Bolt Beranek and Newman Inc.

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CALCULATION OF DAY-NIGHT LEVELS (L_{dn}) RESULTING FROM HIGHWAY TRAFFIC

Supplement

9 November 1979

DRAFT

Myles A. Simpson

Submitted to:

U.S. Environmental Protection Agency
Office of Noise Abatement
Washington, D.C. 20460

Attn: Mr. Steve Starley

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SUMMARY

Two calculation procedures are described in this manual for estimating the day-night sound level (L_{dn}) at locations near major roadways. Both procedures include the use of simple charts and graphs which are designed for individuals who do not have any experience or training in noise prediction or analysis.

The Direct method is a quick-look method designed to yield an approximate estimate of traffic noise exposure, which takes into account only major traffic and site characteristics. The Component method is a more detailed method designed to yield more accurate estimates, as well as the contribution of each category of vehicle on the roadway to the day-night level; it takes into account a variety of traffic, roadway and site characteristics.

PREFACE

This manual was prepared by Bolt Beranek and Newman Inc. under Contract No. 68-01-4388. Mr. Steven Starley was the Project Officer at EPA.

Within BBN, Mr. Harry Seidman was responsible for devlopment and production of the barrier attenuation charts included in Appendix A. Mr. Richard E. Burke assisted with review and with example problems. Mr. Dwight E. Bishop provided overall technical review and guidance throughout the project. Mr. Myles A. Simpson was the project manager and author of the manual.

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DEVELOPMENT OF THE DIRECT AND COMPONENT METHODS, AND COMPARISON WITH OTHER PREDICTION PROCEDURES

C-1. Highway Noise Prediction Framework

For a particular vehicle category, the hourly equivalent sound level L_{eq}, at a distance D feet from an "infinitely" long roadway lane over hard, flat terrain, with a volume of V vehicles, traveling at a speed S miles per hour, can be expressed as[C1]:

$$L_{eq} = EL + 10 \log \frac{V}{SD} + 1.7 \text{ dB}, \qquad \text{(C-1)}$$

where EL is the emission level of that vehicle category. (The emission level is the root-mean-square of the distribution of individual maximum sound levels for a large random distribution of vehicles for a specified category.)

In this manual, the following emission levels are used, at a distance of 50 feet from the path of the vehicle:

$$\left.\begin{array}{ll}
\text{Automobiles:} & EL = 18 + 30 \log S \\
\text{Medium Trucks:} & EL = 28 + 30 \log S \\
\text{Heavy Trucks:} & EL = 69 + 10 \log S \text{ for } S < 50 \text{ mph} \\
 & EL = 52 + 20 \log S \text{ for } S \geq 50 \text{ mph} \\
\text{Motorcycles:} & EL = 33.6 + 25.5 \log S \\
\text{Modified Motor-} & \\
\quad\text{cycles:} & EL = 47.6 + 25.5 \log S
\end{array}\right\} \qquad \text{(C-2)}$$

The day-night sound level, L_{dn}, for a particular vehicle category can be obtained by summation of the 24 hourly equivalent sound levels (with appropriate nighttime weighting applied), or, alternatively, according to the following:

$$L_{dn} = L_{eq} + 10 \log \frac{ADT}{24V} + 10 \log N_{eff}, \qquad \text{(C-3)}$$

where ADT is the 24 hour vehicle volume. N_{eff} is the effective nighttime weighting. If d is the percentage of the ADT occurring during the day (0700-2200 hrs) and n is the percentage occurring during the night (2200-0700 hrs), then

$$\begin{aligned} N_{eff} &= d + 10n \\ &= 1 + 9n, \end{aligned} \qquad \text{(C-4)}$$

since d + n = 1.

With the above equations, the L_{dn} can be determined at a distance D from a roadway lane over hard, flat terrain if values of ADT, S and n are known for a particular vehicle category:

$$L_{dn} = EL + 10 \log \frac{ADT}{24SD} (1 + 9n) + 1.7 \text{ dB} \qquad \text{(C-5)}$$

For terrain which is not hard and flat, an additional factor of -5 log D/50 is added to Equation C-5.

C-2. Development of the Direct Method

The Direct method considers only two vehicle categories, automobiles and heavy trucks. Substituting the emission level equations for these vehicle categories successively into Equation C-5, the automobile and heavy truck L_{dn}'s can then be added together for a total traffic L_{dn}.

By using the total ADT times the truck mix percentage H as the truck 24-hour volume, and the total ADT times (1-H) as the automobile 24-hour volume, Figures 3-2A and 3-2B of the Direct method were generated for values of H = 10%, S = 55 mph and n = 15% from the equation for the total L_{dn}. Figures 3-3 and 3-4 were generated from the same equation for other values of H, S, and n.

C-3. Development of the Component Method

As an alternate to Equation C-1, the hourly L_{eq} can be expressed in terms of the sound exposure level of a particular category of vehicle, rather than the emission level, as follows:

$$L_{eq} = SEL + 10 \log V - 35.6 \text{ dB} \tag{C-6}$$

Comparing Equations C-1 and C-6, the SEL at 50 feet can be expressed in terms of the emission level at 50 feet as:

$$SEL = EL - 10 \log S + 20.3 \text{ dB} \tag{C-7}$$

Using this equation and the emission level equation (C-2) for each vehicle category, sound exposure level equations for each category were determined; these are plotted in Figure 4-5 of the Component method.

Equations C-3, C-4 and C-6 can be combined in the following form:

$$\begin{aligned} L_{dn} &= SEL + 10 \log \frac{ADT}{24} (1 + 9n) - 35.6 \text{ dB} \\ &= SEL + K. \end{aligned} \tag{C-8}$$

Thus

$$K = 10 \log \frac{ADT}{24} (1 + 9n) - 35.6 \text{ dB}. \tag{C-9}$$

From Equation C-9, Figures 4-8A and 4-8B of the Component method were generated.

The attenuation provided by a noise barrier depends upon the path length difference, δ, between the direct path from the source to the receiver and the diffracted path over the top of the barrier, as illustrated in the top portion of Figure C-1. The attenuation for an "infinite" barrier, as a function of δ, is shown in the bottom portion of the Figure.

To generate the barrier attenuation contour charts, each source-barrier-receiver geometry was input into a computer program which calculated the path length difference at each point of a gridwork of points. The gridwork consisted of 20 points spaced 25 feet apart in the horizontal direction, and 31 points spaced 5 feet apart in the vertical direction. At each point, the computer determined the appropriate attenuation using the function depicted in Figure C-1. A surface fitting computer program then developed smooth contour lines by interpolating among the various grid point values.

C-4. Comparison With Other Prediction Methods

In the course of developing this manual, other traffic noise prediction methods were reviewed. The various methods currently available can be categorized by their primary usage as shown in Figure C-2. The first three methods were all developed for the primary purpose of permitting an accurate estimation of the noise from freely flowing traffic on major highways, in the design of highways and of noise abatement measures that are to be incorporated within the highway right-of-way. The 117 method is that contained within the National Cooperative Highway Research Program (NCHRP) Report 117[C2], the original "Design Guide" developed under Transportation Research Board sponsorship in 1971. The RDG method is the "Revised Design Guide"[C3], also developed under sponsorship of the Transportation Research Board. The FHWA method includes both the manual method[C4] of highway noise prediction as well as the latest version of the TSC computer program (Mod 04)[C5].

Because these three methods allow the user to take into account many of the details of a highway and its traffic flow, they are generally considered sophisticated (and, therefore, "accurate"). As shown on the figure, they can also be used in the assessment of environmental impact, and are often used in that area although the primary purpose is with regard to highway design.

The National Roadway Traffic Noise Exposure Model (NRTNEM)[C6] was developed by EPA specifically for the purpose of evaluating the relative noise impact of a variety of noise regulatory strategies. In this regard, the method does not permit the estimation of the noise level at a particular location in the vicinity of a roadway, but rather provides estimates of numbers of people exposed to different levels of noise nationwide. It is thus an assessment tool designed for a single specific purpose.

The Wyle method[C7], developed for EPA, is designed to be used in the assessment of environmental impact or the review of environment impact assessments performed by others.

Both the NBS[C8] and HUD[C9] methods are distinctly different from the preceeding methods in that they are designed for use by land use planners, design architects, and others concerned with land use planning and evaluating the acceptability of a potential development site with regard to its noise exposure. These methods are designed for use by non-acousticians and they therefore rely on simple charts and graphs for the estimation of traffic noise levels.

The NBS method for traffic noise incorporates the "Short Method" noise prediction graphs of the RDG. The HUD method is that in the revised "Noise Assessment Guidelines".

In the following, major elements of the various noise prediction methods will be compared.

C-4.1 Noise Prediction Framework

With the exception of the 117 method, all of the methods utilize a nearly identical framework in which an energy average level (either hourly L_{eq} or L_{dn}) is computed based on average passby (or emission) levels, the volume flow during the period of interest, the average speed, and the distance from the highway to the observer. The 117 method provides L_{10} and L_{50} estimates for hourly periods.

C-4.2 Noise Emission Characteristics

All of the methods have incorporated within them noise emission characteristics for different categories of vehicles. Figure C-3 displays these emission levels as a function of speed. The confused array of lines on the figure are divided into three categories: automobiles, medium trucks, and heavy trucks (all for cruise conditions). It should be noted that the 117 and Wyle methods do not include a medium truck category; the NRTNEM method includes 14 different categories, but for purposes of comparison with the other methods only automobiles, medium trucks and heavy trucks are shown on the figure.

As can be seen in the figure, there is considerable scatter among the various emission levels, particularly for heavy trucks. The scatter is somewhat reduced for the speed range from 30 to 60 miles per hour, the range of most interest for highway noise prediction purposes. Over this speed range, the range in emission levels for automobiles is under 2 dB, for medium trucks just over 2 dB, and as much as 6 dB at the lowest speed for heavy trucks.

It is clear from Figure 1 that is is not possible to select noise emission characteristics that will be consistent with those of every agency, or even with those in different EPA methods. Because of the intended use of this Manual (i.e., land use planning), the selected noise emission characteristics are those of the HUD method. These would be identical to those of the RDG and NBS methods for automobiles and medium trucks, and would vary from the heavy truck characteristics by less than 2.5 dB over the range from 30 to 60 mph.

In comparison with the noise emission characteristics in the two current EPA methods, the characteristics in this manual for automobiles would vary by less than 1 dB for the Wyle method and by less than 0.5 dB for the NRTNEM method; they would vary by less than 2.5 dB for medium trucks for the NRTNEM method; and for heavy trucks they would vary by less than 1 dB for the Wyle method and less than 3 dB for the NRTNEM method (over the 30 to 60 mph range).

In summary, the noise emission characteristics in this manual for automobiles and medium trucks are consistent with those in the RDG, HUD and NBS methods, and are within 2.5 dB of those in both EPA methods and the FHWA method. The noise emission characteristics in this manual for heavy trucks are consistent with those in the HUD method, and within 4 dB of those in the other methods (with the greatest differences occurring at low speeds).

C-4.3 Propagation Characteristics

Most of the noise prediction methods utilize either a 3 dB or a 4.5 dB dropoff rate per doubling of distance from 50 feet, or both, to represent the attenuation of sound with distance from the highway over open terain. Figure C-4 summarizes the propagation rates used in each method. The Wyle method uses a somewhat different approach, but this results in a rate that is identical to the 3 dB rate, within 1 dB. The NRTNEM model uses much different dropoff rates, because the attenuation resulting from buildings located between the highway and the observer is included within the propragation rate (in the other methods this shielding attenuation is determined separately and added to the open terrain attenuation).

In this manual, a 3 dB rate is used for "Urban" terrain, and a 4.5 dB rate is used for "Suburban/Rural" terrain.

C-4.4 Adjustments for Roadway/Site Characteristics

For the sake of consistency, various roadway and site adjustments incorporated within this manual are adapted directly from the HUD and RDG methods, where possible. The adjustments for roadway gradient, stop signs, shielding elements that are less than "infinite", and the area classification adjustment to the barrier attenuation are taken from the HUD method, and are further documented in Reference C10. The adjustments for roadway surface, buildings, and vegetation are taken from the RDG method, and are further documented in Reference C1. The barrier attenuation curve shown in Figure C-1 was derived in Reference C11. This curve, in various forms, is incorporated in the RDG, FHWA, Wyle, and HUD methods.

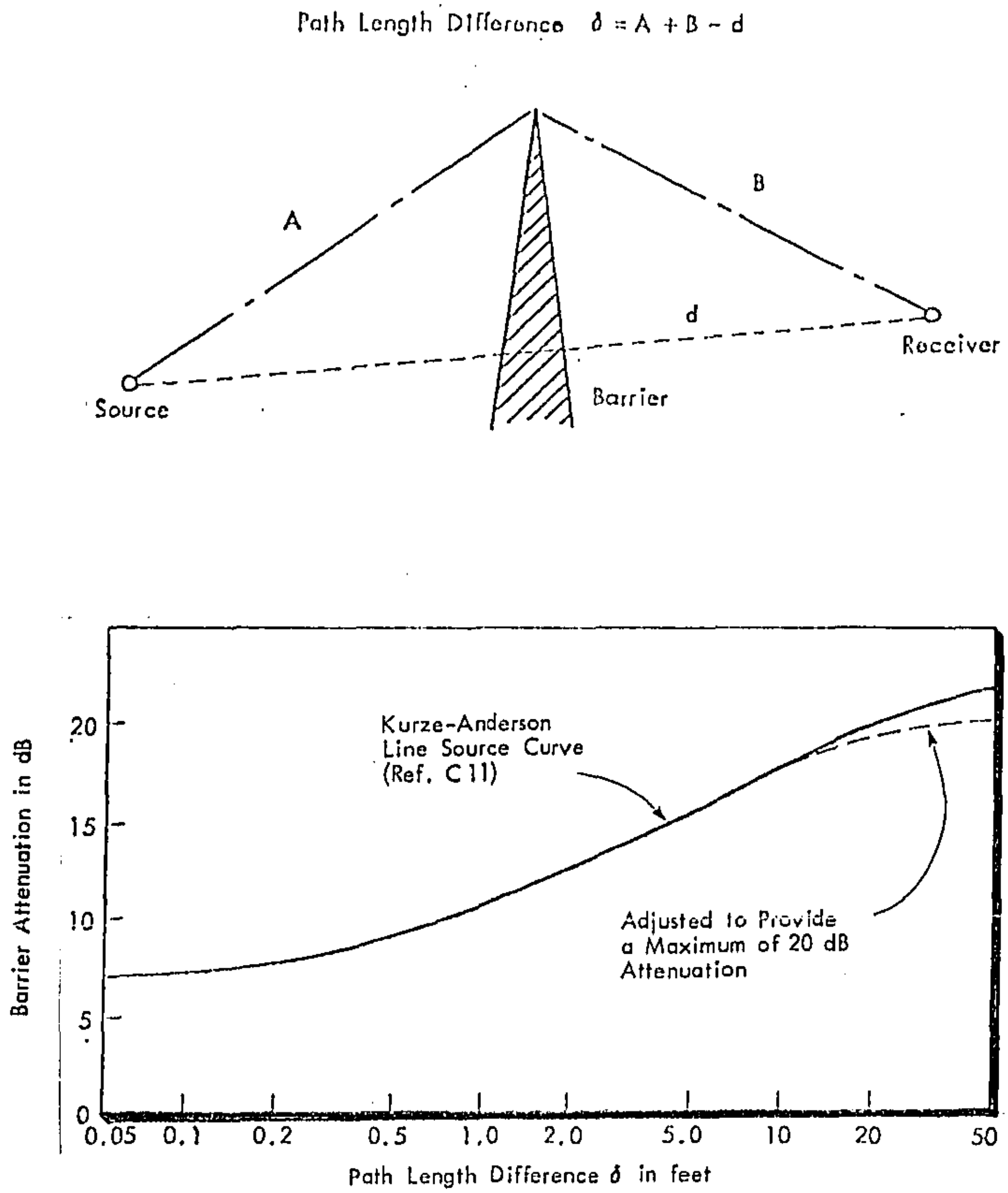

FIGURE C-1. BARRIER ATTENUATION FOR A LINE OF INCOHERENT POINT SOURCES

FIGURE C-2

CLASSIFICATION OF HIGHWAY NOISE PREDICTION METHODS BY USAGE

Method	Highway Design	Environmental Impact Assessment	Land Use Planning, Site Acceptability Assessment
117 (TRB)	P	S	
RDG (TRB)	P	S	
FHWA	P	S	
NRTNEM (EPA)		P	
WYLE (EPA)		P	
NBS			P
HUD			P
EPA Manual			P

Note: P = primary use
S = secondary use

REFERENCES	
117 (TRB)	C2
RDG (TRB)	C3
FHWA	C4,5
NRTNEM (EPA)	C6
WYLE (EPA)	C7
NBS	C8
HUD	C9

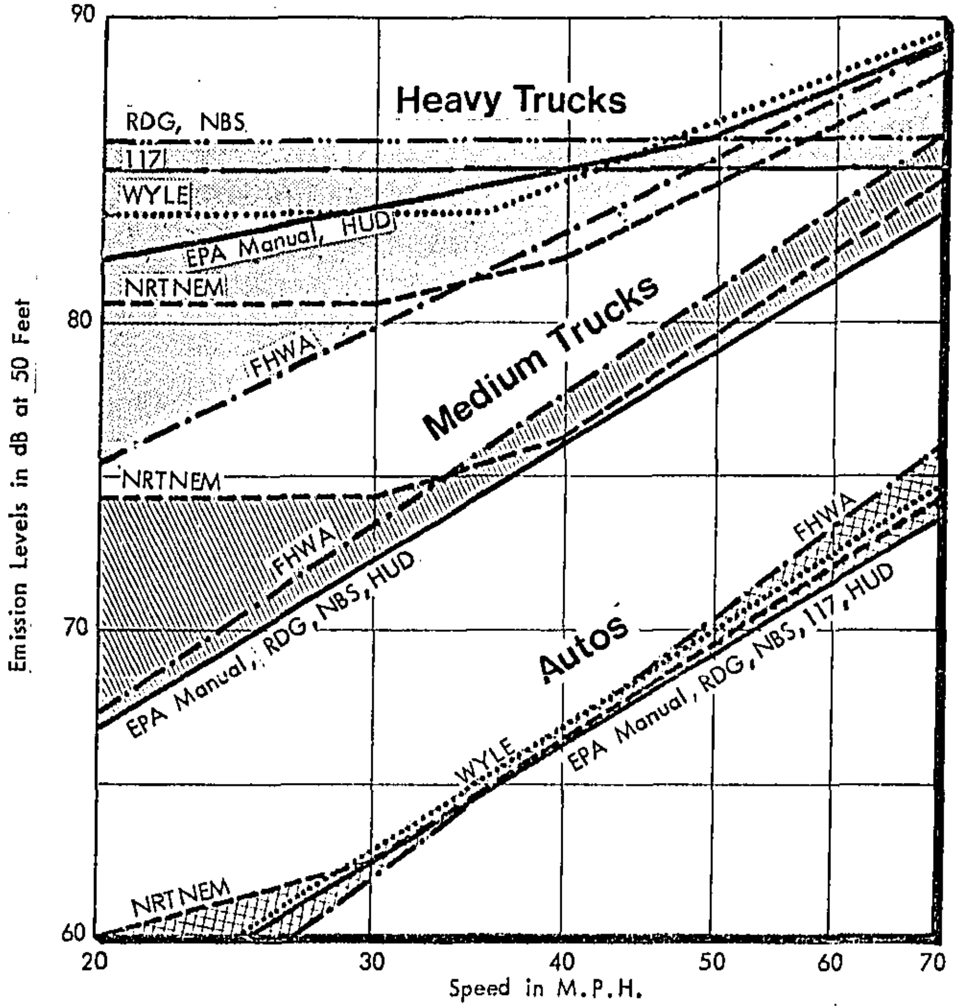

FIGURE C-3. COMPARISON OF VEHICLE NOISE EMISSION LEVELS

FIGURE C-4

PROPAGATION RATES USED IN DIFFERENT PREDICTION METHODS

Method	3 dB per Distance Doubling	4.5 dB per Distance Doubling
117		X
RDG		
Reflective Ground	X	
Absorptive Ground		
Observer ≥ 10 ft. high	X	
Observer < 10 ft. high		X
FHWA		
Reflective Ground	X	
Absorptive Ground		
Observer ≥ 10 ft. high	X	
Observer < 10 ft. high		X
NBS		X
HUD		X
EPA Manual		
Urban Area	X	
Suburban/Rural Area		X

APPENDIX C REFERENCES

C1. "Highway Noise, Generation and Control", NCHRP Report 173, Washington, D. C., 1976.

C2. "Highway Noise, A Design Guide for Highway Engineers", NCHRP Report 117, Washington, D. C., 1971.

C3. "Highway Noise, A Design Guide for Prediction and Control", NCHRP Report 174, Washington, D. C., 1976.

C4. "FHWA Highway Traffic Noise Prediction Model", FHWA-RD-77-108, Washington, D. C., 1977.

C5. "Users Manual: TSC Highway Noise Prediction Code: Mod-04", Report No. FHWA-RD-77-18, Washington, D. C., 1977.

C6. "National Roadway Traffic Noise Exposure Model, Part III: Data Base Description", Draft EPA Report, Washington, D. C., April 1979.

C7. "Highway Noise Impact", EPA Report 550/9-77-356, Arlington, Virginia, 1977.

C8. "Design Guide for Reducing Transportation Noise in and Around Buildings", NBS Building Sciences Series 84, Washington, D. C., 1978.

C9. "Noise Assessment Guidelines", revision of HUD Report TE/NA-171, BBN Report 4003R (draft), July 1979.

C10. "Noise Assessment Guidelines-1979, Technical Background", BBN Report 4024 (draft), submitted to HUD, August 1979.

C11. Kurze, U. J. and Anderson, G. S., "Sound Attenuation by Barriers", <u>Applied Acoustics</u> 4, 1971.

APPENDIX D

GLOSSARY AND LIST OF SYMBOLS

D-1. Glossary

A-Weighted Sound Level: The sound level, in decibels, obtained when an acoustic signal is filtered through the A-weighting network of a sound level meter. The A-weighted sound level is a widely accepted measure of the magnitude of traffic noise.

Area Classification: Classification of the terrain between the observer location and the roadway as either urban or suburban/rural. As used in this manual, an area is classified as urban if the ground between the observer and the roadway is paved. An area is classified as suburban/rural if the ground is irregular, and/or has ground cover, shrubery, occasional trees, etc.

At-Grade Roadway: A roadway that is level with the immediate surrounding terrain.

Automobiles: All vehicles with two axles and four wheels. In this manual, the category of automobiles includes vehicles designed primarily for transportation of passengers, as well as vehicles designed for cargo transportaion (i.e., light trucks). Automobiles generally have a gross vehicle weight of less than 10,000 pounds.

Average Daily Traffic: The number of vehicles that pass over a given roadway during a one day period. The average daily traffic is calculated by determining the total number of vehicles during a given time period in whole days, and dividing by the number of days in that period. If this time period is one year, the average so determined is termed the annual average daily traffic.

Background Noise: The noise at an observer location that is not attributable to a specific noise source.

Barrier: A solid wall or earth berm located between the roadway and observer location, which breaks the line-of-sight between the observer and the roadway noise sources.

Barrier Attenuation: The change in noise level at an observer location caused by the diffraction (or bending) of sound waves over the top or around the sides of a barrier.

Barrier Height: The height of a noise barrier, in feet, above the roadway level.

Centerline Distance: The distance, in feet, between the observer location and the centerline of the roadway.

Component Day-Night Sound Level: The day-night sound level at an observer location resulting from a single vehicle category on a roadway nearby.

Day-Night Sound Level: The energy-average of the A-weighted sound levels occurring during a 24-hour period, with 10 decibels added to the A-weighted sound levels occurring during the period from 10 p.m. to 7 a.m., in decibels.

Depressed Roadway: A roadway that is constructed below the immediate surrounding terrain.

Effective Distance: The distance, in feet, from the observer at which all traffic noise sources on a roadway can be considered to be located for noise prediction purposes.

Elevated Roadway: A roadway that is constructed above the immediate surrounding terrain, either on a land fill or a structure.

Far Lane Distance: The distance, in feet, between the observer and the far edge of the far lane of the roadway.

Gradient: The change in roadway elevation, per 100 feet of roadway, expressed as a percentage.

Heavy Trucks: All vehicles with three or more axles. Heavy trucks generally have a gross vehicle weight in excess of 26,000 pounds.

Heavy Truck Percentage: The average number of heavy trucks in a 24-hour period divided by the average daily traffic, expressed as a percentage.

Hourly Equivalent Sound Level: The energy-average of the A-weighted sound levels occurring durina a one hour period, in decibels.

Line-of-Sight: A straight line between the observer location and a specific noise source.

Medium Trucks: All vehicles with two axles and six wheels. Medium trucks generally have a gross vehicle weight of between 10,000 and 26,000 pounds.

Modified Motorcycle: A motorcycle equipped with an exhaust system which has been altered in a manner which will amplify or increase its emitted noise above that of the exhaust system originally installed on the motorcycle.

Motorcycles: All vehicles having a saddle for the use of the rider and designed to travel on not more than three wheels in contact with the ground, except such vehicles powered by engines not to exceed 5 horsepower and farm tractors.

Near Lane Distance: The distance, in feet, between the observer and the near edge of the near lane of the roadway.

Nighttime Percentage: The number of vehicles passing over the roadway between the hours of 10 p.m. and 7 a.m., divided by the average daily traffic, expressed as a percentage.

Noise Level Reduction: The change in noise level at an observer location due to the presence of a shielding element between the roadway and the observer.

Noise Source: A specific device which generates noise. In this manual, the noise sources considered are automobiles, medium and heavy trucks, and unmodified and modified motorcycles.

Observation Angle: The angles, in degrees subtended by the ends of a roadway as measured at the observer location.

Observer Distance: The distance, in feet, between the observer and the noise barrier.

Observer Location: The location at which noise levels from the roadway are estimated. The observer location in this manual is taken as five feet above ground level.

Population Density: The number of people residing in a small geographic or demographic region which includes the observer location, divided by the total land area in square miles of that region.

Propagation Path: The path over which sound travels between a specific noise source and the observer location.

Segment: A section of roadway with uniform roadway and traffic characteristics. Segments which continue far into the distance are said to have "indefinite" ends, while segments which terminate at specific locations are said to have "definite" ends.

Segment Angle: The angle, in degrees, subtended by the ends of a segment as measured at the observer location.

Shielding Angle: The angle, in degrees, subtended by the ends of a shielding element as measured at the observer location.

Shielding Element: An element located between the roadway and observer which causes a reduction in noise level at the observer location. In this manual, the shielding elements considered are barriers, buildings, and vegetation.

Shielding Ratio: The ratio of the shielding angle measured at an observer location to the segment angle measured at the same location.

Sound Exposure Level: The energy sum of the A-weighted sound levels, in dB, occurring during the time interval of a specific event, in decibels, normalized to a one-second duration.

Source Distance: The distance, in feet, between a specific noise source and a noise barrier.

Source Height: The height, in feet, of a specific noise source above the roadway level. In this manual, source heights are 8 feet for heavy trucks and 0 feet for all other vehicles.

Speed: The average rate of movement of vehicular traffic, in miles per hour.

Surface Condition: The condition of the roadway pavement, classified as either normal, smooth or rough in this manual. Normal condition indicates a moderately rough asphaltic and concrete surface. Smooth condition indicates a very smooth, seal-coated, asphaltic pavement. Rough condition indicates a rough asphaltic pavement with large voids (at least 1/2 inch in diameter), or grooved concrete.

Top of Cut: That line corresponding to the cut line in depressed roadways.

Vehicle Category: Classification of roadway vehicles into categories with uniform noise characteristics. In this manual, the vehicle categories used are automobiles, medium trucks, heavy trucks, motorcycles and modified motorcycles.

D-2. List of Symbols

A - Area classification
ADT - Average daily traffic

D_B - Source distance (to barrier)
D_C - Centerline distance (to observer)
D_E - Effective distance (observer to roadway)
D_F - Far lane distance
D_N - Near lane distance
D_O - Observer distance (to barrier)

H - Heavy truck percentage
H_B - Barrier height
H_S - Source height

L_{eq} - Hourly equivalent sound level
L_{dn} - Day-night sound level

N - Nighttime percentage
NLR - Noise level reduction

S - Speed
SEL - Sound exposure level