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Quieting the Impact of Transportation with Sound Acoustical Planning

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Abstract

Hearing is one of the five basic sensory perceptions that we as human beings use to explore, understand and enjoy the world around us. As such, planning and designing for proper acoustics deserves at least 20% of our attention and resources to ensure a quality life. Transportation systems (highways, airports, railroads, transit systems), and associated construction projects, are the largest producer of environmental noise affecting our lives. Fortunately, several Federal and State agencies have established guidelines for how to measure, predict, evaluate and control these types of ubiquitous noise sources.

Keywords: noise, acoustics, measurements, modeling, criteria, mitigation, control

This paper will summarize the current state-of-the-industry with respect to transportation and construction noise regulations and mitigation controls. Basic acoustical concepts will be defined; the technical approach used to assess and identify noise impacts will be explained; and noteworthy examples of Federal, State and local noise policies will be provided. Lastly, examples of noise control mitigation options will be provided for each mode of transportation noise.

Basic Acoustics Fundamentals

Sound is what we hear when our ears are exposed to small pressure fluctuations in the air. Noise is generally defined as unwanted sound. It is measured in terms of sound pressure level, and is usually expressed in logarithmic decibels (dB) with respect to a reference level of 20×10^{-6} Pascals. In general, human sound perception is such that a change in sound level of 1 dB is just barely noticeable, a change of 3 dB clearly noticeable, a change of 6 dB is obvious, and a change of 10 dB is perceived as a doubling or halving in sound level.

Humans are capable of hearing sound levels over the audible frequency range of 20 Hz to 20,000 Hz. However, humans are not equally sensitive to all frequencies, so noise measurements are weighted more heavily for frequencies to which humans are sensitive in a process called “A-weighting”, with sound level decibels being abbreviated as “dBA”. The A-weighted sound level is widely accepted by acousticians as a proper unit for describing environmental noise.

Typical A-weighted sound levels are show in Figure 1. The following noise descriptors are used for noise measurements, computations, and assessment of noise impacts from transportation projects as described below:

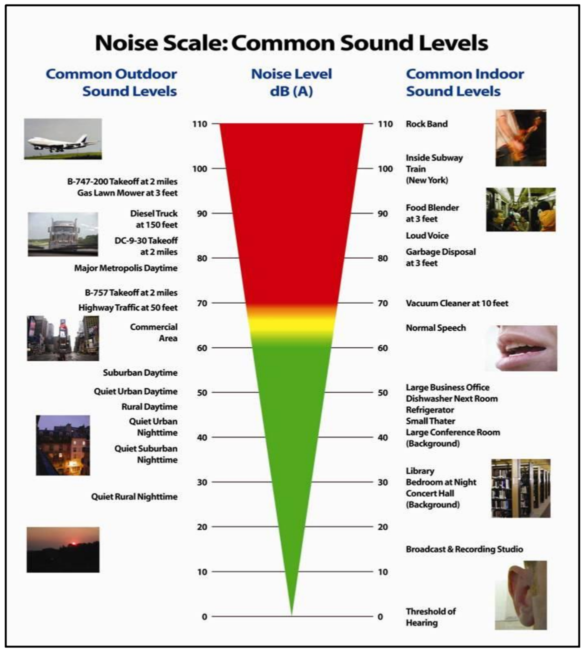


Figure 1. A-weighted Decibel Levels

Lmax - The maximum sound level (Lmax) during a single noise event. For example, as a vehicle approaches, passes by, and then recedes into the distance, the A-weighted sound level rises, reaches a maximum (Lmax), and then fades into the background noise.

SEL - The sound exposure level (SEL) describes a receptor's cumulative noise exposure from a single event, with the results normalized in time to a period of 1 second for relative comparison. Louder events have greater SELs then do quieter ones, and events that last longer in time have greater SELs than do shorter ones. The SEL it is not a sound level that humans would hear per se; rather, it is used to characterize noise sources in prediction models.

Leq - The equivalent sound level, Leq, is the cumulative energy-averaged sound level at a receptor during a defined period of time. It accounts for the moment to moment fluctuations due to all sound sources during that time period combined. The peak- or loudest-hour Leq(h) of the day is typically used for transportation noise analyses.

Ldn - The day-night sound level (Ldn or DNL) is an Leq measured over a 24-hour period with a 10 decibel penalty added to nighttime sound levels between 10 PM and 7 AM. The Ldn accounts for the greater sensitivity and lower background sound levels during nighttime hours, so it is used for transportation noise analyses at locations with nighttime use, such as residences, hospitals and hotels.

Ln% - The sound level percentile (Ln%) is a statistical measure of fluctuating sound levels exceeding a given level over a period of time. For example, the L10 sound level represents the sound level exceeded 10% of the time, and is often used to define intrusive sound levels. Conversely, the L90 sound level would be the sound level exceeded 90% of the time, which is often used to define steady background sound levels.

Federal Noise Guidelines

America made its decision in the 1950s that we were going to be a mobile society based primarily on the automobile. The Federal Aid Highway Act, signed by President Eisenhower in 1956, created the Federal Highway Administration (FHWA) and the first 41,000 miles of the Interstate highways. Its goals were two fold; to link all the contiguous states to promote free commerce and travel, but also to provide a network of roadways for national defense purposes if needed. For example, one mile out of every five along an Interstate highway had to be constructed in a straight line so that a heavy bomber could land on it in an emergency.

This is not to say that America did not vastly expand its heavy and light rail systems and airports as well. Those modes of transportation also expanded greatly due primarily to meet the growing commercial demands to move ever-more products and goods. In 1966, the US Department of Transportation (US DOT) was created which eventually would include the FHWA; the Federal Railroad Administration (FRA) and the Federal Transit Administration (FTA) to oversee heavy and light railways, respectively; and the Federal Aviation Administration (FAA) to manage the growth and safety of the country's civilian airports.

But with all of these modes of transportation came an unwanted byproduct – noise. Noise regulations at the time mainly focused on hearing conservation, not community comfort. Early complains were often met with the response "Sorry, it's the price of freedom." However, is became anecdotally clear that high levels of community noise exposure were directly associated with depressed socio-economic areas, lower learning abilities in grade schools, and general social unrest and crime. There are also individual health concerns associated with long-term exposure to elevated noise levels such as hypertension, ischemic heart disease, annoyance, and sleep disturbance.

Then in 1970, the National Environmental Policy Act (NEPA) was signed into law by President Nixon, soon followed by the Noise Control Act of 1972 which created the US Environmental Protection Agency (EPA). But it was not until 1978 when a seminal EPA community noise study was performed by Theodore Schultz that the adverse effects of community noise exposure were first quantified. The EPA report(1), known as the "Levels Document", prescribed noise emission standards, identified major sources of noise, and determined appropriate noise levels that would not infringe on public health and welfare.

The results, known as the Schultz curve (Figure 2), established an empirical relationship between elevated community noise exposure and people's reaction to it. The percentage of people likely to be highly annoyed (HA%) was a predictable function of the Day-Night Sound Level (Ldn or DNL). The Ldn is a 24-hour acoustic-energy-averaged sound metric expressed in A-weighted decibels in which a 10 decibel penalty is added to the hours from 10 PM to 7 AM to account for people's greater sensitivity to noise intrusion during those hours. The Ldn has sense gone on to be the most often referenced sound metric in setting community noise guidelines.

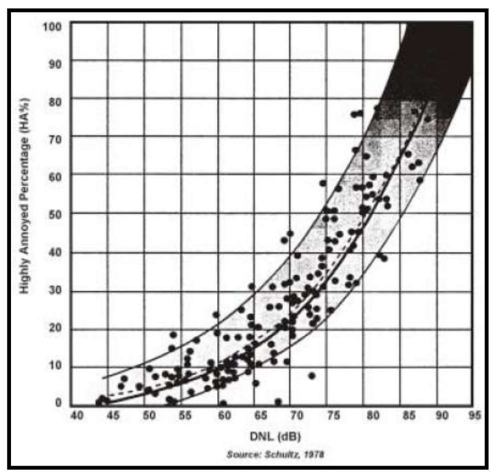


Figure 2. The Schultz Curve

However, one size does not fit all when it comes to establishing appropriate community noise criteria. Each of these Federal agencies promulgate guidelines to regulate transportation noise sources, however they all use different noise metrics to do so. Thus, it can be difficult to determine a community's total noise exposure when multi-modes of transportation affect people simultaneously. This becomes even more problematic when it comes to funding necessary noise mitigation measures; because the agency that makes the noise is responsible to control it.

US DOT Transportation Noise Criteria

<u>FHWA Traffic Noise Criteria</u>

The FHWA has promulgated traffic noise criteria to be used in all Federally-funded highway projects intended to identify community receptors impacted by traffic noise, thus warranting mitigation considerations. FHWA's *absolute* traffic noise abatement criteria, shown in Table 1, come from 23 CFR Part 772: *Procedures for Abatement of Highway Traffic Noise and Construction Noise*[(2)]. In addition, most State Transportation Agencies define a loud *relative increase* in traffic noise as an impact as well. The preferred noise metric is the loudest-hour Equivalent Sound Level (Leq), expressed in A-weighted decibels. Thus, a receptor is defined as being impacted by traffic noise if the future noise level "approaches" the FHWA noise abatement criteria within 1 or 2 dBA, or if the predicted future traffic noise level exceeds the existing traffic noise level by 10 to 15 dBA, depending in which state the project is located.

FHWA's traffic noise criteria differentiate between types of receptor land-use, or activity category, as well as whether the noise is evaluated inside or outside the building. For example, a Category B noise receptor, such as a residence or a multi-family residence, will be considered to be impacted by traffic noise if its future exterior traffic noise level is predicted to be 67 dBA Leq or more or if it is expected to experience an increase of 10 to 15 dBA or more relative to existing traffic noise levels.

Table 1: FHWA Traffic Noise Abatement Criteria (NAC)

FHWA Activity Category	Traffic Noise Criteria Loudest-Hour Leq in dBA	Description of Activity Category (Land-Use)
A	57 (exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purposes.
B	67 (exterior)	Residential.
C	67 (exterior)	Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, daycare centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools, television studios, trails, and trail crossings.
D	52 (Interior)	Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios.
E	72 (Exterior)	Hotels, motels, offices, restaurants/bars, and other developed lands, properties or activities not included in Categories A-D or F.
F	None	Agriculture, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing.
G	None	Undeveloped lands that are not permitted.

Source: 23 CFR Part 772, Procedures for Abatement of Highway Traffic Noise and Construction Noise

FRA/FTA Rail/Transit Noise Criteria

The FRA and the FTA use the same approach to define community noise impacts from heavy or light rail operations. The basic goals of the noise criteria are to minimize the adverse noise impacts on the community and to identify areas where feasible and reasonable noise control may be necessary. FRA/FTA noise impact criteria are founded on the Schultz curve community reaction to absolute noise level as well as on changes in noise levels using a relative increase scale. Although more rail noise is allowed in neighborhoods with high levels of existing noise, as existing noise levels increase, smaller increases in total noise exposure are allowed than in areas with lower existing noise levels.

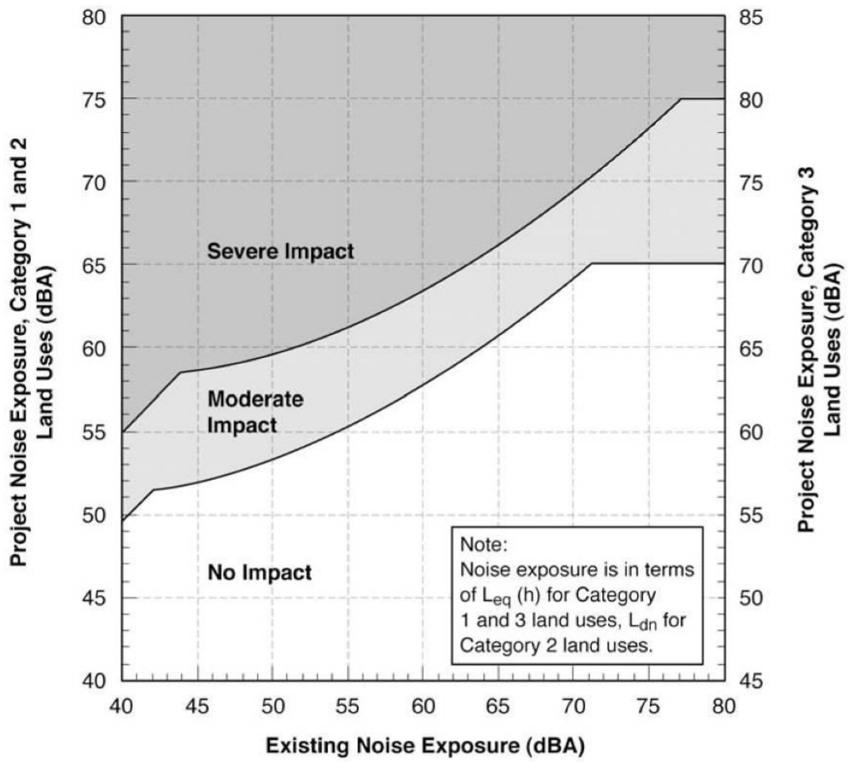
FRA/FTA guidelines(3) define noise impacts for various land-use categories using different noise metrics, as shown in Table 2. For residential receptors (i.e. Category 2) adjoining the transit corridor, the Ldn noise descriptor is used due to the receptor's use for sleeping at night. For institutional and some commercial receptors (i.e. Category 3) involving daytime and evening uses, the Leq(h) noise descriptor is used for the noisiest hour of transit-related activity during which human activities may occur at these locations.

Table 2: FTA Noise Receptor Land-Use Categories

Land-Use Category	Applicable Noise Metric in dBA	Description of Land-Use Category
1	Outdoor $L_{eq}(h)$	Tracts of land where quiet are an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land-used as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.
2	Outdoor L_{dn}	Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor $L_{eq}(h)$	Institutional land-uses with primary daytime and evening use. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation, and concentration on reading material. Places of meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.

Source: US Department of Transportation, Federal Railroad Administration and Federal Transit Administration

FRA/FTA noise impact criteria are based on a comparison of the existing outdoor noise levels (Leq(h) or Ldn depending on land-use category) and the future outdoor noise levels produced by the proposed project. It considers both *absolute* criteria, which is the noise generated solely by the transit noise source, and *relative increase* criteria, which gauges annoyance due to the change in the noise environment caused by the transit project. As shown in Figure 3, noise impact severity is categorized as "No Impact", "Moderate Impact", or "Severe Impact" as determined by comparing the project-generated noise exposure with respect to existing noise exposure at a given receptor's location.



Source: US Department of Transportation,
Federal Railroad Administration and Federal Transit Administration

Figure 3: Noise Criteria Limits for Rail/Transit Projects

FAA Airport/Aircraft Noise Criteria

The FAA's community noise criteria, promulgated in 14 CFR Part 150: *Airport Noise Compatibility Planning*(4) and shown in Table 3, is perhaps the most difficult to understand and to determine on a case by case basis. It is based on the exterior sound level considered to be conducive or compatible with the receptor's intended land-use. Land-uses of various kinds are recognized, each with its own noise criteria expressed in dBA Ldn when inbound and outbound flight operations are *averaged over a full year*. However, receptors can be exposed to louder levels of aircraft noise so long as certain noise control mitigation is incorporated into the buildings, thus providing for a lower interior noise level.

For example, to be eligible for noise mitigation consideration, a residence is defined to be impacted if it is exposed to aircraft noise levels exceeding 65 dBA Ldn. However, a residence exposed to 65 to 75 dBA Ldn can still be considered compatible so long as 25 decibels-worth of noise reduction is built into the structure.

Table 3. FAA Aircraft Noise Land-Use Compatibility

Land-Use	Yearly Day-Night Average Sound Level Ldn in dBA					
	Below 65	65-70	70-75	75-80	80-85	Over 85
Residential						
Residential, other than mobile homes and lodgings	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail - building materials, hardware	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade - general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production, extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables and water recreation	Y	Y	25	30	N	N

Source: 14 CFR Part 150, Airport Noise Compatibility Planning

Notes: Y (Yes) = Land-use and related structures compatible without restrictions.
N (No) = Land-use and related structures are not compatible and should be prohibited.
OINR = Outside to Inside Noise Reduction for a building, measured in decibels (dB).
= Land-use and related structures generally compatible; mitigation to achieve OINR of ## dB must be incorporated into design and construction of structure.
(1) Where the community determines that residential or school uses must be allowed, mitigation to achieve OINR of at least 25 dB and 30 dB should be incorporated into building codes.
(2) Mitigation to achieve OINR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, and noise sensitive areas.
(3) Mitigation to achieve OINR of 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, and noise sensitive areas.
(4) Mitigation to achieve OINR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, and noise sensitive areas.
(5) Land-use is compatible provided special sound reinforcement systems are installed.
(6) Residential buildings require an OINR of 25 dB.
(7) Residential buildings require an OINR of 30 dB.
(8) Residential buildings are not permitted.

Noise Control Mitigation Options

The generation and propagation of transportation noise is a physical phenomenon which can therefore be measured, modeled, mitigated and controlled. In general, control options can be applied to the noise *source,* the *pathway,* or the *receiver*. The degree of noise reduction achieved is a function of the effectiveness of the controls, proper installation of the controls, the frequency range requiring attenuation, and the perception of the receivers. In general, a minimum noise reduction of 5 decibels is needed to provide perceptible benefits, and the practical limit of noise control is a reduction of about 25 decibels.

<u>Source Controls</u>

Noise controls applied at the source are usually the most effective option because they prevent unwanted noise from being generated in the first place. However, it is often impractical or impossible to materially affect the noise source without degrading or preventing the source from performing its intended purpose.

Examples of transportation noise sources control options would include the following:

- Establish quieter vehicle noise emission limits (e.g. Stage 3 aircraft)
- Require improved exhaust mufflers
- Prohibit use of particularly loud vehicles during certain times of day/night
- Provide alternative forms of quieter transportation (e.g. transit systems)

<u>Pathway Controls</u>

Noise can be effectively relocated, blocked or diverted along its propagation pathway. The most notable form of transportation pathway noise control is a noise wall or barrier. To be effective, noise barriers must be long- and tall-enough to completely block the line-of-sight between the noise source and the receivers; must be free of any holes or gaps; and must be built either very close to the noise source or to the receiver.

Noise barriers can be built of any solid mass material providing a surface density of at least 4 lbs/SF. Common noise barrier materials include wooden timbers, concrete, brick, steel or plastic panels, and earthen berms. If designed and built properly, a noise barrier can provide up to 15 decibels of noise reduction. However, the amount of noise reduction is greatest for receivers close to the barrier and is lessened with distance from the barrier. The unit cost for noise barriers can range from $20/SF to $50/SF depending on the material, anchoring system, and labor rates. Note, trees do not provide appreciable noise reduction of transportation systems. While there is a psycho-acoustic benefit of not being able to see an offending noise source, trees planted simply as a vision barrier do nothing to reduce noise. It requires many hundreds of feet of fully mature conifer trees to provide a measureable noise reduction.

Examples of transportation noise pathway control options would include the following:

- Noise walls or barriers (often subject to cost-effectiveness criteria)
- Relocating the transportation system either underground or farther away
- Enclosing the noise source

Receiver Controls

Though typically not the first preference, on occasion noise control options can be applied to directly affect the receivers. This option can become attractive when there are only a few residences in need of noise reduction. Many public and private projects have resorted to receiver noise control measures when source and/or pathways control options are either infeasible or not sufficient.

One form of receiver noise control that does get implemented frequently is to enhance the soundproofing capabilities of people's homes. This is often done around airports and where construction projects might take years to complete. Residential soundproofing consists of augmenting or replacing window and doors, installing AC systems, and reinforcing a "room of preference" (such as bedroom) with additional insulated gypboard walls and ceilings. When done correctly, noise levels inside the home can be reduced by 10 decibels relative to the unmitigated condition. Of course, soundproofing the houses only reduces noise infiltrating into the homes; it does nothing to reduce outdoor noise. From residential soundproofing programs implemented by FAA and FHWA, the cost to soundproof a single-family home would be approximately $30,000/home.

Examples of transportation noise receiver control options would include the following:

- Residential soundproofing
- Relocating the receiver farther away from the noise source
- Wearing hearing protection
- White noise sound masking systems
- Public outreach and education (increases people's tolerance of noise)

Very rarely, and never with public money, monetary compensation can be offered to the aggrieved receiver in return for their signing waivers to stop complaining about the noise. This form of receiver noise control is jokingly referred to as "hush money", but there are times when it is the only pragmatic solution. Specific details and dollar amounts are usually kept confidential.

References

(1) U.S. Environmental Protection Agency, Office of Noise Abatement and Controls: *Information On Levels Of Environmental Noise Requisite To Protect Public Health and Welfare With An Adequate Margin Of Safety* (1974)

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(3) U.S. Department of Transportation, Federal Transit Administration, *Transit Noise and Vibration Impact Assessment* (2006), and Federal Railroad Administration, *High Speed Ground Transportation Noise and Vibration Impact Assessment Manual* (2012)

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