Figure 5 summarizes some of the results for the 24-hour site in North Carolina for selected traffic densities.

These preliminary results show that the values from the TSC model are much higher than the field data (6 to 10 dB), while the Michigan 117 model results are not quite as high, they still remain above the field data. It is also interesting to note how the two models follow each other fairly well, although separated by several dB. Both models exhibit erratic behavior at low traffic volumes.

As I have mentioned, these are only preliminary results from a first pass at the data. We are still in the process of ensuring that the procedures used to structure the input for the models from the raw data are valid and that the noise measurements were not affected by conditions that are not considered by the models (wind, humidity, etc.). These results seem to be holding for the two states processed to date (North Carolina and Florida). We are anticipating additional data from Washington and Colorado.

Coincident with this straightforward processing of the data, we are undertaking an analysis of the field measurements to determine the noise decrease with doubling of distance and the relationship between L_{eq} and V/DS for events where one vehicle type predominates.

Each state is also providing single-vehicle data that will allow us to generate the 50-ft (15.24-m) spectrum for each vehicle class and to then compare these spectra against those used in the models. If appropriate, the spectra of the models will be modified and all of the cases rerun with the modified models to determine the effects of the new spectra, and hopefully, bring the results into closer agreement with the field measurements.

One final word, since the workshop, we have received and implemented the revised design guide on TSC's Decsystem-10. The initial results using this model are encouraging.

EXPERIMENTAL DATA SUPPORTING THE NCHRP 3-7/3 REVISED DESIGN GUIDE FOR HIGHWAY NOISE PREDICTION AND CONTROL

B. Andrew Kugler, Bolt Beranek and Newman, Inc.

Introduction

The revised design guide for highway noise prediction and control, developed as a result of research conducted under NCHRP Project 3-7/3 contains many changes and modifications to the procedure presented in NCHRP Reports 117/144 designed to improve the accuracy and to extend the range of applicability under which the prediction may be used. These changes and modifications resulted from the experience gained through the use of 117/144 and the TSC models by highway departments and from further research conducted under the NCHRP 3-7/3 program. (The TSC model, developed by the Transportation Systems Center is one of two highway noise prediction procedures approved by the FHWA; the other is the NCHRP 117/144 procedure.)

The objective of this presentation is to bring forth field noise data in support of the revised design guide model. Since the revised design guide was only recently completed and since only a very limited amount of field data is available for a valid comparison, this analysis can be judged as preliminary at best. However, the data presented may be viewed as a first order test of the model in the sense that it provides an estimate of the prediction accuracy under a variety of highway conditions.

Before we explore the main topic of this presentation, a few words of comment about the acquisition and analysis of the field noise data are in order. The assumption that any field data regardless of how they were acquired and how well the site parameters are known can be fairly compared to a prediction procedure is false. More often than not such practice has led to incorrect and misleading conclusions as to the accuracy of the model being tested.

The validation of a prediction procedure like the one being offered here requires more than a cursory examination of a field test site. First of all, we must strive to acquire acoustic data that are valid for the type of descriptor (i.e., L_{10}, L_{50}, or L_{eq}) being used in the prediction procedure. It also must be remembered that a prediction procedure of this type, by its very nature, implies that the calculated noise levels are "typical" for the given traffic conditions considered. That is, the prediction procedure will and should predict the noise levels that will be experienced at the given location if this same condition is measured repeatedly.

Second, if the model is to be tested properly, the traffic and geometric roadway parameters that govern the model must be properly measured and identified. There is very little reason to measure the noise levels repeatedly and establish the L_{10} level to within 0.1 dB if only a vague description of the highway, surrounding terrain, and traffic conditions under which the measurements were made are available.

When analyzing the applicability and accuracy of the highway noise model, it is helpful to evaluate separately the major sub-models on which the overall procedure is based. The three major ingredients in the noise prediction model are (a) noise source model, (b) free field propagation model, and (c) barrier noise reduction model.

The noise source model, using the parameters of traffic volume, traffic mix, and average speed, predicts the total magnitude of acoustic energy being generated in terms of sound levels in the close proximity to the roadway. The free field propagation model, using the description of the highway horizontal configuration and surrounding terrain, predicts how this acoustic energy is propagated between the source and receiver. Finally, the "barrier" noise reduction model evaluates how obstructions such as the vertical roadway configuration, walls, houses or other definable terrain characteristics modify and reduce the noise levels reaching the receiver. The experimental data presented here will be analyzed in terms of these three models and the accuracy of the prediction procedure will be discussed in terms of these categories.

Field Test Sites

The field noise data used in the noise source and barrier model analysis were acquired under two separate projects (1,2) for TRB and FHWA. Fourteen test sites are analyzed as identified in Table 1.

Although by no means exhaustive in terms of national coverage, the test noise data collected includes five states and covers a number of weather conditions (i.e., summer in California, winter in Minnesota).

Extensive noise measurements were performed at each site under a wide range of traffic conditions. In each instance, simultaneous microphone locations were monitored and recorded on analog tape. The data were later reduced in terms of the noise descriptors of interest. Reference 1 provides a detailed description of the measurement procedures and data analysis technique. Furthermore, the site identifications utilized in this analysis are kept the same as in the original references for use of comparison.

Noise Source Model Assessment

The assessment of the noise source model was performed by selecting, from each test site, noise measurements that were made at a close proximity to the roadway; typically between 25 to 100 ft (7.62 m to 30.48 m) from the near lane. The controlling requirements in the site selection were that the highway approximates the infinite line geometry [straight and level for at least 1000 ft (304.8 m) in each direction] and that a free field view be afforded from the microphone position to the entire line source. These requirements eliminated from consideration all variables except the traffic conditions present during the measurement.

Each traffic condition for which noise measurements were available was then used to input the revised design guide model and to compute the predicted noise levels. Typically, 10 to 25 independent conditions were computed for each test site and the overall discrepancy at each test site calculated by summing the individual sample discrepancies and dividing by the number of conditions evaluated. Figure 1 presents these data as a function of each site average discrepancy versus site location.

In each case, the individual discrepancy is defined as the difference between measured and predicted noise levels. That is, a positive discrepancy indicates an underprediction of measured values and a negative discrepancy indicates an overprediction of measured values. Ideally, when the prediction and measurement are the same, the discrepancy is zero.

An evaluation of Figure 1 leads to a few important conclusions with respect to the gross accuracy of the source model.

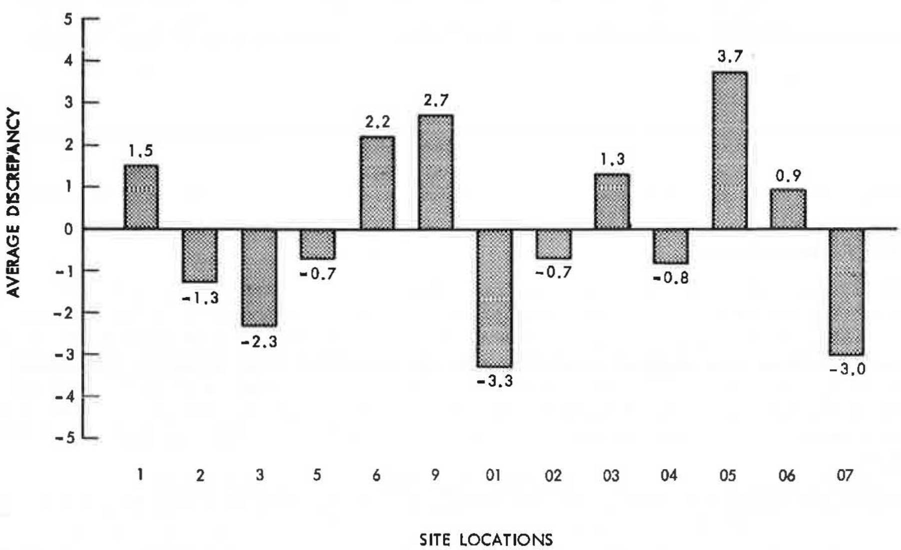
1. The average of the discrepancy between measured and predicted values over all 13 sites is negligible (in the order of 0.02 dB). This suggests that the model, for "an average site in the country," correctly predicts measured values.

2. From one site to the next there is a definite variability resulting in an average overprediction or underprediction of the noise levels. The range of average discrepancy is approximately ±3.5 dB.

Table 1. Location of test sites at which traffic noise data were collected.

Site No.		
1.	1-680 Milpitas, California	(TRB)
2.	US-101 Encino, California	(TRB)
3.	1-405 Van Nuys, California	(TRB)
4.	I-494 Bloomington, Minnesota	(TRB)
5.	I-35W Richfield, Minnesota	(TRB)
6.	I-94 Ypsilanti, Michigan	(TRB)
01.	SR-7 Long Beach, California	(FHWA)
02.	I-605 Long Beach, California	(FHWA)
03.	I-10 San Gabriel, California	(FHWA)
04.	I-75 Allen Park, Michigan	(FHWA)
05.	I-94 Kalamazoo, Michigan	(FHWA)
06.	I-94 Milwaukee, Wisconsin	(FHWA)
07.	I-94 Minneapolis, Minnesota	(FHWA)
09.	I-80 Sacramento, California	(FHWA)

Figure 1. Average discrepancy between measured and predicted noise levels.



3. There is no clear regional tendency as to the underprediction or overprediction of the noise levels. For example site locations 01 and 02 (refer to Table 1) located in Long Beach, California, were measured under the same climatic conditions and due to their proximity, with apparently the same type of vehicle distribution, however, the average discrepancy differed by almost 3.0 dB between these sites. The same conclusion may be arrived at for other sites used in the analysis.

4. There is no apparent climatic dependence as to the overprediction or underprediction of the noise levels. For example, site locations 04, 05, 06, and 07 were measured during the winter period with snow on the ground while the remaining site locations were measured during summer or mild temperature conditions.

To explore further the individual site discrepancy problem, an evaluation of the data based on the traffic parameters used in the source model was conducted as a function of (a) average speed, (b) vehicle class as function of heavy truck to automobile/medium truck ratio, and (c) total volume.

Figure 2 presents a dispersion diagram of all individual data points used in the analysis as a function of discrepancy and average speed. Although only the speed range of 50 to 75 mph (80 to 112 km/h) is covered,the data points out the lack of tendency as a function of speed. Furthermore, the subclassification as a function of the truck/auto ratio does not further explain the discrepancy.

Figure 3 presents a similar comparison, this time as a function of heavy truck to auto ratio (T/A). The T/A covers a range of 0 to 24 percent and again the data show no apparent trend. Finally, the same analysis was performed as a function of total volume and indicated in Figure 4 with the same general conclusion.

Statistical tests in the form of correlation and regression analysis were performed to support the above conclusions. The overall conclusion is that the model predicts source levels correctly based on vehicle class, average speed, and total volume, and that these parameters are not responsible for the observed discrepancies from site to site. The individual standard deviations were approximately 2.5 dB.

The above analysis will seem to indicate that the observed site discrepancy is site dependent and not a function of the model parameters or regional/climatic conditions. A further conclusion is that individual measurements of L_{10} levels at any given site may be different from predicted values by as much as ±4.0 dB with an expected standard deviation of 2.5 dB.

These differences between measured and predicted values may be due to one or a combination of the following:

1. The instability of the L_{10} measure, especially for low traffic volumes;
2. The apparent variability of the actual sources as compared to the "average source" used in the model for each vehicle category;
3. The effect of environmental conditions (i.e., wind and temperature gradients) at the site during the measurement period; and
4. The site topographical factors that are beyond the models capability.

From all these, the site dependent topographical factors is probably the most influential parameter. It remains to be seen if long-term measurements at a given site and given location will show a better agreement with the model, on the average, or if in fact there is a bias error associated with each site that is site dependent and beyond the model capability.

Free Field Propagation Model Assessment

The propagation of traffic noise away from the highway is complicated by the presence of ground plane and environmental factors. The model permits for the use of two propagation constants—3.0 dB and 4.5 dB per distance doubling. Very little field noise data compatible with free field propagation evaluation are available, however, what data exist do confirm the variability of the propagation factor between the above two values.

The data presented below represents a summary of the conclusions reported in Volume 3 of NCHRP Project 3-7/3 (3). Figures 5, 6, and 7 present some typical examples of the measured noise levels as a function of equivalent distance from the roadway for three test sites investigated. The different symbols correspond to different traffic conditions under which simultaneous noise measurements were acquired.

Analysis of the field data brings forth the following conclusions:

1. It is acceptable to assume that the free field noise levels due to highway traffic are proportional to the logarithm of equivalent distance from the roadway, at

Figure 2. Measured minus predicted noise source levels.

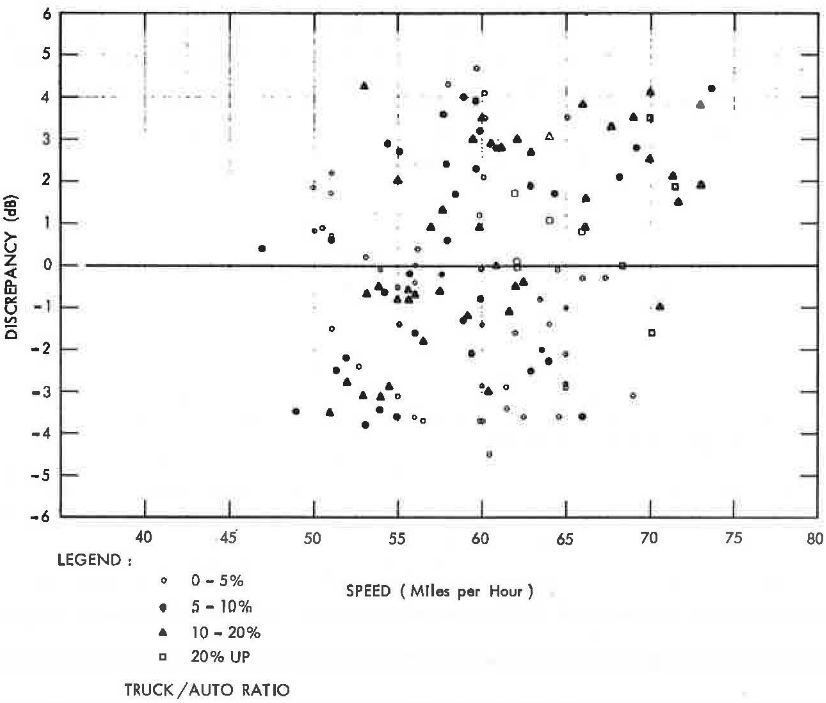


Figure 3. Measured minus predicted noise source levels.

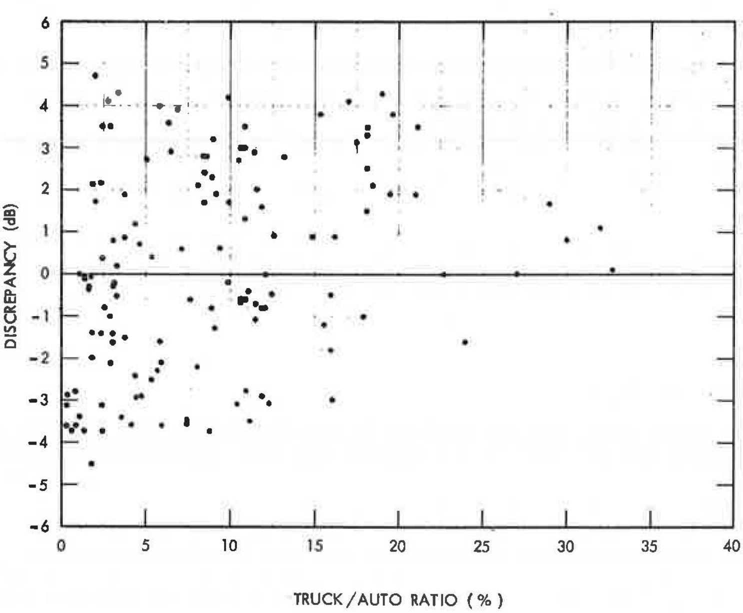


Figure 4. Measured minus predicted noise source levels.

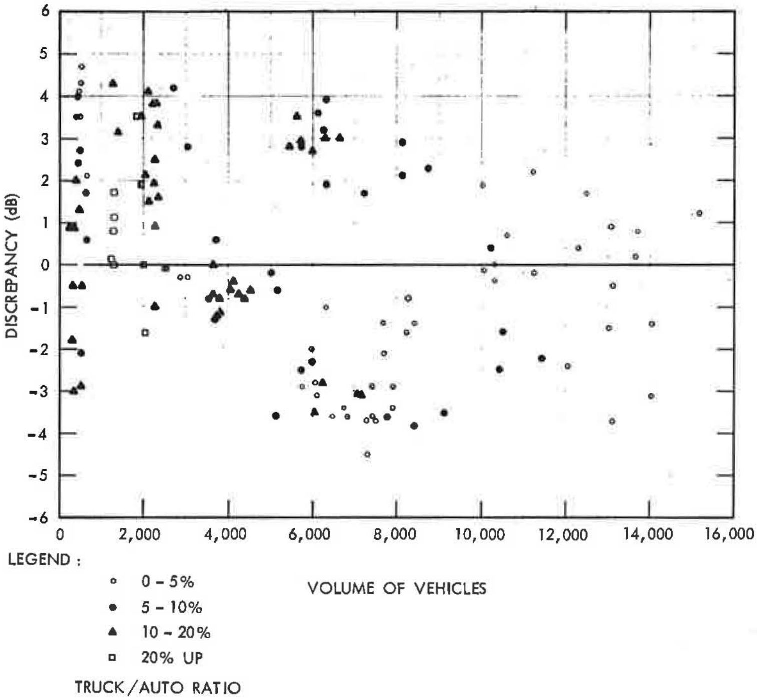


Figure 5. Free field noise propagation measurements at Site 1.

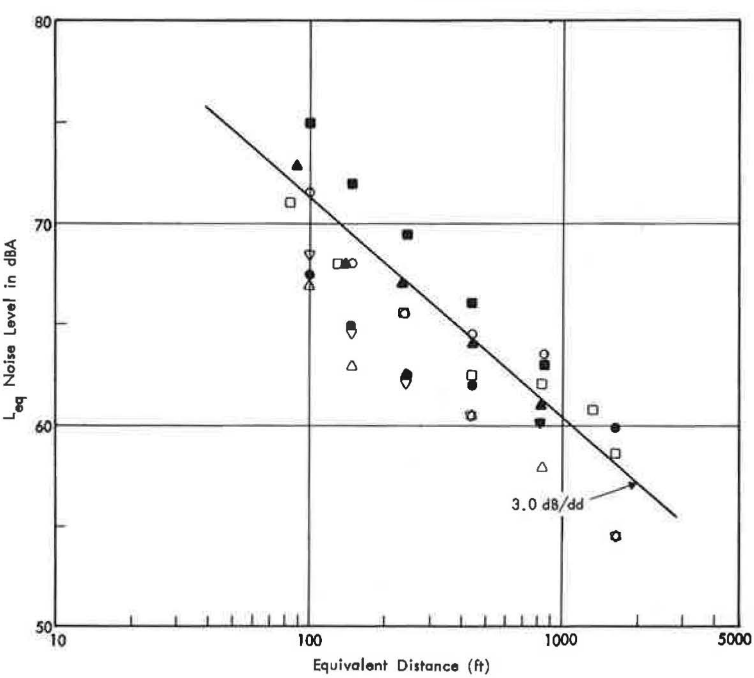


Figure 6. Free field noise propagation measurements at Site 2.

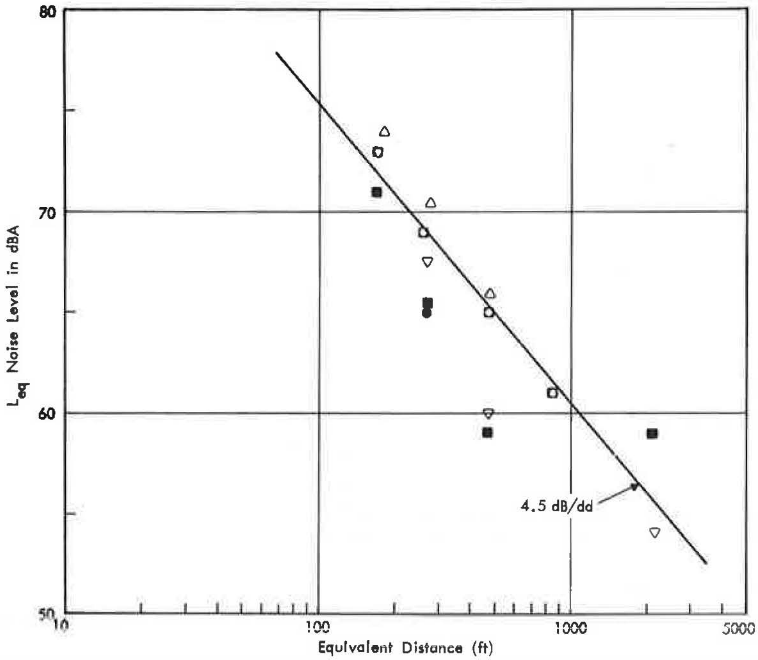
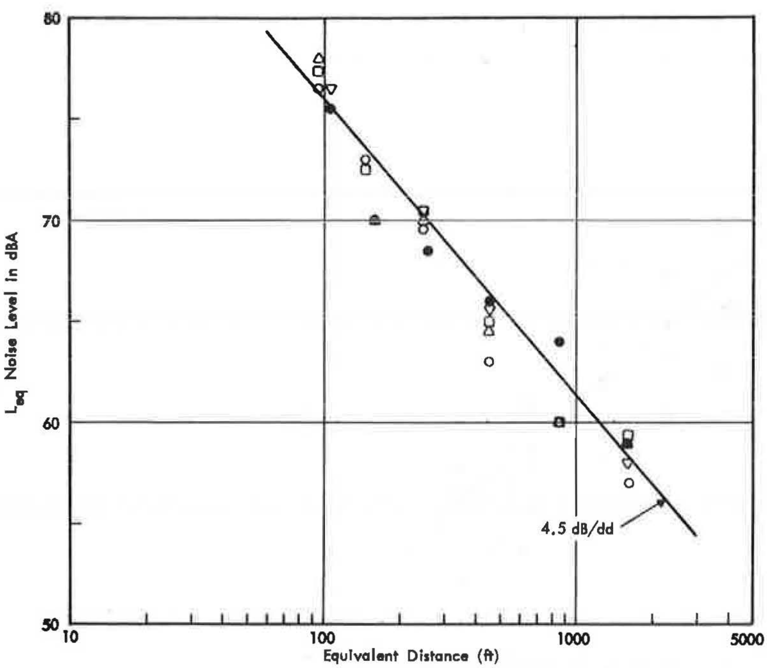


Figure 7. Free field noise propagation measurements at Site 3.



least for distances up to 1600 ft (487.68 m) and traffic volumes down to 250 vph.

2. The constant of proportionality in the relationship (the propagation loss factor) varies about 10 (3 dBA decrease per doubling of distance) for the case of clear, reflective and level ground to about 15 (4.5 dBA decrease per doubling of distance) for the more lush absorptive terrain or for terrain where the line of sight to the highway may be interrupted by small topographical changes (short of barriers). This is given in Table 2.

3. The propagation loss factor does not vary significantly with observer height above the ground up to 15 ft (4.57 m).

4. For relatively high traffic volumes, say greater than 2500 vph, the propagation loss factor does not vary significantly with the percentage level of the noise distribution.

5. For relatively low traffic volumes, say less than 2500 vph, the propagation loss factor for small percentage levels is significantly higher than the loss factor for high percentage levels. An example of this is given in Table 3.

6. The propagation loss factor for mean energy levels (L_{eq}) is stable for all traffic volumes.

The full understanding of what is termed as free field propagation is by no means complete and this study area perhaps is one that most needs further research and validation. However, the correct assessment of the ground conditions in terms of one of the two propagation loss factors gives results which are consistent with the overall prediction procedure accuracy of ±2.0 dB.

Barrier Noise Reduction Model Assessment

The excess noise reduction provided by "barriers" is predicted by the barrier noise reduction model. In this context, the word "barriers" includes the highway vertical configurations such as elevated or depressed and all other continuous physical obstructions between the source and receiver such as walls, berms, and berm-wall combinations.

Accurate field noise data for 12 of the 14 sites described in Figure 1 were available to assess the accuracy of the barrier model. Figure 8 presents a summary of measured minus predicted average discrepancies for all sites evaluated in terms of 5 basic barrier configurations. Each barrier was evaluated by a series of simultaneous noise measurements taken at different distances and heights behind the barrier; these were then repeated for various traffic distributions. In total, 15 to 25 measurement locations were chosen behind each barrier. The average discrepancy for each site represents the average of the individual discrepancies between measurement and prediction evaluated in terms of "Equivalent A-weighted" sound levels (L_{eq}). A more detailed analysis of these data for sites 1, 2, 3 and 5 is presented in Table 4.

The data in Figure 8 show reasonable agreement between measured and predicted values except in the case of berms where the prediction procedure definitely underpredicts measured value by an average of 2.8 dBA. That is, the revised design guide, based on the available data, seems to correctly predict the effect of elevated/depressed highway configurations and walls as long as the "thin edge" geometry can be assumed. When a finite width barrier is considered, such as is the case with berms with a flat top, the prediction procedure underpredicts measured values significantly. This conclusion may be further reinforced by analyzing the data in Figures 9, 10, and 11.

Figure 9 displays a scatter diagram for the case of wall configurations (sites 03, 04 and 07). The data show no apparent trend with a random scatter around the ideal relationship in terms of both increased attenuation and distance from the barrier. The standard deviation for this case is below 2.0 dB. The analysis of the wall-berm combination shown in Figure 10 is similar to the wall configuration with only a slight tendency for underprediction at low attenuation values. However, the case of the finite-width berm shown in Figure 11 shows a definite bias toward underprediction with most of the data lying above the ideal relationship.

Conclusions

The limited field noise data base used to evaluate the accuracy of the revised design guide shows general agreement between measured and predicted values for the three main ingredients of the model. The data further suggest that an accuracy of ±2.5 dBA (one standard deviation) may be expected from this method when applied properly. Without grossly increasing the complexity of the prediction, the author feels that the stated accuracy might be the limit that may be expected. However, further validation of the revised design guide is necessary in order to definitely establish its accuracy and

Table 2. Summary of propagation loss factors for high traffic volumes (L_{eq}).

Site No.	Site Description	Propagation Loss Factor (ε)
1	Freshly plowed farmland	10.9 ± 0.5
2	Planted farmland (an asparagus field)	15.8 ± 0.7
3	Parkland (grass and shrubs)	15.4 ± 1.4

Table 3. Summary of propagation loss factors for low traffic volumes—Site 1.

Propagation Loss Factor (ε) for Various Percentage Levels at Site 1				
L_{01}	L_{10}	L_{50}	L_{90}	L_{eq}
13.6 ± 2.2	10.5 ± 1.8	10.2 ± 1.8	8.7 ± 1.9	10.4 ± 1.3

Figure 8. Average discrepancy between measured and predicted noise reductions at 12 sites.

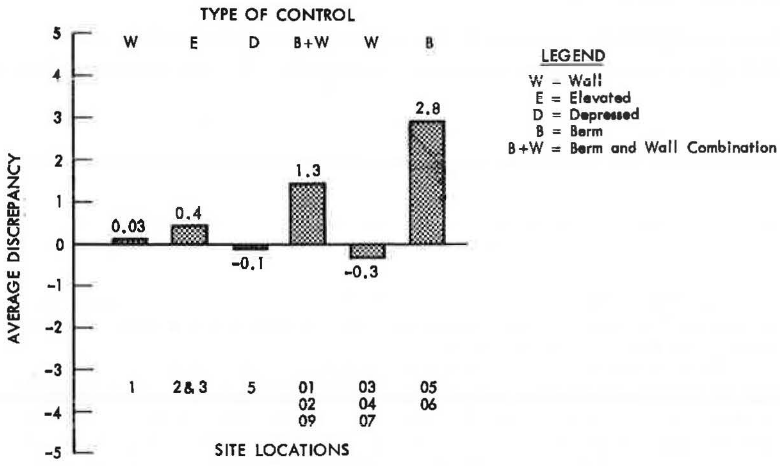


Table 4. Agreement between predicted and measured noise reduction.

Site and Sample Size	Assessment Parameter	Computed Result	Ideal Result	Difference* Statistically Significant?
Roadside Barrier Site 1 n=50	Ave. Discrep., $\bar{\Delta}$	0.03 dBA	0	No
	Std. Dev., s_{Δ}	1.64 dBA	0	--
	Slope, , b	1.19	1.0	No
Elevated Roadway Site 2&3 n=24	Ave. Discrep., $\bar{\Delta}$	0.38 dBA	0	No
	Std. Dev., s_{Δ}	1.39 dBA	0	--
	Slope, , b	1.29	1.0	No
Depressed Roadway Site 5 n=24	Ave. Discrep. $\bar{\Delta}$	-0.10 dBA	0	No
	Std. Dev., s_{Δ}	1.60 dBA	0	--
	Slope, b	0.91	1.0	No

*tested at the 1% level of significance.

Figure 9. Measured versus predicted scatter diagrams for wall configurations.

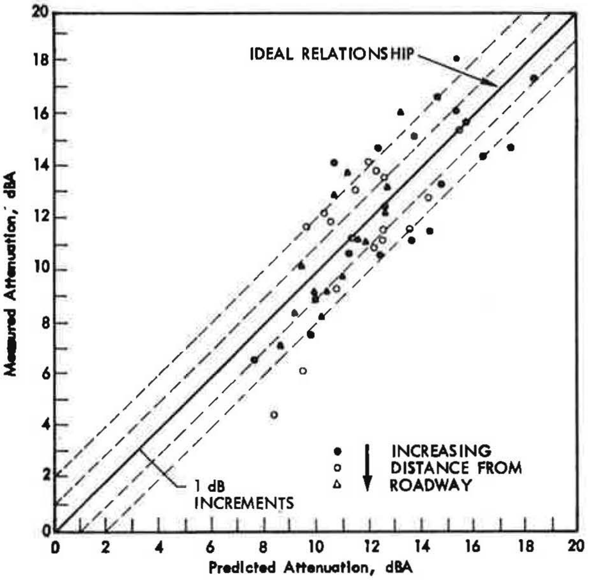


Figure 10. Measured versus predicted attenuation scatter diagrams for berm-wall constructions.

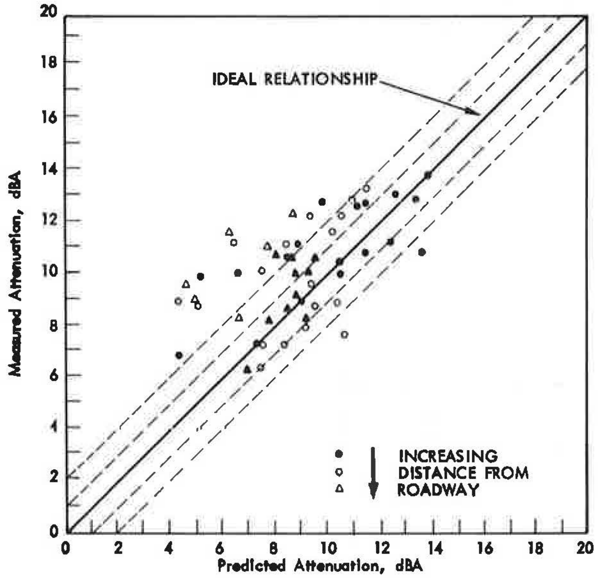
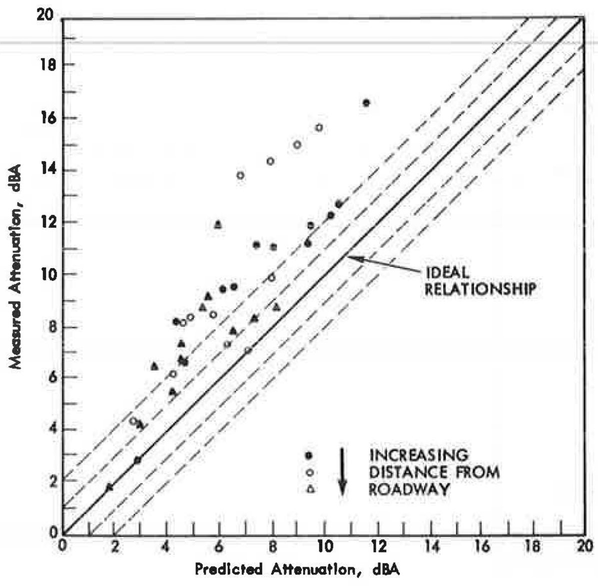


Figure 11. Measured versus predicted attenuation scatter diagram for berm configuration.



applicability. This requires the evaluation of not only simple site configurations as was undertaken in this paper but also of complex geometries where the full extent of the model is exercised. Finally, it is recommended that, as a result of this analysis, further investigation of site-to-site bias error and the noise reduction performance of berms is warranted from this analysis.

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SPECIFIC DIFFERENCES BETWEEN THE "REVISED DESIGN GUIDE" AND THE TWO AUTHORIZED NOISE PREDICTION METHODS OF THE FHWA

Grant S. Anderson, Bolt Beranek and Newman, Inc.

The National Cooperative Highway Research Project 3-7/3 has recently resulted in the publication of a revised design guide for prediction of roadway traffic noise. This guide is a composite product of NCHRP Reports 117/144 and the Transportation Systems Center prediction methods—the two methods authorized by the Federal Highway Administration for use on federal-aid highway projects. The revised design guide (RDG) supplements these two authorized methods (117/144 and TSC) with data taken as part of NCHRP 3-7/3 and as part of an FHWA research project on noise barrier effectiveness. In addition, the RDG supplements the two authorized methods with additional mathematical structuring, derived from physical reasoning, with the hopes of extending the prediction validity to low-volume traffic situations.

In brief, the RDG structure consists of an L_{10} nomograph (similar to the TSC nomograph but with revised source data and revised distance dependence), a barrier nomograph (similar to the FHWA barrier nomograph but with revised distance dependance and revised estimates of the noise around the barrier ends), and a series of worksheets—all leading to a hand-method calculation for simple roadway geometrics. As a partner to the hand method, the RDG includes a computer program (similar to the TSC program but with revised source levels, variable propagation drop-off, revised low-volume mathematics, segment adjustment and many other factors) for the detailed prediction of roadway noise levels, both for complex roadway geometrics and for detailed barrier design. In addition, this computer program contains a diagnosis capability that pinpoints "hot spots" along the roadway and enables the user to balance any barrier design up and down the roadway, to avoid under- or over-design of expensive roadway barriers.

In this paper, these three noise prediction methods (117/144, TSC, and RDG) are coalesced into a common framework, to enable users of these methods (a) to compare the physical assumptions of the methods step by step in the calculation logic; and (b) to anticipate how the RDG will change the predicted noise levels, relative to those predicted by 117/144 and TSC. The common framework consists of three graphs and two equations that coalesce the three methods into the following calculation logic: emission levels (EL) of individual vehicles at 50 ft (15.24 m); to the energy-mean A-level (L_{eq}) at 50 ft (15.24 m), from the entire stream of traffic; to the L_{eq} at any distance D; and finally, to the 10-percentile A-level (L_{10}) at this same distance (with an ad hoc adjustment, necessary only in the 117/144 method).

We first present this common framework, for predicting the L_{10} for an infinite straight roadway. Next, we present three examples using the framework to compute the noise levels for medium, high, and low density traffic. Then we present a series of graphs and tables that complete the comparison of the three prediction methods, in all their finer details. And finally, we summarize the framework and identify under what conditions the RDG predictions will differ from 117/144 and TSC by 5 dBA, by 10 dBA, and by 15 dBA. In this summary, we emphasize the RDG improvements that result from (1) inclusion of medium trucks as a noise source; (2) a variable propagation constant; (3) more realistic low-volume mathematics; and (4) the inclusion of a diagnostic printout in the RDG computer program.