INTRODUCTION AND HISTORY OF HIGHWAY
NOISE PREDICTION METHODS

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As concern with the quality of our environment has grown throughout the world, so too has the need for design tools to evaluate the impact of man's activities on the environment. Of man's many activities, his transportation systems seem to cause the greatest adverse impact, especially due to noise, an undesirable by-product of most moving vehicles. Thus, the growing interest and concern with highway traffic noise. In general, simple simulation models of highway noise levels sufficed for a number of years to compare the relative results of different highway designs, so that relative numbers were sufficient for design evaluation purposes. But, inevitably, absolute numbers must be attached to the results of these simulation calculations, either because of imposed regulations or because of the acceptance of criterion limits intended to maintain the noise levels below reasonable values. As a result, the comparison becomes the real world, and absolute accuracy becomes important to the estimating or simulation procedure.

Highway traffic noise prediction entails the usual basic components of sound generation and propagation—the basic noise source (the vehicle); the interaction of a stream of such sources; the propagation of that sound through the atmosphere; and the effects of obstacles in the propagation path, whether those obstacles are there intentionally to reduce the noise or accidentally as the result of natural topography. Any practical prediction procedure must represent accurately each of these basic components.

Prediction procedures must also consider two other important factors—the noise unit or statistic necessary to represent the impact of the noise on the receiver (the public or highway neighbor), and the mechanics of the procedure itself (manual tabularized computations, nomograph, or computer). These two factors are not so much the subject of this workshop. Even those intimately involved in researching the effect of transportation noise on people cannot agree on the relative merits of L_{10}, L_{eq}, L_{dn}, NPL, TNI, and nauseam. So, we need not waste our time arguing these relative merits ourselves. Similarly, the mechanical format of the procedure is largely irrelevant. If the basic acoustical and mathematical relationships are accepted, these can be arrayed in any number of convenient formats, to the liking of the user.

The purpose of this paper is to examine the basic components of those procedures that are in use, in order to understand their similarities and their differences. Ideally, there should be one simple, universally accepted procedure that provides accurate answers for all practical real-life situations. Recognizing the absurdity of that dream, however, we must instead look to what is available, where these may be deficient, and how they may be improved, if improvement is needed.

The first attempt to represent traffic noise, which I was able to find in the literature, was presented in the 1952 Wright Air Development Center Handbook of Acoustic Noise Control (1). The time-averaged overall sound pressure level was represented by

$$L_{50} = 68 + 8.5 \log (V) - 20 \log (D) \quad \text{dB}$$

where

V = traffic volume in vehicles/hour (vph)
D = distance from traffic lane, in feet.

This relation was indicated for use for average speeds of 35-45 mph (56-72 km/h) and distances greater than 20 ft (6.096 m).

At the Fifth International Congress on Acoustics in 1965, Nickson(2) suggested that traffic noise level could be represented by

$$L_{50} = 50 + 10 \log (V/D) \quad \text{dBA}$$

for vehicles traveling at a mean speed of 40 mph (65 km/h) and a 10 percent commercial vehicle composition. At the same Congress, Lamure(3) proposed an equation corresponding to

$$L_{50} = 52 + 10 \log (V/D) \quad \text{dBA}$$

for traffic volumes in the range of 1200 to 5000 vph containing not more than 15 percent heavy vehicles.

In 1968, Johnson and Saunders(4) developed a more complex relation based on series of traffic noise measurements made in England during 1963 to 1965:

$$L_{50} = 3.5 + 10 \log (VS^3/D) \quad \text{dBA}$$

where S represents the mean vehicle speed in miles per hour (mph). Based on the measured cases, this relation was assumed valid for a traffic mix of 20 percent heavy vehicles, although their data indicated agreement within ± 1 dB over the range of 0 to 40 percent mix of heavy vehicles. The authors also recognized the effects of excess attenuation due to ground cover, and of roadway gradients, and included correction factors for these effects.

In 1968, NCHRP Report 78(5) published the results of Galloway's Monte Carlo simulation of traffic noise levels. Galloway's model simulated a static array of vehicles distributed randomly along a roadway and summed their noise levels at specified points off the roadway. By repeating different static arrays but maintaining vehicle density, he generated statistically time-weighted noise levels, which he approximated by the relation:

$$L_{50} = 20 + 10 \log (VS^2/D) + 0.4\,T \quad \text{dBA}$$

where T represents the percentage of total vehicular flow composed of heavy trucks.

In 1971, NCHRP 117(6) contained the most widely used traffic noise prediction method, representing light-vehicle and heavy-vehicle contributions separately:

(cars) $$L_{50} = 29 + 10 \log (VS^2) - 15 \log (D) + 10 \log [(\tanh (.00119\,VD/S)] \quad \text{dBA}$$

(trucks) $$L_{50} = 95 + 10 \log (V/S) - 15 \log (D) + 10 \log [(\tanh (.00119\,VD/S)] \quad \text{dBA}$$

The noise levels from the two streams of traffic are added (on an energy basis) to obtain the total traffic noise level. An additive factor is also included for calculating L_{10} values from the total L_{50} level. Two new concepts were included in these relations. First, the sound levels fall off with distance at the rate of 4.5 dB per double-distance (15 log D), rather than the usual 3 dB per double-distance (10 log D) characteristic of a line sound source (the traffic stream). Second, truck noise is essentially independent of truck speed and only depends on truck density (vehicles per mile). The NCHRP 117 procedure was subsequently programmed for a time-shared computer by the Michigan Department of State Highways and Transportation.

In 1972, the so-called TSC method was published(7) to provide a computerized highway noise prediction method. Similarly with the NCHRP 117 method, the TSC method calculates light-vehicle and heavy-vehicle noise levels separately and sums them to obtain the total noise. The TSC method also includes a third class of vehicles, for which the octaveband spectrum can be specified and the resultant noise added to the levels calculated for light vehicles and heavy vehicles. The basic relation in the TSC procedure is

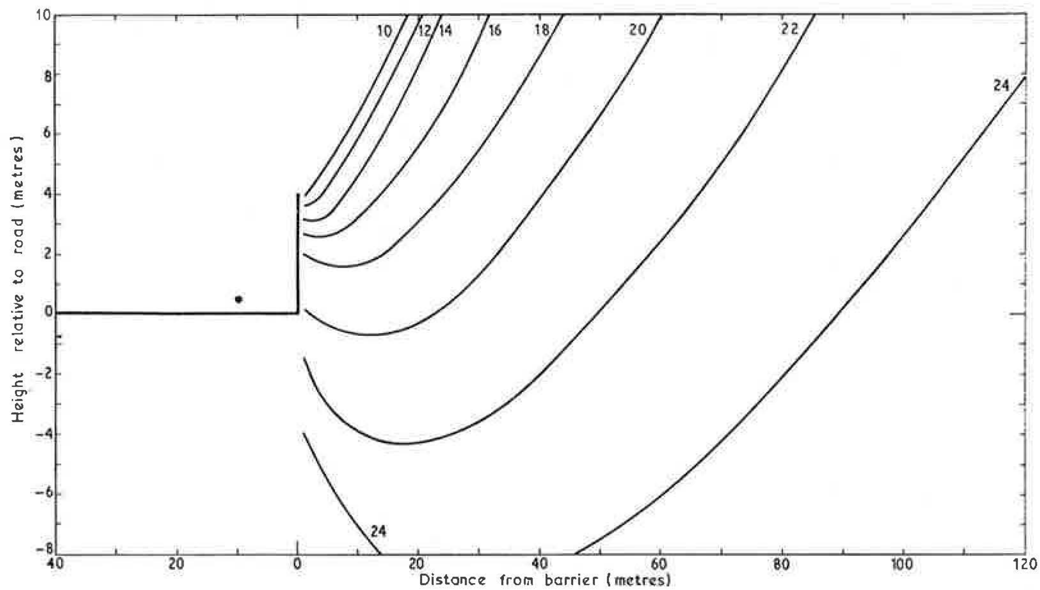
$$L_{eq} = 2.4 + L_{50}' + 10 \log (V/DS) - A \quad \text{dBA}$$

where A represents the sum of various attenuation facturs, due to the atmosphere, ground absorption (shrubbery and thick grass, or tree zones), barriers, and reflections. The TSC manual also includes a simple pencil-and-ruler nomograph for first-approximation calculations of L_{10} levels. Statistical relationships were included in TSC computer program for converting the basic L_{eq} values to L_{10}, L_{90}, L_{50}, and NPL. Also in 1972, Delany(8) published a manual for calculating L_{10} levels from highway traffic noise in support of the British Land Compensation Act of 1973. Delany based his model on analyses of traffic noise measurements in Great Britain and through regression analyses obtained the relation:

$$L_{10} = 21.4 + 8.9 \log (V) + 16.2 \log (S) + .117T \quad \text{dBA @ 10 m.}$$

He then entered distance into his calculations through a series of cross-sectional contours, which included the effects of a variety of barriers (see Figure 1).

Figure 1.



4 metre high barrier, 10 metres from traffic stream

Figure 2.

HIGHWAY TRAFFIC NOISE PREDICTIONS

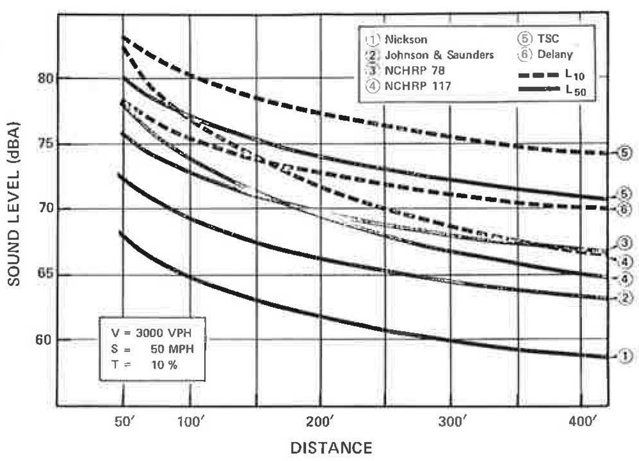
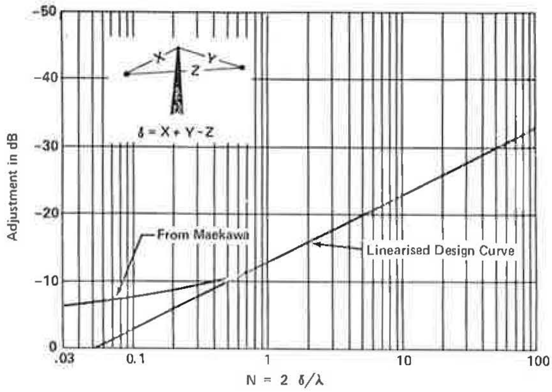
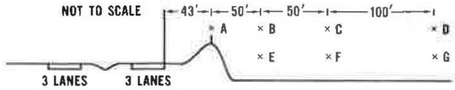


Figure 3.



$$D_B = \begin{cases} 0 & \text{for } N \le -0.2 \\ 20\log\left(\dfrac{\sqrt{2\pi|N|}}{\tan\sqrt{2\pi|N|}}\right) + 5 \text{ dB} & \text{for } -0.2 < N \le 0 \\ 20\log\left(\dfrac{\sqrt{2\pi N}}{\tanh\sqrt{2\pi N}}\right) + 5 \text{ dB} & \text{for } 0 < N \le 12.5 \\ 24 \text{ dB} & \text{for } N > 12.5 \end{cases}$$

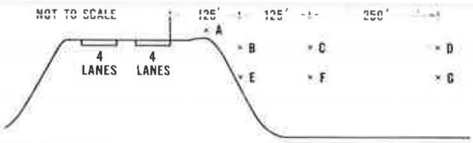
Figure 4.



	A	B	C	D
MEASURED L_{10}(dB(A))	73.1	58.9	56.7	54.7
NCHRP 117	69.2	55.1	52.1	50.9
TSC	71.6	68.2	68.5	63.7

	A	E	F	G
MEASURED L_{10} (dB(A))	73.6	57.0	54.3	53.0
NCHRP 117	71.2	51.1	48.1	45.1
TSC	70.6	54.8	55.1	54.6

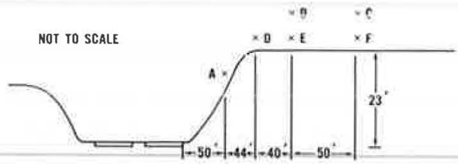
Figure 5.



	A	B	C	D
MEASURED L_{10}(dB(A))	81.2	67.1	68.6	67.3
NCHRP 117	78.5	64.3	63.4	61.6
TSC	83.2	68.6	71.5	72.7

	A	E	F	G
MEASURED L_{10}(dB(A))	81.6	63.4	65.7	67.9
NCHRP 117	78.5	64.8	63.9	62.1
TSC	84.1	66.7	67.1	71.1

Figure 6.



	A	B	C
MEASURED L_{10}(dB(A))	85.9	79.6	73.2
NCHRP 117	83.5	70.6	67.0
TSC	85.3	79.4	74.5

	A	D	E	F
MEASURED L_{10}(dB(A))	85.4	78.2	74.0	69.2
NCHRP 117	77.9	74.8	68.8	65.1
TSC	84.0	81.9	77.9	77.9

More recently, J. J. Hajek(9) and NCHRP Project 3-7/3(10) have also published additional highway noise prediction procedures. These will both be described in more detail in later papers.

Quite obviously, the use of these several relations, described briefly above, will result in somewhat different answers for highway noise levels. Figure 2 displays the results for an assumed situation—single lane, 3000 vph, 10 percent trucks, at 50 mph (80 km/h).

The NCHRP 117 (with the subsequent revisions of NCHRP 144), TSC, and Delany procedures noted above also include provisions for calculating the effects of barriers in the vicinity of the highways under study. All three are based on the work of Maekawa(11). either in graphical form or mathematical representation (Figure 3). The addition of the barrier component will, of course, cause further differences in the results of noise level predictions since another factor is introduced. For example, Figures 4 through 6 illustrate the results of comparisons using the NCHRP 117 procedure (Michigan computerized version) and the TSC procedure to reproduce some of the measurements made preliminary to the NCHRP 144 revision. There seems to be no logical pattern among these results. And, I am sure, we will hear similar inconsistencies and lack of agreement with predictions and the real world throughout this workshop.

Thus, our problem. Is there a "best" highway traffic noise prediction procedure? Can the "best" procedure be further improved? Can we achieve consistency in predicting highway traffic noise levels?

References

1. Handbook of Acoustic Noise Control. WADC Technical Report 52-204, Wright Air Development Center, 1952.

2. A. F. Nickson. Can Community Reaction to Increased Traffic Noise be Forecast? Proc. Fifth International Congress on Acoustics, 1965

3. C, Lamure. Niveaux de Bruit au Voisinage des Autoroutes. Proc. Fifth International Congress on Acoustics, 1965.

4. D. R. Johnson, and E. G. Saunders. The Evaluation of Noise from Freely Flowing Road Traffic. Jour. Sound and Vibration, Vol. 7, No. 2, pp. 287-309, 1968.

5. W. J. Galloway, W. E. Clark, and J. S. Kerrick. Urban Highway Noise: Measurement, Simulation, and Mixed Reactions. NCHRP Report 78, 1969.

6. C. G. Gordon, W. J. Galloway, B. A. Kugler, and D. L. Nelson. Highway Noise: A Design Guide for Highway Engineers. NCHRP Report 117, 1971.

7. J. E. Wesler. Manual for Highway Noise Prediction. Report DOT-TSC-FHWA-72-1, 1972.

8. M. E. Delany. A Practical Scheme for Prediction Noise Levels (L_{10}) Arising from Road Traffic. NPL Acoustics Report Ac 57, 1972.

9. J. J. Hajek. Ontario Highway Noise Prediction Method. Report RR197, 1975.

10. B. A. Kugler, D. E. Commins, and W. J. Galloway. Design Guide for Highway Noise Prediction and Control. BBN Report 2739, NCHRP Project 3-7/3, 1974.

11. Z. Maekawa. Noise Reduction by Screens. Applied Acoustics, Vol. 1, pp. 157-173, 1968.