

3. FUNDAMENTALS OF HIGHWAY TRAFFIC NOISE

As discussed in the introduction, 23 CFR, Part 772 identifies several noise abatement measures that may be available to reduce anticipated traffic-noise impacts associated with existing and proposed highway projects. The scope of this effort included an evaluation of any “non traditional” noise mitigation techniques that may be available for use in the state of Ohio as an alternate to traditional sound barriers. The study focused on those items identified in 23 CFR, Part 772, as well as any other options that have been identified through the review process.

In order to understand the types of noise mitigation options that may be available, it is first important to understand the principals of highway traffic noise generation, analysis and mitigation.

3.1. Background on Sound

Sound is vibratory disturbance created by a moving or vibrating source. The movement of objects causes vibrations in air molecules that move the surrounding air in a manner similar to waves on water. When these vibrations reach our ears, we hear what we call sound. Noise meters are used to measure or quantify the intensity of sound, which is described in terms of decibels. The decibel (dB) is a logarithmic unit which expresses the ratio of sound pressure being measured to a standard reference level.

Most environmental sounds are complex and comprised of multiple frequencies or tones. Many of the frequencies associated with environmental noise are within the range of human hearing (i.e., audible sound) while many are above or below the range of typical human hearing, referred to as ultrasound and infrasound, respectively. Additionally, the human ear does not respond to all frequencies (within the range of audible sound) the same way. To account for these tonal differences, researchers have developed the “A-weighted scale” which places an adjustment on high and low-pitched sounds to best approximate the way the average person hears sounds. Sound pressure levels measured on the A-weighted scale are presented in A-weighted decibels, abbreviated dBA. The A-weighted decibel is the unit of measure applied to transportation noise studies [1].

Using the A-weighted decibel scale (dBA), noise levels can range from 0 dBA, a level which is barely audible to about 120 dBA, a level at which pain is felt by the listener [2]. **Table 1** provides a summary of the typical range of environmental sounds. Referencing this scale, the typical range of human speech communication is in the mid-60 dBA range. Quiet suburban environments are often in the 40 to 50 dBA range, with loud urban environments approaching the 70-75 dBA range.

Table 1: TYPICAL RANGE OF SOUND

Common Outdoor Activities	Noise Level dBA	Common Indoor Activities
Jet Fly-over at 300 m (1000 ft)	--110--	Rock Band
Gas Lawn Mower at 1 m (3 ft)	--100--	
Diesel Truck at 15 m (50 ft), at 80 km/hr (50 mph)	--90--	Food Blender at 1 m (3 ft)
Noisy Urban Area, Daytime	--80--	Garbage Disposal at 1 m (3 ft)
Gas Lawn Mower, 30 m (100 ft)	--70--	Vacuum Cleaner at 3 m (10 ft)
Commercial Area	--60--	Normal Speech at 1 m (3 ft)
Heavy Traffic at 90 m (300 ft)	--50--	Large Business Office Dishwasher Next Room
Quiet Urban Daytime	--40--	Theater, Large Conference Room (Background)
Quiet Urban Nighttime	--30--	Library
Quiet Suburban Nighttime	--20--	Bedroom at Night, Concert Hall (Background)
Quiet Rural Nighttime	--10--	Broadcast/ Recording Studio
Lowest Threshold of Human Hearing	--0--	Lowest Threshold Human Hearing

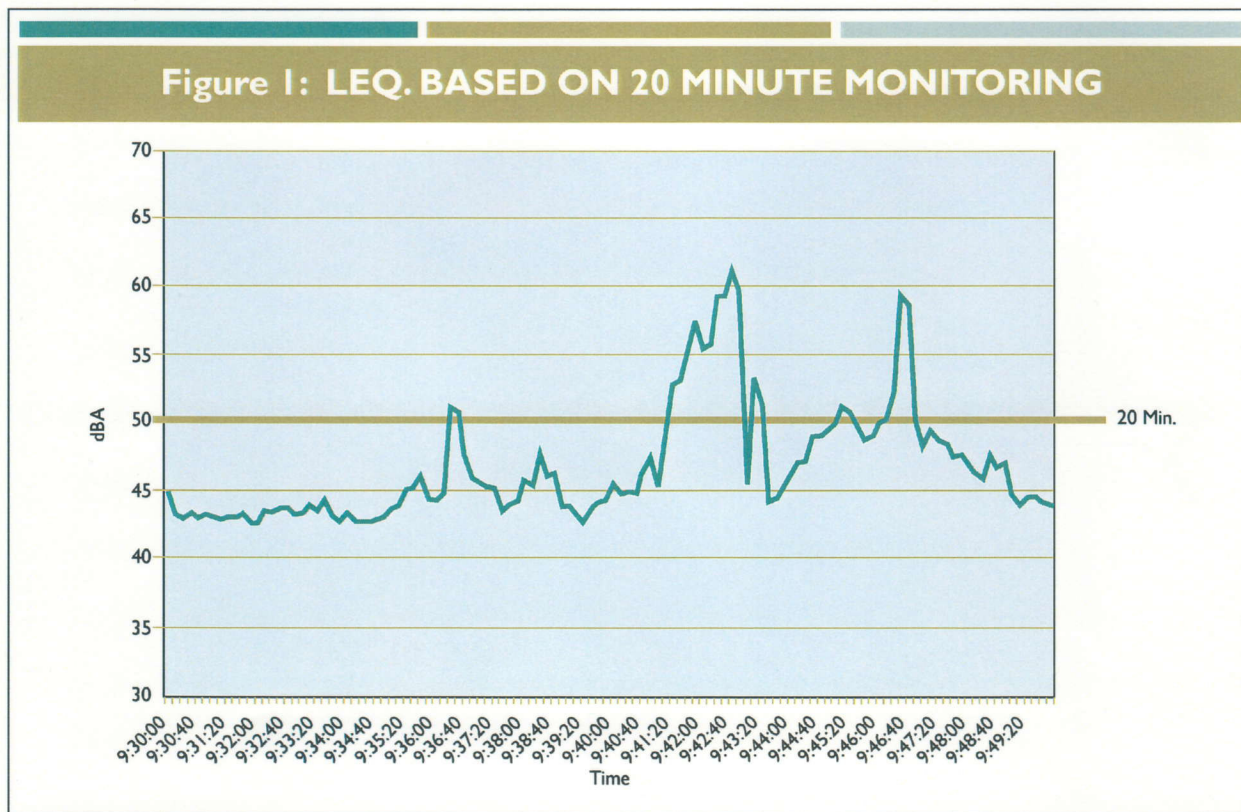
Source: CALTRANS Technical Noise Supplement, 1998

While much of this research effort will attempt to quantify sound levels and potential noise level reductions, it is important to understand the differences between how sound is quantified and how sound is perceived. A sound's loudness is a subjective, rather than an objective description of noise. This may vary from person to person and from sound-source to sound-source. As a result of extensive human testing, researchers have developed a correlation between objective differences in measured sound levels to the subjective response of listeners. **Table 2** provides a summary of measurable changes in sound levels and a description of the perceived change sensed by the listener. As shown, a 3 dBA change in sound is considered barely perceptible, and changes of less than 3 dBA are often imperceptible. A 5 dBA change is considered readily perceptible by most individuals. A 10 dBA increase in sound levels is typically perceived as a doubling of sound, and a 20 dBA increase in sound level is typically perceived as being 4-times as loud as the original level.

Table 2:	
Actual Sound Level Change (dBA)	Perceived Change in Sound Level
+ 20	Four times as loud
+10 dBA	Twice as loud
+5 dBA	Readily perceptible increase
+3 dBA	Barely perceptible increase
0 dBA	Reference level
-3 dBA	Barely perceptible reduction
-5 dBA	Readily perceptible reduction
-10 dBA	Half as loud
-20 dBA	One quarter as loud

Source: Acoustics and your Environment. The Basis of Sound and Highway Traffic Noise. Final Report. 1999.

In addition to noise varying in frequency (or tone), noise intensity also fluctuates with time. Highway traffic noise is never constant. The instantaneous noise level at a given location is constantly changing, based on the volume, speed, and composition of vehicles using a given roadway at a given time. To address the fluctuation of noise over time, highway-related noise assessments use the equivalent (energy-averaged) sound levels (or Leq) as the appropriate “descriptor” to evaluate existing and future noise levels. Leq is defined as the constant, steady-state sound level which, in a given period of time, contains the same acoustical energy as the time-varying level during that same period. Leq is essentially an average noise level over a given period of time, recognizing that the decibel is derived logarithmically. **Figure 1** provides a summary of how Leq is established at a given location. In **Figure 1** noise levels were monitored in a 20-minute period. As shown, instantaneous noise levels during this test ranged from approximately 42 to 61 dBA, with the 20-minute $Leq(20min)$ established at approximately 50 dBA. For ODOT and FHWA purposes, all evaluations are performed to represent the average “worst-case” one-hour periods in a given 24-hour day, represented $Leq(h)$. All levels are reported in A-weighted decibels (dBA). The use of this descriptor is appropriate to ensure that all noise level assessments are performed to address average “worst-case” conditions. These assessments are typically performed to evaluate “rush-hour” travel conditions, a period when peak-hour traffic volumes are traveling at “worst-case” speeds, producing worst-case hourly equivalent noise levels ($Leq(h)$).



Source: McCormick Taylor, 2006

3.2. CAUSES OF HIGHWAY TRAFFIC NOISE

Obviously, noise produced by a highway source is not produced directly by the highway itself, but rather by the individual vehicles using the highway. The principal noise sources of highway vehicles are the engine, the exhaust system, and the tires. Mechanical and aerodynamic noise sources are also present, but generally overshadow the principal noise sources identified above. Generally speaking, exhaust noise is typically controlled by vehicle mufflers, assuming that they are used and functioning properly. Engine noise, as well as most mechanical noise sources can only be controlled by vehicle manufacturers and by proper maintenance, factors that are typically beyond the control of ODOT and FHWA. Tire noise is generated by the interaction between each vehicle's tires with the roadway surface. Currently, considerable research is ongoing related to noise levels associated with the tire/pavement interaction. Pavement type and texture is one factor that is within the control of ODOT and FHWA, and will be explored throughout the next sections of this report.

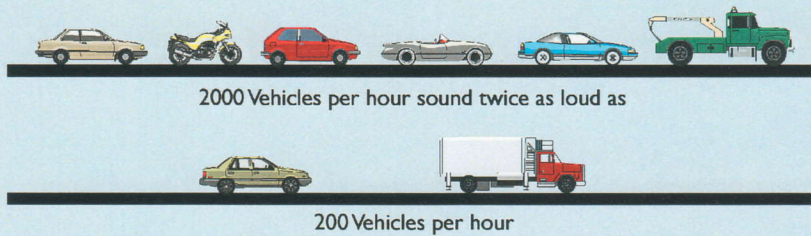
When considering the total noise produced by vehicles on a given roadway, engine and exhaust noise are usually louder than tire noise at vehicle speeds under 30 miles per hour (mph). At speeds greater than 30 mph, tire noise often becomes the dominant noise source from individual vehicles. Applying this rationale, highways and other arterial roadways are typically dominated by tire noise, while local roadways are typically dominated by engine and exhaust noise.

The overall noise level generated by a highway system depends on some additional factors, including the number of vehicles using the roadway, the speeds of the vehicles using the roadway, and the types of vehicles using the roadway. Generally, the loudness of traffic noise is increased by heavier traffic volume, higher speeds, and greater numbers of medium and heavy trucks. There are also many environmental and geographic factors that can influence the actual noise level at a given location adjacent to a roadway corridor. Any condition, such as steep roadway grades, that causes heavy laboring of motor vehicle engines will also increase traffic noise levels at a given location.

Figure 2 provides some general information related to how operational factors such as vehicle volume, speed, and composition can affect noise levels at a given location. As shown, a 10-fold increase in vehicle volume equates to a noise level increase of approximately 10 dBA, or a perceptible doubling in volume. Similarly, FHWA estimates that an increase in speed from 30 to 65 mph would also equate to a noise level increase of approximately 10 dBA, or a perceptible doubling in noise level (or volume). Related to the affects of vehicle composition, as shown in **Figure 2**, one heavy truck at 55 mph contains about the same acoustic energy as approximately 28 cars at that same speed. Given this comparison it is clear that composition of traffic (i.e., the percentages of heavy truck volumes) can have as much (or more) of an effect on final noise levels than volume or speed of traffic.

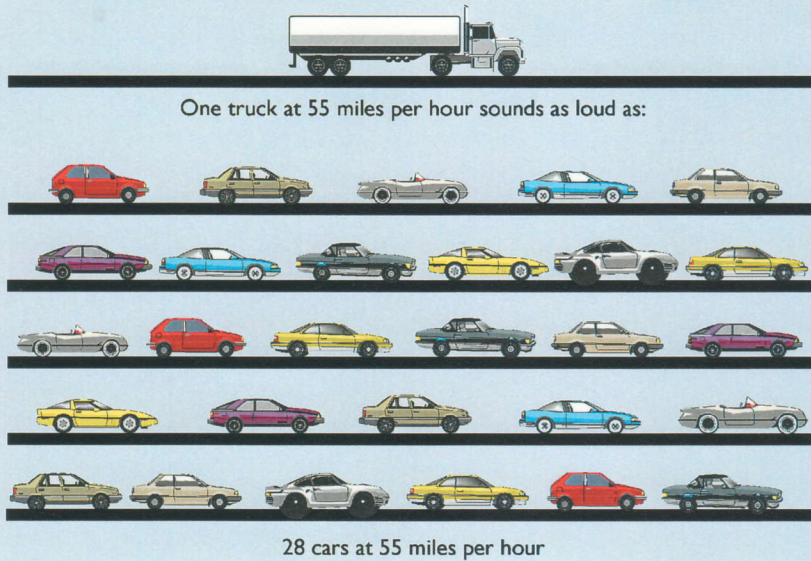
Figure 2: HOW TRAFFIC CHARACTERISTICS AFFECT NOISE LEVELS

HOW TRAFFIC VOLUME AFFECTS NOISE



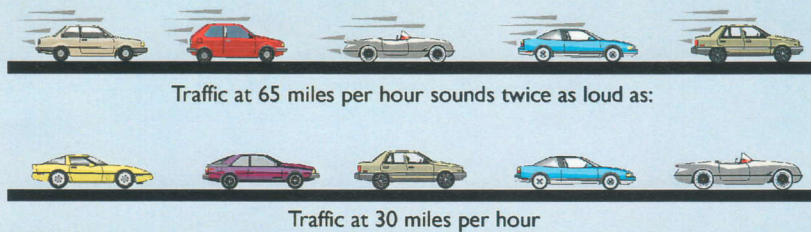
Source: *Making Sound Decisions About Highway Noise Abatement*, Pennsylvania Department of Transportation, 1999

HOW TRUCKS AFFECT TRAFFIC NOISE



Source: *Making Sound Decisions About Highway Noise Abatement*, Pennsylvania Department of Transportation, 1999

HOW SPEED AFFECTS TRAFFIC NOISE



Source: *Making Sound Decisions About Highway Noise Abatement*, Pennsylvania Department of Transportation, 1999

Sound propagation is another factor that should be discussed. The travel (or propagation) of traffic noise depends mainly on three factors: Atmospheric effects, ground effects, and spreading effects. Atmospheric conditions are constantly changing, and these conditions can continually affect how sound propagates from source to receiver. Considerable research is currently ongoing related to atmospheric effects on sound propagation. Generally, atmospheric effects are of greater concern when considering propagation over greater distances, with less impact to propagation directly adjacent to roadway corridors. While atmospheric effects can influence actual noise levels at a given location (and can change those levels from day to day), this factor is not currently considered overly significant at locations directly adjacent to a given roadway. These factors are also beyond the control of ODOT/FHWA, and generally outside of the scope of this study.

Ground conditions can also affect sound propagation. Sound will travel further over "hard", reflective surfaces than over "soft" surfaces covered by vegetation. This is generally due to sound absorption and scattering which occurs when sound travels over absorptive surfaces such as grassy fields or wooded areas. Finally, sound propagation is also affected by "spreading" effects, which diminish sound at a constant rate as the sound travels away from the source. Sound from a line-source (such as a highway) decreases at a rate of approximately 3 dBA per doubling of distance, when no other factors such as absorption are considered. Given this theory, noise levels of 65 dBA at 100 feet from the roadway would drop to 62 dBA at 200 feet (a doubling of distance); to 59 dBA at 400 feet (another doubling of distance); and to 56 dBA at 800 feet (another doubling of distance).

Other geographic factors can help to reduce noise levels at a given location. The presence of intervening terrain (or roadway cut-slopes) can shield the receiver from the source and ultimately reduce noise levels, when compared to areas with clear lines-of-sight to that same roadway. Based on a combination of all of the factors discussed above, as a person moves further away from a given roadway, traffic noise levels are typically reduced by distance, terrain, vegetation, and "shielding" provided by natural and manmade objects.

3.3. EFFECTS OF HIGHWAY TRAFFIC NOISE

Federal and state participation in highway noise studies is driven out of concern for the safety, health and welfare of people who are exposed to highway noise, including those who live, work, go to school, worship, or participate in active or passive recreation activities adjacent to highway corridors. Perhaps one of the most obvious concerns and one often questioned by the public, is the potential for physical hearing damage resulting from continued exposure to highway noise. Fortunately, transportation-related noise levels experienced along highway corridors are typically well below thresholds necessary to produce hearing damage [1]. Other effects of noise exposure include interference with certain activities, including sleeping, relaxation, conversation, study, or recreation activities [3]. Most of the effects of highway traffic noise can be classified as an annoyance or inconvenience; however, impacts associated with highway noise have also been blamed for depreciating property values and impacting the general quality of life adjacent to highway corridors.

Less obvious, but documented, is research suggesting the stress effects of noise. There is ample evidence that noise can cause stress, and thus may be a contributor to stress-related diseases, including anxiety and heart disease [1]. Given these social, personal, financial, and health concerns, FHWA and ODOT actively participate in a program to evaluate and mitigate for noise impacts associated with transportation improvement projects.