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AREA COMPUTER MODEL FOR TRANSPORTATION NOISE PREDICTION

Phase II--Improved Noise Prediction Methods

by

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FOREWORD

This report covers work in support of the development of an area computer model for the prediction of transportation noise known as the NOISE 3 computer program.

The supporting study covered various methods of rating noise, their use by different agencies for the control of environmental noise, and presently available methods for the prediction of noise levels along highways.

It is recommended that NOISE 3 initially use the same basic logic as the present MICNOISE program for highway noise prediction, except that additional options shall be available, such as more flexibility in specifying vehicle noise sources. A choice of six noise ratings is recommended, including L_{dn}, the day-night level now being proposed by the EPA for general use.

NOISE 3 results will be posted on maps of the road network, using the XYNETICS contour program until a new contour program now under development becomes available.

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INTRODUCTION

This report covers a study carried out to support the development of the NOISE 3 area computer model for transportation noise prediction.

Previously, under the Phase I working plan,(1) a simple area model program referred to as NOISE 1 had been developed. That program is described in an earlier report.(2) The current effort was carried out under the Phase II working plan.(3) Details of the NOISE 3 model will be released with a user's manual following a full checkout of the program.

Currently, noise levels are calculated at selected points near highways by the MICNOISE computer program, but its program format is such that all of the relevant data must be fed to the computer for every point at which levels are required. Under the area model concept, noise levels are developed over an area covered by a network of roads, and are presented either in listings or in contour plots.

In contrast to MICNOISE, the area model concept allows for the collection of one data base for all of the highway coordinates including elevations; another for "ridge-line" features, which includes barriers and highway shoulders; another for traffic counts; etc. To calculate the noise level at a given point, one has merely to include the coordinates of that point in a list of data input. Thus a great amount of computer input preparation and computer running time can be avoided using the area concept.

Assuming the ultimate availability of a contour plotting program, noise level contours will become available on transparent paper so that they can be readily overlaid over maps. It is expected that possible applications will include

1. Proof of compliance with Federal Highway Administration (FHWA) requirements

2. Design analysis of noise barriers

3. Reports under Continuing Comprehensive and Cooperative Transportation Planning Program

4. Environmental engineering support for highway location, design, and improvement

5. Impact statements

6. Land-use planning

The study covered by this report was carried out to permit some basic decisions about the analysis of noise levels that would be incorporated into the NOISE 3 computer program. These decisions have been formulated into the recommendations listed at the end of this report, most of which have already been incorporated into the NOISE 3 program.

The most important decision to be made was how to report noise levels on a unified basis so that levels contributed by aircraft and by stationary sources could be included into the highway noise levels to form one overall level. In this connection, it is noted that the Environmental Protection Agency (EPA)[4] has requested that all government agencies use L_{dn} or L_{eq}* (the equivalent day-night level in decibels, and the equivalent level for a specified period, respectively) for reporting all environmental noise. There should be no difficulty in adapting most systems of rating environmental noise to the L_{eq}/L_{dn} format. However, there is a problem with airport environs, because, although it is feasible to calculate L_{dn} values for aircraft, current practice is to calculate NEF, so that the required data base for L_{dn} may not always be available unless the Federal Aviation Administration (FAA) concurs with the EPA's requests. At present, NOISE 3 provides options for up to six descriptors which cover both the FHWA and the EPA requirements.

Another decision to be made has been whether to calculate effects of tire noise, engine noise, etc. separately. This capability is planned as an option in NOISE 3.

*The various noise descriptors referred to in the introduction are defined in the text.

Consideration of an overall impact factor has not led to any firm recommendation because of the lack of any national consensus on how to do this. Also, consideration of developing programs for optimum highway location has been deferred until a better idea is gained of the computer times required.

Initially, NOISE 3 will use the MICNOISE model. However, this model is contained in one subroutine that can be changed in the future.

This report covers a review of methods of rating noise, a review of present limits on noise levels set by various agencies, a summary of present methods of predicting highway noise, descriptors of the NOISE 1 and NOISE 3 programs, and final recommendations.

DESCRIPTORS FOR RATING NOISE LEVELS

Environmental sound pressure levels are generally found initially in terms of the A-weighted decibel level LA (also referred to as the "overall A-weighted sound pressure level", or OASPL), or the band levels, Li, where i = 14, 15 . . . 43 for third-octave bands and i = 15, 18 . . . 42 for one-ocatve bands. The linear level, L (also referred to as the "overall sound pressure level", or OSPL), B-, C-, or D-weighted levels are rarely used.

However, where long-term or daily fluctuations occur, an overall average is generally obtained, while for short-term fluctuations such as in transportation noise, a statistical value is often given. Where frequency content is important, some method of summing the bands is used, or possibly a correction for single tones is applied. Some of the more important descriptors for rating noise levels are summarized in this section.

Average Levels

Equivalent: The H-hr. equivalent level, $L_{eq(H)}$, is the constant level which would have the equivalent 'energy', thus

$$L_{eq(H)} = 10 \log_{10} \left\langle P_A^2 \right\rangle_H + 94 \qquad (1)$$

where P_A is the A-weighted acoustical pressure, in N/m^2, obtained by passing the microphone signal through an appropriate filter and $\langle \; \rangle_H$ denotes averaging over H hours.

When $L_{eq(H)}$ is to be obtained by measurement, several techniques are possible. The most common method is to use the averaging circuit of a sound level meter to obtain the RMS pressure,

P^2_{ARMS}, where

$$P^2_{ARMS}(t) = \frac{1}{RC}\int_{-\infty}^{t} P^2_A(\lambda)e^{(\lambda - t)/RC}d\lambda \quad (2)$$

and RC is the equivalent averaging time, so that

$$P^2_{ARMS}(t) \sim \frac{1}{RC}\int_{t - RC}^{t} P^2_A(\lambda)d\lambda \quad (3)$$

Then the A-weighted sound pressure level is

$$LA = OASPL = 10 \log_{10} P^2_{ARMS}(t) + 94 \text{ dB (re. } 2 \times 10^{-5} N/m^2) \quad (4)$$

The averaging time RC is much less than the overall averaging time H, so that, to a very close approximation, eqq. (1) and (3) combine to give

$$L_{eq(H)} = 10 \log_{10} \left\langle P^2_{ARMS} \right\rangle_H + 94 = 10 \log_{10} \left\langle 10^{LA/10} \right\rangle_H \quad (5)$$

Note that on changing the base of the logarithm

$$L_{eq(H)} = 3.01 \log_2 \left\langle P^2_{ARMS} \right\rangle + 94 = 3.01 \log_2 \left\langle 2^{LA/3.01} \right\rangle_H \quad (6)$$

Thus, when the averaging RMS pressure doubles, its logarithm to base 2 increases by one, so that $L_{eq(H)}$ increases by 3. This increase by 3 dB for a doubling of the quantity involved is referred to as the "3 dB law", and is characteristic of the so-called "power law". Although many noise ratings are based on the power law, a number are based on different laws of combination.

Note that, in terms of LA, the A-weighted RMS pressure is

$$P^2_{ARMS} = 10^{\frac{LA - 94}{10}} = e^{\frac{LA - 94}{4.34}} = 2^{\frac{LA - 94}{3.01}} \quad (7)$$

however, the reference pressure is arbitrary, so that

$$L_{eq(H)} = 10 \log_{10} \left\langle 10^{\frac{LA - R}{10}} \right\rangle_H + R \quad (8)$$

where R can take any value.

Generally, H denotes a specific period of the day, so that

$L_{eq(1)}$ = HNL = HOURLY NOISE LEVEL

based on the peak hour of the day.

$$L_{eq(15)} = L_{d(15)}$$

based on daylight hours from 0700-2200, as an alternative

$$L_{eq(12)} = L_{d(12)}$$

based on the hours 0700-1900, together with

$$L_{eq(3)} = L_e$$

based on the evening hours 1900-2200. In both cases

$$L_{eq(9)} = L_n$$

based on the nighttime hours 2200-0700. Yet again

$$L_{eq(24)} = L_{eq}$$

based on the whole 24 hours.

Composite Levels: A composite average which penalizes nighttime noise by a factor of 10 is

$$L_{dn} = \text{DAY-NIGHT LEVEL}$$

$$= 10 \log_{10} \left\{ \frac{15}{24} \cdot 10^{Ld(15)/10} + 10 \cdot \frac{9}{24} 10^{Ln/10} \right\} \qquad (9)$$

while another which also penalizes evening noise by a factor of 3 is

$$\text{CNEL} = L_{eqc} = \text{COMMUNITY EQUIVALENT NOISE LEVEL}$$

$$= 10 \log_{10} \left\{ \frac{12}{24} 10^{Ld(12)/10} + 3 \cdot \frac{3}{24} \cdot 10^{Le/10} + 10 \cdot \frac{9}{12} \cdot 10^{Ln/10} \right\} \qquad (10)$$

Statistical Levels

Statistical levels are generally based on the peak hours of the day, and are most common in surface transportation applications.

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Exceedence: the E% exceedence level, L_E, is defined by

L_E = E% EXCEEDENCE LEVEL

= Level exceeded E% of the time during the period specified.

Commonly used values are L_{10}, L_{50}, and L_{90}.

Noise Pollution Level: The noise pollution level, N_{PL}, developed by Robinson[5], is defined in terms of $L_{eq(1)}$ and of the standard deviation σ_L of L_E as

$$NPL = L_{NP} = \text{NOISE POLLUTION LEVEL}$$

$$= L_{eq(1)} + 2.56\,\sigma_L \qquad (11)$$

Traffic Noise Index: The traffic noise index is defined in terms of three exceedence levels as

$$TNI = L_{NI} = \text{TRAFFIC NOISE INDEX}$$

$$= 4\,(L_{10} - L_{90}) + L_{90} - 30 \qquad (12)$$

Normal Distribution: By assuming a normal distribution for L_E, the following approximations can be made

$$L_{eq(1)} \sim 10\,\log_{10}\left[\frac{1}{\sqrt{2\pi\sigma}}\int_{-\infty}^{\infty} \exp\left\{\frac{L}{4.34} - \frac{1}{2}\left(\frac{L - L_{50}}{\sigma_L}\right)^2\right\} dL\right]$$

$$= 10\,\log_{10}\,\exp\left\{\frac{L_{50}}{4.34} + \frac{1}{2}\left(\frac{\sigma_L}{4.34}\right)^2\right\}$$

$$= L_{50} + 0.115\,\sigma_L^{\,2} \qquad (13)$$

The standard deviation σ_L is readily obtained from

$$1.28\,\sigma_L = L_{10} - L_{50} = L_{50} - L_{90} \qquad (14)$$

thus the noise pollution level NPL, is obtained by substituting eq. (14) into (11).

$$NPL = L_{NP} = L_{50} + 2.56\,\sigma_L + 0.115\,\sigma_L^{\,2}$$

$$\sim L_{50} + (L_{10} - L_{90}) + (L_{10} - L_{90})^2/60 \qquad (15)$$

Also, TNI for a normal distribution is

$$TNI = 7(L_{10} - L_{50}) + L_{50} - 30 \qquad (16)$$

Corrections for Frequency Content

Perceived Noise Level: There are two standards for calculating perceived noise levels from one-octave or third-octave band levels, L_i, i = 15, 18 . . . 42 or i = 14 . . . 43, respectively.

Loudness: Based on procedures developed by Zwicker(6), Stevens(7), or Robinson(8), the band levels are converted to Sons, where s_i, the value corresponding to L_i, is referred to as the loudness index.

Noisiness: Based on a procedure developed by Kryter and Pearsons(9), the band levels are converted to Noys, where n_i is the value corresponding to L_i.

The above quantities are then summed across the bands

$$S_t = (1 - F)S_{MAX} + F\sum(i)s_i \qquad \text{Sons} \qquad (17A)$$

or

$$N_t = (1 - F)N_{MAX} + F\sum(i)n_i \qquad \text{Noys} \qquad (17B)$$

where F = 0.3 for one-octave bands and 0.15 for third-octave bands.

Finally, the perceived noise level, PNL, is obtained from

PNL = PERCEIVED NOISE LEVEL

$$= 10 \log_2 S_t + 40 \qquad \text{Phons} \qquad (18A)$$

alternatively, and especially for aircraft noise

$$PNL = 10 \log_2 N_t + 40 \qquad \text{PNdB} \qquad (18B)$$

The noisiness, n_i, in band i can be expressed in the form

$$n_i = 2^{\frac{L_i + C_i - 40}{10}} \qquad (19)$$

where C_i is an involved correction to account for the subjective effect of frequency and masking on noisiness, but which is zero at one kHz, so that the perceived noise level can be expressed as

$$PNL = 10 \log_2 \left\{ (1 - F)2^{\frac{(L + C)_{max}}{10}} + F\sum(i)2^{\frac{L_i + C_i}{10}} \right\} \qquad (20)$$

while the expression based on loudness has identical form. In contrast, the derivation of the A-weighted level from the band levels is based on the power law, and can be expressed as

$$LA = 3.01 \log_2 \left\{ \Sigma(i)\, 2^{\frac{L_i + A_i}{3.01}} \right\} \quad (21)$$

where A_i is the amplification of the A-weighting filter at the center frequency of band i. Thus the perceived noise level is not based on the power law of combining frequencies.

The total noisiness, N_t, is often considered to be a measure of the subjective noisiness, so that an increase of 10 dB in PNL, resulting in a doubling of N_t, is taken to represent doubling of the noisiness.

<u>Pure Tone Correction</u>: When there are pure tones, the differences between the appropriate band levels and the background levels are determined by a numerical procedure which is described in FAA Part 36(10) and also by Sperry(11). The maximum difference, ΔL_M, is then used to determine the pure tone correction C as follows

C = PURE TONE CORRECTION FACTOR

$$\left.\begin{aligned} &= 0 \text{ for } \Delta L_M < 3 \\ &= L_M/6 \text{ for } 3 \le \Delta L_M < 20 \\ &= 3\,1/3 \text{ for } 20 \le \Delta L_M \end{aligned}\right\} \quad \begin{aligned} 50 \le f < 500 \text{ Hz} \\ 5000 < f \le 10000 \text{ Hz} \end{aligned} \quad (22A)$$

$$\left.\begin{aligned} &= 0 \text{ for } \Delta L_M < 3 \\ &= \Delta L_M/3 \text{ for } 3 \le \Delta L_M < 20 \\ &= 6\,2/3 \text{ for } 20 \le \Delta L_M \end{aligned}\right\} \quad 500 \le f \le 5000 \text{ Hz} \quad (22B)$$

where f is the band center frequency containing the pure tone.

<u>Tone Corrected Levels</u>: The tone correction is added

LAT = TONE CORRECTED A-WEIGHTED LEVEL

$$= LA + C \quad (23A)$$

PNLT = TONE CORRECTED PERCEIVED NOISE LEVEL

$$= PNL + C \quad (23B)$$

Duration Corrections

Duration Factor: The duration factor D(T) for an event whose level is L (i.e., PNLT, LA, LAT, etc.) is

D(T) = DURATION FACTOR

$$= 10 \log_{10}\left\{ \frac{1}{T} \int_{t_0}^{t_0 + \Delta t_{10}} 10^{L/10} \, dt \right\} - L_{max} \qquad (24)$$

where T is the time base, Δt_{10} is the "10 dB downtime interval", which is the time interval during which L is within 10 dB of L_{max}, the maximum value. Generally, L_{max} is the maximum sample value based on 1/2 second sampling intervals, which is the time taken on presently used equipment to digitize all 30 third-octave bands and to compute PNL. An approximation for D(T) is

$$D(T) \sim 10 \log_{10}\left(\Delta t_{10}/2T\right) \qquad (25)$$

Note that Δt_{10}, and therefore D(T), is dependent on the particular expression used for L.

Duration Corrected Levels: Two levels based on exposure to A-weighted levels were defined in an EPA study[12].

$SEL = L_{EX}$ = SOUND EXPOSURE LEVEL

$$= LA_{max} + D(1) \qquad (26A)$$

and

SELT = TONE CORRECTED SOUND

$$\text{EXPOSURE LEVEL} = LAT_{max} + D(1) \qquad (26B)$$

whereas the level used by the FAA[10] is

EPNL = EFFECTIVE PERCEIVED NOISE LEVEL

$$= PNLT_{max} + D(10) \text{ EPNdB} \qquad (27)$$

Two levels similar to SEL and SELT were used earlier in California[13].

SENEL = SINGLE EXPOSURE NOISE EQUIVALENT LEVEL

and

SENELT = TONE CORRECTED . . .

However, these refer to duration corrected levels in which the 30 dB downtime has been used. According to Bishop et al.[14], the difference between SEL and SENEL is less than 0.3 dB for a typical aircraft flyover. It is generally observed that

$$PNL \sim LA + 13 \text{ PNdB}$$

but

$$D(1) \sim 10\ D(10)$$

Therefore

$$EPNL \sim SEL + 3 \text{ EPNdB} \quad (28)$$

Exposure to Repeated Events

Average Levels: Suppose that L_{dn} is to be calculated based on individual events of different levels, where SELj is the j^{th} sound exposure level. Let N_{dj}, N_{nj} be the numbers of these events during any one 24-hour period occurring in daytime and at night, respectively. Since SEL is based on a one-second duration

$$L_d = 10 \log_{10} \Sigma(j) \frac{24}{15} N_{dj} \cdot 10^{SELj/10} - 49.4 \quad (29)$$

where

$$10 \log_{10} 24 \times 3600 = 49.4$$

Similarly

$$L_n = 10 \log_{10} \Sigma(j) \frac{24}{9} N_{nj} \cdot 10^{SELj/10} - 49.4 \quad (30)$$

Combining these as in eq. (9)

$$L_{dn} = 10 \log_{10} \Sigma(j) \{N_{dj} + 10\ N_{nj}\} 10^{SELj/10} - 49.4 \quad (31)$$

Also, the expression for the hourly noise level is

$$HNL = L_{eq(1)} = 10 \log_{10} \Sigma(i)\ N_{Hj}\ 10^{SELj/10} - 35.6 \quad (32)$$

where N_{Hj} is the number of exposures in one hour, and 35.6 is $10 \log_{10} 3600$.

Community Equivalent Noise Level: A parallel expression for the community equivalent noise level would be

$$CNEL = 10 \log_{10} \{N_{dj} + 3\ N_{ej} + 10\ N_{nj}\} 10^{SELj/10} - 49.4 \quad (33)$$

In eq. (33), $SELT_j$, $SENEL_j$ or $SENELT_j$ could be used in place of SEL_j.

Ratings for Repeated Events at Airports: Some standards for repeated events of a level L at airports are based on the following assumptions:

1) A given rate of exposure during the 9 nighttime hours is 10 times as bad as the same rate during the 15 daytime hours. Therefore, the number of nighttime exposures is to be multiplied by 15/9 x 10 or 16.7.

2) A certain level, say L_{BASE}, experienced once per day, is the baseline exposure, with a cumulative value of 0.

Thus, if a given level, say L_j is experienced N_{dj} times during the day and N_{nj} times during the night, the combined level, CL, is

$$CL = 10 \log_{10} \Sigma(j) \{N_{dj} + 16.7\, N_{nj}\} 10^{Lj/10} - L_{BASE} \qquad (34)$$

Specific examples of combined levels are

NEF = NOISE EXPOSURE FORECAST

$$= 10 \log_{10} \Sigma(j) \{N_{dj} + 16.7\, N_{nj}\} 10^{EPNLj/10} - 88 \qquad (35)$$

$$\sim L_{dn} - 35$$

The approximate relationship between NEF and L_{dn} is derivable from eqq. (28) and (31).

CNR = COMPOSITE NOISE RATING

$$= 10 \log_{10} \Sigma(j) \{N_{dj} + 16.7\, N_{nj}\} 10^{(PNL_{max})_j/10} - 12 \qquad (36)$$

$$\sim L_{dn} + 35$$

The approximate relationship between CNR and L_{dn} is derivable in part from eqq. (28) and (31), but requires the assumption of an average value of Δt_{10}.

Noise and Number Index: The United Kingdom's noise and number index uses the '15 dB law', as follows

NNI = NOISE AND NUMBER INDEX

$$= 15 \log_{10} \Sigma(j) \{N_{dj} + 16.7\, N_{nj}\} 10^{(PNL_{max})_j/10} - 12 \qquad (37)$$

Noise Exposure Index: The noise exposure index used in the Netherlands is derived from the A-weighted level, but is based on a mixed dB law

L_{EXP} = NOISE EXPOSURE INDEX

$$= 20 \log_{10} \Sigma(j)\, k_j\, 10^{(LA_{max})_j/15} - 106 \qquad (38)$$

where k_j is a time-of-day factor.

Störindex: The German "Störindex" is based on a variable law

$$\bar{Q} = \text{STÖRINDEX}$$

$$= \frac{1}{a} \log_{10} \frac{1}{T} \int_{t_0}^{t_0 + T} 10^{aL(t)}\, dt \qquad (39)$$

where a is generally 1/13.3 and L(t) is the A-weighted level, LA, or the perceived noise level, PNL.

Daily Dose: The 'Daily Dose' under the Occupational Safety and Health Act (OSHA)[15] may be expressed in the form

$$D = \Sigma(j)\ \frac{C_j}{8}\ 2^{\frac{LA_j - 90}{5}} \qquad (40)$$

where C_j is the time in hours during which an employee is subjected to an A-weighted level of LA_j. This implies the existence of a level $L_{eq}*$, where

$$L_{eq(8)}* = 5 \log_2 \left\langle 2^{LA/5} \right\rangle_8 \qquad (41)$$

so that the daily dose is unity when $L_{eq(8)}*$ is 90 dB. The justification for the use of the 5 dB law in eq. (41) is that the more intense sound exposures occur for a limited time, so that there is some recovery of temporary threshold shifts in the hearing of persons exposed to the noise. $L_{eq}*$ appears in some U. S. Army specifications.

Miscellaneous Expressions for Noise: Beranek[16,17] has suggested two scales for rating continuous noise in which one-octave spectra are compared with standard overlay curves. They are used in architectural applications and are

NC = NOISE CRITERIA

PNC = PREFERRED NOISE CRITERIA

Also used in applications where verbal communication is important is

PSIL = PREFERRED SPEECH INTERFERENCE LEVEL

which is the average of the one-octave levels, in dB, at 500, 1000, and 2000 Hz.

LIMITATIONS ON NOISE LEVELS

Various federal agencies exercise control over the noise environment, either by defining the noise level limits under which financial support will be provided or by setting noise source limits on products. State and local governments may set limits on permitted noise levels through noise or zoning ordinances. It is sometimes difficult to compare these levels because different agencies use different descriptors for rating noise levels.

Federal Noise Standards

EPA's Levels to Protect Public Health: The EPA[18] has published "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety". Values for $L_{eq(24)}$ and L_{dn} from this document are given for different areas in Table 1. These have no legal force.

Recently, the EPA[4] requested all federal agencies to adopt L_{dn} as the standard designation for environmental noise.

Table 1

SUMMARY OF NOISE LEVELS IDENTIFIED AS REQUISITE TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

Extracted from EPA 550/9-74-004 (Reference 18)

EFFECT	LEVEL	AREA
Hearing Loss	$L_{eq(24)} \leq 70$ dB	All areas.
Outdoor activity interference and annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)} \leq 55$ dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas.
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools.

NOTE: EPA has determined that for purposes of hearing conservation alone, a level which is protective of that segment of the population at or below the 96th percentile will protect virtually the entire population. This level has been calculated to be an L_{eq} of 70 dB over a 24-hour day.

Table 2

DESIGN NOISE LEVEL/ACTIVITY RELATIONSHIPS

Extracted from FHWA Federal Aid Highway Program Manual,
Vol. 7, Chapter 7, Section 3, 1974 (Reference 19)

Activity Category	Design Noise Levels - dBA(a)		Description of Activity Category
	L_{eq}	L_{10}	
A(b)	57 (Exterior)	60 (Exterior)	Tracts of land in 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 purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B(b)	67 (Exterior)	70 (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playgrounds, active sports areas, and parks.
C	72 (Exterior)	75 (Exterior)	Developed lands, properties or activities not included in categories A and B above.
D	--	--	For requirements on undeveloped lands see paragraph 11.a.
E	52 (Interior)	55 (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

(a) Either L_{10} or L_{eq} design noise levels may be used.

(b) Parks in categories A and B include all such lands (public or private) which are used as parks as well as those public lands officially set aside or designated by a governmental agency as parks on the date of public knowledge of the proposed highway project.

FHWA Standards: The FHWA[19] has published highway noise standards, based either on L_{eq} or L_{10}, as shown in Table 2. Both of these quantities are based either on maximum traffic conditions or on the average of the worst three hours of traffic for the day.

Housing and Urban Development: The Department of Housing and Urban Development (HUD)[20] has published "External Noise Standards for New Construction", giving limits on dBA levels for general exposure, as well as a Community Noise Rating (CNR) or Noise Exposure Forecast (NEF) for airport environs. These levels are summarized in Table 3.

Table 3

EXTERNAL EXPOSURE STANDARDS FOR NEW CONSTRUCTION SITES

Extracted from HUD Circular No. 139012 (Reference 20)

GENERAL EXTERNAL EXPOSURES dB(A)	AIRPORT ENVIRONS	
	CNR	NEF
UNACCEPTABLE		
Exceeds 80 dB(A) 60 minutes	Takeoffs and landings exceed 115	
Exceeds 75 dB(A) 8 hours per 24 hours	Runups exceed 95	Exceeds 40
(Exceptions are strongly discouraged and require a 102(2)C environmental statement and the Secretary's approval)		
DISCRETIONARY -- NORMALLY UNACCEPTABLE		
Exceeds 65 dB(A) 8 hours per 24 hours	Takeoffs and landings 100 to 115	
Loud repetitive sounds on site	Runups 80 to 95	30 to 40
(Approvals require noise attenuation measures, the Regional Administrator's concurrence and a 102(2)C environment statement)		
DISCRETIONARY -- NORMALLY ACCEPTABLE		
Does not exceed 65 dB(A) more than 8 hours per 24 hours	As above	As above
ACCEPTABLE		
Does not exceed 45 dB(A) more than 30 minutes per 24 hours	Takeoffs and landings less than 100	
	Runups less than 80	Less than 30

Airport Noise: No general standards exist for noise near airports. However, NEF contours are prepared, as defined in eq. (35), for impact statements relating to airports in the U. S. These replace CNR contours, defined in eq. (36), used earlier. In the United Kingdom, NNI contours are used for the same purpose.

Occupational Safety and Health: The Occupational Safety and Health Act, OSHA[15,21], limits the exposure of workers to the equivalent of 90 dBA for an eight-hour working day as expressed in the form of a daily dose (see eq. (40)) which must be less than unity. The EPA[22] has challenged this standard, and has suggested (1) the equivalent of 85 dBA for an eight-hour day, and (2) the use of a "power" or "3 dB" law.

Federal Noise Limits on Products

In general, the existence of a federal noise limit on a product preempts action by a state or local government in setting limits which are not identical.

Trucks: The EPA[23] has set the limits given in Table 4 on trucks weighing over 10,000 lbs. (22,050 kg). Trucks of lower weight, or automobiles, may therefore be controlled under state laws.

Table 4

PEAK NOISE EMISSIONS FROM VEHICLES OVER 10,000 lbs. (22,050 kg). GROSS IN INTERSTATE COMMERCE (Extracted from EPA Regulation, Reference 23)

Applies to	Condition	Date Enforced	Peak Level, dBA at 50 ft. (15.24 m)
All Vehicles	Speed above 35 mph (56.3 kph)	October 1975	90
	Speed below 35 mph (56.3 kph)	October 1975	85
	Runup	October 1975	88
New Vehicles	Low speed and	1977-1980	83
	high acceleration	1981-1982	80
		1983 on	75

Aircraft: For the purpose of certifying new aircraft, the FAA[10] has set limits on the values of EPNL produced by aircraft at three points on the ground relative to the runway. These values depend on the maximum gross takeoff weight and are not absolute source limits, because EPNL can be reduced by steep descent or by rapid climb on takeoff. The older jet aircraft generally do not meet the standards, and may eventually have to go through a retrofit program in which treated nacelles will be installed. The so-called 'wide-body' jets such as the DC-10, L-1011, and 747-200B do meet these requirements. If NEF contours are to be predicted for an airport, one needs to know (1) the mix of aircraft, (2) the degree of enforcement of the retrofit program, and (3) the degree of enforcement of noise abatement procedures.

Local Government Noise Regulations

Many local noise ordinances have been based on the National Institute of Municipal Law Officers (NIMLO[24]) model noise ordinance, which gives permitted levels in one-octave bands. More recently, there has been a trend towards using A-weighted levels. The ordinances are generally written so that the stated level approximates the L_{dn} value or else different levels are set for daytime and nighttime, and they may include crude pure tone corrections. Typical dBA or L_{eq} limits by land-use category are given in Table 5.

Table 5

NOISE LEVEL LIMITS SET BY LOCAL GOVERNMENTS

COMMUNITY	LA or L_{eq} in dBA					
	RESIDENTIAL		COMMERCIAL		INDUSTRIAL	
	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
Baltimore, Md.	55-70	50-65	58-70	53-65	61-75	56-70
San Francisco, CA	55-60	50-55	70	60	70-75	70-75
Boston, Mass.	60	50	65	55	70	60
Denver, CO	55	50	65	60	80	75
Hawthorne, CA	42	42	-	-	53	53
Loveland, CO	48	45	52	49	56	53
New York	65	45	65	-	80	-
Fountain Valley CA	50-60	45-55	-	-	-	-
Santa Rosa, CA	55	45	60-65	55	70	70
Billings, MT	55	50	60-70	55-65	80	75
Missoula, MT	60	55	65	60	70-80	65-75
Coral Gables, Fla.	35-40	32-35	45	40	50	45
Helena, MT	55	50	60	55	80	75
Wheatridge, CO	37	37	-	-	-	-
Hermosa, CO	45	45	55	54	65	65
Grand Rapids, Mich.	45-52	38-45	52-63	45-56	-	-
Albuquerque, N.M.	55-61	55-61	62-66	62-66	-	-
San Diego, CA	50-60	45-55	60	55	70-75	70-75
Colorado	55	50	60	55	70-80	65-75
Illinois	55-62	45-62	55-62	45-62	61-70	51-70
NIMLO	45	45	53	53	58	58
Chicago, Ill.	55-61	55-61	62-66	62-66	-	-
Dallas, Tex.	56		56-63		56-70	
Minneapolis, Minn.	55		62			
North Carolina	55-60	50-55			70	70
Lakewood, CO	55	50	60	55	80	75
Inglewood, CA	55	45	65	65	70	70
Salt Lake City, Utah	65	55-60	70	65	75-80	75-80

Summary of Noise Level Descriptors

A summary of the different noise level descriptors is given in Figure 1. The relationships used in the derivations are indicated by arrows. For example, to get L_{dn} one either integrates LA directly, as in eq. (9), or one first gets SEL, as in eq. (26), and then gets L_{dn} from eq. (31). Levels selected for use in NOISE 3 and levels used in regulations by various agencies are indicated.

The list of levels is by no means exhaustive. Many variants on these quantities have been proposed. In particular, several countries have their own methods of rating noise exposure around airports. However, practically all ratings start with the A-weighted level, octave band levels, or perceived noise level. A very few use the C-weighted levels.

There have been many attempts to correlate noise levels with subjective response. A good review of such work has been given by Serendipity Inc.[25] It is almost impossible to find statistically significant differences between ratings based on A-weighting and those based on more sophisticated approaches. Thus, if the EPA's request for the adoption of L_{dn} as the standard designation for environmental noise is accepted, there would be little, if any, impact on the general public, but there would be very much less confusion and misunderstanding about the subject of noise and about what the numbers mean.

METHODS OF PREDICTING HIGHWAY NOISE

The NCHRP 117/144 Methods

The methodology for predicting highway noise has been described in the NCHRP 117[26] and 144[27] reports. Several programs incorporating this method have been prepared for a time-sharing computer by the Michigan Department of Highways, the two main versions being referred to as MICHIGAN/117 and MICHIGAN/144. These have been adapted to batch format on the IBM 370 by the Data Processing Division of the Virginia Department of Highways and Transportation as MICNOISE 2 and 5, respectively which have been evaluated in references 28 and 29 together with their variants, and as MICNOISE 10, the latest version.

Theoretical Background: The equivalent level, L_{eq}, can be given for a line of traffic at a distance D from the observer, in terms of the level L_{REF} in A-weighted decibels for one vehicle at a distance D_{REF}, as

$$L_{eq} = L_{REF} - 20 \log_{10} D/D_{REF} + 10 \log_{10} \pi RD/V + 10 \log_{10} \Delta\theta/180 \qquad (42)$$

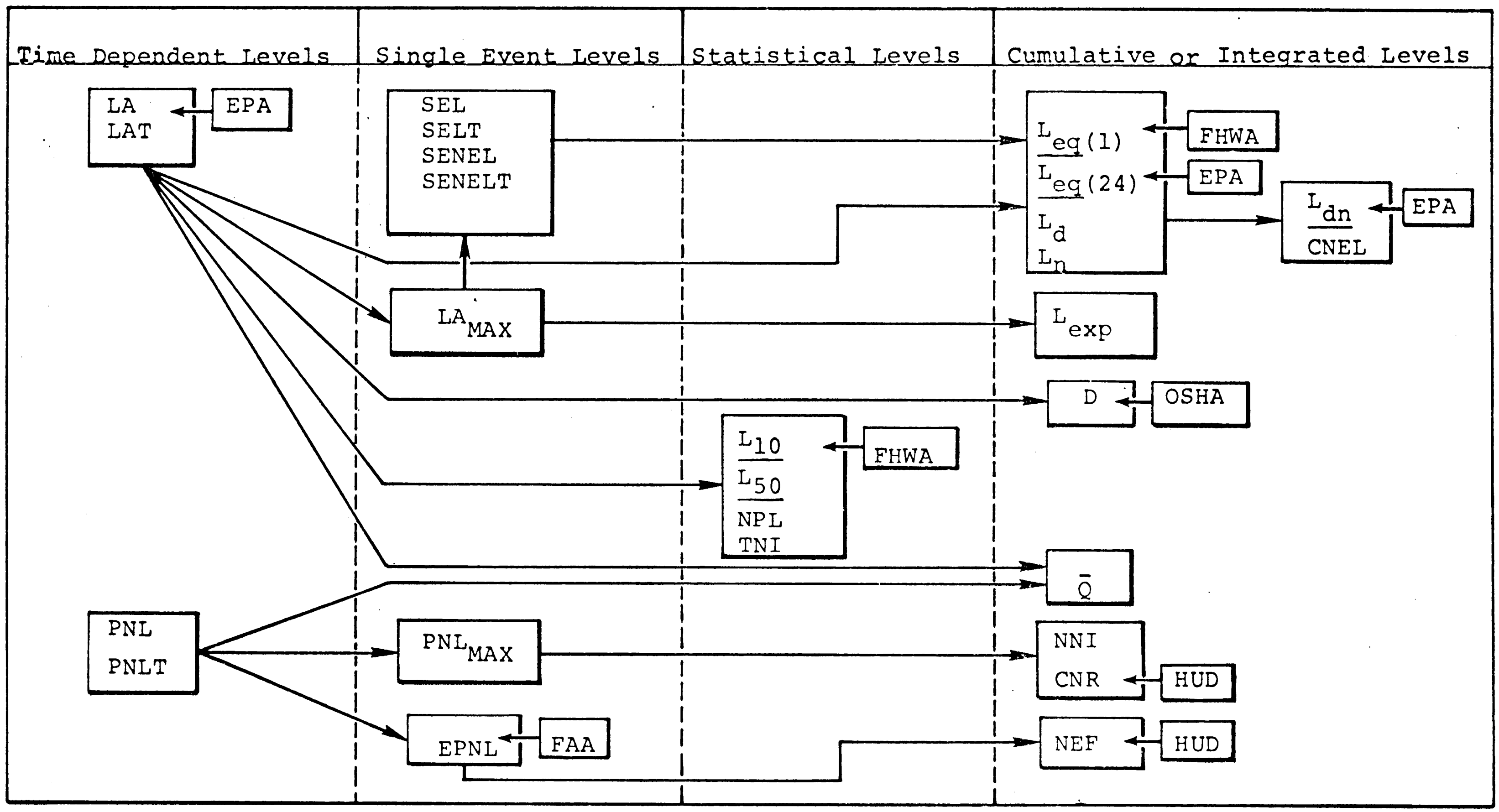

Figure 1. Summary of descriptors for rating noise levels.

Note: Connecting lines indicate derivation

Agencies using descriptors in their regulations indicated by ← agency

Descriptors selected for NOISE 3 indicated thus $\underline{L_{10}}$

where R is the number of vehicles per hour, V is their speed in units consistent with R and D, and $\Delta\theta$ is the subtended angle of the roadway element in degrees, as shown in Figure 2. The value obtained for L_{eq} from eq. (42) does not depend in any way on how the traffic is spaced out, although it does assume that each vehicle is equally noisy. To obtain the statistical level L_E, the level exceeded E% of the time, it is necessary to assume uniform spacing. This leads to the equation

$$L_E = L_{eq} + 10 \log_{10}\left\{\frac{\text{Sinh } 2\,\pi RD/V}{\cosh 2\,\pi RD/V - \cos \pi E/100}\right\} \qquad (43)$$

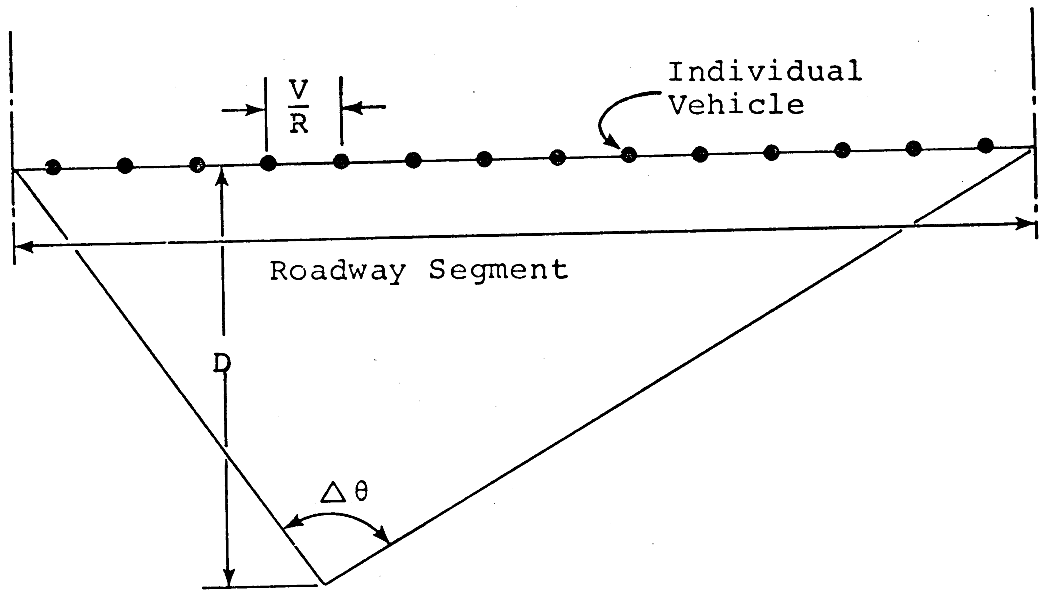

Figure 2. Traffic on an element of roadway.

Average Automobile: An average automobile passing 100 ft. (30.48 m) away at 60 mph (96.6 km/hr) is assumed to emit 64.6 dBA. The acoustical power is assumed to originate at the tires and is taken to depend on the cube of the speed, so that for automobiles, with D_{REF} equal to 100 feet (30.48 m)

$$L_{REF} = 64.6 + 30 \log_{10} S/60 \text{ dBA} \quad (44A)$$

where S is the speed in mph.

Average Truck: The engine of the average truck passing 100 ft. (30.48 m) away is assumed to emit 77.2 dBA, regardless of speed. Thus for trucks

$$L_{REF} = 77.2 \text{ dBA} \quad (44B)$$

Equivalent Levels at 100 ft. (30.48 m): Substituting eqq. (44A) and (44B) in turn into eq. (42) and making appropriate adjustments for the units used, one obtains for automobiles at 100 ft. (30.48 m).

$$L_{eq} = 10 \log_{10} Q_A S_A^2 - 1.0 \text{ dB} \quad (45)$$

and, for trucks at 100 ft. (30.48 m)

$$L_{eq} = 10 \log_{10} Q_T/S_T + 65.0 \text{ dB} \quad (46)$$

where subscripts A and T refer to automobiles and trucks, respectively, Q is the peak hourly traffic rate, and S is the speed in mph (1 mph = 1.609 km/hr.).

L_{50} Levels at 100 ft. (30.48 m): Putting E equal to 50% in eq. (43) and adjusting for units as before, the L_{50} level at 100 ft.=(30.48 m) is

$$L_{50} = L_{eq}(100 \text{ ft}) + 10 \log_{10} \tanh 0.119\, Q/S \quad (47)$$

which applies to automobiles or trucks.

Levels at Any Distance: NCHRP 117 and 144 both recommend a distance correction DEL1 equal to

$$\text{DEL1} = -15 \log_{10} \{D_E/100\} = -4.5 \log_2 \{D_E/100\} \quad (48)$$

for most cases (as is used in MICNOISE), except where the terrain is very smooth, or where the receiver is high off the ground, in which cases the 10 dB (or 3 dB) law is suggested in place of the 15 dB (or 4.5 dB) law.

In eq. (48), D_E is the effective distance from the roadway, as given by

$$D_E = \sqrt{D_N D_F} \qquad (49)$$

in which D_N and D_F are distances from the nearest and furthest lanes, respectively. The correction in eq. (48) does not give the same value as would be obtained on a reevaluation of eqq. (45), (46), and (47). The correction for L_{eq} would be based on -10 dB as opposed to -15 dB, and the correction for L_{50} would be considerably different, as is demonstrated in Table 1 of reference 28.

L_{10} Values: The difference between L_{10} and L_{50} is readily found from eq. (43) to be

$$L_{10} - L_{50} = -10 \log_{10} \{1 - 0.951/\cosh(0.00119QD_E/S)\} \qquad (50)$$

However, this does not correlate well with actual measurements for values of QD_E/S over 300 vehicle feet per mile (equivalent to 56.8 vehicle meters per km). Therefore, the curve shown in Figure 3 has been recommended in the NCHRP 144 report, in which eq. (50) fairs into an empirical curve. The use of eq. (50) in conjunction with eqq. (45) to (49) is not consistent, and must be viewed as partly empirical. The MICHIGAN/144 and MICNOISE 5 and 10 programs actually obtain the curve shown in Figure 3 by interpolation of tables containing the points indicated in Figure 3.

Roadway Length Correction -- DEL2: In accordance with eq. (42), the correction for roadway length is based on the subtended angle $\Delta\theta$ as

$$DEL2 = 10 \log_{10} \{\Delta\theta/180\} \qquad (51)$$

Vertical and Barrier Corrections -- DEL4, DEL6: When sound from a pure tone point source impinges on the edge of a semi-infinite plane, it is diffracted, so that it may penetrate into the shadow zone. It is possible to obtain exact theoretical solutions for cases in which the geometry is very simple. However, the case of a line source of incoherent broad band noise impinging on the top of a barrier, in the presence of ground effects, is considerably more complex. The corrections recommended in the NCHRP 144 report were based on original work by Maekawa[30], as developed by Kurze and Anderson[31]. The method of application of these corrections is shown in Figures 4 and 5. It will be seen that the procedure is to find first the deficiency X + Y - Z, and then to read the curve to find the attenuation DEL4 for elevation effects, or DEL6 for barriers.

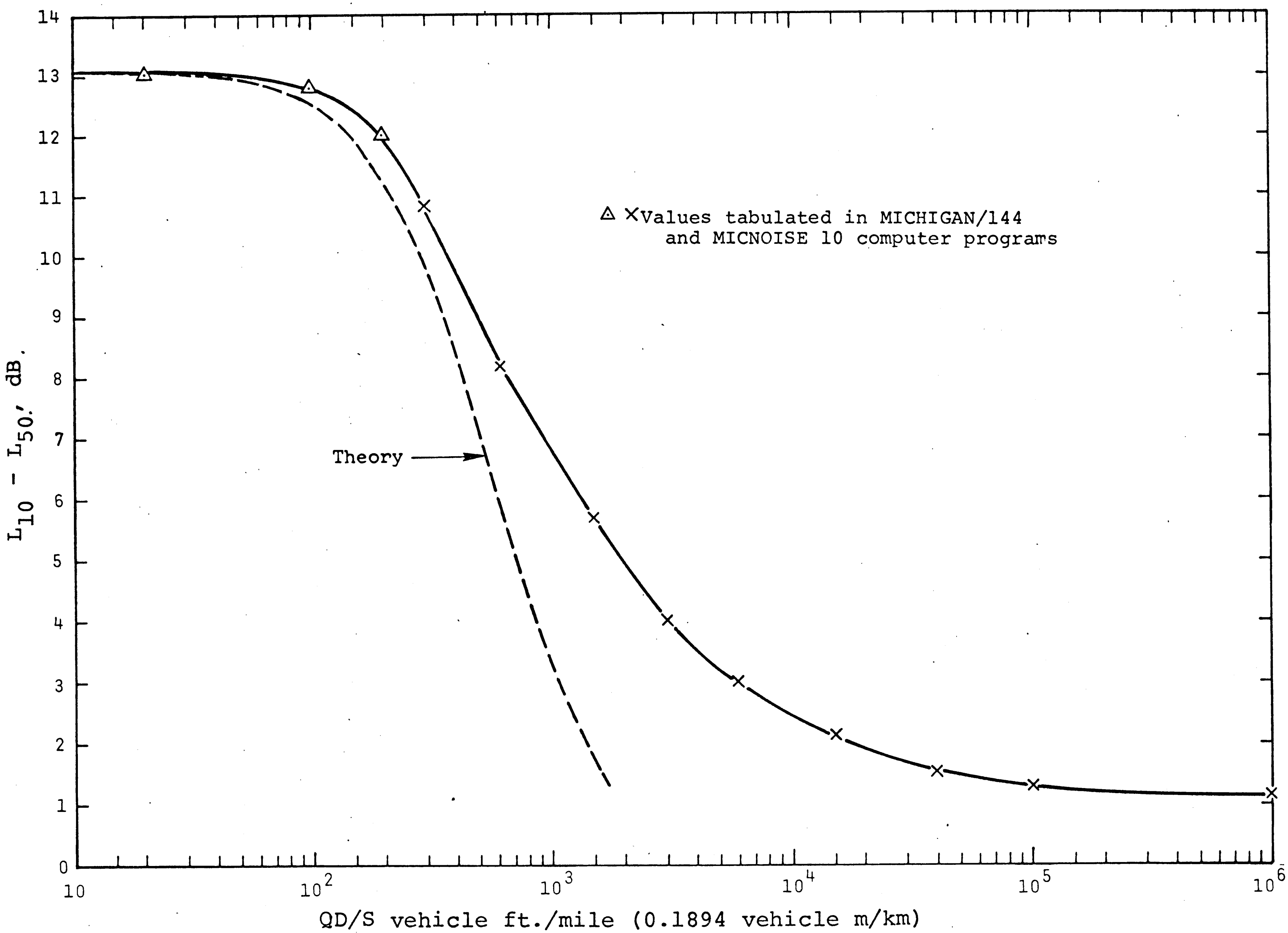

Figure 3. Values of $L_{10} - L_{50}$ vs. vehicle spacing used in NCHRP methods.

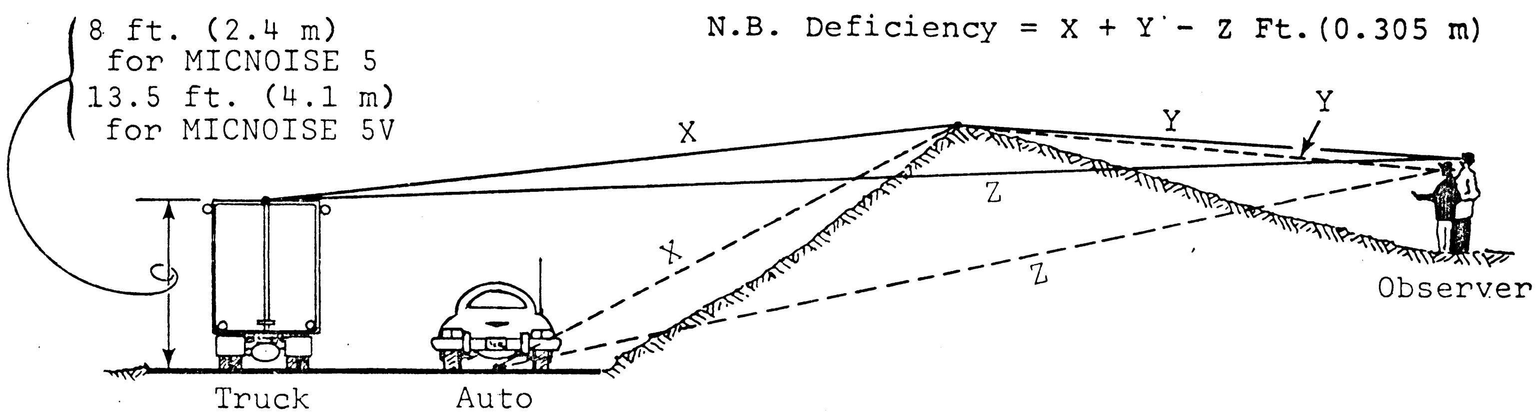

Figure 4. Definition of deficiency used for elevation corrections in NCHRP methods.

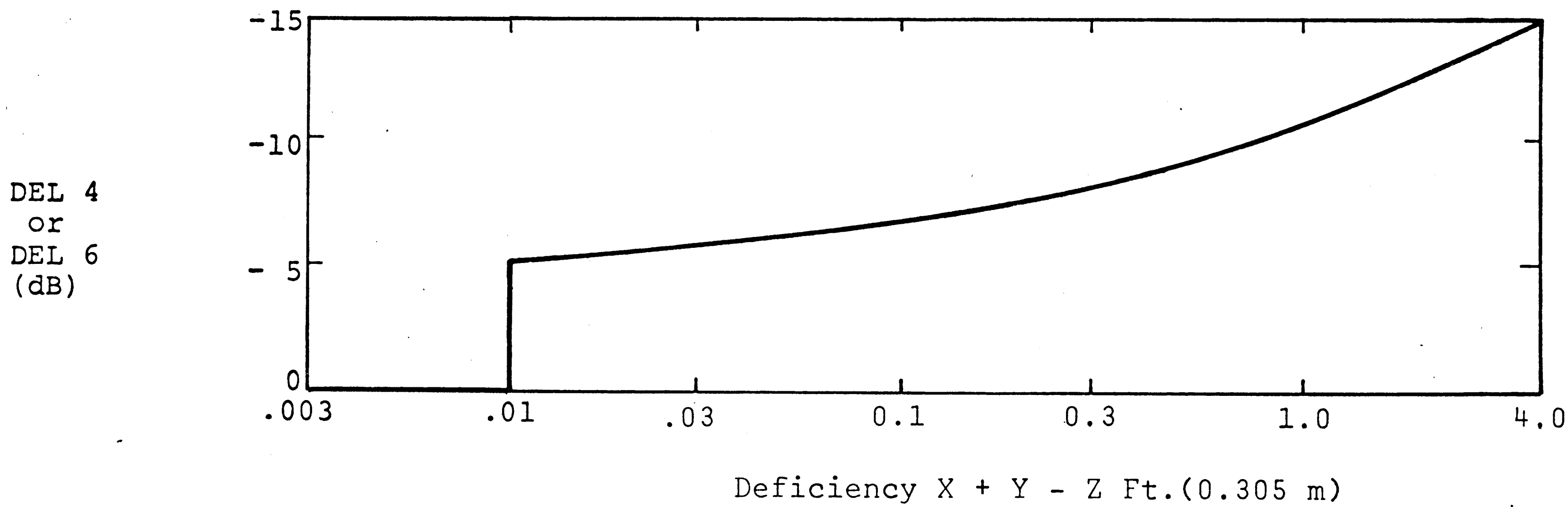

Figure 5. Elevation corrections used in NCHRP methods.

In determining the deficiency, truck sources are assumed to be 8 feet (2.4 m) above the road for MICHIGAN/144 or MICNOISE 5, and 13.5 feet (4.1 m) for MICNOISE 5V or 10. The curve in Figure 5 is represented by interpolation of a table in the computer programs. There is a further correction to DEL6 for barriers of finite length.

Miscellaneous Corrections: Several corrections are made at the option of the user, they are

Grade Correction -- DEL3: From 0 to 4 dB

Roadway Surface Correction -- DEL5: From -5 to 5 dB

Structure Correction -- DEL7: From -10 to 0 dB for intervening buildings, trees, and shrubs.

Combined Levels: First, the effect of automobile or truck traffic from each element of roadway is determined as follows

$$L_{eq(1)} = L_{eq}(100\text{ ft}) + DEL1 + DEL2 + DEL3 + DEL4 + DEL5 + DEL6 + DEL7 \quad (52)$$

$$L_{50} = L_{eq(1)} + 10 \log_{10} \tanh 0.119\, Q/S \quad (53)$$

$$L_{10} = L_{50} + (L_{10} - L_{50}) \quad (54)$$

Then, levels due to automobiles and trucks from the different roadway elements are combined by the power law, according to which

$$L = 10 \log_{10} \Sigma(i)\ 10^{L_i/10} \quad (55)$$

where L_i represents a typical contribution to the total. The operation described in eq. (55) is often referred to as 'dB-summing'.

Output of MICNOISE 10: The output of MICNOISE 10 consists of L_{50}, L_{10}, $L_{eq(1)}$, L_{NP} and TNI, at points designated by the user. Also, it has the capability of finding the distance from a highway at which a given L_{10} value is found.

Comments on MICNOISE: The MICNOISE programs were evaluated in two reports, references 28 and 29. General comments about the program can be summarized as follows:

1) The method of power law combination, or 'dB-summing" of L_{50} and L_{10}, as given in eq. (55), is inherently wrong, although it is correct for L_{eq}.

2) The method fails to recognize the random nature of vehicle noise and spacing, and to establish confidence levels on the results.

3) The method of calculation is not based on physical laws, but rather on empirical laws. For example, neither the -15 dB distance correction nor the handling of distance in the expression for L_{10} can be justified on physical grounds, even though they lead to acceptable predictions of noise level.

4) The dependence of vehicle sources on speed is not handled correctly in most instances. Only tire noise is considered for automobiles and engine noise for trucks.

5) Despite the preceding comments, the 68% confidence limits on errors were found to be ± 3 dB during an evaluation of the MICNOISE program. In fact, by using an earlier version of the elevation correction, the limits could be reduced to ± 2 dB.

The TSC Model

The Transportation Systems Center model by Wesler(32), often referred to as the TSC model, is based on a more rigorous approach to the statistical problem of predicting L_{10} levels than is used in the NCHRP 117/144 methods. There are provisions for handling frequency spectra of vehicle noise, for adding a third vehicle, for grouping vehicles by speed, for including attenuation by atmosphere and by vegetation, and for including the effects of acoustical reflections.

Frequency and Speed Dependence: In addition to grouping vehicles by type (automobiles, trucks, and a third, user-supplied vehicle) and to including the effects of different roadway elements, the TSC method provides for up to nine octave bands and for up to five speed groups. Thus, the final summation is over all of these variables. At the option of the user, the summation of octave levels can be omitted, and the overall levels can be used in the calculations with 500 Hz frequency assumed for acoustical shielding calculations.

Average Vehicles: Whereas the FHWA model treats a line of vehicles as equally spaced point sources, the TSC method treats it as an incoherent line source with a normal distribution and a specified standard deviation. Since the strength of this source is directly proportional to the number of vehicles in a given distance, it is possible to state the reference A-weighted level per vehicle at a given distance from the road. These levels are given in Table 6 for the nine octave bands.

Table 6

REFERENCE A-WEIGHTED OCTAVE LEVELS USED IN TSC METHOD

Band No.	Octave Center Frequency Hz	L_{refi} A-Weighted Level in dB at 50 ft. (15.2 m)		
		Autos at 30 mph (48.3 kph)	Autos at 70 mph (112.7 kph)	Trucks at all Speeds
18	63	38	48	60
21	125	45	57	73
24	250	47	62	78
27	500	55	66	83
30	1000	58	70	82
33	2000	54	72	79
36	4000	49	63	74
39	8000	42	57	60
	OASPL	61	75	87
	Standard Deviation	2.5	2.5	3.5

Levels for automobiles at other speeds are obtained by linear interpolation. For comparison of these levels with those used in the NCHRP method, it should be noted that the levels in Table 6 are essentially L_{50} values, whereas the NCHRP levels are essentially L_{eq} values. Thus, for direct comparison, $0.115\,\sigma^2$ must be added to the values in Table 6. Making this correction for standard deviation to the OASPL values, interpolating for 60 mph (96.6 kph), and correcting to 100 feet (30.48 m), the comparative values in Table 7 can be obtained.

Table 7

PEAK LEVELS IN dBA FOR VEHICLES AT
60 MPH (96.6 KPH) AT 100FEET (30.48 M)

	NCHRP 117/144	TSC	1974-NCHRP
Autos	64.6	66.2	65.3
Trucks	77.2	82.4	79.9

Calculation of L_{eq}: Using essentially the same notation as was used in decribing the NCHRP method, L_{eq} is calculated as

$$L_{eq} = 10 \log_{10} \sum_{\substack{\text{road}\\\text{segments}}} \frac{50^2}{D_E} \frac{\pi\Delta\theta}{180} \sum_{\substack{\text{vehicles}\\\text{speeds}\\\text{frequencies}}} \frac{Q}{5280S}\, 10^{\frac{DEL_i}{10}}\, 10^{\frac{L_{REF_i} + 0.115\sigma^2}{10}} \qquad (56)$$

The calculations are carried approximately as indicated to avoid frequent inefficient 'dB-summing'. However the contribution of one term could be written as

$$\Delta L_{eq} = L_{REF_i} + 0.115\sigma^2 - 10 \log_{10} D_E/100 + 10 \log_{10} Q/S$$
$$+ 10 \log_{10} \Delta\theta/180 + DEL_i - 18.3 \text{ dB} \qquad (57)$$

It will be noted that the distance correction is based on the 10 dB law. There is no correction for speed here because L_{REF} already includes a speed correction. Otherwise corrections for traffic flow and roadway length are similar to those in the NCHRP method. Several other corrections are included in the term DEL_i, and these are as described in the next paragraphs.

Contribution of Atmospheric Attenuation: The contribution to DEL_i from atmospheric attenuation is

$$DEL_i = -10^{-7}\, 4^{\frac{i-15}{3}} \quad dB \tag{58}$$

where i = 18, 21 . . . 39 is the octave band number.

Contribution of Acoustical Shielding: The contribution of acoustical shielding due to barriers and roadway elevation effects is based on the Fresnel angle, N_i, where

$$N_i = 2f_i(X + Y - Z)/c \tag{59}$$

f_i is the octave center frequency, c is the speed of sound, and X + Y - Z is the deficiency, as shown in Figure 4. In calculating these values, noise sources for automobiles are placed on the road surface, noise sources for trucks are placed 8 feet (2.4 m) above the road, while the user can select the height of the noise source for the third vehicle.

Then

$$DEL_i = \begin{cases} 0 & \text{for } N \leq -0.2 \\ -20 \log_{10}\left\{\dfrac{\sqrt{2\pi|N_i|}}{\tan\sqrt{2\pi|N_i|}}\right\} & \text{for } -0.2 < N_i \leq 0 \\ -20 \log_{10}\left\{\dfrac{\sqrt{2\pi N_i}}{\tanh\sqrt{2\pi N_i}}\right\} & \text{for } 0 < N_i \leq 12.5 \\ -24 & \text{for } N_i > 12.5 \end{cases} \tag{60}$$

The above contribution is first evaluated for the nearest point on the road, and for points at the ends of the road segments. Whenever a difference of more than 1 dB is obtained, the roadway element is halved, and the calculation is repeated.

Contributions of Reflections off Barriers: The contributions of reflections are combined with the acoustical shielding effects by dB-summing.

Contribution of Ground Cover: Attenuations of up to 30 dB are calculated for the effects of ground cover, including shrubbery, thick grass, and trees.

Final Values: The TSC program calculates $L_{eq(1)}$ directly, and includes a procedure developed by Kurze[33] for the determination of the standard deviation of the sound level, σ_L. Then, as in eqq. (11), (13), and (14)

$$L_{50} = L_{eq(1)} - 0.115\sigma_L^2 \quad (61)$$

$$L_{10} = L_{50} + 1.28\sigma_L \quad (62)$$

$$L_{NP} = L_{eq(1)} + 2.56\sigma_L \quad (63)$$

The 1974 NCHRP Method

A comprehensive review of highway noise methodology has been carried out by Kugler et al.[34] on behalf of the NCHRP, and has resulted in a new "Design Guide for Highway Noise Prediction Methodology". A copy of this design guide was made available to the writers as the present report went into final draft, consequently it has been possible to give the new design guide only a very cursory review.

The new guide contains a short method, using nomographs and a computer program written in ANSI standard FORTRAN. The program is in two parts; the first will give listed results, whilst the second will produce the input to a CALCOMP plotter program.

Theoretical Background: The new guide gives a method leading directly to the calculation of L_{eq}, from which L_{10} can be obtained. The calculation of L_{eq} is made as follows (in most cases, the terminology of the present report has been used in place of that given in reference 35)

$$L_{eq} = (EL - 4) + 10 \log_{10} Q/DS + 10 \log_{10} \Delta\theta/180 + (1.2 - 5 \log_{10} r_n/50) + DEL_B + 2 \quad (64)$$

where r_n is the distance from the observer to the nearest part of the road element, DEL_B is the barrier or road elevation correction, and EL is the emission level, the remaining symbols have the same meaning as in the section on the NCHRP 117/144 methods.

Average Vehicles: Values for EL are given as follows

Automobiles:

$$EL_1 = 22 + 30 \log_{10} S \quad \text{dB} \quad (65)$$

Medium trucks, a new designation:

$$EL_2 = 32 + 30 \log_{10} S \quad \text{dB} \quad (66)$$

thus the new medium truck is exactly 10 dB noisier than an automobile.

Heavy trucks, i.e., tractor trailers:

$$EL_3 = 90 \text{ dB} \tag{67}$$

Comparison with NCHRP 117/144 Methods: To compare with the older design guide or NCHRP 117/144 methodology, particularly as it appears in MICNOISE 10, it is best, first, to reevaluate eqq. (45) and (46) according to the new guide. These now appear as

Automobiles at 100 ft. (30.48 m):

$$L_{eq} = 10 \log_{10} Q_A S_A^2 - 0.3 \text{ dB} \tag{68}$$

Medium trucks at 100 ft.:

$$L_{eq}(100 \text{ ft}) = 10 \log_{10} Q_M S_M^2 + 9.7 \text{ dB} \tag{69}$$

Heavy trucks at 100 ft.:

$$L_{eq}(100 \text{ ft}) = 10 \log_{10} Q_T/S_T + 67.7 \tag{70}$$

Thus the new guide increases the levels of automobiles by 0.7 dB and heavy trucks by 2.7 dB. However, compared to the earlier guide, many trucks would be taken out of the heavy truck category and placed in the new medium truck category, so that overall noise level predictions may not increase by as much as 2.7 dB.

Distance Correction: The distance correction of eq. (48) now becomes

$$DEL1 = -10 \log_{10} (D_E/100) - 5 \log_{10} (r_n/100) \tag{71}$$

while the roadway length correction is the same as in eq. (51). This new correction is the same as the old one of eq. (48) if the roadway element passes the observer, but is different for a distant element. Although the logic for this change is sound, it means that the total noise predicted for a segment of road depends on how it is subdivided into elements, which is an undesirable feature.

Vertical and Barrier Corrections: The vertical and barrier corrections are similar to those used in the TSC method, with truck noise sources taken at 8 ft. (2.4 m) above the road. However, a completely new nomograph has been drawn for finite barriers, with corresponding tables stored in the computer program.

L_{10} Values: Values of L_{10} are obtained by adding the values in Table 8 to L_{eq}.

Table 8

VALUES OF $L_{10} - L_{50}$ IN NEW 1974 NCHRP DESIGN GUIDE [34]

Vehicle Density Parameter (QD/S)		
Vehicle ft/mile	Vehicle m/km	$L_{10} - L_{eq}$ dB
0	0	0
10	1.894	-5
25	4.74	-2
50	9.47	1
200	37.88	3
3000	568.2	2
16000	3030.0	1

The values given in Table 8 are new, being based on a statistical analysis of the overall problem. Values given for QD/S greater than 200 vehicle ft/mile (37.88 vehicle m/km) are stated to be within ± 2 dB.

Other Corrections: The computer method includes corrections for grades, road surfaces, and structures, as in the MICHIGAN/144 and MICNOISE 10 programs.

Output of 1974 NCHRP Program: The output of the 1974 NCHRP program is basically L_{10}, but there is an option to obtain L_{eq}. Also, a CALCOMP program is available for producing contour plots.

THE NOISE 1 AREA MODEL

Description of NOISE 1 Area Model

The NOISE 1 area model was developed under Phase 1 of this study[1,2]. It was intended to give a quick capability to produce L_{10} noise contours, and to provide experience in working with the general idea before starting on a model of more general usefulness.

To use the NOISE 1 program, one must take the following steps (see Figure 5) before preparing the punched card input to the IBM 370.

1. Identify the boundaries of the contour map to be prepared, and determine certain relevant parameters, such as scale, origin, map dimensions, and angle of rotation. (See item (1) in Figure 5.)

2. Determine the roads to be included in the study, and organize them into a network of numbered sectors surrounded by numbered road segments which must terminate at common nodes (see item (2) in Figure 5). Coordinates of road segments can be punched on cards on equipment in the Aerial Survey Section of the Virginia Department of Highways and Transportation.

3. Determine traffic parameters on all road segments.

4. Determine boundary lines for the study, even if these conform to the map boundaries. (See item (4) in Figure 5.)

5. Define each sector by its surrounding road or boundary segments. (See item (5) in Figure 5.)

6. Determine certain parameters related to plotting the results.

The NOISE 1 program prepares a file which can be read by the XYNETICS contour program. This program in turn produces instructions for the plotter.

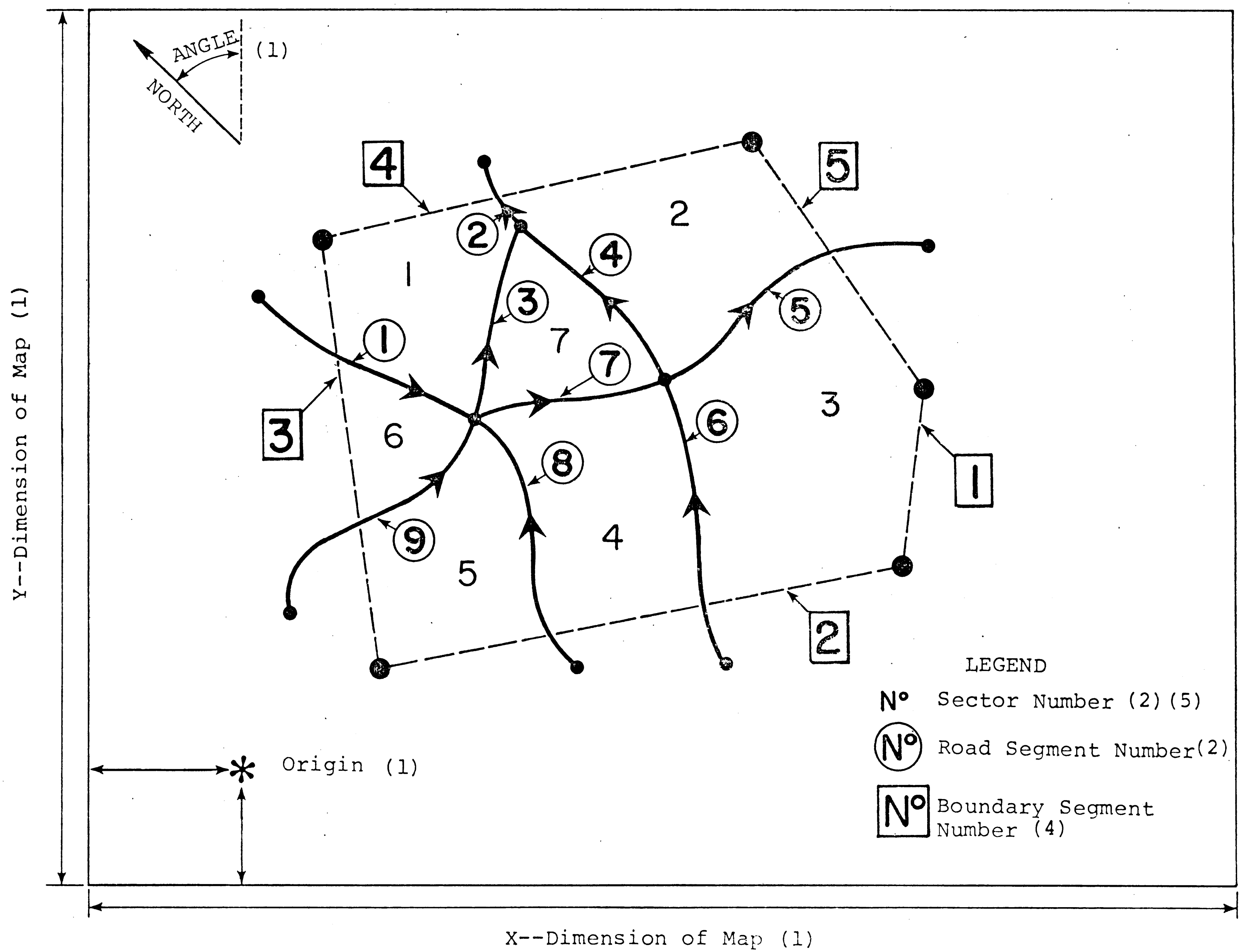

Figure 6. Input to NOISE 1 area model program. (Figures in parentheses are referred to in the text.)

Comments on the NOISE 1 Area Model

One-Shot Nature: The program was prepared without subroutines and therefore lacks flexibility.

Contour Plots: The contour plots produced by the XYNETICS plotter have been of very poor quality. It has been found advisable to post the values of the levels on a rectangular array of grid points and to sketch in new contours using these posted values. To avoid problems with singularities along the roadways, the boundary of each sector is offset from the center of the road by 25 feet (7.6 m). This turns out to be an advantage, because, when sector boundaries are plotted, the result is a road map of the area.

Restrictions on Results: Only L_{10} values can be computed at present, and no acoustic shielding effects can be included.

Computer Time: Relatively large amounts of computer time were needed to do trial calculations for Harrisonburg. This was partly due to a misunderstanding under which too many coordinates were provided along the road segments, whereas the computer time is proportional to the total number of points on the road segments multiplied by the number of grid points. Computation time was improved somewhat by limiting to 3,000 feet (914.4 m) the distance over which traffic could influence the sound levels.

THE RECOMMENDED NOISE 3 AREA MODEL

General Program Features of NOISE 3

Subroutine Structure: A highly organized structure of subroutines using a standardized set of Jobs Control Language Cards has been prepared for NOISE 3. This structure allows the user to operate at three levels of sophistication:

1. To use the program exactly as is.
2. To use his own version of a subroutine consisting entirely of call statements.
3. To insert his own versions of subroutines.

Input Data: Input data are similar to those used in NOISE 1, in fact the format for road segments is identical for the two, however, some additional data can be supplied to NOISE 3. Coordinates of the points at which noise levels are to be calculated must be supplied with NOISE 3, because elevation information is needed, whereas these same points are located automatically on a rectangular grid in NOISE 1. Also, ridge line coordinates are supplied to define shoulders, barriers, or other features which will result in acoustical shielding.

Contour Plots: The subroutine presently included prepares input to the XYNETICS contour program, but calls for posted values, not contours. When the contour program under development becomes available, a suitable subroutine will be prepared for it.

Checkout Feature: An interesting feature of NOISE 3 is the ability to obtain a map of the roads used in the analysis without any further calculation. This can be very useful for checking that the geometric data are correct and complete before expending computer time on noise calculations.

Calculations Performed by NOISE 3

Data Preparation: After data have been read in, points defining the sectors in clockwise order are determined. These include right-of-way offsets from the centers of the roads to avoid problems with irregularities. Then, those points at which noise levels are to be calculated which fall within the various sectors are attached to the vectors of points defining the sectors.

Selection of MICNOISE Highway Noise Model: The highway noise model is contained in a single subroutine, and therefore any desired model can be included by changing that subroutine. For the first subroutine, the following basic decisions have been made.

1. Use adaptation of MICNOISE model. The reason for using this model is that the Council has more information on this model than on any other and has evaluated it under several conditions, as reported in references 28 and 29. Therefore, this model is the most suitable one available for checking out the overall program. Further, the model has FHWA approval.

2. Extend choice of vehicles to a total of ten.

3. Provide for noise dependency on several sources per vehicle, each with different speed dependency.

4. Calculate the following levels:

$L_{eq(1)}$ = Peak hour equivalent level

L_{50} = 50% exceedence level

L_{10} = 10% exceedence level

L_{NP} = Noise pollution level

$L_{eq(24)}$ = 24-hour equivalent level

L_{dn} = day-night equivalent level

However, the user has the option of selecting which values are to be plotted, and the program logic avoids unnecessary calculations.

The selection of the above levels was made on the grounds that (a) L_{10} and $L_{eq(1)}$ should be calculated anyway because these are still called for by the FHWA in reference 19, (b) L_{50} and L_{10} values are presently available from the MICNOISE study,[28,29] and (c) the EPA has requested all agencies to adopt the use of L_{dn}, which will therefore become the standard designation of noise level, (d) L_{NP} is obtained very simply from L_{10} and L_{50}, and (e) $L_{eq(24)}$ is often used in place of L_{dn} for non-residential areas in which nighttime noise is of no special significance.

Description of NOISE 3 - MICNOISE Subroutine:

Traffic input data: The input data include the following traffic information for each road segment and for up to 10 vehicle types.

ADT = Average traffic in 24-hour period

ANT = Average nighttime traffic, 2200-0700 hours

Q = Peak hourly traffic

S = Vehicle speed (mph)

Vehicle type data: For each of up to 10 vehicle types, and for every separate noise source on each vehicle, the following data are supplied:

L_{REF} = Reference level in dBA

D_{REF} = Reference distance in feet

H_{REF} = Reference height above ground, in feet

S_{REF} = Reference speed in mph

N_S = Speed-dependence index

f_{REF} = Reference frequency in Hz

Calculation of levels at 100 feet: For each vehicle on each segment of road the mean square acoustical pressure, P_H, is calculated at 100 feet from

$$P_H = \frac{\pi}{100 \times 5280} \sum_{\text{sources}} \frac{D_{REF}^2}{S} \left(\frac{S}{S_{REF}} \right)^{N_S} 10^{\frac{L_{REF} - 94}{10}} \quad (72)$$

Initially, values for f_{REF} will not be required, however, storage will be provided for possible later modifications of the program. For comparison to MICNOISE 10, values to be supplied for the above quantities would be as given in Table 9.

Table 9

VEHICLE PARAMETERS USED IN NOISE 3 FOR COMPARISON WITH MICNOISE 10

Parameter	Automobile	Truck
L_{REF}	60	77.2 dBA
D_{REF}	100 ft(30.48 m)	100 ft(30.48 m)
H_{REF}	0	13 ft(4.1 m)
S_{REF}	60 mph(96.6 kph)	60 mph(96.6 kph)
n_S	3	0
f_{REF}	--	--

Values for P_H from eq. (72) will be used directly in the following calculations of mean square pressures at 100 feet from each road segment due to all vehicles

$$P_{eq(1)} = \sum_{\text{vehicles}} P_H Q \tag{73}$$

$$P_{50} = \sum_{\text{vehicles}} P_H Q \tanh(0.119\ Q/S) \tag{74}$$

$$P_{10} = \sum_{\text{vehicles}} P_H Q F_{10}\ (100\ Q/S) \tag{75}$$

$$P_{eq(24)} = \sum_{\text{vehicles}} P_H ADT/24 \tag{76}$$

$$P_{dn} = \sum_{\text{vehicles}} P_H (ADT/24 + ANT) \tag{77}$$

Also

$$QDSR = F_{10}^{-1}\ (P_{10}/P_{50}) \div 100 \tag{78}$$

where QDSR is the reference value of the traffic parameter QD/S at one foot distance from the road, and

$$HR_{(1)} = \sum_{\text{vehicles}} P_H Q H_{REF} \div P_{eq(1)} \tag{79}$$

$$HR_{dn} = \sum_{\text{vehicles}} P_H (ADT/24 + ANT) H_{REF} \div P_{dn} \tag{80}$$

where terms HR(1) and HR_{dn} are the average heights in feet above the roadway for acoustical shielding calculations to be used in the $L_{eq(1)}$ (or L_{50}, L_{10}) and the $L_{eq(24)}$ or L_{dn} calculations respectively.

In eq. (75), the function F_{10} is the ratio of mean square pressures for L_{10} and L_{50}, and is defined by

$$F_{10(x)} = 10^{\frac{L_{10} - L_{50}}{10}}$$

$$= 20.785 - 1.49431 \times 10^{-2}\ x - 4.61197 \times 10^{-5} x^2 \quad \text{for } 0 < x \leq 300 \tag{81A}$$

$$= 1.3737 + 3235.7 x^{-1} \quad \text{for } 300 < x \tag{81B}$$

where

$x = QD/S$.

However, F_{10}^{-1} is obtained by interpolation using the original tables in MICNOISE 5 for evaluation of eq. (78).

Calculation of final levels: The final levels are calculated at points selected by the user and supplied with the input, as well as at points defining the sectors. However, no calculations are performed which do not lead to values requested by the user. If the background levels L_{BACK} have been supplied by the user, then

$$P_{BACK} = 10^{\frac{L_{BACK} - 94}{100}} \qquad (82)$$

The following summations are carried out over roadway elements, that is, the small lengths between successive coordinates. Note that there can be several roadway elements in one roadway segment.

$$L_{eq(1)} = 10 \log_{10}\{P_{BACK} + \Sigma P_{eq(1)} R_D R_E\} + 94 \qquad (83)$$

$$L_{50} = 10 \log_{10}\{P_{BACK} + \Sigma P_{50} R_D R_E\} + 94 \qquad (84)$$

$$L_{10} = 10 \log_{10}\{P_{BACK} + \Sigma P_{50} R_D R_E R_{10}\} + 94 \qquad (85)$$

$$L_{np} = L_{50} + (L_{10} - L_{90}) + (L_{10} - L_{90})^2/60 \qquad (86)$$

$$L_{eq(24)} = 10 \log_{10}\{P_{BACK} + \Sigma P_{eq(24)} R_D R_E\} + 94 \qquad (87)$$

$$L_{dn} = 10 \log_{10}\{P_{BACK} + \Sigma P_{dn} R_D R_E\} + 94 \qquad (88)$$

where

$$R_D = \left(\frac{D}{100}\right)^{-3/2} \frac{\Delta\theta}{180} \quad \text{for } D \geq 100 \text{ ft}(30.48 \text{ m}) \qquad (89A)$$

$$= \left(\frac{D}{100}\right)^{-1} \frac{\Delta\theta}{180} \quad \text{for } 100 \text{ ft} > D \geq 20 \text{ ft}(6.10 \text{ m}) \qquad (89B)$$

$$= \left(\frac{20}{100}\right)^{-1} \frac{\Delta\theta}{180} \quad \text{for } 20 \text{ ft} > D \qquad (89C)$$

In the above, D is the perpendicular distance from the receiving point (at which the level is calculated) to the roadway element, and $\Delta\theta$ is the subtended angle of the roadway element. Also, R_E is the elevation correction, calculated as in the 1974 NCHRP method, but with all traffic at a given height $HR_{(1)}$ or HR_{dn} above the road, and with tables converted to read ratios instead of decibel attenuation, using the same values as in the MICNOISE 10 program.

Finally, R_{10} is defined by

$$R_{10} = F_{10}(QDSR \times D) \qquad (90)$$

Proposals for time-saving: Several ideas are being tried to save time on the computer, and three of these are cited below.

1. For each sector, a rectangle is first defined which is 3,000 feet (914.4 m) larger in all directions than the sector itself. Then a subsidiary file of data is created containing only those roadway coordinates which penetrate the rectangle.

2. Distances of noise propagation are limited to 3,000 feet (914.4 m).

3. The contributions to the summation symbols in eqq. (83) to (88) from infinite roadways are examined. If these are less than 1/2 P_{BACK}, they are ignored.

Comments on NOISE 3 calculations: The methods of calculations used for NOISE 3 differ in a few respects from those used for MICNOISE 10. In particular:

1. The method of handling L_{10} is not identical in the two methods, but should lead to results which are very close. A great amount of computer time is required to reproduce the MICNOISE 5 calculations exactly, as was done in NOISE 1.

2. The handling of acoustical shielding is different in detail in the two methods, but should lead to similar results.

3. It appears feasible to include noise in airport environs by supplying coordinates of approach and takeoff paths with road coordinates, provided that suitable values for LA_D can be found.

RECOMMENDATIONS

This report covers the evaluation of different methods of predicting and classifying environmental noise from all sources that was carried out in order to select the most suitable methods for the Phase II area model.

The Phase II computer model is presently in the checkout stage, therefore, all of the important decisions have been made and implemented.

Recommendations made as a result of this study follow.

1. Methods of Rating Noise: Since the EPA has requested all government agencies to report values of L_{dn}, so that there will be a common basis of reporting noise levels, it is evident that L_{dn} should be considered. However, the FHWA requirements are not yet changed, therefore it is recommended that the area model have the capability of computing and drawing contour plots for the following six noise level ratings --

   $L_{eq(1)}$, L_{50}, L_{10}, L_{NP}, $L_{eq(24)}$, L_{dn}.

   Of these, L_{dn} is recommended by the EPA, $L_{eq(1)}$ and L_{10} are presently required by the FHWA, L_{50} and L_{10} were calculated in the MICNOISE evaluation(28,29), L_{NP} is a simple derivative of L_{50} and L_{10}, and $L_{eq(24)}$ is an alternative to L_{dn} for areas in which no one needs quiet at night. It is feasible to calculate L_{10}, L_{eq} or L_{dn} for aircraft, if combined levels are to be obtained, but somewhat difficult to obtain the basic input data.

2. Subroutine Structure of NOISE 3: NOISE 3 should have an organized subroutine structure that could be built on in the future. The subroutines have been developed and a standardized Job Control Language has been written so that the user has the option of (a) using the program as is, (b) using a simple subroutine consisting entirely of call statements to modify the basic job, or (c) inserting new subroutines.

3. Basic MICNOISE Model: Initially, the basic MICNOISE model should be used, except where changes can be made to save computing time without making significant changes in the results. The primary reason for this is to permit us to evaluate NOISE 3 results against previous MICNOISE results.

4. Later Models: Improved models should be developed. Both the TSC(32) model and the new Design Guide(34) introduce improved methods which could be evaluated in conjunction with a program of barrier evaluation. It will be relatively easy to replace the present MICNOISE model with a new one because only a subroutine is involved.

5. Additional Vehicles: Provision should be made for additional vehicles, which could include aircraft. Up to 10 have been allowed for, with provision for several noise sources for each vehicle, so that tire,

engine, and exhaust noises can be considered separately.

6. Contour Plots: Computer levels should be posted so long as the XYNETICS contour program is used, and no attempt should be made to draw contours. However, once the new program is available in the Data Processing Division, this should be used instead, which will merely require the preparation of a new subroutine.

Two further items were studied, but are given negative recommendations. They follow.

7. Overall Impact Factor: The closest to an overall impact factor which has emerged on a national scale has been the EPA recommendation to use L_{dn} for all applications. However, no further ideas on combining noise with, for example, air pollution levels, have been suggested. Therefore, no further recommendation can be made at this time beyond the use of L_{dn}.

8. Optimum Highway Location: No progress towards the idea of optimum highway location can be made until computing times are reduced at least an order of magnitude over those in the NOISE 1 program. It is not yet clear how much improvement has been made with NOISE 3. Therefore, no recommendation can be made at this time.

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