HIGHWAY NOISE STUDY

FINAL REPORT

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ABSTRACT

Noise impacts due to traffic on a new or improved highway facility have become a major environmental consideration in highway development. This requires that proper techniques of noise level measurements and predictions be used to determine noise impacts.

This research was undertaken primarily to develop standard techniques of sound level measurements and data analysis directed toward the needs of the Department. A secondary aim was to investigate methods currently available for predicting traffic generated noise levels and compare the results with actual field measurements.

Three noise level measurement systems have been investigated and made operationa. They are:

1. Graphic Level Recording Method
2. Periodic Sampling Method
3. Environmental Noise Classifier Method

The relative accuracy of the three systems were compared by simultaneous field measurements of traffic noise. Other factors such as equipment portability, data analysis requirements, and expertise requirements were also compared.

Two major noise prediction methods were investigated and compared. They are:

1. NCHRP Report 117 - Noise Prediction Method
2. Transportation Systems Center (TSC) Noise Prediction Method

Noise level predictions using the two methods were compared to actual field measurements. The relative ease of use of each was also compared.

The major findings of this study are:

1. Either the periodic sampling or environmental noise classifier methods of noise measurement should be used for the majority of ambient noise measurements.

2. The NCHRP Report 117 noise prediction method should be the basic method used for noise level predictions. The TSC method should be used only where, because of complex geometrics, the NCHRP Report 117 method is impractical.

IMPLEMENTATION

The purpose of this project was to investigate and make operational standard techniques of noise measurement and predictive procedures for immediate Department use; thus, all recommendations contained in this report have been fully implemented by the Department during the course of the study.

INTRODUCTION

Environmental considerations are playing an increasingly important role in the planning, design, construction and operation of our highways. Traffic noise has been identified as one of the major environmental pollutants and, as such, must be considered in all phases of highway development.

The highway engineer must have sufficient data available in order to properly evaluate noise impacts due to traffic on a new or improved facility. Basic data requirements consist of ambient or existing noise levels and a prediction of future traffic noise levels in the area of the proposed project. Thus proper techniques of noise level measurement and traffic noise predictions are vital to the accurate determination of highway noise impacts.

PURPOSE AND SCOPE

This research was undertaken primarily to develop standard techniques of sound level measurements and data analysis directed toward the needs of the Department. A secondary aim was to investigate methods currently available for predicting traffic generated noise levels and compare the results with actual field measurements.

FUNDAMENTALS OF SOUND AND TRAFFIC NOISE

This chapter presents a few basic fundamentals of sound and traffic noise. For a more detailed understanding the reader is referred to the literature.

Sound is the result of minute fluctuations in air pressure which cause the ear drum to vibrate. These vibrations are perceived by the ear as sound. Noise has generally been defined as unwanted sound. Thus the classification of a particular sound as noise and the degree of noisiness is a subjective reaction of the individual and therefore varies with each individual.

Sound as well as other vibrations is characterized by its intensity and frequency. Both of these measures are very important in subjective judgments of "noisiness" of sound. The intensity of sound is measured in decibels while frequency is described in terms of hertz (Hz) or cycles per second.

The range of sound pressure levels which can be perceived by the ear without pain is very large. In fact the largest sound pressure perceived without pain is in the order of one million times greater than the weakest sound pressure which can be perceived (1). Because of this large range of numbers it was decided long ago to use a more convenient scale. The unit selected was the decibel. The decibel is defined as ten times the logarithm to the base ten of a ratio of power levels. Since sound power is related to the square of the sound pressure, the decibel scale in acoustics is defined as follows:

$$\text{Sound Pressure Level} = 10 \log \left(\frac{P^2}{P_o^2}\right) = 20 \log \frac{P}{P_o} \text{ dB}$$

where P_o is the reference sound pressure level (.0002 microbar) and P is the sound pressure being measured (1).

Perhaps it is well to point out at this time that, since decibels are logarithmic units, they cannot be added by ordinary arithmetic means. They must be added

* Underlined number in parenthesis refer to "References".

logarithmically. Thus, for example, if we add two equal sound pressure levels of 70 dB we obtain 73 dB and not 140 dB.

As previously mentioned, frequency is also important in describing sound characteristics. The loudness of sounds of equal intensity but different frequency content is judged differently. Up to approximately 8000 Hz, high frequency sounds will be judged louder than low frequency sounds of equal intensity. Thus any measure of loudness must take into account both the frequency and intensity of the sound pressures.

A number of methods have been devised to provide a simple measurement system which correlates well with human subjective judgment of loudness. One of the simplest and easiest to use methods is the use of the "A" weighted network of a standard sound level meter. It has been found that traffic noise measurements using the "A" scale closely corresponds to human judgments of loudness. The "A" scale gives more weight to sound levels in the higher frequency ranges and less to the lower frequencies. To signify that measurements have been made using the "A" scale the unit is denoted as dBA.

The time varying characteristics of environmental noise also complicate the description of a noise environment. Noise levels vary considerably during different periods of the day. Should an environment be characterized by its peak noise levels, average noise levels, or some other statistical descriptor? The Federal Highway Administration in Policy and Procedure Memorandum 90-2 (2) has based its Design Noise Levels on the level which is exceeded for ten percent of the time during the peak noise period. This value is denoted as L_{10} and is in units of dBA.

The following relationships will perhaps serve to provide some feel for traffic noise characteristics (3).

1. Traffic noise is decreased by from 3-6 dB per distance doubling from the source depending on noise source and surrounding environment. An average of 4.5 dB can be used for quick calculations.

2. Under field conditions a 1 dB change in noise levels cannot be noticed. A 3 dB change is just noticeable. A 10 dB change is judged as a doubling or halving of noise levels.

3. A doubling or halving of noise source energy will only result in a 3 dB change in noise levels. For example, doubling traffic volumes will increase noise levels by only 3 dB while a 50 percent reduction in traffic volumes will only cause a 3 dB decrease in noise levels.

NOISE MEASUREMENT SYSTEMS

There are numerous techniques and equipment combinations which can be used to measure noise levels. During the course of this study the following methods were successfully used.

1. Graphic Level Recording Method
2. Periodic Sampling Method
3. Environmental Noise Classifier Method

Each method is described in the following paragraphs. It should be remembered that, since Federal Highway Administration standards for design noise levels are based on L_{10} noise levels, the measurement systems were directed toward L_{10} measurements.

GRAPHIC LEVEL RECORDING METHOD

This technique is based on procedures used by the Texas Transporation Institute (4) and the California Division of Highways (5). Basic equipment consists of a general purpose sound level meter, calibrator, and graphic level recorder. In essence this method involves the graphic recording of the sound level meter output on a strip chart. The strip chart is then analyzed in the office to obtain the desired information.

Equipment

The following equipment was successfully used during this study for the graphic level recording method of noise measurements.

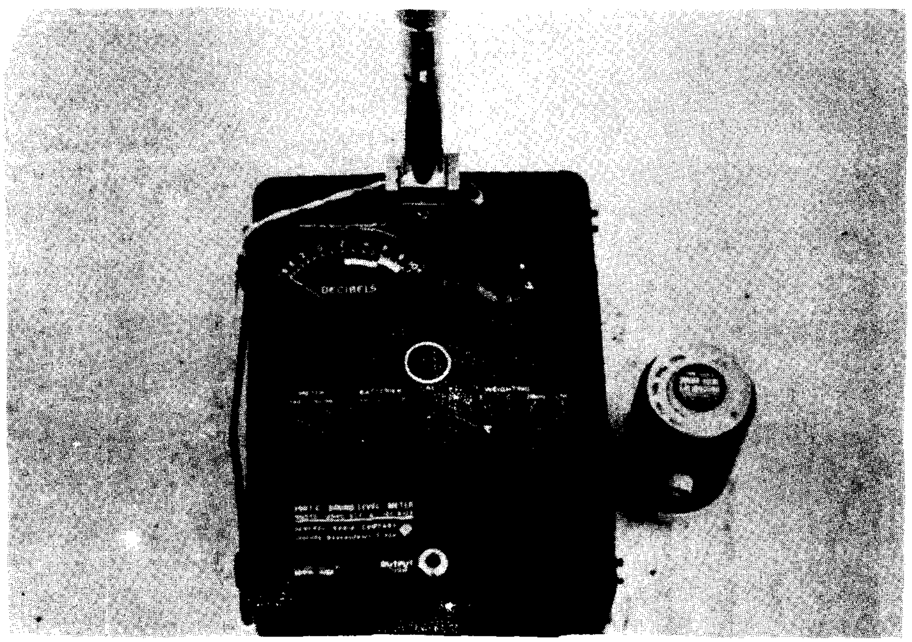
a.) General Radio Type 1551-C Sound Level Meter - This meter meets the American National Standards Institute (ANSI) standards for a Type 2 general purpose sound level meter. The meter has a builtin GR 1560-P5 microphone. Any one of four response characteristics (A, B, C and flat response weighting networks) can be selected. Fast or slow meter response can also be selected. (See Figure 1).

b.) General Radio Type 1562-A Calibrator - The calibrator provides a sound pressure level of 114 dB at 5 ANSI preferred frequencies (125, 250, 500, 1000 and 2000 Hz). (See Figure 1)

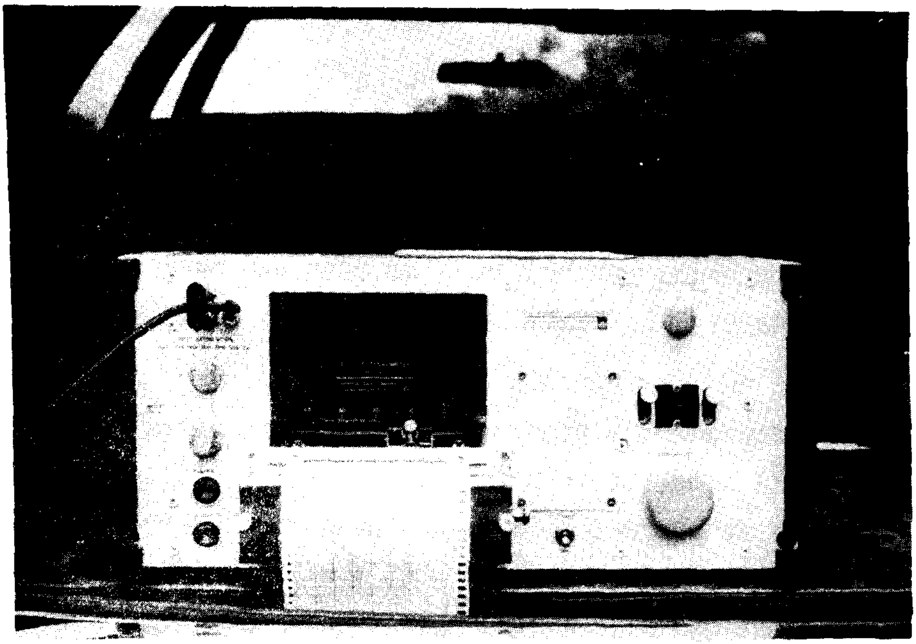
c.) General Radio Type 1521-B Graphic Level Recorder - When electrically coupled to the sound level meter the recorder produces a permanent strip chart record of noise levels. The instrument used is capable of recording sound levels over a 40 dB range as a function of time. Chart speeds of 0.5, 1.5, 5 and 15 in./min. were available. (See Figure 2).

d.) Accessory Equipment - Accessory equipment required for field measurements consists of a tripod to mount the sound level meter, an inverter to convert DC voltage to AC for the operation of the recorder, a 10 foot extension cord, a microphone windscreen and a 100 foot length of coaxial cable to connect the sound level meter to the graphic level recorder.

A typical field set up is shown in Figure 3.



General Radio Type 1551-C Sound Level Meter and Type 1562-A Calibrator
FIGURE 1



General Radio Type 1521-B Graphic Level Recorder
FIGURE 2

Typical Field Set Up Using Graphic Level Recording Equipment
FIGURE 3

Measurement Procedure

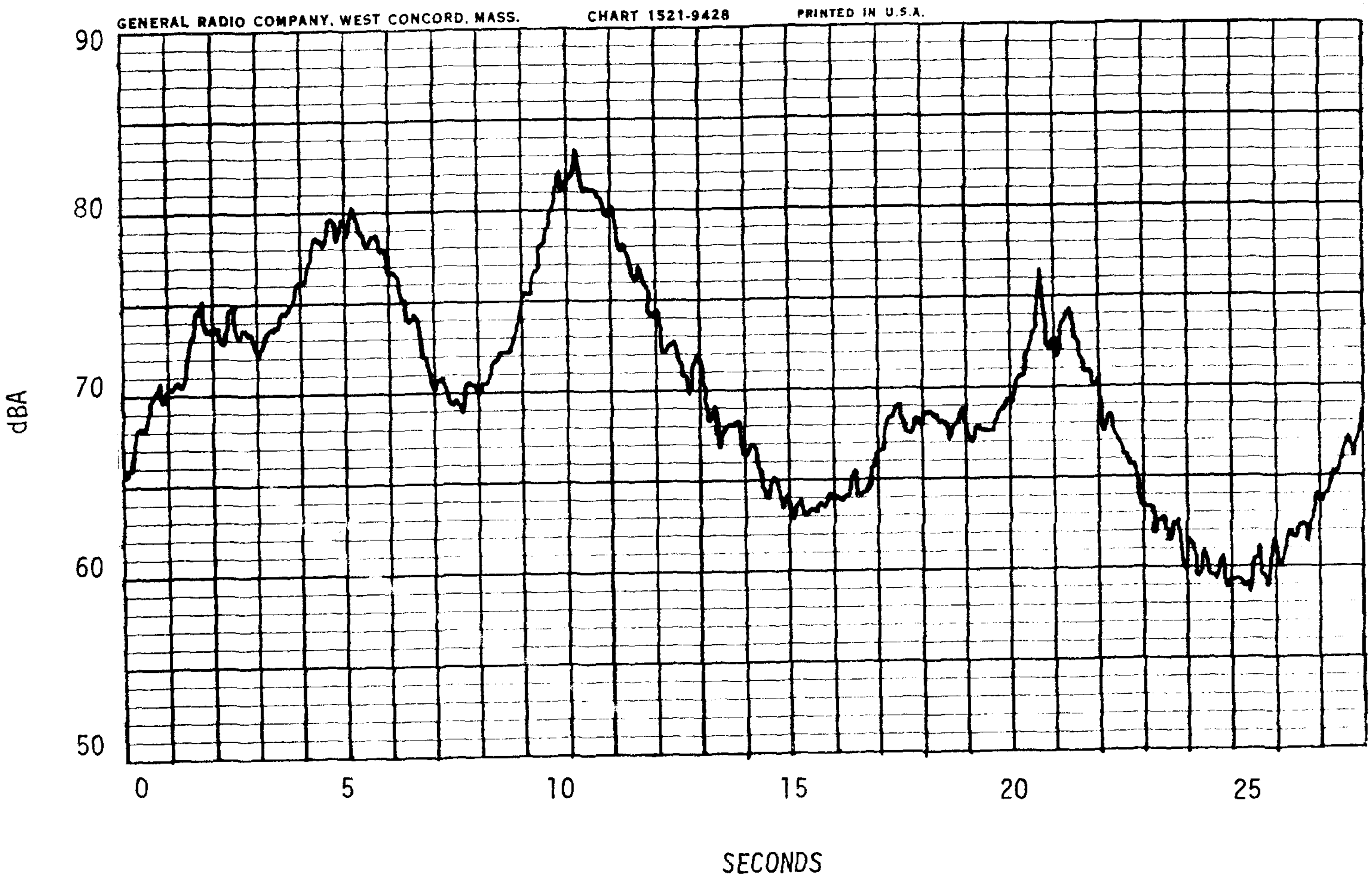
Before going into the field, all equipment should be checked to ensure that it is in proper working order. Battery checks should be made on sound level meter and calibrator. Periodic checks of inverter should also be made to ensure that proper voltage and frequency are being supplied.

Once in the field the sound level meter is set on a tripod 4 to 5 feet above ground level at the desired location. The output of the meter is connected to the graphic level recorder by a coaxial cable. Power is furnished to the recorder by means of an inverter which converts the 12 volt DC supply of the automobile electrical system to 115 volt AC voltage. The automobile should be located in back of and as far away as practical from the sound level meter in order to minimize sound reflections or blockage.

The sound level meter and recorder are then calibrated (see Appendix A for detailed calibration procedures). The response range of the meter is set to slow and the A weighting network is selected. A windscreen is placed on the microphone if it is judged that wind noise will affect noise readings. The sound level meter base scale attenuator setting is selected by trial and error. It should approximately equal the average sound levels at the measurement location. The center of the chart on the graphic recorder will be equivalent to the attenuator setting. It is important that the attenuator setting be written on the strip chart in order to avoid errors in data reduction. The recorder input attenuator is set to 30 and the writing speed to 10.

It should be remembered that the graphic level recorder has a much wider range (40 dB) than that of the meter (16 dB). Thus, although the needle indicator on the sound level meter tops or bottoms out from time to time the indicator on the recorder may remain well within its range. The chart speed of the recorder is set at 15 in./min. This speed is necessary for proper data reduction. If, however, the purpose of the recording is other than for determining the L_{10} noise levels a slower chart speed may be selected.

An example of the data output from the graphic level recorder is shown in Figure 4.



Typical Output of Graphic Level Recorder

FIGURE 4

Data Analysis

As mentioned above, the chart speed used during field measurements was 15 in./min. This speed was selected in order to facilitate data reduction. A chart speed of 15 in./min. combined with a chart scale of 4 divisions per inch yields a time scale of one second per division. Thus sound level readings for each one second interval could easily be obtained from the graphic recording chart. The one second interval was chosen as a compromise between practicality and accuracy.

Data obtained from the chart is then grouped by determining the frequency of occurrence of each noise level reading to the nearest decibel. Once this is done a cumulative frequency table is then made, converted to percentages, and the L_{10} noise level is determined. The L_{10} is determined by either interpolation from the table values or from a plot of the cumulative frequencies on a graph.

PERIODIC SAMPLING METHOD

This technique was presented by the firm Bolt Beranek and Newman, Incoporated, in a noise training course under contract to the Federal Highway Administration. It is described in a textbook Fundamentals and Abatement of Highway Traffic Noise (3) developed by Bolt Beranek and Newman for the course.

Basic equipment consists of a general purpose sound level meter and a stop watch. Noise readings are sampled every 10 seconds and a statistical procedure is used to determine when sufficient data is obtained to provide an accurate estimate of the L_{10} noise levels.

Equipment

The following equipment was used during this study.

a.) General Radio Type 1551-C Sound Level Meter - As described in previous section.

b.) General Radio Type 1562-A Calibrator - As described in previous section.

c.) Accessory Equipment - Accessory equipment required for field measurements consists of a tripod to mount the sound level meter, data sheets, wind-screen and a stop watch or watch with a large second hand.

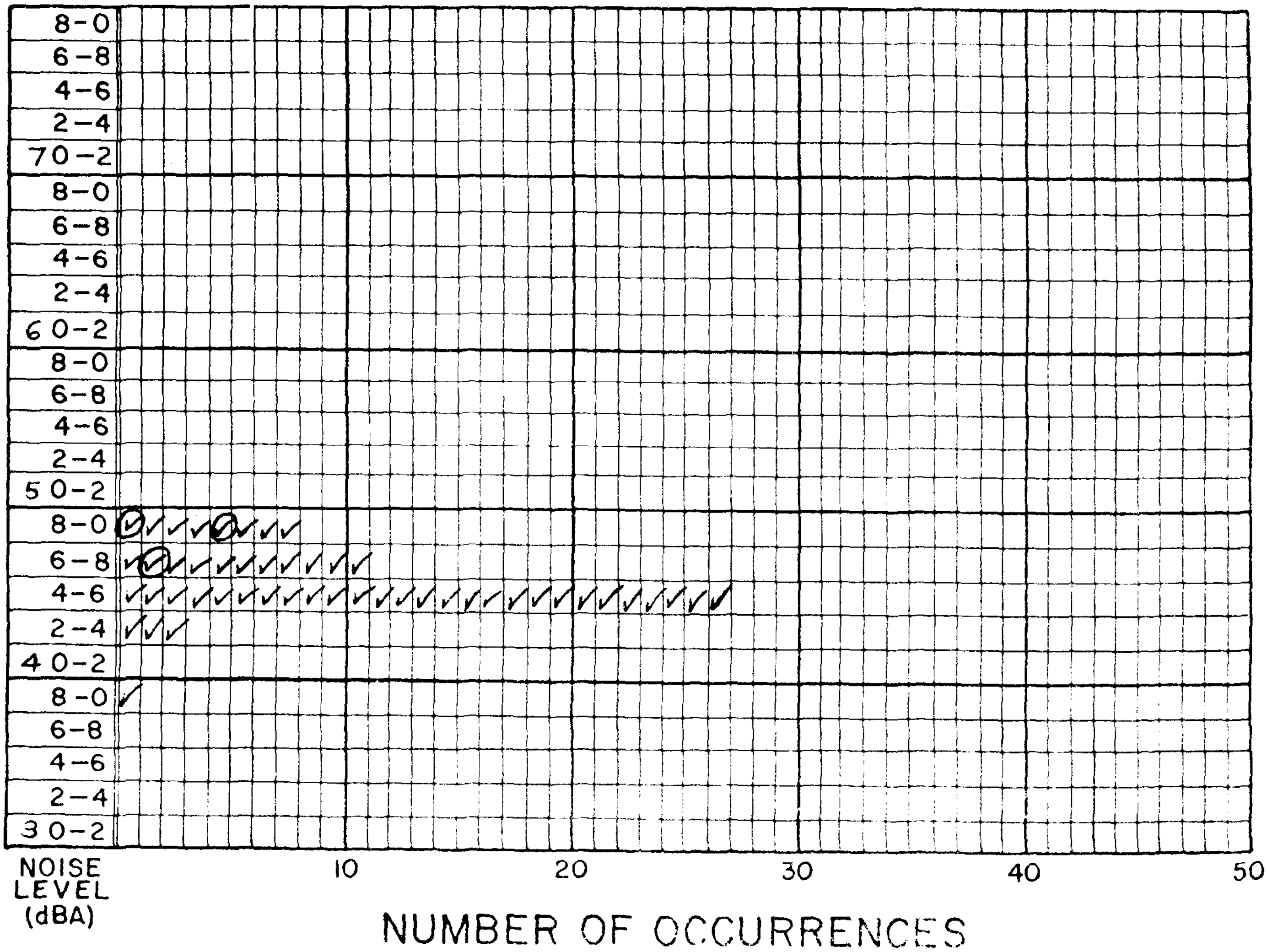
See Figure 5 for typical field set up.

Typical Field Set Up for Periodic Sampling Method
FIGURE 5

Measurement Procedure

The sound level meter is set on a tripod 4-5 feet above ground level at the desired location. The meter is then calibrated (see Appendix A for detailed calibration procedure). If wind noise is a problem a windscreen should be used. The response range is set to slow and the A weighting network is selected. The following procedure is then used.

1. The meter reading is sampled every 10 seconds. The data is recorded by check marks in the appropriate window on the data sheet. Note that the windows are 2 dB wide. (See Figure 6)
2. After every 50 samples, the data are tested by the procedure below to determine if enough samples have been taken. If not, another 50 samples are taken and the data retested.
3. The test procedure involves the table on page 14.



Example of Periodic Noise Measurement Data Sheet (50 Samples)

FIGURE 6

Total Number of Samples	Upper Error Limit	L_{10}	Lower Error Limit	Allowable Skewing
50	1st. sample	5th sample	10th sample	none
100	5th	10th	17th	once
150	8th	15th	23th	once
200	12th	20th	29th	once
250	16th	25th	35th	once
300	20th	30th	41st	once
350	25th	35th	47th	once

During the sampling procedure, the samples are automatically ordered, from highest noise level to lowest noise level. After 50 samples are taken, the first sample, the fifth sample and the tenth (all as counted off left to right and downward from the top of the ordered samples) are noted.

Criterion: If these three samples fall into three adjacent level windows, then the measurements are complete.

In the example shown in Figure 6, the first and the fifth samples fall into the same level window. This resulted in an even more compact grouping than the criterion required, and so the measurements were complete.

After 100 or more samples, one skewing is allowed. This could be either upward or downward, as long as both limits are shifted in the same direction. In this way the limit window can be shifted one sample in either direction without changing its width, to attempt to satisfy the criterion. For example, if the criterion is not met after 100 samples by testing the 5th, 10th and 17th samples, the 4th, 10th and 16th samples or the 6th, 10th and 18th samples can be used without sacrificing accuracy. Note that the L_{10} sample is not shifted.

4. Once the criterion is satisfied, then the measured L_{10} has been determined, with 95 percent confidence, to be within the upper and lower error limits. Since these limits fall in windows adjacent to the L_{10} window, the maximum error is plus or minus 3 dBA. For the example shown,

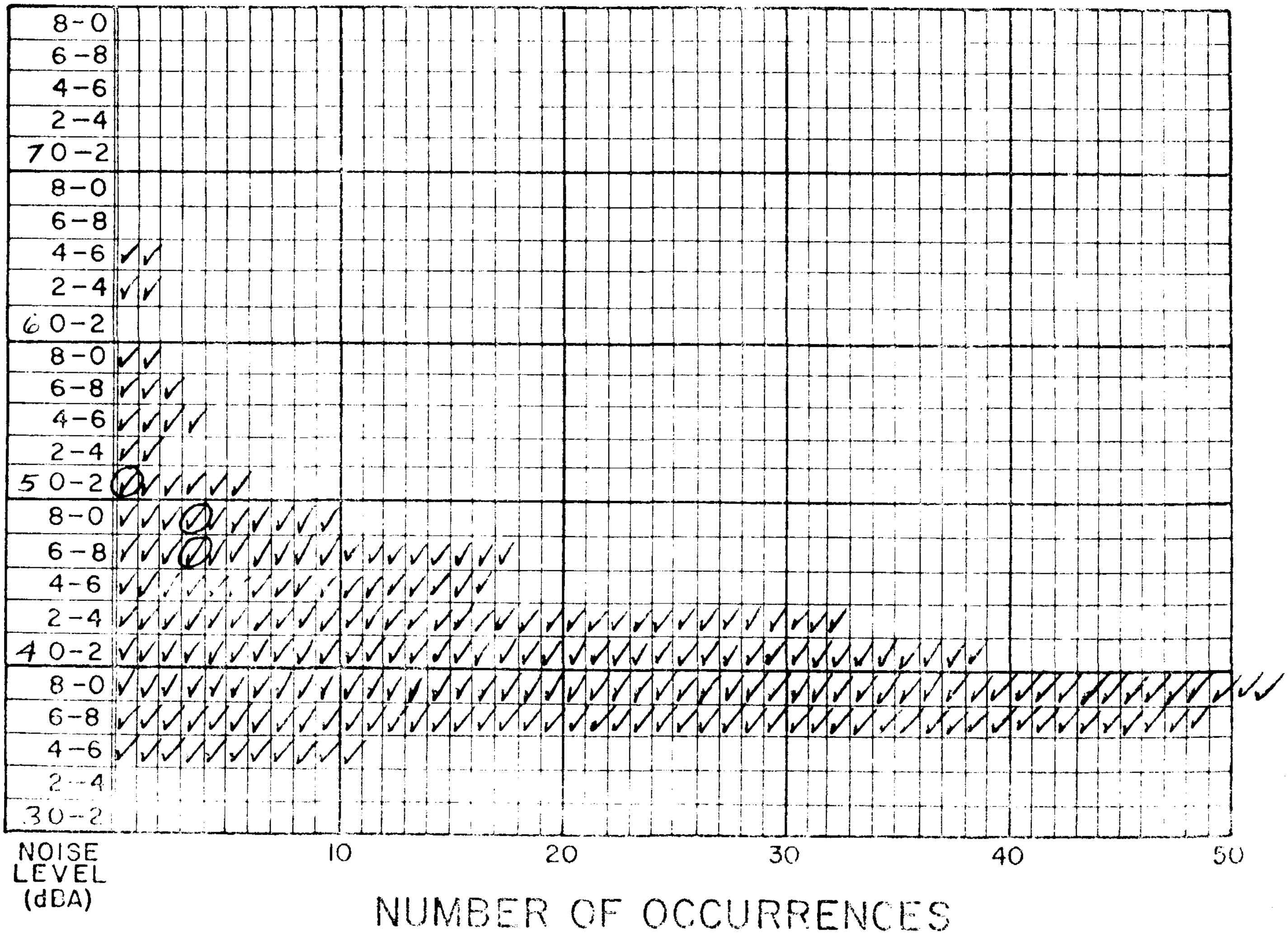
   L_{10} = 49 dBA, within maximum limits of 46 dBA and 50 DBA, i.e.,

   $L_{10} = 49 \text{ dBA} \begin{smallmatrix} +1 \text{ dBA} \\ -3 \text{ dBA} \end{smallmatrix}$

A very complex sampling is shown in Figure 7. The final tally, after 250 samples, is shown. At each 50-sample interval, the criterion was applied.

After 50 samples, L_{10} =	47 dBA	plus 5 dBA,	minus 7 dBA
100	55	5	7
150	53	5	5
200	51	5	3
250	49	3	3

The upper and lower limits after 250 samples are shown in the example as circled samples.



Example of Periodic Noise Measurement Data Sheet (250 Samples)
FIGURE 7

Data Analysis

Due to the very nature of this method data analysis is accomplished concurrently with the measurements; therefore, additional data analysis is not required.

ENVIRONMENTAL NOISE CLASSIFIER METHOD

This technique was developed when a new piece of equipment, the Environmental Noise Classifier, became available for noise measurements. Although originally intended for industrial uses the classifier was adapted for highway noise studies.

Equipment

The following equipment was successfully used during the study:

a.) B & K Model 166-S45 Environmental Noise Classifier - This instrument meets ANSI Type 2 general purpose sound level meter specifications. It divides the measured noise level into eleven amplitude classes of alternate 2 and 3 dB band widths. The time that the signal dwells in each band, the time that the signal is above the highest band and the test duration is totaled. The special S45 model allows an analysis range of 27 dB starting at a base level of 45 dBA. Additional selections of base levels of 60 dBA to 100 dBA in 5 dB increments are possible. A one inch ceramic microphone, B & K Model 4117, is supplied with the classifier. (See Figure 8)

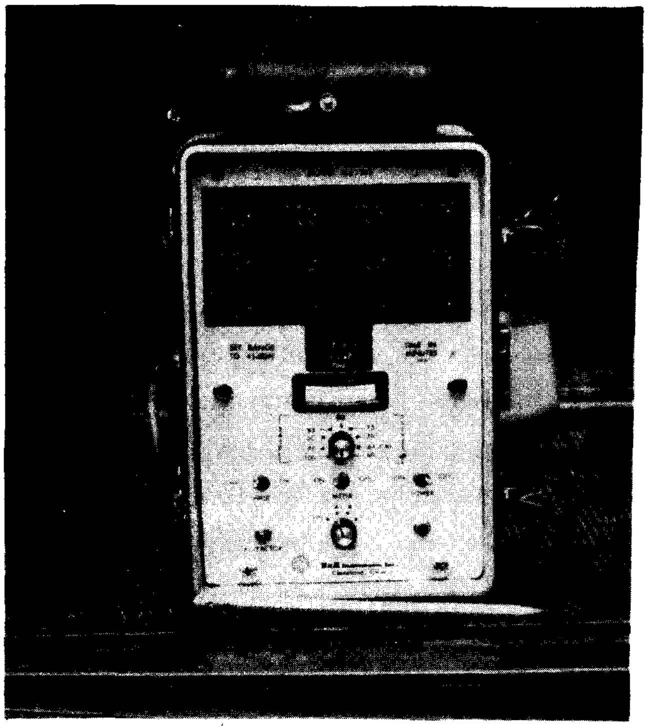
b.) B & K Model 4230 Calibrator - The calibrator provides a sound pressure level of 94 dB, ± .3 dB, at 1000 Hz.

c.) Accessory Equipment - A tripod is used to mount the microphone remote from the classifier, a 100 foot length of coaxial cable is used to connect the microphone to the classifier. Additional equipment includes an inverter to convert the DC voltage of the automobile electrical system to AC to power the classifier, special data sheets and a microphone windscreen.

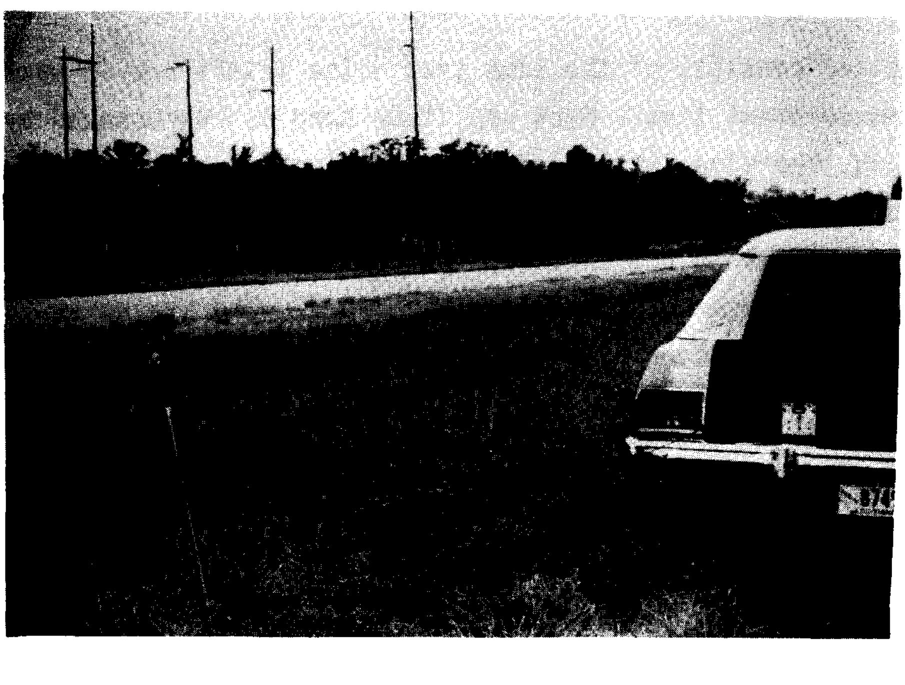
See Figure 9 for a typical field set up.

Measurement Procedure

Before going into the field the calibrator battery should be checked. The inverter should also be checked periodically to insure that it is in proper working order.



B & K Model 166-S45 Environmental Noise Classifier and
B & K Model 4230 Calibrator
FIGURE 8



Typical Field Set Up Using EnvironmentalNoise Classifier Method
FIGURE 9

Once in the field the microphone is placed on the tripod at a height of 4 - 5 feet at the desired location. The microphone is connected to the classifier by a coaxial cable. Power to the classifier is supplied by an inverter which converts the 12 volt DC voltage of the automobile to 115 volt AC voltage. The automobile should be located in back of and as far away from the microphone as possible to minimize sound reflections or blockage.

The classifier is then calibrated (see Appendix A for detailed calibration procedure). The input is switched to Mic. and the weighting selector is set on the A scale. The meter switch is placed in the off position (note: for this instrument the meter is used for calibration purposes only). All counters should be zeroed. The base scale is selected. Generally for ambient noise measurements the lowest base scale of 45 dB will be selected. A windscreen is placed on the microphone if needed.

When it is desired to begin a measurement the power switch on the classifier is turned on. At the end of the measurement period the power switch is turned off. All counter readings are then recorded on the data sheet.

Data Analysis

Field data obtained consists of the time that noise levels are in each amplitude band, and the total measurement time. Each amplitude band is represented by the lowest noise level in the band. The time is then added cumulatively from the highest to the lowest noise level bands. Each time is then converted to a percentage of total time. The percentages thus determined represent the percent of time that noise levels are equal to or greater than the lowest noise level in each band. The L_{10} noise level value is determined by interpolation or by a graphical representation of the cumulative distribution. An example of a completed data form is shown in Figure 10.

COMPARISON OF FIELD NOISE MEASUREMENTS

Field measurements were conducted at a number of locations using all three noise measurement systems simultaneously. The results of these measurements are shown in Table 1.

ENVIRONMENTAL NOISE CLASSIFIER

AMBIENT NOISE DATA SHEET

LOCATION: I-410 NEAR TRAFFIC ST. PROJECT NO.: 452-16-14

DATE: 9/14/73 TIME: Begin 3:45 PM End 4:00 PM

WEATHER: Sky PARTLY CLOUDY Wind 5-10 MPH RECORDER TEMPLET

TOTAL TIME: 15.0 MIN. L_{10}: 66 dBA

(A) NOISE BANDS dBA	INTERVAL TIME MINUTES	CUMULATIVE TIME MINUTES	(C) CUMULATIVE PERCENT
> 72	.8	.8	5.3
70 - 72	.3	1.1	7.3
67 - 70	.2	1.3	8.7
65 - 67	.5	1.8	12.0
62 - 65	.9	2.7	18.0
60 - 62	2.4	5.1	34.0
57 - 60	2.9	8.0	53.3
55 - 57	1.8	9.8	65.3
52 - 55	3.0	12.8	85.3
50 - 52	1.2	14.0	93.3
47 - 50	.8	14.8	98.7
45 - 47	.1	14.9	99.3
45 <	(B) .1		

(D) L_{10} CALCULATIONS

$L_{10} = 65 + \left(\frac{12-10}{12-8.7}\right)2$

$= 65 + \left(\frac{2}{3.3}\right)2$

$= 65 + 1.2$

$= 66$

(A) Enter noise bands from high to low values

(B) Equals total time minus total of interval times

(C) Equals cumulative time divided by total time

(D) Determine L_{10} to nearest decibel by interpolating to ten percentile value in cumulative percent column.

(Use back for additional notes and sketch)

Example of Completed Data Form for Environmental Noise Classifier Method

FIGURE 10

It should be noted that the periodic sampling technique would normally be continued until the error limits were a maximum of plus or minus 3 dB. Since the period of noise measurement was a pre-set time in order that the systems could be effectively compared, the periodic sampling method was not continued to its normal conclusion in all cases.

The graphic recording method of measurement was used as a basis of comparison since it was considered to be the most accurate. The data were compared using a null hypothesis based on the t-test to determine if the differences in noise measurements were statistically significant. It was found that the differences were not significant at the one percent level of significance. (8)

TABLE 1
COMPARISON OF SIMULTANEOUS FIELD NOISE MEASUREMENTS OF THREE MEASUREMENT SYSTEMS

Location	Graphic Recorder	Periodic Sampling		Classifier	
	L_{10} (dBA)	L_{10} (dBA)	Diff.[A]	L_{10} (dBA)	Diff.[A]
1	75	75 (+5,-5)	0	75	0
2	69	67 (+3,-1)	-2	69	0
3	65	67 (+1,-5)	+2	65	0
4	61	61 (+3,-3)	0	61	0
5	71	73 (+3,-3)	+2	73	+2
6	65	67 (+3,-3)	+2	68	+3
7	58	59 (+3,-1)	+1	-	-
8	55	57 (+3,-1)	+2	58	+3
9	70	71 (+3,-5)	+1	73	+3
10	71	75 (+5,-5)	+4	73	+2
11	68	67 (+3,-3)	-1	66	-2
12	69	71 (+5,-5)	+2	69	0
13	68	69 (+1,-3)	+1	69	+1
14	73	73 (+5,-3)	0	74	+1
15	73	75 (+5,-3)	+2	74	+1
		AVERAGE DIFFERENCE	+1.1[B]		+.9[B]

A Difference refers to difference between subject measurement and graphic recorder measurement.

B Average differences were found to be insignificant at the one percent level of significance.

ADVANTAGES AND DISADVANTAGES

In the following paragraphs the three noise measurement systems are compared and the relative advantages and disadvantages are listed.

Graphic Level Recording Method - This method is the most accurate of the three and provides a permanent record of noise level fluctuations. Data analysis is time consuming and increases proportionately with the length of measurement time. It requires the most equipment and an AC power supply and is therefore the least portable of the three.

Periodic Sampling Method - This method is sufficiently accurate for most ambient noise measurement requirements. It requires the least amount of equipment and is the most portable of the three. Data analysis is completed in the field by the operator at the time of the measurement. The length of measurement time is controlled by the statistical requirements of the technique. A skilled operator thoroughly trained in this technique is required.

Environmental Noise Classifier Method - This method is accurate and requires the least operator expertise. Measurement time can vary from a few minutes up to 1000 minutes with no increase in data analysis time. Data analysis is straightforward and simple and requires very little time. The equipment is portable but its portability is limited due to AC power requirements.

CONCLUSIONS AND RECOMMENDATIONS

All three noise measurement systems investigated were found to be useable for ambient noise measurements. Based on the above findings, however, the following recommendations are made.

1. The graphic level recording method should be used only when accuracy is of utmost importance and/or a permanent graphic recording of noise level fluctuations is desired.
2. Either the periodic sampling method or the environmental noise classifier method should be used for routine ambient noise measurements.

TRAFFIC NOISE PREDICTION METHODS

Two basic noise prediction methods were investigated and made operational during the course of this study. They are:

1. NCHRP Report 117 Method(6)
2. Transportation Systems Center (TSC) Noise Predictions Method (7)

Each of these will be discussed in the following paragraphs.

NCHRP REPORT 117 NOISE PREDICTION METHOD

This method is a handbook method developed by the consulting firm of Bolt Beranek and Newman, Incorporated, under contract to the National Cooperative Highway Research Program. It is based on the determination of noise levels for given traffic volumes and speeds under certain ideal conditions. Adjustments are then made to the reference values based on actual roadway geometry, observer distances, shielding, etc.

The following is an outline of some of the basic steps which this method requires. This outline is not complete or sufficiently detailed for use in predictions but is presented merely to provide insight into the effort required to use this method. The reader is referred to NCHRP Report 117 for detailed information on the use of this method.

This method is divided into four main sections:

1. Roadway Element Identification
2. Traffic Parameters Identification
3. Roadway Characteristics and Observer Characteristic Identification
4. Noise Levels Estimation

1. Roadway Element Identification - This involves the break up of a roadway into elements which have constant cross - section and traffic flow characteristics. For each roadway element identified the following must be calculated.

   a. Observer - near lane distance
   b. Element length
   c. Included angle between observer and element.

   It should be pointed out that for each new observer location the observer - near lane distance and included angle must be recalculated.

2. Traffic Parameter Identification - For each of the roadway elements identified the vehicle volume and average speed is required separately for automobiles and trucks.

3. Roadway Characteristics and Observer Characteristics Identification - This involves consideration of the following parameters for each roadway element:

   a. Flow characteristics (interrupted or uninterrupted)
   b. Pavement characteristics (width and number of lanes)
   c. Gradient (percent change in elevation)
   d. Vertical configuration (roadway elevation in relation to ground)
   e. Roadway surface (smoothness)
   f. Position parameter (observer - equivalent lane distance)
   g. Shielding effects (barriers, buildings, other)
   h. Terrain effects (observer elevation relative to ground)

   A number of these parameters must also be recalculated for each new observer location.

4. Noise Levels Estimation - This involves the estimation of noise levels at the observer due to the proposed highway using the data previously gathered. Reference noise levels are determined. Appropriate adjustments based on the data and charts and tables in the handbook are then made to the reference noise levels to arrive at an estimation of noise levels contributed by each element. The contribution of each element is then totaled to arrive at the predicted noise level due to the proposed highway.

The Michigan Department of State Highways has developed a computerized version of the NCHRP Report 117 handbook method. All data must be manually calculated as outlined above. The computer program calculates the reference noise levels, all necessary adjustments and sums the noise level contributions from each element to provide the total predicted noise level.

TSC NOISE PREDICTION METHOD

This method is a computer program made operational by the Transportation Systems Center of the Federal Highway Administration. All pertinent traffic, roadway geometrics, shielding and other data are programmed into the computer and the L_{10} among other noise descriptors is outputed.

A brief description of the data information required is presented in the following paragraphs. For a detailed description and users manual the reader is referred to Report No. DOT-TSC-FHWA-72-2, Manual for Highway Noise Predictions.

Information is programmed with up to five blocks of data. The data blocks provide information describing the following:

1. Program initialization parameters
2. Road and vehicle parameters
3. Barrier parameters
4. Ground cover parameters
5. Receiver parameters

1. Program Initialization Parameters - Under most conditions these parameters will be the same for each problem. It includes such information as standard deviations of noise levels for cars and trucks, source heights for cars and trucks, number of frequency bands, receiver heights and a provision for the inclusion of information as a "new vehicle."
2. Road and Vehicle Parameters - The roadways and vehicular traffic on each roadway is described in this data block. Each roadway section is defined by Cartesian coordinates in the x, y and z planes. The volume and speed of both cars and trucks is also specified for each roadway section.

3. Barrier Parameters - Information concerning barriers or obstacles in the path of sound propagation is entered in this data block. The location of the barrier is specified in the same format as the end points of the roadway section. The barriers can be described as either a reflecting or an absorbing barrier.
4. Ground Cover Parameters - Absorptive ground strip data is entered in this data block. The centerline of the ground cover is described with x, y and z coordinates and the width of the cover is also entered. It can be identified as either grass and shrubbery or trees.
5. Receiver Data - Receiver locations are indicated by x, y and z coordinates.

Generally a grid is drawn on plan and profile sheets of the subject project. The x, y and z coordinate data for the various parameters can then be easily determined. The number of receiver locations has no effect on the time and effort required using this method.

The TSC computer program was also used to develop a simple nomograph for the approximate prediction of traffic noise levels. Data input consists of vehicle volume, truck percentage, vehicle speed and receiver - roadway distance. It is a very simplified approach for ideal conditions and is intended for preliminary estimates only. The nomograph and a detailed description of its use can be found in Report No. DOT-TSC-FHWA-72-2, Manual for Highway Noise Predictions.

PREDICTED VERSUS MEASURED NOISE LEVELS

Noise levels were predicted using the NCHRP Report 117 and TSC methods at a few locations and compared to actual field measurements. Traffic volume counts were conducted at all locations. Speeds were measured at one location and estimated at all other locations. A comparison of the noise level predictions and measurements are shown in Table 2.

TABLE 2

COMPARISON OF PREDICTED AND ACTUAL NOISE LEVELS AT SELECTED SITES

Site	Distance	Measured dBA	TSC dBA	TSC Diff.	NCHRP 117 dBA	NCHRP 117 Diff.
1	50'	77.1	80.3	+3.2	79.0	+1.9
	100'	74.7	78.7	+4.0	74.9	+ .2
	200'	71.3	76.5	+5.2	69.6	-1.7
2	50'	71.4	76.7	+5.3	74.4	+3.0
	100'	65.4	75.0	+9.6	71.1	+5.7
	200'	58.4	67.9	+9.5	60.0	+1.6
	400'	55.4	67.6	+12.2	57.1	+1.7
3	50'	74.6	79.4	+4.8	76.7	+2.1
	100'	68.5	75.8	+7.3	70.7	+2.2
	200'	64.8	73.7	+8.9	66.4	+1.6
	400'	60.6	70.9	+10.3	60.6	0
4	50'	75.5	80.1	+4.6	78.5	+3.0
	100'	72.0	77.8	+5.8	73.5	+1.5
	200'	68.4	75.0	+6.6	68.4	0
	400'	59.5	70.8	+11.3	61.5	+2.0

The comparisons shown in Table 2 is not purported to be a comprehensive evaluation of the accuracy of the two noise predictive methods. It does provide some indication, however, of the relative accuracy of the two methods. Although the NCHRP 117 method generally over-predicted noise levels, the TSC method over-predicted consistently and by a much greater margin. This indicates that the TSC method should be used with caution until further correlation work is available.

ADVANTAGES AND DISADVANTAGES

During the course of this study certain advantages and disadvantages of each noise prediction method became apparent. These are summarized below:

1. The NCHRP Report 117 method was found to be very simple and easy to use under most conditions experienced. However, as roadway geometrics became more complex and the number of observer locations increased, the computations required incresed tremendously. New

observer roadway element distances and included angles among other parameters must be calculated for each individual element for each observer location. The Michigan computer program did not aid in this respect since they still must be calculated manually for input data.

2. The TSC computer program was also found to be fairly easy to use under most situations. Complex geometrics could be handled without a large increase in data preparation time. Preparation time was also independent of the number of observer locations. Because of this, this method appears especially suited to the noise level predictions when complex geometrics such as interchanges are involved.
3. The TSC nomograph method is very easy to use. It is useful as a preliminary estimate of noise levels.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the above findings the following recommendations are made:

1. The NCHRP Report 117 handbook method of noise level predictions should be the basic method used for all noise level predictions. At certain locations, having complex geometrics and requiring numerous observer locations, this method may become impractical, however.
2. The TSC noise prediction program should be used only at those locations, described above, where the use of the NCHRP Report 117 method is impractical. In these situations this method is much more efficient in regards to user time. The user should be aware, however, that it may tend to considerably over-predict noise levels.
3. The use of the Michigan NCHRP Report 117 computer program does not appear to be a great aid since the manual calculation of input data is still required. It should be used in special circumstances only.
4. The TSC nomograph method should be used only for a preliminary estimate of noise levels. It should never be used where accurate predictions are required.

SUMMARY OF STUDY CONCLUSIONS AND RECOMMENDATIONS

This study was directed toward two areas of highway noise analysis. They were:

1. Noise Measurement Systems
2. Traffic Noise Prediction Methods

A summary of the findings and recommendations of each of these are as follows:

Noise Measurement Systems

1. Each of the three noise measurement systems investigated was found to be usable for environmental noise measurements.
2. Due to the considerable time required for data analysis, the graphic level recording method should be used only when accuracy is of upmost importance and/or a permanent graphic recording of noise level fluctuations is desired.
3. Either the periodic sampling method or the environmental noise classifier method should be used for routine ambient noise measurements.

Traffic Noise Prediction Methods

1. The NCHRP Report 117 handbook method should be the basic method used for all noise level predictions. At certain locations having complex geometrics and requiring numerous observer locations, this method may become impractical, however.
2. The TSC noise prediction program should be used only at those locations, described above, where the use of the NCHRP Report 117 method is impractical. In these situations this method is much more efficient in regards to user time. The user should be aware, however, that it may tend to considerably over predict noise levels.
3. The use of the Michigan NCHRP Report 117 computer program does not appear to be a great aid since the manual calculation of input data is still required. It should be used in special circumstances only.
4. The TSC nomograph method should be used only for a preliminary estimate of noise levels. It should never be used where accurate predictions are required.

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APPENDIX A

CALIBRATION OF NOISE MEASUREMENT EQUIPMENT

CALIBRATION PROCEDURE FOR NOISE MEASUREMENT EQUIPMENT

Calibration procedures are described for the following equipment used in traffic noise level measurements:

1. General Radio Type 1551-C Sound Level Meter
2. General Radio Type 1521-B Graphic Level Recorder
3. B & K Model 166-S45 Environmental Noise Classifier

General Radio Type 1551-C Sound Level Meter (SLM)

Before going into the field:

1. Test SLM batteries

   Raise the microphone to turn SLM on. Switch to each of the battery test positions, FIL 1, 2 and PL. Good batteries will read above the center of the white band marked BAT on the meter.

2. Calibrate electrically

   This is an internal calibration of the meter. The weighting switch is rotated to CAL. The base selector switch is rotated to CAL. The meter should then rest in the white band of the meter marked CAL. The CAL button is used to adjust the meter if needed.

3. Calibrate acoustically

   Set the base selector switch to 110 and the weighting switch to the C scale. Check the acoustical calibrator battery then switch to 500 Hz. The calibrator supplies 114 dBC. Place the calibrator on the microphone. Rotate the CAL control so that a 114 dBC reading is obtained. Switch the weighting switch to the A scale. The meter should read 111 dBA within plus or minus 0.5 dBA. This completes the calibration procedure. The 500 Hz setting is the most accurate factory setting of the calibrator. Only the General Radio Type 1562-A calibrator should be used.

Field procedure

Before each measurement in the field step 3 as described above is repeated. It should be remembered that field measurements are made with the A weighting network. Under most conditions the slow meter response will be used.

General Radio Type 1521-B Graphic Level Recorder

Since the recorder and SLM are used simultaneously they must be calibrated simultaneously. The SLM should be checked as described above before going into the field. Once in the field the following procedure is followed:

1. With the SLM and recorder both turned off, the recorder is plugged into a 115 volt AC power source.
2. The output of the SLM is connected to the input of the recorder by a coaxial cable. The ground of the coaxial cable goes to the black terminal and the center lead goes to the red terminal.
3. The INPUT ATTENUATOR on the recorder is set to 30 and the WRITING SPEED to 10.
4. A pen is inserted in the recorder and the power switch is turned on. The SLM is also turned on. Acoustically calibrate the meter at 500 Hz and 114 dBC. The recorder pen should land four lines to the left of center. Adjust pen position with the CAL button on the recorder. Switch to A scale on the SLM. The recorder should now be one line to the left of center (111 dBA). The recorder is now calibrated. From here on, the base range selected on the SLM will become the centerline of the chart. If the SLM base range is set to 70 dBA the center of the chart will be 70 dBA and the recorder will have a range of 50 to 90 dBA (20 divisions either side of center). Always mark the base range selection on the chart. If the range is changed the chart should be stopped and the change noted.
5. For accurate L_{10} noise level determinations a chart speed of 15 in/min is normally used.

B & K Model 166-S45 Environmental Noise Classifier

1. In preparation for calibration the following control settings are used:
   a. Reset all counters to 000.0
   b. Set input to MIC
   c. Set filter to A
   d. Switch meter to on
   e. Set base level to 65 CAL
   f. Leave power OFF

2. Connect microphone to classifier. The microphone can be mounted on a gooseneck which screws into the top of the unit or it can be located remote from the unit and connected by a coaxial cable.
3. Turn power switch ON. If some counters actuate reset them to zero.
4. With the control settings as described above, place the calibrator (B & K Model 4230) on the microphone (B & K Model 4117). Actuate the calibrator. The meter on the classifier should deflect. Turn the "K" factor adjustment with a screwdriver to increase or decrease the meter reading until it corresponds to the calibration level of the calibrator. The calibration value is located in the top cover of the calibrator. The unit is now calibrated.
5. Before beginning measurements switch meter to OFF, select proper base level and reset all counters.

APPENDIX B

DATA SHEETS FOR PERIODIC SAMPLING AND ENVIRONMENTAL NOISE CLASSIFIER METHODS OF AMBIENT NOISE MEASUREMENTS

PERIODIC SAMPLING

AMBIENT NOISE DATA SHEET

LOCATION: ____________________ PROJECT NO. ____________________

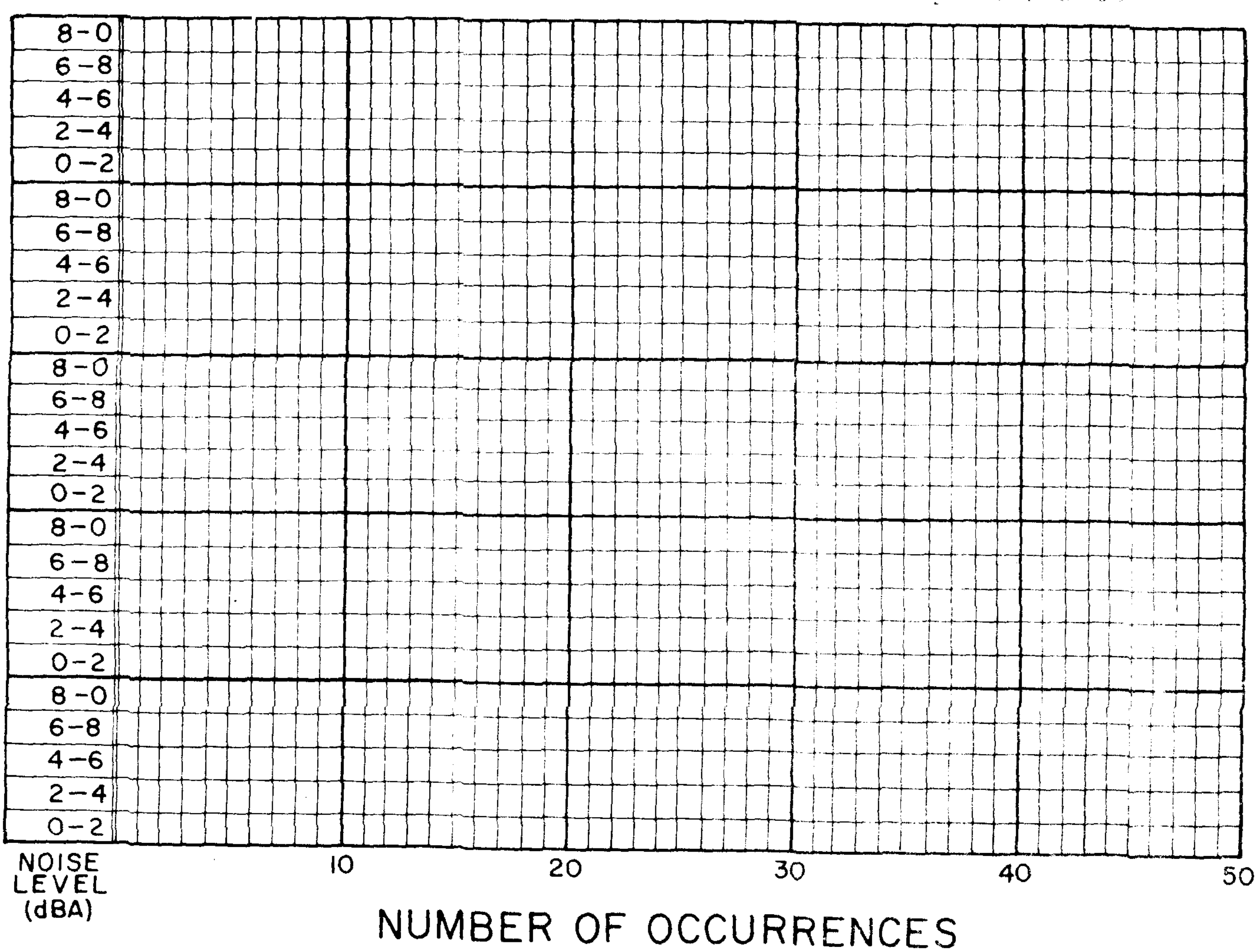
DATE: __________ TIME: Begin __________ End __________

WEATHER: Sky __________ Wind __________ RECORDER: __________

L_{10}: __________

Total # Samples	Upper Limit	L_{10}	Lower Limit
50	1st	5th	10th
100	5th	10th	17th
150	8th	15th	23rd
200	12th	20th	29th
250	16th	25th	35th
300	20th	30th	41st
350	25th	35th	47th

sample from the top



ENVIRONMENTAL NOISE CLASSIFIER

AMBIENT NOISE DATA SHEET

LOCATION: ______________________ PROJECT NO.: ______________

DATE: ____________ TIME: Begin ______________ End ____________

WEATHER: Sky ______________ Wind ____________ RECORDER ____________

TOTAL TIME: ________________ L_{10}: ________________

(A) NOISE BANDS dBA	INTERVAL TIME MINUTES	CUMULATIVE TIME MINUTES	(C) CUMULATIVE PERCENT
>			
-			
-			
-			
-			
-			
-			
-			
-			
-			
-			
-			
<	(B)		

(D) L_{10} CALCULATIONS

(A) Enter noise bands from high to low values

(B) Equals total time minus total of interval times

(C) Equals cumulative time divided by total time

(D) Determine L_{10} to nearest decibel by interpolating to ten percentile value in cumulative percent column.

(Use back for additional notes and sketch)

APPENDIX C

SITE DESCRIPTION OF LOCATIONS USED FOR MEASURED VERSUS PREDICTED NOISE LEVEL COMPARISONS

SITE	LOCATION	DESCRIPTION
1	I-10 near Turnbull Street in Metairie, Jefferson Parish	6-lane urban freeway with 60 foot median
2	La. 1, one mile south of Plaquemine, Iberville Parish	2-lane rural roadway
3	La. 1, four miles south of Port Allen, West Baton Rouge Parish	4-lane rural roadway with 45 foot median
4	U.S. 61, 1.6 miles south of La. 73, East Baton Rouge Parish	4-lane rural roadway with 43 foot median

NOTE: All locations were at grade with no curvature or barriers.