Criteria for assessment of noise annoyance

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(Received 2004 March 31; revised 2005 January 16; accepted 2005 September 02)

Day-night average sound level (DNL) and the relationship between DNL and community annoyance to noise are often presented to a community as part of a noise-assessment process, usually as established scientific fact. In reality, there is great scatter and variability in the attitudinal survey data that are the basis for the DNL-response relationship. As a result, there is significant uncertainty around the corresponding curves that are fitted to the data. This paper collects, tabulates, and compares recommended minimum DNL criterion levels for various types of communities and settings. The paper summarizes some of the recommended adjustments to DNL that are contained in ISO 1996-1:2003 and other factors that reduce the variations between predicted and reported community noise annoyance. The paper recommends that the appropriate DNL criterion level in residential areas should be between 50 dB and 55 dB. Differences between attitudinal survey data on community annoyance and predicted community responses can be minimized by use of adjustments, most of which are contained in ISO 1996-1:2003. © *2005 Institute of Noise Control Engineering*.

Primary subject classification: 69.3; secondary subject classification: 68.3

1 INTRODUCTION

Environmental noise is the unwanted sound received at an outdoor location from all sources in a community. Environmental noise excludes sounds that are experienced by listeners in occupational settings as well as the sounds emitted by consumer products and experienced by listeners in their homes. Major sources of environmental noise include road, rail, and air traffic; industries; construction and public works; lawn and garden equipment; snow-removal equipment; and amplified music.

The extent of the environmental noise problem is very large. In the USA in the early 1970s, over 40 % of the population was estimated to be exposed to A-weighted sound levels from vehicular traffic that exceed 55 dB [1][1]; in the European Union and Japan, this percentage is even higher [2]. In contrast to many other environmental problems, the population exposed to unacceptable noise continues to grow, accompanied by an ever-increasing number of complaints [3].

Environmental noise is frequently assessed in the United States by means of the day-night average A-weighted sound level (abbreviated DNL for day-night average sound level where the A-frequency weighting is understood). In countries in the European Union, the day-evening-night average sound level (abbreviated DENL) is now required for assessments of environmental noise [4].

Day-night average sound level and day-evening-night average sound level have units of decibels (dB) relative to the standard reference pressure of 20 μPa. Day-night average sound level differs from a 24-hour average sound level in that a 10-dB factor is added to sound levels occurring during nighttime hours in a determination of DNL. Day-evening-night average sound levels use a 5-dB factor added to sound levels occurring in evening hours and a 10-dB factor for sound levels occurring during nighttime hours.

The American National Standards Institute [5] and the U.S. National Research Council [6] recommend DNL for assessment of environmental noise as do most federal agencies and administrations. The International Organization for Standardization [7] recommends similar measures for assessments of environmental noise.

The degree of noise annoyance in a community is related to the level of the noise by means of so called "dose-response" relationships. These relationships have been under development for the past 50 years and are developed from meta-analyses of attitudinal survey data. Examples of the development of the response relationships include the seminal study by Schultz [8], the study by Finegold, Harris, and von Gierke [9], and the more-recent study by Miedema and Vos [10]. Examples of the application for these relationships can be found in documents by the U.S. Environmental Protection Agency [1], the U.S. Federal Interagency Committee on Urban Noise [11], and the U.S. Federal Interagency Committee on Noise [12].

There is a strong consensus that DNL is a good descriptor[2] for assessment of the noise from individual modes of transportation such as vehicles or aircraft. While there are other descriptors that can be used to assess transportation noise, yearly-average DNL (YDNL) is the descriptor of choice for assessments of the long-term annoyance caused by individual noise source types.

The choice of noise descriptor, however, is but half the problem. More important than the descriptor are the values of the descriptor chosen to represent various degrees of adversity. If the criteria are too high, they will fail to provide an acceptable living environment; conversely, if the criteria are too low, then they will require unnecessarily expensive mitigation measures and will probably be ignored. A poor

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[1] *Numbers enclosed within brackets represent citations in the list of references.*

[2] *Noise descriptors are also known as 'metrics.'*

choice for descriptor with appropriate criterion levels can do a fair job in portraying the community reaction to noise, but the best descriptor will fail if the criterion levels are too high or too low.

This paper collects, tabulates, and compares recommended appropriate minimum criteria levels for the long-term DNL descriptor in various types of communities and settings. The analysis is primarily from a USA perspective; however the conclusions should be equally applicable in any industrialized country. This paper also looks at the available basic data on which many of the criteria were based. Finally, this paper summarizes some of the recommended adjustments to DNL that are contained in [7] and other factors that reduce the variations between predicted and reported community noise annoyance.

This paper is concerned with noise annoyance in areas where people reside. It does not deal with noise annoyance in other settings such as at work, or in parks and wilderness areas. This paper does not deal with non-auditory effects of noise such as hearing loss or direct impacts of noise on health or sleep. This paper does not deal with cognitive or other non-annoyance effects of noise in schools, the workplace, or the home.

2 REVIEW OF DESCRIPTORS AND CORRESPONDING CRITERIA FOR ASSESSING NOISE ANNOYANCE

2.1 U.S. Federal Agencies that recommend minimum day-night average sound levels of about 65 dB

2.1.1 Federal Aviation Administration

The U.S. Federal Aviation Administration (FAA), a part of the U.S. Department of Transportation, uses DNL as the preferred descriptor for assessing aircraft noise in so-called "Airport Part 150 Studies." Part 150 studies are noise-compatibility/land-use studies designed to identify and evaluate measures to mitigate the impact of aircraft noise in the vicinity of airports. Outdoor day-night average sound levels ranging upward from 65 dB are considered in such studies [13]. For an airport Part 150 study[3], residential areas do not differentiate between urban, suburban, or rural areas. With virtually no exceptions, the FAA provides noise-mitigation funds for residential areas only when the DNL exceeds, or is predicted to exceed, 65 dB. The FAA regards a DNL of 65 dB as "the level of significance for assessing noise impacts" [13].

2.1.2 Department of Defense

The U.S. Department of Defense (DoD) uses DNL to evaluate noise in environmental assessments and in "Air-Installation Compatible Use Zone Studies" [14]. AICUZ studies are noise-compatibility/land-use studies designed to help mitigate the impact of the noise produced by operations of military aircraft at residential locations in the vicinity of air installations. Outdoor day-night average sound levels ranging upward from 65 dB are considered in such studies. Sometimes, for purposes of information, a DNL contour line is presented at a level of 60 dB.

For an AICUZ study, the description of a residential area does not differentiate between urban, suburban, or rural areas. The same factors that influenced the FAA's choice of 65 dB as the minimum criterion level also influenced the DoD's choice, although aircraft operated by agencies of the DoD have never been designed to minimize noise levels in a community around an airfield.

In addition to aircraft noise, agencies of the DoD that operate weapons as part of military training and readiness exercises are concerned about the noise levels in neighboring communities. Day-night average sound level [hereafter shortened to day-night sound level] is the preferred descriptor for the sounds produced by weapons and explosive devices[4].

2.1.3 Department of Housing and Urban Development

The U.S. Department of Housing and Urban Development (HUD) noise policy was first published in 1971 [15]. However, HUD has no cognizance over the sound produced by any noise source. The HUD Noise Assessment Guidelines are included here for completeness. In a 1985 document [16], outdoor day-night sound levels ranging from 65 dB to 75 dB are described as "normally unacceptable [for housing]" and DNLs from 60 dB to 65 dB are described as being "normally acceptable." DNLs less than 60 dB are termed in the HUD Guidelines as "clearly acceptable."

2.2 Agencies and Boards of the U.S. Federal Government that recommend minimum day-night average sound levels of about 55 dB

Many administrations, agencies, commissions, and boards of the U.S. Federal Government, other than the FAA and the DoD, have oversight over noise-producing sources. The Federal Transit Administration, the Federal Railroad Administration, the Surface Transportation Board, the Federal Highway Administration, and the Federal Energy Regulatory Commission are five of the more important. Moreover, a mission of the National Research Council, a part of the National Academy of Science, is to provide advice on scientific matters to the entire Federal Government, including advice on preferred descriptors for evaluating noise in residential communities.

2.2.1 The Federal Transit Administration

The Federal Transit Administration (FTA), a part of the U.S. Department of Transportation, uses the DNL descriptor

[3] *Part 150 refers to a part of Title 14 of the U.S. Code of Federal Regulations.*

[4] *A-weighted sound exposure is used for the sound of small arms. For large weapons, C-weighted sound exposure is measured or predicted and then converted to an equivalent A-weighted sound exposure as described in [5] and [7].*

to assess noise from mass transit activities [17]. Mass transit includes rapid rail transit or light rail transit, commuter rail, diesel buses, electric buses and trackless trolleys, bus storage yards, rail-transit storage yards, maintenance facilities, stations, and subways. Figure 1 illustrates the FTA criteria for assessing the noise of transit activities. These criteria vary with the land use at the location of the noise receiver and with the existing outdoor noise exposure at the receiver.

In Figure 1, the abscissa is the noise exposure that is present at a location in the vicinity of a transit activity. The left ordinate is the projected noise exposure for Category 1 and 2 land uses when the proposed transit activity is operating. The right ordinate is the projected noise exposure for Category 3 land uses. Categories of land use are described in [17]. Noise exposure is the greatest hourly average A-weighted sound level in a 24-h period for Categories 1 and 3 land uses; noise exposure is day-night sound level for Category 2 land uses. Category 2 includes residences and buildings where people normally sleep such as detached homes, apartments, hospitals, and hotels.

Figure 1 shows, for example, that if the existing DNL at a location is 55 dB, then the start of impact for a new or revised Category 2 project occurs when the projected DNL from the new or revised transit activity in combination with the existing noise sources exceeds 55.5 dB at a receiver location. For an area around a transit activity where the existing DNL is less than 40 dB, adverse impact begins when the DNL from the new noise source in combination with the existing noise sources is less than 50 dB. In areas where the existing DNL is 65 dB, the DNL from transit activities can only be just over 60 dB to avoid an adverse impact. The FTA criteria in Figure 1 are much lower than the FAA/DoD minimum criterion of 65 dB for day-night sound level of aircraft noise.

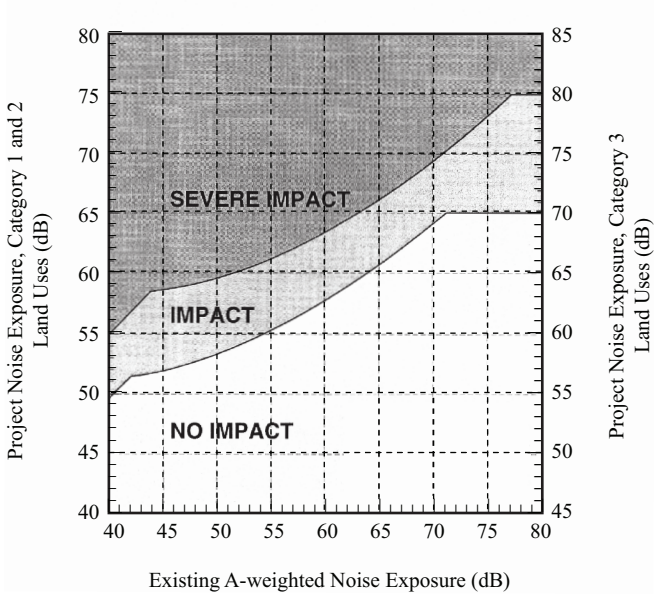

Fig. 1—Criteria of the U.S. Federal Transit Administration [17] for assessment of the noise produced by transit projects in various land-use categories; land-use Category 2 is for residential housing.

The FTA Guidance Manual [17] includes a background discussion about the development of their noise impact criteria; the Manual cites the U.S. Environmental Protection Agency recommendation [1] for a DNL of 55 dB as the basis for the FTA recommendations for the boundaries of the impact zone. The FTA Manual states that a DNL of 65 dB was used to determine the lower boundary of the region of severe impact.

2.2.2 The Federal Railroad Administration

The Federal Railroad Administration (FRA), another part of the U.S. Department of Transportation, uses the DNL descriptor to assess the noise from mass transit activities. This effort was motivated in part by the FRA's need to assess the noise from new, high-speed trains. The FRA uses exactly the same criteria as used by the FTA. Like the FTA, the FRA terms the noise level represented by a DNL of 65 dB as "severe impact" [18].

2.2.3 The Surface Transportation Board

The Surface Transportation Board (STB), another part of the U.S. Department of Transportation, uses the DNL descriptor to assess the noise from railroads that transport freight. The STB uses the same criteria as the FTA and FRA; see, for example, the requirements laid on the proposal of two railroads to acquire the assets of Conrail [19].

2.2.4 The Federal Highway Administration

The Federal Highway Administration (FHWA), another component of the U.S. Department of Transportation, does not use DNL for noise assessment. Their procedure [20] is included here for completeness. The FHWA uses two other descriptors. One is termed "the 10th-percentile A-weighted sound level for a busy hour" with letter symbol L_{10}. The other is termed "the hourly average A-weighted sound level for a busy-hour" with letter symbol L_{1h} or L_{eq1h}.

At a location at the exterior of a residence in the vicinity of a roadway, the FHWA requires that the estimated or measured hourly average sound level for the busiest traffic hour of a day be at most 67 dB and that the 10th–percentile sound level for the busiest traffic hour of the day be at most 70 dB.

However, state highway agencies are required to select a tolerance limit of at least 1 dB around the federal requirements and are free to select somewhat higher tolerance limits. Thus, with the minimum tolerance, the FHWA criteria are, at most, 66 dB for busy-hour hourly average sound level or 69 dB for the 10th-percentile sound level in the busiest traffic hour. While some relation exists between the FHWA noise descriptors and DNL, the correlation is not particularly good or well documented.

2.2.5 The Department of Transportation

The U.S. Department of Transportation (DoT) recognizes that the various modes of transportation within the responsibility of the Department have different models, noise descriptors, and criteria. In a report to Congress [21] they stated:

"A unified DoT multi-modal noise model is feasible and

desirable. It would enable the evaluation of the noise impacts from multiple sources without the need for multiple models. As an example, using MNM [Multi-modal Noise Model], evaluation of the noise impacts of an airport with several highways and a rapid transit line running to the airport would no longer require the use of two computerized models and one non-computerized model to perform an assessment. In addition to facilitating analysis, a multi-modal model would enable one to more clearly assess and compare the contributions of each source to the total noise exposure. In the present situation, the commonly used noise descriptors differ from one mode to another. Even for the same transportation mode, criteria values would differ [i.e., there would be different criteria from one mode to another when using the same descriptor]."

Clearly, in 2000 the DoT recognized that there is no common noise descriptor or criterion within the DoT, let alone within the Federal Government, for assessing the noise from transportation modes.

2.2.6 The Federal Energy Regulatory Commission

The Federal Energy Regulatory Commission (FERC) has issued regulations [22] that require:

"the noise attributable to any new compressor stations, compression added to an existing station, or any modification, upgrade or update of an existing station, must not exceed a day-night average sound level of 55 dB at any pre-existing noise-sensitive area (such as schools, hospitals, or residences)."

FERC developed this policy based on the level of significance identified by the USEPA at a DNL of 55 dB.

2.2.7 The Environmental Protection Agency

The U.S. Environmental Protection Agency [1] recommended a DNL of 55 dB as the "level requisite to protect health and welfare with an adequate margin of safety." The USEPA recommended the use of DNL and the DNL criterion level of 55 dB to other federal agencies.

In a recent letter [23], a USEPA regional administrator, Ms. Mindy Lubber, asked the FAA to assess the noise of a proposed new runway at Boston's Logan Airport using DNL at a criterion level of 55 dB.

2.2.8 The National Research Council

The National Research Council (NRC), Committee on Hearing, Bioacoustics and Biomechanics (CHABA), developed guidelines for preparing environmental impact statements on noise [6]. The NRC selected DNL as the preferred noise descriptor and a criterion level of 55 dB to represent the beginning of noise impact in residential areas.

Figure 2 shows the NRC requirements for noise assessments in various situations. The requirements are in terms of the yearly day-night average sound level, YDNL, in decibels. The abscissa is the existing or expected YDNL at a receiver location with the sound from noise sources in a 'project' not present. A

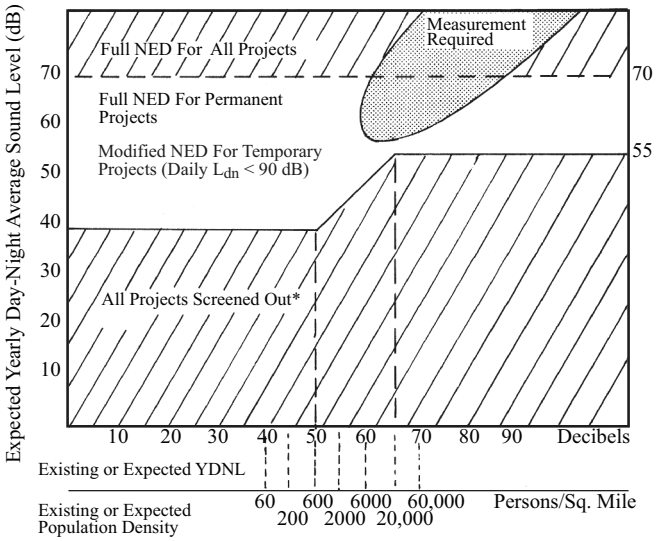

Fig. 2—Screening diagram from the U.S. National Research Council [6] for the expected yearly day-night average sound level (YDNL) of an intruding noise source, relative to the existing or expected YDNL at a receiver location, to determine whether 'full' or 'modified' Noise Environmental Documentation (NED) is required.

'project' could be any new activity (highway, airport, airplane flight paths, railroad, unloading and loading of ships, freight or truck depot, delivery trucks for a supermarket, or building or road construction) that contains sources that could increase the existing YDNL at a receiver location. The ordinate is the YDNL expected at the receiver location when the new sources of noise are present.

For a project, actions that may be required to assess the noise of the project range from the requirement to produce a 'full' Noise Environmental Documentation (NED), to a 'modified' NED, to no action if the expected YDNL is sufficiently low (i.e., the project is 'screened out'). A project may be permanent (e.g., a highway) or temporary (e.g., road construction). For temporary projects, a modified NED is required if the daily DNL is less than 90 dB; if the daily DNL equals or exceeds 90 dB, a 'full' NED is required.

Figure 2 shows, for example, that if the existing DNL is 50 dB, then full environmental documentation is required when the expected YDNL for a permanent project is equal to or greater than 40 dB. The NRC recommendations in Figure 2 for project environmental documentation are more stringent than the corresponding guidelines or recommendations by all other Agencies and Boards of the U.S. Federal Government and much more stringent than a DNL criterion level of 65 dB.

2.3 National Standards Setting Bodies

2.3.1 American National Standards Institute (ANSI)

American National Standard ANSI S12.9/Part 4 [5] recommends DNL as the preferred descriptor of environmental noise. American National Standard ANSI S12.9/Part 5

establishes a DNL criterion of 55 dB for housing and similar noise-sensitive land uses [24].

2.3.2 American Public Transit Association

The American Public Transit Association [now known as the American Public Transportation Association] (APTA) uses the maximum A-frequency-weighted (and time-weighted) sound level during a passby to describe the noise of vehicles used for public transportation [25]. This usage is consistent with requirements given in similar documents from the Society of Automotive Engineers and in International Standards prepared under the auspices of the International Organization for Standardization (ISO).

A maximum sound level is clearly different from a time-average sound level. Maximum sound level is determined with one of the two standardized exponential time weightings (F or S for 'fast' or 'slow', with nominal exponential time constants of 125 ms or 1000 ms, respectively). A time-average sound level (as used to determine day-night sound level) is determined from the time-mean-square of the instantaneous sound pressure signal, time averaged over a stated time interval and without exponential time weighting.

APTA noise criteria depend on housing density and type. Residential zones are divided into three groups (with low, normal, and high-density housing) and two types (single-family and multi-family). Table 1 gives the APTA criteria. For example, for single-family homes in a low-density residential zone, the maximum A-weighted sound level from a source of public transportation should not exceed 70 dB at the location of a dwelling.

TABLE 1—Maximum A-weighted (and time weighted) sound-level criteria from the American Public Transportation Association (APTA) [25] for the passby sound of a single vehicle used for public transportation (bus, train, or trolley) as measured outdoors at a residence.

Housing density	Residential Zone Description	Maximum A-weighted sound level (dB)	
		Housing type	
		Single-family	Multi-family
Low	Open space, parks, suburban residential or recreational areas; no nearby highways or boulevards	70	75
Normal	Quiet apartments and hotels, open space, suburban residential, or occupied outdoor areas near busy streets	75	75
High	Average semi-residential/ commercial areas, urban parks, museums, and non-commercial public building areas	75	80

2.4 International Bodies

2.4.1 The World Health Organization

The World Health Organization (WHO), an agency of the United Nations, recommends [3] a 16-hour daytime average sound level of not more than 55 dB and, approximately, an 8-h nighttime average sound level of not more than 45 dB to prevent "serious annoyance" in residential areas. These daytime and nighttime average sound levels are equivalent to a day-night sound level (DNL) of 55 dB. During nighttime, the maximum A-frequency-weighted sound level from any single sound source should not exceed 60 dB to avoid disruption of sleep. Table 2 summarizes the recommendations of the WHO regarding noise levels in residential areas for avoidance of serious and moderate annoyance.

TABLE 2—Criteria for A-weighted sound level from the World Health Organization [3] for assessment of annoyance to sources of environmental noise in residential areas. Criteria for maximum sound levels are for protection against disruption of sleep. Actual sound levels should not exceed the criterion levels to avoid serious or moderate annoyance.

Impact characterization	16-h daytime average sound level (dB)	8-h nighttime average sound level (dB)	Approximate day-night average sound level (dB)	Nighttime maximum sound level (dB)
Serious annoyance	55	45	55	60
Moderate annoyance	50	40	50	60

2.4.2 The World Bank Group

The World Bank Group (WBG) has a strong program [26] in pollution management so as to ensure that their projects in developing countries are environmentally acceptable. Noise is one of the pollutants covered by their policy. Table 3 shows the WBG limits for A-weighted sound level at locations outside the boundary of general industrial projects including foundries, iron and steel manufacturing, and thermal power plants for which the World Bank Group provides, or guarantees, loans.

TABLE 3—World Bank Group limits on A-weighted sound level at receptor locations outside the boundary of an industrial project for which WBG money is lent [26].

Receptor	Time period	Time-period average sound level (dB)	Corresponding day-night average sound level (dB)
Residential, institutional, educational	Daytime	55	55
	Nighttime	45	
Industrial, commercial	Daytime	70	76
	Nighttime	70	

2.4.3 The International Organization for Economic Co-operation and Development

The International Organization for Economic Co-operation and Development (OECD) has concerns similar to those expressed by the policy of the World Bank Group. The OECD report on environmental criteria for transportation modes [2] states:

"Noise finds a place among these criteria on account of the high level of concern about noise from motorized transport and the possible adverse impacts of noise on human health and quality of life."

The OECD report supports the noise limits recommended by WHO in Table 2. Further, the report recommends the limits on A-weighted sound levels shown in Table 4 for urban and rural land areas, namely, an outdoor DNL limit of 55 dB at residential locations in urban areas, and, in rural areas, an outdoor DNL limit of 50 dB.

TABLE 4—Limits on A-weighted sound level recommended by the OECD [2] for transportation noise sources in the land areas indicated.

Land area	Time period	Time-period average sound level (dB)	Corresponding day-night average sound level (dB)
Urban	Daytime	55	55
	Nighttime	45	
Rural	Daytime	50	50
	Nighttime	40	

3 DISCUSSION OF CRITERION LEVELS

3.1 Agencies, Boards, Standardization bodies, and International Organizations

The FAA, DoD, and HUD use a DNL criterion level of 65 dB as a 'level of significance.' What the FAA terms "the Federal Government's level of significance for assessing noise impacts," the FTA and FRA term "severe impact." The majority of U.S. Federal Administrations, Agencies, Boards, and Commissions use DNL as the preferred noise descriptor and a DNL criterion level of 55 dB, or less, as a 'level of significance.'

The NRC goes further, and, in some instances, recommends assessments when the project noise is estimated to exceed a DNL of 40 dB—a level that is less than the criterion level of all other U.S. Federal Agencies and Boards and 25 dB less than the FAA/DoD criterion level.

ANSI, WHO, The World Bank Group, and the OECD all recommend a DNL criterion level of 55 dB for residences; OECD recommends a DNL criterion level of 50 dB for residences in rural areas.

Nearly all U.S. policies that set DNL criterion levels at about 55 dB were established in 1995, or later, and, thus, were based on 25 more years of research on noise-effects and noise-control technology than the noise-assessment policies of the FAA, DoD, and HUD.

3.2 Attitudinal survey data

Figure 3 shows a recent summary by Fidell and Silvati [27] of attitudinal-survey noise-annoyance data versus DNL. This summary included virtually all noise-survey data available, and reported in the English language, with applicable response and noise descriptor categories. For a given DNL, there was a wide range to the response data, especially for DNLs from about 55 dB to 75 dB.

The data in Figure 3 represent responses to the sound from noise sources in three transportation groups: (1) aircraft operations around airports, (2) road traffic, and (3) railroads. Second-order polynomial curves were fitted to the response data for aircraft noise (solid line) and railroad noise (dashed line). A curve fit to the road-traffic data would lie between the aircraft and railroad curves. These curves show a systematic difference among the three groups with, in general, aircraft noise engendering the greatest degree of annoyance and railroad noise engendering the least annoyance for a given DNL.

The use of transitional functions has been suggested instead of three second-order polynomials because, at some noise level, the annoyance obviously ends at 100% of the population being highly annoyed. However, such curve fitting requires an assumption for the DNL at which the 100% of a community is highly annoyed and also for the DNL at which none of the community is highly annoyed.

The percentage highly annoyed indicated by such a transitional function can be moved by a large amount depending on the assumptions for the DNL at 100% and 0% highly annoyed, especially in the critical region for DNL between 55 dB and 75 dB. For example, if one assumes 0% highly annoyed at a DNL of 40 dB and 100% annoyed at a DNL of 120 dB, one gets much lower apparent annoyance at a DNL of 65 dB than if one were to assume 0% annoyed at a DNL of 20 dB and 100% annoyed at a DNL of 90 dB.

This paper does not present the equations for the second-order curve fits to the responses to the noise of aircraft, road traffic, and railroads because it is not the purpose of this paper to add to the debate about what type of curve should be fitted to the data. Rather, the purposes of showing the curves in Figure 3 are only (1) to show that there are systematic differences in the annoyance responses among the three transportation groups, and (2) that, for a given DNL, there is great variation in the response data.

As shown in Figure 4, Miedema and Vos [10] found the same trends as Fidell and Silvati. For noise from the transportation groups, at a given DNL, the noise of aircraft was the most annoying while the noise of railroads was the least annoying. For this reason, the new ISO 1996-1:2003 [7] recommends 3 dB to 6 dB penalties and bonuses for aircraft and train noise, respectively.

Figure 5 shows the data of Figure 3 with the Federal Interagency Committee on Noise (FICON) curve overlaid [12]. The FICON curve generally understates the average percentage of a community that is highly annoyed. At a DNL of 65 dB, the average percentage of a community that is highly annoyed by aircraft noise is 28% by the analysis shown in Figure 3; the corresponding prediction by the FICON curve fit is 12%. At a DNL of 60 dB, the average percentage of a community that is highly annoyed by aircraft noise is predicted by the curve fit of Figure 3 to be 17%; the average percentage of a community that is highly annoyed by the sound from all sources of transportation noise in the 5-dB-wide bin centered at a DNL of 60 dB is 27%. In contrast, the average percentage of the community that is highly annoyed by aircraft noise is predicted by the FICON curve fit to be just 7%.

The data in Figure 5 show that the percentages of

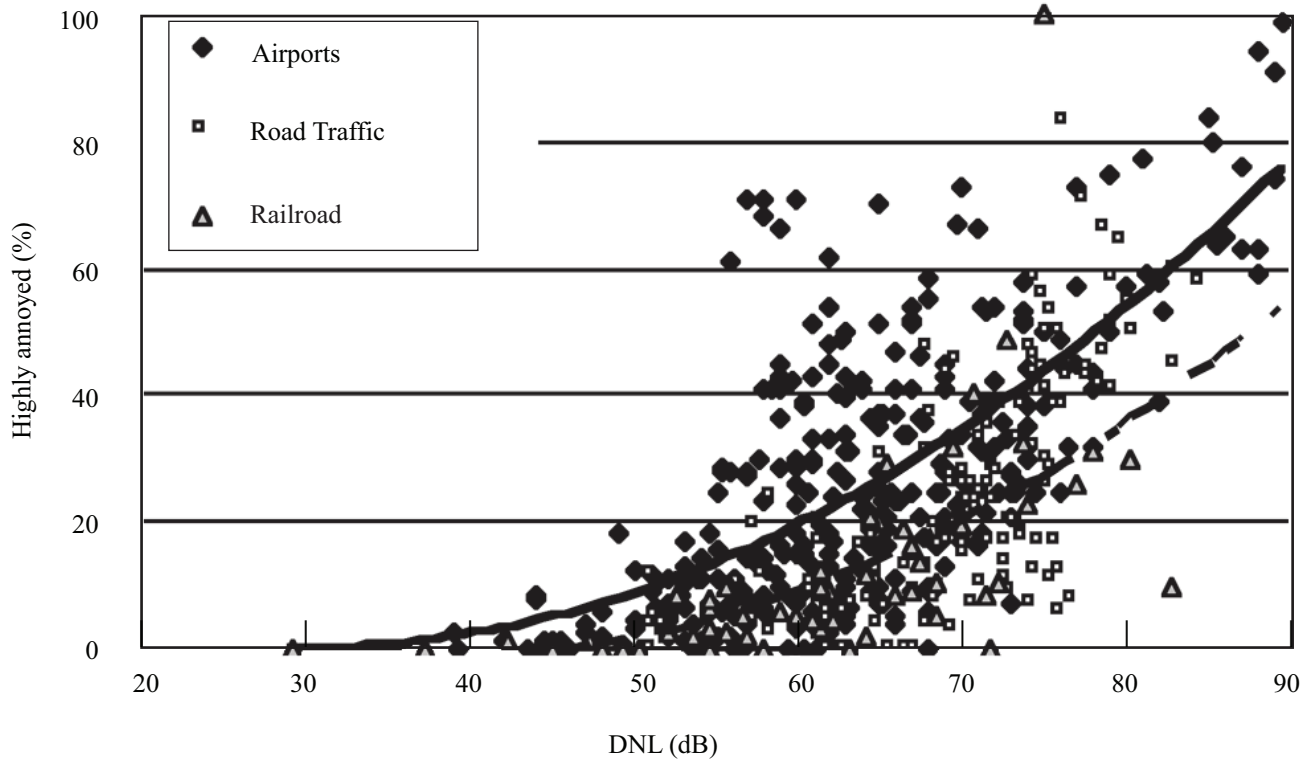

Fig. 3—Compilation by Fidell and Silvati [27] of surveys of the annoyance response to noise from aircraft operations from airports, road traffic, and railroads. The top solid-line is a second-order curve fit to the aircraft noise data; the bottom dashed-line curve is a similar fit to the railroad noise data. The curve fit to the road-traffic noise data lies between the curves for aircraft and railroad noise.

a population that were highly annoyed by sources of transportation noise started to decrease rapidly at a DNL of about 55 dB with a further drop to near 0% at a DNL of about 50 dB, i.e., in the gray-shaded region in Figure 5. Thus, to minimize the percentage of a population that is highly annoyed by sources of transportation noise, it appears that a DNL criterion level should be selected in the range from 50 dB to 55 dB, based on the totality of applicable worldwide noise annoyance survey data. Such a choice would be consistent with the recommendations of the World Health Organization and the U.S. National Research Council.

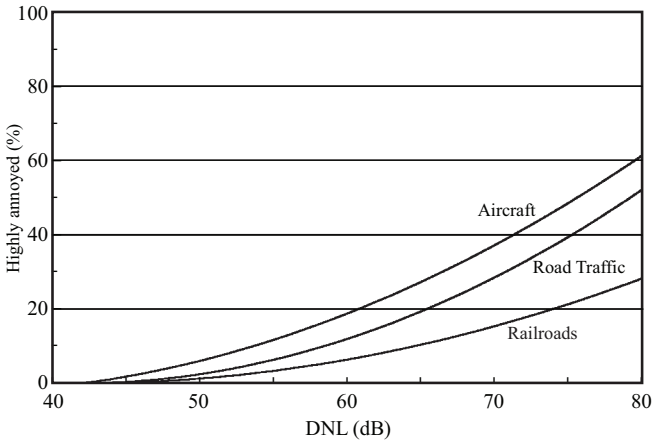

Fig. 4—Results of a meta-analysis by Miedema and Vos [10] of noise annoyance using all applicable world-wide survey data on attitudes of residents in a community to intruding noise from aircraft, road traffic, and railroads.

4 ADJUSTMENT FACTORS

4.1 A History of adjustment factors

A great deal of energy has been expended on fitting a variety of "dose-response" curves to the cloud of attitudinal survey data such as that shown in Figures 3 and 5. The scatter in the

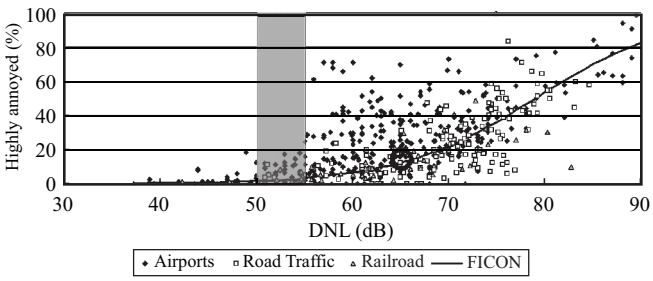

Fig. 5—Annoyance response data of Fidell and Silvati with curve fit from the FICON study [12] and the 65-dB point highlighted. The gray-shaded area is the region where there is a transition from moderate to substantial degrees of annoyance to little-to-no annoyance.

data can be traced to at least three causes: (1) response bias, (2) descriptor shortcomings, and (3) measurement bias and uncertainty.

An example of response bias is public relations. It has been shown that people are more accepting of a noise if they feel the authorities are concerned with their well-being and are doing virtually all that they reasonably can to mitigate the exposure to the noise. On the other hand, if people feel that it is a case of "you can't fight city hall," then annoyance may increase over that present in a neutral situation.

An example of "descriptor shortcomings" is the difference in the annoyance to the sound from aircraft, road traffic, and railroad noise sources. If one used loudness-weighted sound exposure instead of A-frequency-weighted sound exposure to determine day-night average sound level, as suggested by Schomer [28,29], then these differences tend to lessen or disappear. Other examples of "descriptor shortcomings" are the difficulties in describing the sound when tonal components are present or when the sound is impulsive.

Measurement bias might be the result of setting a high sound-level threshold for an unattended airport noise monitor so as to ensure that only aircraft noise is included in the measured results. Such an action could bias the reported measurements low because of the exclusion of aircraft noise that was actually present at the location but was not high enough to exceed the threshold. For a single measurement of sound exposure, measurement uncertainty is basically the tolerances around the design goals for the instruments, their placement and operation, how often the acoustical sensitivity is checked, and the spectrum and temporal characteristics of the sound. Measurement uncertainty, at the 95% confidence interval, can be of the order of a few decibels in a measurement of A-weighted sound exposure level. In this section, we are concerned with "response bias" and "descriptor shortcomings."

The 1974 EPA report [1] attempted to relate day-night average sound levels with community reaction as measured by complaints and threats of legal actions as shown in Figure 6. A given response category was associated with a wide range of day-night sound levels. For example, at a DNL of 55 dB, Figure 6 shows that community reactions ranged from "no reaction" to "severe threats of legal action or strong appeals to local officials to stop the noise."

In an attempt to reduce the scatter to the community response data, the EPA [1] suggested the use of "normalized" DNL. Normalized DNL is the measured or predicted DNL with a number of adjustments added to account for specific characteristics of the sound. Table 5 shows the EPA-suggested adjustment factors and their magnitudes. Adjustment factors included seasonal considerations, consideration of the level of background noise present at a location, consideration of the influence of previous exposure and community relations, and consideration of the character of the intruding sound (e.g., tonal or impulsive). Figure 7 shows the data from Figure 6 after having been adjusted using this procedure. The data in Figure 7 are substantially compressed and there is much less scatter than was present in Figure 6.

The adjustment factors in Table 5 were in use long before the EPA's Office of Noise Abatement and Control came into being in 1973. In 1953, the adjustment factors in Table 5 were

TABLE 5—EPA-recommended adjustments [1] to be added to the measured or predicted DNL of an intruding noise at a residential location.

Type of adjustment	Description of condition	Adjustment to be Added to Measured DNL (dB)
Seasonal considerations	Summer (or year-round operation)	0
	Winter only (or windows always closed)	−5
Adjustment for outdoor background noise measured in the absence of intruding noise	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near an industrial activity)	+5
	Urban residential community (not immediately adjacent to heavily traveled roads or industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	−5
	Very noisy urban residential community	−10
Adjustment for previous exposure and community attitudes	The community has no prior experience with the intruding noise.	+5
	Community has had some previous exposure to the intruding noise, but little effort is being made to control the noise. This adjustment may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona-fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise and the noisemaker's relations with the community are good.	−5
	Community is aware that the operation causing the noise is very necessary and will not continue indefinitely. This adjustment can be applied for an operation of limited duration and under emergency circumstances.	−10
Pure tone or impulsive sound	No pure tone or impulsive character	0
	Pure tone or impulsive character present	+5

TABLE 6—Adjustments from ISO 1996-1:2003 [7] to be added to measured or predicted day-night sound levels depending on the type of sound source, the character of the sound, and the time of day.

Adjustment type	Specification	Adjustment to add to day-night sound level (dB)
Sources of sound	Road Traffic	0
	Aircraft	+3 to +6
	Railway	-3 to –6
	Industry	0
Character of the sound	Regular impulsive	+5
	Highly impulsive	+12
	High-energy impulsive	See Annex B of ISO 1996-1:2003
	Prominent tones	+3 to +6
Time period	Evening	+5
	Night	+10
	Weekend daytime	+5
NOTE 1	When a range of adjustments is given, the amount to be added to a measured or predicted DNL shall be determined by appropriate local authorities.	
NOTE 2	Weekend adjustments on sound sources subject to regulation may be applied to a measured or predicted DNL to permit adequate rest and recuperation and to account for the greater numbers of people at home during the weekend.	
NOTE 3	If more than one adjustment applies for a type of sound source or for the character of a given single sound source, only the largest adjustment shall be applied. However, time period adjustments always are added to the otherwise adjusted day-night sound levels.	
NOTE 4	Adjustments for the impulsive character of a sound shall be applied only for impulsive sound sources that are audible at the receiver location. Adjustments for tonal character shall be applied only when the total sound is known to be audibly tonal at the receiver location.	

incorporated in the first Air Force Land Use Planning Guide [30]. The principles of the 1953 Guide were later simplified for ease of application and recommended by the Air Force and the Federal Aviation Administration [31,32].

4.2 Adjustments included in ISO 1996-1:2003

ISO 1996-1:2003 contains adjustments that are to be applied to measurements or predictions of day-night sound level outdoors at a receiver location. Table 6 describes the adjustments and gives the ranges of adjustment values to be considered.

Equation (D.1) in ISO 1996-1:2003 is the original 1978 Schultz curve [8] showing the percentage of a community that is highly annoyed by transportation noise sources as a function of the long-term day-night average sound level.

Annex D also contains notes for application of Equation (D.1) as paraphrased below.

- Equation (D.1) is applicable only to evaluation of long-term environmental sounds using an appropriate descriptor such as the yearly day-night average sound level (YDNL). The equation should not be used for assessments of community response over short time periods such as weekends, a single season, or "busy traffic days." Equation (D.1) is not applicable to a short-term environmental sound such as that resulting from an increase in road traffic caused by a short-duration construction project; the equation is applicable only to existing situations.

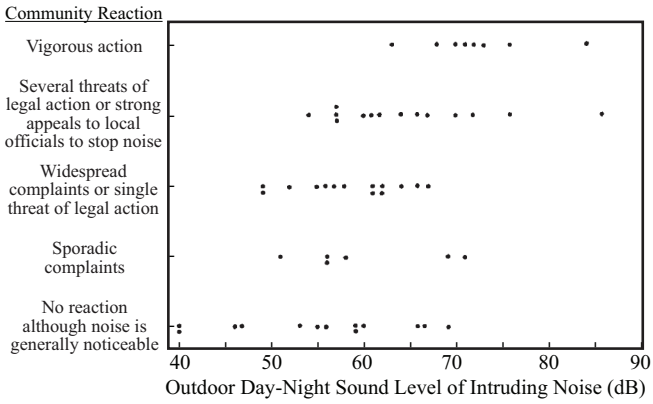

Fig. 6—Community reactions to intruding noise (after the U.S. EPA [1]) as a function of the measured or predicted outdoor DNL of the intruding noise (non-normalized).

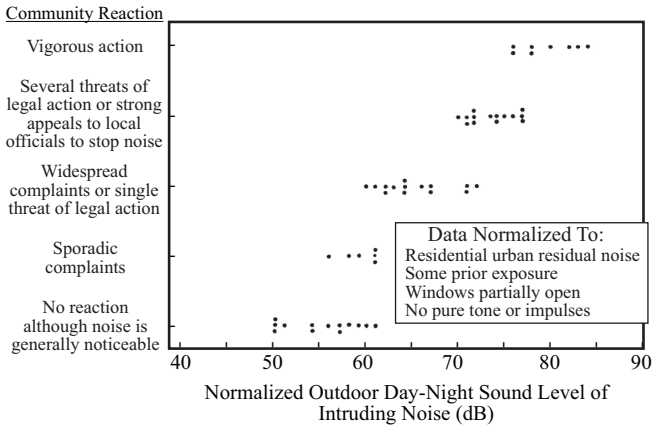

Fig. 7—Community reactions to intruding noise (after the U.S. EPA [1]) as a function of the measured or predicted outdoor DNL of the intruding noise with the normalizing adjustments of Table 5 included.

- For new situations, especially when the community is not familiar with the sound source in question, greater community annoyance than predicted by application of the equation can be expected; the difference may be as much as +5 dB.
- There is a greater expectation for, and value placed on, "peace and quiet" in rural settings; this expectation may be equivalent to a DNL adjustment of as much as +10 dB. These last two factors are additive. A new, unfamiliar sound source in a quiet rural area can engender much greater annoyance than would be estimated by relations like Equation (D.1) and may be equivalent to an additional adjustment of as much as +15 dB to be added to a measured or predicted DNL.

4.3 Adjustments NOT included in ISO 1996-1:2003

Several potential adjustments for the annoyance caused by an intruding noise are not included in ISO 1996-1:2003. Two notable adjustments that were omitted are (1) what is sometimes called "public relations," and (2) the additional annoyance caused by audible rattles of the structural elements of a building or its contents.

4.3.1 "Public relations"

The influence of "public relations" is sometimes discussed in terms of the concept of "misfeasance," which alternatively can be thought of as "people do not believe that bona-fide efforts are being made to control the noise." Only scant information is available to quantify the adjustment for "public relations," but it is believed that this factor can range from a 5-dB penalty to a 5-dB bonus depending on the quality of the relations between the noisemaker and the community.

The meta-analyses of Fields [33] confirm that the attitude engendered by "public relations" is an important modifier of annoyance. However, this is only one of five attitudes confirmed as important. In addition to "noise prevention beliefs," Fields listed "fear of danger from the noise source," "beliefs about the importance of the noise source," "annoyance with non-noise impacts of the noise source," and "general noise sensitivity."

In a more detailed study of attitudes, Staples, *et al.* [34] combined elements of Fields' "noise prevention beliefs," "beliefs about the importance of the noise source" and "annoyance with non-noise impacts of the noise source" into a 10-item environmental noise risk scale. Staples had 351 subjects that were living in an area where the DNL was between 55 dB to 60 dB in the vicinity of a former military airfield that had been converted to a civil airport. The dependent variable was a 14-item "noise-disturbance" scale that combined activity-disturbance questions with annoyance questions. Using stepwise multiple regression analyses, they found that the environmental noise risk scale accounted for 36% of the variation in individual disturbances from noise. Particularly powerful were four items loaded on a statistical factor that they labeled: "appraisal of one's neighborhood as inadequately protected and vulnerable to future increases in noise." The four items were:

- *If airport noise increases, it will make my neighborhood a less desirable place to live.*
- *My neighborhood is exposed to more noise than other neighborhoods near the airport.*
- *Airport and government officials are doing all they can do control noise.*
- *Airport noise probably will not increase much over the next 5 to 10 years.*

These four questions accounted for 43% of the variation in individual disturbances from noise, more than what was accounted for by the use of the entire noise scale when it was used in the regression. "Noise sensitivity," one of the attitudes confirmed by Fields, was positively correlated with general annoyance but was unrelated to environmental noise risk. In addition to confirming the importance of the attitudes identified by Fields, Staples, *et al.*, confirmed the importance of expectations and prior exposure. When added to the stepwise multiple-regression analyses, "noise relative to expectations" increased the fraction of the explained variance to 45%. The addition of "noise relative to prior exposure" as a third variable raised the fraction of the explained variance to 48%.

Schomer [35] found almost a 5-fold increase in the percent highly annoyed for those who thought "a great deal," "quite a bit," or " a fair amount" can be done to reduce noise but "not very much" or "nothing at all" is being done, when compared with the reactions of all other respondents in the study. More-recent evidence about the influence of "public relations" on annoyance comes from a railway noise survey in Germany by Schreckenberg, *et al.* [36] that showed a relatively high correlation between railway noise annoyance and misfeasance or the belief that the authorities were not doing what they could to reduce the noise.

In a Swiss noise study in 2000, Wirth, *et al.* [37] found a standardized linear-regression coefficient of –0.1 between annoyance and "trust the noise maker."

In summary, there is little question that community attitudes can be swayed by public relations and that these attitudes can have positive or negative effects on the annoyance by a sound. The 1974 EPA recommendation [1] for a "public-relations" factor was 5 dB. This adjustment can be a –5-dB 'bonus' if there are very good relations. Conversely, if there is a strong feeling of misfeasance and distrust, then the true adjustment may be a +5-dB 'penalty'.

4.3.2 Rattles

The second adjustment factor not included in ISO 1996-1:2003 is the presence of observable (heard but not necessarily felt) rattles induced by a noise. Blazier [38] was one of the first to comment on noise-induced rattles in building elements. He was concerned about rattles induced by the low-frequency sound and vibration generated within heating and ventilating systems in an office setting. He noted that there was a "high probability that noise-induced vibration levels in light-weight wall and ceiling constructions will be clearly noticeable." ANSI S12.2-1995 [39] incorporated this suggestion in the Room Criterion (RC) procedure of Blazier and the Balanced Noise Criterion (NCB) procedure of Beranek as methods to evaluate noise in rooms. In essence, the evaluation procedures

recommend the inclusion of acoustical design features so as to limit the sound pressure levels in a room to less than 75 dB in the octave bands with nominal midband frequencies of 16 Hz and 31.5 Hz.

Schomer has specifically studied the equivalent increase in annoyance when there is audible sound from noise-induced vibration. The subjects need only hear the rattle sounds; there is no tactile perception of vibration. In one study by Schomer and Averbuch [40], simulated blast sounds were presented to subjects both with and without noticeable rattle sounds. The blast-sound-induced rattle noise was virtually unmeasurable compared with the blast sound yet it increased the level of equivalent annoyance by 6 dB at low blast sound levels and by 13 dB at the highest blast sound levels used in that study. In another study by Schomer and Neathammer [41] using real helicopters to generate the test sounds, the mere addition of noticeable rattle sounds increased the equivalent level of subjective annoyance judgments by 10 dB to 20 dB. Again, the rattle sounds were virtually unmeasurable compared with the sound of the helicopter. Subsequent studies showing an increase in annoyance when sound was accompanied by vibration include the following: Sato [42], Zeichart, *et al.* [43], Paulsen and Kastka [44], Öhrstrom and Skånberg [45], Öhrstrom [46], and Lercher, *et al.* [47].

At this time, an adjustment of +10 dB is recommended when an intruding noise produces, or is expected to produce, noticeable rattle sounds, although the evidence suggests that the magnitude of this adjustment may be variable and may be larger than +10 dB at times. It should be noted that rattle sounds occur because the low-frequency sounds that vibrate building elements may be manifested as the much-higher-frequency sounds of the rattle of windows or bric-a-brac.

5 CONCLUSIONS

1. Nearly all Agencies and Boards of the U.S. Federal Government, standards setting bodies, and international organizations that have cognizance over noise-producing sources use day-night average sound level (DNL) as the preferred noise descriptor and a DNL criterion level of 55 dB as the threshold for adverse noise impact in urban residential areas. Of the large number of Agencies, Boards, standards setting bodies, and international organizations, only the U.S. Department of Defense, the U.S. Federal Aviation Administration, and the U.S. Department of Housing and Urban Development recommend a DNL criterion level that is greater than 55 dB.
2. The policies of FAA, DoD, and HUD all were developed in the early 1970s or earlier. On the other hand, most of the concerned U.S. Federal Agencies and Boards, standard setting bodies, and international organizations established their noise policies after 1995. In particular, the recommendations of the World Health Organization were based on over 25 years of additional worldwide research into noise effects than were the earlier policies of the FAA and DoD.
3. Significant evidence exists to suggest that the noise of aircraft is more annoying than the noise of road traffic and railroads for the same DNL. ISO 1996-1:2003 recommends that an adjustment ranging from +3 dB to +6 dB be applied to the measured or predicted DNL of aircraft noise to assess a community's annoyance response. Selection of an appropriate adjustment in the range of allowed adjustments is to be made by appropriate local authorities.
4. Examination of the totality of applicable, English-language attitudinal survey data suggest a DNL criterion level in the 50 dB to 55 dB range to ensure a minimum acceptable annoyance response in a residential community.
5. Agencies and Boards of the U.S. Federal Government that are charged with the mission of promoting the activities of a particular noise producer may not be as free of bias as more-neutral bodies such as the U.S. National Research Council or the World Health Organization. The World Health Organization terms a DNL of 55 dB as engendering serious annoyance and creating an unhealthy environment; a DNL of 50 dB is considered as engendering moderate annoyance. The National Research Council went further, and, in many instances, recommended acoustical engineering assessments when the estimated DNL of a project exceeds 40 dB.
6. No single DNL criterion level is equally applicable to all residential situations and all types of residential communities. For this reason, ISO 1996-1:2003 includes recommendations for adjustment factors that should be applied in a noise analysis. Additional adjustments should be included when an intruding sound produces, or is expected to produce, noticeable noise-induced rattle sounds.
7. Community relations (good or bad) are believed to be equivalent to a –5-dB 'bonus' or a +5-dB 'penalty' in assessments of community response. Although good community relations should be observed, it is not recommended that any "public relations" adjustment be added to a measured or estimated DNL to account for the effect of public relations.

6 RECOMMENDATIONS

1. The recommended adjustment factors of ISO 1996-1:2003 should be applied in analyses of environmental noise. In addition, adjustments should be included when the intruding sound is known, or predicted, to cause noticeable noise-induced rattle sounds inside a residence.
2. An adjustment of +5 dB should be added to measured or predicted day-night average sound levels caused by aircraft noise in the vicinity of airports when relating the DNL to the expected annoyance response of residents in the surrounding community.
3. After addition of the adjustment factors from ISO 1996-1:2003 and the +5 dB aircraft-noise adjustment, as applicable, the DNL criterion level for assessing the minimum acceptable degree of annoyance to intruding sounds in noise-sensitive areas such as residential housing should be 55 dB, or less.

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