays in emergency evacuation. Concerned owners and engineers are realizing that mere compliance with current code requirements may not adequately deal with today's threats. Fire protection and equipment specifying engineers are beginning to write specs that incorporate intelligibility testing. The federal government is moving quickly to implement stronger intelligibility requirements in its own facilities. Will the private sector also pick up the pace of adopting similar changes?

Voice is a powerful tool for communicating specific emergency instructions, assuming the audience can clearly hear and understand it. In recent years, there has been a growing awareness of the need for intelligibility. U.S. fire codes are moving toward mandating that the intelligibility of voice messages in new buildings be objectively measured and meet minimum standards. While fire codes have always implied that voice messages should be clearly understood, a consensus has only recently developed around testing methods that are practical, repeatable and, most importantly, objective.

What Do The Codes Say About Intelligibility?

According to the 2002 edition of NFPA 72, section 7.4.1.4, "Where required, emergency voice/alarm communications systems shall be capable of the reproduction of prerecorded, synthesized, or live (for example, microphone, telephone handset, and radio) messages with voice intelligibility."

According to Appendix A of the same code, section A.7.4.1.4: "Voice intelligibility should be measured in accordance with the guidelines in Annex A of IEC 60849, Second Edition: 1998, *Sound Systems for Emergency Purposes*. When tested in accordance with Annex B, Clause B1, of IEC 60849, the system should exceed the equivalent of a common intelligibility scale (CIS) score of 0.70."

The federal mass notification standard also references IEC-60849 and NFPA 72, A.7.4.1.4 in defining intelligibility requirements.

The International Electrotechnical Commission (IEC) standard 60849 recognizes several methods of measuring intelligibility. Some are subject based (use human listeners); other methods use instrumentation.

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The IEC standard includes a scale for rating intelligibility called the Common Intelligibility Scale (CIS). Each of the approved test methods in the specification has a scale that can be equated to the others, using the CIS. For example, an STI (Speech Transmission Index) rating of 0.5 equates to a CIS rating of 0.70. It's analogous to converting a temperature reading from Fahrenheit to Centigrade.

Voice evacuation messages are often unintelligible in areas of high ambient noise.

These methods are meant to be absolute measures of intelligibility (including environmental factors that might interfere with hearing). The only inherent assumptions in the methodologies are that the speaker and listener are both assumed to be "normal" or unimpaired. A CIS rating of 0.7 generally equates to the ability of a "jury" of trained listeners to be able to correctly decipher 80-percent of a series of unrelated words read into a PA system. A CIS rating of 1.0 would indicate perfect intelligibility. Obviously, environmental factors such as background noise and poor room acoustics would result in a lower intelligibility score, all other things being equal.

NFPA does not define intelligibility directly, but references the IEC 60849 standard.

What makes the CIS scale practical is the availability of portable, hand-held instruments that are capable of measuring intelligibility with only a 15-20 second "sample." Repeatability and objectivity require that the measurement instrument be thoroughly tested in a recognized laboratory. For example, the STI-CIS analyzer marketed by SimplexGrinnell and others has been extensively tested at the Dutch National Labs TNO Human Factors in The Netherlands (reports available).

At the 2002 NFPA World Safety Conference and Exposition, the NFPA attempted to strengthen the voice intelligibility requirements, with a proposal to narrow the applicable definitions and establish measurement testing standards. However, doubts were raised about the existence of a large-scale speech intelligibility problem and the need for new regulations. These included the specter of higher costs for compliance testing and inspection.

Voters turned down the proposed intelligibility code changes. Although the regulations and recommendations were not approved, even those questioning the new rules agreed that an emergency system is of little or no value if nobody can understand it. In essence, the impact of the vote was to leave code requirements for voice intelligibility unchanged.

Speech intelligibility will continue to be an important issue that affects any number of constituencies, including design engineers, architects, electrical contractors, and building owners.

Voice Intelligibility Can Be Objectively Measured

Perhaps the most significant issue facing AHJs (authorities having jurisdiction) charged with enforcing the codes has been the lack of a practical means for measuring the intelligibility of an alarm/notification system.

Typically, measurement has been a time-consuming, costly ordeal. It was not unusual, when measuring speech intelligibility in a high-profile facility, to require the services of five to 20 trained listeners for up to a week.

Using technology originally developed for NATO to improve the intelligibility of military communications, a portable intelligibility analyzer now exists that can measure voice intelligibility in both new and existing buildings. Some of the devices now available are as easy to use as the dBA meters that have been used for years to measure the loudness of emergency evacuation tones or messages. The SimplexGrinnell and Gold Line analyzers respond to a proprietary STI-PA™ test tone developed at the Dutch National Labs TNO-Human Factors Group, developers of the STI method. The SimplexGrinnell analyzer is subject to patents issued and/or pending by Bose Corporation, and is manufactured under license by Gold Line.

All of the factors that affect intelligibility are taken into account in the CIS score. The STI-CIS analyzer is compatible with all brands of fire alarm voice communications panels, provides automatic error detection, and comes with calibrated excitation signal and injector. It is battery or AC powered and includes an "A-weighted" sound level meter meeting ANSI specification S1.4a for sound level meters, Type 2 requirements as called for in NFPA 72. "A-weighting" adjusts the sound pressure levels in various frequency bands to match what the human ear would sense.

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A Typical Test Procedure

The STI-CIS analyzer is designed for use by service technicians, engineers, AHJs and building owners. As a special test tone is played through a building's voice system, the user simply presses one button on the analyzer to initiate an intelligibility measurement. After a 15-second countdown, the CIS level is displayed. The analyzer can also measure the level of ambient background noise in dBA as well as the level of the test or actual evacuation signals. The tone is embedded on a CD that is played through a small powered speaker and introduced through the microphone of the Fire Panel. This equipment is provided as an accessory to the Analyzer (called a "TalkBox"). The tone is proprietary to TNO/Bose/Gold Line and will only work with a compatible analyzer.

Testing with realistic ambient noise is essential, but that's easier said than done. Testing a facility during normal occupancy is the most accurate method, but the test tone can get disruptive and annoying after a few minutes. It sounds like what you hear when you take your car through a car wash or a driving rainstorm.

It is possible to create simulated background noise while testing an unoccupied space. While this is a convenient and simple approach, it doesn't account for "large audience" effects. People are sound absorbing, so a full room will generally be less reverberant than an unoccupied room. You can simulate background noise with a boom box, but you can't easily simulate the sound absorption of a crowd without a crowd. A logical alternative would be to take samples of background noise during normal occupancy, test unoccupied space and combine signals using a laptop computer.

important to have speakers deployed uniformly throughout the room (i.e. good coverage) to maintain intelligibility throughout the room. Difficulty with reflections can be corrected in the same way as for high reverberation and in addition by deploying signal delay electronics.

A trained professional can often diagnose the causes of intelligibility problems by observation and a few simple measurements. In more acoustically challenging spaces, computer modeling may be required to diagnose and correct problems.

For high reverberation, the solution may be to add sound absorbing materials to the space and/or move speakers closer to occupants while reducing the loudness of each speaker.

This method is accurate, unobtrusive and non-disruptive but requires more sophisticated user training and a computer.

While speech intelligibility is usually not a major issue in office spaces where ambient background noise is minimal and speaker distribution is adequate, it is a very common problem in transportation centers such as airports and sports facilities, and in buildings with large, open atriums, such as shopping malls. Managers and owners of such high-profile facilities, who have become acutely aware of security issues, are also beginning to realize that an intelligible evacuation system is necessary to optimize protection in their buildings. It's certainly not a message lost on enforcement authorities, including fire marshals and inspectors.

Most Problems Are Easily Corrected

When intelligibility testing indicates a problem, what does it typically take to make the voice system intelligible? Low CIS readings can be caused by several factors, including:

- Inadequate number of speakers or poor speaker coverage
- Inadequate speaker power (low signal-to-noise ratio)
- Excessive sound reverberation, reflections or echoes

The solution for low signal to noise ratios can be to increase system signal power, increase speaker power, add more speakers, and/or adjust output based upon variable ambient noise level. For high reverberation, the solution may be to add sound absorbing materials to the space and/or move speakers closer to occupants while reducing the loudness of each speaker.

When testing a large room with an inadequate number of speakers, you may get some passing intelligibility scores if you are testing near a speaker. However, as you move away from it, the intelligibility will drop off. It is

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Intelligibility testing is not without some issues. If new buildings are tested for intelligibility prior to the installation of carpeting and furniture, the readings could be either better or worse than when the building is fully ready to occupy. Changes in occupancy and in ambient noise levels can also affect intelligibility.

To the degree that computer modeling can be used to simulate the impact of furnishings, occupancy and ambient noise, AHJs may consider requiring this kind of documentation.

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Voice Intelligibility Begins With Good Design

Now that it is practical to measure intelligibility in buildings, the focus of the industry will undoubtedly shift to better up-front design. Good design is a prerequisite for good voice intelligibility.

When developing a building evacuation system, the designer must take many factors into account, including the volume and shape of the room, reverberance of the room (construction materials and room contents), ambient background noise (HVAC, machinery, people, external sources), and occupancy (auditorium, airport concourse, etc.). Designers must also consider voice system design parameters, including the signal generation equipment (microphone and amplifier), speaker characteristics an placement, and the delivered signal-to-noise ratio.

Changes in occupancy and ambient noise levels have a major impact on intelligibility.

In a presentation to the NFPA Congress, Kenneth Jacob, Chief Engineer for Bose Corporation Professional Systems, pointed out that while speech intelligibility has been an active topic scientifically and commercially for 25 years, it is still relatively new to many of the people who benefit from it or who could be held liable for not providing it. Safety professionals, from firefighters to specifying engineers, face an ever-growing menu of issues and options in meeting the speech intelligibility requirements associated with their jobs.

Newer computer modeling and design software allows accurate prediction of speech intelligibility during the design stage, and also provides the ability to diagnose poorly designed existing voice systems and pre-test corrective actions prior to installation.

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The modeling technologies used to measure intelligibility are worthy of consideration for large public areas such as auditoriums, arenas, convention centers, or transportation centers. They are particularly appropriate for spaces with very high ceilings, hard surfaces (marble, plaster, glass) and high ambient noise. But such sophisticated design tools are not needed for many typical building environments. In office areas, corridors, classrooms, etc., with low to moderate ambient noise levels and eight- to 10- foot high ceilings with acoustic tile, an intelligible voice system design can easily be achieved through the use of simple design guidelines for establishing required spacing and power settings for speakers.

Adequate speaker coverage is usually the key determinant of whether or not the voice system will be intelligible. To cut costs, some designers may try to limit the number of speakers used in a room and compensate by setting the few speakers used at very high power settings. This is the equivalent of trying to provide good task lighting at all workstations from a single, very high intensity lighting source mounted at one end of the room. While there may be enough power being consumed to do the job, it won't do much good for most of the occupants in the room if it is poorly distributed.

Tools and Skills Are Available Today.

Knowledgeable suppliers have the skills and tools required to design intelligible voice evacuation systems. However, until the fire codes mandate voice intelligibility testing, it is up to the design engineer to clearly specify intelligibility as called for in the NFPA code and to meet the minimum CIS score of 0.70 as reflected in the Annex Material (appendix A.7.4.1.4). The NFPA code does not yet mandate intelligibility testing even though it mandates that voice systems should be intelligible. Local governmental agencies typically adopt the NFPA code requirements after they are written. However, it is possible for a local code official to require intelligibility testing, even though the NFPA code does not yet do so.

Although some would argue that intelligibility is not a problem, testing of many existing buildings indicates otherwise. While adequate to meet audibility requirements, the outdated method of using a small number of high power speakers must change, even if the initial installation costs are higher.

Virtually all design engineers and enforcement officials agree that intelligible voice evacuation systems are vital to protecting building occupants during emergencies. Now the fire protection industry appears to agree about defining what intelligibility means and ensuring that it will be the standard rather than the exception in voice evacuation system design.

MC35-1-004