

# SCHOMER AND ASSOCIATES

## **A White Paper: ASSESSMENT OF NOISE ANNOYANCE**

**April 22, 2001**

**Paul Schomer, Ph.D., P.E.**

**Schomer and Associates, Inc.**

**(217) 359-6602**

**Champaign, IL 61821**

# **A White Paper: ASSESSMENT OF NOISE ANNOYANCE**

April 22, 2001

## **I. INTRODUCTION**

### **1. Background**

Environmental noise is defined as the noise emitted from all sources except in the industrial workplace. The major sources of environmental noise are road, rail and air traffic, industries, construction and public works, and the neighborhood. The extent of the environmental noise problem is very large. In the United States, over 40 percent of the population are exposed to transport noise levels exceeding 55 dB(A), and in the EC and Japan, these percentages are even higher (OECD, 1993). In contrast to many other environmental problems, noise pollution continues to grow, accompanied by an ever-increasing number of complaints (WHO, 1999). Figure 1 shows a recent USA Today first page picture of noise complaints. Industry, aircraft and road traffic are the clear leaders in the generation of noise complaint.

The first principle of the World Health Organization (WHO) Constitution is its definition of health that is given as: "A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." According to this WHO definition of health, noise impacts such as population annoyance, interference with communication, and impaired task performance are health issues. Noise has a significant impact on the quality of life and is a health problem in accordance with the World Health Organization's (WHO) definition of health (WHO, 1999).

The effects of noise are seldom catastrophic, and are often only transitory, but adverse effects can be cumulative with prolonged or repeated exposure. Sleep disruption, the masking of speech and television, and the inability to enjoy one's property or leisure time impair the quality of life. In addition, noise can interfere with the teaching and learning process, disrupt the performance of certain tasks, and increase the incidence of antisocial behavior. There is also some evidence that noise can adversely affect general health and wellbeing in the same manner as chronic stress. (WHO, 1999; Passchier-Vermeer and Passchier, 2000).

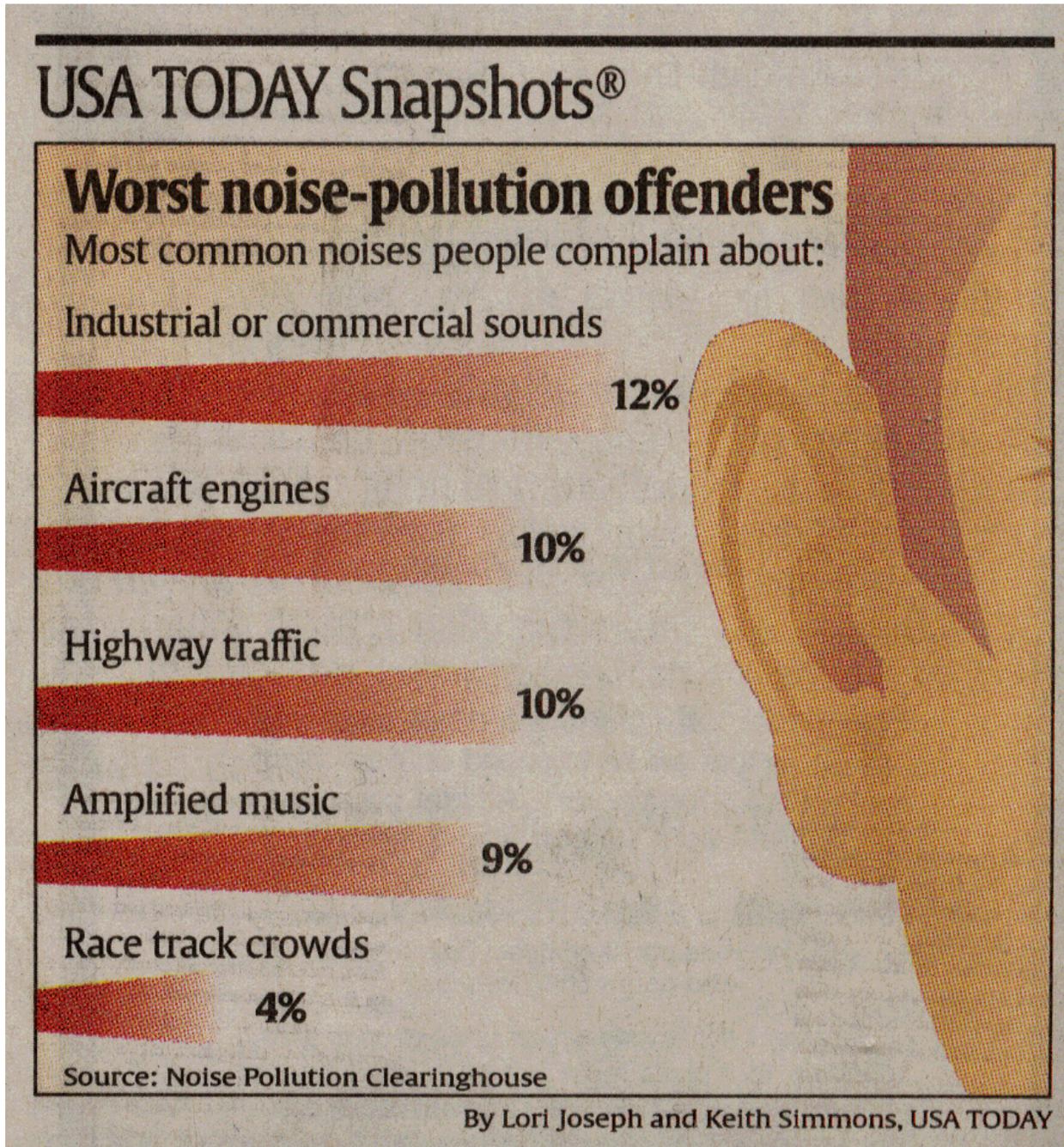


Figure 1. Most common noises that people complain about (USA Today, 2000)

**2. Scope**

This paper deals with airport noise annoyance in areas where people reside. It does not deal with noise annoyance to people 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 other direct impacts 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.

**3. Introduction to Noise Metrics**

A "metric" is defined as something "of, involving, or used in measurement." As used in environmental noise analyses, a metric refers to the unit or quantity that quantitatively measures the effect of noise on the environment. Therefore, the noise metric must correlate with the desired response. For noise studies, this has typically resulted in a confusing proliferation of noise metrics as individual researchers have attempted to understand and represent the effects of noise. As a result, past literature describing environmental noise or environmental noise abatement has included many different metrics.

In the United States, the current metric for assessing aircraft or railroad noise is the A-weighted day-night sound level. This metric embodies several relatively simple concepts.

- (a) The "A" frequency-weighting is used to filter the sound in a manner that tends to account for how people respond to noise—an approximation to loudness.
- (b) All the sound energy from an event such as a single airplane flyby is summed to account for the event duration as well as its loudness.
- (c) The sound energy of each event is summed separately into the total.
- (d) The sound energy of each event at night is multiplied by ten before it is added into the total.

First, we predict or measure the A-weighted sound exposure (SE) of each flyby. Sound exposure is basically a measure of the loudness multiplied by the time it takes for the aircraft to flyby or the train to passby; i.e. loudness times duration.

Second, we add up the sound exposure from each individual aircraft operation in order to develop the total sound exposure. In this way we are accounting for the repetitions of each type of aircraft.

Finally, we multiply the sound exposure of each aircraft flyby or train passby that occurs at night by ten before adding it into the daily total. In this manner, we apply a nighttime penalty.

Table 1 provides a very simplified example. Near a small very hypothetical airport, the listed aircraft fly by a given location. For example, each B-727-200 produces 1 sound exposure unit. There are 12 of these flybys during daytime, so, in total, they produce 12 sound exposure units. At night only two of these B-727 flybys results in 20 sound exposure units (2 sound exposure units multiplied by the nighttime penalty of 10). In addition, there are other new, quieter aircraft such as the B-737-800. A flyby of this aircraft produces only 0.05 sound exposure units, so even with many more of this type of aircraft, the total in Table 1 is dominated by the B-727 aircraft. In fact, the total in Table 1 is dominated mainly by just the two nighttime B-727 operations.

<b>Time Period</b>	<b>Sound Source</b>	<b>Sound Exposure (SE)</b>	<b>Number of Events</b>	<b>Total SE</b>
Daytime	B-727-200	1	12	12
	B-737-800	0.05	100	5
	Daytime Total Sound Exposure			17
Nighttime	B-727-200	1	2	20
	B-737-800	0.05	8	4
	Nighttime Total Sound Exposure			24
Day/Night	TOTAL Day-Night Sound Exposure (DNSE)			41

Table 1. Computation of the total day-night sound exposure near to a very hypothetical airport  
 Note: sound exposures at night are multiplied by ten

In summary:

- (a) We measure or calculate the sound exposure (SE) for each event.
- (b) We multiply the SE of each nighttime event by ten.
- (c) We accumulate the total day-night sound exposure (DNSE).

Typically, the average DNSE of some long period of time is used for environmental noise assessment. Normally, this period of time is a year. That is, the metric used for environmental noise assessment is the yearly-average total day-night sound exposure (YA-DNSE). As Table 1 shows, this metric is very sensitive to individual loud events and to events at night.

Unfortunately, the scientific community uses logarithms to convert this simple linear unit to decibels—a unit of relative energy. This corresponding logarithmic unit is termed the day-night sound level (DNL) and is given by Eq. (1).

$$DNL = 10 \times \lg(DNSE) + 44.6 \tag{1}$$

where lg denotes the logarithm base 10 of DNSE. Yearly average DNL (YA-DNL) also is given by (1) using YA-DNSE. Table 2 gives the relation between DNL and DNSE for several characteristic values of DNL.

Day-Night Sound Level (DNL) (dB)	Equivalent Total Day-Night Sound Exposure (DNSE)	
	Precise Value	Approximate Value
75	1088	1000
70	347	333
65	109	100
60	35	33
55	11	10
50	3.5	3
45	1.1	1

Table 2. Relation between day-night sound level (DNL) and total day-night sound exposure (DNSE)

There is a strong consensus that DNL is a good metric with which to describe transportation noise sources. DNL was developed by the US Environmental Protection Agency in the early 1970's. The American National Standards Institute (ANSI, 1996) and the National Research Council (NRC, 1977) recommend the use of DNL as do most federal agencies and administrations. The European Union plans to use day-evening-night sound level, a variant of DNL for noise assessments there, and the International Organization for Standardization (ISO, 1983 and 2000) recommends similar measures. Clearly, although there are other metrics (see Annex A) that can be used to describe aircraft noise, YA-DNL is the metric of choice to describe noise annoyance.

The noise metric, however, is but half the picture. More important than the noise metric are the criteria values chosen to represent various degrees of adversity. A poor metric with appropriate criteria values can do a fair job in portraying the community reaction to noise, but the best metric will fail if the criteria values are too large or too small.

#### **4. Purpose**

The purpose of this paper is to collect and tabulate recommended appropriate minimum criteria values for the DNL metric in various types of communities and settings. Included in this collection are all recommendations by USA boards and agencies that have cognizance over noise producing sources, all national and international standards setting bodies, and international organizations in which the USA participates.<sup>1</sup>

(a) This paper shows that nearly all agencies and boards, standards setting bodies, and international organizations that have cognizance over noise producing sources use a DNL criterion value of 55 dB as the threshold for defining noise impact in urban residential areas. In fact, of this large number of agencies, boards, standards setting bodies, and international organizations, only the Department of Defense and the Federal Aviation Administration suggest a criterion value for DNL that is higher than 55 dB.<sup>2</sup>

---

<sup>1</sup> This collection does not include agencies or boards that do not use the DNL metric—notably just the Federal Highway Administration.

<sup>2</sup> The Department of Housing and Urban Development has no cognizance over noise sources. However, they term DNL levels from 65 dB to 75 dB as “normally unacceptable” and DNL levels from 60 to 65 dB as “normally acceptable.” Levels below 60 dB are termed “clearly acceptable.” (HUD, 1985)

- (b) The policies of FAA/DOD (and HUD) all were developed in the early 1970's and earlier (e.g., HUD, 1971). In contrast, most of the agencies and boards, standard setting bodies, and international organizations have established their policies after 1995. In particular, the World Health Organization recommendations (WHO, 1999) are based on over 25 years more worldwide research into noise effects than are the earlier FAA/DOD policies.
- (c) This paper shows that no single DNL criterion is equally applicable to all residential situations and all types of residential communities. A sizeable number of agencies and boards, standards setting bodies, and international organizations that have cognizance over noise producing sources recommend a DNL criterion value that is less than 55 dB as the threshold for defining noise impact in sparse suburban and rural residential areas.
- (d) This paper shows that significant evidence exists to suggest that aircraft noise is more annoying than is road traffic noise for the same DNL level.

## II. METRICS AND CORRESPONDING CRITERIA FOR ASSESSING NOISE ANNOYANCE

### 1. Agencies and Boards that Recommend Higher Criterion Values for DNL

#### a. The Federal Aviation Administration

The Federal Aviation Administration (FAA) uses the DNL metric for assessing the noise in environmental assessments and so-called "Airport Part 150 Studies." These latter are noise compatibility/land use studies designed to help mitigate noise impact in the vicinity of airports. The FAA recommends a minimum criterion value of 65 DNL to assess impact in residential areas (FAA, 2000). They do not differentiate between urban, suburban or rural areas. Rather, their recommendation of 65 DNL is independent of the type of residential area. With virtually no exceptions, the FAA provides noise mitigation funds in residential areas only when the DNL exceeds or is predicted to exceed 65 DNL. The FAA terms a DNL level of 65 dB as "the level of significance for assessing noise impacts" (FAA, 2000).

#### b. Department of Defense

The Department of Defense (DOD) uses the DNL metric for assessing noise in environmental assessments and so-called "Air-Installation Compatible Use Zone Studies."<sup>3</sup> These latter are noise compatibility/land use studies designed to help mitigate noise impact in the vicinity of air installations. The DOD recommends a minimum criterion value of 65 DNL to assess impact in residential areas (DOD, 1977). They do not differentiate between urban, suburban or rural areas. Rather, their recommendation of 65 DNL is independent of the type of residential areas.

#### c. Department of Housing and Urban Development

The Department of Housing and Urban Development (HUD) noise policy was developed in 1971 (HUD, 1971). However, HUD has no cognizance over noise sources. Rather, they are included here for completeness. In a more recent 1985 document (HUD, 1085), they term DNL levels from 65 dB to 75 dB as "normally unacceptable [for housing]" and DNL levels from 60 to 65 dB as "normally acceptable." Levels below 60 dB are termed "clearly acceptable." (HUD, 1985)

---

<sup>3</sup> The DOD (notable the Army) uses related metrics and procedures to assess the impulsive noise from weapons such as small arms, artillery and demolition.

## 2. Agencies and Boards of the Federal Government that Recommend Lower Criterion Values for DNL<sup>4</sup>.

In addition to the FAA and the DOD, many other administrations, agencies, commissions, and boards of the Federal Government have oversight over noise producing sources. These include the Federal Transit Administration, the Federal Railroad Administration, the Surface Transportation Board, the Federal Highway Administration, and the Federal Energy Regulatory Commission. Further, a mission of the National Research Council, a part of the National Academy of Science, is to be an advisor on scientific matters like this to the entire Federal Government.

### a. The Federal Transit Administration

The Federal Transit Administration (FTA, 1995) uses the DNL metric for assessing the noise from mass transit activities. Mass transit includes such items as rail rapid transit or light rail transit, commuter rail, diesel buses, electric buses and trackless trolley, bus storage yards, rail transit storage yards, maintenance facilities, stations, and subways. Figure 2 gives the FTA criteria. These criteria change with the noise receiver land use and with the existing noise at the receiver.

In the FTA report they explain the land use categories and corresponding metrics by which to interpret Figure 2. However, in this figure, Category 2 includes residences and buildings where people normally sleep. This category includes homes, hospitals and hotels, and the metric for Category 2 is DNL. Figure 1 shows, for example, that if the existing DNL is 55 dB, then start of impact for a new or revised project occurs when its noise exceeds DNL 55.5. In fact, for an area where the existing noise is very low, impact begins when the new noise source levels are less than 50 dB. In very loud areas where the existing noise is DNL 65 dB, a new project can only produce just over 60 dB. These FTA criteria are much lower than the FAA/DOD criterion of DNL 65 dB.

---

<sup>4</sup> For completeness, this section also includes the only Federal Agency or Board that does not use the DNL metric—the Federal Highway Administration.

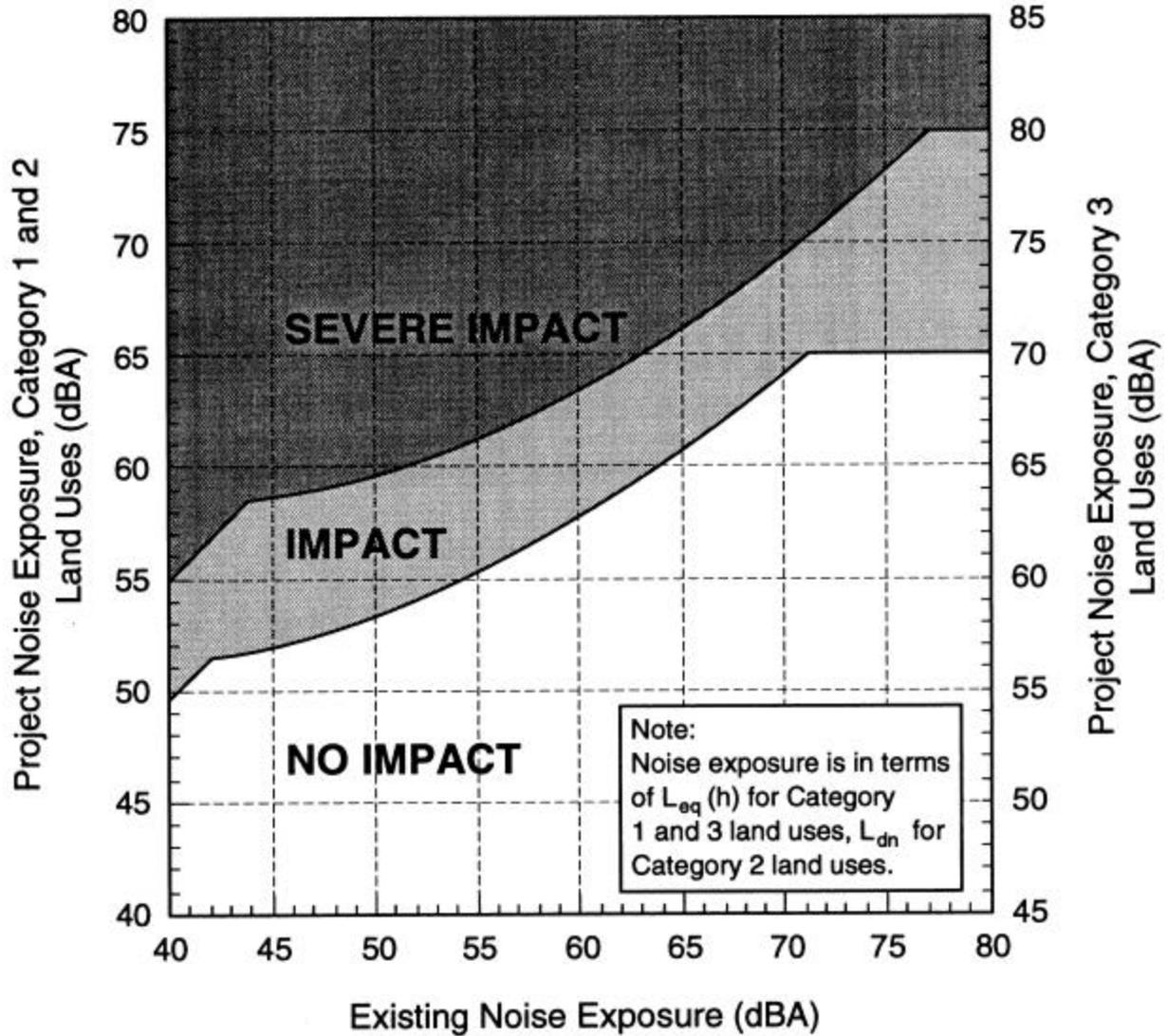


Figure 2. FTA noise impact criteria for transit projects.

The FTA (1995) includes a background discussion about their development of their noise impact criteria. In this background, they cite the US Environmental Protection Agency (EPA, 1974) recommendation of DNL 55 dB to develop their curve of impact. Further, the FTA states that they use the FAA/DOD criteria of DNL 65 dB to define their curve of severe impact.

**b. The Federal Railroad Administration**

The Federal Railroad Administration (FRA, 1998) uses the DNL metric for assessing the noise from mass transit activities. This effort has been motivated in part by the need to assess new, high-speed trains. The FRA uses exactly the same criteria as is used by the FTA as given above. Like the FTA, the FRA terms the noise level represented by DNL 65 dB as “severe impact.”

**c. The Surface Transportation Board**

The Surface Transportation Board (STB, 1998) uses the DNL metric for assessing the noise from freight railroads. The STB uses the same criteria as is used by the FTA and FRA as given above.

**d. The Federal Highway Administration**

The Federal Highway Administration (FHWA, 1995) does not use DNL for noise assessment. Rather, they use two other metrics. One is termed “the busy-hour L10.” The other is termed “the busy-hour LEQ.” For criteria, the FHWA requires that the LEQ for the busiest hour of the day be at most 67 dB or that the L10 for the busiest hour of the day be at most 70. However, state agencies are required to select a tolerance of at least one decibel and are free to select a somewhat higher tolerance. Thus, with the tolerance, the FHWA criteria are, at most, 66 dB for the LEQ metric or 69 dB for the L10 metric. While some relation exists between these metrics and DNL, the correlation is not particularly good or well documented. For example, some measurements of DNL show it to be greater than the busy-hour LEQ and others show it to be less.

In summary, the FHWA uses metrics and criteria that differ greatly from DNL. Moreover, the FHWA allows states latitude in the tolerance chosen with which to define onset of impact.

**e. The Department of Transportation**

The Department of Transportation (DOT) recognizes that the various modes within the department have different models, metrics, and criteria. In a report to Congress (DOT, 2000) they state:

“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 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 [metrics] would differ from one mode to another. Even for the same transportation mode, criteria values would differ [different criteria from one mode to another when using the same metric].”

Clearly, the DOT recognizes that there is no common noise metric or criteria within the DOT let alone within the Federal Government.

f. The Federal Energy Regulatory Commission

The Federal Energy Regulatory Commission (FERC) has issued regulations (FERC, 1999) 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 level (L<sub>dn</sub>) of 55 dBA at any pre-existing noise-sensitive area (such as schools, hospitals, or residences).”

FERC developed this policy based on the USEPA-identified level of significance of DNL 55 dB. Applied to an airport, the FERC rules would require, for example, that if a new runway were added then the airport levels would have to be below DNL 55 dB at all existing residences in the vicinity of the airport.

g. The US Environmental Protection Agency

The US Environmental Protection Agency (EPA, 1974) recommended the DNL metric and 55 dB and the “level requisite to protect health and welfare with an adequate margin of safety.” The USEPA recommends the criterion level of 55 DNL to other federal agencies. For example, in a recent letter, the USEPA regional administrator, Ms. Mindy Lubber, asks the FAA to assess

the noise of a proposed new runway at Boston's Logan Airport using DNL and a criterion value of 55 dB (EPA, 2000).

h. The National Research Council

The National Research Council (NRC) Committee on Hearing, Bioacoustics and Biomechanics developed guidelines for preparing environmental impact statements on noise (NRC, 1977). The NRC has chosen DNL 55 dB as the criterion value for noise impact in residential areas.

Figure 3 shows the NRC screening requirements for noise assessments in various situations. This figure shows, for example, if the existing DNL is 50 dB, then full environmental documentation is required for project DNLs down to 40 dB. This NRC requirement for project documentation down to 40 dB is lower than the recommendation by all other Bodies and Boards and it is much lower than the FAA/DOD level of 65 dB. On the basis of sound energy, the National Research Council recommends documentation of sound energies that are 1/300th the energy recommended by the FAA/DOD.

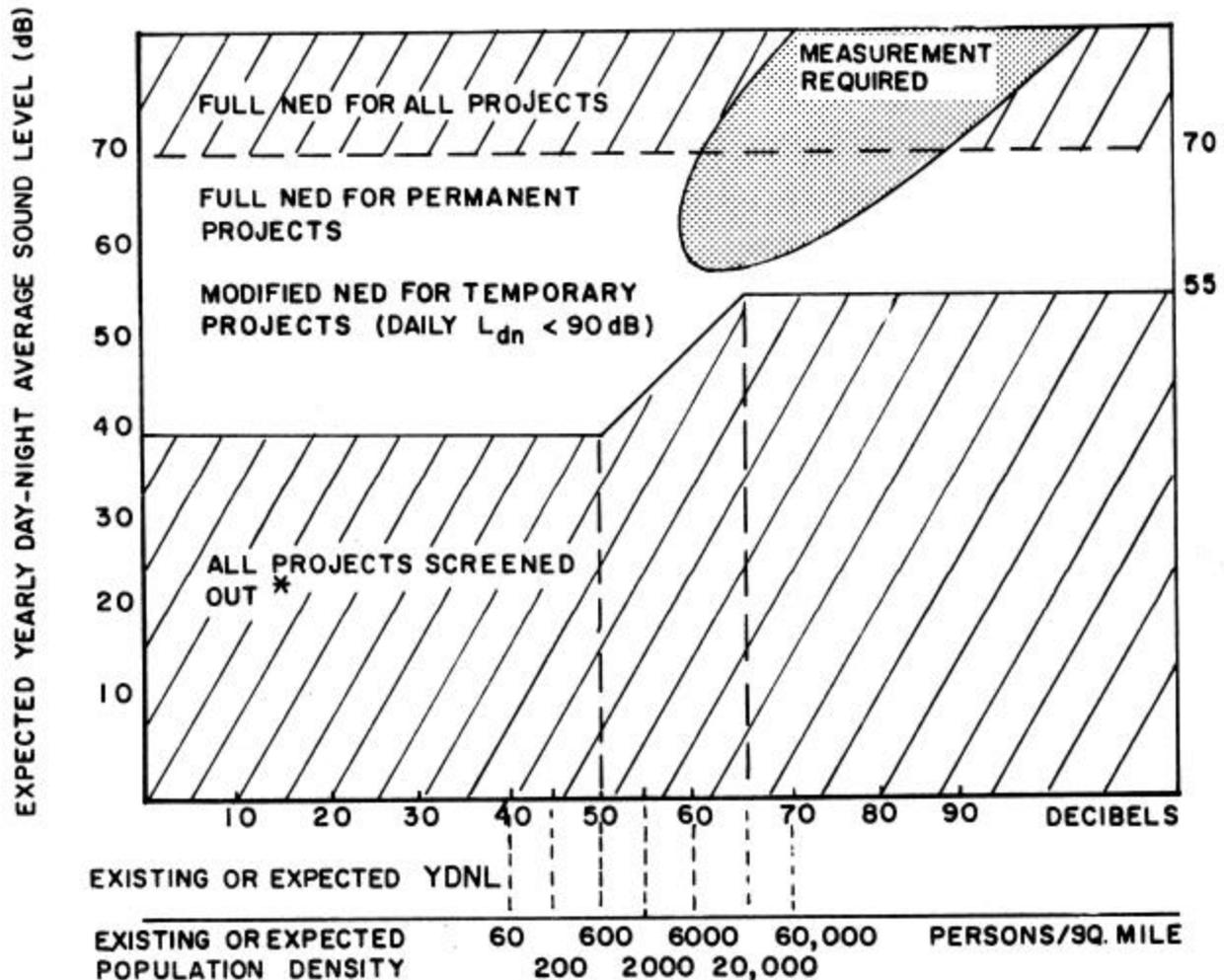


Figure 3. NRC screening diagram for the expected yearly average DNL to determine whether or not full noise environmental documentation (NED) is required

### 3. National Standards Setting Bodies

#### a. American National Standards Institute

As noted above, the American National Standards Institute (ANSI, 1996) recommends the DNL metric. The criterion level set by ANSI for housing and similar noise sensitive land uses is a DNL of 55 dB (ANSI, 1998).

b. American Public Transit Association

The American Public Transit Association (APTA) uses the A-weighted maximum sound level (LAmax—see Annex A) during a passby for their metric. Their criteria depend on the land category and housing type. They divide residential zones into three groups (low, normal, and high density) and two types (single family and multi-family). Table 3 gives the APTA criteria. For example, for low-density single family homes, they recommend an LAmax of 70 dB.

Density	Residential Zone Description	Housing Type	
		Single Family	Multifamily
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

Table 3. APTA (1989) LAmax criteria for noise as a function of residential zone and housing type (The LAmax apply to the passby noise from any single vehicle [e.g., bus, train, or trolley].)

**4. International Bodies**

a. The World Health Organization

The World Health Organization (WHO, 1999) recommends (Table 4) a 16-hour daytime LEQ of 55 dB and, approximately, a 45 dB nighttime LEQ to prevent “serious annoyance.” These numbers are equivalent to a DNL of 55 dB. WHO further recommends that, during the night, the maximum level (fast) of any single event not exceed 60 dB. To prevent annoyance, WHO recommends levels that are 5 decibels lower—a daytime LEQ of 50 dB and a nighttime LEQ of 40 dB. These numbers are equivalent to a DNL of 50 dB.

<b>Impact Characterization</b>	<b>Daytime LEQ</b>	<b>Nighttime LEQ</b>	<b>Approximate DNL</b>	<b>Nighttime Lamax</b>
Serious Annoyance	55	45	55	60
Moderate Annoyance	50	40	50	60

Table 4. WHO DNL criteria for noise annoyance in residential areas (The LAmax level is for protecting from sleep disruption.)

b. The World Bank Group

The World Bank Group (WBG, 1998) has developed a strong program in pollution management so as to insure that their projects in developing countries are environmentally sound. Noise is one of the pollutants covered by their policy. They set the following noise limits for general industrial projects including foundries, iron and steel manufacturing, and thermal power plants (Table 5):

Receptor	Time Period	Time Period LEQ	Equivalent DNL
Residential, institutional, educational	Daytime	55	55
	Nighttime	45	
Industrial, commercial	Daytime	70	--
	Nighttime	70	

Table 5. World Bank Group noise limits for industrial projects to which money is lent

c. The International Organization for Economic Co-operation and Development

The International Organization for Economic Co-operation and Development (OECD) has similar concerns to those expressed by the policy of the World Bank Group. OECD has set “Pollution Prevention and Control Environmental Criteria for Sustainable Transport” (OECD, 1996). They state:

“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.”

OECD goes on to support the levels recommended by WHO. Further, they suggest the following environmentally sustainable transport noise levels based on the (noise) receiving community (Table 6). Clearly, like the WBG, OECD recommends a DNL of 55 dB, and, in rural areas, it lowers its recommendation to DNL 50 dB.

Land Area	Time Period	Time Period LEQ	Equivalent DNL
Urban	Daytime	55	55
	Nighttime	45	
Rural	Daytime	50	50
	Nighttime	40	

Table 6. OECD suggested transport noise levels for the land area indicated

### **5. A Discussion on Criterion Values**

The vast majority of federal administrations, agencies, boards, and commissions use DNL 55 dB or lower as a level of significance. Only the FAA, DOD, and HUD use DNL 65 dB as a level of significance. In terms of terminology, what the FAA terms “the Federal Government’s level of significance for assessing noise impacts,” the FTA and FRA term “severe impact.” These policies stem from the early 1970s (e.g., HUD, 1971).

The NRC goes further, and, in many instances, recommends assessments when the project noise exceeds a DNL 40 dB—a level that is below the criterion level of all other agencies and boards and is 25 dB below the FAA/DOD level. In terms of sound energy, the NRC recommendation is at a value that is 1/300th the FAA/DOD value.

ANSI, WHO, The World Bank Group and OECD all recommend a DNL criterion value of 55 dB and OECD recommends an even lower criterion level in rural areas.

For some of those organizations and groups that use metrics that differ from DNL, it is possible to examine their criteria against various noise sources. For example, the APTA criterion of 70 dB LA<sub>max</sub> for low-density single-family housing areas is frequently exceeded by aircraft noise several to many miles from an airport and is exceeded by road traffic noise about 250 ft from a highway. The WHO nighttime limit of 60 dB LA<sub>max</sub> is frequently exceeded by aircraft noise many miles from an airport, by road traffic noise about 500 to 1000 ft from a highway, and by train noise about 1000 ft or more from the tracks.

Nearly all of the policies that set lower criterion values for DNL stem from 1995 or later and, thus, are based on 25 more years of noise effects research.

Of all of the boards and agencies, standards setting bodies, and international organizations, one should consider the World Health Organization and the National Research Council as primary authorities on acceptable levels of pollutants. They are charged with creating this type of scientific position activity. WHO terms DNL 55 dB as engendering serious annoyance and creating an unhealthy environment, and WHO terms DNL 50 dB as engendering moderate annoyance. The NRC goes further, and, in many instances, recommends assessments when the project noise exceeds a DNL 40 dB.

### III. ASSESSMENT CRITERIA BASED ON TYPE OF LAND AREA

#### 1. A History of Normalization Factors

As previously noted, DNL is commonly used to quantify and assess environmental noise. A keystone to noise assessment is the dose-response relationship. With such a relationship, one can relate community response to noise level. Since the seminal work by Schultz (1978), “high annoyance” has been the response measure of choice—especially in the United States. Figure 4 shows the relationship developed by Schultz between the DNL for various transportation noise sources and the corresponding community response expressed as the percentage “highly annoyed.” One hallmark of this figure, and many like it, is the large amount of scatter to the data. The 90 percent prediction intervals are quite large. In this figure, the 90 percent prediction intervals are about 20 to 25 percent wide at mid levels. The prediction interval can be understood to mean that if one were to survey many communities where the DNL was, for example, 65 dB, then one would expect to find that the rate of high annoyance was between about 5 and 28 percent in 90 percent of the communities surveyed, with even larger variations in one of ten communities.

The EPA (1974) adopted the use of DNL for noise assessment. In their report they again attempted to relate noise levels with community reaction as measured by complaints and legal actions. Figure 5 shows basic data available at that time showing community reaction versus DNL. Obviously there is a great deal of scatter to these data. At 55 DNL, reactions range from “no reaction” to “severe threats of legal action or strong appeals to local officials to stop noise.” Some may question the usefulness of figures like Figure 5 in view of the large amount of scatter to the data. There is just too much scatter to the DNL data.

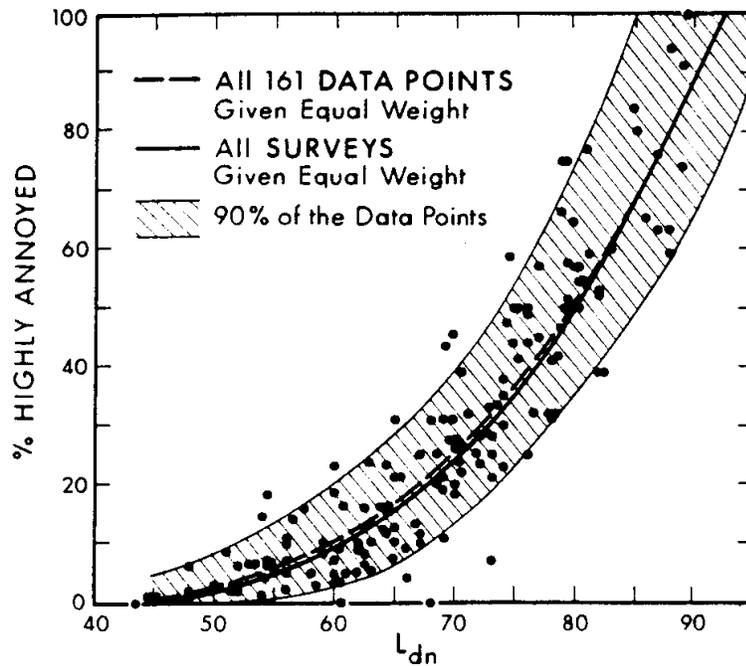


Figure 4. The Schultz relationship between percent highly annoyed and DNL for transportation noise sources

In an attempt to reduce the scatter to the DNL data, the EPA (1974) suggested the use of “normalized” DNL. Normalized DNL is the basic DNL level with a number of adjustments added to account for specific characteristics and factors of the sound. Table 7 shows the EPA-suggested adjustment factors and the amounts of the adjustments. Factors include seasonal corrections, corrections for the setting, corrections for previous exposure and community relations, and corrections for sound character (tonal or impulsive). Figure 6 shows the data from Fig. 5 after they have been normalized using this procedure. Clearly, in Fig. 6 the data compress and there is much less scatter to the data than in Fig. 5.

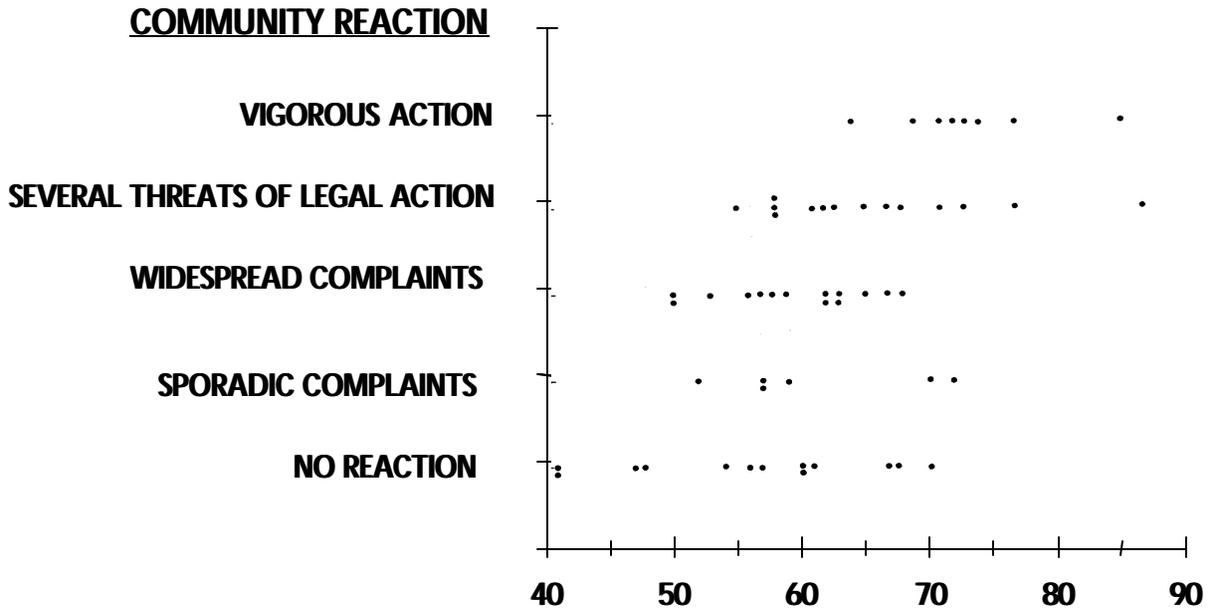


Figure 5. Community reaction for the non-normalized DNL indicated. (After EPA, 1974)

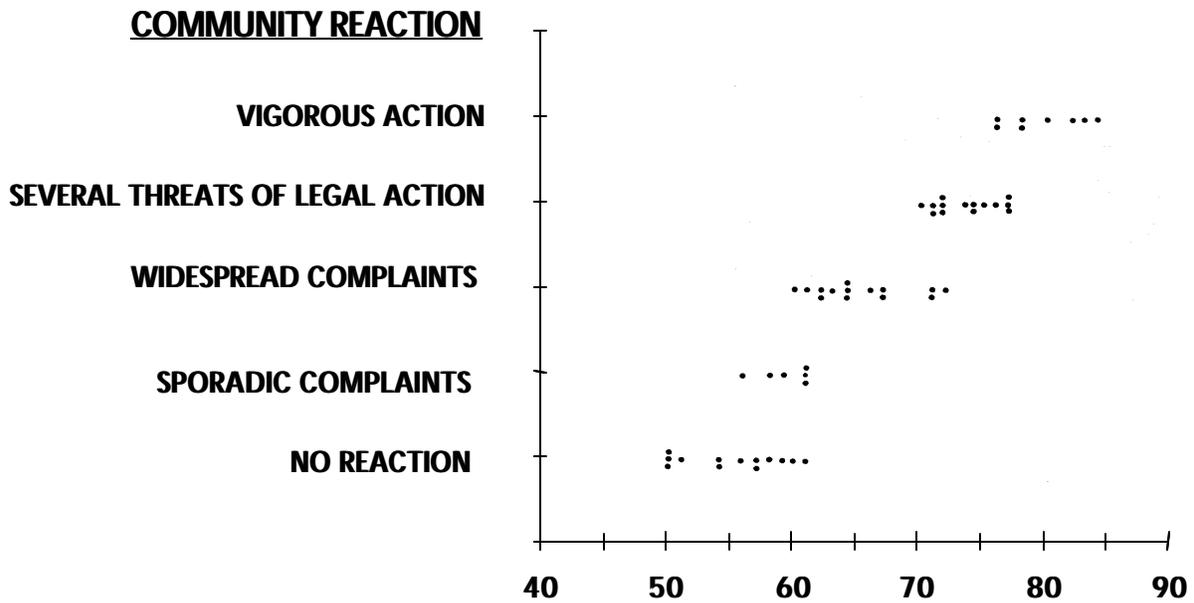


Figure 6. Community reaction for the normalized DNL indicated. (After EPA, 1974)

Type of Correction	Description	Amount of Correction to be Added to measured DNL (dB)
Seasonal Correction	Summer (or year-round operation) Winter only (or windows always closed)	0 -5
Correction for Outdoor Noise Level Measure in Absence of Intruding Noise	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking) Normal suburban community (not located near industrial activity) Urban residential community (not immediately adjacent to heavily traveled roads and industrial areas) Noisy urban residential community (near relatively busy roads or industrial areas) Very noisy urban residential community	+10 +5 0 -5 -10
Correction for Previous Exposure and Community Attitudes	No prior experience with the intruding noise  Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction 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.  Community has had considerable previous exposure to the intruding noise and the noisemaker's relations with the community are good  Community aware that operation causing noise is very necessary and it will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances.	+5  0  -5  -10
Pure Tone or Impulse	No pure tone or impulsive character Pure tone or impulsive character present	0 -5

Table 7. Corrections to be added to the measured DNL of intruding noise to obtain normalized DNL (EPA, 1974)

In reality, the normalization factors in Table 7 were in use long before the EPA’s Office of Noise Abatement and Control (ONAC). The adjustment method was incorporated in the first Air Force Land Use Planning Guide in 1957 (USAF, 1957) and was later simplified for ease of application by the Air Force and the Federal Aviation Administration.

Today, the same issues exist as in the 1950s, 60s and 70s. Dose-response relationships are used to relate DNL to high annoyance and to complaints, but there is great uncertainty to these relationships. Figure 7 shows a more recent analysis of attitudinal survey data including the original Schultz-studied surveys and many additional surveys (Finegold *et al.*, 1994). If anything, with more data, the scatter is greater and the prediction intervals are larger still. At DNL 65, the 90 percent prediction interval in Fig. 7 ranges from about 1 to 40 percent.

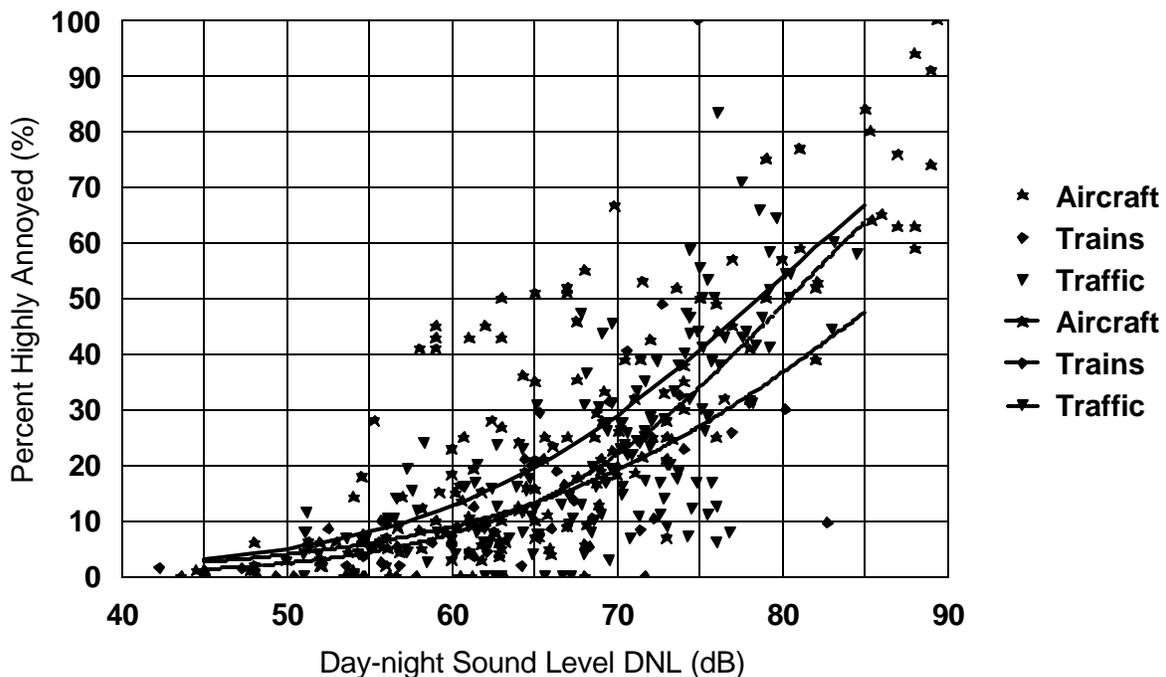


Figure 7. A recent compilation of attitudinal survey results including the original Schultz data and many additional surveys (Note the large amount of scatter to the data.)

## 2. Normalization for Community Type or “Type of Neighborhood”

The following discussion is focussed on Factor 2 in Table 7: Correction for Outdoor Noise Level Measured in Absence of Intruding Noise. Some have interpreted this factor to be focussed on the difference between the existing noise levels and the noise levels generated by the source in question. This is not a correct interpretation. In fact, several researchers (e.g., Fields, 1998; Taylor *et. al*, 1980) have shown that the background noise in an area has little effect on the annoyance engendered by aircraft noise. But this Factor 2 of the EPA is not a correction for background; it is a correction for the community setting.

As early as 1977, the FAA (1977) in a report entitled *Impact of Noise on People* states:

“Type of neighborhood – instances of annoyance, disturbances and complaint associated with a particular noise exposure will be greatest in rural areas, followed by suburban and urban residential areas, and then commercial and industrial areas in decreasing order. The type of neighborhood may actually be associated with one’s expectations regarding noise. People expect rural neighborhoods to be quieter than cities. Consequently, a given noise exposure may produce greater negative reaction in a rural area.

In 1985 the FAA (1985) says much the same in a report entitled *Aviation Noise Effects*. Here they state:

“Type of Neighborhood. Instances of annoyance, disturbances and complaint associated with a particular noise exposure will be greatest in rural areas, followed by suburban and urban residential areas, and then commercial and industrial areas in decreasing order. The type of neighborhood may actually be associated with one’s expectations regarding noise there. People expect rural neighborhoods to be quieter than cities. Consequently, a given noise exposure may produce greater negative reaction in a rural area.

Willits *et al.* (1990) provides proof for these FAA and EPA assertions. He has studied community expectations in rural settings. Table 6 reproduces Willits’ data. Many potentially positive attributes of rural living are given. Of these, the number one expectation to rural living is “peace and quiet.” This positive attribute of rural living ranks far above virtually all other perceived rural attributes. For example, peace and quiet is much more expected than is a low

crime rate, and these expectations are about the same for rural, urban, and suburban respondents. That is, everyone expects rural areas to be bastions of peace and quiet.

Not only the Air Force and the EPA have recommended these normalization factors. In a feature article in Noise News International, Eldred and von Gierke (1993), two of the most respected names in environmental noise assessment, recommend these normalization factors. The NRC recommends that required environmental noise documentation levels be based on population density (Figure 3) which is a good surrogate for type of community. The OECD recommends a criterion level of 50 dB in rural areas and a criterion level of 55 dB in urban areas, and the APTA sets lower limits in low-density single family areas than in higher density areas or in areas with multi-family housing. Very recently, ISO affirmed a draft revision to ISO 1996 (2000). This Draft International Standard qualifies use of the "Schultz Curve," for assessing degree of annoyance by stating:

"Research has shown that there is a greater expectation for and value placed on "peace and quiet" in quiet rural settings. In quiet rural areas, this greater expectation for "peace and quiet" may be equivalent to up to 10 dB."

Item	Rural (N=571) <sup>a</sup>			Urban (N=384)			Suburban (N=284)		
	Agree	Undecided	Disagree	Agree	Undecided	Disagree	Agree	Undecided	Disagree
Rural life brings out the best in people.	63.2	20.8	15.9	46.5	27.2	26.4	48.9	26.4	24.6
Rural families are more close-knit and enduring than other families.	71.6	13.0	15.4	61.2	11.7	27.1	66.7	11.3	22.0
Because rural life is closer to nature, it is more wholesome.	85.6	7.2	7.2	73.7	8.1	18.2	72.9	7.7	19.4
Rural communities are the most satisfying of all places to live, work and play.	68.8	13.7	17.5	39.8	18.0	42.2	43.7	13.7	42.6
Rural people are more likely than other people to accept you as you are.	65.7	13.1	21.2	53.4	14.6	32.0	51.4	13.7	34.9
Neighborliness and friendliness are more characteristic of rural communities than other areas.	77.7	8.8	13.5	69.0	11.2	19.8	64.8	10.9	24.3
Life in rural communities is less stressful than life elsewhere.	69.3	8.1	22.6	60.7	8.6	30.7	63.0	8.8	28.2
There is less crime and violence in rural areas than in other areas.	73.4	8.1	18.6	67.4	9.7	23.0	70.8	10.6	18.7
<b>Rural areas have more peace and quiet than do other areas.<sup>b</sup></b>	<b>94.6</b>	<b>1.9</b>	<b>3.5</b>	<b>89.3</b>	<b>3.4</b>	<b>7.3</b>	<b>91.9</b>	<b>1.8</b>	<b>6.3</b>

a Number of cases varies slightly from item to item due to missing data.

b Emphasis added.

Table 2. Responses in percent from rural, urban and suburban residents to items dealing with positive images of rural life (after Willits *et al.*, 1990).

**2. The Present Situation**

Virtually all environmental noise analyses ignore the EPA normalization factors. The FAA ignored the normalization factors in their analysis of the so-called Expanded East Coast Plan (Muldoon and Miller, 1989) and in the siting of the new Denver Airport (Colorado, 1997). In both cases the community reaction was and is far in excess of that predicted without the use of normalizing factors. In particular, the FAA ignored the normalization factor that deals with the type of community. This, in spite of the FAA's own documents attesting to the importance of this factor (FAA, 1977; FAA, 1985).

**3. Discussion**

The EPA normalization factors for the type of community are justified and needed not on the basis of the background sound but on the basis of the community expectations for a quiet environment. The best surrogate for community type is population density as suggested by the NRC. For purposes of noise assessment, a population density of less than 500 people per square kilometer (about 1250 per square mile) is suggested as the threshold for a rural area where the criteria for DNL should be lowered by 10 dB. Also, a population density of less than 2000 people per square kilometer (about 5000 per square mile) is suggested as the threshold for a quiet suburban area where the criteria should be lowered by 5 dB. These population densities are based on ANSI (1993).

#### IV. ADDITIONAL DISCUSSION

It is clear that a large majority of federal agencies, administrations, commissions, and boards use DNL 55 dB as their criterion for noise impact. It is also clear that non-government cognizant groups like the American National Standards Institute and quasi-government groups like the National Research Council recommend DNL 55 dB as the appropriate criterion in residential and other similarly noise sensitive areas. It is further clear that all of the major international cognizant bodies including the World Health Organization, the World Bank Group, and the Organization for Economic Co-operation and Development use the equivalent of DNL 55 dB as their criterion, or a yet lower level. Only the aircraft sector in the United States espouses a higher DNL criterion level.

One can ask why the aircraft sector might espouse a higher criterion level. One hypothesis is that for the same measured noise level, aircraft noise is perhaps 10 dB less annoying than road traffic, railroad or industrial noise.

This hypothesis is testable. Finegold *et al.* (Figure 7) shows community annoyance as a function of DNL separately for aircraft, road traffic, and railroad noise. His results show that for the same DNL, aircraft noise is more annoying than the other forms of transportation noise. Miedema and Vos (1998) have performed a similar analysis on an even bigger database (Figure 8) and find that for the same DNL, aircraft noise tends to be significantly more annoying than are other forms of transport noise. These studies by Finegold *et al.* and by Miedema and Vos use virtually all the available noise attitudinal data collected worldwide during the last 50 years. Thus, on the basis of the large world body of scientific data, the correct criterion for aircraft noise should probably be lower for aircraft noise than for other noise. For this reason, the recently approved ISO Draft International Standard on this subject (ISO, 2000) recommends a 3 to 6 dB penalty for aircraft noise compared with road traffic noise. So one can conclude that aircraft noise, for the same DNL, more annoying than is other transportation noise. One cannot claim that a higher criterion level for aircraft noise is justified on any scientific basis.

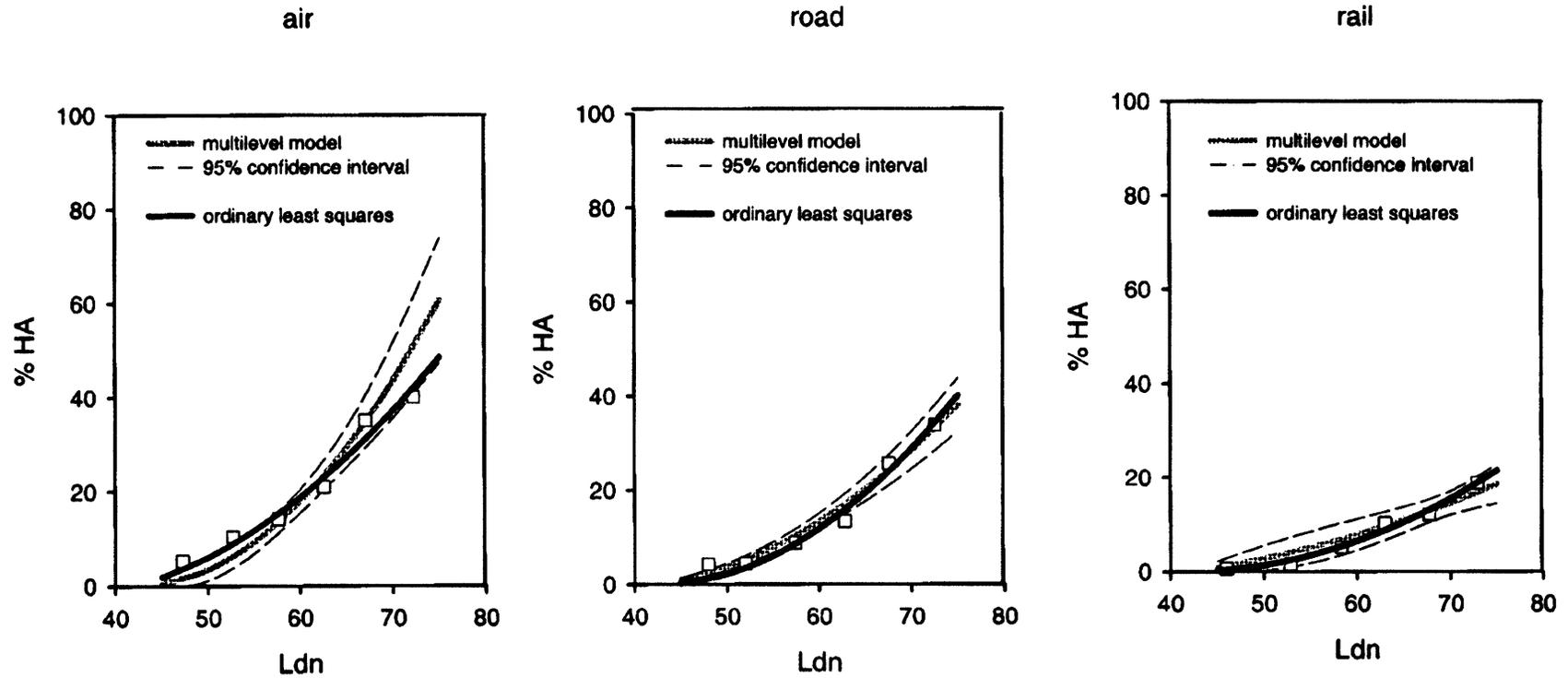


Figure 7. A recent meta-analysis of noise annoyance versus sound level by Miedema and Vos (1998) using all applicable world-wide noise attitudinal survey data.

## V. CONCLUSIONS

1. Nearly all agencies and boards, standards setting bodies, and international organizations that have cognizance over noise producing sources use a DNL criterion value of 55 dB as the threshold for defining noise impact in urban residential areas. In fact, of this large number of agencies, boards, standards setting bodies, and international organizations, only the Department of Defense and the Federal Aviation Administration suggest a criterion value for DNL that is higher than 55 dB.

2. The policies of FAA/DOD (and HUD) all were developed in the early 1970's and earlier (e.g., HUD, 1971). In contrast, most of the agencies and boards, standard setting bodies, and international organizations have established their policies after 1995. In particular, the World Health Organization recommendations (WHO, 1999) are based on over 25 years more worldwide research into noise effects than are the earlier FAA/DOD policies.

3. Significant evidence exists to suggest that aircraft noise is more annoying than is road traffic noise for the same DNL level.

4. Of all of the boards and agencies, standards setting bodies, and international organizations, one should consider the World Health Organization and the National Research Council as the primary authorities on acceptable levels of pollutants. They are charged with developing this type of scientific position and have clearly spoken. WHO terms DNL 55 dB as engendering serious annoyance and creating an unhealthy environment, and WHO terms DNL 50 dB as engendering moderate annoyance. The NRC goes further, and, in many instances, recommends assessments when the project noise exceeds a DNL 40 dB.

5. No single DNL criterion is equally applicable to all residential situations and all types of residential communities. A sizeable number of agencies and boards, standards setting bodies, and international organizations that have cognizance over noise producing sources recommend a DNL criterion value that is less than 55 dB as the threshold for defining noise impact in sparse suburban and rural residential areas. Rural areas require a criterion that is 10 dB lower than the criterion used in normal urban areas.

6. For residential areas and other similarly noise sensitive land uses, noise impact becomes significant in urban areas when the DNL exceeds 55 dB. In suburban areas where the population density is between 1250 and 5000 inhabitants per square mile, noise impact

becomes significant when the DNL exceeds 50 dB. And in rural areas where the population density is less than 1250 inhabitants per square mile, noise impact becomes significant when the DNL exceeds 45 dB.

## REFERENCES

ANSI (1996). American National Standards Institute (ANSI) Quantities and Procedures for Description and Measurement of Environmental Sound—Part 4: Noise Assessment and Prediction of Long-term Community Response, Standards Secretariat, Acoustical Society of America, New York. 1996.

ANSI (1996). American National Standards Institute (ANSI) Quantities and Procedures for Description and Measurement of Environmental Sound—Part 3: Short-Term Measurements with an Observer Present, Standards Secretariat, Acoustical Society of America, New York. 1993.

ANSI (1998). American National Standards Institute (ANSI) Quantities and Procedures for Description and Measurement of Environmental Sound—Part 5: Sound Level Descriptors for Determination of Compatible Land Use, Standards Secretariat, Acoustical Society of America, New York, 1998.

APTA, (1981). Guidelines for Design of Rail Transit Facilities, Section 2-7, "Noise and Vibration," American Public Transit Association (APTA)

Colorado (1997). District Court, Adams County Colorado, Case No. 97 DV 0498, Division C, Thomas H. James and Jerilyn J. James Plaintiffs, v. City and County of Denver, a body politic and body corporate of the State of Colorado, Defendant, 1997.

Brooks, Bennett, (2000). Personnel communications. United Acoustic Consultants, Vernon, CT.

DOD, (1977). Air Installations Compatible Use Zones, Department of Defense Instruction 4165-57.

DOT, (2000). Report to Congress: Feasibility of a United States Department of Transportation Multi-Modal Noise Model, Office of the Assistant Secretary for Transportation Policy, Office of the Secretary, US Department of Transportation, Washington DC, January 2000.

Eldred, K, and H. von Gierke, (1993). "Effects of Noise on People," *Noise News International*, 1(2), 67-89, June 1993.

EPA (1974). Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, US Environmental Protection Agency, Office of Noise Abatement and Control (ONAC), Report EPA550/9-74-004, Washington D.C.

EPA, (2000). Letter from Ms. Mindy Lubber, Regional Administrator, EPA to Mr. Vincent Scarano, Director of Aviation, Federal Aviation Administration, re. Supplemental draft EIS for Boston Logan Airport, November 6, 2000.

FAA, (March 1977). Aviation Noise Effects, US Department of Transportation, Federal Aviation Administration, Office of Environmental and Energy, FAA-EE-85-2, Washington DC, March 1985.

FAA, (May 1977). Impact of Noise on People, US Department of Transportation, Federal Aviation Administration, Office of Environmental Quality, FAA-EQ-78-12, Washington DC, May 1977.

FAA, (2000). Aviation Noise Abatement Policy 2000, Department of Transportation, Federal Aviation Administration, Docket No.: 30109, Federal Register 65(136), July 14, 2000.

FERC, (1999). Revision of Existing Regulations Under Part 157 and Related Sections of the Commission's Regulations Under the Natural Gas Act, Federal Energy Regulatory Commission, 18 CFR Part 157.206(d)(5), Docket No. RM98-9-001; Order No. 603-A, September 29, 1999.

FHWA, (1995). Highway Traffic Noise Analysis and Abatement Policy and Guidance, US Department of Transportation, Federal Highway Administration, Washington DC, June 1995.

Finogold, Lawrence S., C. Stanley Harris, and Henning E. von Gierke, (1994). "Community annoyance and sleep disturbance: Updated criteria for assessing the impacts of general transportation noise on people", *Noise Control Eng. J.*, 42(1), 25-30 (1994 January-February).

Fields, J.M., (1998). "Reactions to environmental noise in an ambient noise context in residential areas," *J. Acoust. Soc. Am.* 104(4), 2245-2260.

FRA, (1998). High-Speed Ground Transportation Noise and Vibration Impact Assessment, US Department of Transportation, Federal Railroad Administration, Final Draft, Report No. 293630-1, Washington DC, December 1998.

FTA, (1995). Transit Noise and Vibration Impact Assessment, US Department of Transportation, Federal Transit Administration, DOT-T-95-16, Washington DC, April 1995.

HUD, (1971). Noise Assessment Guidelines, US Department of Housing and Urban Development, BBN Report No. 2176, August 1971.

HUD, (1985). The Noise Guidebook, US Department of Housing and Urban Development, HUD 953-DPC, March 1985.

ISO, (1987). Acoustics—Description and measurement of environmental noise—Part 2: Acquisition of data pertinent to land use, International Organization for Standardization, International Standard ISO-1996/2-1987, Geneva, 1987.

ISO, (2000). Acoustics—Description, measurement and assessment of environmental sound—Part 1: Basic Quantities and assessment procedures, International Organization for Standardization, Draft revised International Standard Approved at the ISO Technical Committee 43, sub-committee 1 Plenary Meeting in Newport Beach CA , DIS 1996/1, Geneva, December 2000.

Miedema, Henk M.E., and Henk Vos, (1998). "Exposure-response relationships for transportation noise," *J. Acoust. Soc. Am.*, **104**(6), 3432-3445, (December, 1998).

Muldoon, J.P., and R.L. Miller, (1989). "Low levels of aircraft noise from Expanded East Coast Plan operations," *Inter-noise 89*, 665-670, Newport Beach, CA, 1989.

NRC, (1977). Guidelines for Preparing Environmental Impact Statements on Noise, National Research Council, Assembly of Behavioral and Social Sciences, Committee on Hearing, Bioacoustics and Biomechanics (CHABA), Washington DC, 1977.

OECD, (1993). Indicators for the Integration of Environmental Concerns Into Transport Policies, Organization for Economic Co-Operation and Development, OCDE/GD(93)150, Paris, 1993.

OECD, (1996). Environmental Criteria for Sustainable Transport, Report on Phase 1 of the Project on Environmentally Sustainable Transport (EST), Organization for Economic Co-Operation and Development, OCDE/GD(96)136, Paris, 1996.

Passchier-Vermeer, Willy, and Wim F. Passchier, (2000). "Noise Exposure and Public Health," *Environmental Health Perspectives*, **108**(Supp 1), March 2000.

Schultz, T.J. (1978). "Synthesis of social surveys on noise annoyance," *J. Acoust. Soc. Am.* **64**(2), 377-405.

STB, (1998). "Proposed Conrail Acquisition," Draft Environmental Impact Statement, Finance Docket No. 33388, CSX Corporation and CSX Transportation, Inc., Norfolk Southern Corporation, and Norfolk Southern Railway Company—Control and Operating Leases/Agreements—Conrail Inc. and Consolidated Rail Corporation.

Taylor, S., F. Hall, and S. Birnie, (1980). "Effect of background levels on community responses to aircraft noise," *J. Sound and Vib.*, **71**(2), 261-270, 1980.

USA Today, (2000). Page 1, 15-17 December 2000—weekend edition, 2000.

USAF, (1977), Community Noise Exposure Resulting from Aircraft Operations: Volume 2. Acoustic Data on Military Aircraft: Air Force Bomber/Cargo Aircraft, Aerospace Medical Research Laboratory, Wright Patterson AFB, Ohio, November 1977.

Willits, F.K., R.C. Bealer, and V.L. Timbers, (1990). "Popular Images of 'Rurality': Data from a Pennsylvania Survey," *Rural Sociology*, **55**(4), 559-578, Winter 1990.

WBG, (1998). Pollution Prevention and Abatement Handbook, General Environmental Guidelines, World Bank Group July 1998.

WHO, (1999). Guidelines for Community Noise, Edited by Birgitta Berglund, World Health Organization, Thomas Lindvall, and Dietrich Schwela, Geneva, April 1999.

## Annex A: OTHER COMMON SOUND LEVEL METRICS

### Maximum Sound Level (L<sub>max</sub>)

The highest sound level measured during a single event in which the sound level changes value as time goes on (e.g., an aircraft overflight or a truck driveby) is called the maximum sound level. It is usually abbreviated by L<sub>max</sub>. Two different time periods may be used to determine L<sub>max</sub>: 0.125s (fast response) or 1.0 s (slow response). The “A” frequency weighting typically is used with L<sub>max</sub> and is identified as LA<sub>max</sub>.

### Peak Sound Pressure Level (L<sub>pk</sub>)

The peak sound pressure level, L<sub>pk</sub>, is the highest instantaneous level obtained by a sound level measurement device. The peak sound pressure level is typically measured using a 20 μs or faster sampling rate. L<sub>pk</sub> is typically based on unweighted or linear response of the meter.

### Sound Exposure Level (SEL)

Individual time-varying noise events have two main characteristics: a sound level which changes throughout the event and a period of time during which the event is heard. Although the maximum sound level, described above, provides some measure of the intrusiveness of the event, it alone does not completely describe the total event. The period of time during which the sound is heard is also significant: The longer the event, the more intrusive it will be. The Sound Exposure Level (abbreviated SEL) combines both of these characteristics into a single metric. It has the physical units of pressure-squared multiplied by duration (time).

Note that sound exposure level is a composite metric that represents both the intensity of a sound and its duration. It does not directly represent the sound level heard at any given time, but rather provides a measure of the net impact of the entire acoustic event. It has been well established in the scientific community that Sound Exposure Level measures this impact much more reliably than just the maximum sound level.

Sound Exposure Levels are usually A-weighted (ASEL). Because the Sound Exposure Level and the maximum sound level are both expressed in decibels, there is sometimes confusion between the two, so the specific metric used should be clearly stated.

**Equivalent Level (LEQ)**

Equivalent level is a measure of the sound energy average over a stated time period, e.g. one hour. The equivalent level (LEQ) is formed from the sum of the sound exposures of each truck drive by, or each plane flyby, divided by the time period in seconds. For example, if the time-period is one hour, then the divisor is 3600 seconds. This quotient is then converted to its decibel quantity. LEQ usually is A-weighted (ALEQ).