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November 30, 1973

H.3.24

MEMORANDUM TO: J. R. Harbison
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report No. 379; "Evaluation of the Traffic Noise Prediction Procedure;"
KYP-72-24; HPR-1(9), Part III.

Report No. 375 ("Vehicle Noise Survey in Kentucky;" September 1973) presented analyses of more than 10,000 isolated vehicle noise measurements. The report now submitted presents corrections which have been found to improve the accuracy of the "Procedure for Predicting Traffic Noise Levels" (Design Memorandum No. 1-72). These corrections are based on analyses of 270 noise-level measurements at 39 sites. It is recommended that the noise prediction procedure now in use be revised to include these corrections. They are applicable directly to "clear" or "free field" situations and, so may be carried through the prediction procedure.

This is our third report concerning noise; the first was a brief, literature review (No. 322, February 1972).

We have reviewed draft reports of NCHRP Project 3-7, Phase III -- one volume of which is expected to be published as Report 144 and which will contain corrections for the effects of barriers and obstructions in that portion of the prediction procedure. The reports reviewed allude to the possible need for corrections to the "free field" model but provide none. The reports also mentioned in a reminding way that the original model (NCHRP Report No. 117) was developed from and is applicable to so-called "freeways;" and, so, we infer from this that our corrections should be most significant where traffic volumes are low and when the distance from the roadway is short.

The noise generated by and(or) reflected by different types of pavements or surfaces offers some possibilities for further corrections and also the possibility of qualifying projects to meet noise-level restrictions by selection of pavement surface types. The adjustments allowed in the existing procedure appear to be too general and too subjective. In order to further define the effects of pavement surfaces in this way, measurements have been made at several road sites (50-ft distance, same automobile, scheduled speeds) surfaced with sand-asphalts, with open-graded plant-mix seal, with Class I, and with portland cement concrete. It appears that porous bituminous surfaces produce less noise. The analyses and derived factors will follow in a subsequent report.

Respectfully submitted,

A handwritten signature in cursive script, appearing to read "Jas. H. Havens".

Jas. H. Havens
Director of Research

JHH:dw
Attachment
cc's: Research Committee

1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Evaluation of the Traffic Noise Prediction Procedure				5. Report Date November 1973	
				6. Performing Organization Code	
7. Author(s) Kenneth R. Agent Charles V. Zegeer				8. Performing Organization Report No. 379	
9. Performing Organization Name and Address Division of Research Kentucky Bureau of Highways 533 South Limestone Lexington, Kentucky 40508				10. Work Unit No.	
				11. Contract or Grant No. KYP-72-24	
				13. Type of Report and Period Covered Interim	
12. Sponsoring Agency Name and Address				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the US Department of Transportation, Federal Highway Administration Study Title: Noise Abatement					
16. Abstract Approximately 270 noise-level recordings were obtained at 39 highway sites and compared with the noise-level predictions obtained by the procedure outlined in NCHRP Report 117. The measured noise levels were computed in terms of the A-weighted L_{10} value (level exceeded 10 percent of time) and then compared to the predicted noise levels. A significant discrepancy was found between predicted and measured noise levels; generally, the predicted values exceeded the measured values. Average error per location was 4.8 dBA; the maximum error was 13 dBA. A nomograph was devised to correct the predicted value; this nomograph involves observer-to-roadway distances, truck volumes, and automobile speeds. By applying correction factors, the average error was reduced to 1.9 dBA, a 60-percent reduction in error. Based on these findings, it is recommended that the nomograph be used to correct noise predictions in Kentucky.					
17. Key Words nomograph dBA L_{10} noise level prediction procedure			18. Distribution Statement		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	22. Price

Research Report
379

**EVALUATION OF THE TRAFFIC
NOISE PREDICTION PROCEDURE**

KYP-72-24; HPR-1(9), Part III

by

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and

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Bureau of Highways. This report does not constitute a standard, specification, or regulation.

November 1973

INTRODUCTION

Policy and Procedure Memorandum 90-2 (1) of the Federal Highway Administration stated that after July 1, 1972, all highways constructed must conform to specific design noise levels. To predict future noise levels of highways, a noise-prediction procedure has been employed. The procedure provides for the determination of the L_{10} noise level (level exceeded 10 percent of the time) based on such factors as observer-roadway distance and shielding. The procedure has not been thoroughly validated, and questions remain as to its accuracy. If discrepancies do exist, adjustment factors may need to be applied to more accurately forecast noise levels.

PROCEDURES

To evaluate the presently used noise-prediction procedure, it was necessary to obtain field noise recordings and compare them with noise levels estimated from the prediction model. All recordings were taken at locations with zero grade, with the observer level with the roadway, and with no shielding in order to reduce the number of variables that might affect accuracy of the prediction. Figure 1 shows a typical recording site. It was considered essential that gradient, vertical elevation, shielding, element, and "interrupted" adjustments should be evaluated separately from the basic situation -- that is, a straight, level section of roadway on unobstructed terrain. The only exceptions to these criteria were some locations in downtown areas, chosen because of high volume, low speed traffic, where it was necessary to use the interrupted adjustment because of the high number of traffic signals. Therefore, the only data required to predict noise level were the distance from observer to roadway, surface type, and car and truck volumes and speeds. The predicted noise level was determined using the procedure outlined in NCHRP Report 117 (2). Basic tables and figures used in the prediction procedure are presented in APPENDIX A. This procedure is now being used by the Kentucky Bureau of Highways (3). Since only straight, level sections of roadway were considered, Figures A2, A3, A4, A8, A11, and A12 were the only figures used in the prediction procedure. Methods to predict the effectiveness of traffic noise reduction measures would not alter the results of this study since they were not considered. Revisions in Figure A11 have been suggested by others, but those minor changes would have little effect on results of this study.

Noise recordings were made using a Bruel and Kjaer, precision sound-level meter, Type 2203 (Figure

2), and a strip chart recorder, Type 2305 (Figure 3). Noise recordings were made (each recording was of 10 minutes duration) at locations listed in APPENDIX B. The A-weighting network in the meter was employed. A total of 270 recordings were obtained. Use of the strip chart recorder offered certain advantages. It enabled the observer to note effects of any unrelated influences such as wind, airplanes, etc. The observer could adjust or disregard the section of the measurement affected. Also, the observer could continually check for agreement between the meter indication and the recorded measurement. From the 10-minute recordings, noise levels at intervals slightly greater than one second were determined in the laboratory utilizing a digital data reduction system, Gerber Model GDDRS-3B, as shown in Figure 4. The output was punched onto computer cards through direct coupling with a card punch unit. By means of a simple computer program, the L_{10} noise level was computed. The L_{10} noise level is the standard for federal limitations on allowable traffic noise. The measured, L_{10} noise level was then compared with the predicted level.

FINDINGS

The primary objective of this study was to determine if a significant discrepancy exists between predicted noise levels and measured noise levels. Figure 5 clearly indicates the prediction procedure tends to yield higher values. The average error per location was found to be 4.8 dBA; the maximum error was 13 dBA. The differences were found to be significant at the .01 level (4). Details of statistical tests are presented in APPENDIX C.

To determine the reason for this discrepancy, several computer plots were prepared (presented in APPENDIX D); differences between predicted (uncorrected) and measured noise levels were plotted against several variables which affect noise level. An optimal linear fit was determined. Variables considered were:

- observer-to-roadway distance (D_N),
- total volume,
- car volume,
- truck volume,
- car volume-truck volume ratio,
- car speed,
- truck speed, and
- percent trucks.

The plots clearly indicate some relationships between several of the variables considered and the prediction procedure error. Figure 6 shows a relationship with the observer-to-roadway distance. For short observer-to-roadway distances, the prediction procedure usually yielded higher values than measured values. As

the distance increased, the error decreased until the predicted values were below measured values at greater distances.

A nomograph was employed to correct noise levels obtained from the prediction procedure. A combination of variables should be considered when making the corrections. For example, an observer-to-roadway distance of 50 feet (15 m) yields a predicted value which is too high at locations having low truck volumes, but it is accurate for locations having high truck volumes. The nomograph, of necessity, should permit a reduction of values for locations (observer-to-roadway distance of 50 feet (15 m)) having low truck volumes, but no correction should be made for locations having high truck volumes. A small value should be added for very high volumes. Similar corrections should be made for other variables.

Variables which showed a definite relationship to the prediction procedure error were selected (APPENDIX D). These variables were then used in various combinations for preparation of trial nomographs. The nomograph (Figure 7) which yielded the best results (greatest overall reduction in error) involved observer-to-roadway distance, truck volume, and car speed. The procedure for using the nomograph is outlined in APPENDIX E.

Correction factors were obtained for each of the 270 recordings to determine the predicted (corrected) noise levels. Results are shown in Figure 8. The optimal linear fit of the points lies very close to the 45-degree line, which represents the line where predicted noise levels equal measured noise levels. Plots were also made of variables involved versus error in "corrected" noise levels. Figure 9 shows the error for the observer-to-roadway distance and the "corrected" noise level. As may be seen, the optimal linear fit line lies very close to zero error for all distances. Remaining plots are presented in APPENDIX F.

The average error per location, after corrections were applied, was 1.9 dBA and represents a 60 percent reduction in error from the "uncorrected" predictions. This error reduction is significant at the .01 level. After correction, the residual error between measured and corrected values was found not being statistically significant at the 0.1 level, but significant at the 0.2 level. This remaining error might have been due to several factors. Imperfections in data collection are possible causes. The noise-level meter was calibrated each day before recordings were made, and the strip chart recorder was continuously compared to the sound-level meter to insure accurate readings, but some degree of error might be expected. Variable pavement types can cause variations in sound levels, and the adjustment for pavement type is probably inadequate

since it simply provides for an adjustment of plus or minus 5 dBA for rough or smooth pavements, respectively. In addition, types of cars and trucks which pass during recording periods vary. For example, the prediction procedure cannot provide for the percentage of tractor-trailer trucks which might pass. For a particular location and a given truck volume, the noise level will increase markedly as the percentage of tractor-trailer trucks increases. The prediction procedure also does not account for differences in noise levels of a particular type of vehicle. Therefore, if an abnormal number of quiet or loud vehicles passes while the recording is being made, the measured noise level would differ from the predicted noise level.

Table 1 shows the distribution of differences between predicted and measured noise levels before and after corrections were applied. The number of locations with large errors was greatly reduced when the predicted noise level was corrected.

APPENDIX G lists results of a detailed evaluation of the prediction procedure errors for each of the variables considered. Tables G1 through G8 show the range and distribution of the variables and the average error before and after correction of the predicted noise level.

A statistical test was performed to evaluate the variability which remained after corrections were applied. Results indicated error variability before correction was significantly larger than error variability after correction to the .01 level of significance.

CONCLUSIONS

The objective of the study was met and following are conclusions drawn from the analyses:

1. A significant discrepancy was found between predicted noise levels and measured noise levels. The average error was 4.8 dBA.
2. A nomograph, developed for the correction of predicted noise, resulted in a significant reduction in errors. Significant corrections were necessary for:
 - A. short observer-to-roadway distance and low truck volume (correction = 3 to 10 dBA, depending on average car speed),
 - B. short observer-to-roadway distance and low mean car speed (correction = 5 to 10 dBA depending on truck volume), and
 - C. short observer-to-roadway distance, low truck volume, and low mean car

- speed (correction ≈ 10 dBA).
- Although errors were substantially reduced, remaining errors (an average of 1.9 dBA) indicate further study of other variables should be made. In particular, more accurate adjustments are necessary for various pavement types. Variations of noise levels emitted from different vehicles cause error between predicted and measured noise levels and further adjustments may be forthcoming.

IMPLEMENTATION

Presently-used noise prediction procedures yield results which significantly differ from measured noise levels. Use of the nomograph significantly reduces error between measured and predicted noise levels. It is recommended that the nomogram be incorporated into Kentucky's noise prediction procedure as a means of improving its accuracy.

REFERENCES

- Policy and Procedure Memorandum 90-2*, Federal Highway Administration, April 26, 1972.
- Gordon, C. G.; Galloway, W. J.; Kugler, B. A.; and Nelson, D. L.; *Highway Noise -- A Design Guide for Highway Engineers*, National Cooperative Highway Research Program Report No. 117, Highway Research Board, 1971.
- Procedure for Predicting Traffic Noise Levels, Design Memorandum No. 1-72*, Kentucky Bureau of Highways, January 14, 1972.
- Experimental Statistics*, National Bureau of Standards Handbook 91, August 1, 1963.

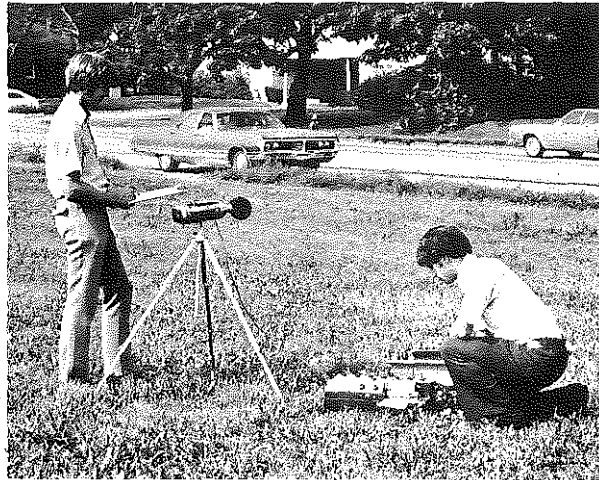


Figure 1. Typical Recording Site.

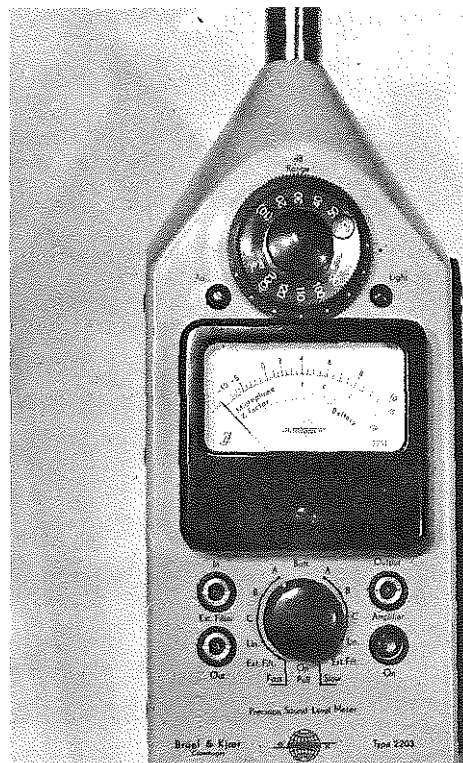
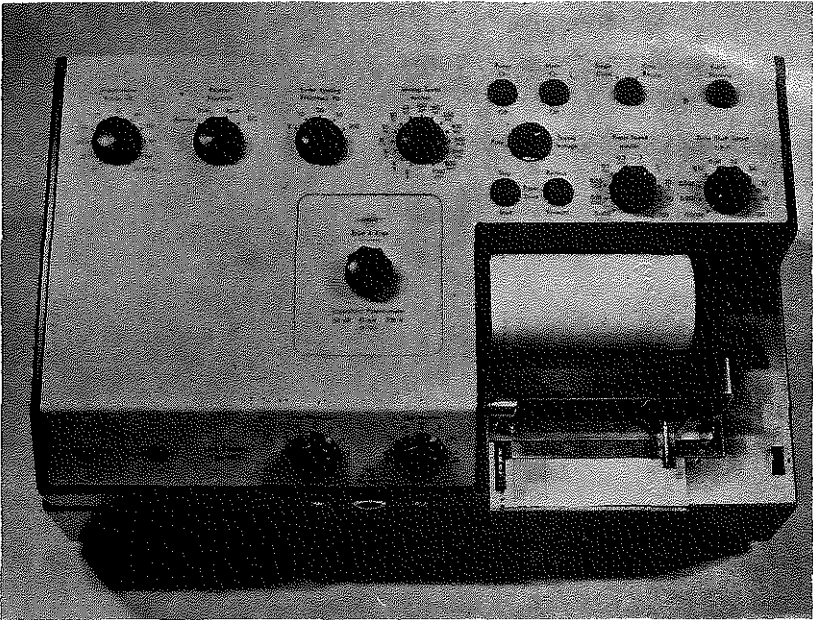
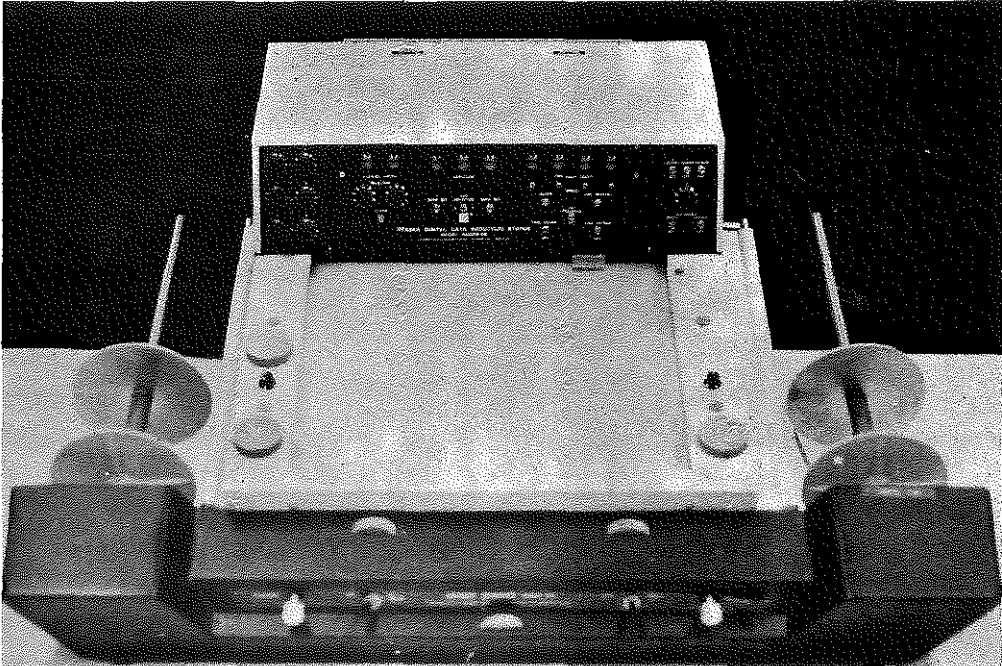


Figure 2. Bruel and Kjaer Precision Sound-Level Meter, Type 2203.

**Figure 3. Bruel and Kjaer Strip Chart Recorder,
Type 2305.**



**Figure 4. Gerber Model GDDRS-3B, Digital Data
Reduction System.**



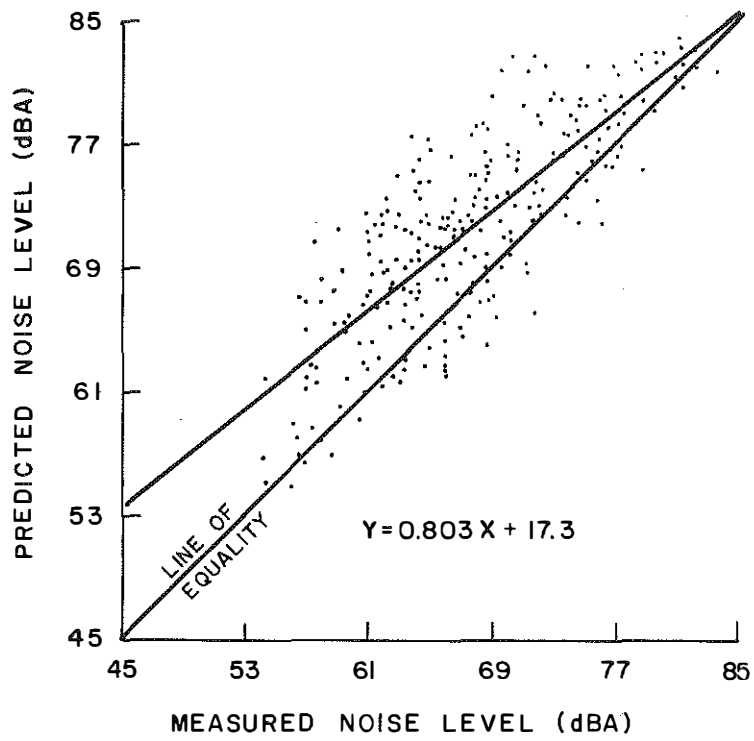


Figure 5. Predicted Noise Levels versus Measured Noise Levels.

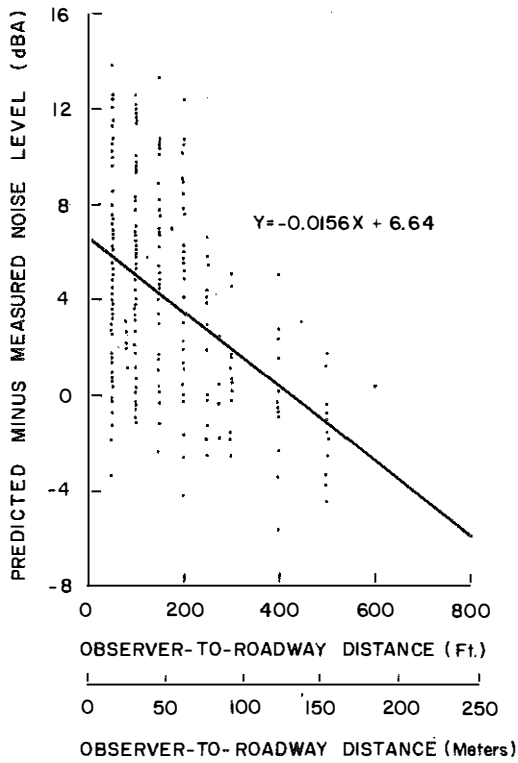


Figure 6. Prediction Procedure Error versus Observer-to-Roadway Distance.

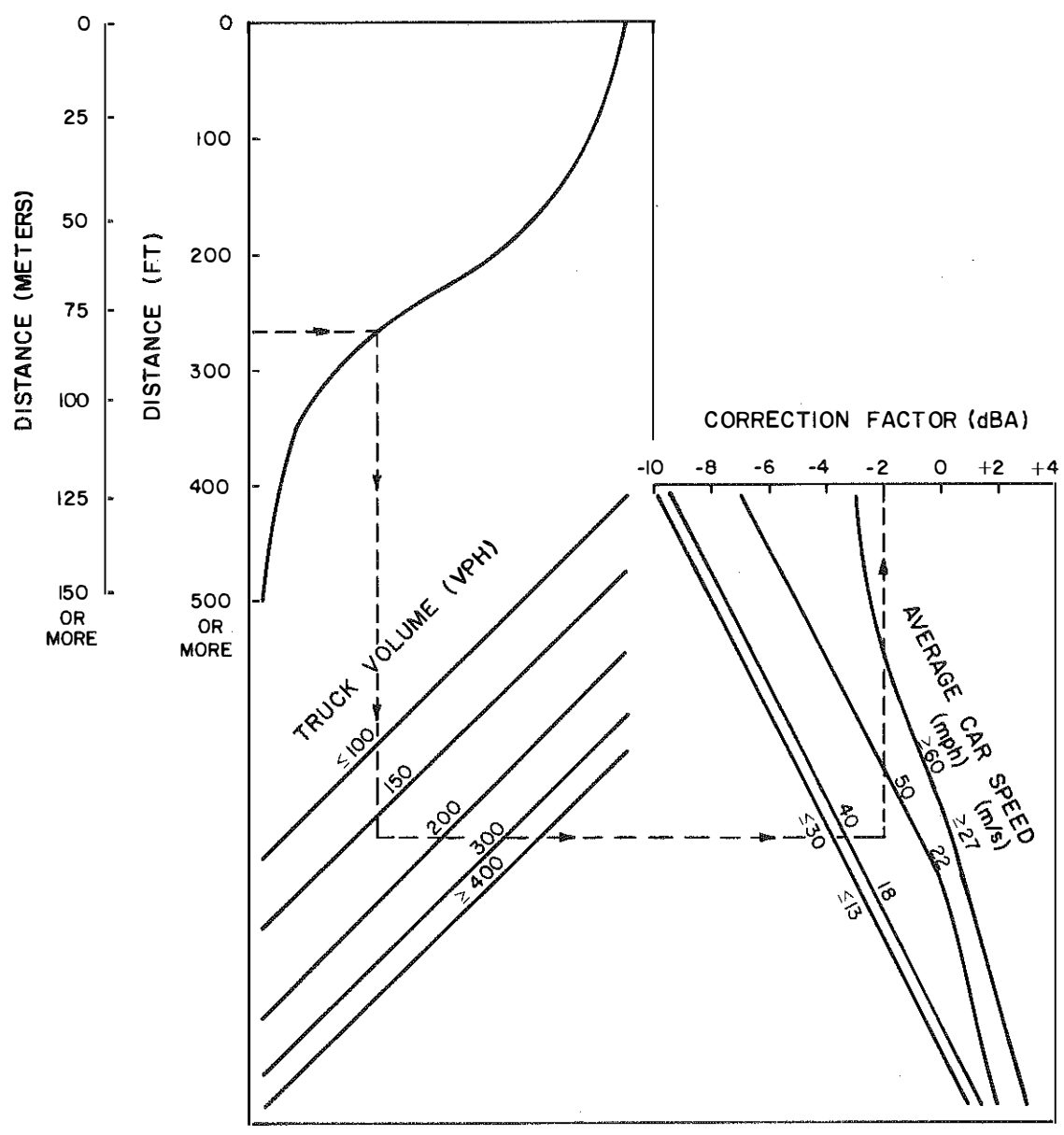


Figure 7. Prediction Correction Factor.

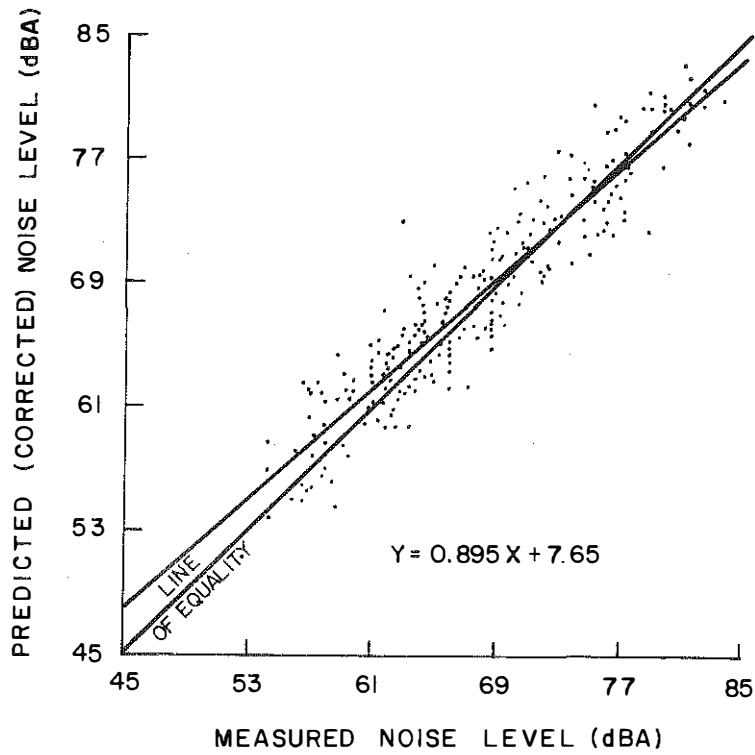


Figure 8. Predicted (Corrected) Noise Levels versus Measured Noise Levels.

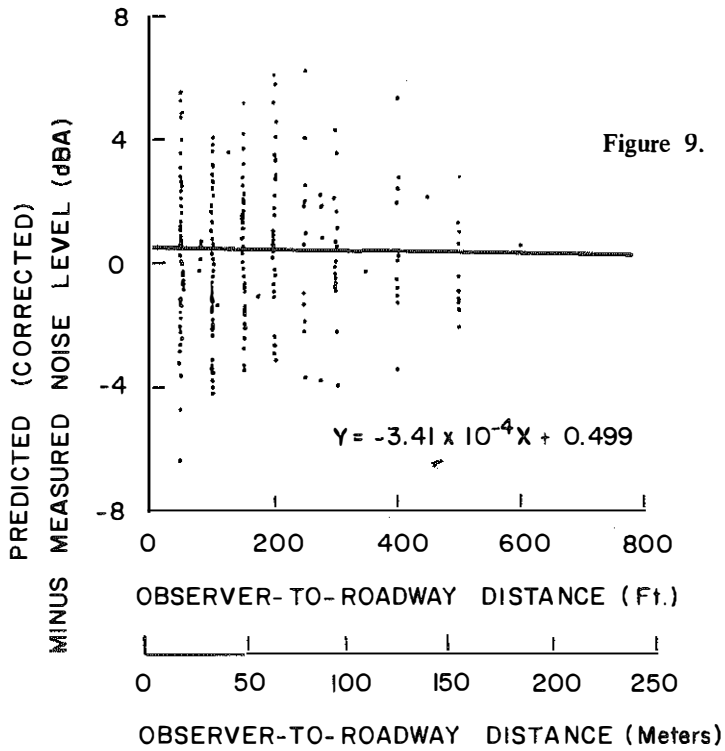


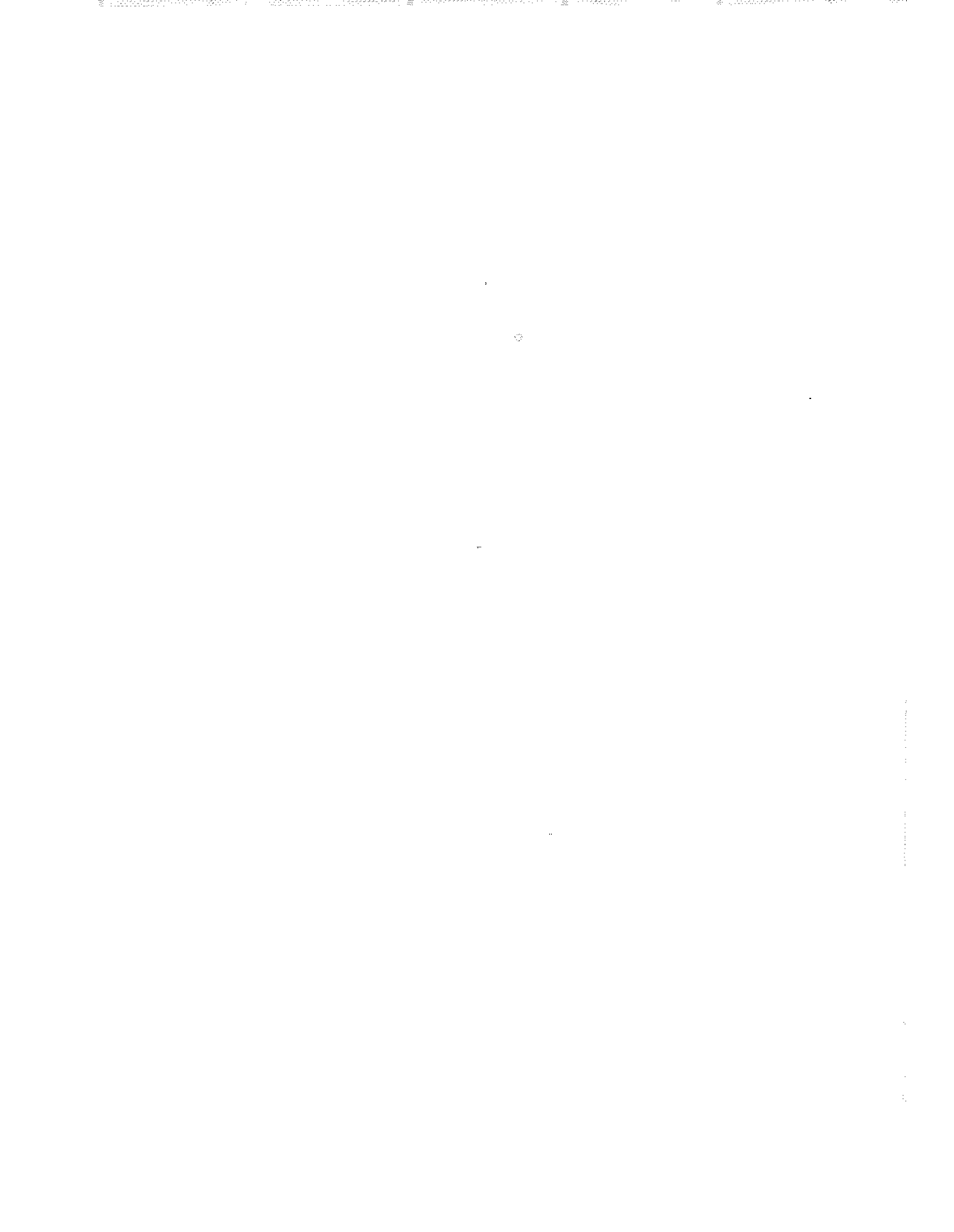
Figure 9. Predicted (Corrected) Noise Level Error versus Observer-to-Roadway Distance.

TABLE 1
DISTRIBUTION OF ERRORS

DIFFERENCE BETWEEN PREDICTED AND MEASURED NOISE LEVELS (dBA)	BEFORE CORRECTION		AFTER CORRECTION	
	NUMBER OF LOCATIONS	PERCENTAGE OF LOCATIONS EXCEEDING A GIVEN NOISE LEVEL	NUMBER OF LOCATIONS	PERCENTAGE OF LOCATIONS EXCEEDING A GIVEN NOISE LEVEL
0 - .9	38	100.00	78	100.00
1 - 1.9	41	85.93	67	71.11
2 - 2.9	22	70.74	74	46.30
3 - 3.9	25	62.59	26	18.89
4 - 4.9	26	53.33	15	9.26
5 - 5.9	21	43.70	7	3.70
6 - 6.9	29	35.93	3	1.11
7 - 7.9	14	25.18	0	0
8 - 8.9	9	20.00	0	0
9 - 9.9	13	16.67	0	0
10 - 10.9	17	11.85	0	0
11 - 11.9	8	5.56	0	0
12 - 12.9	5	2.59	0	0
13 - 13.9	2	7.41	0	0

APPENDIX A
PROCEDURE FOR PREDICTING
TRAFFIC NOISE LEVELS





I. PROCEDURE FOR PREDICTING TRAFFIC NOISE LEVELS

A. DEFINITIONS

1. dBA -- decibels on the "A" weighting network.
2. L_{50} -- noise level that is exceeded 50 percent of the time, or median noise level.
3. L_{10} -- noise level that is exceeded 10 percent of the time.
4. Single-lane equivalent -- the single-lane representation of a roadway which, to the observer, is acoustically similar to the real roadway.
5. D_N -- distance between observer and centerline of the nearest lane.
6. Element -- section of roadway with constant characteristics of geometry and vehicular operating conditions.
7. Finite Element -- when an element starts and finishes within a length of $8 D_N$ (see Figure A5).
8. Semi-Infinite Element -- when an element extends across $4 D_N$ in one direction but terminates within a length of $8 D_N$ (see Figure A5).
9. Infinite Element -- when the element length is greater than $8 D_N$ (see Figure A5).

B. RULES FOR ELEMENT IDENTIFICATION

C. *Alinement (Curves)*: To satisfy requirements of a single-element definition, the element must be effectively straight. The following rules apply:

1. Stretches of road separated by curves must, in general, be regarded as separate elements.
2. When the ratio of curve radius to observer distance exceeds 10 and when the observer lies within the triangle formed by the normal intersects of the roadway at the curve tangency points, the curve itself should be represented by a straight element to provide a "best fit" representation of the curve.
3. A roadway having compound curves may be represented by a "best fit" straight roadway as long as deviations from this representation do not exceed ± 20 percent of the mean observer-roadway distance.

D. *Gradients*: To satisfy the requirements of a single-element definition, the element must not contain a change in grade of greater than 2 percent.

E. *Cross Section*: To satisfy the requirements of a single-element definition, the cross section along the length of the element must be effectively unchanging. Significant changes are defined as follows:

1. a change in the differential in roadway elevation with respect to the terrain (parameter H for elevated or depressed roadways) of more than ± 10 percent about the midpoint value,
2. a change in total roadway width (including median) of more than ± 25 percent about the midpoint value, and
3. a change, on the observer side, of the roadway cut distance or the roadway shoulder distance, for depressed and elevated configurations, respectively, of more than ± 25 percent about the midpoint value.

F. *Traffic Flow*: To satisfy the requirements of a single-element definition, the traffic flow conditions along the length of the element must be effectively constant. Significant changes are defined as follows:

1. a flow volume change of ± 10 percent,
2. an average speed change of ± 10 percent, and
3. a change from uninterrupted to interrupted flow conditions.

With regard to the last item, interrupted flow imposed by a traffic control signal is assumed to have an influence on the operating noise of a vehicle over a distance of 1,000 feet (300 m) centered at the signal. This length would therefore define the element length.

II. SELECTION OF THE REFERENCE L_{50} AT 100 FEET (30 m)

- A. Using the given ADT as a base, calculate the number of vehicles per hour for the hours of the day desired. Figure A1 gives the percent of ADT for the various times of day.

- B. Using the given auto/truck mix and the result from Step A, calculate the number of automobiles per hour and the number of trucks per hour.
- C. Using the given average speed and results from Step B, obtain L_{50} for cars from Figure A2 and L_{50} for trucks from Figure A3.
- D. Enter the results of Step C in Line 1 of the Noise Prediction Worksheet (Table A1).

III. SELECTION AND CALCULATION OF THE PROPER ADJUSTMENTS

A. Distance and Roadway Width

In nearly all cases, the distance between the points in question will be other than 100 feet (30 m). Also, since Figures A2 and A3 were developed using an "equivalent single lane" concept, an adjustment is necessary for the number of lanes involved. Both adjustments may be accounted for simultaneously by using Figure A4. Enter that result on Line 2 of the Noise Prediction Worksheet.

B. Element

After separating the roadway in question into individual elements, classify each element as Type I, II, or III. If the element is Type I, there is no adjustment to be entered. If the element is Type II or Type III, measure the angle ϕ as shown in Figure 5 and use this in Figure A6 for a semi-infinite element or in Figure A7 for a finite element to obtain the adjustment to be entered on Line 3 of the Noise Prediction Worksheet.

C. Gradient

Noise emission levels for automobiles are constant for any condition of gradient. However, trucks emit higher levels of noise when going up or down a hill. Obtain the proper adjustment for gradient from Table A2 and enter that number on Line 4 of the Noise Prediction Worksheet.

D. Vertical

When a roadway is depressed or elevated, its noise levels will be reduced to some extent, depending on various factors. To obtain that adjustment, use Figure A9. To determine the value of D_E for use in Figure A9, use Figure

A8. Enter the adjustment obtained from Figure A9 on Line 5 of the Noise Prediction Worksheet.

E. Shielding by vertical, roadside barriers

In many cases, traffic noise levels may be reduced by placing a "wall" adjacent to a roadway. Use Figure A10 to determine the adjustment for a barrier extending the entire length of the element (or $8 D_N$ in the case of an infinite element). For barriers that extend for more than two-thirds but not for the entire length of the element, deduct 3 dB from the adjustment. For barriers whose length is from one-third to two-thirds that of the element, deduct 6 dB from the adjustment. For barriers shorter than one-third the length of element, deduct 10 dB from the adjustment. Enter that adjustment on Line 7(a) on the Noise Prediction Worksheet.

F. Shielding by structures

Subtract 3 dB per row of houses or structures, provided there is no direct line-of-sight between the roadway and the observer. That adjustment should never exceed a maximum of 9 dB.

G. Shielding by plantings

Subtract 5 dB for every 100 feet (30 m) depth of plantings provided the plantings are at least 15 feet (5 m) in height and sufficiently dense so that no direct line-of-sight exists between the roadway and the observer. That adjustment should never exceed 10 dB.

Enter the sum of shielding by structures and plantings on Line 7(b) on the Noise Prediction Worksheet.

IV. ADJUSTMENT FOR L_{10}

- A. After completing the addition as set forth on Lines 8 and 9 of the Noise Prediction Worksheet, it is now necessary to make adjustments required to arrive at L_{10} . The first step is to determine the ($L_{10} - L_{50}$) adjustment. Use Figure A11 with

$$A_v = \sqrt{D_E/S},$$

$$V = \text{number of vehicles per hour,}$$

D_E = equivalent lane distance (ft),
and

S = average speed (mph).

Enter the result on Line 10.

- B. When continuous traffic flow is interrupted by a stop sign or signal, the median noise level, L_{50} , is not significantly changed. Research has shown that some of the louder vehicles will show an increase in noise output. Therefore, use Table A3 whenever interrupted flow conditions exist. Enter that result on Line 11 on the Noise Prediction Worksheet. Complete the addition indicated on Line 12.

V. CALCULATING TOTAL NOISE LEVELS

- A. Lines 9 and 12 on the Noise Prediction Worksheet are subtotals which should be totaled to determine the correct traffic noise level at a given location. The procedure for that totaling is as follows:

1. Do **NOT** add numbers directly. Noise levels are logarithmic in nature and must therefore be added logarithmically. Figure A12 has been prepared for this purpose. Complete the following example problems as a familiarization with Figure A12:

$45 \text{ dBA} + 48 \text{ dBA} = 49.8 \text{ dBA} = 50 \text{ dBA}$,
 $49 \text{ dBA} + 49 \text{ dBA} = 52 \text{ dBA}$, and
 $51 \text{ dBA} + 57 \text{ dBA} = 58 \text{ dBA}$.

2. With use of Figure A12, add the auto and truck levels for each element and enter those results in the appropriate L_{50} or L_{10} blocks on Line 13.
3. Again with the use of Figure A12, add the element totals for L_{50} and L_{10} on Line 13. The sums result in grand totals for L_{50} and L_{10} as called for on Line 14. Results are noise levels used as design criteria.

TABLE A1
NOISE PREDICTION WORK SHEET

Acoustic Characteristics	Line	Road Element		Number							
		Type									
		Time Interval									
		Vehicle Type		Auto	Truck	Auto	Truck	Auto	Truck	Auto	Truck
	1	Reference L_{50} at 100 feet									
	2	Adjustment	Distance								
	3		Element								
	4		Gradient		-		-		-		-
	5		Vertical								
	6		Surface								
	7		Shielding		(a) Barriers						
				(b) Structures & Plantings							
	8	Total Adjustment (Sum of Lines 2 through 7)									
	9	L_{50} at Observer (Line 1 plus Line 8)									
	10	$L_{10} - L_{50}$ Adjustment									
	11	Interrupted Adjustment									
	12	L_{10} at Observer (Sum of Lines 9, 10, and 11)									
	13	Element Total		L_{50}							
				L_{10}							
	14	Grand Total		$L_{50} = \quad \text{dBA}$				$L_{10} = \quad \text{dBA}$			
	15			$L_{10} - L_{50} = \quad \text{dBA}$							

TABLE A2

ADJUSTMENT FOR GRADIENT
(FOR TRUCKS ONLY)

GRADIENT (PERCENT)	ADJUSTMENT (dBA)
2	0
3-4	+2
5-6	+3
7	+5

TABLE A3

INTERRUPTED FLOW ADJUSTMENT

VEHICLE TYPE	ADJUSTMENT (dBA) FOR	
	L ₅₀	L ₁₀
Automobile	0	+2
Truck	0	+4

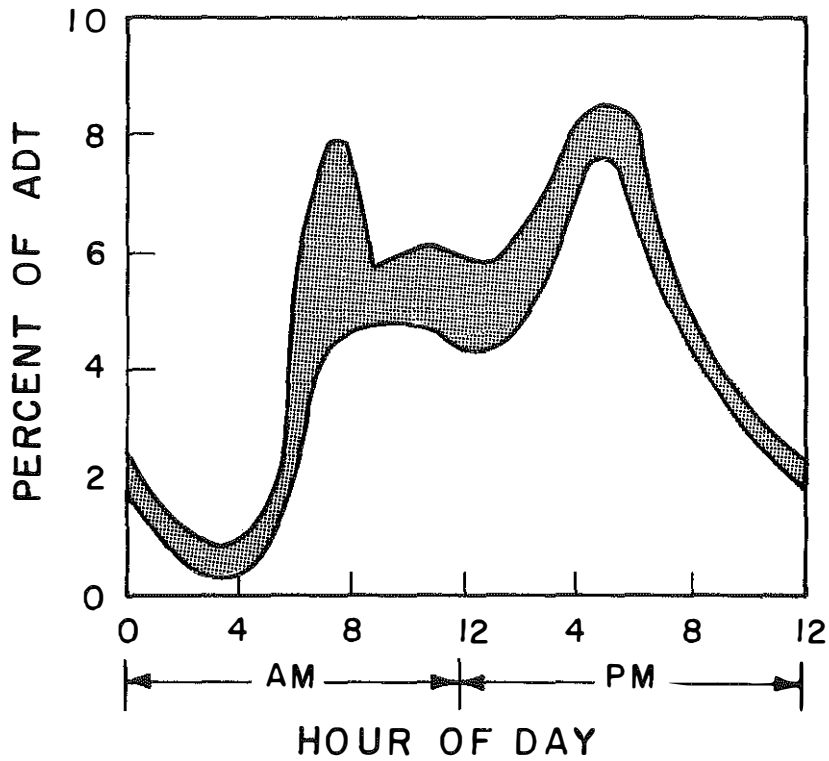


Figure A1. Percent of ADT and Hour of Day.

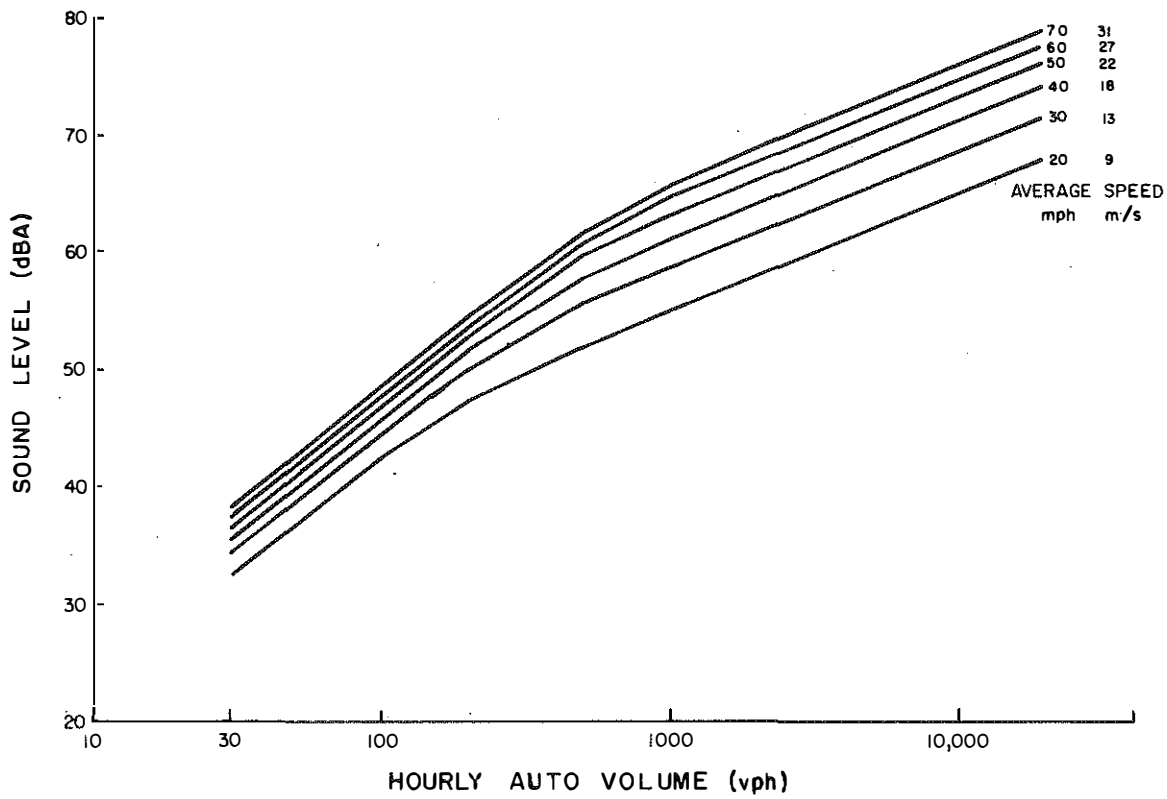


Figure A2. Plot of L_{50} for Automobiles as a Function of Volume and Average Speed.

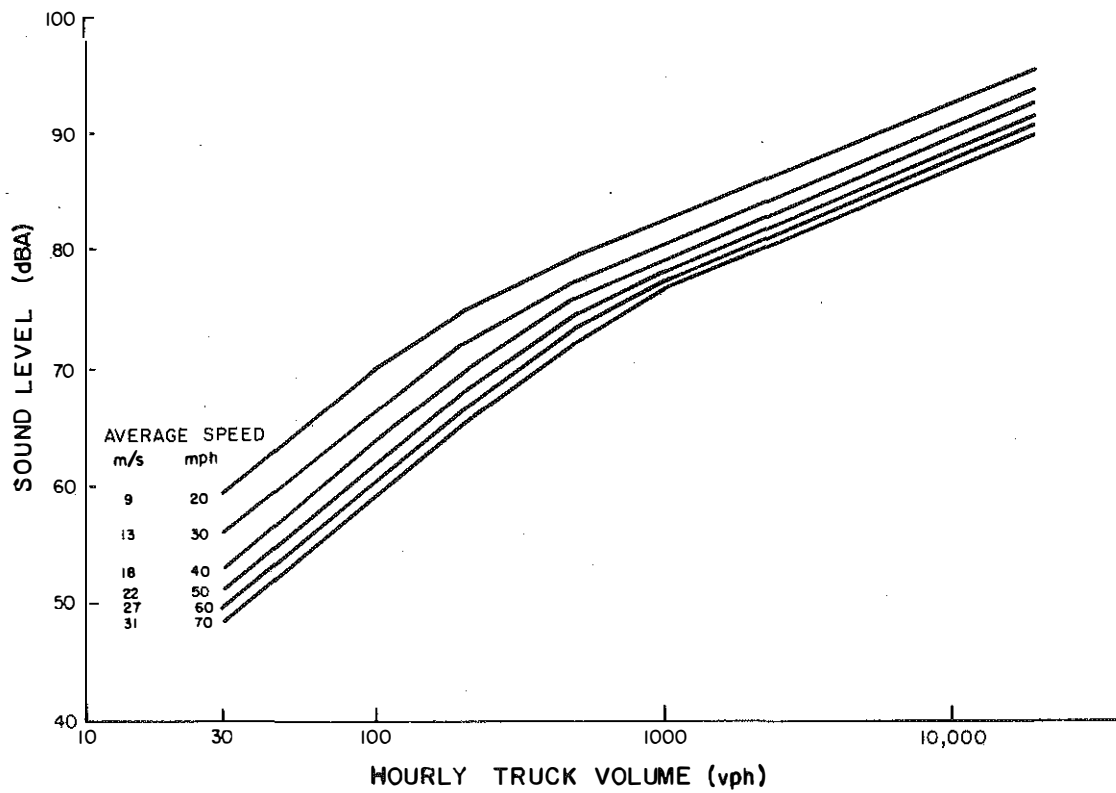


Figure A3. Plot of L_{50} for Trucks.

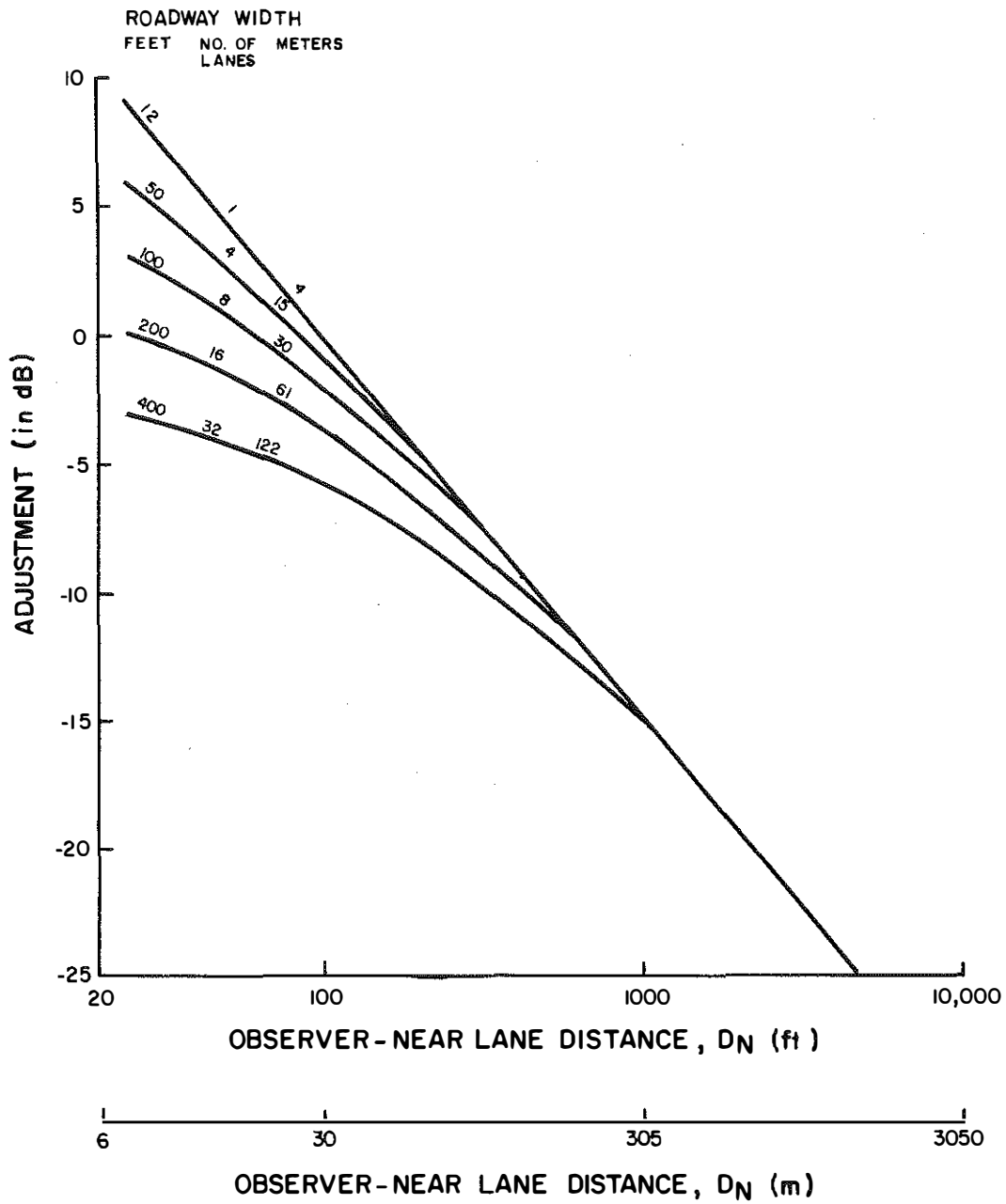
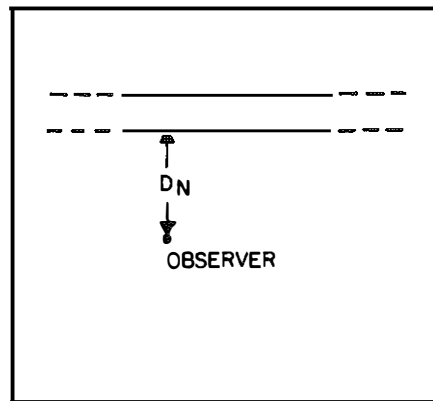
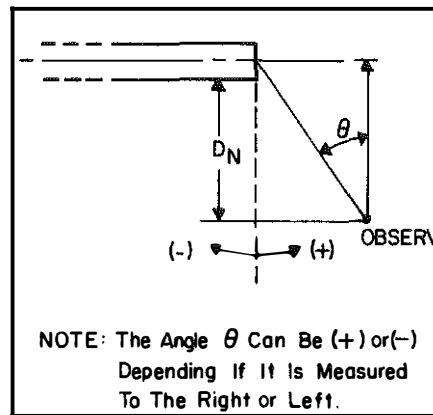


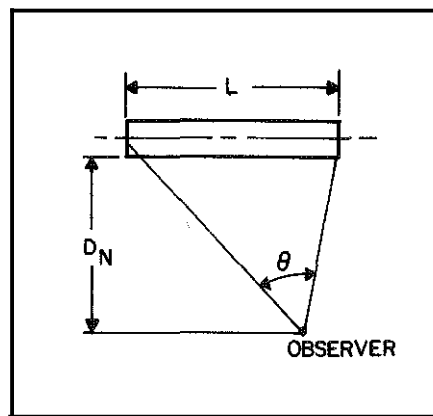
Figure A4. Distance Adjustment to Account for Observer-Near Lane Distance and Width of Roadway.



(a) INFINITE ELEMENT
TYPE I



(b) SEMI-INFINITE ELEMENT
TYPE II



(c) FINITE ELEMENT
TYPE III

Figure A5. Illustrations of Element Types.

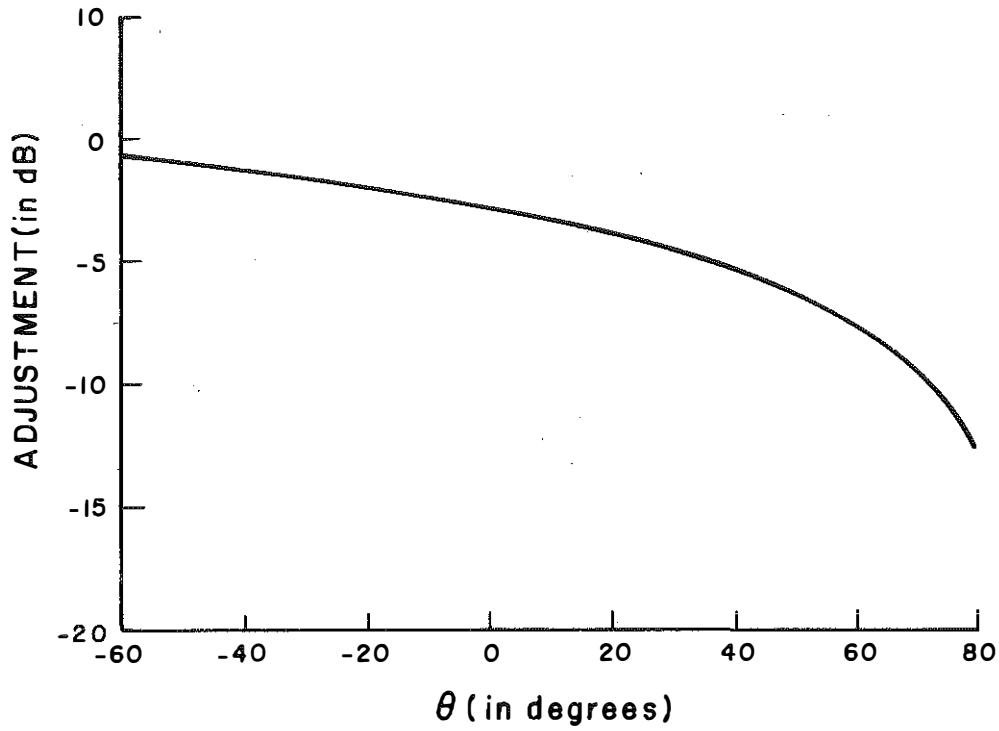


Figure A6. Adjustment to Account for Semi-Infinite Element Length.

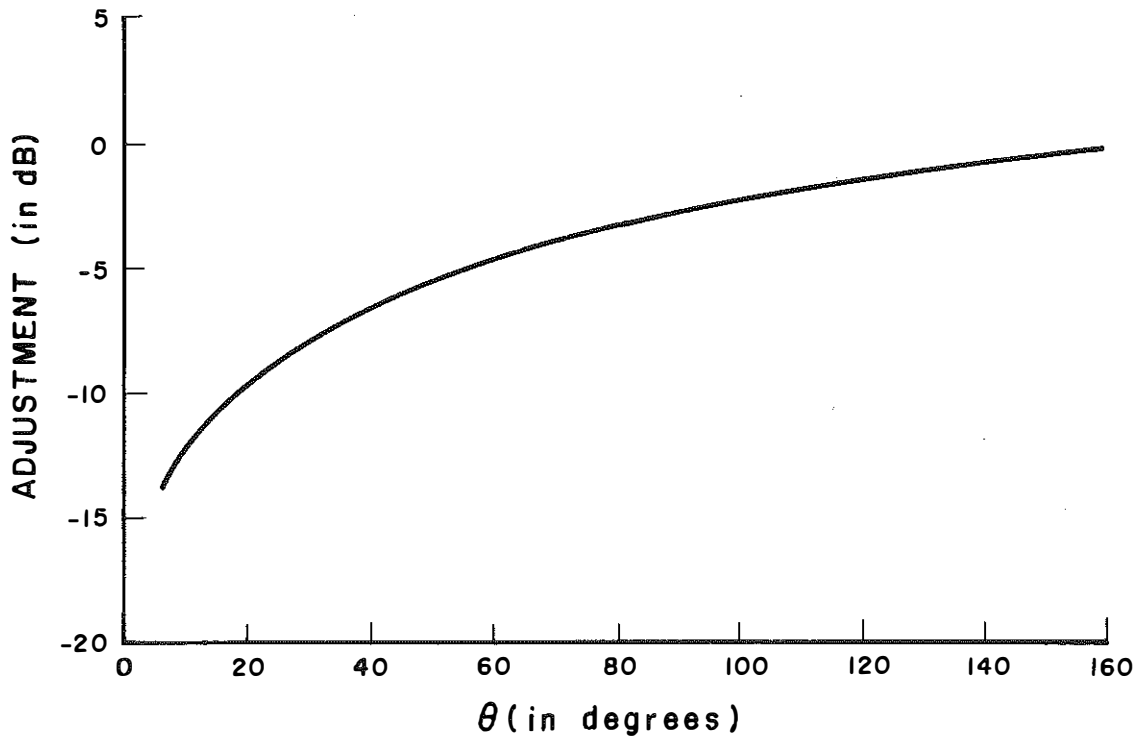


Figure A7. Adjustment to Account for Finite Element Length.

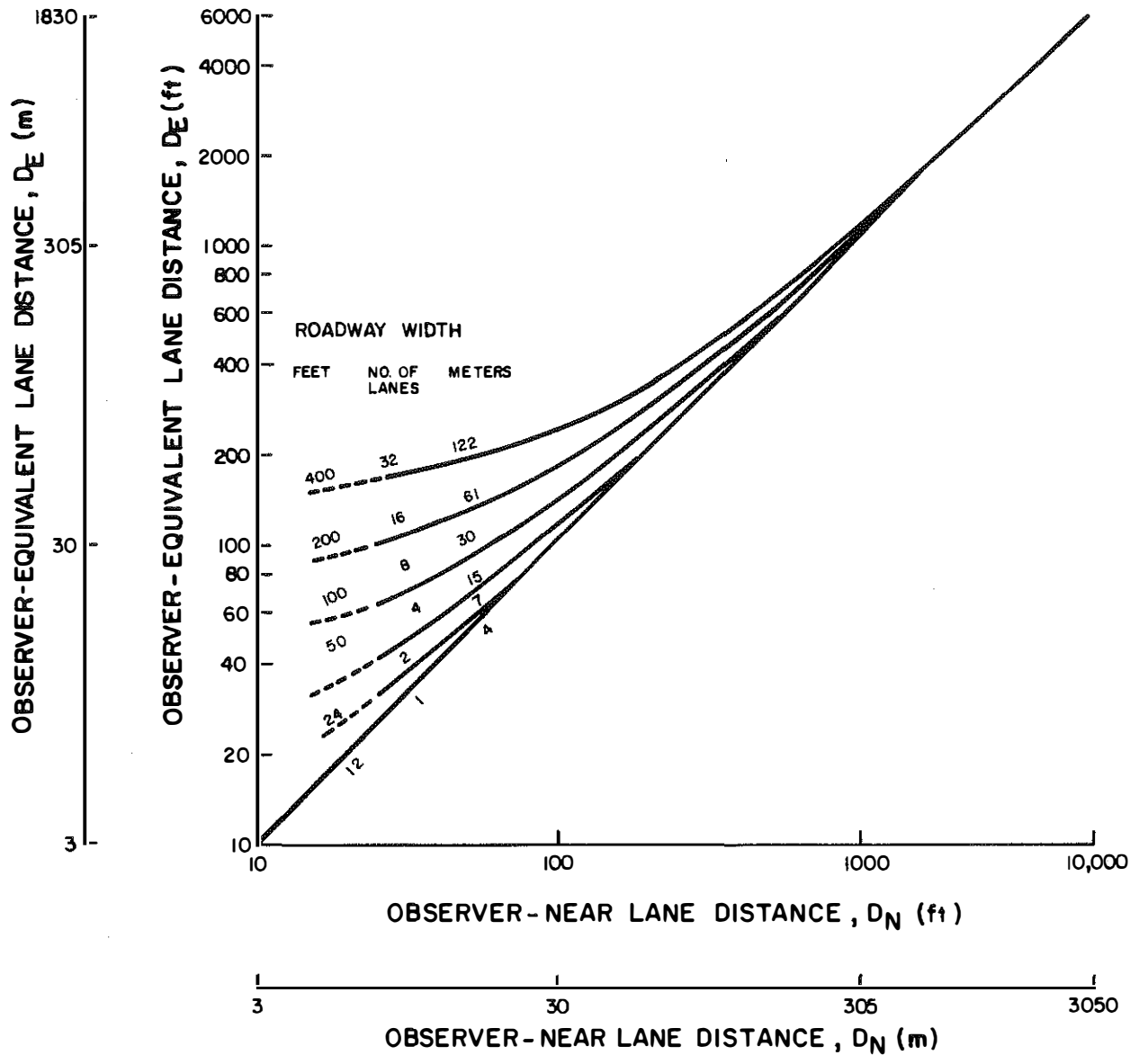
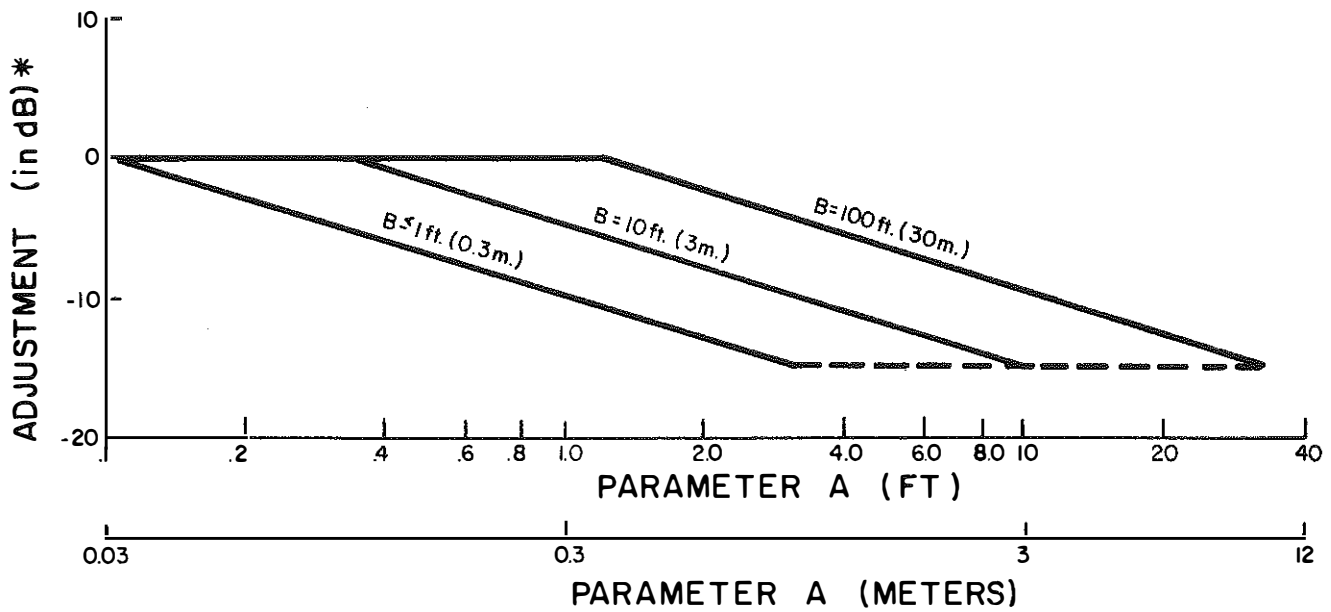
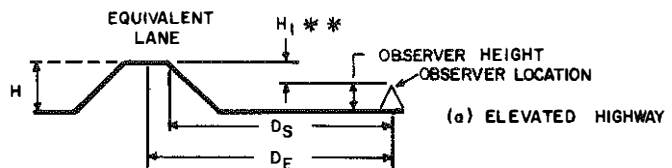


Figure A8. Observer-Equivalent Lane Distance as a Function of Near-Lane Distance and Width of Roadway.



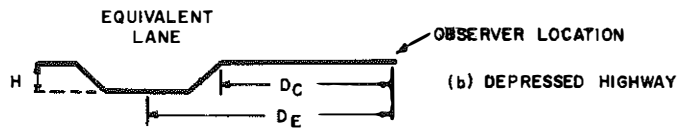
PARAMETER $A = H_1^2 / D_S$

PARAMETER $B = H_1^2 / (D_E - D_S)$



PARAMETER $A = H^2 / (D_E - D_C)$

PARAMETER $B = H^2 / D_C$



* FOR TRUCKS ADD +5 DB TO VALUE GIVEN BY FIGURE
 ** HEIGHT OF ELEVATED FREEWAY ABOVE OBSERVER (H_1)

Figure A9. Adjustment for Elevated and Depressed Roadway.

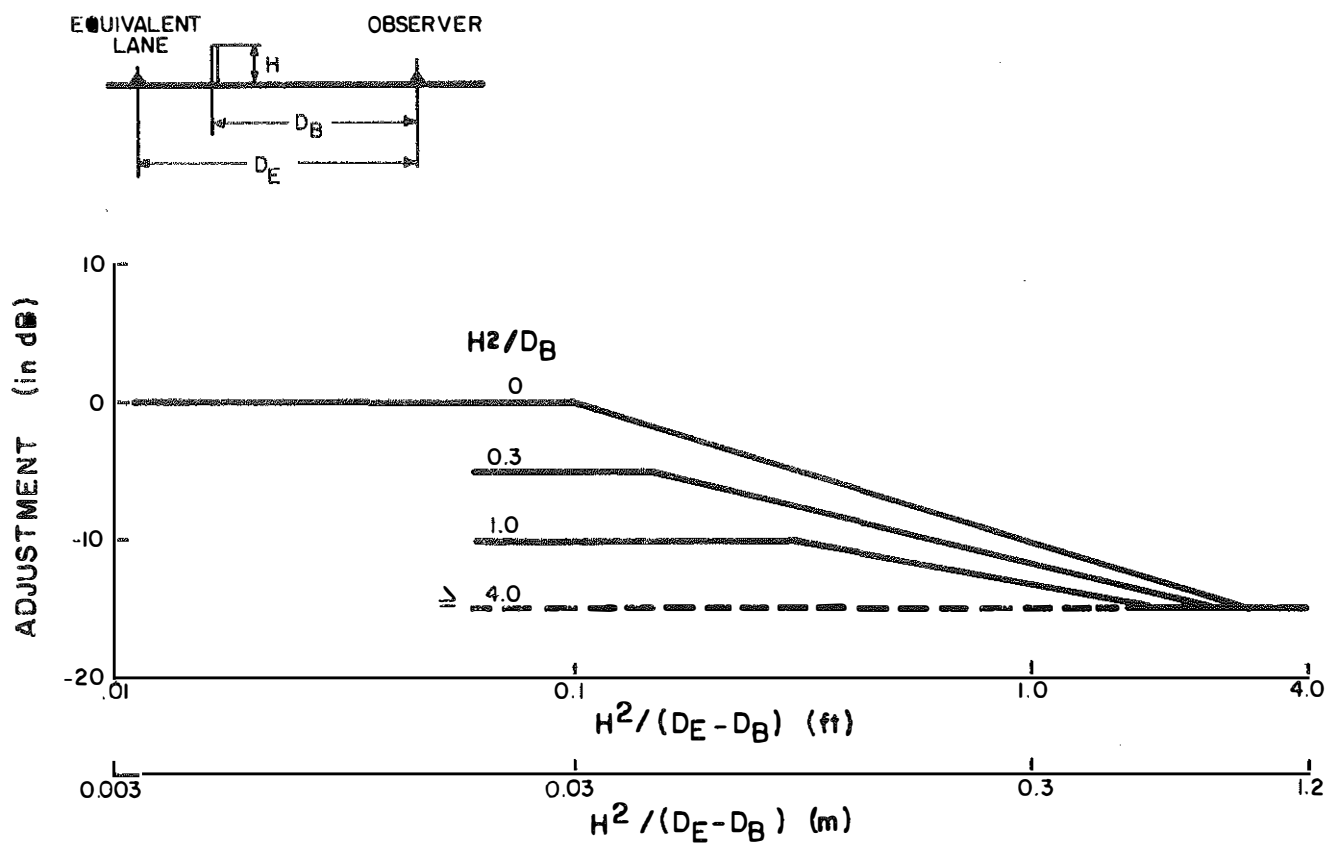


Figure A10. Adjustment for Roadside Barriers.

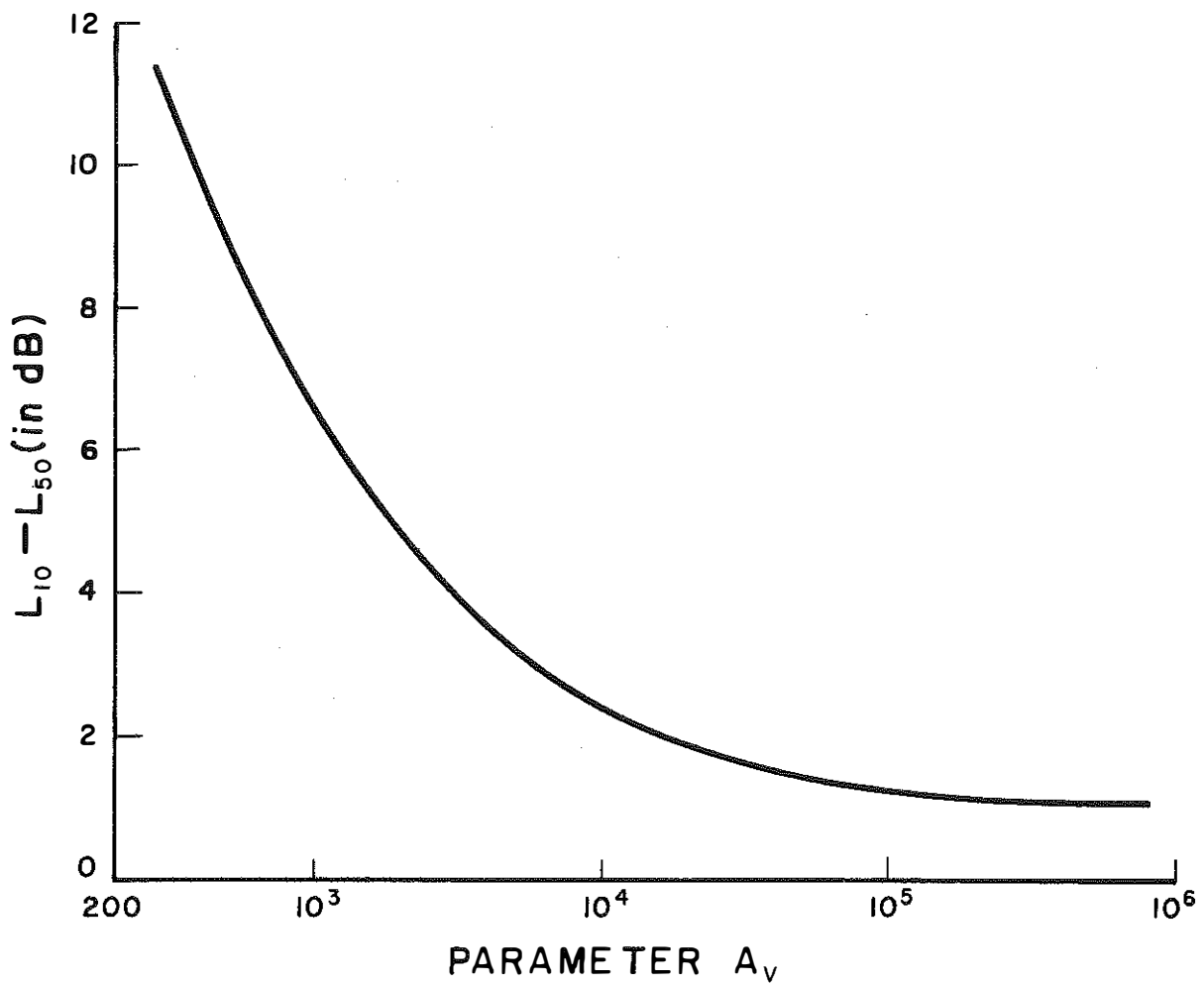


Figure A11. Adjustment to L_{50} to Obtain L_{10} .

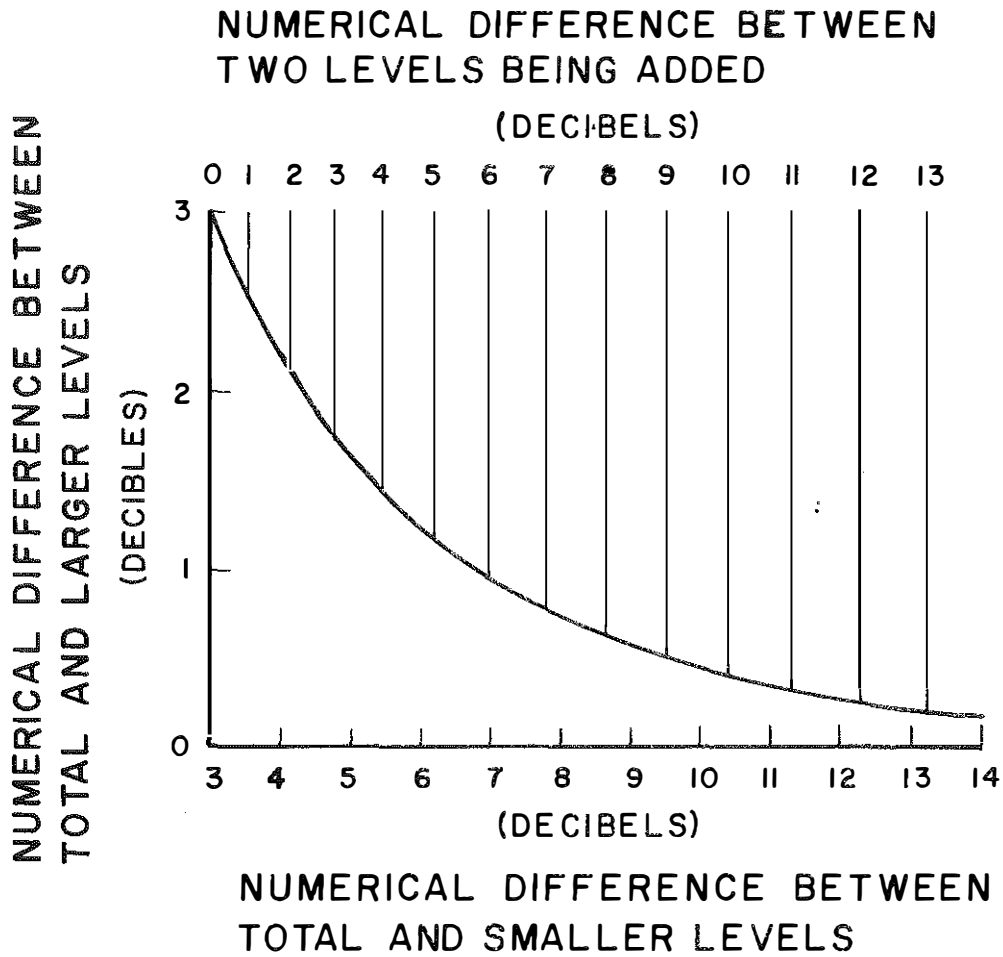


Figure A12. Procedure for Adding Noise Levels.

APPENDIX B
LOCATIONS OF TRAFFIC NOISE RECORDINGS

I 75 2.0 miles (3.2 km) south of Georgetown exit
 I 75 MP 107
 I 75 0.5 mile (0.8 km) north of White Hall exit
 I 75 0.75 mile (1.2 km) north of Delaplain Road
 I 75 2.0 miles (3.2 km) south of Mt. Vernon
 I 75 MP 70.7
 I 75 0.5 mile (0.8 km) north of MP 106
 I 75 0.5 mile (0.8 km) south of rest area, Boone County
 I 64 1.0 mile (1.6 km) west of Depot exit
 I 64 1.0 mile (1.6 km) east of Mountain Parkway exit
 I 75 Fayette County
 I 264 Wattersson Expressway, Louisville
 US 421 Leestown Pike, approximately 1.5 miles (2.4 km) north of Lexington
 US 27 Nicholasville Road, near Devondale Baptist Church, Lexington
 US 68 Harrodsburg Road, 1.5 miles (2.4 km) west of KY 4, Lexington
 US 421 Leestown Pike, 1.0 mile (1.6 km) north of KY 4, Lexington
 US 68 Harrodsburg Road, near Turfland Mall, Lexington
 US 25 Richmond Road, near Shriner's Hospital, Lexington
 US 60 1.0 mile (1.6 km) east of I 64, Franklin County
 US 25 Richmond Road, near Idle Hour Shopping Center, Lexington
 US 60 Versailles Road, Woodford County
 US 60 Versailles Road, near Bluegrass Parkway
 US 60 approximately 5 miles (8 km) west of Versailles
 US 60 approximately 4 miles (6 km) east of Frankfort
 US 60 2.0 miles (3.2 km) west of US 62
 US 60 approximately 7 miles (11 km) west of Versailles
 US 421 approximately 3 miles (5 km) south of Lexington
 US 60 Versailles Road, near Parkway Golf Course
 US 27 South Limestone Street, Lexington
 US 68 South Broadway, Lexington
 US 27 South Limestone, near Division of Research Laboratory, Lexington
 US 27 South Limestone, near Central Baptist Hospital, Lexington
 KY 4 across from Quantrell Cadillac, Lexington
 KY 922 Newtown Pike, near IBM, Lexington
 KY 4 near IBM, Lexington
 KY 4 0.5 mile (0.8 km) north of Harrodsburg Road, Lexington
 KY 4 1.0 mile (1.6 km) south of Versailles Road, Lexington
 KY 1974 Tates Creek Road, Lexington
 Cooper Drive, Lexington

APPENDIX C
STATISTICAL TESTS

STATISTICAL TESTS

Four statistical tests were performed in this study. They were as follows:

1. comparison of predicted (uncorrected) noise levels with measured noise levels,
2. comparison of predicted noise levels (corrected) with measured noise levels,
3. comparison of percent error of the uncorrected noise levels with the percent error of the corrected noise levels, and
4. comparison of variability of percent error of uncorrected with corrected noise levels.

Percent error was used instead of dBA units because percent error gives a value relative to the magnitude of each measured value. Also, percent error values were used for these statistical tests even though noise levels are logarithmic. Thus, care should be taken in the interpretation of these test results.

Percent error values were calculated for each of the 270 measured noise levels. For example, a measured L_{10} value was 75 dBA, the predicted value was 85 dBA, and the predicted (corrected) value was 77 dBA. The error between the measured and predicted value was 10 dBA, a $100 \times 10/75$ or 13.3 percent error, used in the first statistical test indicated above. The error between measured and predicted (corrected) noise levels was 2 dBA or 2.7 percent, used in the second statistical test. The difference in percent error was also computed for each location and used in the third statistical test. For this example, that difference would be $13.3 - 2.7 = 10.6$ percent.

In making the statistical comparisons, the following definitions of terms were used:

- n = number of noise measurements,
- \bar{X}_d = average difference in percent error for the noise levels being compared,
- S_d = standard deviation in percent error for the 270 values,
- α = level of significance of the test,
- μ = a constant = $t_{(1-.5 \alpha)} S_d / \sqrt{n}$,
- t = percentile of the t distribution,
- S_B = standard deviation of percent error before correction,
- S_A = standard deviation of percent error after correction,
- F = a constant = S_B^2 / S_A^2 , and
- $F_{1-\alpha}$ = a constant value for n_{A-1} , n_{B-1} degrees of freedom.

1. FIRST STATISTICAL TEST

$$\begin{aligned} \alpha &= 0.01 \\ \bar{X}_d &= 5.67 \\ S_d &= 15.14 \\ n &= 270 \\ \sqrt{n} &= 16.43 \\ t &= 2.576 \text{ (from t-test chart)} \\ \mu &= (2.576) (15.14) / (16.43) = 2.37 \end{aligned}$$

Since $\bar{X}_d > \mu$, there is a significant difference between the predicted (uncorrected) and measured noise levels at the .01 significance level.

2. SECOND STATISTICAL TEST

$$\begin{aligned} \alpha &= 0.1 \\ \bar{X}_d &= 0.61 \\ S_d &= 6.38 \\ n &= 270 \\ \sqrt{n} &= 16.43 \\ t &= 1.960 \text{ (from t-test chart)} \\ \mu &= (1.960) (6.38) / (16.43) = 0.76 \end{aligned}$$

Since $\mu > \bar{X}_d$, there is no significant difference.

$$\begin{aligned} \text{Choose } \alpha &= 0.2, \\ t &= 1.282 \text{ (from t-test chart)} \\ S_d &= 6.38 \\ \sqrt{n} &= 16.43 \\ \mu &= (1.282) (6.38) / (16.43) = 0.50 \end{aligned}$$

Since $\bar{X}_d > \mu$, there is a significant difference. Therefore, no significant difference exists between the corrected and measured values at the 0.1 level, but the difference is significant at the 0.2 level.

3. THIRD STATISTICAL TEST

$$\begin{aligned} \alpha &= 0.01 \\ \bar{X}_d &= 3.85 \\ S_d &= 6.0 \\ n &= 270 \\ \sqrt{n} &= 16.43 \\ t &= 2.576 \text{ (from t-test chart)} \\ \mu &= (2.57) (6.0) / (16.43) = 0.94 \end{aligned}$$

Since $\bar{X}_d > \mu$, there is a significant difference. Thus, a significant reduction in error was achieved by the correction nomograph at the .01 significance level.

4. FOURTH STATISTICAL TEST

$$\begin{aligned} \alpha &= .01 \\ F_{1-\alpha} &= 1.00 \text{ (from table for percentiles of F distribution)} \\ F &= S_B^2 / S_A^2 = 5.63 \end{aligned}$$

Since $F > F_{1-\alpha}$, the variability of error was reduced significantly by the correction nomograph at the .01 level.

APPENDIX D
PLOTS OF PREDICTION PROCEDURE ERROR
VERSUS SEVERAL VARIABLES

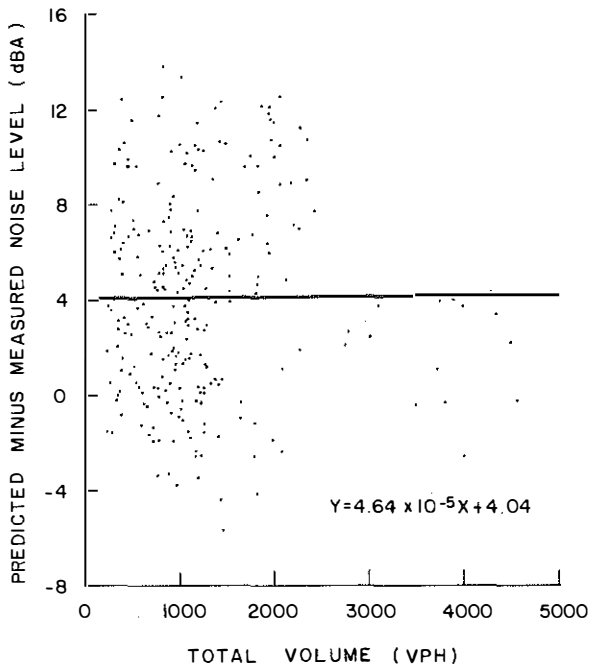


Figure D1. Prediction Procedure Error versus Total Volume.

Figure D2. Prediction Procedure Error versus Car Volume.

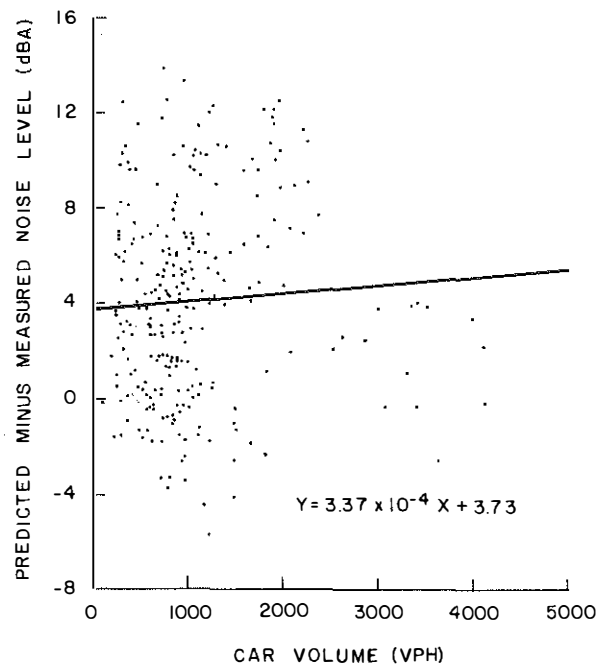
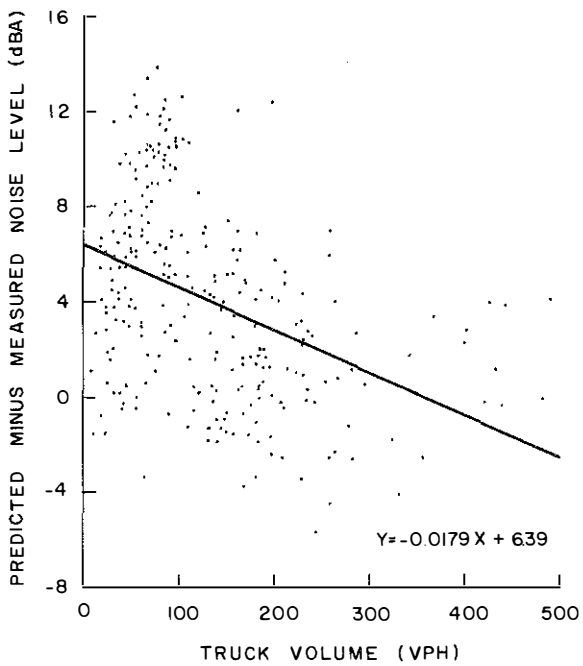


Figure D3. Prediction Procedure Error versus Truck Volume.



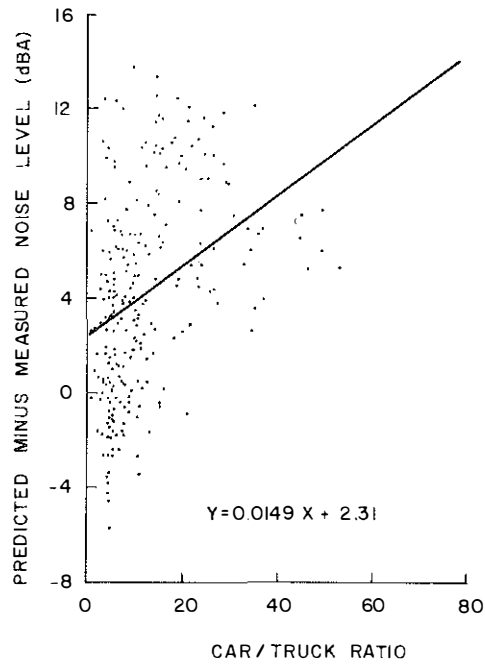


Figure D4. Prediction Procedure Error versus Car-Truck Ratio.

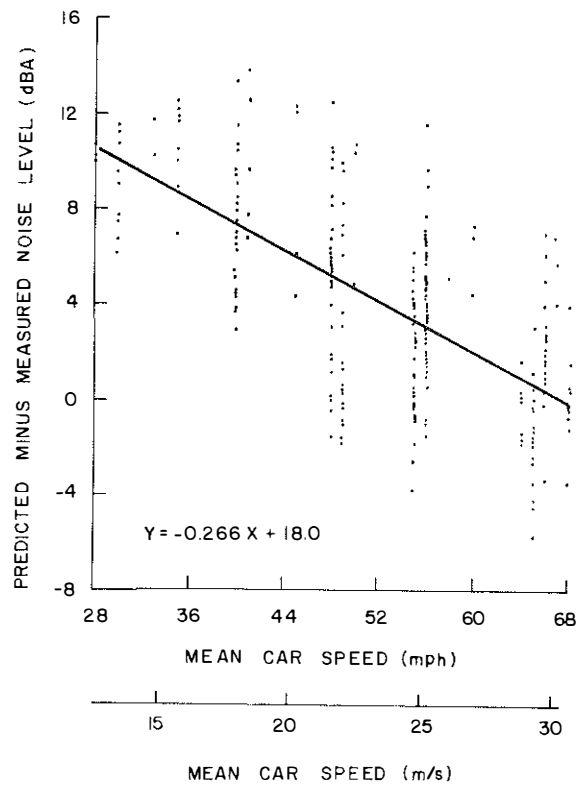


Figure D5. Prediction Procedure Error versus Car Speed.

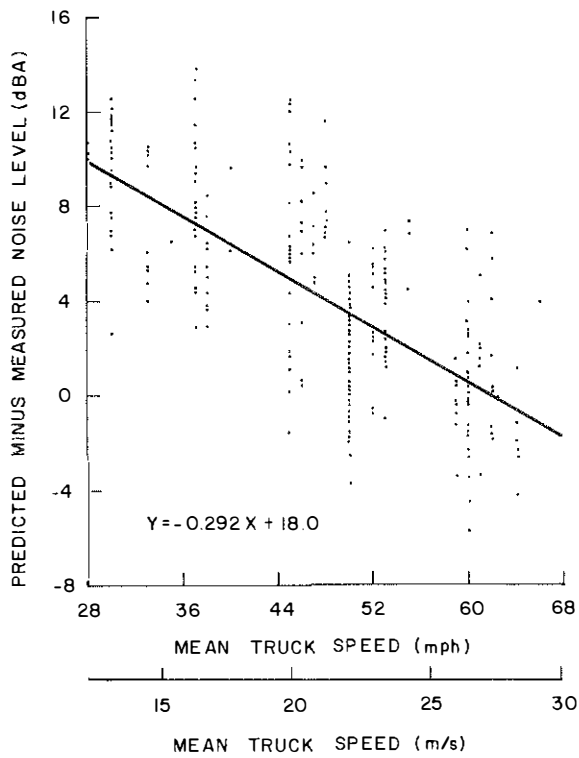


Figure D6. Prediction Procedure Error versus Truck Speed.

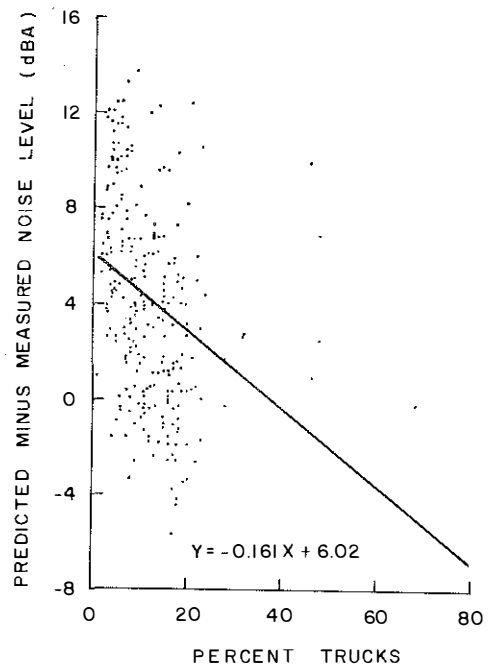


Figure D7. Prediction Procedure Error versus Percent Trucks.

APPENDIX E
USE OF NOMOGRAPH TO DETERMINE
CORRECTION FACTORS



USE OF NOMOGRAPH TO DETERMINE CORRECTION FACTORS

To determine correction factors from the nomograph, the following must be known:

1. observer-to-roadway distance (ft),
2. truck volume (vph), and
3. average car speed (mph).

The following example illustrates use of the nomograph in Figure D1. A level, straight, four-lane roadway with a "normal" surface has a truck volume of 150 vph, car volume of 500 vph, average truck speed of 40 mph (18 m/s), and mean car speed of 50 mph (22 m/s). Noise readings are taken at 200 feet (61 m), and there are no barriers or traffic interruptions (such as traffic signals).

The prediction procedure yields a final L_{10} value of 70.8 dBA. To determine the correction from the nomograph, first find the distance of 200 feet (61 m) on the scale in the upper left-hand corner of the nomograph. Draw a horizontal line until it intersects the curved line. Then draw a vertical line downward to the lines which represent truck volume. Where the vertical line intersects the point which represents the truck volume of 150 (interpolation will be necessary in many cases), a horizontal line is then drawn to the lines representing mean car speed. Where the horizontal line intersects the line for car speed of 50 mph (22 m/s) (interpolation will again be necessary in many cases), draw a vertical line until it intersects the scale which provides the correction factor. Read the correction factor of -3.2 dBA and add it (algebraically) to the 70.8 dBA which was obtained from the prediction procedure. Thus, the corrected value is 67.6 dBA.

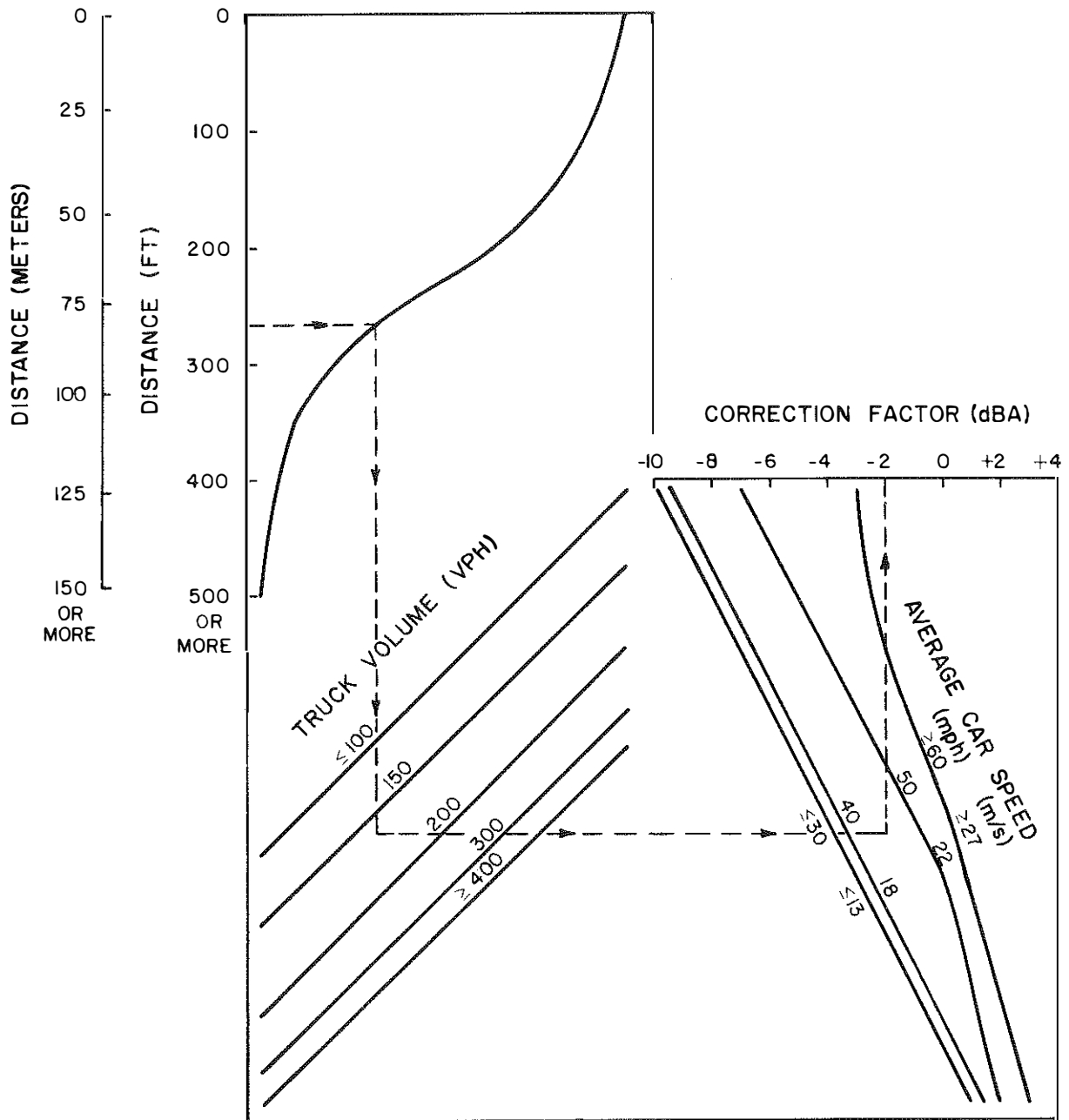


Figure E1. Prediction Procedure Correction Factor.

APPENDIX F
PLOTS OF PREDICTION PROCEDURE (CORRECTED) ERROR
VERSUS SEVERAL VARIABLES

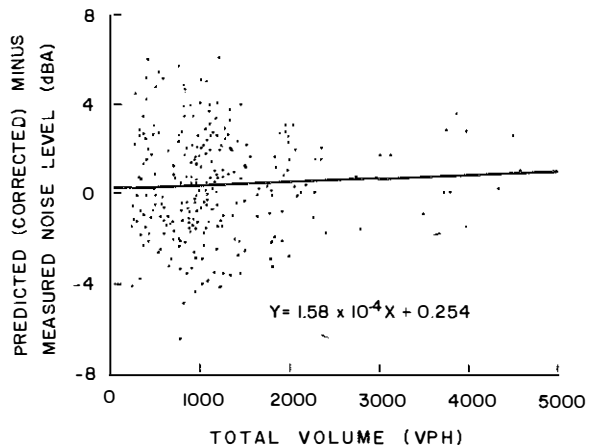


Figure F1. Predicted (Corrected) Noise Level Error versus Total Volume.

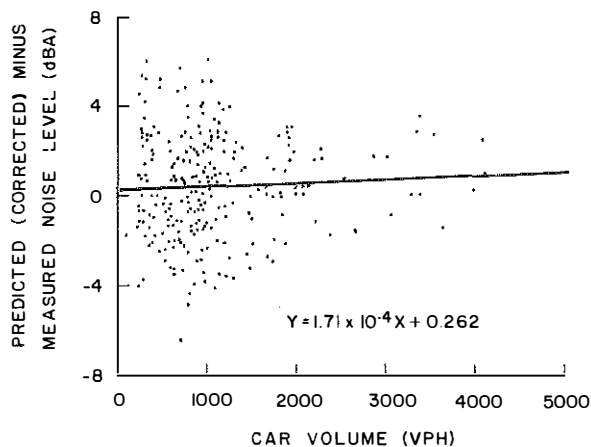


Figure F2. Predicted (Corrected) Noise Level Error versus Car Volume.

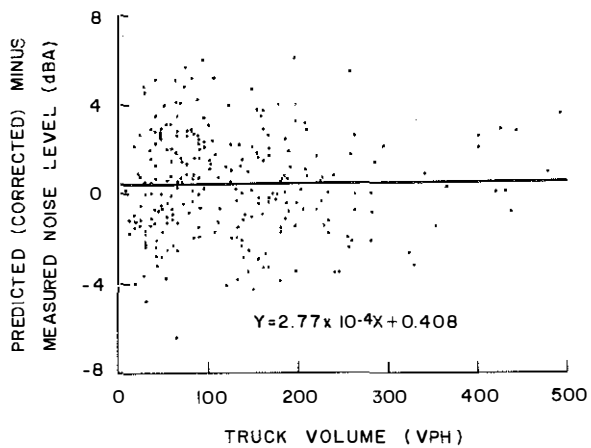


Figure F3. Predicted (Corrected) Noise Level Error versus Truck Volume.

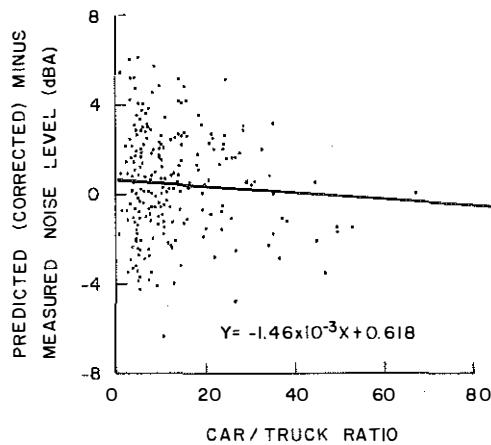


Figure F4. Predicted (Corrected) Noise Level Error versus Car/Truck Ratio.

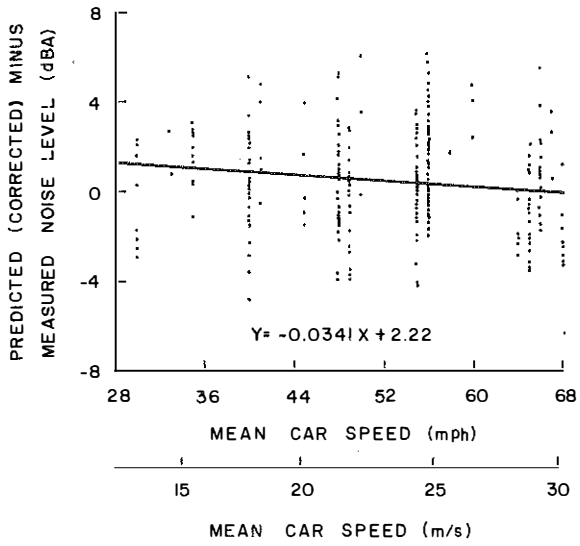


Figure F5. Predicted (Corrected) Noise Level Error versus Car Speed.

Figure F6. Predicted (Corrected) Noise Level Error versus Truck Speed.

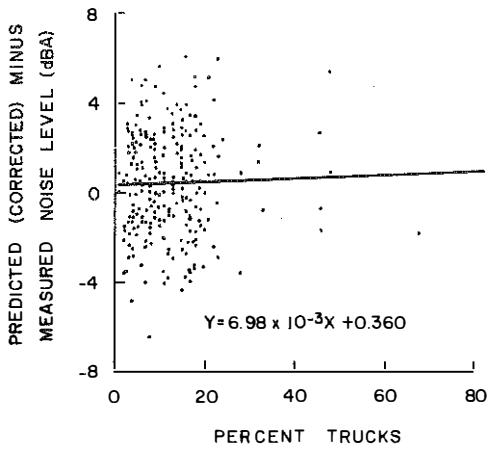
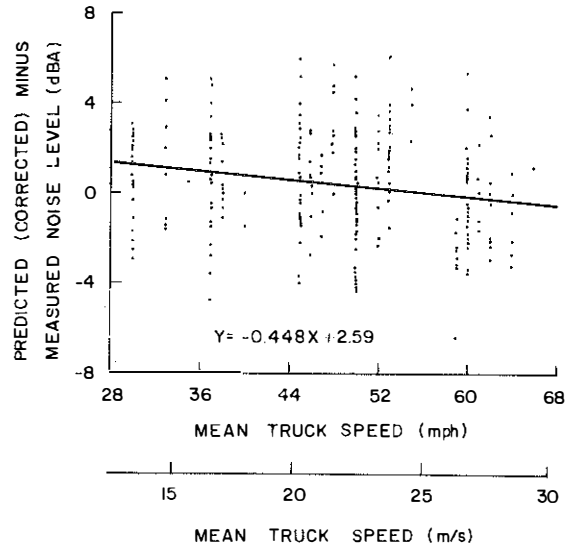


Figure F7. Predicted (Corrected) Noise Level Error versus Percent Trucks.

APPENDIX G
TABLES OF MEAN ERROR BEFORE AND AFTER
CORRECTION FOR SEVERAL VARIABLES

TABLE G1
MEAN ERROR BEFORE AND AFTER CORRECTION
FOR OBSERVER-TO-ROADWAY DISTANCE

DISTANCE		NUMBER OF LOCATIONS	MEAN ERROR BEFORE CORRECTION (dBA)	MEAN ERROR AFTER CORRECTION (dBA)	MEAN ERROR REDUCTION (dBA)
(FEET)	(METERS)				
50	15	72	5.5	2.0	3.5
100	30	59	5.7	1.9	3.8
150	46	38	5.7	1.8	3.9
200	61	32	5.2	2.1	3.1
250	76	14	3.1	2.3	.8
300	91	15	1.8	1.5	.3
350	107	1	1.1	.4	.7
400	122	12	2.2	1.6	.6
450	137	1	3.0	2.0	1.0
500	152	12	2.0	1.2	.8
OTHER		14	2.3	1.3	1.0

TABLE G2
MEAN ERROR BEFORE AND AFTER CORRECTION
FOR TOTAL VOLUME

TOTAL VOLUME (VPH)	NUMBER OF LOCATIONS	MEAN ERROR BEFORE CORRECTION (dBA)	MEAN ERROR AFTER CORRECTION (dBA)	MEAN ERROR REDUCTION (dBA)
< 400	24	4.2	1.9	2.3
401 - 700	36	4.4	2.1	2.3
701 - 1000	68	4.3	1.9	2.4
1001 - 1500	84	4.5	2.0	2.5
1501 - 2000	29	6.9	1.5	5.4
2001 - 2500	15	7.0	1.2	5.8
2501 - 3000	2	2.4	1.1	1.3
> 3000	12	2.3	1.6	.7

TABLE G3
MEAN ERROR BEFORE AND AFTER CORRECTION
FOR CAR VOLUME

CAR VOLUME (VPH)	NUMBER OF LOCATIONS	MEAN ERROR BEFORE CORRECTION (dBA)	MEAN ERROR AFTER CORRECTION (dBA)	MEAN ERROR REDUCTION (dBA)
< 400	37	4.8	2.2	2.6
401 - 700	43	2.4	1.8	1.6
701 - 1000	84	4.2	1.9	2.3
1001 - 1500	57	5.2	2.0	3.2
1501 - 2000	27	7.5	1.5	6.0
2001 - 2500	8	7.9	1.2	6.7
2501 - 3000	3	2.4	1.3	1.1
> 3000	11	2.3	1.6	.7

TABLE G4
MEAN ERROR BEFORE AND AFTER CORRECTION
FOR TRUCK VOLUME

TRUCK VOLUME (VPH)	NUMBER OF LOCATIONS	MEAN ERROR BEFORE CORRECTION (dBA)	MEAN ERROR AFTER CORRECTION (dBA)	MEAN ERROR REDUCTION (dBA)
0 - 100	135	6.3	2.0	4.3
101 - 200	89	3.4	1.8	1.6
201 - 300	32	2.6	1.5	1.1
301 - 400	5	2.7	1.7	1.0
> 400	9	2.1	1.8	.3

TABLE G5
MEAN ERROR BEFORE AND AFTER CORRECTION
FOR CAR – TRUCK RATIO

CAR - TRUCK RATIO	NUMBER OF LOCATIONS	MEAN ERROR BEFORE CORRECTION (dBA)	MEAN ERROR AFTER CORRECTION (dBA)	MEAN ERROR REDUCTION (dBA)
0 - 5.0	65	3.2	2.1	1.1
5.1 - 10	90	3.8	1.8	2.0
10.1 - 15	51	4.9	1.7	3.2
15.1 - 20	19	8.1	2.0	6.1
20.1 - 25	17	7.4	2.0	5.4
25.1 - 30	10	7.9	2.1	5.8
> 30	18	6.1	1.5	4.6

TABLE G6
MEAN ERROR BEFORE AND AFTER CORRECTION
FOR CAR SPEED

CAR SPEED		NUMBER OF LOCATIONS	MEAN ERROR BEFORE CORRECTION (dBA)	MEAN ERROR AFTER CORRECTION (dBA)	MEAN ERROR REDUCTION (dBA)
(mph)	(m/s)				
30 - 35	13 - 15	25	9.9	1.8	8.1
36 - 40	16 - 18	29	6.9	1.8	5.1
41 - 45	19 - 20	10	9.1	2.0	7.1
46 - 50	21 - 22	57	4.9	2.0	2.9
51 - 55	23 - 24	37	2.5	1.5	1.0
56 - 60	25 - 26	53	4.3	2.1	2.2
61 - 65	27 - 29	28	1.8	1.7	.1
66 - 70	30 - 31	31	2.5	1.9	.6

TABLE G7
MEAN ERROR BEFORE AND AFTER CORRECTION
FOR TRUCK SPEED

TRUCK SPEED		NUMBER OF LOCATIONS	MEAN ERROR BEFORE CORRECTION (dBA)	MEAN ERROR AFTER CORRECTION (dBA)	MEAN ERROR REDUCTION (dBA)
(mph)	(m/s)				
< 30	< 13	26	9.6	1.8	7.8
31 - 35	14 - 15	10	7.3	2.4	4.9
36 - 40	16 - 18	34	7.4	1.9	5.5
41 - 45	19 - 20	25	5.3	2.2	3.1
46 - 50	21 - 22	81	3.6	1.6	2.0
51 - 55	23 - 24	36	3.9	2.0	1.9
56 - 60	25 - 26	35	2.0	2.0	0
61 - 65	27 - 29	22	2.4	1.5	.9
66 - 70	30 - 31	1	3.9	1.2	2.7

TABLE G8
MEAN ERROR BEFORE AND AFTER CORRECTION
FOR PERCENT TRUCKS

PERCENT TRUCKS	NUMBER OF LOCATIONS	MEAN ERROR BEFORE CORRECTION (dBA)	MEAN ERROR AFTER CORRECTION (dBA)	MEAN ERROR REDUCTION (dBA)
0 - 5	57	7.1	1.8	5.3
6 - 10	75	5.1	1.8	3.3
11 - 15	62	4.0	1.8	2.2
16 - 20	54	2.9	2.0	.9
> 20	22	3.5	2.3	1.2