The general summary for all study sites as given in Table 5 clearly indicates that the comparative results were poor with the 87.0 dBA heavy-duty-vehicle spectrum and 3.0 dBA drop-off rate. The margin of error for this particular pair of variables is shown to be 8.8 dBA ± 1.8 dBA at 200 ft (60.96 m) from the roadway, and this degree of overprediction is clearly unacceptable. The 82.0 dBA heavy-duty-vehicle spectrum and 4.5 dBA drop-off rate produced the best overall correlation between measured and predicted data. All of the test data clearly support the use of a 4.5 dBA per doubling of distance drop-off rate for better predictive accuracy with the TSC Program. The test data do not, however, overwhelmingly support the 82.0 dBA heavy-duty-vehicle emission level over the 86.0 dBA emission level. The test data do infer that slightly higher individual truck emission levels may occur on some interstate highways and major urban freeways. This inference may be correct in that the percentage of 5 or more axle tractor trailers to the total number of heavy trucks will be higher on these types of highway facilities and this particular subclass of trucks will be transporting the greatest payload with the net result of producing louder overall noise levels.

The North Carolina Division of Highways has not had the opportunity to perform noise abatement barrier evaluations with the TSC Program involving pre-existent traffic noise conditions. Nevertheless, the North Carolina Division of Highways has utilized the TSC Program to evaluate noise barriers for probable future traffic noise conditions. Until program modifications were recently issued to eliminate a path length difference error associated with sound wave diffraction, much uncertainty existed concerning the noise reduction effectiveness of both natural and artificial barriers. It is anticipated that this program modification will prove beneficial in making more accurate assessments of future noise abatement considerations.

The Federal Highway Administration is encouraged to bring to prompt completion its investigations pertaining to noise emission levels from heavy duty vehicles as well as drop-off rate determinations. Issuances from these findings will provide program modifications that should improve the accuracy of the TSC Program. Recent findings concerning tire-pavement surface noise level relationships should also be investigated to determine the feasibility of utilizing pavement surface correction factors either generally or on specific types of highway evaluations. The Federal Highway Alministration is also encouraged to perform additional studies to authenticate the claim that the optimum Level of Service 'C' traffic condition generates higher traffic noise levels than less desirable traffic flow conditions.

MINNESOTA'S EXPERIENCE WITH TRAFFIC NOISE PREDICTION

Ronald M. Canner, Jr., Minnesota Department of Highways

Introduction

The Minnesota Highway Department is grategul to those who had the foresight to initiate traffic noise research and develop a noise prediction model under the National Cooperative Highway Research Program (NCHRP). Reports 78 and 117 (3 and 4) could not have been timed better to meet our needs. We would have little hope of completing our interstate freeway program in Minnesota without a way to predict noise and mitigate noise from proposed urban freeways.

We are also grateful to the Federal Highway Administration (FHWA) who assisted us in our first noise barrier design and participated in its construction as an experimental project. FHWA also arranged for the National Highway Institute training class on Fundamentals and Abatement of Highway Traffic Noise and the Noise Measurement Equipment Demonstration, which were helpful to us.

Implementing NCHRP 117

As we became familiar with the format of the NCHRP 117 model, we found that it could be streamlined for use by our highway engineers and technicians. We consolidated charts and tables and developed a one-page work sheet (now revised several times). We later developed tables for the commonly used parts of the charts eliminating the need for repeated visual interpolation.

One of the most useful changes we made in the manual prediction charts was in the shielding chart, a change that eliminated trial and error from the barrier design process. To do this we adapted Maekawa's chart in the 117 report using a simple trigonometric approximation (which yields an error of one to two decibels when the source or receiver is less than one unit of barrier height from the barrier). The revisions in

144 have altered that simple relationship so I will not go into the mathematics involved. We hope to develop a similar chart and computer program that will enable direct barrier height design for simple situations. We already have a mathematical procedure to do so, using a pocket slide rule calculator (Fig. 1).

We have programmed the 117 model into a desk top Hewlett Packard calculator (model 9810) with a typewriter terminal. The input sheet is simple; the output is complete (Figs. 2 and 3). The program is stored on one small program card and is easily reproduced. Each district design office has been trained in the use of the program. It has cut prediction time in half and costs about 80 cents per run after the input has been determined. Our computer program stores or computes all of the noise parameters as does the Michigan terminal model (5). (We did not have on-line capability at the time so we resorted to programable desk top calculators, which we did have.)

One feature of our desk top calculator program is the direct use of D_e for computation of L_{50}. This procedure improves L_{50} predictions at receptors closer than 100 ft (30.48 m) to the source. The program also enables a prediction of a double barrier, using Maekawa's relationships (10). Information is desired to verify the benefits and problems associated with double shielding, man-made or natural.

We have tried the TSC (DOT Transportation Systems Center) program (15) on our IBM 360 but have had problems getting reliable answers and excessive computer costs. We did not have people or time to de-bug it so we had to drop it for the time being. We would prefer a model like TSC that, when given topographic and traffic data input, does the rest. We are aware of the susceptibility of 117 to error because of the judgment needed to properly select elements in complex situations. Inputs for home and vegetation shielding, pavement noise, and interrupted traffic flows also require judgment. Neither our computer program nor Michigan's eliminated these judgment decisions. Therefore, the user must be well trained and experienced to assure useful predictions. We are hopeful that the problems with TSC or the new NCHRP (Project 3-7/3) computer model can be overcome so that the element selection problem can be eliminated.

To design a noise barrier a number of representative sites are chosen and predictions are made using our adaptation of the 117 model. The barrier height is designed and checked for each site for all possible exposures to the freeway traffic. One quick way we use to obtain a preliminary barrier profile is to make a simple prediction for abutting receptors every 200 ft (60.96 m) along the road, assuming an infinite roadway element for each site. We then go back, using the prediction model, and check the preliminary barrier top profile with representative receptors to assure that blanking and "leaks" do not occur over low places. Inclusion of distant lengths of roadway that come into audible range when a barrier is erected helps assure against flanking. Subdivision of wide roadways into 2 separate roadways will help to account for the lesser barrier effectiveness that accompanies the greater source to barrier distance of the far lane. An 8-ft source height for trucks is used to account for their higher centroid of noise.

Trucks and other loud moving point sources (motorcycles, some cars) are not normally numerous enough to be considered a line source. Barriers and other shielding are more efficient in reducing point source noise. Also, roll-off of sound level with distance is usually greater for point sources than line sources. These two phenomena combine to reduce the accuracy of the model but tend to improve the practical efficiency of noise barriers. The proposed NCHRP Revised Design Guide (RDG) (2) probably handles moving point sources better than previous models.

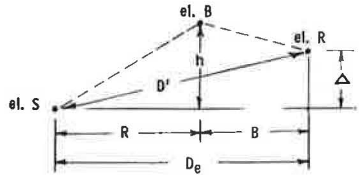
Some additional descriptions of our use of the 117 prediction model are included in the following examples. Some problems encountered are also described.

Example 1: Noise Barrier

Our first major use of the 117 was in designing an experimental noise barrier subsequently built along a section of I-35W in Minneapolis. It cost $400,000 to construct. I-35W is a 6-lane freeway carrying about 100,000 vehicles daily including some 6,000 trucks. The site selected was 3,900 ft (1188 m) long. The fronting homes are about 250 ft (76.2 m) from the freeway centerline and at varying elevations. The barrier design heights were provided by R. F. Lambert, an acoustical consultant who subsequently evaluated the completed barrier. Some of his findings may be of interest here. His report also includes an annoyance survey by T. J. Bouchard, Jr., a consulting behavioral scientist (9).

Sound level predictions for pre-barrier and post-barrier conditions tended to vary both ways from measured levels. However, measured reductions in L_{50} averaged 3 decibels less than predicted by the 117 model. Differences in L_{10} reductions were greater. These observed differences are apparently due to a complex interaction of a number of factors in the model and measurements.

Figure 1. BARRIER ELEVATION FORMULA



el. S = source elevation
el. R = receiver elevation
el. B = barrier top elevation

$\Delta = \text{el. } R - \text{el. } S$

$D' = \sqrt{D_e^2 + \Delta^2}$ $\qquad\qquad \alpha = D' + \delta$

δ = path length difference corresponding to a chosen attenuation Fig. C-1 NCHRP 144.

$$h = \frac{\Delta \pm \sqrt{\left[\Delta^2 - 2B\left(\frac{D_e}{R}\right)\right] \cdot \left[D_e - \alpha + \frac{\Delta^2}{2B}\right]}}{\frac{D_e}{R}}$$

$\text{el. } B_e = \text{el. } S \pm h$

Note: $\frac{h}{R} \leq 1$ and $\frac{h - \Delta}{B} \leq 1$

Figure 2.

Computed by
Date
Checked by
Date

MINNESOTA HIGHWAY DEPARTMENT
TRAFFIC NOISE PREDICTION
for use with
Hewlett Packard Model 9810

Traffic Year ______ Level of Service ____ Land Use _____

T.H. 335

S.P. 2788-01 Location Station 810 + 00

Cross Section No.

Listener Position No.

TRAFFIC	Element Number		1	2	3	4
	Total Hourly Volume	HV	3000	3000	3000	
	Truck %	Tr%	7	7	7	
	Auto Speed	SA	50	50	50	
	Truck Speed	ST	45	45	45	
GEOMETRY	Equivalent Lane Dist.	DE	310	200	235	
	Subtendend Angle	ANG.	25	93	61	
	Ground Elevation	GE	852	852	852	
	Barrier Elevation 1	BE 1	850	862	850	
	Barrier Elevation 2	BE 2	–	–	–	
	Highway Elevation	P.G.	846	847.5	849	
	Barrier Distance 1	R-1	95	90	60	
	Barrier Distance 2	R-2				
ADJUSTMENT	Gradient	Grade	0	0	0	
	Pavement	Pavt.	0	0	0	
	Bldg. Vegetation	Misc.	0	0	0	
	Interrupted	Floa	0	0	0	
	Traffic	Flot	0	0	0	

Figure 3.

MINNESOTA HIGHWAY DEPARTMENT
TRAFFIC NOISE PREDICTION
TH 335 SP 2788.001

CROSS SECTION NO 1
LISTENER POS NO 1
ELEMENT NO 1

HV= 3000	Tr%= 7.0	Va= 2790	Vt= 210	Sa= 50	St= 45
De= 310.0	Ang= 25.0	GE= 852.0	BE= 850.0	PG= 846.0	R = 95.0
Grade 0	Pavt 0	Misc 0	Flo A 0	Flo T 0	

AUTO L50= 51.5 TRUCK L50= 52.8

AUTO L10= 53.5 TRUCK L10= 58.4

ELEMENT NO 2

HV= 3000	Tr%= 7.0	Va= 2790	Vt= 210	Sa= 50	St= 45
De= 200.0	Ang= 93.0	GE= 852.0	BE= 862.0	PG= 847.5	R = 90.0
Grade 0	Pavt 0	Misc 0	Flo A 0	Flo T 0	

AUTO L50= 46.8 TRUCK L50= 53.0

AUTO L10= 49.1 TRUCK L10= 59.8

ELEMENT NO 3

HV= 3000	Tr%= 7.0	Va= 2790	Vt= 210	Sa= 50	St= 45
De= 235.0	Ang= 61.0	GE= 852.0	BE= 850.0	PG= 849.0	R = 60.0
Grade 0	Pavt 0	Misc 0	Flo A 0	Flo T 0	

AUTO L50= 57.2 TRUCK L50= 58.5

AUTO L10= 59.4 TRUCK L10= 64.8

TOTAL L50= 62.5 TOTAL L10= 67.6

CROSS SECTION NO

Figure 4.

DOMINANT ELEMENT EFFECT

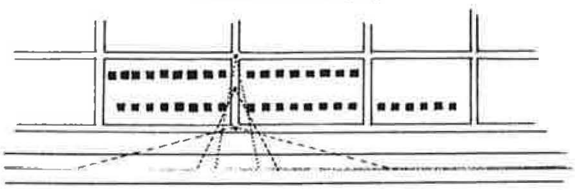
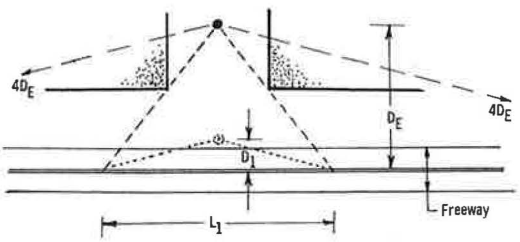


Figure 5.

DOMINANT ELEMENT ADJUSTMENT



$D_1 = \frac{L_1}{8}$

Par A $= \frac{VD_1}{S}$

D_1 Is used as an effective D_E

One factor is that noise prediction is highly sensitive to kind of trucks assumed. The percentage of diesel trucks, and the percentage of heavy trucks (three axles or more), and some knowledge of the sound level distribution of these is essential to produce an accurate prediction. However, urban truck data are often very sparse and predictions of future truck traffic volumes and noise-related characteristics are fraught with difficulties, particularly in urban areas. If strict national truck noise maximums are set, they will tend to greatly narrow the distribution of noise levels generated. Hopefully vehicle emission levels will then be better defined than at present.

Another uncertainty that was troublesome to the barrier evaluation, and continues to be so, is the question whether the correct value for building shielding was applied. Some other measurements we have made indicate that rows of very closely spaced 2-story homes will reduce noise levels to a greater degree than the 144 report indicates. More definitive quantification of this factor is needed.

Another factor involved properly accounting for pre-barrier measurement site conditions in pre-barrier predictions. While predicted pre-barrier L_{50} averaged only 2 decibels higher than measured, predicted pre-barrier (L_{10} - L_{50}) was up to 4 dB higher than measured. However, Lambert suspected some site characteristics peculiar to pre-barrier conditions could account for some of the differences observed, because they were not provided for in the 117 prediction procedure. Pre-barrier measurement sites in streets perpendicular to the freeway were partially shielded by rows of homes parallel to the freeway. The angular opening to the freeway at the end of the street was relatively smaller for sites further from the freeway. The observed variation (L_{10} - L_{50}) of the noise did not decrease with distance but was about the same for all sites. After the barrier was built, the effects of partial shielding from the homes was not as significant and observed (L_{10} - L_{50}) did decrease with distance. Traffic exposed by these street openings apparently was the predominant source of noise observed at the measurement sites before the barrier was built (Fig. 4). This noise was more variable than expected because the number of vehicles exposed in the opening at any time is smaller than the number of vehicles influencing the observed noise after the barrier was completed. This variation increases as the degree of adjacent shielding is increased or as the observers' distance from the opening increases.

Lambert suggested a way to roughly compensate for the dominant element effect just described (Fig. 5). To determine parameter A he used a fictitious distance D_1 computed as follows:

$$\frac{D_1}{D_e} = \frac{L_1}{L_{total}}$$

Since L_{total} is usually considered in 117 to be about 8 times D_e:

$$D_1 = L_1 \times \frac{D_e}{8D_e}; \text{ or } D_1 = \frac{L_1}{8}$$

This step essentially assumes the dominant element is the only source and treats it as an infinite element for purpose of determining (L_{10} - L_{50}) and L_{10}. Using the dominant element correction, correlation of the predicted variance (L_{10} - L_{50}) with that measured was improved from up to a 4-decibel discrepancy to about 1 decibel.

The 117 model was used to predict reflections using a virtual image of the source behind the opposing barrier. The addition of a reflective image source increases the apparent distance thereby reducing (L_{10} - L_{50}) as calculated from Par A = VD/S (Fig. 6). At close locations reflected noise from far side barriers appears to decrease L_{10}.

Even with the dominant element correction and consideration of reflections predicted, L_{10} was about 2 decibels high for the pre-barrier situation and about 1 decibel low for the post-barrier situation. These total to about a 3-decibel overprediction of expected reduction due to the barrier (Figs. 7 and 8). From a practical standpoint, this is about as close as we could expect, considering other uncertainties in truck emissions and home shielding values and variables involved.

Use of the 144 barrier curve may improve predictions. However, neither the 144 nor the proposed NCHRP RDG models appear to include the dominant element effect on (L_{10} - L_{50}). However, we note that Kurze does recognize the problem and handles it in the mathematical derivation of the RDG model. Equation G.14 (2, Vol. 3, p. G20) shows that variance is dependent on the length of intercepted angle of element observed. However, as far as we can tell, this relationship has not been incorporated into the model itself. Perhaps it should be. We need a way to cope with gaps, as we get numerous requests for visual openings from residents or businesses behind proposed barriers.

Figure 6.

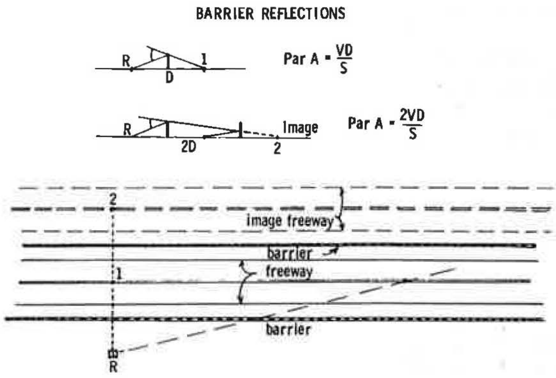
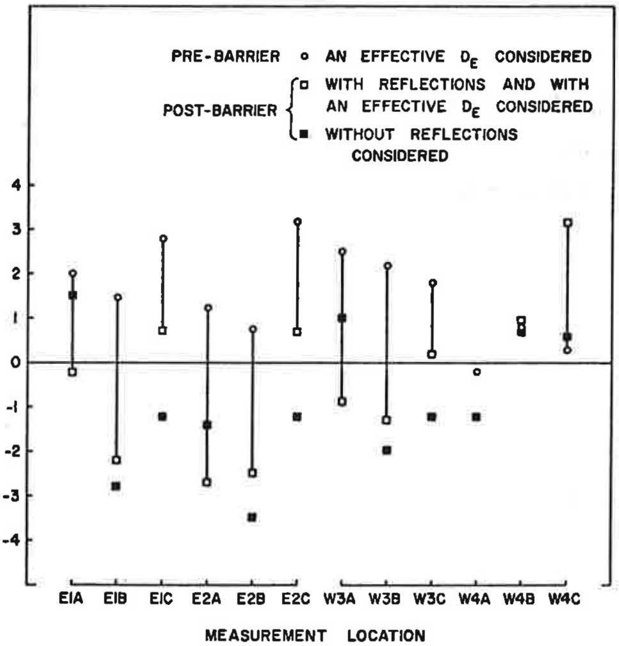
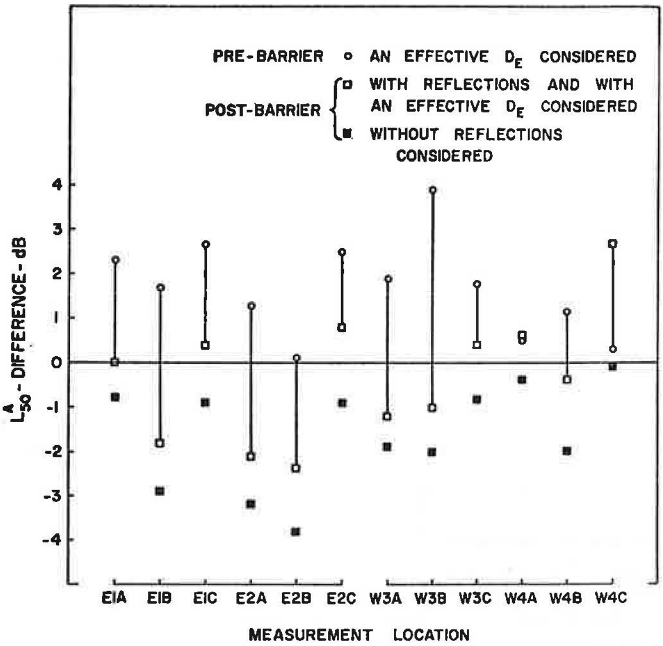


Figure 7.



$(L^A_{10})_{pred.} - (L^A_{10})_{exp.}$ FOR PRE AND POST BARRIER CONDITIONS

Figure 8.

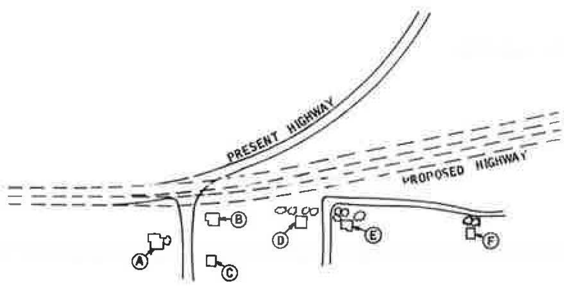


$(L^A_{50})_{pred.}-(L^A_{50})_{exp.}$ FOR PRE AND POST BARRIER CONDITIONS

Figure 9.

US-169 Blue Earth Minnesota

Traffic:	Autos	290-350
	Trucks	60- 85
	Speed	30 mph
Homes:	80' to 200' from road	
Measurements:	Check off method (dbA)	
	30 second reading interval	
	45 minute measurement period	



Summarizing, the barrier evaluation showed we slightly overpredicted the value of the barrier. However, it also shows that further work is needed to develop rational modifications to the model to make it more responsive to the realities of traffic noise, terrain, and shielding conditions.

Example 2: Environmental Impact

Usually we measure sound levels along a proposed route for use as a basis for assessing the environmental impact of a proposed highway. Predicted future levels are compared with ambient (measured) levels at each site. We also make a prediction using the traffic volumes counted at the time of measurement to calibrate the model with site conditions. Often the predicted levels differ from measured levels. If so, we may adjust the predicted future level by an amount equal to the difference between the present predicted and measured levels.

For example, this practice was used to evaluate reconstruction of an existing 2-lane highway to 4 lanes at Blue Earth, Minnesota. The predicted sound levels exceeded measured levels by 3 to 9 decibels. The adjusted 1990 L_{10} was 62 to 64 dBA, a more acceptable level than the 71 to 75 dBA uncorrected prediction (Fig. 9, Table 1).

We feel that some caution is required when comparing predictions with measured sound levels. We attempt to limit any adjustments to the site where the measurement was made. Notice the wide variation in adjustment between sites in this example. There are just too many unquantified site conditions and ground effects that may not apply to a site other than that where the adjustment is made. Another factor perhaps often overlooked is wind. A light breeze (5 to 10 mph) can apparently have an effect on the sound level received from the roadway being surveyed. Measured levels upwind or downwind can differ from predicted levels by several decibels. An adjustment based on such measured levels may well be in error, one way or the other, if wind during model calibration measurements is ignored.

Prevailing light winds also seem to cause greater noise impacts to downwind receptors. We have noticed that downwind receptors complain more than upwind receptors at a site with prevailing winds. Some research papers seem to show that even a light breeze may negate the benefits of a noise barrier to downwind receptors. Further research may be needed to quantify wind effects and incorporate them into the prediction model. Perhaps meteorological statistics used in traffic air quality analysis will be useful in noise analysis also. Those interested in wind effects may refer to Refs. 1 and 12.

Example 3: Urban Arterial Street

One general case that we have great difficulty handling with any available noise model is the low-traffic city arterial or rural farm-to-market roads. These streets and highways do not normally lend themselves to barrier construction. Their relocation away from the adjacent residents is contradictory to the purpose they serve. Yet, we are asked to assess noise impacts of these roads and may be required to meet state ambient standards soon. Some measurements of noise from a city arterial street were made as part of the FHWA Region 15 noise equipment demonstration project in Minnesota. This street carries about 9000 ADT, 7½ percent trucks. Flow during the measurement period was 750 veh/h and 7½ percent trucks at about 30 mph (48 km/ph). Because of nearby traffic signals, flow was highly queued with lulls between. Reflections occurred from a row of homes across the street from the park where measurements were made. The ground was snow covered and low banks of plowed snow lined the street.

Analysis of the data shows that traffic flow was non-Gaussian and better described by a Poisson distribution. The "roll off" with distance was 10 dB per doubling distance. By correcting the distance adjustment and vehicle emissions to conform to the measured values, and assuming a Poisson distribution we predict within 0 to 2 decibels of measured values (Table 2). We feel that these adjustments were made with mathematical and statistical logic that fit field conditions observed. In this case, truck emissions fit the model well but auto emissions were higher than expected. The distance roll-off was unusually high. Perhaps a procedure is needed whereby certain field conditions, such as distance roll-off and vehicle acoustical power, can be measured and then empirically introduced into a model on a site-by-site basis. A semi-empirical model may be the only way to adequately handle complex urban situations.

The Future

Improvements and refinement of traffic noise prediction models are particularly important to Minnesota. In 1974 the state established ambient noise standards based on public

Table 1.

L_{50} (dbA)

site	measured 1974	predicted 1974	predicted 1990	adjusted 1990	adjustment
A	56	63	64	57	-7
B	60	65	63	58	-5
C	52	60	62	54	-8
D	53	62	63	53	-9
E	53	60	60	56	-7
F	-	-	60	-	avg = -7

L_{10} (dbA)

site	measured 1974	predicted 1974	predicted 1990	adjusted 1990	adjustment
A	69	74	74	69	-5
B	73	76	75	72	-3
C	61	70	71	62	-9
D	64	72	74	66	-7
E	63	69	73	67	-6
F	-	-	68	-	-
					avg = -6

Table 2.

Urban Arterial Traffic Prediction

Distance	L_{10}	L_{50}	Leq	Data
35'	73	64	69	
70'	64	57	61	Measured
100'	60	54	56	
35'	78	66	-	Predicted:
70'	76	64	-	NCHRP 117
100'	74	63	-	and 144
35'	71	62	68	
70'	63	57	61	Predicted:
100'	60	54	57	Minn. Hwy. Dept.*

*Using observed values of:

Truck emissions = PWL (T) = 125

Auto emissions = PWL (A) = 115

Distance roll-off = 35 log $\frac{D_2}{D_1}$

Poisson distribution of traffic.

Table 3.

MINNESOTA STATE REGULATION

NPC - 2

NOISE STANDARDS

Noise Received By:	Day 0700-2200 L_{50}	L_{10}	Night 2200-0700 L_{50}	L_{10}
Residential	60	65	50	55
Commercial	65	70	65	70
Industrial	75	80	75	80

measured in dbA - loudest hour

health and welfare. The standards were issued after public hearing by the state Pollution Control Agency under authority of a 1971 state law (Table 3) (11). These standards are more stringent and more comprehensive than the FHWA guideline in Federal Highway Program Manual 7-7-3. Maximum levels for both L_{10} and L_{50} levels are set for peak daytime and nighttime hours. Therefore, an L_{10} and L_{50} prediction model is essential to our state. There is no legal enforcement regulation for these standards, as yet, but the Department of Highways is attempting to meet them where reasonably attainable. The Minnesota Pollution Control Agencies are currently developing regulations to enforce the standards along both new and existing highways. Implementation of the state standards on all roadways (not just freeways) will require a model that accurately predicts noise from low traffic volumes and speeds, particularly in urban streets with congested, interrupted, or intermittent flows and some within reverberant "canyons" formed by tall buildings.

Another rather unique event occurred this summer. The state legislature directed the department to spend one percent of its share of the state gas tax on noise abatement along residential areas adjacent to existing interstate freeways in metropolitan areas. With 90 percent federal aid, this program will amount to over $10,000,000 annually. With the advent of this rather sizable commitment of funds to a state highway noise abatement ("highway retrofit") program, we are especially concerned that we are designing adequate barriers, yet not overdesigning them and wasting money.

These developments, together with the continuing need to evaluate environmental impacts, substantiate our need for a reliable noise prediction model (although one sometimes wonders that, if the 117 had not been available, all this would have occurred as soon). This need led us to review as much material on noise prediction as we could obtain. Several items that should give food for thought have emerged from regarding our work. I will but mention them because they are really a little beyond the bounds of my assigned project.

1. The distribution of traffic at volumes below 1,000 veh/h is usually not Gaussian and probably is more closely represented by a Poisson distribution. Vehicles are not equally spaced but tend to bunch up.

2. The distribution of trucks mixed in moderate freeway traffic is also usually not Gaussian and also resembles a Poisson distribution.

3. The errors of determining L_{eq} from measured sound pressure levels should be investigated.

4. Longer sampling periods may be needed to assure that traffic volumes measured truly represent the hour's traffic particularly at low volumes or slow speeds. The statistical tests used in the "check off" measurement method indicate whether sound measurements reliably represent the traffic actually passing during the sampling period. They do not tell if the measurement period represents the traffic passing during the hour.

5. L_{eq} is a measure of average intensity but does not relate to how those intensities are distributed. Perhaps L_{eq} should be used with an appropriate indicator of statistical variance when representing variable traffic noise.

We are generally pleased with the advances of the proposed NCHRP-RDG model. The developer has obviously taken pains to describe and quantify such essentials as vehicle emission levels and distance roll-off rates. On the other hand, we are still vitally concerned that we have a more accurate L_{10} and L_{50} prediction model. Several recent technical papers are of interest and should be reviewed in depth. If valid, the findings should be incorporated into a new L_{10} model (8, 13, and 14). These papers develop some mathematical bases for estimating the variance of traffic noise depending on traffic characteristics and site conditions not available in present or proposed models. We welcome opportunities to discuss further some of the statistical attributes of traffic noise modeling with others concerned.

Summary of Needs

The following items should be researched, quantified, and modeled, particularly with the effects on L_{10}, $(L_{10} - L_{50})$, as well as L_{50} and L_{eq}:

1. Model low-volume traffic conditions; often queued and intermittent flow, apparently requiring the application of non-Gaussian statistics to model. Actually, truck traffic on most roads, even freeways, fits this category.

2. Determine what are the real health benefits, if any, associated with noise abatement below hearing loss thresholds. Is physical or mental health at stake and, if

so, to what degree? Is annoyance reduction the best measure of benefit or is some health-related parameter needed? How do we quantify benefits?

3. Develop appropriate model for effects of barriers on noise statistics such as $(L_{10} - L_{50})$ and L_{10}.

4. Develop appropriate model for effects of dominant roadway elements and reflections on noise statistics such as $(L_{10} - L_{50})$ and L_{10}.

5. Categorize and quantify shielding provided by various sizes, spacing, and alignment of homes and other buildings.

6. Develop a procedure for measuring vehicle acoustical power levels to be used in and introduced into the model.

7. Categorize and quantify effects of reflections and scattering of sound due to air turbulence, trees, and buildings above and behind barriers.

8. Develop noise rating of tire-pavement systems so that reductions available from resurfacing can be predicted. This will become more critical when truck noise is reduced enough so that tire-pavement noise dominates.

9. Determine effects of prevailing winds on upwind and downwind receptors, particularly behind barriers; techniques to correct field measurements to calm conditions.

10. Determine value of barriers in reducing noise impacts to indoor receptors particularly with windows shut, conversely the value of "sound proofing" buildings behind barriers or natural shielding. This item relates to low-frequency sounds passing over and through noise barriers and through building walls.

I trust these remarks will not be viewed as mere criticism but rather as a springboard for further discussion and research. The NCHRP 117 and 144 models have served us well. We have already spent over $8,000,000 on noise abatement works based on its predictions, and, as far as we can tell, with substantial and beneficial reductions in noise impacts near freeways.

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ONTARIO HIGHWAY NOISE PREDICTION METHOD

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This paper describes the development, accuracy, reliability, and application of a new Ontario highway noise prediction method. It is an empirical method based on 135 sound level measurements taken at 120 locations near rural and urban freeways, highways, and along residential streets.

At the beginning of the report, measured sound levels were compared with the sound levels calculated by the Design Guide and Delany methods. The results of this comparison indicated a need for a more accurate highway noise prediction method. The less complex Delany method was found to be more accurate for nonfreeway locations than the more comprehensive Design Guide method.

The report, then, outlines the construction and the statistical evaluation of mathematical models that form the basis of the Ontario highway noise prediction method. The Ontario highway noise prediction method enables calculations of L_{50} and L_{10} sound levels with a higher level of accuracy than the two methods evaluated. The standard error of estimate for L_{10} levels calculated by the Ontario method was about 2.2 dBA. This indicated that 3 predictions out of 4 will be within ±2.5 dBA. The standard error of estimate for L_{50} levels was about 2.8 dBA.

The paper also briefly outlines a procedure for the application of the method.

Introduction

A reliable highway noise prediction method is an essential tool for predicting the impact of new highways on the environment and for evaluating different highway noise attenuation features and strategies. The highway noise prediction method should enable planners and designers to utilize fully and efficiently the land surrounding highways and to minimize the adverse effects of highways on the environment.

The highway noise prediction method most widely used in Ontario was developed by the firm of Bolt, Beranek and Newman (1). The method will be referred to as the Design Guide Method or simply as the BBN method. Earlier studies indicated that the BBN method does not provide noise estimates with the desired precision (2).

Since 1970, the Ontario Ministry of Transportation and Communications has been collecting data on sound levels in the vicinity of proposed and existing provincial freeways and highways for various planning and design purposes. Due to the amount and comprehensiveness of these data, it was decided to utilize them in a study with the following objectives: (a) to determine the accuracy and reliability of existing highway noise prediction methods using province-wide data, and if warranted, (b) to develop a more accurate highway noise prediction method.

Data Base

Description of Locations

Most of the data used in this study were collected on a day-to-day basis between 1970 and 1973. To make generalizations with unbiased estimates from observed data, the observations should be chosen in a random manner from all possible observations in the area where future predictions are to be made. Since this requirement could not be satisfied (data had already been collected), all available, suitable observations were included in this study to eliminate any personal bias.

Some of the observations were rejected if any of the essential variables such as distance, traffic volumes, and shielding effects were missing or if a number of observations (i.e., noise measurements) were conducted at the same location.