Speech Intelligibility

INTRODUCTION

In situations where egress is complex or difficult, such as in high-rise buildings or large factories, human voice is often used to provide *information*. Failure to understand message content can result in several ways. A message that is not *intelligent* may not be understood. A message spoken in Spanish to an audience that only understands Cantonese will not be understood. A person talking rapidly or with a speech impediment can cause a message to not be understood. Even a well-spoken, intelligent message in the language native to the listener can be misunderstood if it is not audible or if its delivery to the listener is distorted. These last failure mechanisms are the basis for the specification, modeling, and measurement of speech *intelligibility* performance.

THE PROBLEM

Fires such as the King's Cross fire in London in 1987 and an apartment fire in York, Ontario, have been cited as situations where the lack of intelligible voice communication to occupants was a contributing factor in the losses.[1, 2] We often see paging systems in places such as airports and meeting spaces with speakers every eight to twelve feet (three to four meters). How will the speech intelligibility of the adjacent fire alarm system compare when it has speakers spaced 40 to 70 feet (10 to 20 meters) apart?

No one argues that a tone signal must be audible to the listener and that a voice transmission must be intelligible. Disagreements regarding audibility led the fire alarm industry to adopt audio industry definitions and measurement methods. This moved the industry from using *subjective* evaluations of audibility to *objective* methods.

In 1997, the Notification Appliances Committee of NFPA 72 began working with the audio industry to learn more about speech intelligibility and how to establish objective performance requirements for emergency voice alarm communication (EVAC) systems. The goal was to define speech intelligibility performance in a way that could be objectively measured, eliminating subjective evaluations.

WHAT IS SPEECH INTELLIGIBILITY?

Figure 1[3] is useful in understanding the path of a voice signal from a talker to a listener.

The figure shows the types of error that can be introduced into the message at each stage. Problems or faults have a cumulative effect on message understanding. For example, a person might speak with an accent but still be understood by a listener who is face-to-face with the talker. The communications system might add distortion that results in the message not being understood. Or perhaps it's understood when there is little or no background noise, but not understood when there is background noise.

Researchers are addressing the two ends of the communications chain shown in Figure 1.[4, 5] For the purposes of this article, speed of talking, language, and talker articulation are not directly addressed. They are indirectly addressed because a system that reliably delivers a message, with a limited amount of distortion, reverberation, and echo, is more likely to be understood even when a talker introduces problems or when a listener has impaired hearing. A system with a higher degree of intelligibility can offset some, but not all, deficiencies introduced by the talker or the listener.

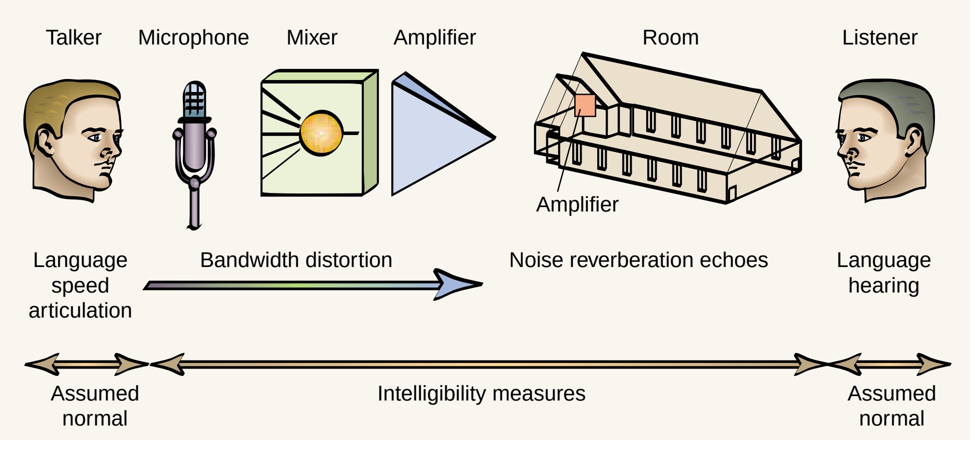
Speech intelligibility is the measure of the effectiveness of speech. The measurement is usually expressed as a percentage of a message that is understood correctly.[6] Speech intelligibility does not imply speech *quality*. A synthesized voice message may be completely understood by the listener, but maybe judged to be harsh, unnatural, and of low quality. A message that lacks quality may still be intelligible.

FACTORS AFFECTING SPEECH INTELLIGIBILITY

For speech to be intelligible, it must have adequate *audibility* (sound pressure level) and adequate *clarity*.

For audibility, we are concerned with the signal-to-noise ratio. Voice is highly modulated, and so while intelligibility measurements do incorporate audibility, it is not to the same standards used for audibility of tone generating systems.

Figure 1. Voice Signal Path (Courtesy of K. Jacob, Bose® Professional Systems[3])



Thus, a tone and a voice message that are both perceived as equally loud may have considerably different readings on a dB or dBA meter using fast or even slow time constants. That is one reason that audibility measurements are not required by the *National Fire Alarm Code* for voice signals.

Phonemes are the smallest phonetic unit capable of conveying a distinction in meaning in a particular language and are instrumental in accurate word recognition.[7] Examples are the *m* of *mat* and the *b* of *bat* in English. Clarity is the property of sound that allows phonemes to be distinguished by a listener.[8] Clarity is the freedom of these sound units from distortion introduced by any part of the sound system or environment. Recently, a major U.S. cellular telephone company has implemented a television ad campaign playfully pointing out the very real problem of phoneme clarity.

Clarity can be reduced by: 1) amplitude distortion caused by the electronics/hardware; 2) frequency distortion caused by either the electronics/hardware or the acoustic environment; and 3) time domain distortion due to reflection and reverberation in the acoustic environment.

Designers and engineers have the greatest effect on speech intelligibility by their choice of equipment, the number and distribution of loudspeakers, and the power at which they are driven.

MEASURING SPEECH INTELLIGIBILITY

The system hardware and the acoustic environment cannot be separated when evaluating speech intelligibility. Installation choices, such as wire size and routing, affect power levels and induced noise. Mounting locations and surfaces affect sound fields, and construction materials and furnishings affect acoustic parameters. Thus, the performance metric for speech intelligibility must assess all of the requisite parameters.

International Electrotechnical Commission (IEC) and International Standards Organization (ISO) standards already incorporate objective methods for evaluating speech intelligibility. The standard, IEC 60849, *Sound systems for emergency purposes*,[8] is similar to NFPA 72. Some of the methods recognized in the standard are subject-based, and others use instrumentation. ISO 9921 also references established methods.[6] For each of the recognized methods, there already exists an internationally accepted standard for the test method/protocol.

The IEC standard includes a chart that equates the scales for each of the different test methods to a common scale called the Common Intelligibility Scale (CIS). Evaluation of speech intelligibility may use any one of several methods cited in the standard. Four of these methods use test instruments. Three subject-based methods are also permitted. One method has both a subject-based solution and an instrument-based solution. These are summarized below in Table 1.

For the four instrument-based solutions, at present there are at least six different instruments available from four different manufacturers. Consult the references for more detail on each of the test methods.

The recommended minimum performance level for EVAC systems is that the average CIS score, less one standard deviation, be 0.70 or greater. This permits deviations, does not require an exact score, and

Table 1. Speech Intelligibility Test Methods

Method	Standard Ref. in IEC 60849	Comments
STI – Speech Transmission Index	IEC 60268-16 The objective rating of speech intelligibility by speech transmission index, 1998	This is an objective, instrument-based method. Requires hardware and software for measurement and solution. Available in a computer-based solution, as a feature of some multi-function audio analysis equipment, and as a handheld meter.
RASTI – Rapid Acoustics Speech Transmission Index	IEC 60268-16 The objective rating of speech intelligibility by speech transmission index, 1998	This is an objective, instrument-based method. Reduced STI method. Available in a handheld format.
PB – Phonetically Balanced Word Scores	ISO/TR 4870 Acoustics – The construction and calibration of speech intelligibility tests, 1991	This is an objective, subject-based method. ANSI S3.2 Method for measuring the intelligibility of speech over communication systems, 1989, is a better reference for evaluations using the English language. Notification Appliances Chapter permits ANSI S3.2 use, although ISO/TR 4870 is also permitted.
MRT – Modified Rhyme Test	No reference given	This is an objective, subject-based method. No standard listed. ANSI S3.5 notes that the method has the same limits as given in ISO/TR 4870 (PB). Good reference is ANSI S3.2 Method for measuring the intelligibility of speech over communication systems, 1989.
AI – Articulation Index	ANSI S 3.5, Methods for the calculation of the articulation index, 1969 ANSI S 3.5, Methods for the calculation of the speech intelligibility index (SII), 1997	This is an objective, instrument-based method. The 1969 version is referenced. This has been updated to the 1997 edition. Requires hardware and software for measurement and solution.
$\%AL_{cons}$ – Articulation Loss of Consonants	Peutz, V.M.A., "Articulation loss of consonants as a criteria for speech transmission in a room," *J. Aud. Eng. Soc.* 19, 12, December 1971	This is an objective, instrument-based method or an objective, subject-based method. Available in a computer-based solution.

ensures that approximately 84% of the space has a score of 0.70 or better – assuming a normal distribution of the results. The 2002 edition of the *NFPA 72 Handbook* contains a discussion of why a CIS of 0.70 was used as a baseline.[9]

PLANNING, DESIGN, INSTALLING, TESTING, AND USING

A reliable communication system must be properly planned, designed, and installed. Testing uncovers faults and allows corrections to be made, but also shows successful techniques for future reference. One issue that designers and authorities must face when planning a system is the question of where intelligible voice communication is needed.

In a large space used for public meetings, conventions, and trade shows, an EVAC system needs to be reliably intelligible because it is intended to give information to the general public that is not familiar with the space. In large public spaces, a person should not have to move any great distance to find a place where they can understand the message.

However, in a high-rise apartment building, is voice intelligibility required in all spaces? It may not be necessary for the EVAC system to be *intelligible* in all parts of the apartment even though it must be audible in all parts. It may be sufficient to provide a speaker in a common space to produce an adequate audible tone to awaken and alert. When the voice message follows, it may not be intelligible behind closed bedroom and bathroom doors. The occupants, in a familiar space, can move to a location where a repeating message can be intelligibly heard. The same signaling plan may work for office complexes – a person may have to open their office door to reliably understand the message.

Once the design team plans to have some type of a system and decides that the system must be intelligible in certain spaces or areas, the fire alarm code's requirements and recommendations for intelligibility may become part of the *performance design objectives* or goals. It is important that all of the stakeholders, including the code officials, agree on the design goals and objectives.

By agreeing upon specific design goals and objectives, multiple approaches can be used to achieve the desired performance. The *National Fire Alarm Code* permits designers to use any and all reasonable means to achieve the objectives. Designers and installers who are new to the subject or who want to learn more about proper voice system design and installation should consult more in-depth resources.[10]

Just as fire protection engineers can model fires, acoustic and audio engineers can model speech intelligibility before a building is built and before a system is installed. Acoustic properties of materials are well documented and result in reliable evaluations of proposed designs in the same way that a fire protection engineer might evaluate flame spread and smoke contribution of materials. The electronic performance of the communications system can be adjusted in the models based on data from the system manufacturer.

At this time, there is no requirement in the body of the *National Fire Alarm Code* that speech intelligibility actually be measured. The measurement methods are discussed only in the Annex of the *Code*. However, if it is decided to measure intelligibility, how many tests should made in a particular space? Currently, there is no guidance for *audibility* measurements regarding the number and locations of test points nor for *intelligibility* measurements. With audibility, we have an intuitive sense of where a system might fail, and we tend to concentrate our testing plan in those areas. How many designers, technicians, and authorities have such intuition regarding intelligibility? This is not an argument to not test intelligibility. That would just be a head-in-the-sand reaction. Rather, it means that we need to start testing and that we are likely to test a larger number of points initially as we gather experience.

As with audibility, there are methods to test when a space is not occupied and then "add in" the expected or measured noise level at a later time during analysis. This permits less-invasive testing. It is common practice to test the audibility of systems before a space is occupied. Experience and available data permit us to estimate the expected noise level and compare it to the nonoccupied system performance. Similar procedures are done for intelligibility measurements. However, the required data may not be readily available or apparent to the fire protection engineer. Also, as with audibility measurements, intelligibility measurements in a space cannot be reliably made unless those parts of the interior finish that affect sound transmission and attenuation have been installed. ▲

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Editor's Note – About This Article

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