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DETERMINATION of TRUCK NOISE LEVELS FOR NEW JERSEY

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SUMMARY AND CONCLUSIONS

The New Jersey Department of Transportation (NJDOT) is required by federal standards to predict traffic noise levels for all proposed federal-aid highway construction projects. NJDOT has been using the MOD-04 version of the Transportation Systems Center (TSC) Computer Program [1]* to make these predictions. In this program, the reference noise levels for trucks represent an average of the truck noise levels measured in the states of Florida, Colorado, North Carolina, and Washington as part of a four state inventory. These noise levels were measured for trucks operating at cruise conditions on flat roadways at speeds of between 50 and 100 kilometers per hour (31.2 and 62.5 mi/hr). The inventory showed significant differences in the truck noise levels measured in the various states. Thus, there is some inherent inaccuracy when these average reference levels are applied to New Jersey's trucks or to any trucks operating at non-cruise conditions on upgrade and downgrade roadways or ramps.

The objective of this study is to improve the accuracy of the TSC MOD-04 prediction method by determining the reference noise emission levels of New Jersey's trucks on various types of roadways. This objective was achieved as follows: (1) the noise levels produced by trucks travelling New Jersey highways were measured, (2) from analysis of these noise levels trucks were grouped into two classes, (3) the average noise emission levels and noise spectra for these classes were determined for various types of roadways, and (4) these levels were used as input to the TSC program and changes which occurred in predicted noise levels were noted in this report.

*Reference number in brackets

This report covers work performed between May 1977 and June 1979. It deals primarily with the analysis of truck noise data and the findings of this study. But in addition, material from the first interim report, which dealt with the selection of measurement sites and the development of a measurement methodology and data reduction procedure, is presented in the Appendix.

The project was conducted in the following manner.

A measurement methodology was developed which permitted the accurate measurement of the noise produced from the pass-by of an individual truck at a distance of 50 feet (15.2m). Each truck was acoustically isolated in the field by specifying a minimum allowable distance between it and nearby vehicles. Isolation was verified in the lab by checking for a 6 dB rise and fall of the target truck's sound level about its peak level. Noise measurements were taken for 13 classes of trucks which ranged in size from two axle, dual rear wheeled, single unit body trucks to six axle tractor - semitrailer combinations. Two axle dual rear wheeled buses and three axle buses were considered as trucks in terms of noise and were included as two of these 13 classifications.

Representative noise measurement sites were selected. These sites were located adjacent to controlled access and non-controlled access highways with flat ($\leq$ 2% grade), upgrade (> 2% grade) and downgrade (> 2% grade) roadway sections and several sites adjacent to different types of ramps. Physical site criteria were established in order to minimize measurement errors due to acoustic reflections.

Data acquisition resulted in a total of nearly 5,000 measurements of the noise emission levels of individual trucks. Measurements were made at 37 sites. The information collected in the field consisted of tape recordings of truck noise and truck description, speed and weather measurements, and site descriptions.

The tape recorded truck noise data was reduced in the lab to obtain a peak A-weighted noise level and corresponding frequency spectrum (63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz octave bands) for each truck through the use of a 1/3 octave real time analyzer and a graphic level recorder. After eliminating invalid measurements, noise data for 4,536 trucks was inputted to a computer file for analysis.

The noise data on file was analyzed to determine the truck classifications required to represent New Jersey's (N.J.'s) truck population in terms of noise and the reference noise emission levels for these classifications. It was found that the noise generated by this population can be accurately described by the consideration of trucks as two classes - Type 1, medium trucks and buses; Type 2, heavy trucks - with their respective reference noise emission levels. To determine equations which would predict noise emission levels for these two classes, emission levels were regressed versus truck speed in miles per hour. A linear equation in the logarithm of speed was found to be satisfactory. Noise emission levels were found to be correlated with truck speed though the correlation was not very strong.

Truck noise emission levels predicted by the equations were compared for the various roadway types along which measurements were taken. Because of the variations in predicted emission levels which were observed between level, upgrade, and downgrade roadways and between non-controlled and controlled access roadways, separate noise emission levels were specified for each of these six roadway types. Ramps were examined by themselves. From the limited data collected, the variation in emission levels for ramps was found to be best explained by truck operating condition. Thus, emission levels for ramps were specified in terms of equations for accelerating and non-accelerating trucks.

In this report, equations which predict noise emission levels for the two truck types are presented for each of the roadway types investigated. Both energy mean and arithmetic mean emission levels are given for overall truck noise. Emission level equations for individual octave bands are also presented.

Examination of the levels specified by the prediction equations revealed many trends. A few are mentioned below.

With regard to all of the roadway types excluding ramps:

- For normal speeds, 30-60 mi/hr (48-96 Km/hr), the difference in overall energy mean emission level between the two truck classes was usually 3-4 decibels (heavy trucks were louder).
- For speeds of 35-50 miles per hour (56-80 Km/hr), upgrade roadways had the highest overall emission levels; level roadways, the next highest; and downgrade roadways, the lowest.
- For a speed of 55 miles per hour (88 Km/hr), the emission levels for all roadway types varied by less than 3 dB.
- The respective differences between the emission levels for the various roadway types usually increased with a decrease in speed.

- Overall emission levels were less dependent on speed for upgrade roadways than for level or downgrade roadways.
- For most roadway types, emission levels for medium trucks and buses were more speed dependent than those for heavy trucks.

With regard to overall emission levels for ramps:

- At typical speeds (20-30 mi/hr, 32-48 Km/hr), the emission level for accelerating trucks was higher than that for non-accelerating trucks though only by about 2 decibels.
- At typical speeds, the overall energy mean emission levels for heavy trucks were generally 4-6 dB higher than those for medium trucks and buses.

With regard to octave band emission levels for all of the roadway types excluding ramps:

- The highest levels usually occurred for the 500 and 1000 Hz octave bands.
- In general, the 63, 125, and 250 Hz octave band levels were less speed dependent than the levels for octave bands of 500 Hz and higher.
- At 50 mi/hr (80 km/hr), the 250 Hz octave band contributed slightly more to the overall level of medium trucks and buses than it did to the overall level of heavy trucks. At 50 mi/hr (80 km/hr), for upgrade roadways the 250 Hz octave band in general contributed more to overall truck noise levels than for downgrade or level roadways.

With regard to octave band emission levels for ramps:

- In general the 125 and 250 Hz octave band levels were higher relative to the other octave bands than they were for the other roadway types. In fact, for typical speeds (20-30 mi/hr, 32-48 km/hr), the 250 Hz octave band had, in some instances, the highest level of all octave bands.

When N.J.'s truck emission levels for level roadways were compared to those contained in the FHWA noise prediction method [2], the following result was obtained. For controlled access level roadways, N.J.'s energy mean emission levels for trucks were 1-2.5 dB higher than the FHWA's levels. For non-controlled access level roadways, N.J.'s energy mean emission levels for trucks usually varied by less than a decibel from the FHWA's levels. When a comparison was made between the FHWA's truck emission levels (for level roadways) and N.J.'s truck emission levels for upgrade and downgrade roadways and ramps, the following differences were noted. For upgrade roadways (controlled and non-controlled), N.J.'s emission levels for trucks were 2-5 dB higher than the FHWA's levels for typical speeds of 35-50 mi/hr (56-80 km/hr). For downgrade roadways (controlled and non-controlled), N.J.'s energy mean emission levels for trucks usually varied by less than a decibel from the FHWA's levels for speeds of 40-60 mi/hr (64-96 km/hr). For ramps, N.J.'s energy mean emission levels for trucks were generally higher than the FHWA's levels (2.5-6.0 dB at 25 mi/hr (40 km/hr).

A statistical evaluation of N.J.'s noise data indicated that for a given truck type and roadway type there was considerable variation in noise emission levels - as much as 10 dB for certain speeds. At best 20% of this variation was explained by the relation of emission level to truck speed.

The unexplained variation is apparently due in part to other factors which affect truck noise such as type and condition of tires, engine, and muffler, etc. Some of the variation is no doubt the result of combining individual truck classes into a general truck type. Normality of the noise data was examined, and for most cases truck emission levels were found to be nearly normally distributed.

In summary, for New Jersey's highways, the noise prediction accuracy of the TSC method should be improved by utilizing truck emission levels developed from direct measurement of N.J. trucks rather than national average truck emission levels. In terms of noise, N.J. trucks can be represented by two truck classes (medium trucks and buses,and heavy trucks) with their respective noise emission levels defined for the type of roadway on which they are travelling. Because New Jersey's truck noise emission levels are, for most roadway types, higher than the FHWA's national average truck noise levels, the use of New Jersey's truck levels with the TSC MOD-04 prediction method will in general result in higher predicted noise levels.

RECOMMENDATIONS

It is recommended that the reference truck noise emission levels which were determined for this study be used to make highway noise predictions within New Jersey. It is suggested that presently this be accomplished by incorporating these reference levels into the TSC MOD-04 highway noise prediction computer program. At a later date, it may be desirable to utilize these reference levels with the computerized version (STAMINA) of the FHWA Highway Traffic Noise Prediction Model. If noise predictions are made based on the reference levels provided by this study, then predictions for truck speeds outside the range of speeds for which the reference level prediction equations were developed (given on page 135), should be made with caution.

It is further recommended that additional research be conducted in regard to truck emission levels on interchange ramps for the purpose of determining more accurate levels than those presented in this report. Because of the large variation in ramp site characteristics, study of truck emission levels for ramps is made more difficult. A larger data base than thus far obtained for this study is required in order to obtain more meaningful results. Considerable variation exists in the geometrical design of ramps and in the grades encountered on ramps. In addition, diverse modes of truck operation occur; for example, in some instances, individual trucks will accelerate and decelerate at different points on the same ramp. These factors all complicate the nature of truck emission levels for ramps and they require further study.

INTRODUCTION

Background

On all proposed federal-aid highway construction projects, NJDOT conforms to federal noise standards contained in The Federal-Aid Highway Program Manual, Volume 7, Chapter 7, Section 3, "Procedures for Abatement of Highway Traffic Noise and Construction Noise" (FHPM 7-7-3)[3]. These standards require that future traffic noise levels adjacent to a proposed highway or highway improvement be predicted. These predicted levels are utilized in assessing the expected environmental noise impact of the proposed highway. If future levels will exceed the design noise levels in the federal noise standards, NJDOT is also required to consider noise abatement measures such as traffic noise barriers.

NJDOT uses the MOD-04 version of the Transportation Systems Center (TSC) Predictor Program to predict traffic noise. This computer program is approved by the Federal Highway Administration (FHWA) as described in FHPM 7-7-3.

Statement of the Problem

Noise levels predicted by the TSC MOD-04 program are not as accurate as required. Some inaccuracy occurs because of the nature of the reference truck noise emission levels which are contained in the program. These reference levels are national averages based on truck noise measurements made in the states of Florida, Colorado, North Carolina, and Washington as part of a four state noise inventory [4] conducted in conjunction with the Federal Highway Administration.

One source of prediction inaccuracy is pointed out by the results of this four state inventory which indicated that because of regional trends in vehicle types, truck reference levels were significantly different between states. Consequently, if national average reference levels for trucks are used for noise prediction in New Jersey, an overprediction or underprediction of noise levels can be expected.

Additional prediction inaccuracy is due to the fact that the national average reference levels were developed from noise measurements taken for trucks operating at cruise conditions on flat roadways at speeds between 50 and 100 kilometers per hour (31.2 and 62.5 mi/hr). Accordingly, inaccurate predicted levels can be expected when TSC MOD-04 is used for situations involving non-cruise conditions or speeds below 50 km/hr (31.2 mi/hr). These types of situations can occur on upgrade or downgrade roadways and on ramps.

Thus, it is possible that predicted future noise levels may exceed design noise levels due to an overprediction which occurs for the reasons mentioned. In these cases, unwarranted and costly consideration of noise abatement measures -- and even possible implementation of these measures -- may occur.

Objective

The objective of this study is to more accurately predict noise levels when using the TSC MOD-04 prediction program by determining the reference noise emission levels of New Jersey's trucks on various types of roadways.

Reference levels will be determined from direct measurement of the pass-by noise of individual trucks as they travel on flat, upgrade, and downgrade roadways and on ramps.

Based on the noise measurements obtained for many types of trucks, several general truck classes will be established to represent all trucks. This will be done for the purpose of simplifying the noise prediction process. Reference noise emission levels will be specified for these general truck classes. TSC MOD-04 will be modified to utilize New Jersey's truck reference levels rather than the national average truck reference levels presently contained in the program.

Scope of the Project

The scope of the project includes measurements of the peak noise levels of all types of trucks having three or more axles as well as for two axle trucks with dual rear tires. This corresponds roughly to measuring the noise levels produced by trucks having gross vehicle weight ratings of over 10,000 pounds (4536 kg). It also includes noise level measurements for buses with three or more axles and two axle buses with dual rear wheels.*

The noise levels of trucks on the following types of roadways were measured:

1. Highways with control of access (roadways of grade less than or equal to 2%).
2. Highways with control of access (roadways of greater than 2% upgrade).

*With regard to noise, buses can be viewed as light and medium weight trucks.

3. Highways with control of access (roadways of greater than 2% downgrade).

4. Highways with non-controlled access (roadways of grade less than or equal to 2%).

5. Highways with non-controlled access (roadways of greater than 2% upgrade).

6. Highways with non-controlled access (roadways of greater than 2% downgrade).

7. Ramps.

The project was divided into the work tasks which follow.

Task 1. Development of Measurement Methodology - A methodology was developed which assured that accurate measurements were taken of the peak A-weighted noise levels of individual trucks passing the microphone position.

Task 2. Selection of Measurement Sites - Criteria for selecting of sites were established. Measurement sites were selected so that they were representative of New Jersey highways. In addition, to assure accurate measurement, criteria which specify a site's physical environment were chosen. Several sites were selected for each of the roadway types mentioned.

Task 3. Data Acquisition - Using the measurement methodology developed in Task 1, truck noise was tape recorded at the sites selected. Corresponding speed measurements and other pertinent data were also taken.

Task 4. Data Reduction and Analysis - The tape recorded truck noise data was reduced in the laboratory to obtain a peak A-weighted noise level and frequency spectrum for each truck pass-by.

The reduced data was then analyzed, and the overall peak A-weighted noise level, the peak level standard deviation, and the octave frequency spectrum for each truck classification and roadway type were determined.

Task 5. Reports - An interim report (NJDOT Report No. 78-008-7791) [5] was completed in May 1978. It covered work done on this project from September 1976 to May 1977; namely, the development of a measurement methodology (truck classifications, field procedures, valid measurements, and equipment), the development of site criteria, the selection of measurement sites, and the establishment of a data reduction methodology (procedures and equipment).

MEASUREMENT METHODOLOGY

This section contains a summary of the measurement methodology presented in the first interim report. Any changes made in the original methodology are noted in this section. A more detailed discussion is presented in Appendix A, pages 147-165.

As mentioned, a measurement methodology was developed which insured the accurate measurement (at a distance of 50 feet (15.2m) from the center of the lane of travel) of the peak A-weighted noise level and frequency spectrum produced by the pass-by of an individual truck.

Development of the measurement methodology began with deciding what vehicles would be considered as trucks. Since the noise produced by a large group of trucks was to be measured, a system for classifying the trucks was established. Next, to insure that the noise level which was measured was that produced by an individual truck and not significantly affected by the noise of other highway vehicles, a criteria for accepting a noise level measurement as valid was established. Then, the procedure for conducting noise measurements in the field was developed and the noise measurement equipment which would be used was selected. Finally, the sample size (the number of individual truck noise level measurements) which was required to accurately estimate the average peak noise level of the population of trucks of a particular classification was determined using statistical methods.

Truck Classifications

Noise measurements were taken for two axle trucks with dual rear wheels, three, four, five, and six axle trucks, two and three axle truck tractors, and two and three axle buses. These types of "trucks" are illustrated in Figure 1, page 16, and form truck classifications 1 to 13. For this study, vehicles in Classes A & B of Figure 1 were not considered as trucks in keeping with the truck definition contained in the federal noise standards (Reference 1). The thirteen "truck" classifications considered in this study are listed below. Corresponding codes are in parentheses.

(1) Two axle trucks with dual rear wheels (2/6)

(2) Two axle, dual rear wheeled truck tractors without semitrailers (2T)

(3) Three axle truck tractors without semitrailers (3T)

(4) Two axle buses with dual rear wheels (2B)

(5) Three axle buses (3B)

(6) Three axle, single unit body trucks (3)

(7) Four axle, single unit body trucks (4)

(8) Trucks with two axle tractors and one axle semitrailers (2-1)

(9) Trucks with two axle tractors and two axle semitrailers (2-2)

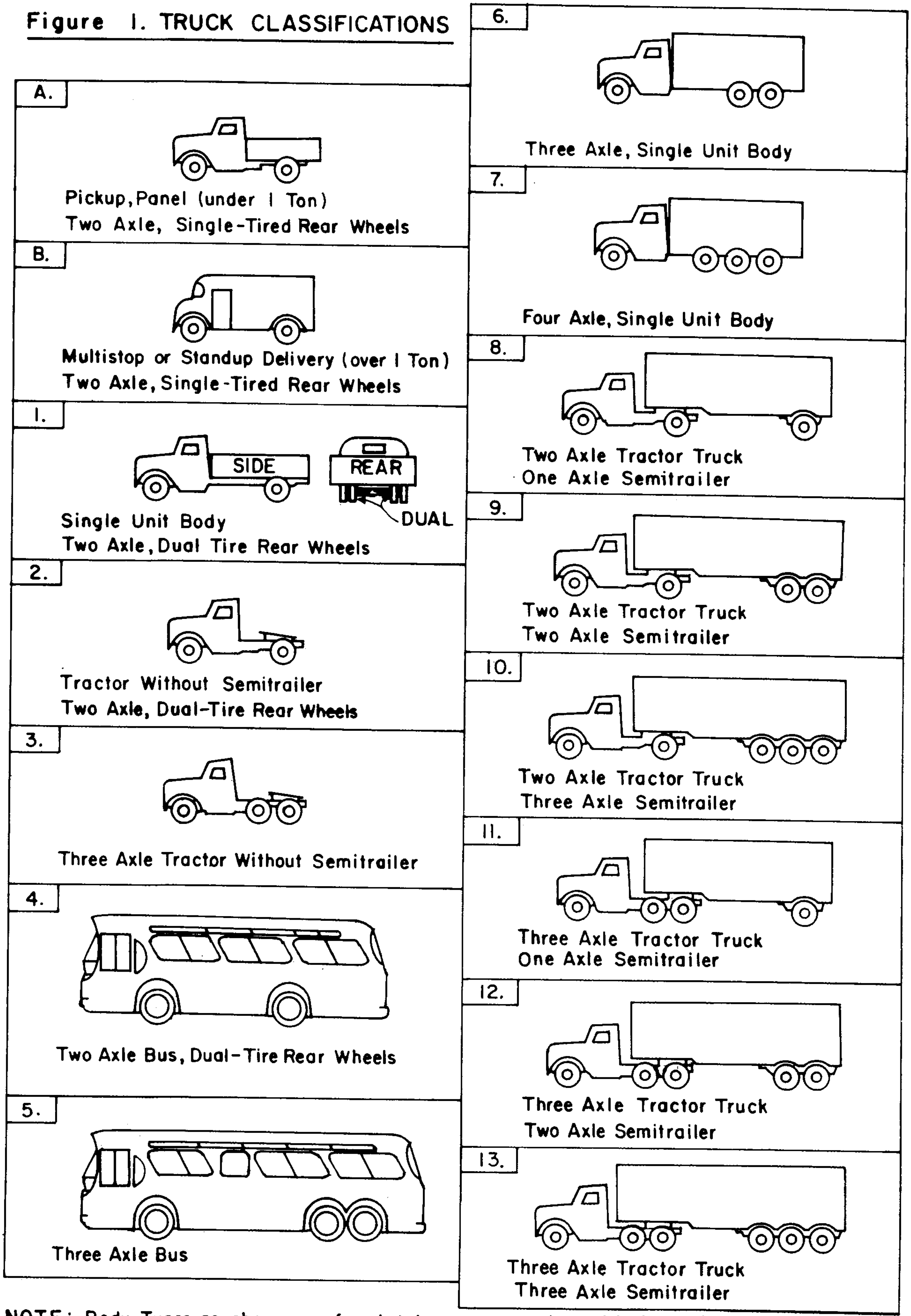
(10) Trucks with two axle tractors and three axle semitrailers (2-3)

(11) Trucks with three axle tractors and one axle semitrailers (3-1)

(12) Trucks with three axle tractors and two axle semitrailers (3-2)

(13) Trucks with three axle tractors and three axle semitrailers (3-3)

Figure 1. TRUCK CLASSIFICATIONS



NOTE: Body Types as shown are for sketch purposes only, and it is not intended to imply that they are the only body types encountered in these classifications.

A Valid Measurement

In order to obtain an accurate measurement of the noise produced by an individual truck, that truck must be isolated from other highway traffic. This isolation is necessary because the noise produced by highway vehicles is summed at an observer. In other words, if an individual truck was not isolated at the time of measurement, the noise due solely to this individual truck could not be separated from the noise due to other highway vehicles.

With this in mind, the following vehicle spacing requirements were established for field use. The noise produced from the pass-by of an individual target truck was tape recorded if the target truck was at least 100 ft. (30.5m) away from passenger cars and 250 ft. (76.2m) away from other trucks.

The use of this vehicle spacing insured some degree of isolation but a final, more accurate check for isolation was done in the laboratory when tape recorded truck pass-by noise was reduced. The valid measurement criterion (check for isolation) was as follows:

> A truck pass-by noise measurement was considered valid if the total sound level (as observed on a graphic level recorder trace) rose and fell at least 6dB about the peak level.

This rather technical criterion is explained in detail in Appendix A, pages 151-157. Establishment of this criterion insured that the measurement of a truck's peak noise level was accurate to within approximately 0.5 dB. If the recording of a truck's pass-by noise did not meet this valid measurement criterion, the peak noise level was assumed to be inaccurate and was not included in further analysis.

Data Collection Procedures

Data collection procedures for use in the field were established for the purpose of conducting noise level measurements and obtaining corresponding speed information and weather information.

The noise data collection procedure takes into consideration the vehicle spacing requirements which were established to insure individual truck isolation. It provides for the collection of accurate peak A-weighted noise levels, and corresponding frequency and truck description information. The noise produced by an individual truck pass-by and a description of each truck were tape recorded while in the field and later played back and reduced in the laboratory.

A detailed noise recording procedure is included in Appendix A, pages 158-161. The only change made to this procedure, since its presentation in the interim report, by virtue of field experience, was to record the noise produced by a truck pass-by on Channel 1 and the voice description on Channel 2 of the tape recorder. This change was made near the end of the data collection phase of this project due to a minor problem with tape-head contact which occasionally occurred on Channel 2.

Speed information for each truck for which a noise measurement was made was collected in order to establish if a relationship existed between speed and noise level. Meteorological data was collected because it was known that noise levels can be affected by certain atmospheric conditions. Details of the speed and meteorological data collection procedures are included in Appendix A, pages 161 and 162.

For a listing of the data collection equipment and a description of each piece see Appendix B, pages 166-170.

Sample Size

The truck noise levels obtained for this study are represented as being typical of the New Jersey truck population in general. Thus, noise level information about the entire truck population is inferred from a random sample of limited size. Statistical methods specify the random sample size required in order that a statistic from the sample can be applied, with a particular degree of confidence, to the population in general.

To estimate the population mean peak noise level of any of the specific truck classes listed on page 15 to a precision of $\pm$ 1 decibel (confidence interval = sample mean $\pm$ 1 dB), statistical methods indicated that a sample of 62 peak noise level measurements were required.* The 62 measurements include trucks of various highway speeds. (See Appendix A, pages 162 - 165, for a more detailed discussion of sample size determination.)

This sample size was only exceeded for several of the specific truck classes - notably, Classes 1, 6, 9, and 12 - since the trucks in some classes make up a very small part of the New Jersey truck population. Thus, estimates of the population mean peak noise levels of some of the specific truck classes were not as precise as $\pm$ 1 decibel.

In order to simplify the noise prediction process, it was decided to combine the 13 specific truck classes outlined on page 15 into several more useful, general groups. The statistics which were used for this

* A population standard deviation of 4.0 was assumed to obtain a worst case estimate.

purpose were the sample mean peak noise levels for the specific classes. Mean peak noise levels were compared and truck classes were grouped together if there was no significant statistical difference.

Since a 62 measurement sample was not obtained for most of the 13 specific truck classes, a statistical test which was valid for unequal sample sizes was used for the comparison. The test employed the Student t distribution to compare means of two independent samples.

After the specific truck classes were regrouped into general truck classes, the sample sizes for the general classes for Roadway Types 1 - 6 were quite large and exceeded the sample size required for estimating the population mean noise level to ± 1 decibel precision. However, for one of the general classes for Roadway Type 7 (Ramps), only 40 peak noise level measurements were obtained with a standard deviation of 4.1; thus ± 1 decibel precision was not achieved for the estimate of the population mean peak noise level for this class.

Because of the relationship which was found to exist between truck speed and peak noise level, results for this study are also presented in terms of regressions of peak noise level versus speed. The regressions were developed using all of the data in a general class.

SELECTION OF MEASUREMENT SITES

This section is a summary of the information on site selection presented in the first interim report. Any changes made in site selection are described here. A detailed description of the site selection process and physical site criteria, and a list of the measurement sites are included in Appendices C & D, pages 171-187.

Roadway Types

Measurement sites were selected for controlled and non-controlled access highways along roadway sections of less than or equal to 2% grade, greater than 2% upgrade, and greater than 2% downgrade. Sites were also selected alongside several types of ramps. The seven roadway types considered in this study are outlined below.

Roadway Type

(1) Controlled access ($\leq$ 2% grade)

(2) Controlled access (> 2% upgrade)

(3) Controlled access (> 2% downgrade)

(4) Non-controlled access ($\leq$ 2% grade)

(5) Non-controlled access (> 2% upgrade)

(6) Non-controlled access (> 2% downgrade)

(7) Ramps

These types of roadways were selected in order to investigate their influence on the magnitude and character of truck noise. Highways were divided into controlled and non-controlled access because (1) in general, different average speeds and operating conditions exist on these types of highways and (2) the federal noise standards outlined in [3] make this distinction in defining highway projects. Since the TSC Computer Program [1] is limited to consideration of freely flowing road traffic at cruise conditions, selection of roadway types which involve grades or acceleration will expand the available truck noise data base and broaden the application of the TSC program. Ramps were considered on recommendation of the noise group of NJDOT's environmental section who found them a problem area in noise prediction. Consideration of ramps will provide noise levels for trucks with speeds of less than 30 miles per hour (48.3 km/hr) (a speed range for which available truck noise data is incomplete).

Selection of Sites for Roadway Types 1-6

The objective of site selection with regard to these types of roadways was to select test sites from which noise measurements of a representative sample of the truck population in New Jersey could be collected. To meet this objective, most sites were selected along highways on which NJDOT's truck weighing stations are located.

All sites which were selected were required to meet the physical site criteria outlined in Appendix C, pages 175 - 179 in order to assure accurate noise level measurement. Guidelines were developed for the selection of these sites. These guidelines stressed (1) statewide geographical representation, (2) practical considerations pertaining to the number of valid measurements per hour, and (3) selection of roadway grades of varied steepness and length for Roadway Types 2, 3, 5 and 6.

Selection of Sites for Roadway Type 7

Measurement sites adjacent to ramps were also required to meet the physical site criteria in Appendix C. Ramp sites were selected along the roads visited during the selection of the sites for Roadway Types 1-6. Guidelines for the selection of ramp sites stressed obtaining (1) ramps of different configurations and grades, (2) ramps on which trucks were being driven under different operating conditions, and (3) ramps at which a reasonable number of valid measurements per hour could be taken. Geographical representation was not a factor in selecting ramp sites.

List of Measurement Sites

The measurement sites which were originally selected for this project were listed in the Appendix of the first interim report. Measurements were not taken at several sites on this list; they were taken, however, at several additional sites.

An updated site list is contained in Tables D-1 to D-7, Appendix D, pages 181 - 187 of this report. One table is presented for each roadway type. Sites have been renumbered as required. These tables contain site location, highway description, and traffic information.

In all, noise measurements were obtained at 37 sites. The number of sites visited for Roadway Types 1 to 7 was 5, 6, 5, 5, 4, 5 and 7, respectively.

DATA ACQUISITION

Between May 6 and December 28 of 1977, truck noise measurements were conducted at the 37 measurement sites. During this period, 4,967 individual truck noise tape recordings were obtained from 82 site visits.* Measurements were taken on weekdays, Monday through Friday. The majority of measurements were taken between 10 A.M. and 3 P.M. Data collection was conducted by a two man field crew.

The data which was collected in the field consisted of (1) tape recordings of the noise of individual truck pass-bys and of truck description, (2) speed measurements, (3) weather measurements, and (4) detailed site description information. Site description information consisted primarily of grade steepness and length, pavement type (bituminous or portland cement concrete), shoulder and median details, the elevation of the ground at the microphone position relative to that of the lane of travel, and an account of the noise reflecting objects in the measurement area and measurement zone (see physical site criteria, Appendix C, pages 175 - 179). Grade length was measured with the instrument vehicle's odometer; grade steepness and relative microphone elevation, with a transit. The roadway grade was measured over a 200 foot distance with the point of measurement at the middle of this distance. Field data which was not tape recorded was entered on log sheets.

*4,536 of these recordings were found to be valid measurements during data reduction.

All of the 37 sites were visited at least once. Each ramp site was visited twice. Sites for the other roadway types were visited in keeping with the data acquisition objective which is explained below.

Because of possible site-to-site variation in the average peak noise levels obtained for a particular class of truck, it was decided that the most representative truck noise levels for a particular roadway type would be obtained by giving greater representation to those sites at which truck traffic was greater.

Thus, an objective of data acquisition was to obtain a greater number of valid measurements for these higher truck volume sites. Therefore, when the average peak noise level is determined from all the measurements taken for a truck class, truck noise measurements taken at sites with very little truck traffic do not inequitably contribute to the average.

This meant trying to keep the ratio of valid measurements to the average annual daily truck traffic* at a site approximately equal to a constant value for all of the sites within a given roadway type.

This data acquisition objective required that some sites had to be visited two or three times while others were visited only once. This occurred because at many of the high truck volume sites, it was difficult to achieve truck isolation. Thus, less valid measurements were obtained per hour at these sites than at sites with much lower truck volumes.

*[Average Annual Daily Traffic (AADT)] X [Truck Percentage]

Several sites were visited an additional time(s) because some or all of a day's measurements were rejected as invalid due to calibration tone irregularities.

Table 1 on page 27 lists the number of valid truck noise measurements which were obtained at each of the 37 sites. The total for each roadway type is also indicated, as well as totals which summarize all measurements.

Table G-1, Appendix G, page 201 lists the number of truck noise measurements obtained for Roadway Types 1 to 7 broken down in terms of the 13 truck classifications mentioned on page 15. Percentages of the total number of measurements are also indicated. The table shows that approximately 54% of all measurements were taken for Truck Class 12 — trucks with three axle tractors and two axle semitrailers. Nearly 23% of all measurements were taken for Truck Class 1 — two axle trucks with dual tire rear wheels. Thus, about 77% of all the truck noise measurements were obtained for these two truck classes. Noise measurements for two and three axle buses comprised only 1% of the total. See Appendix G for further discussion of this table.

TABLE 1. NUMBER OF TRUCK NOISE MEASUREMENTS

ROADWAY TYPE 1
Controlled Access
(≤ 2% grade)

Site Number	Site Visits	Number of Measurements
1	2	113
2	1	40
3	3	187
4	4	310
5	3	67
Total	13	717

ROADWAY TYPE 2
Controlled Access
(> 2% upgrade)

Site Number	Site Visits	Number of Measurements
6	2	160
7	1	84
8	2	185
9	1	65
10	2	187
11	2	133
Total	10	814

ROADWAY TYPE 3
Controlled Access
(> 2% downgrade)

Site Number	Site Visits	Number of Measurements
12	2	180
13	2	120
14	2	150
15	3	114
16	2	188
Total	11	752

ROADWAY TYPE 4
Non-Controlled Access
(≤ 2% grade)

Site Number	Site Visits	Number of Measurements
17	3	146
18	3	128
19	3	123
20	2	77
21	2	62
Total	13	536

ROADWAY TYPE 5
Non-Controlled Access
(> 2% upgrade)

Site Number	Site Visits	Number of Measurements
22	1	63
23	2	25
24	3	251
25	2	94
Total	8	433

ROADWAY TYPE 6
Non-Controlled Access
(> 2% downgrade)

Site Number	Site Visits	Number of Measurements
26	1	48
27	3	230
28	2	112
29	3	178
30	4	69
Total	13	637

ROADWAY TYPE 7
(Ramps)

Site Number	Site Visits	Number of Measurements
31	2	108
32	2	62
33	2	114
34	2	86
35	2	85
36	2	126
37	2	66
Total	14	647

SUMMARY TOTALS

ROADWAY TYPE	SITE VISITS	NUMBER OF MEASUREMENTS
Controlled Access	34	2,283
Non-Controlled Access	34	1,606
Ramps	14	647
GRAND TOTAL	82	4,536

DATA REDUCTION

Truck noise measurement data previously tape recorded in the field was reduced in the laboratory and inputted to a computer file for storage. There were 4,967 truck noise measurements which were reduced. Of these, 4,536 were inputted to the computer file; the remainder were found to be invalid measurements and were not analyzed.

The data reduction procedure consisted of the following steps:

(1) Tape recorded field data, which consisted of truck noise level and truck description information, was reduced in the laboratory. The channel containing noise data was simultaneously played back into an overall level detector, 1/3 octave real time analyzer, and a graphic level recorder. In the process, the A-weighted peak noise level and the 1/3 octave frequency spectrum at the peak level was obtained for each truck pass-by. The other channel was played back in order to obtain a description of each truck (axle configuration, exhaust configuration, speed, etc.).

(2) The graphic level recorder trace produced in Step 1 for each truck pass-by was examined to check that the valid measurement criterion (see page 17) was satisfied.

(3) For truck noise measurements satisfying the criterion of Step 2, peak noise level, frequency spectrum and truck description information were entered on data code sheets and, after keypunching, inputted to a computer data file. Truck noise information from measurements not satisfying the criterion for a valid measurement was not entered on the computer file.

A detailed description of the data reduction procedure is given in Appendix E, pages 188 - 196. A block diagram of the equipment setup used for data reduction is shown in Figure E-1, Appendix E, page 189, and a description of each piece of equipment is given in Appendix F, pages 197 - 199.

DATA ANALYSIS

The valid truck noise data stored on the computer file was analyzed to determine (1) the truck classifications which were needed to represent New Jersey's truck population in terms of noise, and (2) the reference noise emission levels for these truck classifications. These reference levels were defined in relation to truck speed by means of simple regression equations with the peak overall truck noise level as the dependent variable and a function of speed as the independent variable.* Separate reference noise emission levels were determined for trucks travelling on each of the roadway types considered in this study. Since the data bases for most of the roadway types were large (see Table 1 page 27), regression analysis was made on the entire block of data for a roadway type.

Data analysis was conducted using a computer program written as part of this project, several standard statistical computer packages, and various statistical and graphical methods.

Data analysis consisted of the following tasks:

(1) using computer analysis to obtain elementary statistics as well as linear regressions of peak overall truck noise levels and eight frequency octave levels versus 10 times the logarithm of speed,

*Regression analysis is a statistical method of analysis which establishes a functional relationship between variables. This relationship is expressed as an equation of the form $y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_p X_p$, where y is the dependent variable, X_1, X_2, ..., X_p are the independent variables, and b_0, b_1, b_2, ..., b_p are the regression coefficients. The method of least squares is used to determine values of the regression coefficients which give the best fit curve for a particular set of data.

(2) determining which, if any, of the 13 original truck classes could be combined to form several general truck groups, thereby simplifying noise prediction considerably,

(3) checking several types of regression equations to determine if any define the relationship between truck noise emission level and truck speed significantly better than the regression involving the logarithm of speed,

(4) comparing the emission level regression equations obtained for Roadway Types 1-6 to determine if truck noise data obtained for two or more roadway types could be pooled and the new data group represented by a single regression equation, and

(5) examining the noise data for Roadway Type 7 (ramps) on an individual site basis to study the effects of geometric design, roadway grade, and truck operating condition on noise level, and to determine how ramp emission levels should be specified in terms of these variables.

Each of these tasks is discussed in the following sections.

Truck Noise Data Processing Computer Program

A computer program labeled "TRKPR" was written in FORTRAN IV. It processed the truck noise data which was stored on the computer data file. This program is capable of processing the data for any specified group whether an initial group (a group defined by one of the roadway types and truck classes outlined on pages 21 and 15) or a combination of initial groups. Thus, several roadway types or truck classes can be combined prior to processing.

For any specified roadway type and truck class group, the data processing performed by the program was as follows:

(1) development of a frequency distribution of peak truck noise levels,

(2) calculation of elementary statistics,

(3) development of a linear regression of A-weighted overall peak truck noise levels versus ten times the logarithm of speed,

(4) computation of the A-weighted mean octave levels* and standard deviations for octave bands with center frequencies of 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz, respectively, and

(5) development of linear regressions of A-weighted octave levels versus ten times the logarithm of speed for the eight octave bands just noted in (4).

Some of the elementary statistics which were calculated are:

(1) mean peak A-weighted noise level,

(2) standard deviation and variance of peak noise levels,

(3) L_{50} - the 50th percentile of the peak noise levels,

(4) L_{eq} - the sound pressure level associated with a truck having average sound intensity,

(5) PL_{eq} - a derived L_{eq} based on the assumption of normally distributed data. $PL_{eq} = \text{Mean} + .115\,(\text{standard deviation})^2$,

(6) Chi-square Statistic - a statistical test of data normality, and

(7) mean and standard deviation of speed.

*As mentioned, the octave levels were those which occurred at the peak overall level.

Additional statistics calculated for the regression analyses included the regression coefficients, the correlation coefficient, the standard error of estimate, and the F-test. The computer output listed all of the statistics mentioned above and several more which are not discussed. See Appendix G, pages 205 - 208 for a sample output.

Other portions of the processing program performed the regrouping of roadway types and truck classes. This was done either manually as desired by the user, or in the case of truck classes, automatically by the use of a subprogram which employed a statistical method based on the sample means of classes (Duncan's Multiple Range Test [6]). As noted, the processing program could recalculate the statistics and regressions for any new grouping.

Complete documentation of this truck noise data processing program is not included in this report because the program utilizes subprograms which are unique to the NJDOT computer installation.

Truck Reclassification

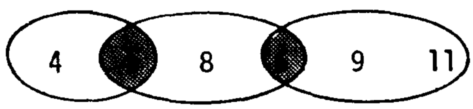
In an effort to simplify the noise prediction process, combining the 13 original truck classes was considered. The results of statistical tests, computer results for various truck class groupings, and practical considerations were factors in selecting the final combined truck class groups. Truck noise measurements for Roadway Types 1-6 were analyzed for purposes of truck reclassification.

As a first step, the mean peak noise levels of truck classes were compared two at a time to determine if a statistically significant difference between the mean levels existed. If no significant difference was found, the two truck classes in question were considered capable of being combined into a single truck class.

A standard statistical method which utilized Student's t distribution was employed for this comparison. The method is given in [6], pages 260 - 266. It assumes the two means which are being compared are calculated from random samples independently drawn from normal populations of equal but unknown variances.* The mean noise level, standard deviation, and number of observations for each truck class were required for the comparison. These statistics were obtained from the output of the truck noise computer processing program. The mean levels were not adjusted in any way for truck speed since the average speeds for truck classes of a particular roadway type varied by less than five miles per hour. Comparisons of the mean peak levels of the truck classes were made for each roadway type separately. Nevertheless, a truck class for a particular roadway type might contain observations from as many as six measurement sites. Usually, truck classes having more than five observations were compared. Table G-2, Appendix G, page 203 lists the mean peak noise levels for Roadway Types 1 to 6 for each of the thirteen truck classifications considered in this study. The number of measurements from which each mean level was calculated is also given in this table.

The Student t test comparisons, at a 5% level of significance, did not indicate mutually exclusive groups. That is, truck class groups often overlapped each other in a manner similar to the example given below.

Truck Class



*Most of the samples for the various truck classes were found to be normally distributed when checked with a chi-square goodness-of-fit test.

This example, with truck classes ranked in terms of mean noise level, shows that Truck Classes 1 and 6 each fall in either of two groups.

Based on the results of the t tests, the Duncan Multiple Range Test*, and practical considerations (particularly in regard to number of axles), it appeared that three general truck classes could be specified to represent the 13 original truck classes. However, these general classes were not well defined.

Accordingly, three separate schemes of classification, each with three general classes, were examined. They were:

<u>Classification Scheme 1</u>

Class I - Dual rear wheeled two axle trucks, two axle tractors, dual rear wheeled two axle buses, and three axle buses (1, 2, 4, and 5)**,

Class II - Three and four axle trucks (3, 6, 7, 8, 9, and 11), and

Class III - Five and six axle trucks (10, 12, and 13).

<u>Classification Scheme 2</u>

Class I - Dual rear wheeled two axle trucks, dual rear wheeled two axle buses, and three axle buses (1, 4, and 5),

Class II - Three and four axle tractor semitrailer combinations, and two and three axle tractors (2, 3, 8, 9 and 11), and

Class III - Five and six axle tractor semitrailer combinations and three and four axle single unit body trucks (6, 7, 10, 12 and 13).

*As modified by C. Y. Kramer [7] to allow use with unequal sample sizes. This test supported the t tests but resulted in greater overlapping among groups.

**Classes 1, 2, 4 and 5 from original list of thirteen truck classifications. See page 15 for class definitions and page 16 for illustrations.

Classification Scheme 3

Class I - Dual rear wheeled two axle trucks, dual rear wheeled two axle buses, and three axle buses (1, 4 and 5),

Class II - Two and three axle tractors, and two axle tractors with semitrailers (2, 3, 8, 9 and 10), and

Class III - Three and four axle single unit body trucks, and three axle tractors with semitrailers (6, 7, 11, 12 and 13).

The truck noise data processing program was run for Roadway Types 1 through 6 for each of these three classification schemes using the appropriate general classes. For each of the three computer runs, the mean peak noise levels obtained for the general classes within a classification scheme were compared. The comparison indicated that for all three of the classification schemes, Class III had the highest mean peak noise level, and Class I, the lowest. In addition, for each classification scheme, the difference between the mean peak noise levels of Classes I and II for Roadway Types 1 through 6 was, on the average, approximately 4 decibels*. Likewise, the mean peak level difference between Classes II and III was, on the average, approximately 1 decibel.

The 1 decibel difference between Classes II and III was judged not great enough to warrant the use of both of these louder classes. Consequently, Classes II and III were combined to form Class IV. Class IV was the same for all classification schemes, as was Class I, except for the two and three axle tractor classes (2 and 3)**. The two and three axle tractor classes were removed from Classes I and IV. As a result Classes I and IV were as follows:

*Mean peak noise levels were not adjusted for speed because the average speeds of Classes I, II, and III varied by less than 3 miles per hour (4.8 Km/hr).
**Original truck classifications, page 15.

Class I - Two axle trucks with dual rear wheels, two axle buses with dual rear wheels, and three axle buses (1, 4 and 5),

Class IV - All trucks with three or more axles (6 through 13).

In an attempt to classify two and three axle tractors into either Class I or Class IV, the noise data processing program was rerun for the two and three axle tractor classes, as well as for the new Classes I and IV. A comparison of mean peak noise levels of Class I, Class IV, and 2 and 3 axle tractors was made for Roadway Types 1 to 6. Because the amount of data for the two and three axle tractors was very small the mean noise levels for these two classes were not very precise. Consequently, the mean level comparison did not give any definite indications as to where the tractors should be placed; however, certain trends were shown. In general, the mean level of the two axle tractors was nearer to the mean level of Class I than it was to the mean level of Class IV. Conversely, in general, the mean level of the three axle tractors was nearer to the mean level of Class IV than it was to Class I. Because of these reasons and the practical consideration that present traffic data for New Jersey is only available in terms of total number of axles, two axle tractors were placed in Class I; and three axle tractors, in Class IV.

The truck noise data processing program was rerun with truck Classes I and IV with tractors included. The results showed that for Roadway Types 1 to 6 the average difference in the mean noise level of Classes I and IV was approximately 4.7 decibels*. This large difference indicated that these two truck classes should not be combined further.

*Means not adjusted for speed differences.

Thus, the thirteen original truck classifications listed on page were regrouped to form two general truck classifications, Classes I and IV. Hereafter, trucks in Class I will be referred to as Type 1 trucks; and those in Class IV, Type 2 trucks.

In summary, truck reclassification resulted in two types of trucks. They are:

Type 1 Trucks - Two axle trucks with dual tire rear wheels (2 axle tractors included), two axle buses with dual tire rear wheels, and three axle buses as illustrated in Figure 2, page 39. Type 1 Trucks are those from original truck classifications 1, 2, 4 and 5 -- namely, medium trucks, and city transit, school, and commuter buses.

Type 2 Trucks - Three, four, five, and six axle trucks (3 axle tractors included) as illustrated in Figure 3, page 40. Type 2 trucks are those from original truck classifications 3, 6, 7, 8, 9, 10, 11, 12 and 13 -- namely, heavy trucks.

Mean peak noise levels, mean speeds, and number of measurements for Truck Types 1 and 2 for Roadway Types 1 to 6 are shown in Table 2, page 41. This table indicates that for Roadway Types 1 to 6 the differences between the mean peak noise levels for Truck Types 1 and 2 ranged from 4.3 - 5.4 dB.

From here on, these two truck types will be used in analyzing the truck noise data for all roadway types.

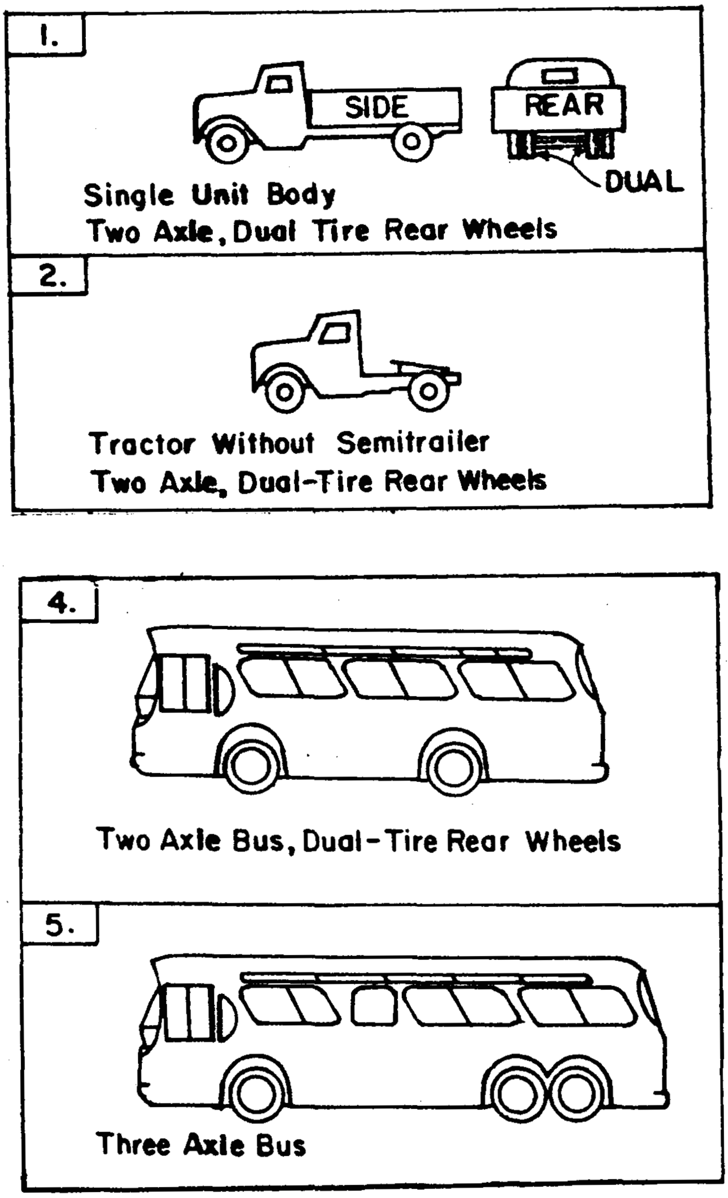


Figure 2. TRUCK TYPE I
(MEDIUM TRUCKS & BUSES)

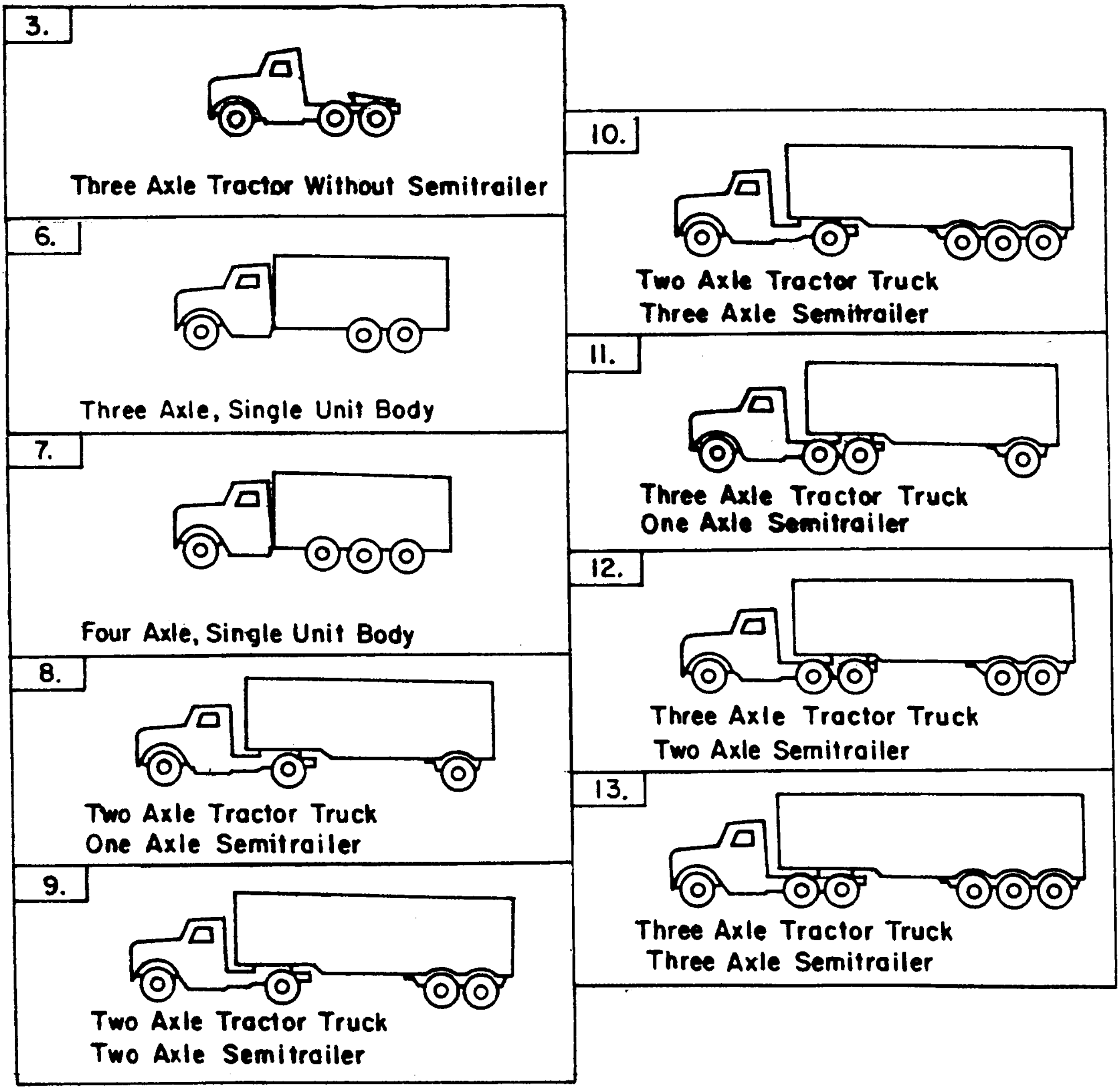


Figure 3. TRUCK TYPE 2

(HEAVY TRUCKS)

TABLE 2

DATA SUMMARY FOR TRUCK TYPES 1 & 2

Roadway Type	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	Number of Measurements	Mean Peak Level (dBA)	Mean Speed (mph)	Number of Measurements	Mean Peak Level (dBA)	Mean Speed (mph)
1 Controlled Access, Level	127	82.3	52.9	590	86.8	55.0
2 Controlled Access, Upgrade	109	81.6	50.6	705	86.4	48.7
3 Controlled Access, Downgrade	132	81.2	55.6	620	86.0	57.4
4 Non-controlled Access, Level	224	79.1	49.1	312	83.7	50.2
5 Non-controlled Access, Upgrade	126	80.6	44.8	307	86.0	46.0
6 Non-controlled Access, Downgrade	256	79.2	50.7	381	83.5	50.9
7A Ramps (Acceleration)	40	75.2	30.0	331	81.0	26.0
7B Ramps (Non-acceleration)	78	75.5	31.4	198	79.4	28.7
Total	1092			3444		

Regression Equations

The truck noise data processing computer program was written to perform linear regressions of peak truck noise levels versus the logarithm of speed. This regression analysis resulted in equations of the form:

$$L = A + B (\log V)$$

where:

L = peak noise level in dBA,

$\log V$ = logarithm to the base 10 of speed in mi/hr., and

A and B are constants.

Regression equations of this form were selected because they are generally used to describe the relationship between motor vehicle noise emission levels and vehicle speed. (See [2, 8, and 9])

To find out if better results could be obtained with other regression equations, regressions using linear equations in speed ($L = A + B (V)$) and two degree polynomial equations in speed ($L = A + B (V) + C(V)^2$, C is a constant) were also performed. Regression analyses were performed on the peak truck noise levels obtained for the seven roadway types using the NJDOT's interactive statistical computations package (STATPACK).

It was found that in most cases regression analyses using either linear equations in speed or two degree polynomial equations in speed produced slightly better results than linear equations in logarithm of speed. However, these other types of equations did not produce significantly better results since, in general, they explained less than an additional 1% of the variation in the noise data. Consequently, regression equations in log of speed were satisfactory.

Thus, for the remaining data analysis, all relationships established between peak truck noise levels and truck speed are presented in terms of an equation relating peak noise level to the logarithm of speed. The relationships of octave band levels to truck speed are presented in the same manner.

Emission Level Comparisons for Roadway Types 1 - 6

Emission level regressions for Type 1 and Type 2 trucks for all roadway types were compared graphically by plotting the curves defined by the regression equations. In addition, regressions for two groups of data were compared using a statistical method which utilized an F statistic computed for a system of regression equations as in [10].

Emission level regression equations were compared in order to determine if the data for any two roadway types could be pooled and represented by a single regression equation.

The emission level equations for Roadway Type 7 (Ramps) were not compared to those of the other roadway types because it had been previously decided not to combine noise data for ramps with any other roadway type. Frequent accelerating and decelerating of traffic occurs on ramps, while essentially freely flowing traffic operates on the other six roadway types.

A. Truck Type 2 - Overall Noise Emission Levels - Figure 4, page 44 is a graph of the emission level equations obtained for Type 2 (heavy) Trucks for Roadway Types 1 - 6. Overall peak noise level is plotted against truck speed.

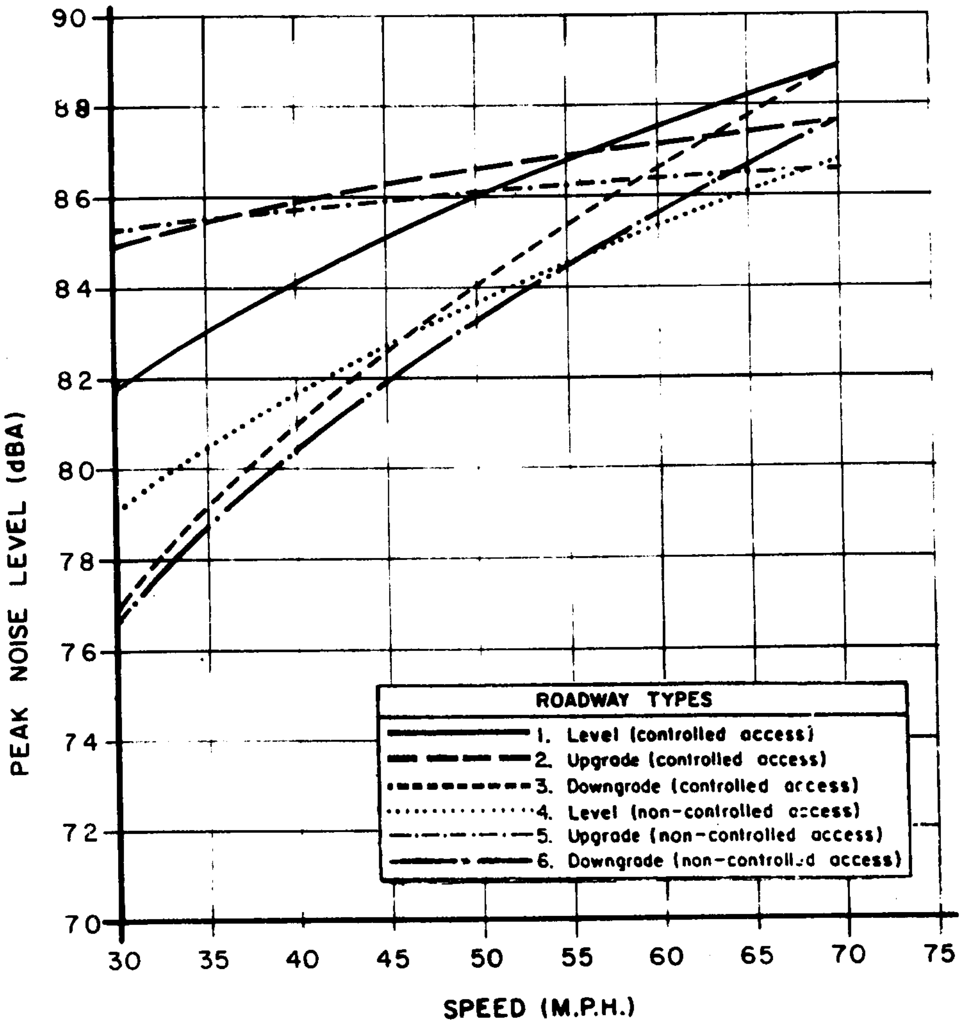


Figure 4. OVERALL NOISE EMISSION LEVELS FOR TRUCK TYPE 2 (HEAVY TRUCKS) FOR ROADWAY TYPES 1-6.

Figure 4 shows that the regression curves for Roadway Types 2 and 5 vary from each other by less than 1 decibel for any given speed. Similarly, the curves for Roadway Types 3 and 6 vary from each other by less than 1.5 decibels for any given speed. On the other hand, the regression curves for Roadway Types 1 and 4 don't pair off very well with any of the other curves.

The closeness of the curves for Roadway Types 2 and 5 indicates that the overall emission levels vary with speed in nearly the same manner for both of these roadway types. This most likely is due to the fact that roadways of Types 2 and 5 are greater than 2% upgrades. They differ in that roadways of Type 2 are controlled access highways, while roadways of Type 5 are non-controlled access highways.

Figure 4 also shows that the overall emission levels of Roadway Type 3 and Roadway Type 6 vary in nearly the same manner with speed. Roadways of Types 3 and 6 are greater than 2% downgrades. They differ by virtue of the fact that roadways of Type 3 have controlled access while those of Type 6 have non-controlled access.

Roadways of Type 1 and those of Type 4 are level highways of less than or equal to 2% grade. Like the others, these roadway types differ in access control. Yet, Figure 4 indicates that the overall emission levels of roadways of Type 1 and 4 differ by at least 2 decibels for any given speed.

The greater than 2 decibel emission level difference between Roadway Types 1 and 4 (level) appeared to be significant, while the emission level differences -- generally less than 1 decibel -- between Roadway Types 2 and 5 (upgrades) and between Roadway Types 3 and 6 (downgrades) appeared insignificant.

Thus, based on the curves in Figure 4, it appeared that for Type 2 Trucks, Roadway Types 1 and 4 (level) should not be combined. On the other hand, Figure 4 showed no significant difference between Roadway Types 2 and 5 (upgrades) or any between Roadway Types 3 and 6 (downgrades); thus, indicating that these pairs of roadway types could be combined.

Further examination of the regression equations was done by performing statistical tests. A method which employed an F statistic for a system of regression equations was used to compare two groups of data. This method, which utilized qualitative explanatory variables, is explained in [10], pages 85-94.

The statistical testing* indicated that noise data should not be combined for Roadway Types 1 and 4 (level) or for Roadway Types 3 and 6 (downgrades); however, noise data for Roadway Types 2 and 5 (upgrades) could be pooled.

B. Truck Type 1 - Overall Noise Emission Levels - Figure 5, page 47 is a graph of the overall noise emission levels for Truck Type 1 (medium trucks and buses) for Roadway Types 1 - 6. This figure does not show the same degree of pairing of emission level curves as does Figure 4.

The emission level curves for Roadway Types 2 and 5 (upgrades) were once again close to each other. They varied by less than 1.5 decibels except for speeds below 30 miles per hour (48 Km/hr).

The emission level curves for Roadway Types 3 and 6 (downgrades) were reasonably close to each other above 40 miles per hour (64 Km/hr) but varied by 2 to 5 decibels for speeds below 40.

*At a 5% level of significance.

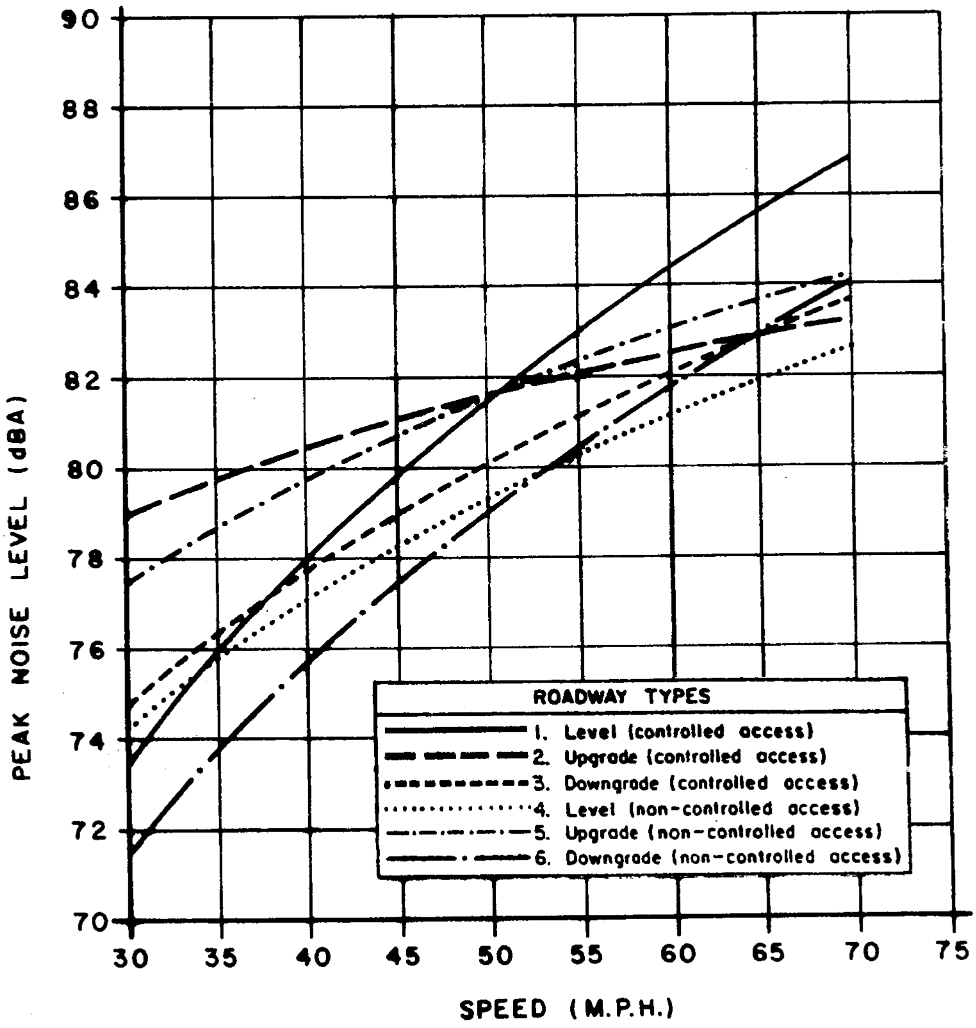


Figure 5. OVERALL NOISE EMISSION LEVELS FOR TRUCK TYPE I (MEDIUM TRUCKS & BUSES) FOR ROADWAY TYPES 1-6

As in Figure 4, the emission level curves for Roadway Types 1 and 4 varied considerably at almost all speeds.

Based on an examination of the curves in Figure 5, it appeared that for Type 1 Trucks both Roadway Types 2 and 5 (upgrades) and Roadway Types 3 and 6 (downgrades) could be combined. In contrast, this figure demonstrated that significant differences existed between the emission curves for Roadway Types 1 and 4 (level).

As before, regressions were examined further by performing statistical tests. The same statistical method was used as with the emission levels for the Type 2 Trucks.

The statistical tests indicated that the noise data could be combined for Roadway Types 2 and 5 (upgrades), as well as for Roadway Types 3 and 6 (downgrades). The statistical tests indicated that the noise data for Roadway Types 1 and 4 (level) should be kept separate.

C. <u>Truck Type 2 - Octave Band Levels</u> - A graph of octave band levels versus truck speed was prepared for each of eight octave bands - 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. The curves which were constructed were those defined by the regression equations calculated by the truck noise data processing computer program. The curves for Roadway Types 1 - 6 were drawn on each octave band level graph so that comparisons could be made. Figure 6, page 49 illustrates one of these graphs.

The octave band level graphs were examined in regard to the combining of Roadway Types 1 and 4, 2 and 5, and 3 and 6, respectively. For the four octave bands with the highest levels - 250, 500, 1000 and 2000 Hz - the same trends were observed as in the graph of the overall emission levels (Figure 4). However, for the 63, 125, 4000 and 8000 Hz octave bands,

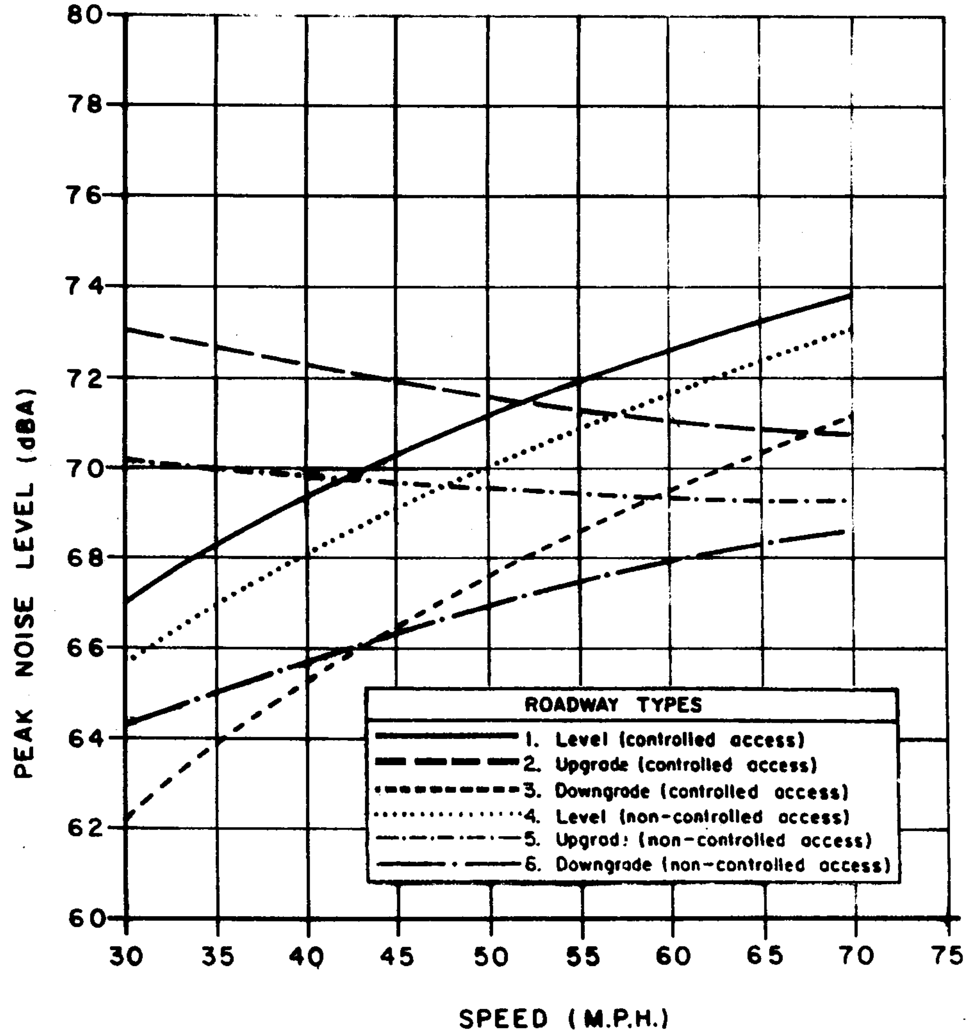


Figure 6. 125Hz OCTAVE BAND EMISSION LEVELS FOR TRUCK TYPE 2 (HEAVY TRUCKS) FOR ROADWAY TYPES 1-6

significant differences in emission levels (greater than 2dB) existed between Roadway Types 2 and 5 (upgrades). The 125 Hz octave band level graph, Figure 6, page 49, is presented to illustrate the type of emission level differences which occurred between Roadway Types 2 and 5 (upgrades) for Type 2 Trucks. Significant differences in emission levels between Roadway Types 3 and 6 (downgrades) occurred only in the 8000 Hz octave band. None of the octave band level graphs indicated that Roadway Types 1 and 4 (level) should be combined.

D. Truck Type 1 - Octave Band Levels - Graphs of octave band levels versus truck speed were prepared for Truck Type 1 in the same manner as for Truck Type 2. Once again the graphs were examined in regard to the combining of Roadway Types 1 and 4, 2 and 5, and 3 and 6, respectively.

In general, the octave band level graphs showed differences in emission levels between Roadway Types 1 and 4, 2 and 5, and 3 and 6, respectively, which were greater than those observed for Type 2 Trucks. Emission level differences between Roadway Types 2 and 5 (upgrades), as well as, between Roadway Types 3 and 6 (downgrades) bordered on being significant even for the four octave bands with the highest levels - 250, 500, 1000, and 2000 Hz. Significant differences in emission levels between Roadway Types 2 and 5 (upgrades) and Roadway Types 3 and 6 (downgrades), respectively, were observed for octave bands 63, 125, 4000 and 8000 Hz. The 125 Hz octave band level graph, Figure 7, page 51, is shown to illustrate the type of emission level differences which occurred between Roadway Types 2 and 5 (upgrades) and between Roadway Types 3 and 6 (downgrades) for Truck Type 1. As before, significant emission level differences were observed between Roadway Types 1 and 4 (level) for almost all of the octave bands.

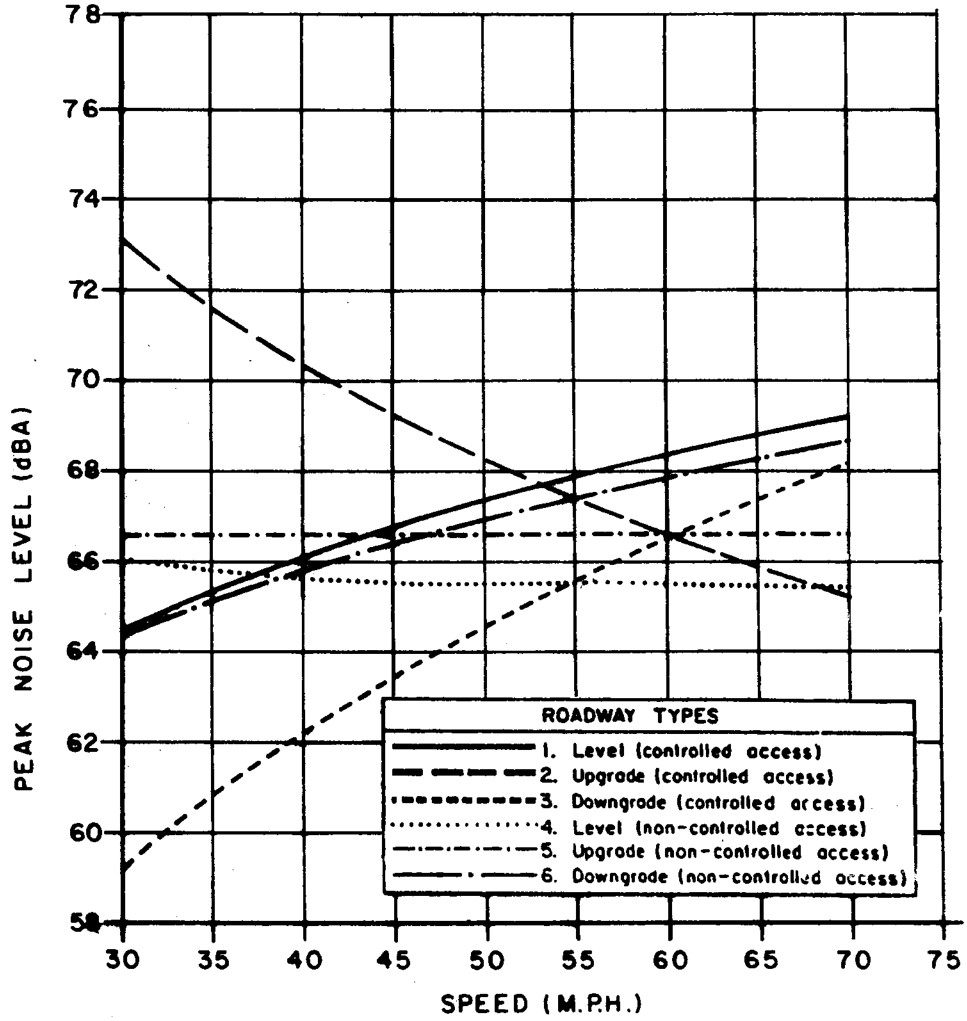


Figure 7. 125Hz OCTAVE BAND EMISSION LEVELS FOR TRUCK TYPE I (MEDIUM TRUCKS & BUSES) FOR ROADWAY TYPES 1-6

E. <u>Findings From Emission Level Comparisons</u> - Considering the results for Type 1 and Type 2 trucks, it was decided that the emission levels for Roadway Types 1 and 4 (level) should be defined by two separate emission level regression equations. The emission level differences which were observed between these two roadway types were apparently due at least in part to differences in the mixes of Type 1 and Type 2 trucks which existed on the two roadway types. For instance, five axle tractor semitrailers comprised 77% of the Type 2 Trucks which were measured on Roadway Type 1, while they comprised only 62.5% of the Type 2 Trucks measured on Roadway Type 4. Similar differences occurred for other axle configurations. As expected, truck mixes varied due to the fact that roadways of Type 1 were controlled access highways; whereas, roadways of Type 4 were non-controlled. Thus, differences in truck mix may partially explain some of the observed emission level variation for these two roadway types.*

While there was evidence to support the combining of Roadway Types 2 and 5 (upgrades), as well as Roadway Types 3 and 6 (downgrades), it was decided to represent each roadway type with a separate emission level regression equation. Following are the reasons this decision was made:

(1) to be consistent with the manner in which the emission levels for Roadway Types 1 and 4 (level) were presented, and the manner in which Roadway Types 1 and 4 would be dealt with during noise prediction,

(2) to more accurately describe the overall emission levels for Roadway Types 1 - 6. Though in some instances the emission

*Though methods of access control caused similar differences in the truck mixes of Roadway Types 2 and 5, as well as, Roadway Types 3 and 6, apparently the nature of these roadways (upgrades and downgrades) served to minimize the effects of these differences.

level differences between roadway types were small, a certain amount of accuracy would be lost following any combination of roadway types, and

(3) to more accurately represent the octave band emission levels for Roadway Types 1 - 6. In certain instances, significant octave band emission level differences occurred between Roadway Types 2 and 5 (upgrades), as well as, between Roadway Types 3 and 6 (downgrades).

In addition to these reasons, it was found that the use of a separate emission level equation for each roadway type did not substantially increase the time required to make noise predictions. Thus, increased prediction time was not a sufficient practical reason not to use separate emission level equations.

The overall and octave band emission level equations for Truck Types 1 and 2 for Roadway Types 1 - 6 are presented in the discussion of results, pages 60 - 69.

Noise Emission Levels for Roadway Type 7 (Ramps)

As mentioned, truck noise measurements were made at the seven ramp sites listed in Table D-7, page 187. These seven sites represent ramps of different geometric configurations and roadway grades. In addition, operating conditions on these ramps varied considerably so that trucks on some ramps were accelerating while those on others were not accelerating (travelling at constant speed or coasting).* In fact, in quite a few

*"Accelerating" refers only to trucks that are increasing their speed through further power application. "Not accelerating" or "Non-accelerating" includes all trucks not meeting this description.

instances, trucks at different points on the same ramp were operating under different conditions. Indeed, for one ramp site (Site 35) trucks measured at the same point were operating under different conditions depending upon which of two roadways they used to enter the ramp. Since the point at which noise measurements were taken is important, illustrations of the seven ramp sites are shown in Figure 8, page 55 with the measurement point indicated by a black dot. As before, measurements were taken at a distance of 50 feet (15.2 m) from the center of the lane of travel.

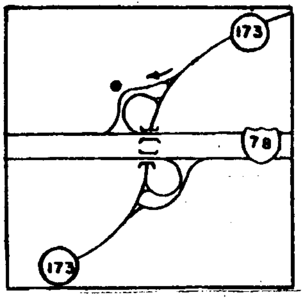
Because the ramps under study were considerably different in their characteristics, the noise data for ramps was analyzed on an individual site basis. With analysis done in this manner, mean peak noise levels for Type 1 Trucks (medium trucks and buses) could not be used for comparisons between sites. So few Type 1 Truck measurements were made for most ramp sites that the mean peak noise levels calculated for this type of truck may not have been representative. Thus, site-by-site comparisons were made based on the mean peak noise levels obtained for Type 2 (Heavy) Trucks since they occurred in much greater numbers.*

Site-by-site comparisons were made in terms of geometric configuration, roadway grade, and operating condition. These comparisons indicated that of these three variables, the one which most satisfactorily explained the differences in mean peak noise levels between sites was truck operating condition. For example, Sites 33 and 37 both had the same geometric configuration - inner loop connecting ramps of partial cloverleaf interchanges - yet there existed a significant (greater than 2 decibels) difference between

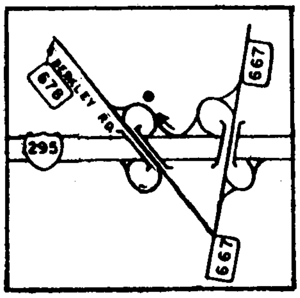
*Mean peak levels were not adjusted for average speed differences.

Figure 8

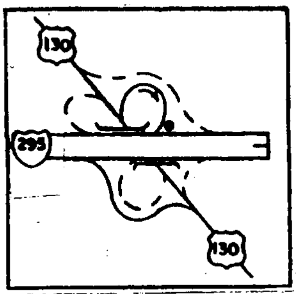
DIAGRAMS OF RAMP SITES.



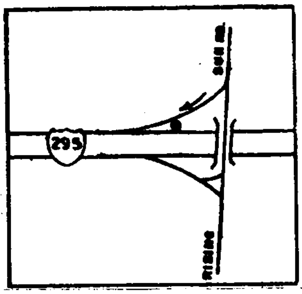
SITE 31



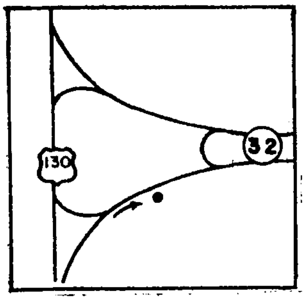
SITE 32



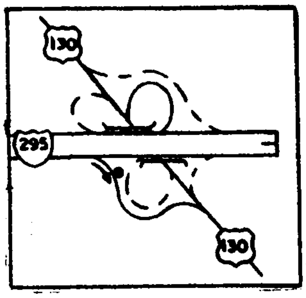
SITE 33



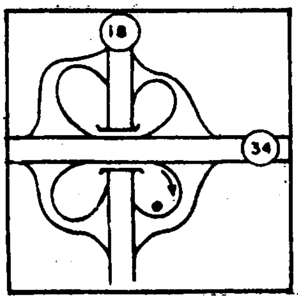
SITE 34



SITE 35



SITE 36



SITE 37

the mean peak noise levels of Type 2 Trucks for these two sites. See Table 3, page 57. The fact that Type 2 Trucks at Site 33 were accelerating while those at Site 37 were not apparently explains this difference.

The same types of situations occurred when roadway grades were examined. The two upgrade roadway ramp sites (Sites 32 and 33) showed a mean peak level difference of about 2 decibels. Likewise, the two downgrade roadway ramp sites (Sites 34 and 37) also had about a 2 decibel difference in level. It was felt that slight differences in grade between sites did not explain the differences in noise level. This conclusion was based on the observation that Site 32 had a steeper upgrade than Site 33, yet higher truck noise levels were measured at Site 33. Similarly, Site 34 had a steeper downgrade than Site 37, yet lower levels were measured at Site 37. Once again these differences were apparently due to the fact that Type 2 Trucks were accelerating on only one of the two ramps in each of these roadway grade categories. In addition, for all of the cases mentioned, the mean peak noise levels for ramps with accelerating trucks were higher than those with non-accelerating trucks.

The ramp sites which were compared in each of the above situations were located along different roads in different areas of the state; thus, differences in Type 2 truck mix, as well as other site dependent factors, may have accounted for some of the observed differences in mean peak noise levels. However, Site 35 provides further evidence that for this study truck operating condition was a more important explanatory variable than either geometric design or roadway grade. As noted, at Site 35 both accelerating and non-accelerating trucks passed by the measurement point.

TABLE 3

SITE BY SITE RAMP STATISTICS

TYPE 2 TRUCKS

Site Number	No. of Samples	Mean Level (dBA)	Mean Speed (MPH)	Geometric Design	Roadway Grade	Operating Condition
31	103	80.2	23.0	Outer Connecting	Level	Acceleration
32	53	79.4	24.6	Outer Connecting	Upgrade	No Acceleration
33	98	81.3	26.3	Inner Loop	Upgrade	Acceleration
34	80	80.3	26.0	Diagonal	Downgrade	Acceleration
35	50	82.9	31.1	Diagonal	Level	Acceleration
35	14	80.9	40.6	Diagonal	Level	No Acceleration
36	94	79.6	30.8	Outer Connecting	Level	No Acceleration
37	37	78.2	24.7	Inner Loop	Downgrade	No Acceleration

Accordingly, a comparison of the levels measured for accelerating and non-accelerating Type 2 Trucks at this site should indicate a difference due primarily to operating condition since geometric design and roadway grade would be constant for this comparison. The comparison showed that accelerating trucks produced a mean peak noise level which was approximately two decibels higher than the level produced by non-accelerating trucks. This occurred despite the fact that accelerating trucks had an average speed which was almost 10 miles per hour less than non-accelerating trucks.

Based on these site-by-site comparisons of the mean peak noise levels of Type 2 Trucks, it was decided to determine a separate noise emission level for accelerating and non-accelerating trucks travelling on ramps. Consequently, noise data from ramp sites with accelerating trucks - Sites 31, 33 and 34 - was pooled. Likewise, noise data from ramps with non-accelerating trucks - Sites 32, 36 and 37 - was also pooled. Data from Site 35 was placed in either group as appropriate.

To simplify further discussion, Roadway Type 7, which included all ramp sites, will be divided into two groups. Roadway Type 7A is defined as ramp sections with accelerating trucks, while Roadway Type 7B is defined as ramp sections with non-accelerating trucks. Since on many ramps, trucks operate in both an accelerating and non-accelerating condition, noise emission levels for Roadway Types 7A and 7B might both be used in the noise prediction for a single ramp.

Truck noise data for Roadway Types 7A and 7B was processed in the same manner as that for the other roadway types. Regressions were performed for overall noise emission level versus speed and octave band levels versus speed. Regressed overall levels and octave band levels are compared in the sections which follow.

Since ramp sites varied in geometrical configuration, roadway grades, and vehicle operating conditions, noise level comparisons were done on a site-to-site basis. This was made difficult by the limited number of measurements which were obtained, particularly for Truck Type 1. If a larger amount of data had been collected, the analysis of noise emission levels for ramps would have been more meaningful.

RESULTS WITH DISCUSSION

This section presents the equations which predict noise emission levels for Truck Types 1 and 2, medium trucks and buses, and heavy trucks, respectively, for each of the seven roadway types which were considered in this study. The coefficients which define these equations for overall emission levels and octave band emission levels are presented in tabular form. For overall levels, the prediction equations, themselves, are given in the text. Emission levels are presented in a manner which allows them to be incorporated into the TSC MOD-04 Highway Noise Prediction Code with a minimum of effort. This section also includes (1) an evaluation of New Jersey's emission levels, (2) a comparison of these levels to the FHWA's national survey emission levels, and (3) a statistical evaluation of the noise data collected for this study.

Truck Noise Emission Level Prediction Equations

The TSC MOD-04 highway noise prediction method [1] bases its noise predictions on the reference energy mean emission levels of motor vehicles. These energy mean emission levels are adjusted for traffic flow, distance from source, roadway segment characteristics, and shielding (barriers and ground cover) to arrive at the predicted sound levels - usually L_{eq} or L_{10}.

The reference energy mean emission level is related to the average value of the peak pass-by sound level for a vehicle type by the following relationship:

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\sigma^2,$$

where

$(\bar{L}_0)_E$ = the energy mean emission level (dBA),

$\bar{L}_0$ = the arithmetic mean of peak pass-by sound levels (dBA) (that is, the arithmetic mean emission level), and

σ = the standard deviation of the peak sound levels.

This equation is based on the assumption that the peak pass-by sound levels for a vehicle type are normally distributed. It applies to the overall mean emission level as well as to the energy mean emission level of individual octave bands.

For a large data base where regression analysis is used this equation can be rewritten in the form:

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\ (SE)^2,$$

where

SE is the standard error of estimate for the regression line [11].

For a particular vehicle type, the complex relationship between all of the individual vehicle noise sources - tires, engine, exhaust, fan, etc. - is implicitly defined by the values of $\bar{L}_0$ and SE. Thus if $\bar{L}_0$ and SE are determined, $(\bar{L}_0)_E$ is also.

The truck noise emission levels obtained in this study are presented in terms of prediction equations for $\bar{L}_0$ and corresponding values of SE. The equations for $\bar{L}_0$ were determined as noted in the analysis section of this report; that is, by regressing the emission levels measured for trucks travelling on a particular roadway type versus the logarithm of truck speed in miles per hour. The equation which results is:

$$\overline{L}_0 = A + B (\log V)$$

where

A and B are the regression coefficients, and

log V is the logarithm of V to the base ten.

Emission levels were presented in terms of $\overline{L}_0$ because it appeared that in this form they can be most easily built into the TSC MOD-04 Highway Noise Prediction Code.

Prediction equations for $\overline{L}_0$ and corresponding values of SE were determined for Truck Types 1 and 2 for each of the roadway types considered in this study. Values of the coefficients A and B, which define the relationship between arithmetic mean emission level and truck speed, for trucks of Type 1 and 2 as they operate on roadways of Types 1 to 7 are presented in Table 4, pages 63 - 66. Values of A and B for the overall emission levels as well as for the octave band emission levels are included in this table. In addition, values of SE are given. It should be noted that the noise emission levels defined by the coefficients in Table 4 are A-weighted and referenced to 50 feet from the source vehicle as required for use with TSC MOD-04.

Table 4 is summarized by the emission level equations on pages 67-69 which represent overall levels only. In addition to the arithmetic mean emission levels, $\overline{L}_0$, from this table, energy mean emission levels, $(\overline{L}_0)_E$, are also given. As noted, $(\overline{L}_0)_E$ equals $\overline{L}_0 + 0.115 (SE)^2$ for a normal distribution of emission levels. Again, log V is logarithm to the base ten of truck speed in miles per hour. Corresponding energy mean emission level prediction equations for speed in kilometers per hour are given in Table G-3, Appendix G, page 204.

TABLE 4

COEFFICIENTS OF REFERENCE NOISE EMISSION LEVEL EQUATIONS FOR TRUCK TYPES 1 & 2

-------- ROADWAY TYPE 1 --------
(CONTROLLED ACCESS, LEVEL)

	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	A	B	SE	A	B	SE
OAL*	19.812	36.319	2.9205	53.274	19.284	2.4704
63	27.545	17.707	6.6008	122.711	-35.518	6.0453
125	45.128	13.062	4.5630	39.244	18.761	4.4618
250	30.521	25.084	5.2124	75.568	0.693	3.8651
500	11.461	37.229	3.3736	39.426	23.453	3.3304
1000	1.170	43.615	2.8790	31.495	28.837	2.4611
2000	-1.637	43.847	3.1826	39.312	22.606	2.4216
4000	-0.394	38.343	3.8372	18.472	29.948	3.2027
8000	-0.635	33.237	4.0530	1.737	33.732	3.0169

-------- ROADWAY TYPE 2 ---------
(CONTROLLED ACCESS, UPGRADE)

	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	A	B	SE	A	B	SE
OAL	61.543	11.784	3.2043	73.892	7.464	2.6482
63	89.062	-18.381	5.9965	54.189	5.110	7.2806
125	104.770	-21.403	5.2811	82.461	-6.311	4.4495
250	69.322	1.497	5.5900	82.998	-3.962	3.9887
500	34.136	23.791	4.2652	62.171	10.290	3.7483
1000	33.598	24.402	3.1635	61.096	11.789	2.9595
2000	34.830	22.647	3.0478	61.371	10.256	2.6715
4000	27.114	23.039	3.3340	52.997	10.859	3.1213
8000	23.756	19.878	3.0895	44.240	9.962	3.1012

*OAL is the overall noise emission level

-------- ROADWAY TYPE 3 --------
(CONTROLLED ACCESS, DOWNGRADE)

	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	A	B	SE	A	B	SE
OAL	38.979	24.208	3.3649	29.356	32.220	2.8323
63	17.067	23.327	4.9541	64.850	-3.578	4.1973
125	23.142	24.410	4.7019	26.244	24.338	4.1147
250	44.094	15.358	5.6166	70.217	2.136	4.3643
500	14.161	34.822	3.6010	18.066	34.628	3.2899
1000	32.984	24.106	4.0324	14.115	38.250	3.1596
2000	25.153	27.289	3.8668	8.052	40.245	3.0393
4000	10.551	31.624	3.6079	-5.654	43.789	3.3267
8000	-9.002	37.709	3.3312	-21.210	46.929	3.0004

-------- ROADWAY TYPE 4 --------
(NON-CONTROLLED ACCESS, LEVEL)

	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	A	B	SE	A	B	SE
OAL	40.507	22.850	3.2514	48.053	20.997	2.8435
63	51.575	2.610	4.9426	60.228	0.380	6.7776
125	68.602	-1.762	4.6796	35.682	20.248	4.1294
250	42.692	16.892	4.7533	69.126	3.482	3.8541
500	21.863	30.305	3.7740	25.153	30.723	3.3289
1000	29.472	25.274	3.5478	38.562	23.046	3.2155
2000	25.764	25.533	4.1925	39.958	20.444	4.0757
4000	25.140	21.406	4.9784	29.243	22.285	4.6945
8000	19.521	20.088	4.9681	24.514	19.317	4.5736

-------- ROADWAY TYPE 5 ----------
(NON-CONTROLLED ACCESS, UPGRADE)

	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	A	B	SE	A	B	SE
OAL	50.040	18.552	3.5199	79.931	3.632	3.2336
63	92.188	-22.003	6.6478	75.031	-8.244	7.8032
125	66.422	0.110	5.3831	73.591	-2.316	5.3190
250	57.350	9.323	5.7964	92.717	-8.682	4.9153
500	38.533	21.444	3.8807	68.907	6.048	4.0097
1000	35.458	23.205	3.5945	68.711	6.774	2.9971
2000	13.164	34.802	3.4992	60.102	10.130	3.2813
4000	27.953	21.076	4.1183	60.831	5.090	3.9250
8000	37.494	10.599	5.1694	56.894	1.540	3.8373

-------- ROADWAY TYPE 6 --------
(NON-CONTROLLED ACCESS, DOWNGRADE)

	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	A	B	SE	A	B	SE
OAL	21.316	33.980	3.0156	31.666	30.418	3.1025
63	54.380	1.155	5.2387	50.383	4.492	5.2536
125	49.092	8.942	4.4676	46.696	11.912	4.4528
250	47.234	12.997	5.4775	66.367	4.119	4.6706
500	7.740	38.242	3.6323	12.399	37.729	3.6365
1000	1.593	41.771	3.2849	16.447	36.271	3.1074
2000	-7.555	45.770	3.3502	12.167	37.428	3.3464
4000	-25.132	51.701	3.7310	0.926	39.156	3.8330
8000	-5.894	35.850	3.5972	19.244	22.833	3.6915

-------- ROADWAY TYPE 7A --------
(RAMPS, ACCELERATION)

	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	A	B	SE	A	B	SE
OAL	60.782	9.824	4.0889	64.135	11.956	3.3858
63	56.185	1.004	6.8541	55.833	3.458	7.3370
125	44.041	14.547	5.3116	39.083	21.794	5.2293
250	40.775	18.462	4.9738	49.056	16.579	4.6703
500	76.598	-6.553	3.6402	65.365	5.778	4.3154
1000	61.099	4.235	4.8666	61.866	8.874	3.6760
2000	40.936	15.684	5.7600	60.534	7.955	3.8706
4000	43.263	9.558	5.8490	60.807	3.298	4.1330
8000	53.689	-1.799	5.7610	52.779	2.308	4.5155

-------- ROADWAY TYPE 7B --------
(RAMPS, NO ACCELERATION)

	TRUCK TYPE 1 (Medium Trucks & Buses)			TRUCK TYPE 2 (Heavy Trucks)		
	A	B	SE	A	B	SE
OAL	45.030	20.511	3.4509	68.199	7.711	3.4168
63	36.244	13.426	6.5396	70.246	-8.508	6.5195
125	40.977	15.316	4.9161	80.220	-9.052	4.9330
250	30.997	25.336	5.2862	60.917	7.881	4.5599
500	51.954	11.540	4.2473	53.244	13.262	3.7855
1000	32.747	22.454	2.9566	61.860	6.664	3.6116
2000	17.900	31.049	3.4876	55.961	9.478	3.5748
4000	14.038	27.906	4.3392	56.404	3.668	4.9298
8000	2.645	29.834	4.5858	43.064	6.295	5.2533

Roadway Type 1 (Controlled Access, ≤ 2% Grade)

Truck Type 1 - Medium Trucks and Buses:

$$\bar{L}_0 = 19.81 + 36.32 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(2.92)^2 = 20.79 + 36.32 \log V$$

Truck Type 2 - Heavy Trucks:

$$\bar{L}_0 = 53.27 + 19.28 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(2.47)^2 = 53.98 + 19.28 \log V$$

Roadway Type 2 (Controlled Access, > 2% Upgrade)

Truck Type 1 - Medium Trucks and Buses:

$$\bar{L}_0 = 61.54 + 11.78 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(3.20)^2 = 62.72 + 11.78 \log V$$

Truck Type 2 - Heavy Trucks:

$$\bar{L}_0 = 73.89 + 7.46 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(2.65)^2 = 74.70 + 7.46 \log V$$

Roadway Type 3 (Controlled Access, > 2% Downgrade)

Truck Type 1 - Medium Trucks and Buses:

$$\bar{L}_0 = 38.98 + 24.21 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(3.36)^2 = 40.28 + 24.21 \log V$$

Truck Type 2 - Heavy Trucks:

$$\bar{L}_0 = 29.36 + 32.22 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(2.83)^2 = 30.28 + 32.22 \log V$$

Roadway Type 4 (Non-controlled Access, ≤ 2% Grade)

Truck Type 1 - Medium Trucks and Buses:

$$\bar{L}_0 = 40.51 + 22.85 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(3.25)^2 = 41.72 + 22.85 \log V$$

Truck Type 2 - Heavy Trucks:

$\bar{L}_0 = 48.05 + 21.00 \log V$

$(\bar{L}_0)_E = \bar{L}_0 + 0.115\ (2.84)^2 = 48.98 + 21.00 \log V$

<u>Roadway Type 5 (Non-controlled Access, > 2% Upgrade)</u>

Truck Type 1 - Medium Trucks and Buses:

$\bar{L}_0 = 50.04 + 18.55 \log V$

$(\bar{L}_0)_E = \bar{L}_0 + 0.115\ (3.52)^2 = 51.46 + 18.55 \log V$

Truck Type 2 - Heavy Trucks:

$\bar{L}_0 = 79.93 + 3.63 \log V$

$(\bar{L}_0)_E = \bar{L}_0 + 0.115\ (3.23)^2 = 81.13 + 3.63 \log V$

<u>Roadway Type 6 (Non-controlled Access, > 2% Downgrade)</u>

Truck Type 1 - Medium Trucks and Buses:

$\bar{L}_0 = 21.32 + 33.98 \log V$

$(\bar{L}_0)_E = \bar{L}_0 + 0.115\ (3.02)^2 = 22.36 + 33.98 \log V$

Truck Type 2 - Heavy Trucks:

$\bar{L}_0 = 31.67 + 30.42 \log V$

$(\bar{L}_0)_E = \bar{L}_0 + 0.115\ (3.10)^2 = 32.77 + 30.42 \log V$

<u>Roadway Type 7A (Accelerating Trucks on Ramps)</u>

Truck Type 1 - Medium Trucks and Buses:

$\bar{L}_0 = 60.78 + 9.82 \log V$

$(\bar{L}_0)_E = \bar{L}_0 + 0.115\ (4.09)^2 = 62.70 + 9.82 \log V$

Truck Type 2 - Heavy Trucks:

$\bar{L}_0 = 64.14 + 11.96 \log V$

$(\bar{L}_0)_E = \bar{L}_0 + 0.115\ (3.39)^2 = 65.45 + 11.96 \log V$

Roadway Type 7B (Non-accelerating Trucks on Ramps)

Truck Type 1 - Medium Trucks and Buses:

$$\bar{L}_0 = 45.03 + 20.51 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(3.45)^2 = 46.40 + 20.51 \log V$$

Truck Type 2 - Heavy Trucks:

$$\bar{L}_0 = 68.20 + 7.71 \log V$$

$$(\bar{L}_0)_E = \bar{L}_0 + 0.115\,(3.42)^2 = 69.54 + 7.71 \log V$$

Examination of New Jersey's Truck Noise Emission Levels

Overall energy mean emission levels for Truck Types 1 and 2 and Roadway Types 1 - 6 are graphed versus truck speed (mph) in Figures 9 and 10, pages 70 and 71. These figures are very similar to Figures 4 and 5, pages 44 and 47, which were presented in the data analysis section of this report. They differ in that Figures 4 and 5 illustrate arithmetic mean emission levels. For Roadway Types 1 - 6, the difference between energy mean and arithmetic mean emission levels -- the adjustment 0.115 times $(SE)^2$ -- ranged from 0.7 to 1.4 decibels.

An examination of Figures 9 and 10 reveals the following:

(1) The emission level for upgrade roadways (Types 2 and 5) is less speed dependent than that of level and downgrade roadways.

(2) In general, the emission level for downgrade roadways (Types 3 and 6) is the most speed dependent.

(3) For most roadway types, emission levels for Truck Type 1 (medium trucks and buses) are more speed dependent than those of Truck Type 2 (heavy trucks).

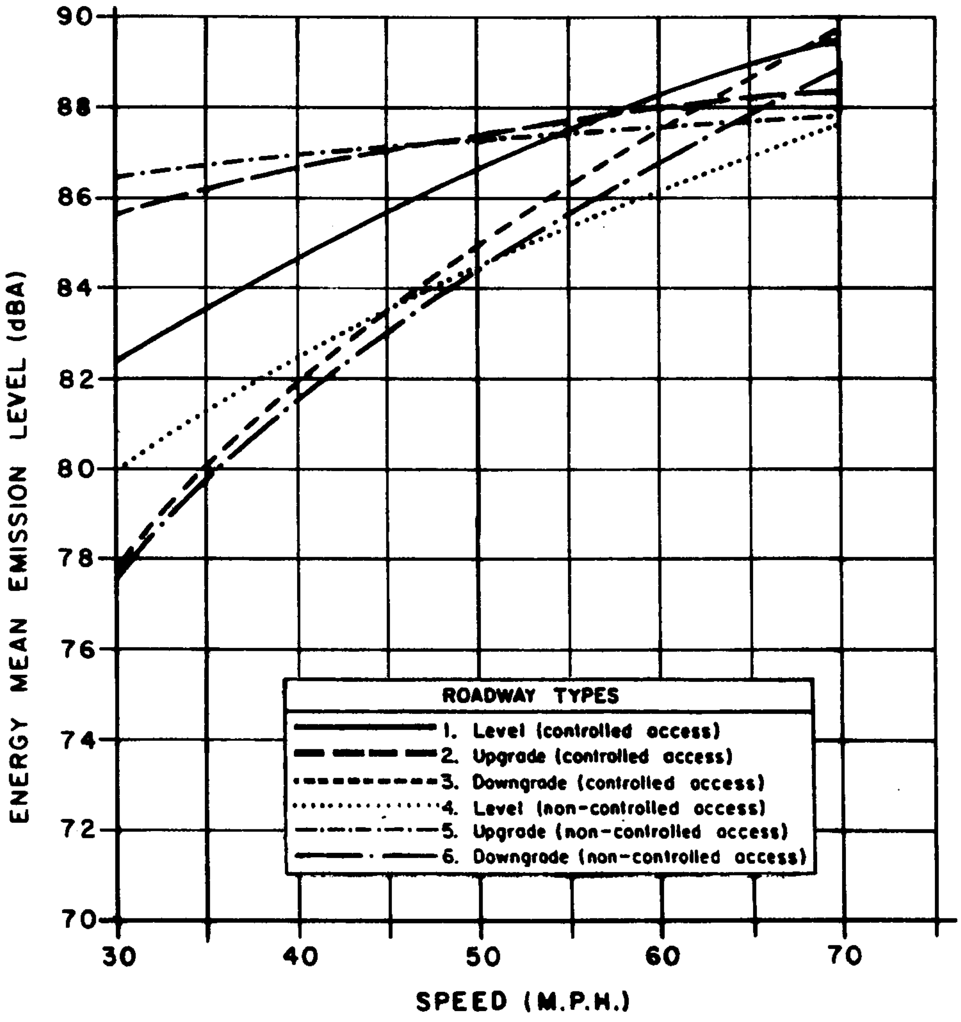


Figure 9. OVERALL ENERGY MEAN EMISSION LEVELS FOR TRUCK TYPE 2 (HEAVY TRUCKS) FOR ROADWAY TYPES 1-6.

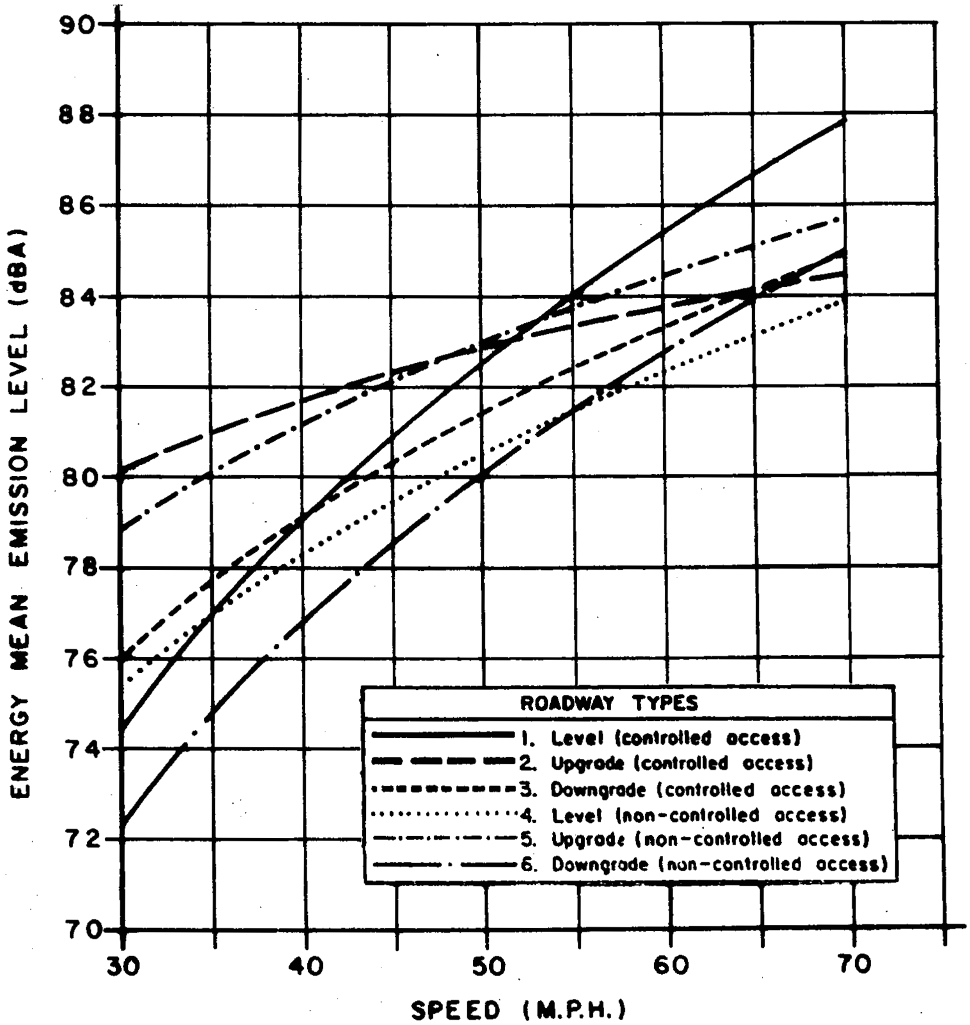


Figure 10. OVERALL ENERGY MEAN EMISSION LEVELS FOR TRUCK TYPE 1 (MEDIUM TRUCKS & BUSES) FOR ROADWAY TYPES 1-6

(4) For speeds of 35-50 mi/hr (56-80 km/hr), upgrade roadways (Types 2 and 5) have the highest emission levels; level roadways (Types 1 and 4), the next highest; and downgrade roadways (Types 3 and 6), the lowest.

(5) The respective differences between the emission levels for the various roadway types usually increase with a decrease in speed.

(6) For speeds of 55 and 60 mi/hr (88 and 96 km/hr), the emission levels for all roadway types vary by less than 3.1 decibels for both Type 1 and Type 2 Trucks.

Overall emission levels for Roadway Type 7 (ramps) are graphed versus truck speed in Figure 11, page 73. Emission levels for accelerating trucks on ramps (Type 7A) and non-accelerating trucks on ramps (Type 7B) are shown. Also, emission levels for both Type 1 and Type 2 Trucks are included in this same figure. Note that the speed range has been changed to reflect the lower truck speeds occurring on ramps. An examination of the figure reveals the following:

(1) For heavy trucks (Truck Type 2), the emission levels for acceleration on ramps (Roadway Type 7A) are higher than those for non-acceleration on ramps (Roadway Type 7B) for all speeds. At typical speeds of 25-30 mi/hr (40-48 km/hr) the emission level for Roadway Type 7A is about 2 dB higher. The difference between the emission levels for these roadway types increases with an increase in speed.

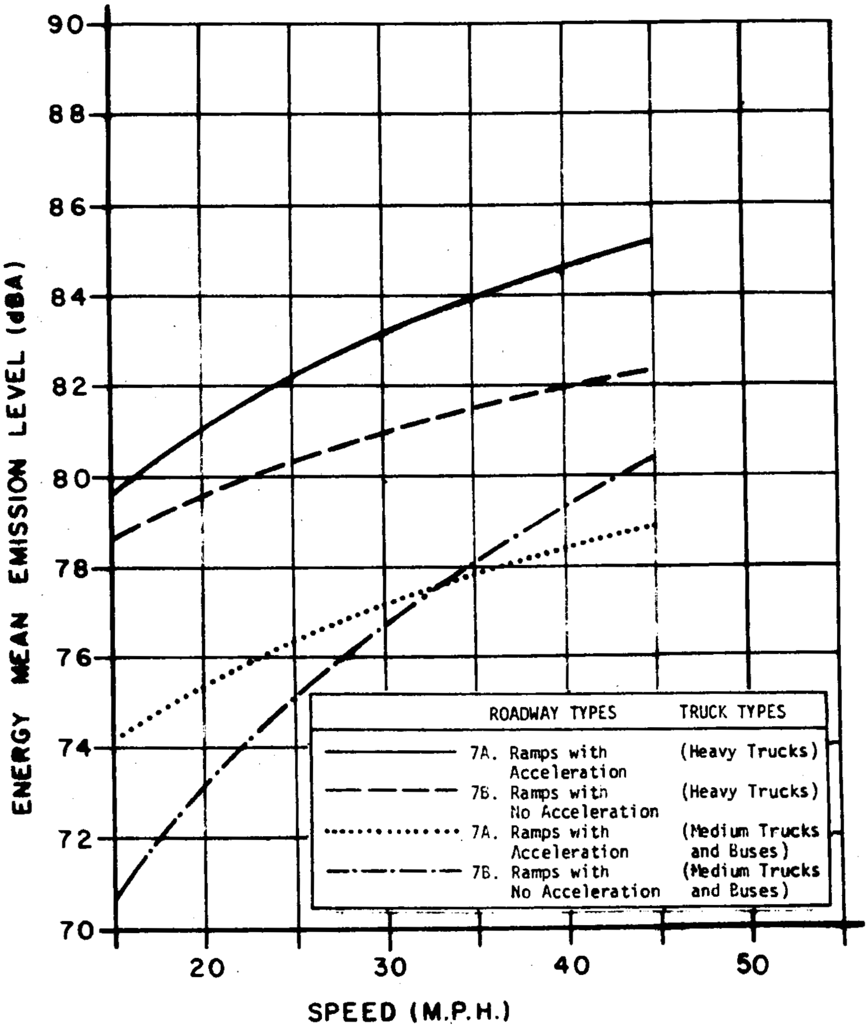


Figure 11. OVERALL ENERGY MEAN EMISSION LEVELS
FOR TRUCK TYPES 1 & 2
FOR ROADWAY TYPE 7 (RAMPS)

(2) For medium trucks and buses (Truck Type 1), the emission level for acceleration on ramps (Roadway Type 7A) is higher than that for non-acceleration on ramps (Roadway Type 7B) below 30 mph. However, for typical speeds of 25-30 mi/hr (40-48 km/hr), Type 7A's emission level was usually less than a decibel higher. Above 35 miles per hour (56 km/hr), the emission level for Roadway Type 7B (no acceleration) is higher than that for Type 7A (acceleration). This result was not expected and may have occurred since relatively few valid measurements were obtained for medium trucks and buses (Type 1 Trucks) for Roadway Types 7A and 7B ---- 40 measurements for Type 7A; 78 for Type 7B.

The arithmetic mean octave band levels, $\overline{L_0}$, specified by the coefficients in Table 4 were not directly examined. Instead, an equation for energy mean emission level $(\overline{L_0})_E$, was calculated for each octave band by adding 0.115 $(SE)^2$ to the arithmetic mean level regression equation. Graphs of energy mean emission levels versus truck speed in miles per hour were constructed for Truck Types 1 and 2 for each of the eight roadway types - a total of 16 graphs. These graphs are presented as Figures 12-1 to 12-16, pages 78 to 93. Each figure consists of a plot of the overall level and the eight corresponding octave band levels (63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz).

The figures for Roadway Types 1-6 were compared to each other and the following trends were observed:

(1) At typical speeds*, the four octave bands with the highest levels were the 250, 500, 1000 and 2000 Hz bands. At these speeds, these four octave bands had levels significantly higher than the 63, 125, 4000 and 8000 Hz octave bands. In fact, the contribution of the 63, 125, 4000 and 8000 Hz octave bands towards the overall level was in general on the order of 1/2 a decibel.

(2) At typical speeds, the two highest octave band levels were usually the 1000 and 500 Hz octave bands for both Truck Types 1 and 2. At typical speeds, the 500 Hz octave band often had the highest level for Truck Type 1; however for Truck Type 2, the 500 Hz octave band never had the highest level. At 50 mi/hr (80 km/hr), the 250 Hz octave band contributed slightly more to the overall level of Truck Type 1 than it did to that of Truck Type 2.

(3) At 50 mi/hr (80 km/hr), on upgrade roadways (Types 2 and 5), the 250 Hz octave band in general contributed more to the overall level than on downgrade roadways (Types 3 and 6). This trend can be seen when Roadway Type 5 is compared to Roadway Type 6 for Type 1 Trucks. In addition, at 50 mi/hr (80 km/hr), on non-controlled access upgrade roadways (Type 5), the 250 Hz octave band contributed more to the overall level than on non-controlled access level roadways (Type 4).

*For Truck Types 1 and 2, the average speed obtained from field measurements was used as the typical speed for a roadway type, see Table 2, page 41.

(4) At 50 mi/hr (80 km/hr), on downgrade roadways (Types 3 and 6), the 2000 Hz octave band in general contributed more to the overall level than on level and upgrade roadways (1, 2, 4 and 5). This can be seen when Roadway Type 3 is compared to Roadway Type 1 for Truck Type 2. This trend was more pronounced for Truck Type 2.

(5) For all six roadway types, as truck speed is decreased the 250 Hz octave band level makes a greater contribution to the overall level for both Truck Types 1 and 2. This same trend was also observed in quite a few cases for the 125 Hz octave band.

(6) For upgrade roadways (Types 2 and 5), octave band emission levels were usually less speed dependent for Truck Type 2 (heavy trucks) than they were for Truck Type 1 (medium trucks and buses).

(7) In general, the 63, 125, and 250 Hz octave band levels were less speed dependent than the 500, 1000, 2000, 4000 and 8000 Hz octave band levels for all roadway types.

(8) In some instances the 63, 125, and 250 Hz octave bands show an inverse relationship with speed; i.e., the emission level decreases with an increase in speed. This relationship occurred most often for upgrade roadways (Types 2 and 5).

A comparison of the figures for Roadway Type 7 (Ramps) indicated the following:

(1) As with Roadway Types 1-6, at typical speeds*, the four octave bands with the highest levels for Type 2 Trucks on ramps were 250, 500, 1000 and 2000 Hz. However, for Type 1 Trucks the four

*See footnote page 75.

octave bands with the highest levels were 125, 250, 500 and 1000 Hz. Thus, for Type 1 Trucks on ramps, the 125 Hz octave band level was relatively higher and the 2000 Hz octave band level relatively lower than for Type 1 Trucks on Roadway Types 1-6.

(2) Whereas, for typical speeds on Roadway Types 1-6 the 500 Hz and 1000 Hz octave bands usually had the highest levels for both Truck Types 1 and 2, for Roadway Type 7, the 250 Hz octave band often had the highest level. Indeed, on Roadway Type 7B (non-accelerating trucks on ramps), the 250 Hz octave band had the highest level for both Type 1 and Type 2 Trucks. It was also the highest level octave band for Truck Type 1 (medium trucks and buses) for both Roadway Types 7A and 7B.

(3) The 1000 Hz octave band made a greater contribution to the overall level for Truck Types 1 and 2 on Roadway Type 7A (ramps with accelerating trucks) than it did for trucks on Roadway Type 7B (ramps with non-accelerating trucks) for a speed of 30 mi/hr (48 km/hr).

(4) As with Roadway Types 1-6, the 63 and 125 Hz octave band levels for Roadway Type 7 showed an inverse relationship with speed in several instances. However, for Type 1 Trucks on Roadway Type 7A (ramps with accelerating trucks), the 500 and 8000 Hz octave bands showed this inverse relationship. Once again, it is suspected that the limited number of measurements (40) for this roadway type and truck type may have accounted for these unusual results.

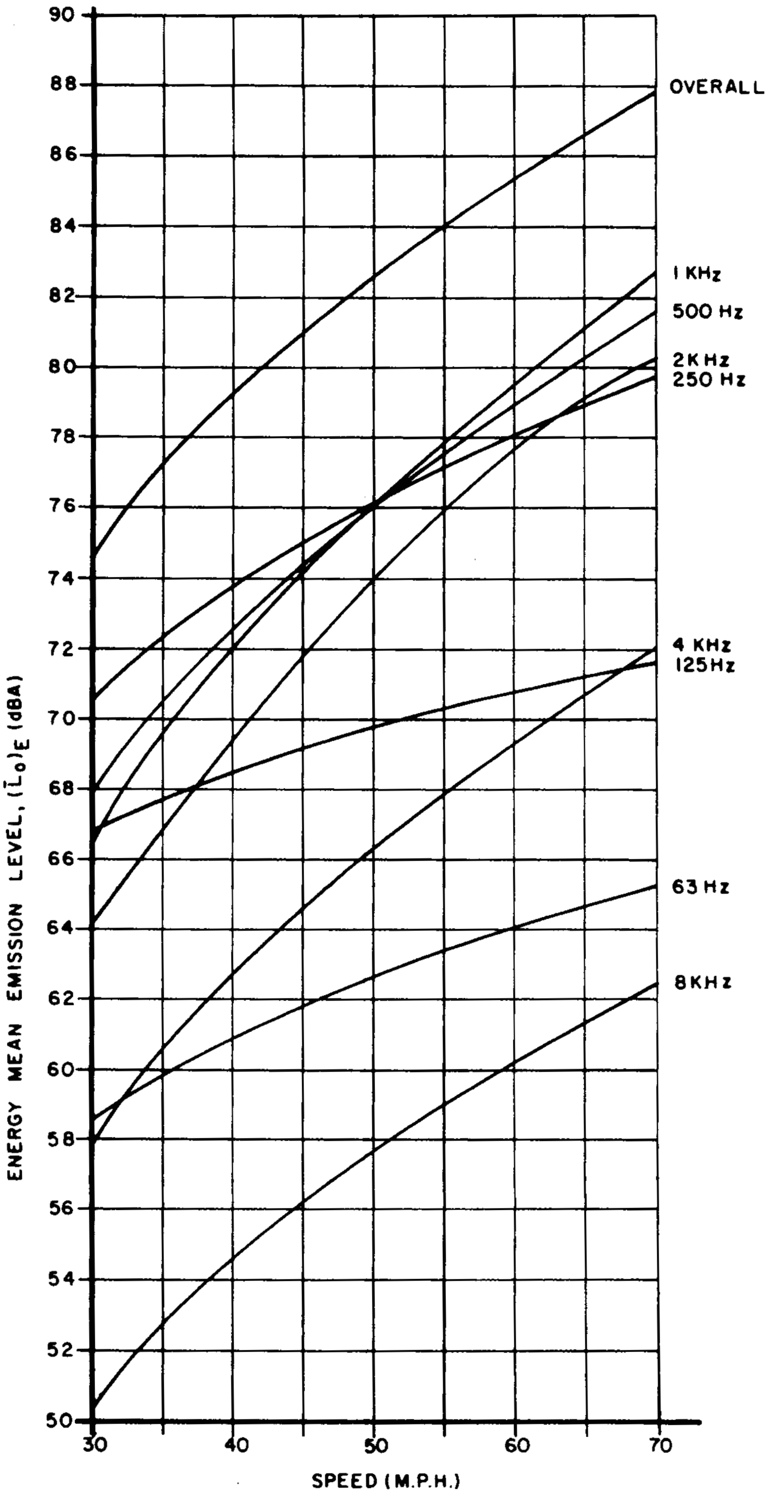


Figure 12-1. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE I (LEVEL, CONTROLLED ACCESS)
TRUCK TYPE I (MEDIUM TRUCKS & BUSES)

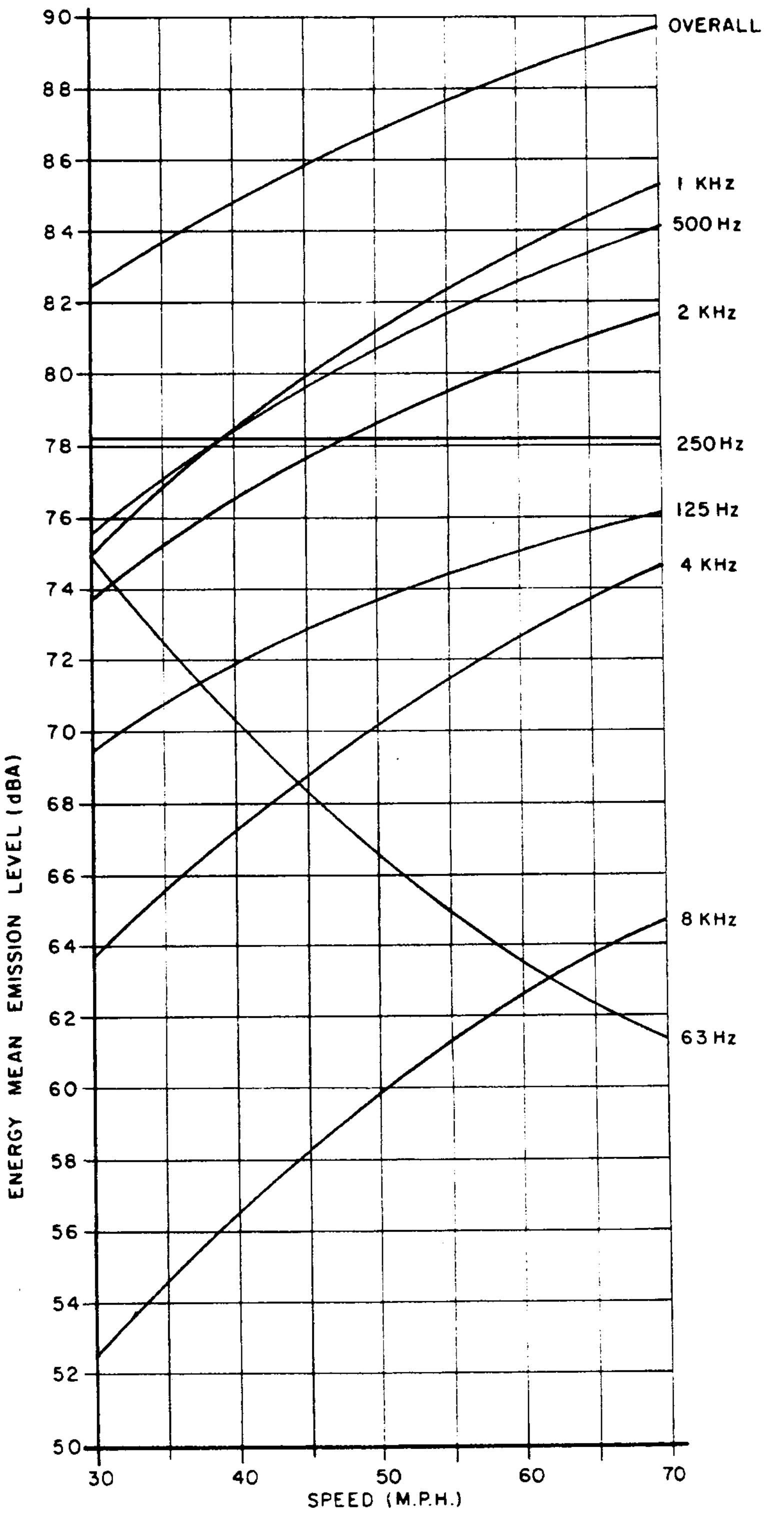


Figure 12-2. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 1 (LEVEL, CONTROLLED ACCESS)
TRUCK TYPE 2 (HEAVY TRUCKS)

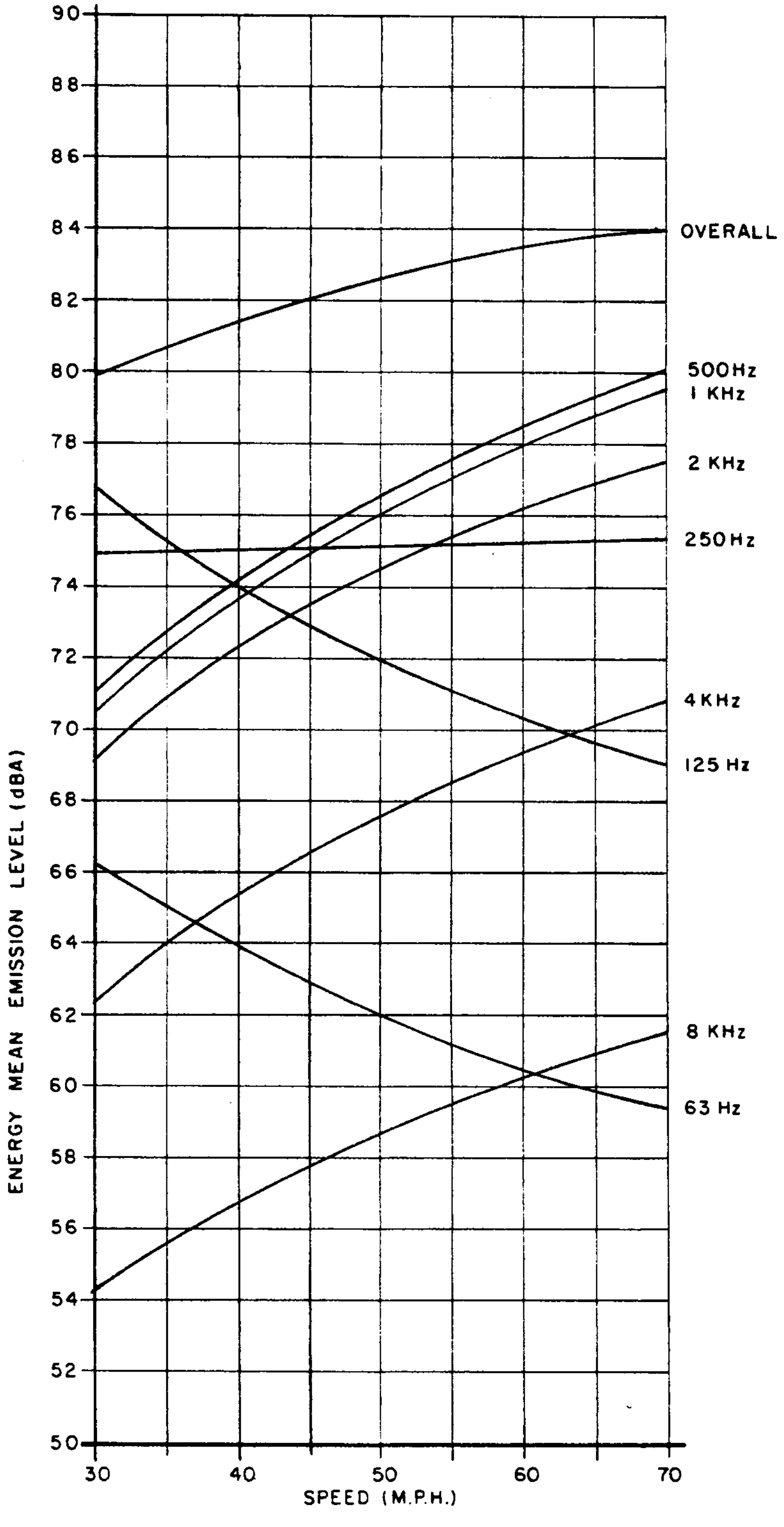


Figure 12-3. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 2 (UPGRADE, CONTROLLED ACCESS)
TRUCK TYPE 1 (MEDIUM TRUCKS & BUSES)

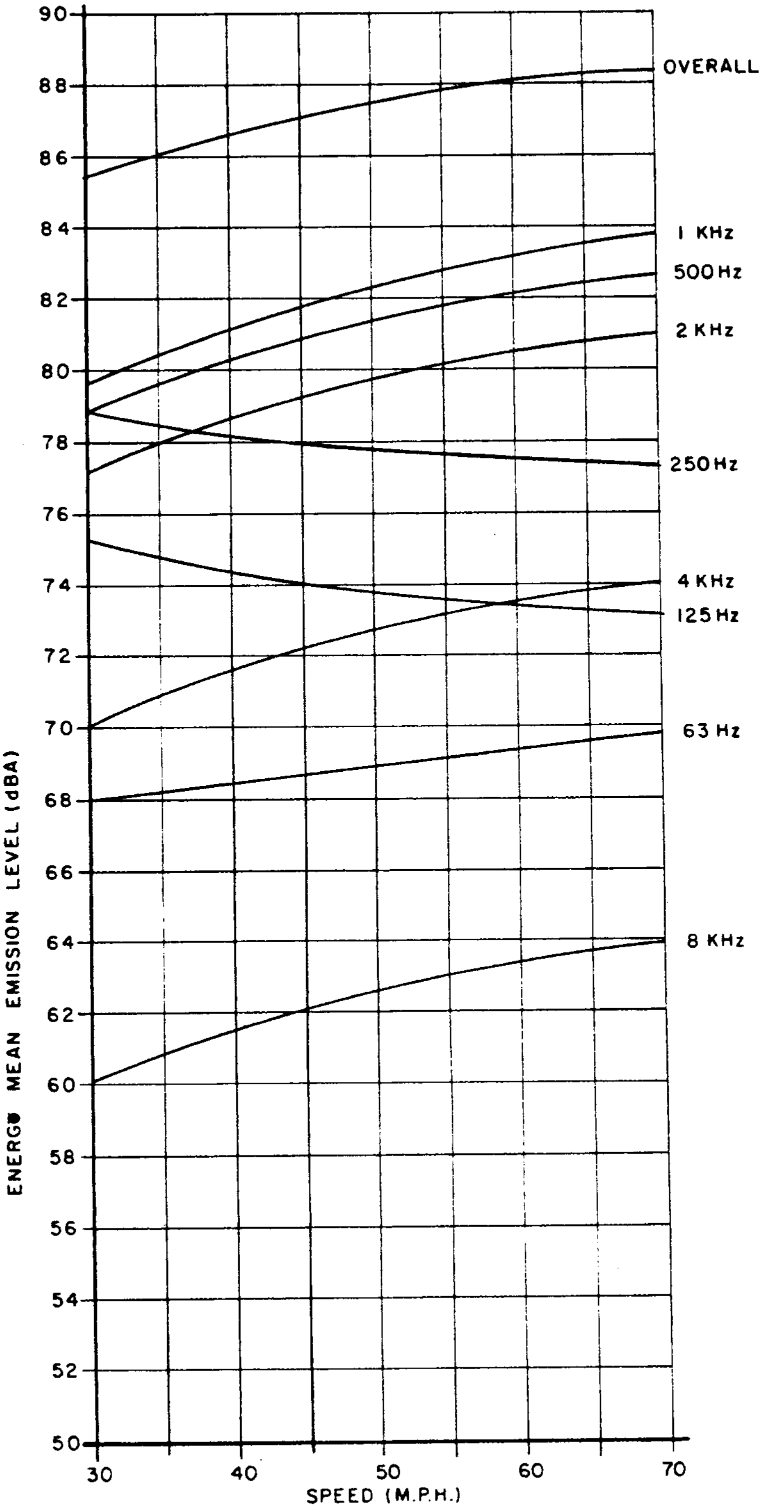


Figure 12-4. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 2 (UPGRADE, CONTROLLED ACCESS)
TRUCK TYPE 2 (HEAVY TRUCKS)

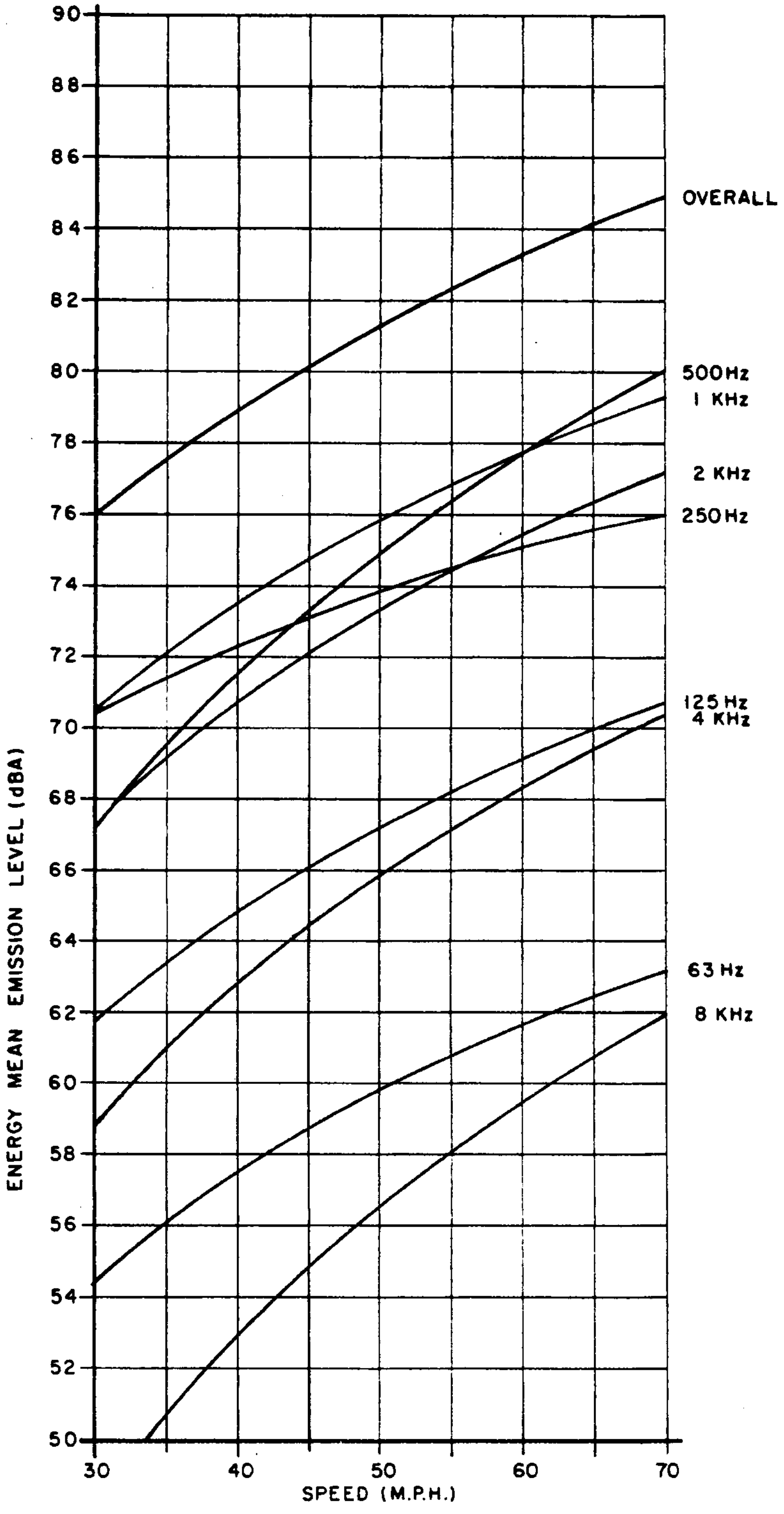


Figure 12-5. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 3 (DOWNGRADE, CONTROLLED ACCESS)
TRUCK TYPE I (MEDIUM TRUCKS & BUSES)

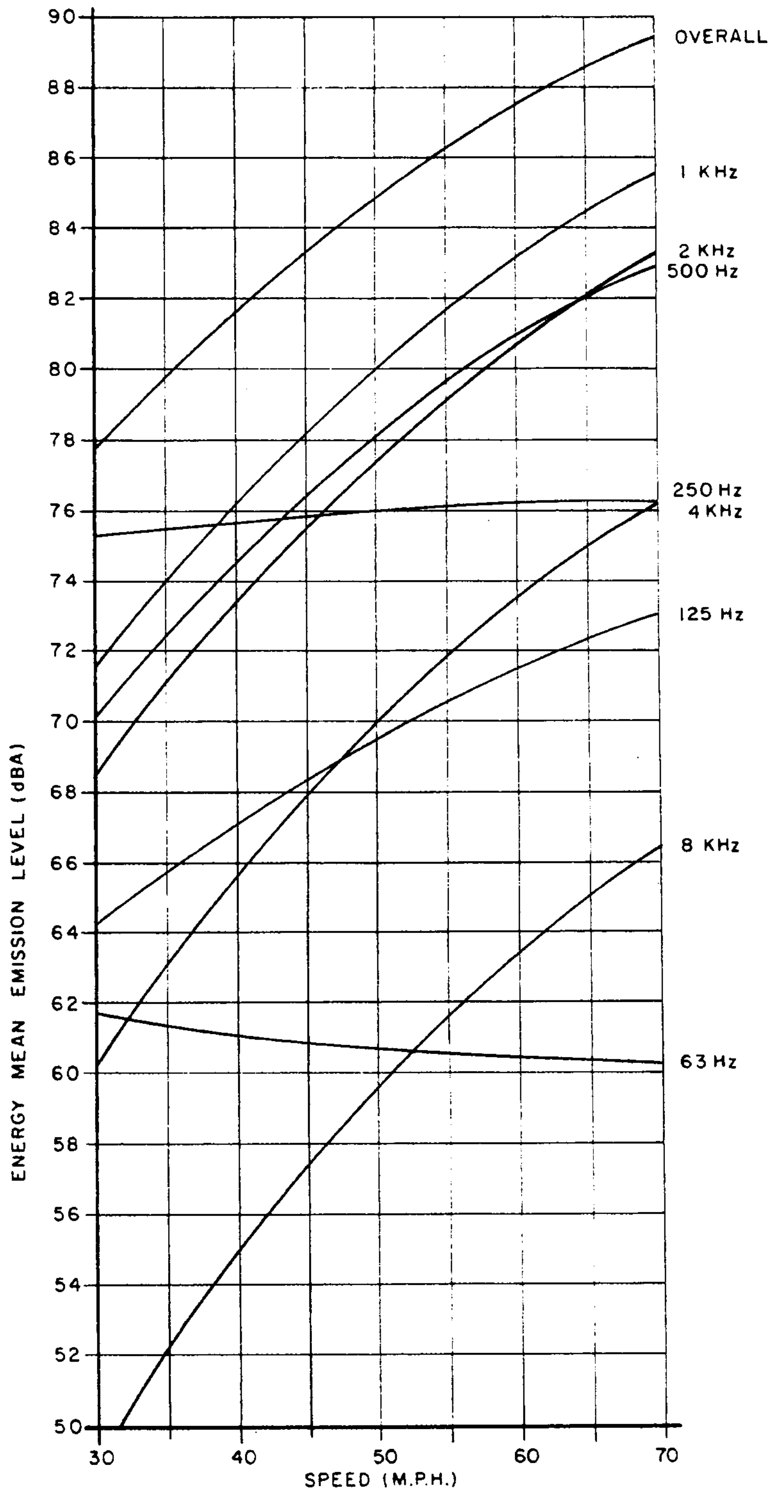


Figure 12-6. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 3 (DOWNGRADE, CONTROLLED ACCESS)
TRUCK TYPE 2 (HEAVY TRUCKS)

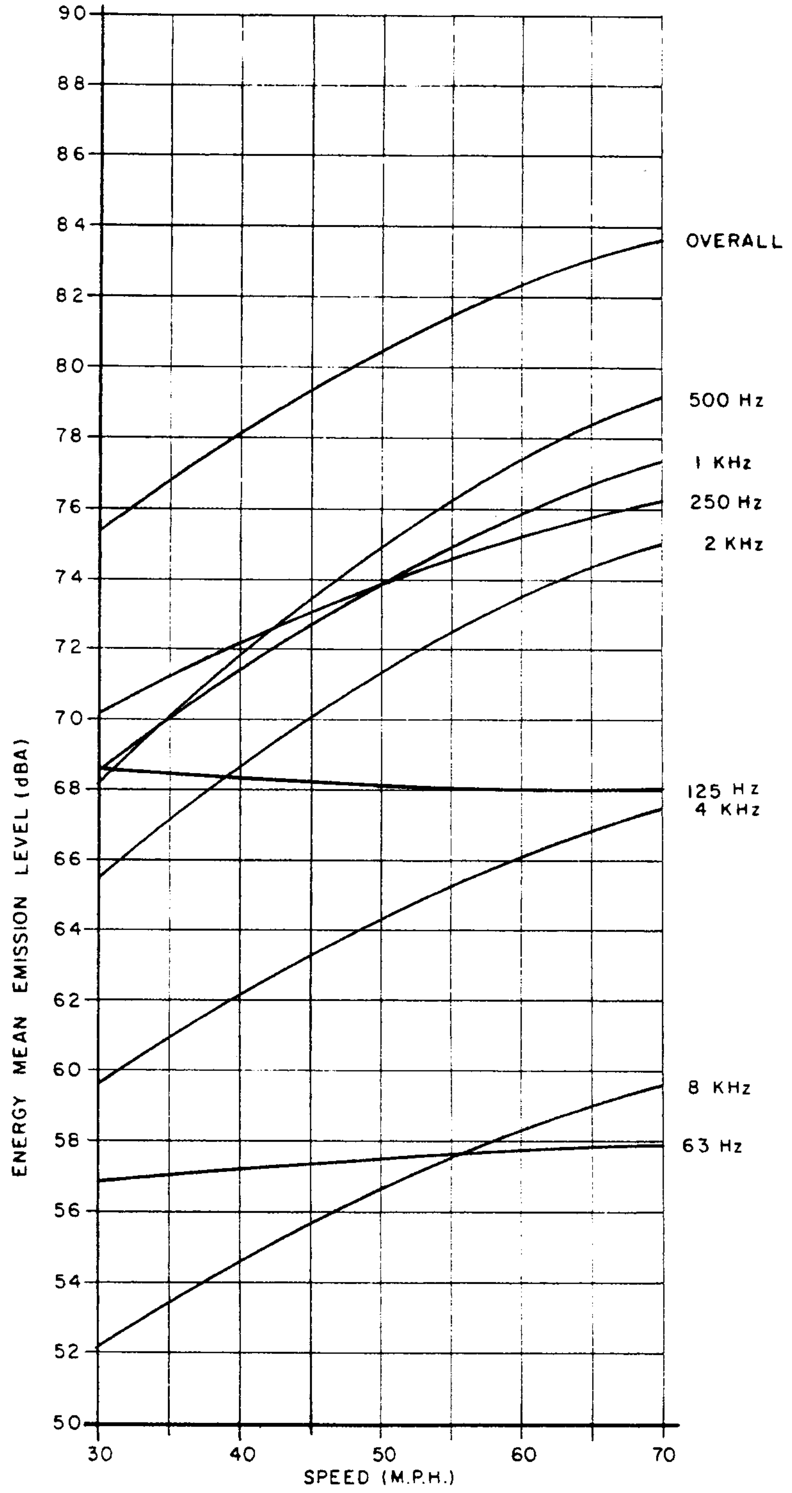


Figure 12-7. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 4 (LEVEL, NON-CONTROLLED ACCESS)
TRUCK TYPE I (MEDIUM TRUCKS & BUSES)

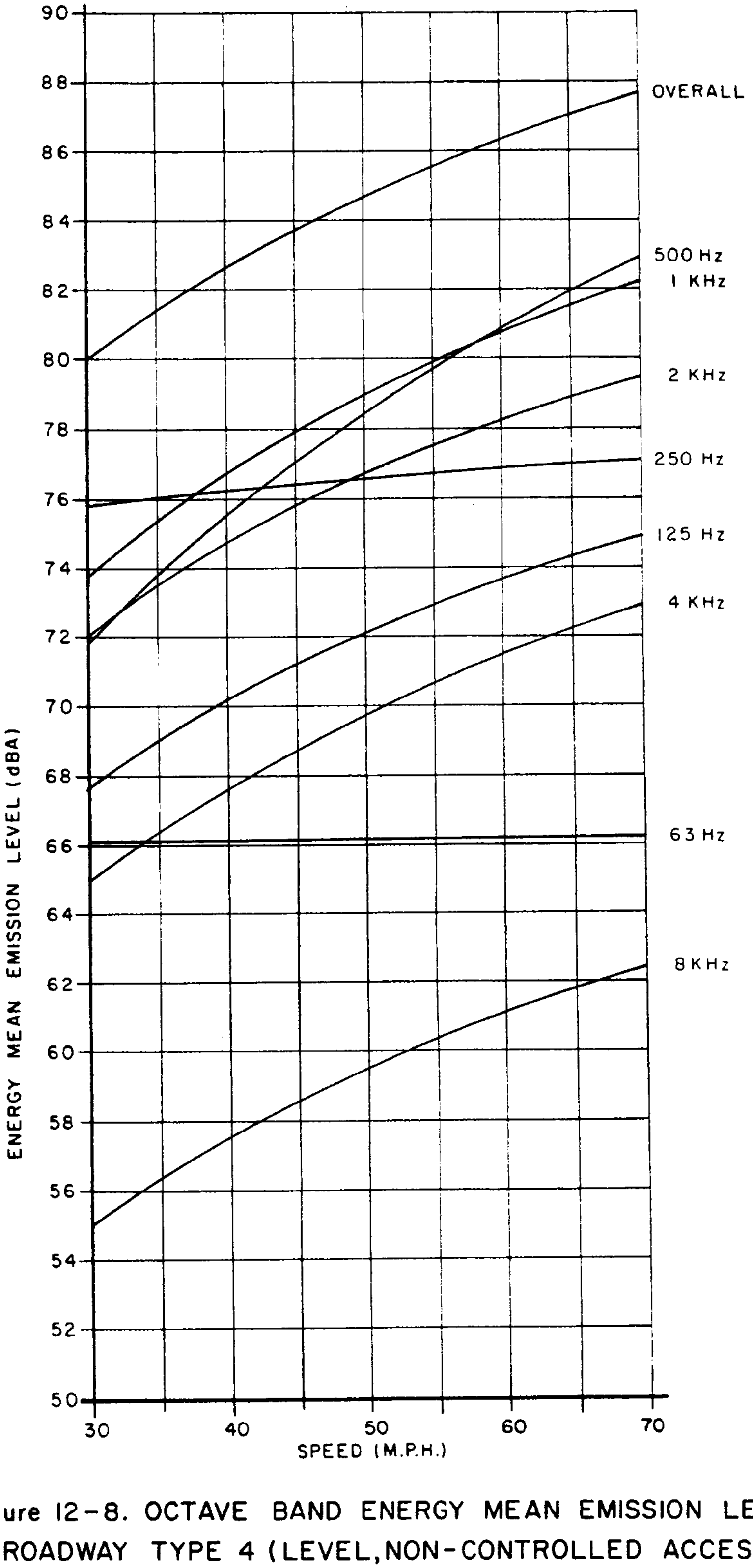


Figure 12-8. OCTAVE BAND ENERGY MEAN EMISSION LEVELS ROADWAY TYPE 4 (LEVEL, NON-CONTROLLED ACCESS) TRUCK TYPE 2 (HEAVY TRUCKS)

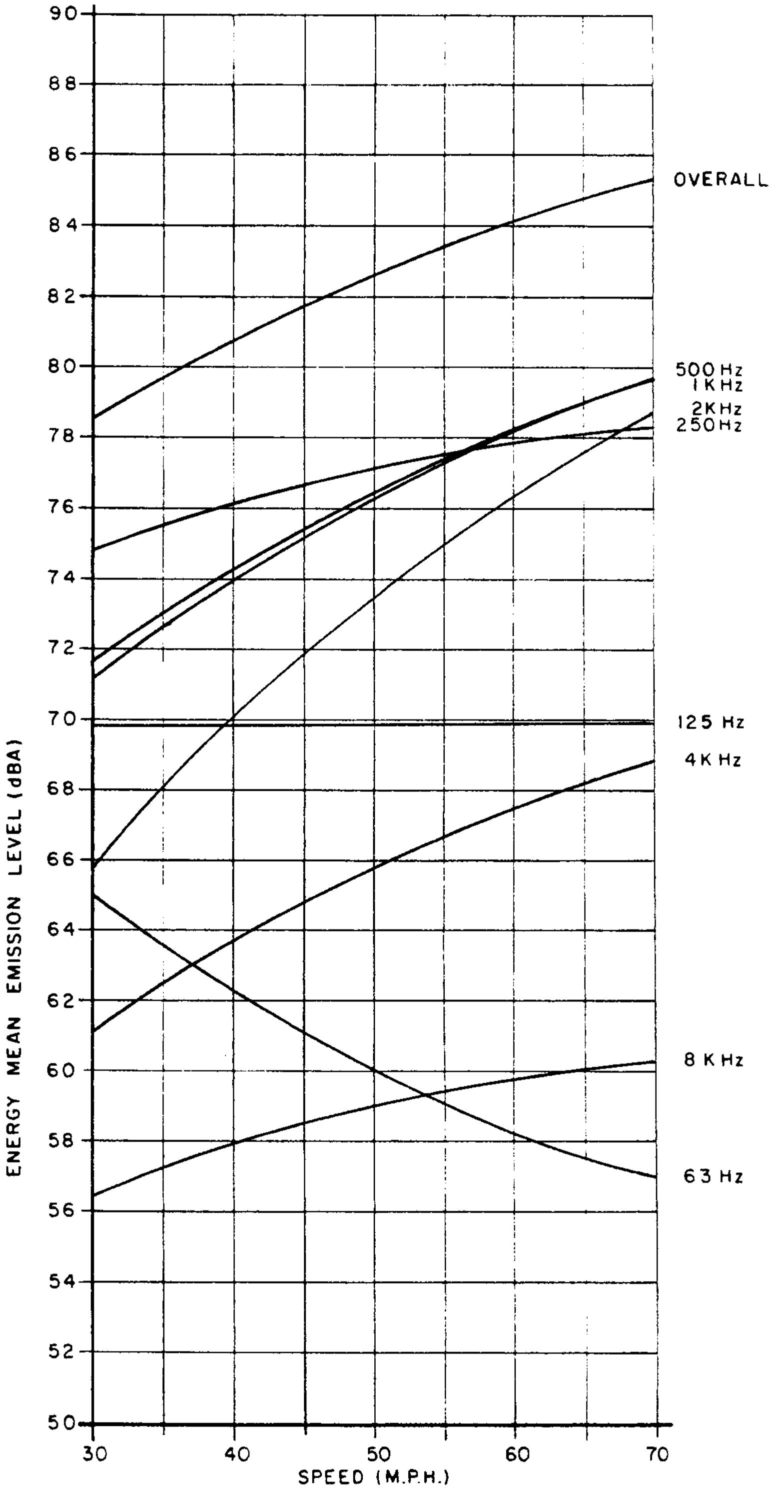


Figure 12-9. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 5 (UPGRADE, NON-CONTROLLED ACCESS)
TRUCK TYPE I (MEDIUM TRUCKS & BUSES)

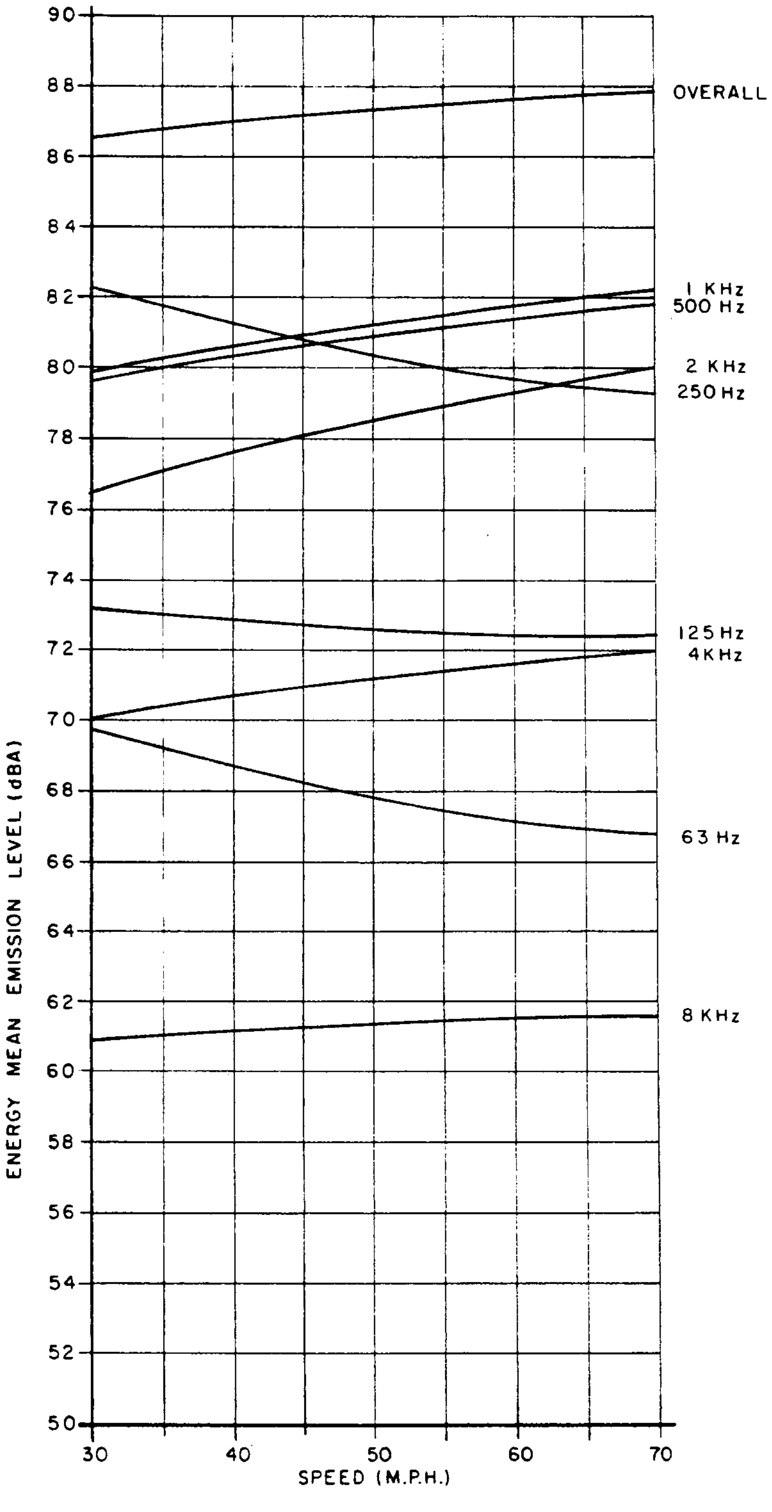


Figure 12-10. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 5 (UPGRADE, NON-CONTROLLED ACCESS)
TRUCK TYPE 2 (HEAVY TRUCKS)

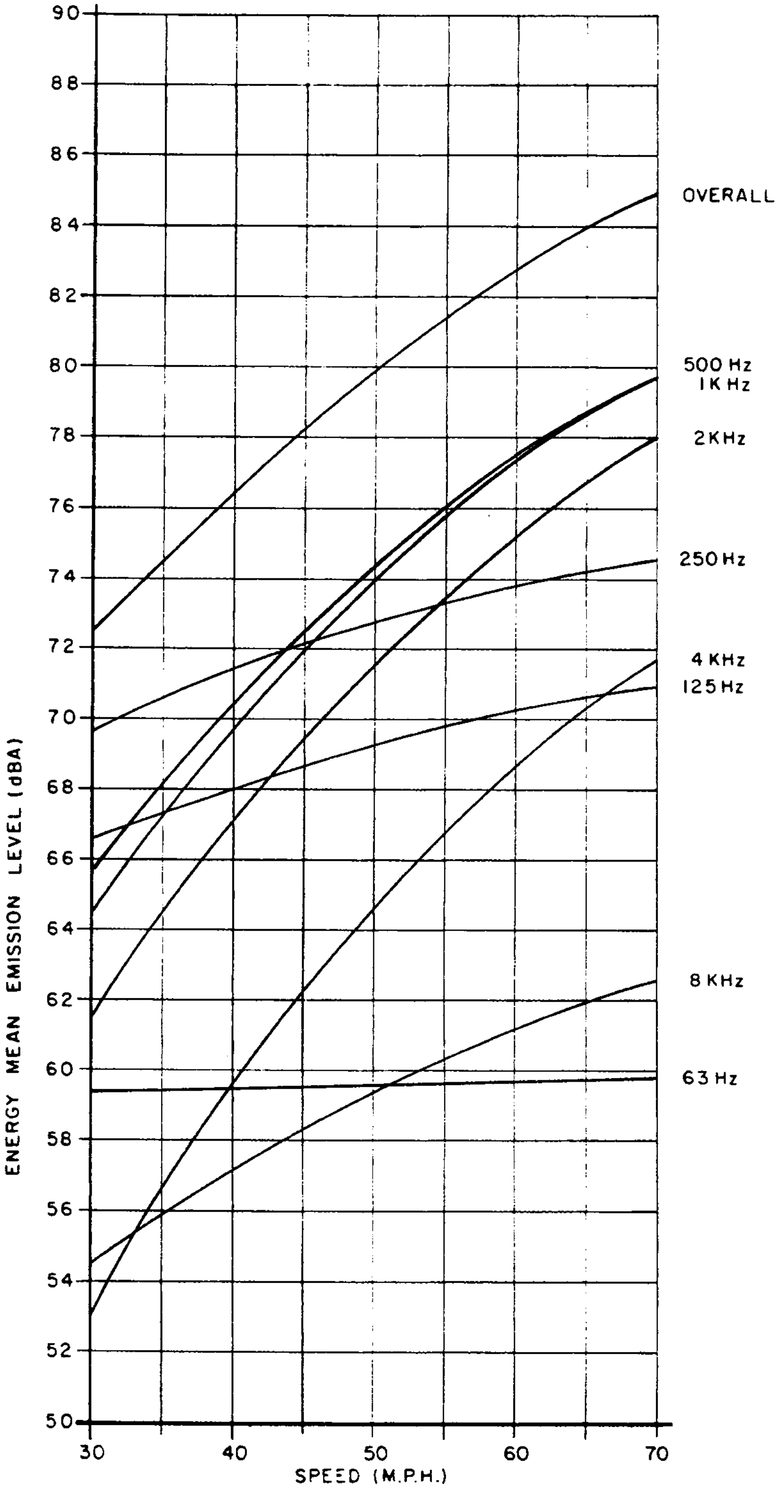


Figure 12-11. OCTAVE BAND ENERGY MEAN EMISSION LEVELS ROADWAY TYPE 6 (DOWNGRADE, NON-CONTROLLED ACCESS TRUCK TYPE 1 (MEDIUM TRUCKS & BUSES)

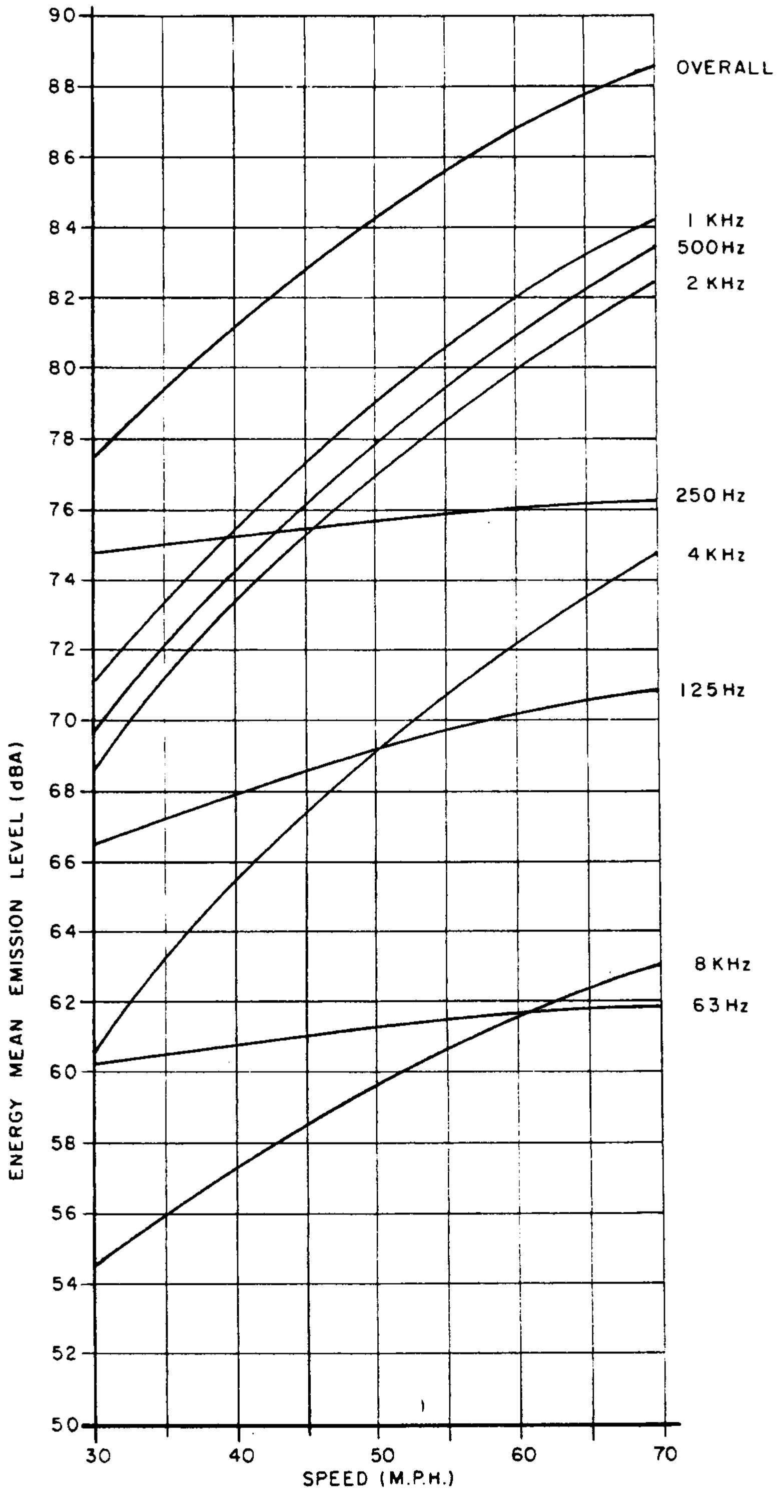


Figure 12-12. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 6 (DOWNGRADE, NON-CONTROLLED ACCESS)
TRUCK TYPE 2 (HEAVY TRUCKS)

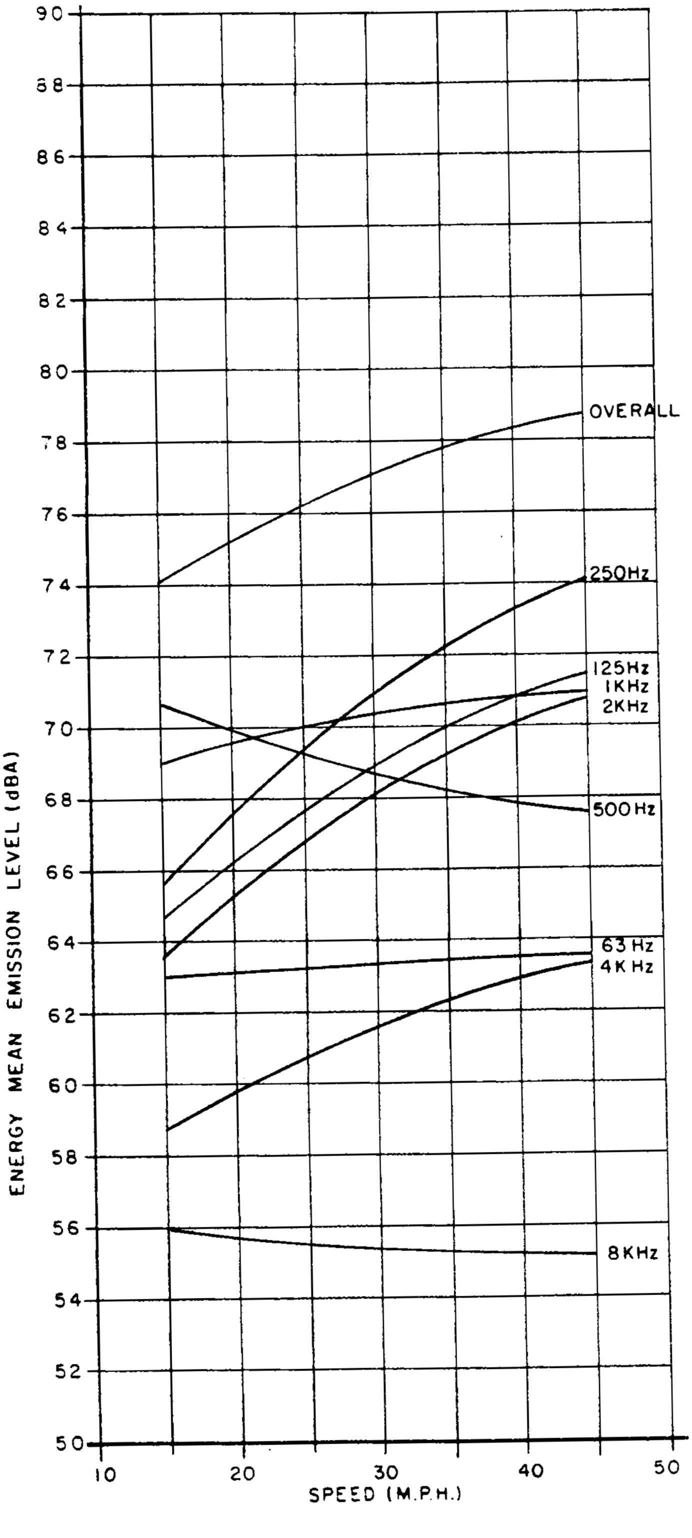


Figure 12-13. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 7A (RAMPS, ACCELERATION)
TRUCK TYPE I (MEDIUM TRUCKS & BUSES)

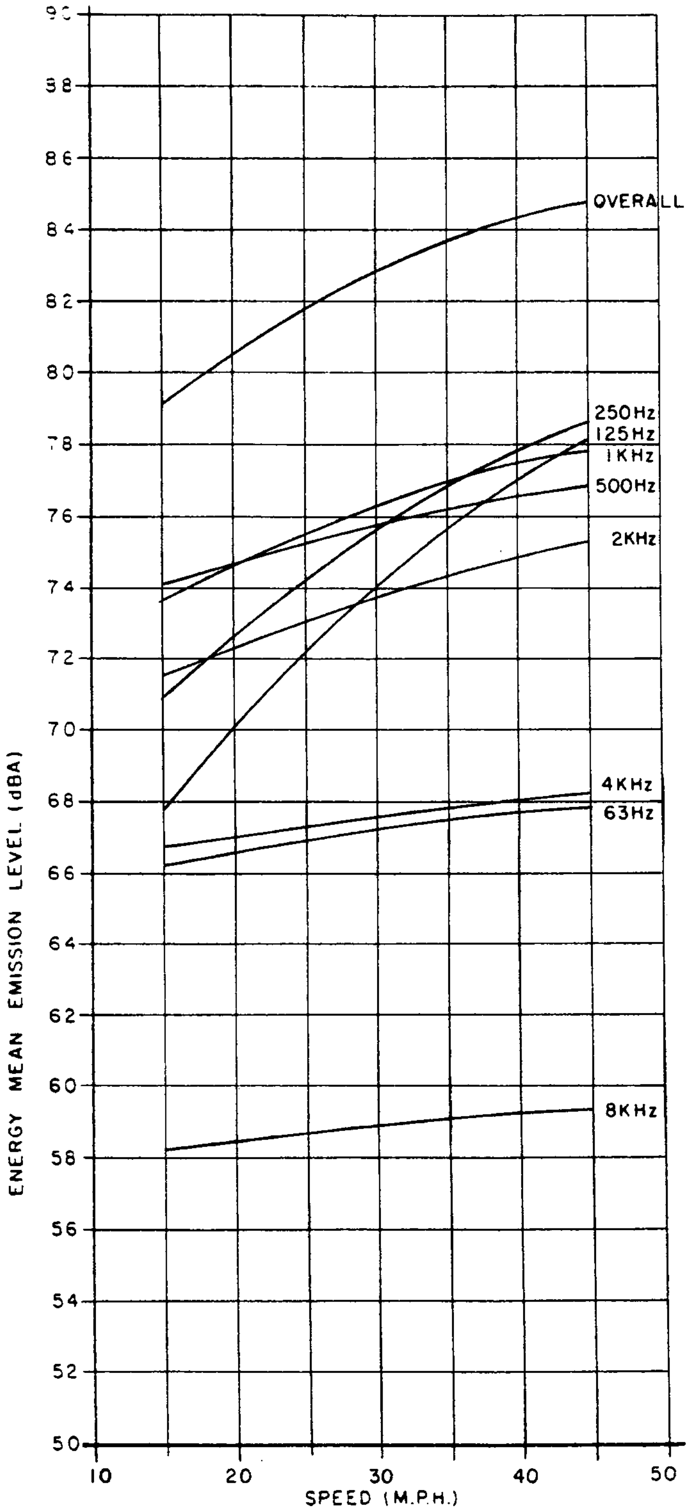


Figure 12-14. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 7A (RAMPS, ACCELERATION)
TRUCK TYPE 2 (HEAVY TRUCKS)

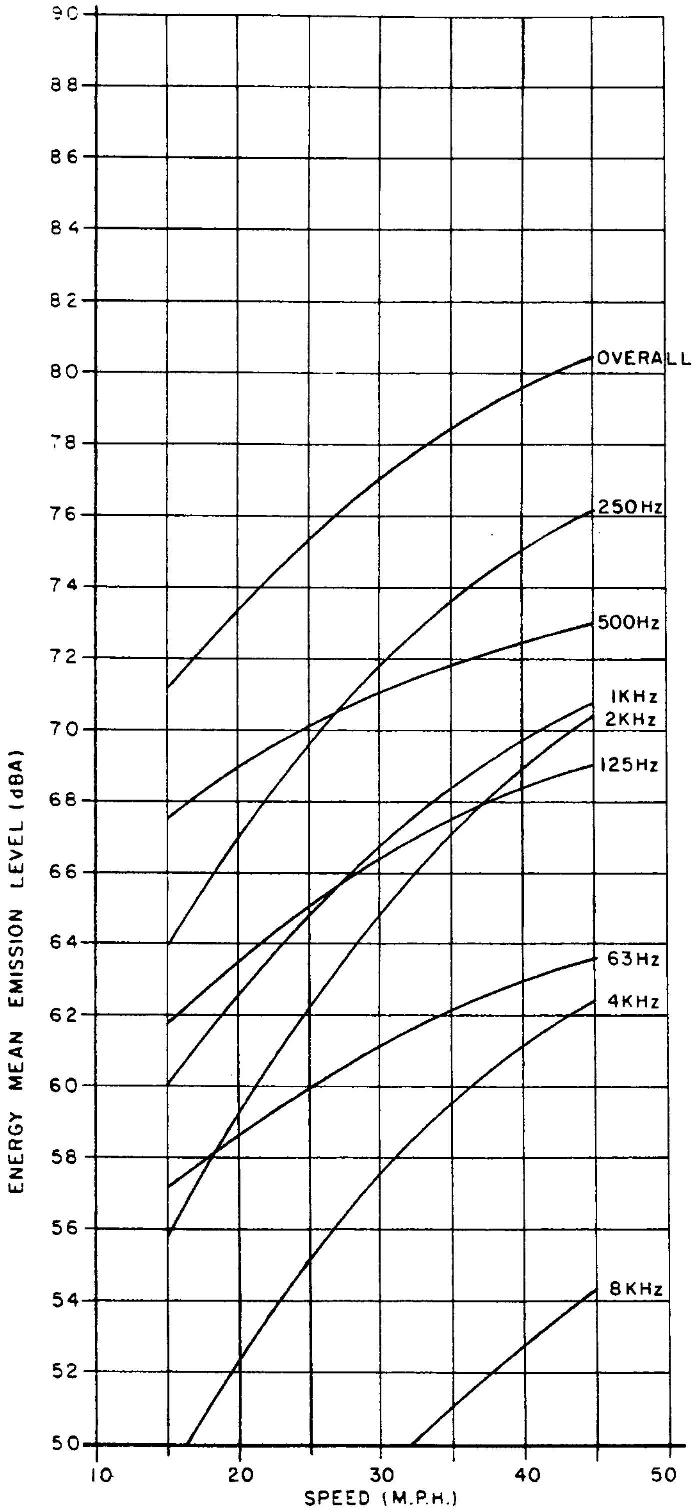


Figure 12-15. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 7B (RAMPS, NO-ACCELERATION)
TRUCK TYPE 1 (MEDIUM TRUCKS & BUSES)

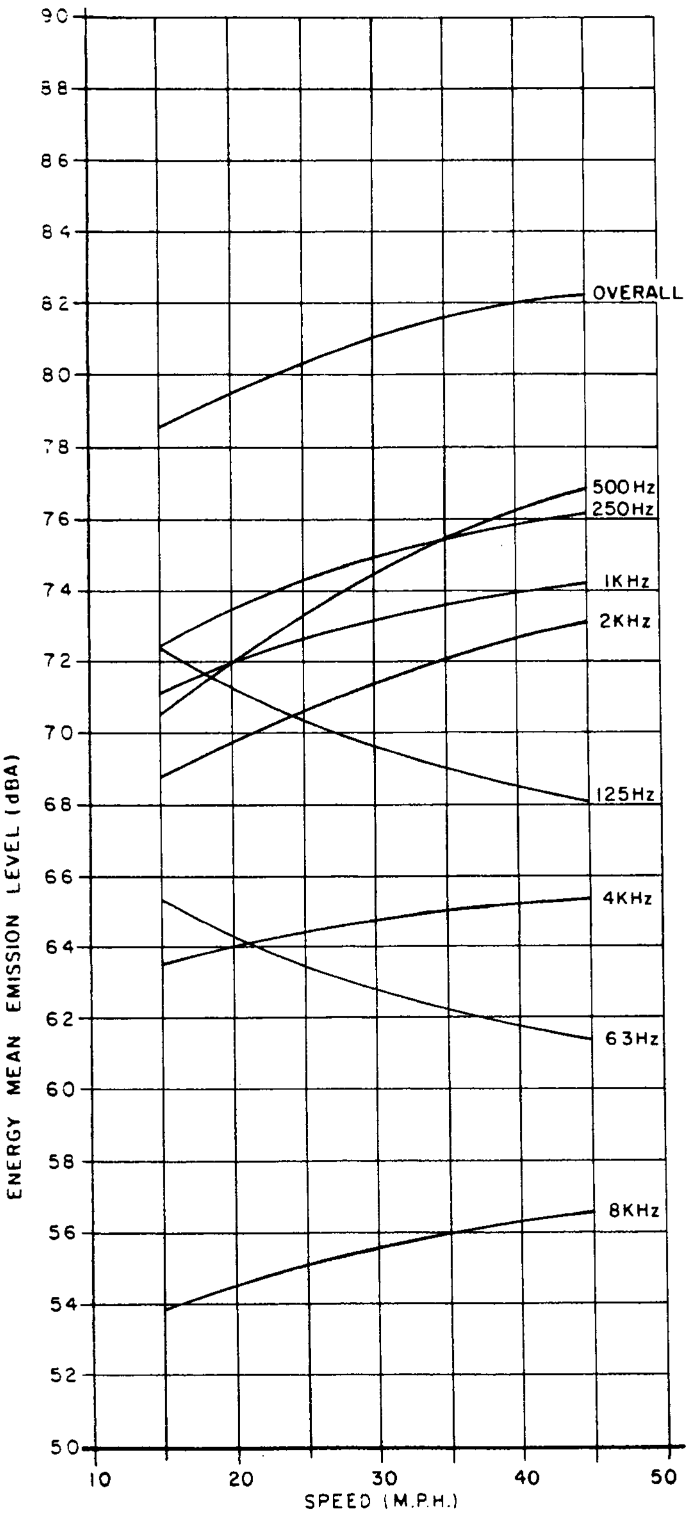


Figure 12-16. OCTAVE BAND ENERGY MEAN EMISSION LEVELS
ROADWAY TYPE 7B (RAMPS, NO-ACCELERATION)
TRUCK TYPE 2 (HEAVY TRUCKS)

Source heights for Truck Types 1 and 2 were estimated from reference to the current literature because they could not be determined from the results of this study. It is suggested that the source heights for medium and heavy trucks specified in [2] (The FHWA Noise Prediction Model) be used for N.J.'s Type 1 and Type 2 Trucks, respectively. Accordingly, the source height suggested for Truck Type 1 (medium trucks and buses) is 0.7 meters (2.3 feet) above the surface of the roadway; for Truck Type 2 (heavy trucks), 2.44 meters (8 feet) above the roadway surface. It is recommended that these source heights be used for Roadway Types 1 to 7.

Because it was found for this study, that certain octave bands had relatively higher or lower levels for different roadway types, it is possible that effective source height may vary slightly according to roadway type. For example, for upgrade roadways (Types 2 and 5), the 250 and 500 Hz octave bands were relatively higher when compared to the other octave bands than they were for level roadways (Types 1 and 4). It may be that the relative increase in noise level at these frequencies indicates that one of the components of truck noise (tire, engine, and exhaust noise, etc.) may be taking on greater importance for these roadways. A change in the relative importance of these components may alter source height to some degree.

Information about exhaust configuration was collected for this study as part of data acquisition. It is presented here, in Table 5, because this information may be of interest to those who are working with source heights for trucks. In this table, the percentages of vertical and horizontal exhausts are given for Truck Type 1 and 2 for all roadway types.

TABLE 5

EXHAUST CONFIGURATION
(Vertical vs. Horizontal)

Roadway Type	Truck Type 1 (Medium Trucks & Buses) % Vertical	Truck Type 1 (Medium Trucks & Buses) % Horizontal	Truck Type 2 (Heavy Trucks) % Vertical	Truck Type 2 (Heavy Trucks) % Horizontal
1 Controlled Access Level	4.1	95.9	91.8	8.2
2 Controlled Access Upgrade	4.7	95.3	91.5	8.5
3 Controlled Access Downgrade	9.4	90.6	90.1	9.9
4 Non-controlled Access Level	5.4	94.6	85.4	14.6
5 Non-controlled Access Upgrade	7.6	92.4	90.5	9.5
6 Non-controlled Access Downgrade	5.1	94.9	86.0	14.0
7A Ramps (Acceleration)	7.9	92.1	86.7	13.3
7B Ramps (Non-acceleration)	1.3	98.7	84.8	15.2

The table shows that for each roadway type over 90% of the Type 1 Trucks have horizontal exhausts. It further indicates that about 90% of the Type 2 Trucks on controlled access roadways (Types 1, 2 and 3) have vertical exhausts. For non-controlled access roadways (Types 4, 5 and 6) and ramps, the percentage of vertical exhausts for Type 2 Trucks is slightly lower.

Comparison of New Jersey's and the FHWA's Truck Noise Emission Levels

In this section the truck noise emission levels determined for this study are compared to those presented in the FHWA report entitled "FHWA Highway Traffic Noise Prediction Model", December 1978 [2]. This comparison has been included since federal noise standards will require that the FHWA's truck noise emission levels be used with highway traffic noise prediction methods as of January 1, 1980. Thus, until the results of this study are implemented, New Jersey will use the FHWA's levels with the TSC MOD-04 prediction method. Graphs of A-weighted overall energy mean emission levels are used for this comparison. These graphs are Figures 13-1 to 13-8, pages 99 to 106.

The figures show New Jersey's truck emission levels for Truck Types 1 and 2 for Roadway Types 1 to 7. Emission level is plotted versus truck speed in miles per hour. Each figure also contains a plot of the FHWA's truck emission levels. Though the FHWA's emission levels were developed for trucks at cruise conditions on level roadways and thus, in the strictest sense, apply only to Roadway Types 1 and 4, they were included in each figure for purposes of comparison. Emission level plots for New Jersey's (N.J.'s) Type 1 and Type 2 Trucks as well as for the FHWA's medium and heavy trucks are presented in each figure. New Jersey Truck Type 2 (heavy trucks) is compared to the FHWA's heavy trucks; New Jersey Truck Type 1 (medium trucks and buses), to the FHWA's medium trucks.

A. Level Roadways ($\leq$ 2% Grade) - For level, controlled access roadways (Roadway Type 1), N.J.'s noise emission levels for both heavy trucks,and medium trucks and buses are higher than the FHWA's levels for all speeds

(30-70 mi/hr, 48-112 km/hr). At a speed of 55 mi/hr (88 km/hr), N.J.'s emission levels for heavy trucks are 1 dB higher: for medium trucks and buses, 1.5 dB higher.

For level, non-controlled access roadways (Roadways Type 4), N.J.'s emission levels for heavy trucks are lower than the FHWA's for all speeds --- 3/4 dB lower at 50 mi/hr (80 km/hr), 1/2 dB lower at 40 mi/hr (64 km/hr). For medium trucks and buses, N.J.'s emission levels are lower than the FHWA's above 47.5 mi/hr (76 km/hr). N.J.'s emission levels for medium trucks and buses are 1/2 dB lower than the FHWA's levels at 55 mi/hr (88 km/hr); 1.5 dB higher, at 35 mi/hr (56 km/hr).

B. <u>Upgrade Roadways (> 2% Upgrade)</u> - For controlled access upgrade roadways (Roadway Type 2), N.J.'s emission levels for heavy trucks,and medium trucks and buses are higher than the FHWA's levels for speeds of 30-60 mi/hr (48-96 km/hr). N.J.'s levels for both heavy trucks,and medium trucks and buses are 2 dB higher than the FHWA's at 50 mi/hr (80 km/hr); 4 dB higher, at 40 mi/hr (64 km/hr).

For non-controlled access upgrade roadways (Roadway Type 5), N.J.'s emission levels for heavy trucks,and medium trucks and buses are higher than the FHWA's levels for speeds of 30-62.5 mi/hr (48-100 km/hr). For heavy trucks, N.J.'s levels are 3 dB higher at 45 mi/hr (72 km/hr); 5 dB higher, at 35 mi/hr (56 km/hr). For medium trucks and buses, N.J.'s levels are 3 dB higher at 45 mi/hr (72 km/hr); 4.5 dB higher, at 35 mi/hr (56 km/hr).

C. <u>Downgrade Roadways (> 2% Downgrade)</u> - For controlled access downgrade roadways (Roadway Type 3), N.J.'s emission levels for heavy trucks are approximately the same as the FHWA's levels at 55 mi/hr (88 km/hr). Above 55 mi/hr (88 km/hr), N.J.'s levels are higher but not significantly - 1/2 a decibel at 60 mi/hr (96 km/hr). For medium trucks and buses, N.J.'s emission levels are approximately the same as the FHWA's for a speed of 57.5 mi/hr (92 km/hr). At 55 mi/hr (88 km/hr), N.J.'s levels are less than 1/2 a decibel higher than the FHWA's.

For non-controlled access downgrade roadways (Roadway Type 6), N.J.'s emission levels for heavy trucks,and medium trucks and buses are lower than the FHWA's for all speeds (30-70 mi/hr, 48-112 km/hr). N.J.'s heavy truck levels are 1 dB lower than the FHWA's at 55 mi/hr (88 km/hr); 1.5 dB, at 40 mi/hr (64 km/hr). For medium trucks and buses, N.J.'s emission levels are about 1 dB lower for all speeds.

D. Ramps (Accelerating and Non-accelerating) - For ramp sections with accelerating trucks (Roadway Type 7A), N.J.'s emission levels for heavy trucks are generally higher than the FHWA's for speeds of 15-45 mi/hr (24-72 km/hr). At 25 mi/hr (40 km/hr), N.J.'s heavy truck levels are 4 dB higher; at 35 mi/hr (56 km/hr), 2 dB higher. For medium trucks and buses, N.J.'s emission levels are 6 dB higher at 25 mi/hr (40 km/hr); 2 dB higher at 35 mi/hr (56 km/hr).

For ramp sections with non-accelerating trucks (Roadway Type 7B), N.J.'s emission levels for heavy trucks are higher than the FHWA's below 35 mi/hr (56 km/hr); while for medium trucks and buses, N.J.'s levels are higher for all speeds (15-45 mi/hr, 24-72 km/hr). At 25 mi/hr (40 km/hr), N.J.'s heavy truck levels are 2.5 dB higher. At 25 mi/hr (40 km/hr), N.J.'s levels for medium trucks and buses are 4.5 dB higher; at 35 mi/hr (56 km/hr), 2.5 dB higher.

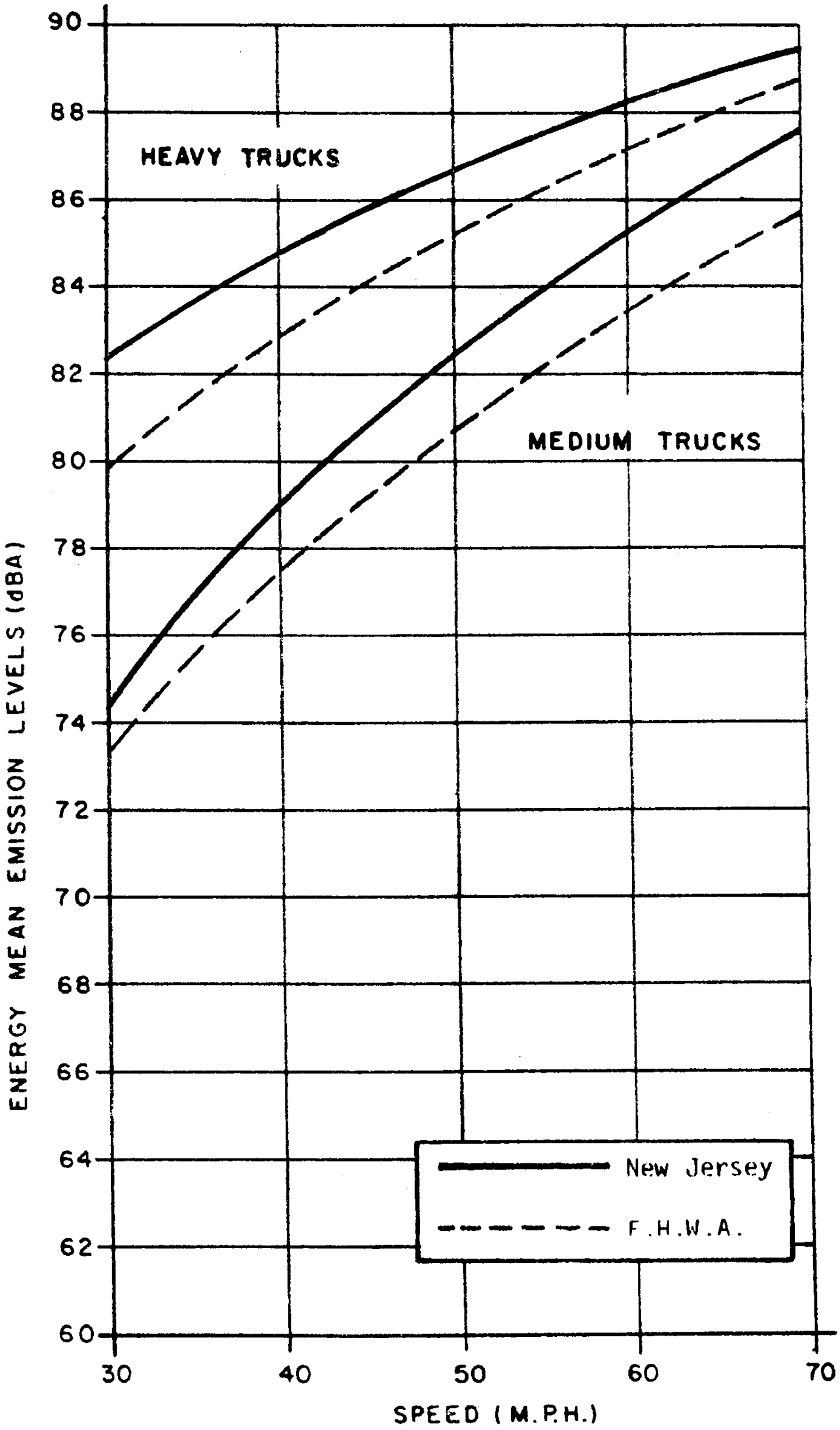


Figure 13-1. OVERALL ENERGY MEAN EMISSION LEVELS
NEW JERSEY & FHWA
ROADWAY TYPE I (LEVEL, CONTROLLED ACCESS)

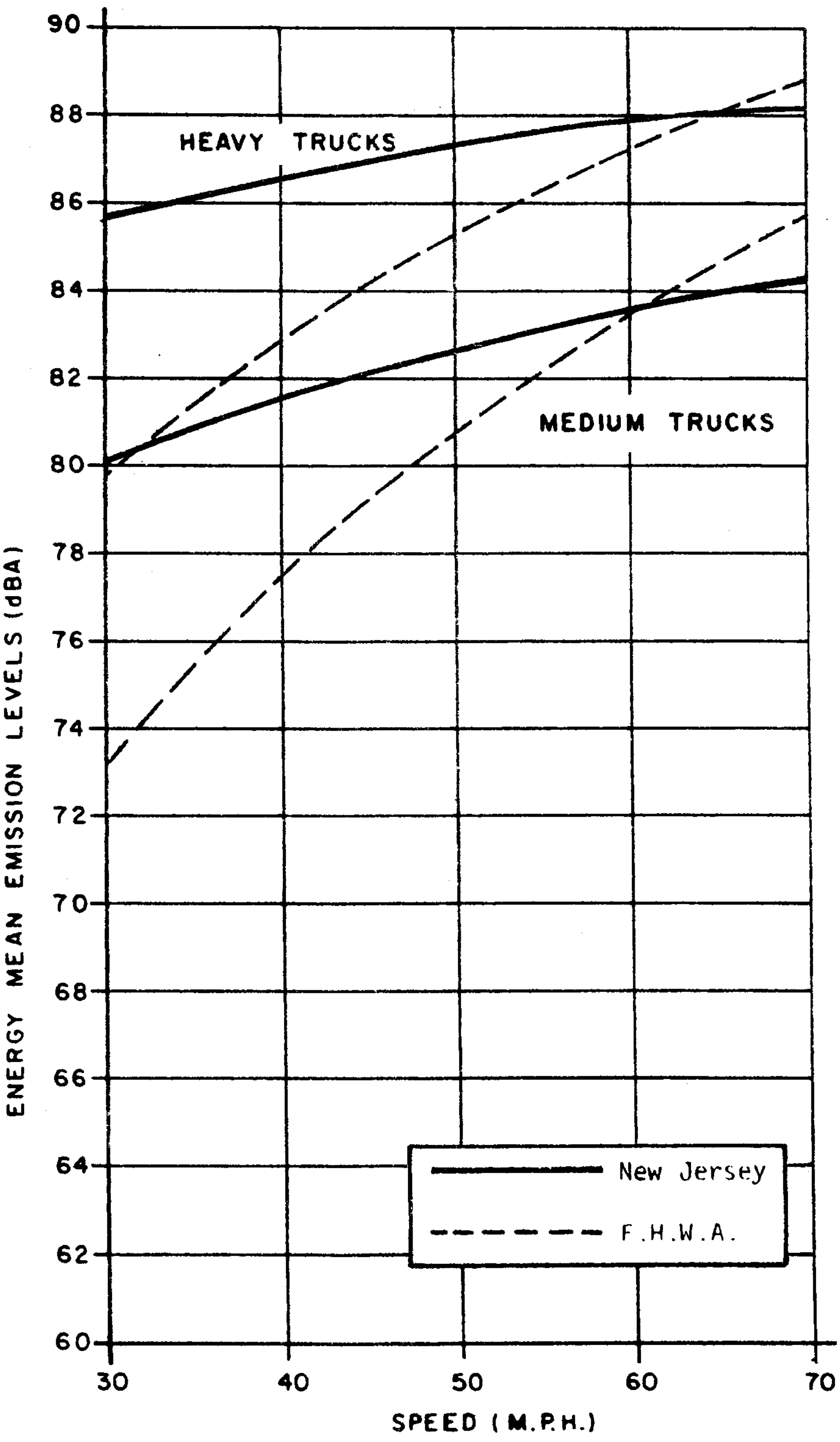


Figure 13-2. OVERALL ENERGY MEAN EMISSION LEVELS
NEW JERSEY & FHWA
ROADWAY TYPE 2 (UPGRADE, CONTROLLED ACCESS)

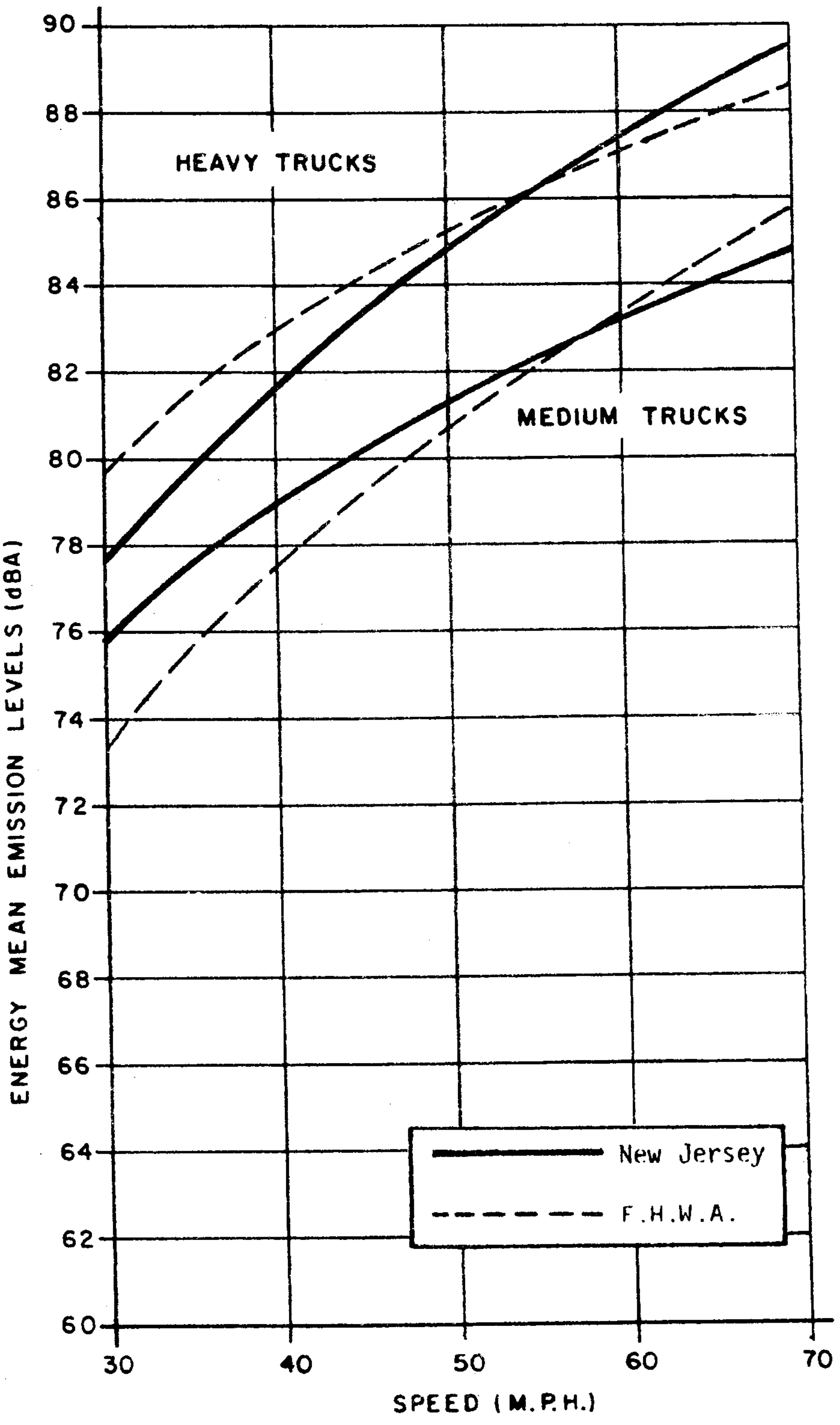


Figure 13-3. OVERALL ENERGY MEAN EMISSION LEVELS
NEW JERSEY & FHWA
ROADWAY TYPE 3 (DOWNGRADE, CONTROLLED ACCESS)

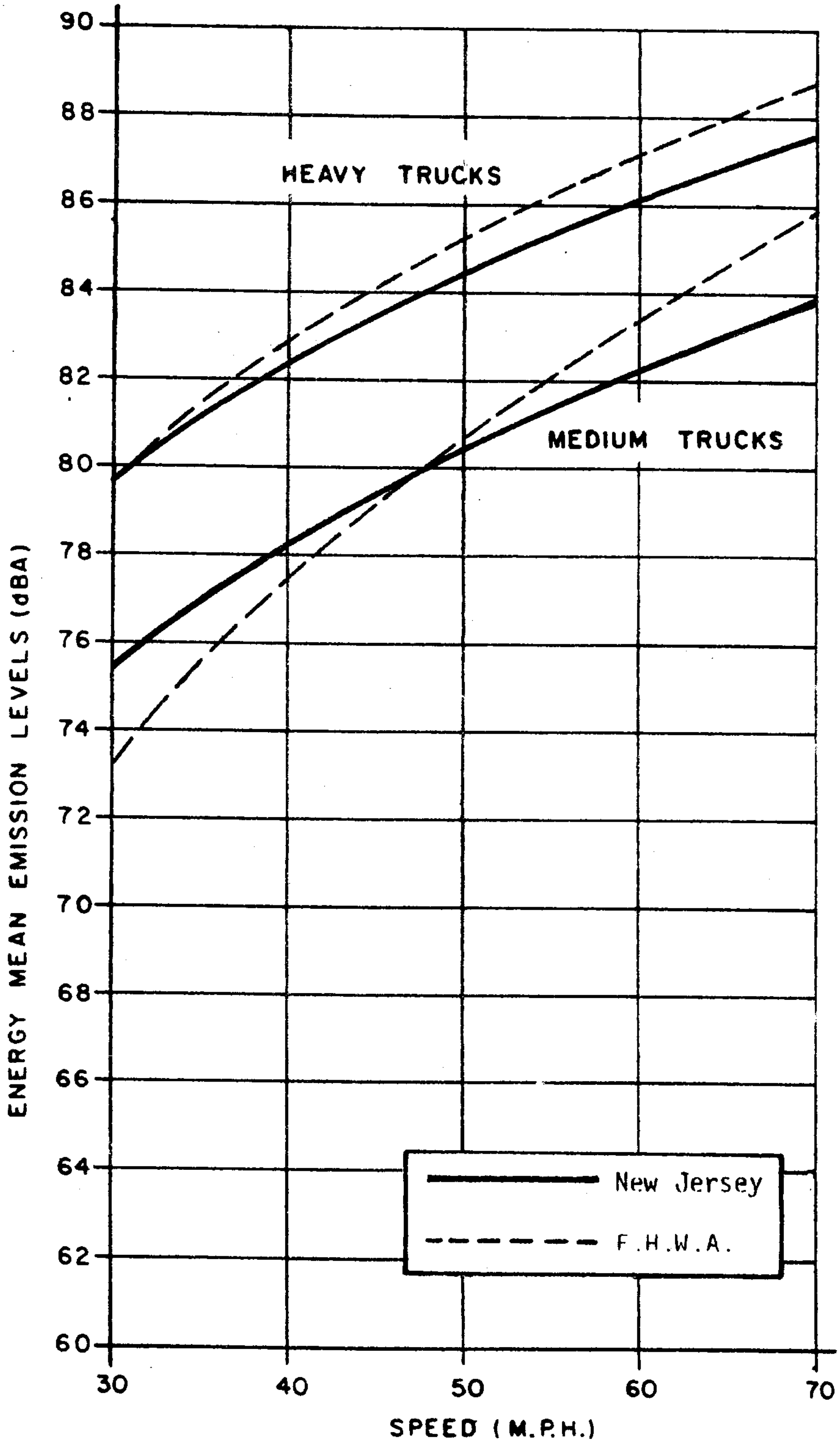


Figure 13-4. OVERALL ENERGY MEAN EMISSION LEVELS
NEW JERSEY & FHWA
ROADWAY TYPE 4 (LEVEL, NON-CONTROLLED ACCESS)

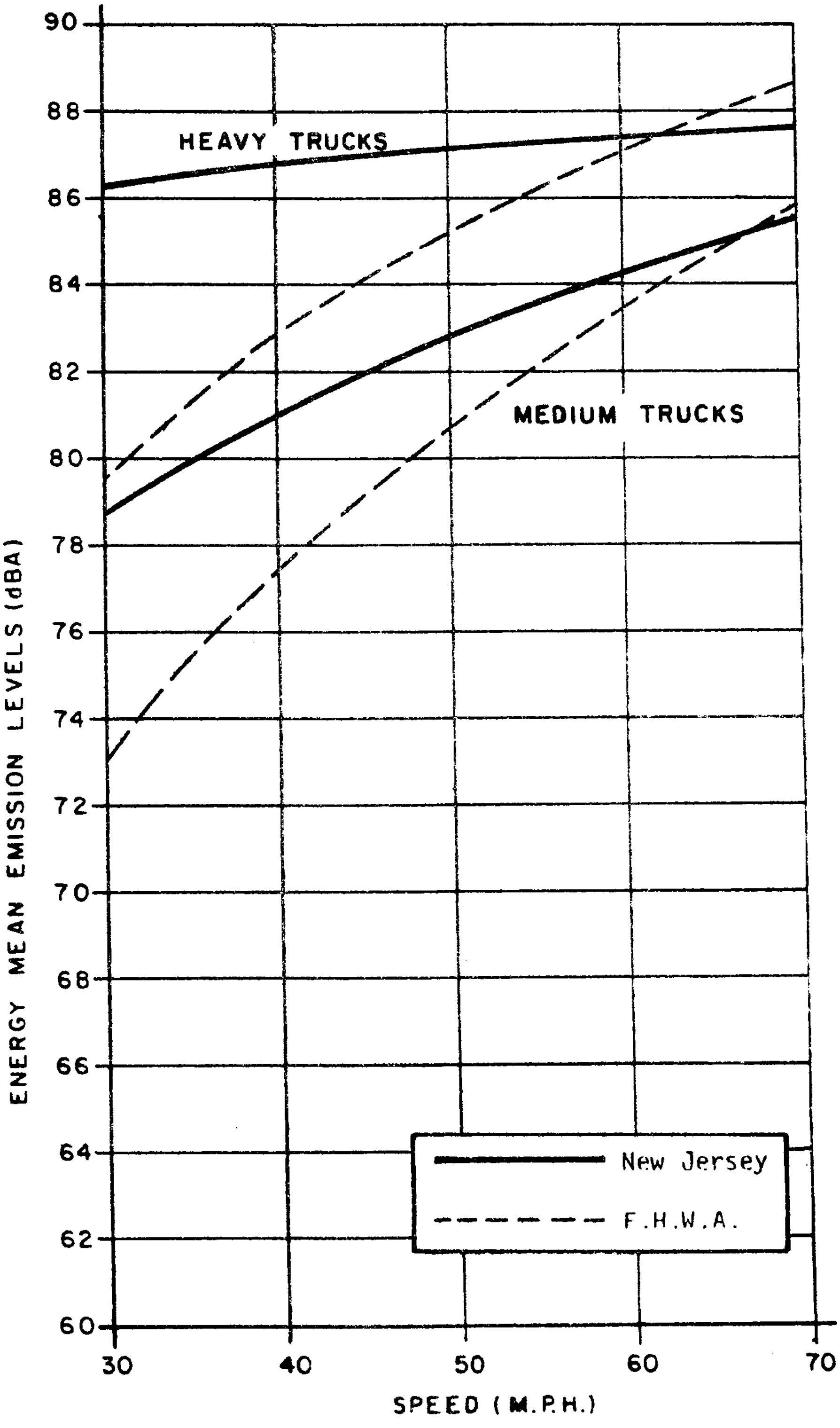


Figure 13-5. OVERALL ENERGY MEAN EMISSION LEVELS
NEW JERSEY & FHWA
ROADWAY TYPE 5 (UPGRADE, NON-CONTROLLED ACCESS)

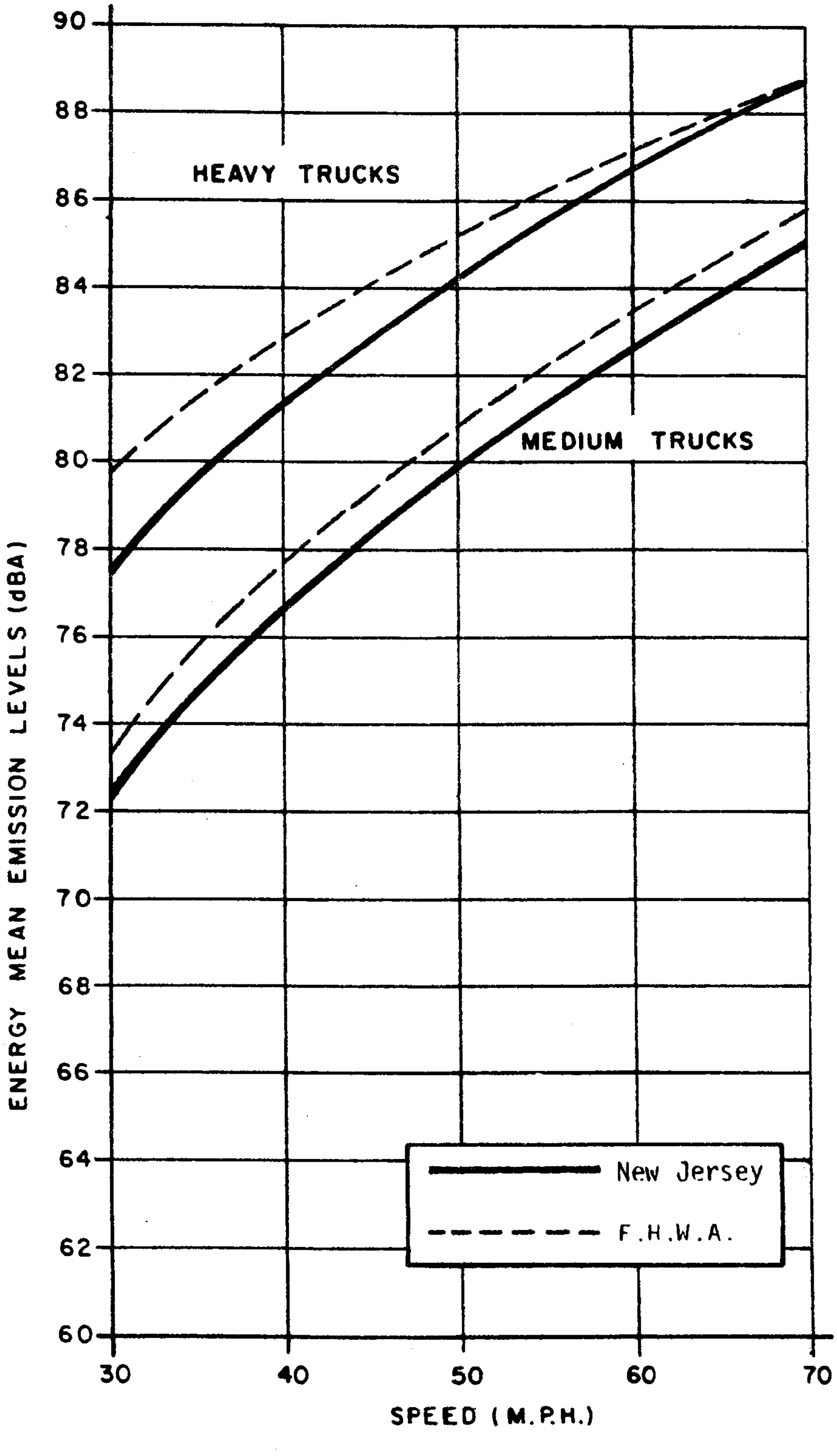


Figure 13-6. OVERALL ENERGY MEAN EMISSION LEVELS
NEW JERSEY & FHWA
ROADWAY TYPE 6 (DOWNGRADE, NON-CONTROLLED ACCESS)

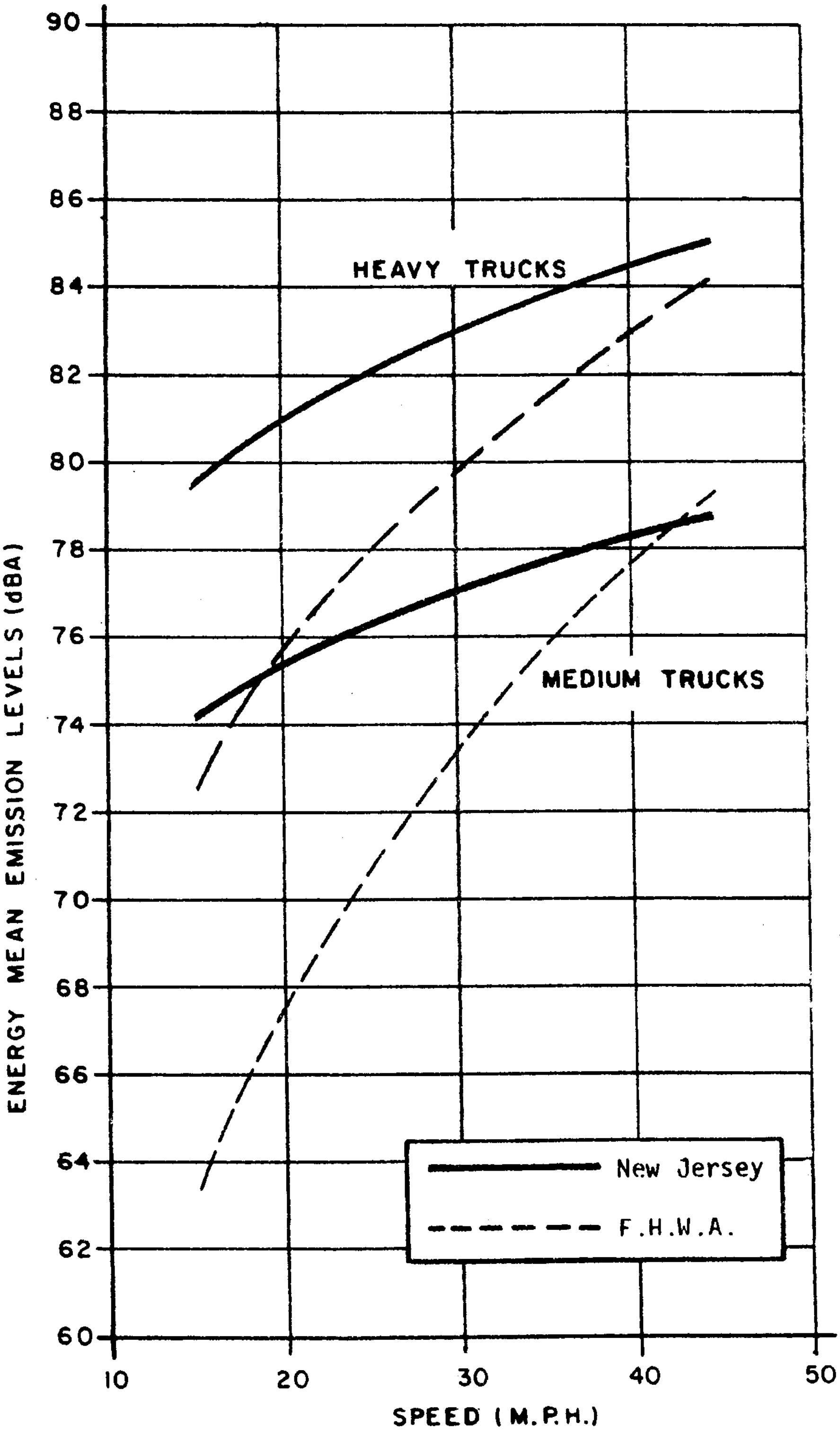


Figure 13-7. OVERALL ENERGY MEAN EMISSION LEVELS
NEW JERSEY & FHWA
ROADWAY TYPE 7A (RAMPS, ACCELERATION)

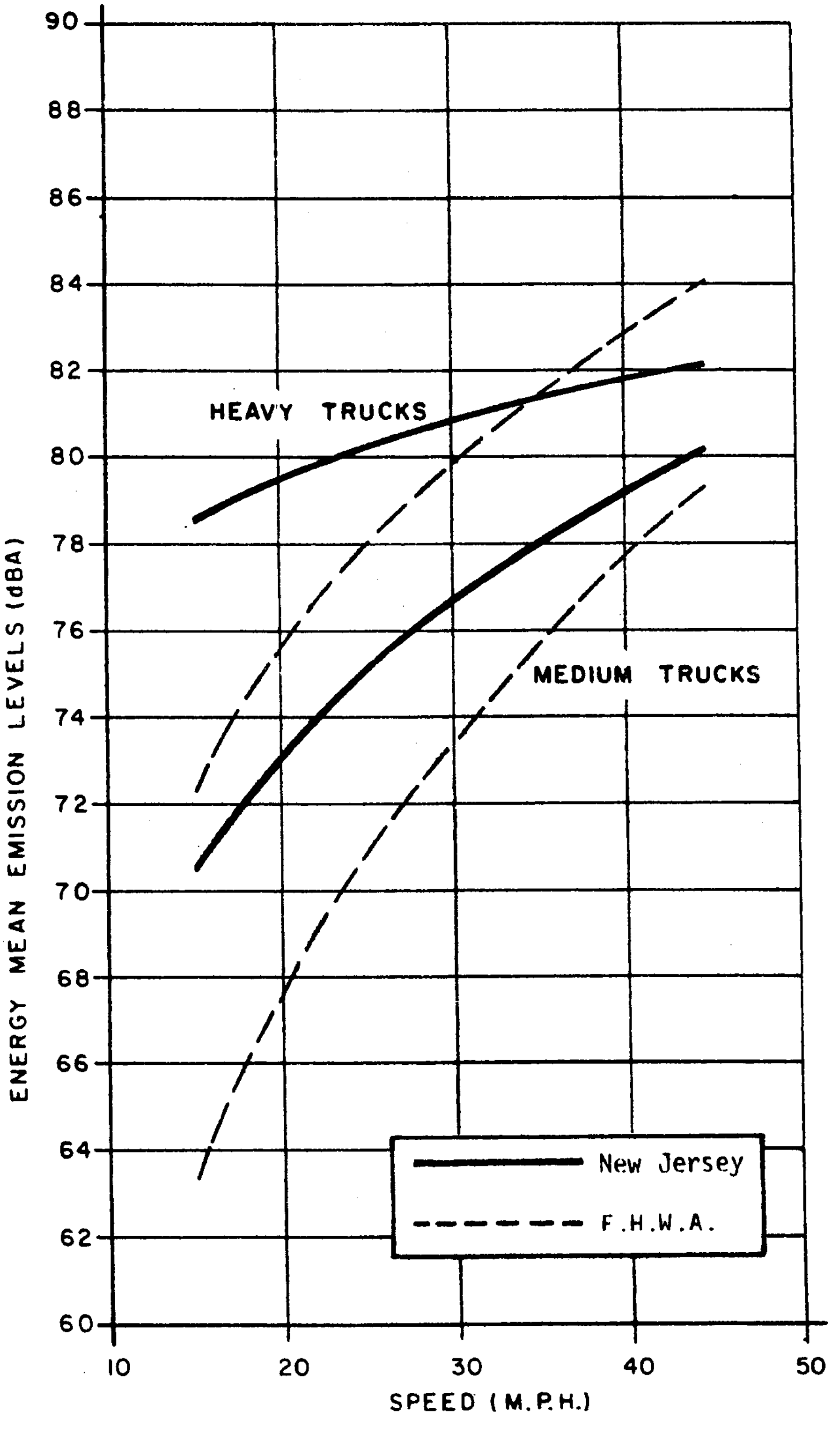


Figure 13-8. OVERALL ENERGY MEAN EMISSION LEVELS
NEW JERSEY & FHWA
ROADWAY TYPE 7B (RAMPS, NO ACCELERATION)

E. Summary of Comparisons - Following is a summary of the comparisons of New Jersey's and the FHWA's truck noise emission levels:

(1) For controlled access level roadways (Roadway Type 1), N.J.'s emission levels are 1 - 2.5 dB higher.

(2) For non-controlled access level roadways (Roadway Type 4), N.J.'s emission levels vary by less than a decibel from the FHWA's levels.

(3) For upgrade roadways, N.J.'s emission levels are generally higher --- 2-4 dB higher for controlled access upgrades (Roadway Type 2) at speeds of 40-50 mi/hr (64-80 km/hr), 3-5 dB higher for non-controlled access upgrades (Roadway Type 5) at speeds of 35-45 mi/hr (56-72 km/hr).

(4) For downgrade roadways (Roadway Types 3 and 6), N.J.'s emission levels usually vary by less than a decibel from the FHWA's levels for speeds of 40-60 mi/hr (64-96 km/hr).

(5) For acceleration on ramps (Roadway Type 7A) and non-acceleration on ramps (Roadway Type 7B), N.J.'s emission levels are generally higher. At 25 mi/hr (40 km/hr), N.J.'s levels for heavy trucks, and medium trucks and buses, respectively, are about 4.0 dB and 6.0 dB higher for Roadway Type 7A; 2.5 dB and 4.5 dB higher for Roadway Type 7B.

An indication of the extent to which the differences between New Jersey's and the FHWA's truck noise emission levels will affect predicted noise levels is given here. Energy mean emission levels were used for the foregoing comparison because differences in these levels can be directly related to differences in predicted L_{EQ} (hourly equivalent sound level). For instance, with all other factors held constant, a 2 dB difference in the energy mean emission level of heavy trucks would result, at a given receiver location, in a 2 dB difference in predicted L_{EQ} for heavy trucks. In practice, however, predicted L_{EQ} is determined by the noise contributed by automobiles as well as trucks. When the percentage of trucks in the total traffic mix is low, the sound energy contributed to L_{EQ} by automobiles is significant. In these cases, a 2 dB increase in predicted L_{EQ} for trucks will result in less than a 2 dB increase in the predicted L_{EQ} for the total traffic situation assuming the automobile noise contribution has remained the same. Accordingly, the greater the percentage of trucks in the total traffic flow, the greater will be their influence, and the closer the difference in the energy mean emission level for trucks will be to the difference in predicted L_{EQ}. Thus, for some traffic situations (those with low truck percentages) differences in predicted noise levels will not be nearly as large as the differences between New Jersey's and the FHWA's truck noise emission levels.

Statistical Evaluation of New Jersey's Truck Noise Emission Levels

In this section the statistics associated with the regressions of truck emission level versus speed are presented, as well as scatterplots and histograms of the noise data for all roadway types. Normality of the noise data is also discussed.

A. <u>Regression Statistics</u> - Statistics related to the regressions of truck emission level versus truck speed are presented in Table 6, pages 110 - 113.* As noted, the regression equation used for the overall noise level and octave band levels was $\bar{L}_0 = A + B \log V$, where $\bar{L}_0$ is emission level in dBA, log V is the logarithm to the base ten of speed in miles per hour, and A and B are coefficients which are constant for each set of data. Five statistics are presented in Table 6. They are R, R^2, SE, A, and B. R, the correlation coefficient, indicates the goodness-of-fit of the regression model. Its numerical value lies between -1 and 1 with a value near 1 or -1 indicating a very good fit. R^2, the coefficient of determination, indicates the proportion of the total variability in the dependent variable, $\bar{L}_0$, explained by the independent variable, V. For example, an R^2 value of 0.30 means that 30% of the variability in $\bar{L}_0$ has been explained by independent variable V. SE, the standard error of estimate, is an indicator of the typical variation of data about the regression line. Lower values of SE indicate less variation about the regression line. A and B are the regression coefficients which define the relationship between the dependent and independent variable. For the linear regression mentioned above, A is the intercept coefficient; B, the slope coefficient. For a more rigorous explanation of these statistics the reader is referred to a statistics text such as [12].

(1) <u>Standard Error of Estimate (SE)</u> - Table 6 shows that for Roadway Types 1-6 the standard error of estimate of the overall emission level was

*The form of this table is similar to that of Table 4.2 in [8].

TABLE 6

STATISTICS ASSOCIATED WITH ARITHMETIC MEAN EMISSION LEVEL REGRESSIONS
-------------- TRUCK TYPE 1: MEDIUM TRUCKS AND BUSES ---------------

SOUND LEVEL	ROADWAY TYPE* 1		2		3		4	
Overall	0.516	0.266	0.226	0.051	0.313	0.098	0.340	0.115
	2.92		3.20		3.36		3.25	
	19.81	36.32	61.54	11.78	38.98	24.21	40.51	22.85
Octave Bands 63 Hz	0.129	0.017	0.190	0.036	0.211	0.044	0.027	0.001
	6.60		6.00		4.95		4.94	
	27.55	17.71	89.06	-18.38	17.07	23.33	51.76	-2.61
125 Hz	0.137	0.019	0.248	0.062	0.231	0.054	0.019	0.000
	4.56		5.28		4.70		4.68	
	45.13	13.06	104.77	-21.40	23.14	24.41	68.60	-1.76
250 Hz	0.227	0.052	0.017	0.000	0.124	0.015	0.180	0.032
	5.21		5.59		5.62		4.75	
	30.52	25.08	69.32	1.50	44.09	15.36	42.65	16.89
500 Hz	0.471	0.222	0.333	0.111	0.405	0.164	0.382	0.146
	3.37		4.27		3.60		3.77	
	11.46	37.23	34.14	23.79	14.16	34.82	21.86	30.31
1000 Hz	0.592	0.350	0.438	0.192	0.264	0.070	0.344	0.118
	2.88		3.16		4.03		[illegible]	
	1.17	43.61	33.60	24.40	32.98	24.11	29.47	25.27
2000 Hz	0.555	0.308	0.425	0.181	0.308	0.095	0.299	0.089
	3.18		3.05		3.87		4.19	
	-1.64	43.85	34.83	22.65	25.15	27.29	25.76	25.53
4000 Hz	0.436	0.190	0.400	0.160	0.373	0.139	0.216	0.047
	3.84		3.33		3.61		4.98	
	-0.39	38.34	27.11	23.04	10.55	31.62	25.14	21.41
8000 Hz	0.369	0.136	0.377	0.142	0.460	0.212	0.204	0.041
	4.05		3.09		3.33		4.97	
	-0.64	33.24	23.76	19.88	-9.00	37.71	19.52	20.09
SAMPLE SIZE	127		109		132		224	

$\overline{L}_0 = A + B(\log V)$, V in mi/hr

SE = standard error of estimate
R = correlation coefficient

Key

R	R^2
SE	
A	B

*See page for definition of roadway types

TABLE 6

STATISTICS ASSOCIATED WITH ARITHMETIC MEAN EMISSION LEVEL REGRESSIONS
-------------- TRUCK TYPE 1: MEDIUM TRUCKS AND BUSES --------------

SOUND LEVEL		ROADWAY TYPE			
		5	6	7A	7B
Overall	R	0.274	0.481	0.204	0.469
	R^2	0.075	0.232	0.042	0.220
	SE	3.52	3.02	4.09	3.45
	A	50.04	21.32	60.78	45.03
	B	18.55	33.98	9.82	20.51
Octave Bands 63 Hz	R	0.176	0.011	0.013	0.180
	R^2	0.031	0.000	0.000	0.033
	SE	6.65	5.24	6.85	6.54
	A	92.19	54.38	56.19	36.24
	B	-22.00	1.15	1.00	13.43
125 Hz	R	0.001	0.097	0.231	0.268
	R^2	0.000	0.009	0.053	0.072
	SE	5.38	4.47	5.31	4.92
	A	66.42	49.09	44.04	40.98
	B	0.110	8.94	14.55	15.32
250 Hz	R	0.087	0.115	0.306	0.394
	R^2	0.008	0.013	0.094	0.155
	SE	5.80	5.48	4.97	5.29
	A	57.35	47.23	40.78	31.00
	B	9.32	13.00	18.46	25.34
500 Hz	R	0.286	0.456	0.154	0.236
	R^2	0.082	0.208	0.024	0.056
	SE	3.88	3.63	3.64	4.25
	A	38.53	7.74	76.60	51.95
	B	21.44	38.24	-6.55	11.54
1000 Hz	R	0.330	0.527	0.075	0.562
	R^2	0.109	0.277	0.006	0.315
	SE	3.59	3.28	4.87	2.96
	A	35.46	1.59	61.10	32.75
	B	23.21	41.77	4.24	22.45
2000 Hz	R	0.474	0.554	0.230	0.623
	R^2	0.224	0.307	0.053	0.388
	SE	3.50	3.35	5.76	3.49
	A	13.16	-7.56	40.94	17.90
	B	34.80	45.77	15.68	31.05
4000 Hz	R	0.267	0.559	0.140	0.498
	R^2	0.071	0.313	0.020	0.248
	SE	4.12	3.73	5.85	4.34
	A	27.95	-25.13	43.26	14.04
	B	21.08	51.70	9.56	27.91
8000 Hz	R	0.110	0.437	0.027	0.503
	R^2	0.012	0.191	0.001	0.253
	SE	5.17	3.60	5.76	4.59
	A	37.49	-5.89	53.69	2.64
	B	10.60	35.85	-1.80	29.83
SAMPLE SIZE		126	256	40	78

$\bar{L}_0 = A + B\,(\log V)$, V in mi/hr

SE = standard error of estimate
R = correlation coefficient

Key

R		R^2
	SE	
A		B

TABLE 6

STATISTICS ASSOCIATED WITH ARITHMETIC MEAN EMISSION LEVEL REGRESSIONS
-------------------- TRUCK TYPE 2: HEAVY TRUCKS --------------------

SOUND LEVEL	ROADWAY TYPE 1	ROADWAY TYPE 2	ROADWAY TYPE 3	ROADWAY TYPE 4
Overall	0.294 0.087 2.47 53.27 19.28	0.261 0.068 2.65 73.89 7.46	0.399 0.159 2.83 29.36 32.22	0.372 0.139 2.84 48.05 21.00
Octave Bands 63 Hz	0.226 0.051 6.05 122.71 -35.52	0.067 0.005 7.28 54.19 5.11	0.033 0.001 4.20 64.85 -3.58	0.003 0.000 6.78 60.23 0.38
125 Hz	0.164 0.027 4.46 39.24 18.76	0.135 0.018 4.45 82.46 -6.31	0.220 0.049 4.11 26.24 24.34	0.257 0.066 4.13 35.68 20.25
250 Hz	0.007 0.000 3.87 75.57 0.69	0.095 0.009 3.99 83.00 -3.96	0.019 0.000 4.36 [illegible] [illegible]	0.049 0.002 3.85 69.13 [illegible]
500 Hz	0.268 0.072 3.33 39.43 23.45	0.254 0.065 3.75 62.17 10.29	[illegible] 0.139 3.29 18.07 34.63	0.448 0.201 [illegible] [illegible] 30.72
1000 Hz	0.419 0.176 2.46 31.49 28.84	0.357 0.127 2.96 61.10 11.79	0.420 [illegible] 3.16 14.11 38.25	[illegible] [illegible] [illegible] 38.56 23.05
2000 Hz	0.345 0.119 2.42 39.31 22.61	0.345 0.119 2.67 61.37 10.26	0.451 0.204 3.04 8.05 40.25	0.263 0.069 4.08 39.96 20.44
4000 Hz	0.346 0.120 3.20 18.47 29.95	0.316 0.100 3.12 53.00 10.86	0.449 0.202 3.33 [illegible] 43.79	0.250 0.062 4.69 29.24 [illegible]
8000 Hz	0.403 0.163 3.02 1.74 33.73	0.294 0.087 3.10 44.24 9.96	0.513 0.263 3.00 -21.21 46.93	0.224 0.050 4.57 24.51 19.32
SAMPLE SIZE	590	705	620	312

$\overline{L}_0 = A + B (\log V)$, V in mi/hr

SE = standard error of estimate
R = correlation coefficient

Key

R	R^2
SE	
A	B

TABLE 6

STATISTICS ASSOCIATED WITH ARITHMETIC MEAN EMISSION LEVEL REGRESSIONS
-------------------- TRUCK TYPE 2: HEAVY TRUCKS --------------------

SOUND LEVEL	ROADWAY TYPE 5		ROADWAY TYPE 6		ROADWAY TYPE 7A		ROADWAY TYPE 7B	
Overall	0.059	0.003	0.448	0.201	0.259	0.067	0.202	0.041
	3.23		3.10		3.39		3.42	
	79.93	3.63	31.67	30.42	64.14	11.96	68.20	7.71
Octave Bands 63 Hz	0.055	0.003	0.044	0.002	0.036	0.001	0.119	0.014
	7.80		5.25		7.34		6.52	
	75.03	-8.24	50.38	4.49	55.83	3.46	70.25	-8.51
125 Hz	0.023	0.001	0.136	0.018	0.301	0.091	0.166	0.027
	5.32		4.45		5.23		4.93	
	73.59	-2.32	46.70	11.91	39.08	21.79	80.22	-9.05
250 Hz	0.092	0.008	0.045	0.002	0.260	0.068	0.156	0.024
	4.92		4.67		4.67		4.56	
	92.72	-8.68	66.37	4.12	49.06	16.58	60.92	7.88
500 Hz	0.079	0.006	0.469	0.220	0.101	0.010	0.305	0.093
	4.01		3.64		4.32		3.79	
	68.91	6.05	12.40	37.73	65.37	5.78	53.24	13.26
1000 Hz	0.117	0.014	0.513	0.263	0.180	0.032	0.166	0.028
	3.00		3.11		3.68		3.61	
	68.71	6.77	16.45	36.27	61.87	8.87	61.86	6.66
2000 Hz	0.159	0.025	0.497	0.247	0.154	0.024	0.236	0.056
	3.28		3.35		3.87		3.57	
	60.10	10.13	12.17	37.43	60.53	7.95	55.96	9.48
4000 Hz	0.068	0.005	0.463	0.214	0.060	0.004	0.068	0.005
	3.93		3.83		4.13		4.93	
	60.83	5.09	0.93	39.16	60.81	3.30	56.40	3.67
8000 Hz	0.021	0.000	0.302	0.091	0.039	0.002	0.109	0.012
	3.84		3.69		4.52		5.25	
	56.89	1.54	19.24	22.83	52.78	2.31	43.06	6.30
SAMPLE SIZE	307		381		331		198	

$\bar{L}_0 = A + B\,(\log V)$, V in mi/hr

SE = standard error of estimate
R = correlation coefficient

Key

R	R^2
SE	
A	B

generally lower for heavy trucks than for medium trucks and buses. It ranged from 2.92-3.52 for medium trucks and buses; from 2.47-3.23 for heavy trucks. Somewhat higher values of SE occurred for Roadway Type 7 - 4.09 for medium trucks and buses on Roadway Type 7A. With regard to octave band levels, SE's were once again usually lower for the regressions of heavy trucks than for the corresponding regressions of medium trucks and buses. Much higher SE's occurred for the octave bands. For the 63 Hz band, SE's of 6 and 7 occurred. Usually, SE's were highest for the lower frequency octave bands (63, 125 and 250 Hz), and were usually lowest for the octave bands of 500, 1000 and 2000 Hz. Standard errors were also usually higher for ramps (Roadway Type 7).

(2) Correlation Coefficient (R) and Coefficient of Determination (R^2) - Correlation coefficients for Roadway Types (RT) 1-6 for the overall emission level regressions ranged from 0.226 (RT2) - 0.516 (RT1) for medium trucks and buses; from 0.059 (RT5) - 0.448 (RT6), for heavy trucks. These correspond to a range of R^2 of 0.051-0.266 for medium trucks and buses, and 0.003-0.201 for heavy trucks. Thus, at best, the independent variable V (truck speed) explains about 20-25% of the variation in overall emission level. The additional variation is apparently due to other factors related to truck noise, such as condition and type of engine, tires, muffler, etc., truck weight, and condition and type of pavement on which a truck operates. Some of the variation occurs because of differences which exist between the truck classes which were combined for a truck type. For Roadways 1-6, R and R^2 were lowest for Roadway Types 2 and 5 (upgrades) indicating that for both truck types, truck speed explains less than 8% of the variation

in overall emission level for these upgrade roadways. Roadway Type 7A (ramps with acceleration) also had low values of R^2 - 0.042 for medium trucks and buses, 0.067 for heavy trucks.

With regard to octave band emission levels for Roadway Types 1-6, the highest values of R^2 occurred for octave bands 500, 1000 and 2000 Hz; the lowest values for octave bands 63, 125 and 250 Hz. Values of R ranged from 0.001 (RT5, 125 Hz) - 0.592 (RT1, 1000 Hz) for medium trucks and buses; from 0.003 (RT4, 63 Hz) - 0.513 (RT3, 8000 Hz and RT 6, 1000 Hz), for heavy trucks. Values of R^2 ranged from approximately 0.000 (63, 125 and 250 Hz, several roadway types) - 0.350 (RT1, 1000 Hz) for medium trucks and buses; from approximately 0.000 (63, 250 and 8000 Hz, several roadway types) - 0.263 (RT3, 8000 Hz and RT6, 1000 Hz), for heavy trucks. Thus, for some octave bands, consideration of speed explained over 30% of the variation in emission level: while for others, it explained almost none of the variation. In addition, R and R^2 were generally lower for Roadway Types 2 and 5 (upgrades) and higher for Roadway Types 3 and 6 (downgrades).

The highest values of R and R^2 for octave band level regressions occurred for Roadway Type 7B (ramps with no acceleration): they were 0.623 and 0.388, respectively for the 2000 Hz octave band. Conversely, low values occurred for Roadway Type 7A. Also, Roadway Type 7A (ramps with acceleration) was the only roadway for which the best correlation for octave band levels occurred for the 125 and 250 Hz bands.

(3) Intercept Coefficient (A) - The values of coefficient A for the overall emission level regressions ranged from 19.81 (RT1) - 61.54 (RT2) for medium trucks and buses; from 29.36 (RT3) - 79.93 (RT5) for heavy trucks.

For octave band levels, with the exception of Roadway Type 7A, values of A were generally higher for the lower frequency octave bands. The highest and lowest values of A were 104.77 (RT2, 125 Hz) and -25.13 (RT6, 4000 Hz), respectively, for medium trucks and buses; 122.71 (RT1, 63 Hz) and -21.21 (RT3, 8000 Hz), respectively, for heavy trucks.

(4) Slope Coefficient (B) - For Roadway Types 1-6 the value of coefficient B for the overall level regressions ranged from 11.78 (RT2) - 36.32 (RT1) for medium trucks and buses; from 3.63 (RT5) - 32.22 (RT3), for heavy trucks. Roadway Types 2 and 5 (upgrades) had the lowest values. Values of B for Roadway Type 7 (ramps) fell within these ranges except for a value of 9.82 for Roadway Type 7A for medium trucks and buses. In most cases for Roadways 1-6, high values of B were accompanied by low values of A and vice versa. This was expected since all of the emission level regression lines converge at higher speeds as indicated in Figures 9 and 10, pages 70 and 71.

For the octave band level regressions, the highest values of B usually occurred for the higher octave bands. As with the overall levels, B was usually lower for Roadway Types 2 and 5 (upgrades). The highest and lowest values of B were 51.70 (RT6, 4000 Hz) and -22.00 (RT5, 63 Hz), respectively, for medium trucks and buses; 46.93 (RT3, 8000 Hz) and -35.52 (RT1, 63 Hz), respectively, for heavy trucks.

Negative values of B indicate an inverse relationship between noise level and truck speed. These values occurred for several of the 63, 125 and 250 Hz octave bands for Roadway Types 1-6 and 7B. For Roadway Type 7A (ramps with acceleration), however, they occurred for the 500 Hz and 8000 Hz octave bands.

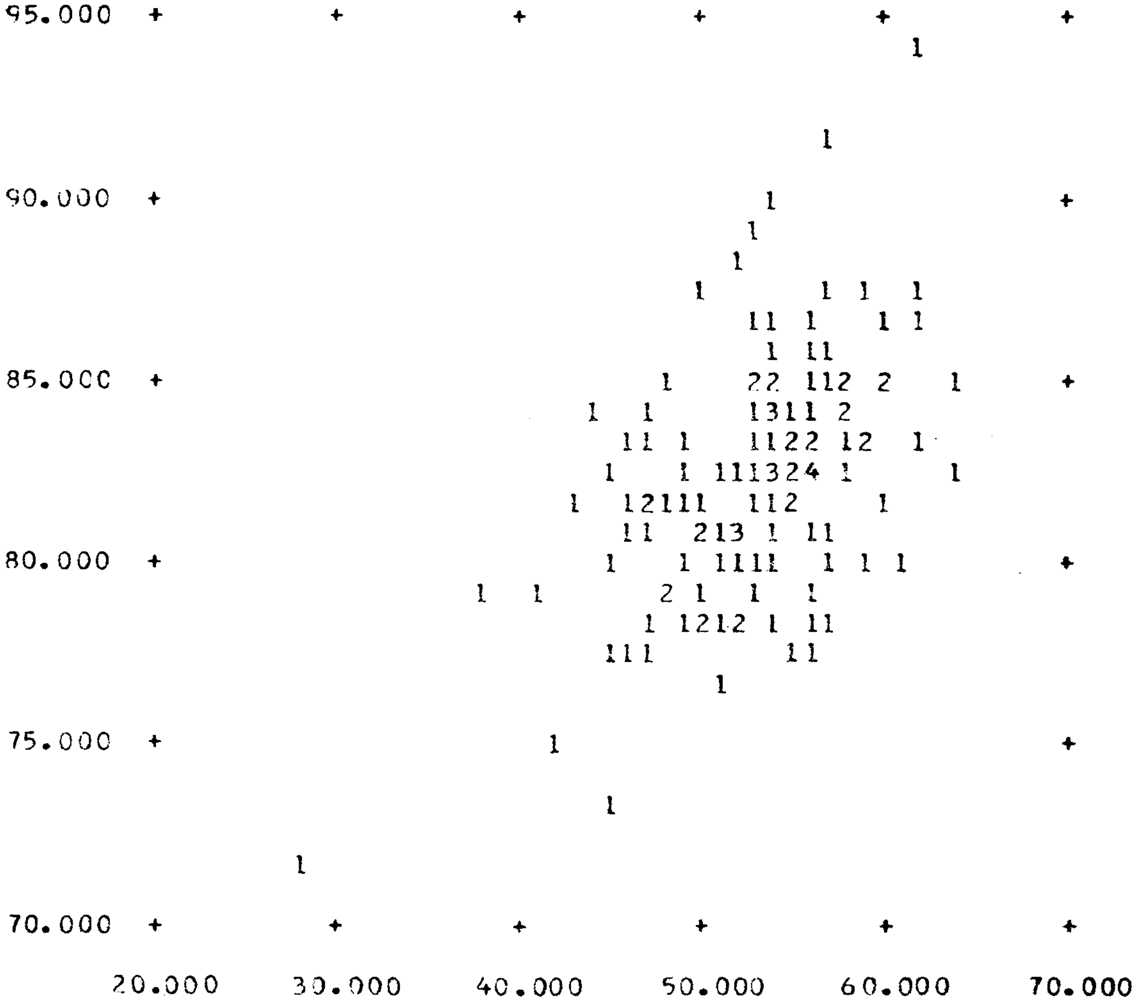
Regression coefficient B indicates the degree of speed dependence of the emission level. Thus, the higher values of B for Roadway Types 3 and 6 (downgrades) and for octave bands of 500 Hz and above indicate that the emission levels for these roadway types and octave bands are more strongly dependent on truck speed than the levels for Roadway Types 2 and 5 (upgrades) and octave bands 63, 125 and 250 Hz for which low values of B are found. This trend was observed earlier when the octave band emission level graphs in Figures 12-1 and 12-16, pages 78 to 93 were discussed.

Throughout this discussion of statistics, Roadway Type 7A (accelerating trucks on ramps) has been the exception to many of the general trends which were observed. Apparently quite different truck emission levels are occurring on this roadway type because it is the only one on which accelerating trucks were measured. However, the fact that the sample size for medium trucks and buses for Type 7A was only 40 observations tends to compromise this result.

B. <u>Scatterplots and Histograms</u> - The noise level data on which the regressions of truck emission level versus speed were based is displayed in Figures 14-1 to 14-16, pages 118 to 133. There are two scatterplots for each roadway type, one each for Truck Types 1 and 2. Each figure contains a scatterplot of overall noise emission level (dBA) versus truck speed in miles per hour. Overall noise emission levels were obtained from direct measurements of individual trucks at the measurement sites. These levels are the peak levels from truck pass-bys; that is, they are referenced to a distance of

FIGURE 14-1.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 1(LEVEL,CONTROLLED ACCESS)
TRUCK TYPE 1(MEDIUM TRUCKS & BUSES)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

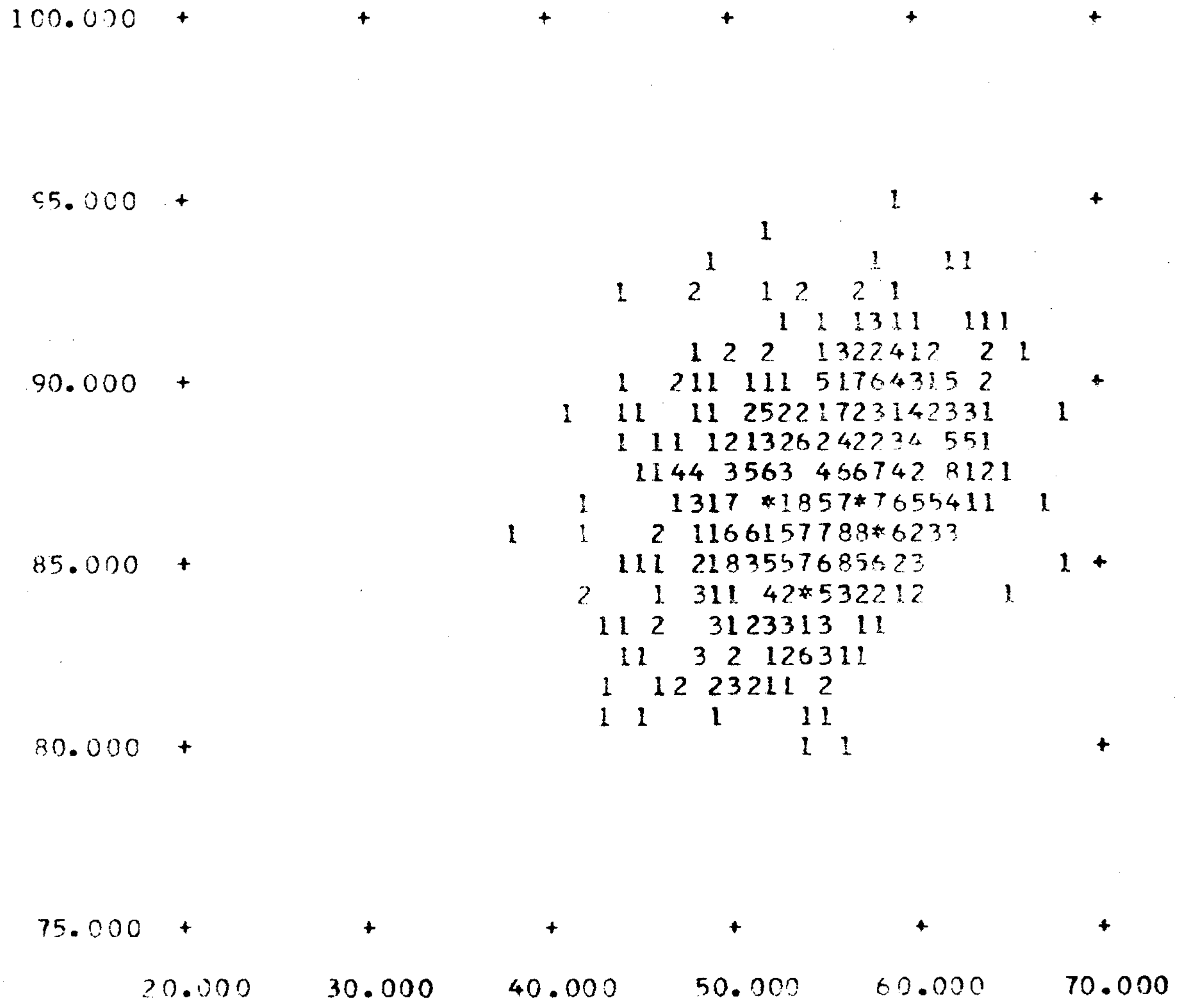
UPPER LIMIT	FREQUENCY	
73.667	2	XX
75.533	1	X
77.400	4	XXXX
79.267	16	XXXXXXXXXXXXXXXX
81.133	23	XXXXXXXXXXXXXXXXXXXXXXX
83.000	28	XXXXXXXXXXXXXXXXXXXXXXXXXXXX
84.867	24	XXXXXXXXXXXXXXXXXXXXXXXX
86.733	15	XXXXXXXXXXXXXXX
88.600	9	XXXXXXXXX
90.467	2	XX
92.333	1	X
94.200	1	X

$(x'')^2 = 12.63$

$x^2_{.05}(10) = 18.3$

FIGURE 14-2.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 1(LEVEL,CONTROLLED ACCESS)
TRUCK TYPE 2(HEAVY TRUCKS)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

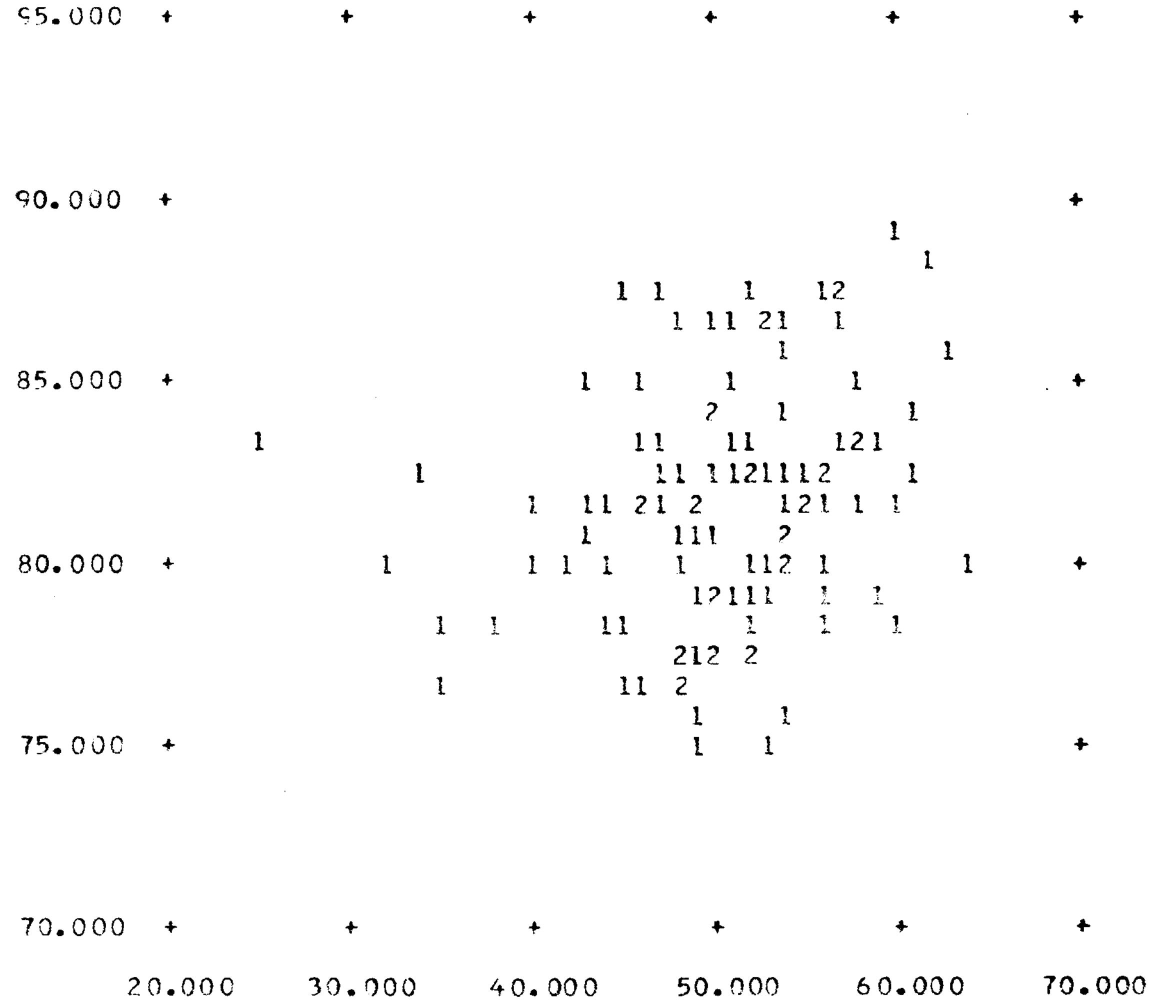
UPPER LIMIT	FREQUENCY	
81.433	9	XXX
82.667	26	XXXXXXXXXX
83.900	42	XXXXXXXXXXXXXXX
85.133	79	XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
86.367	103	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
87.600	129	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
88.833	67	XXXXXXXXXXXXXXXXXXXXXXXX
90.067	72	XXXXXXXXXXXXXXXXXXXXXXXXXX
91.300	37	XXXXXXXXXXXXX
92.533	13	XXXXX
93.767	10	XXXX
95.000	2	X

$(x'')^2 = 37.00$

$x^2_{.05}(23) = 35.2$

FIGURE 14-3.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 2(UPGRADE,CONTROLLED ACCESS)
TRUCK TYPE 1(MEDIUM TRUCKS & BUSES)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

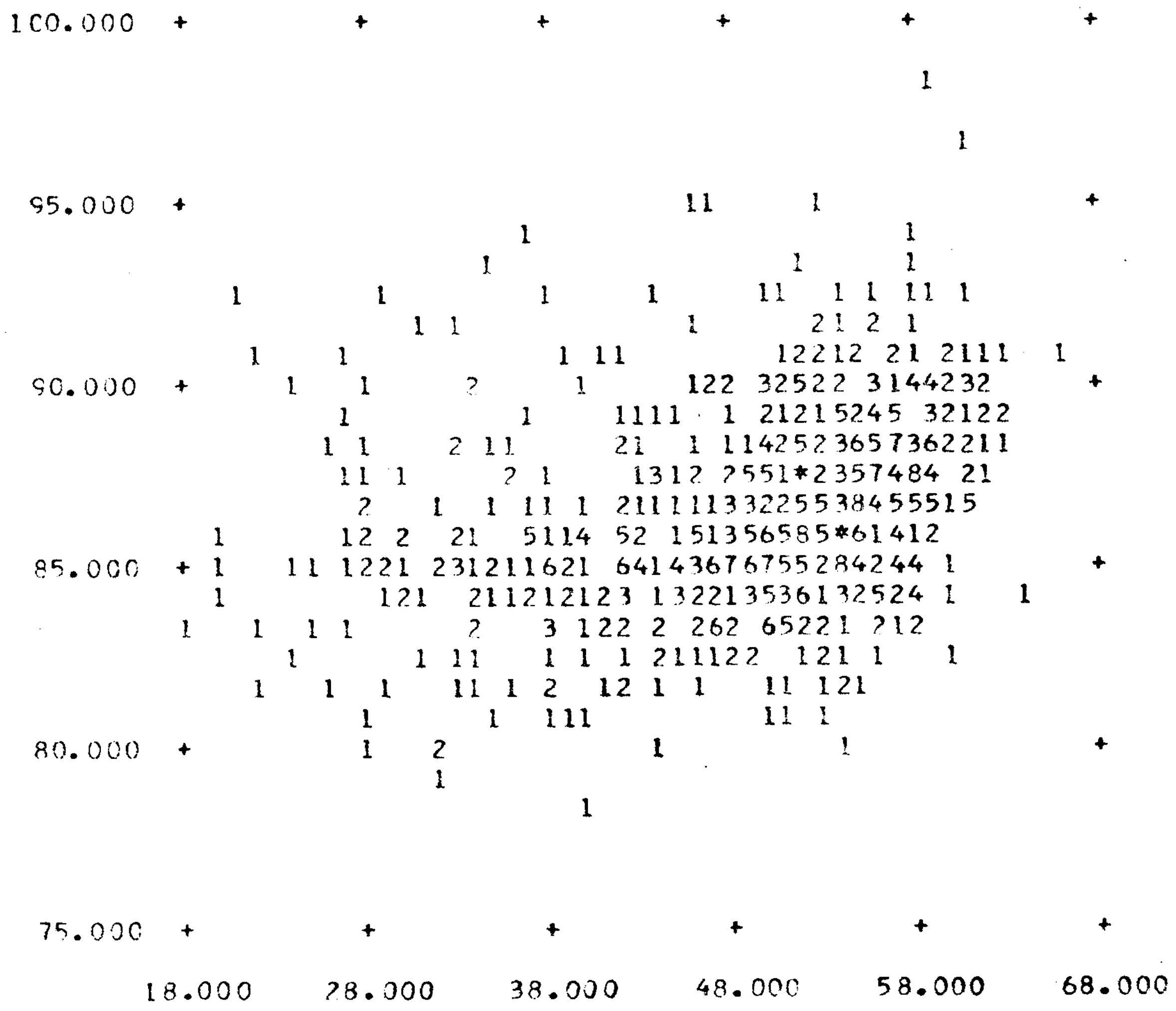
UPPER LIMIT	FREQUENCY	
76.083	3	XXX
77.267	8	XXXXXXXX
78.450	11	XXXXXXXXXXX
79.633	11	XXXXXXXXXXX
80.817	13	XXXXXXXXXXXXX
82.000	12	XXXXXXXXXXXX
83.183	20	XXXXXXXXXXXXXXXXXXXX
84.367	9	XXXXXXXXX
85.550	5	XXXXX
86.733	8	XXXXXXXX
87.917	7	XXXXXXX
89.100	2	XX

$(x'')^2 = 13.76$

$x^2_{.05}(9) = 16.9$

FIGURE 14-4.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 2(UPGRADE,CONTROLLED ACCESS)
TRUCK TYPE 2(HEAVY TRUCKS)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

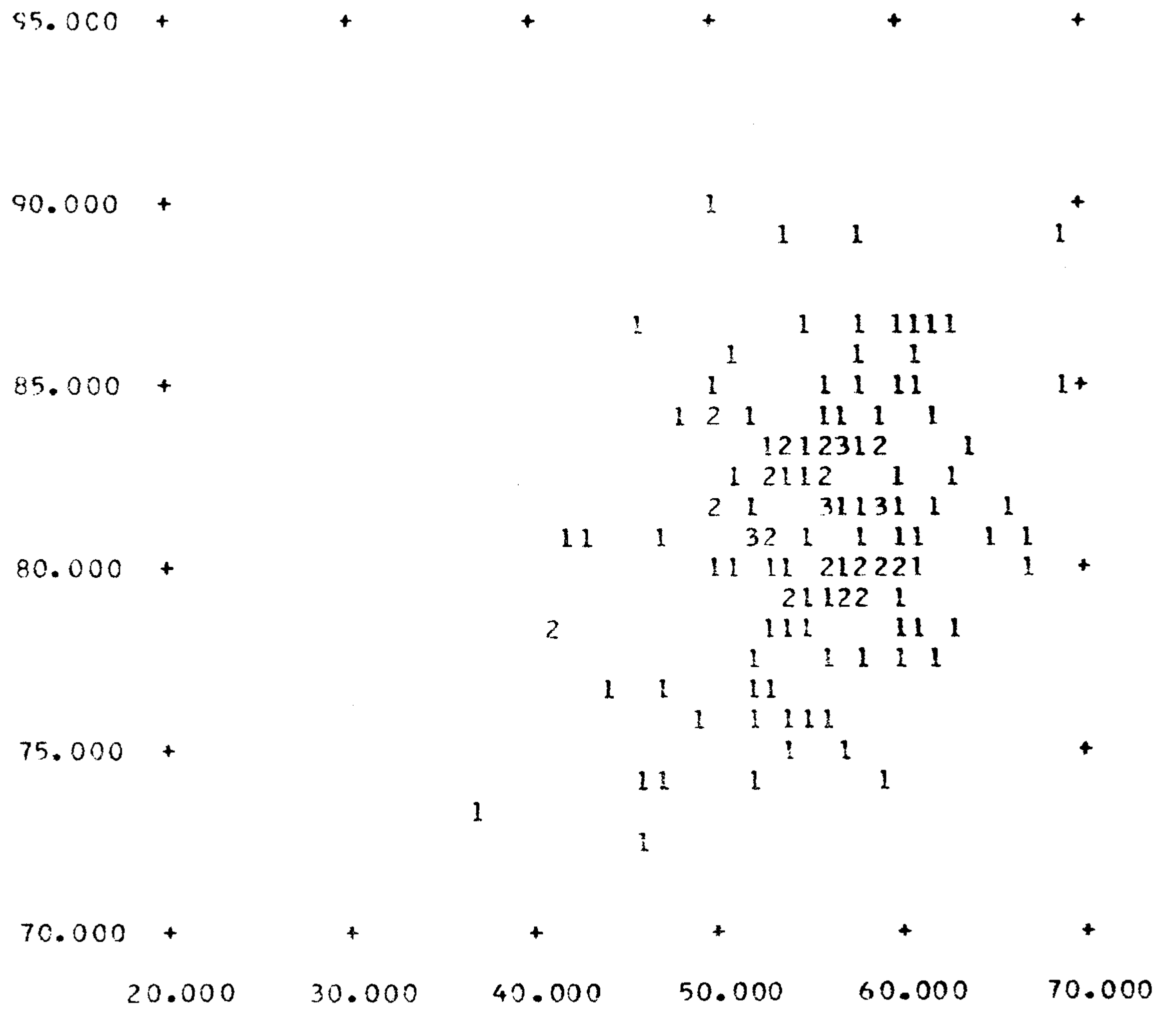
```
UPPER LIMIT     FREQUENCY
  80.175          6 XX
  81.850         18 XXXXX
  83.525         70 XXXXXXXXXXXXXXXXXXXXX
  85.200        158 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  86.875        169 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  88.550        139 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  90.225         83 XXXXXXXXXXXXXXXXXXXXXXXXX
  91.900         38 XXXXXXXXXXX
  93.575         16 XXXXX
  95.250          4 X
  96.925          2 X
  98.600          1 X
```

$(x'')^2 = 40.07$

$\chi^2_{.05}(25) = 37.7$

FIGURE 14-5.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 3(DOWNGRADE,CONTROLLED ACCESS)
TRUCK TYPE 1(MEDIUM TRUCKS & BUSES)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

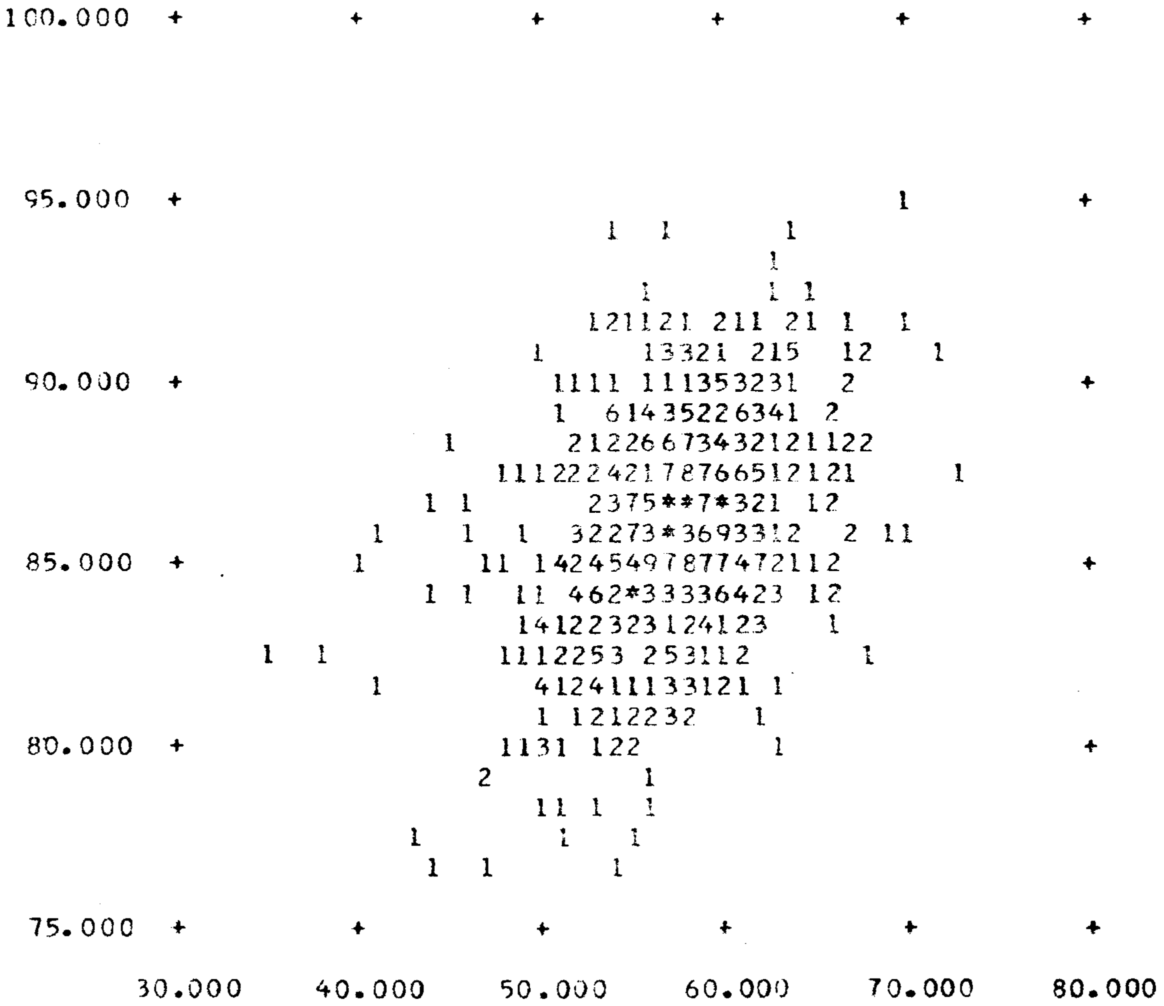
UPPER LIMIT	FREQUENCY	
74.125	5	XXXXX
75.550	5	XXXXX
76.975	6	XXXXXX
78.400	13	XXXXXXXXXXXXX
79.825	13	XXXXXXXXXXXXX
81.250	26	XXXXXXXXXXXXXXXXXXXXXXXXXX
82.675	20	XXXXXXXXXXXXXXXXXXXX
84.100	19	XXXXXXXXXXXXXXXXXXX
85.525	11	XXXXXXXXXXX
86.950	8	XXXXXXXX
88.375	2	XX
89.800	4	XXXX

$(x'')^2 = 7.82$

$x^2_{.05}(10) = 18.3$

FIGURE 14-6.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 3(DOWNGRADE,CONTROLLED ACCESS)
TRUCK TYPE 2(HEAVY TRUCKS)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

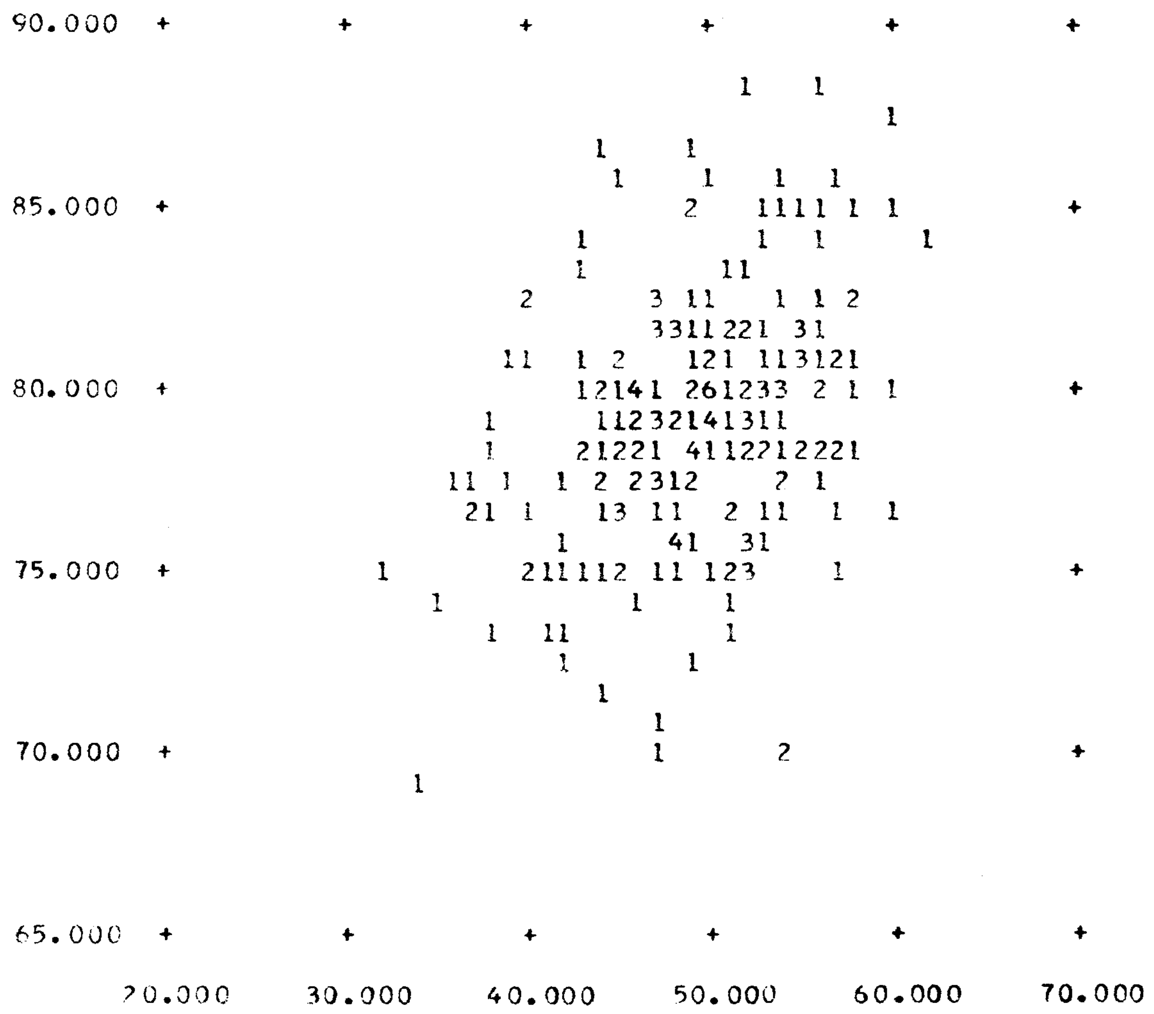
UPPER LIMIT	FREQUENCY	
78.242	8	XXX
79.783	7	XXX
81.325	28	XXXXXXXXXXX
82.867	53	XXXXXXXXXXXXXXXXXXXX
84.408	87	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
85.950	110	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
87.492	130	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
89.033	102	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
90.575	49	XXXXXXXXXXXXXXXXXXX
92.117	36	XXXXXXXXXXXXXX
93.658	4	XX
95.200	4	XX

$(x'')^2 = 33.09$

$x^2_{.05}(28) = 41.3$

FIGURE 14-7.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 4(LEVEL,NON-CONTROLLED ACCESS)
TRUCK TYPE 1(MEDIUM TRUCKS & BUSES)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

```
UPPER LIMIT     FREQUENCY
  70.625          4 XXXX
  72.250          2 XX
  73.875          6 XXXXXX
  75.500         23 XXXXXXXXXXXXXXXXXXXXXXX
  77.125         25 XXXXXXXXXXXXXXXXXXXXXXXXX
  78.750         43 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  80.375         49 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  82.000         37 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  83.625         14 XXXXXXXXXXXXXX
  85.250         11 XXXXXXXXXXX
  86.875          7 XXXXXXX
  88.500          3 XXX
```

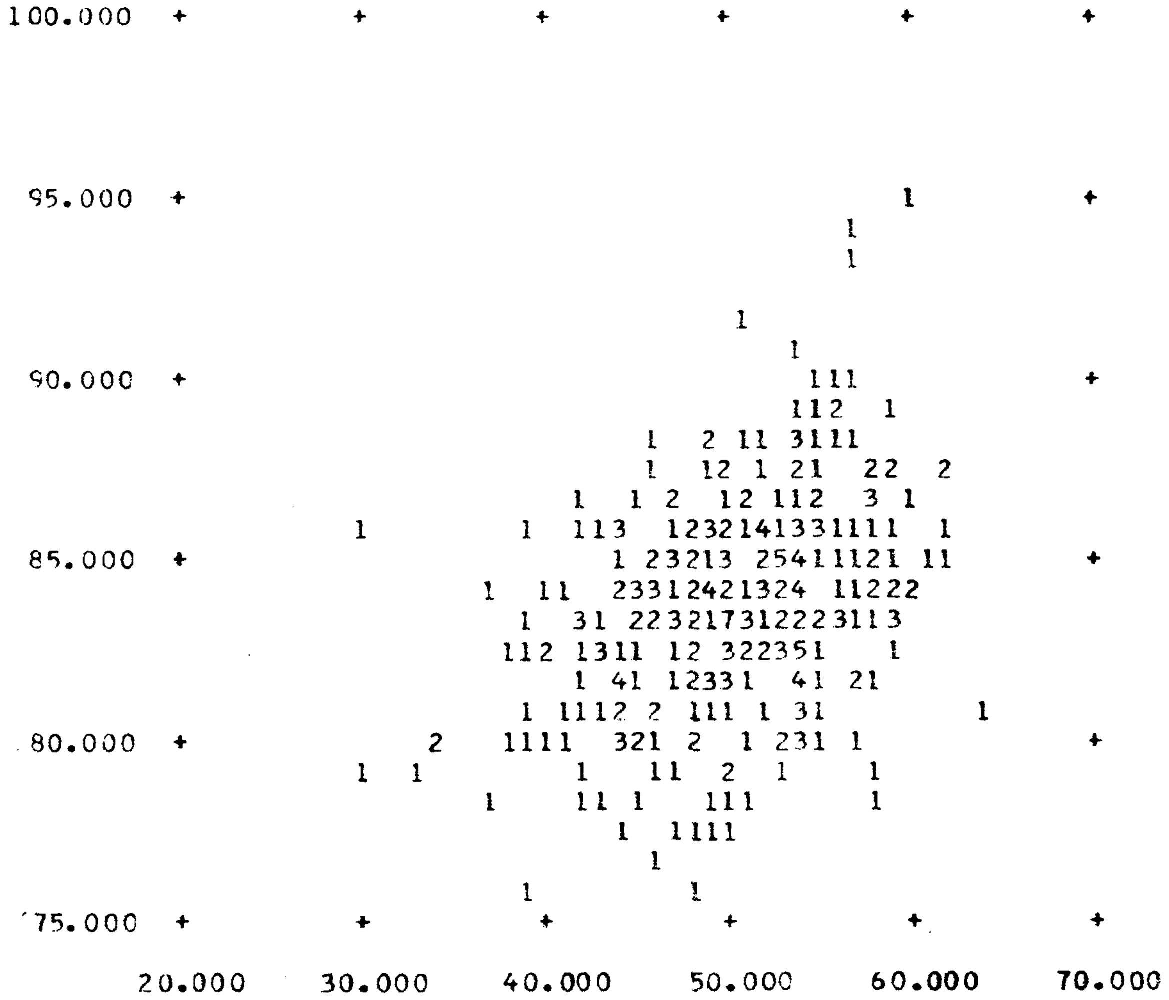
$(x'')^2 = 13.72$

$x^2_{.05}(12) = 21.0$

FIGURE 14-8.

SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 4(LEVEL,NON-CONTROLLED ACCESS)
TRUCK TYPE 2(HEAVY TRUCKS)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

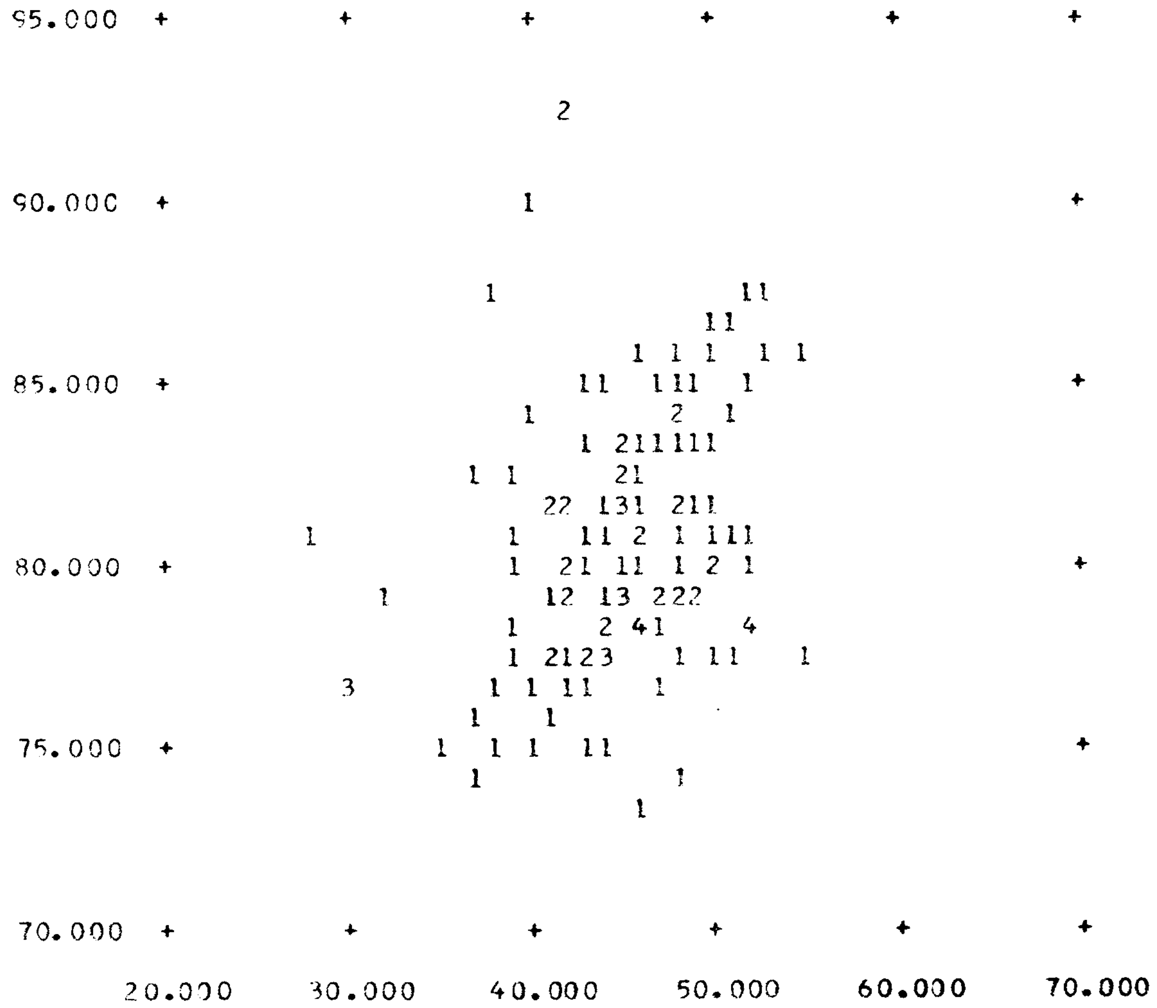
```
UPPER LIMIT    FREQUENCY
  77.125        3 XX
  78.750       13 XXXXXXXXX
  80.375       31 XXXXXXXXXXXXXXXXXXXXX
  82.000       41 XXXXXXXXXXXXXXXXXXXXXXXXXXX
  83.625       62 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  85.250       75 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  86.875       44 XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  88.500       27 XXXXXXXXXXXXXXXXXX
  90.125       11 XXXXXXX
  91.750        1 X
  93.375        2 X
  95.000        2 X
```

$(x'')^2 = 22.04$

$x^2_{.05}(24) = 36.4$

FIGURE 14-9.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 5(UPGRADE,NON-CONTROLLED ACCESS)
TRUCK TYPE 1(MEDIUM TRUCKS & BUSES)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

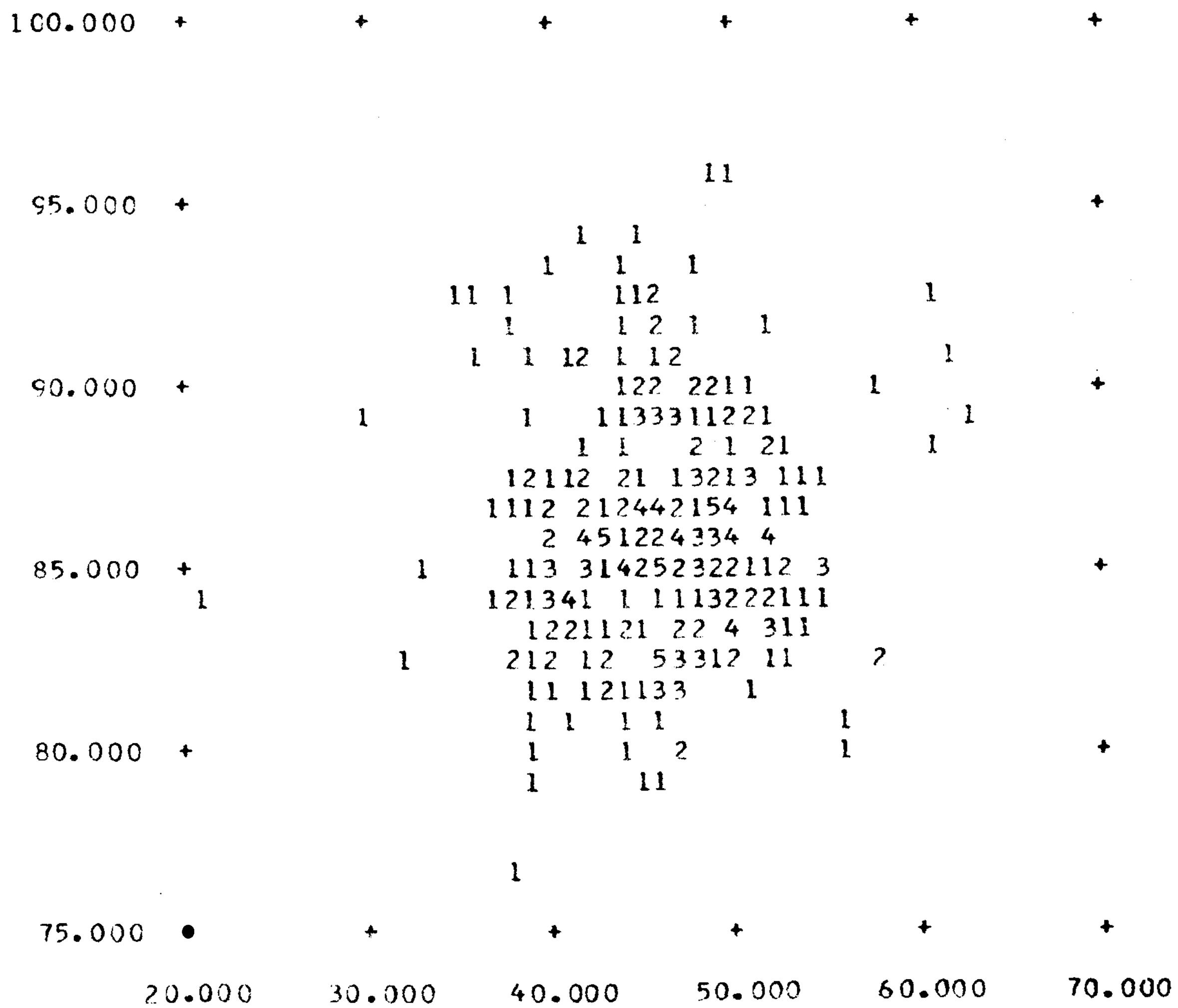
UPPER LIMIT	FREQUENCY	
75.233	7	XXXXXXX
76.767	9	XXXXXXXXX
78.300	23	XXXXXXXXXXXXXXXXXXXXXXX
79.833	20	XXXXXXXXXXXXXXXXXXXX
81.367	18	XXXXXXXXXXXXXXXXXX
82.900	18	XXXXXXXXXXXXXXXXXX
84.433	12	XXXXXXXXXXXX
85.967	8	XXXXXXXX
87.500	7	XXXXXXX
89.033	1	X
90.567	1	X
92.100	2	XX

$(x")^2 = 9.67$

$x^2_{.05}(11) = 19.7$

FIGURE 14-10.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 5(UPGRADE,NON-CONTROLLED ACCESS)
TRUCK TYPE 2(HEAVY TRUCKS)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

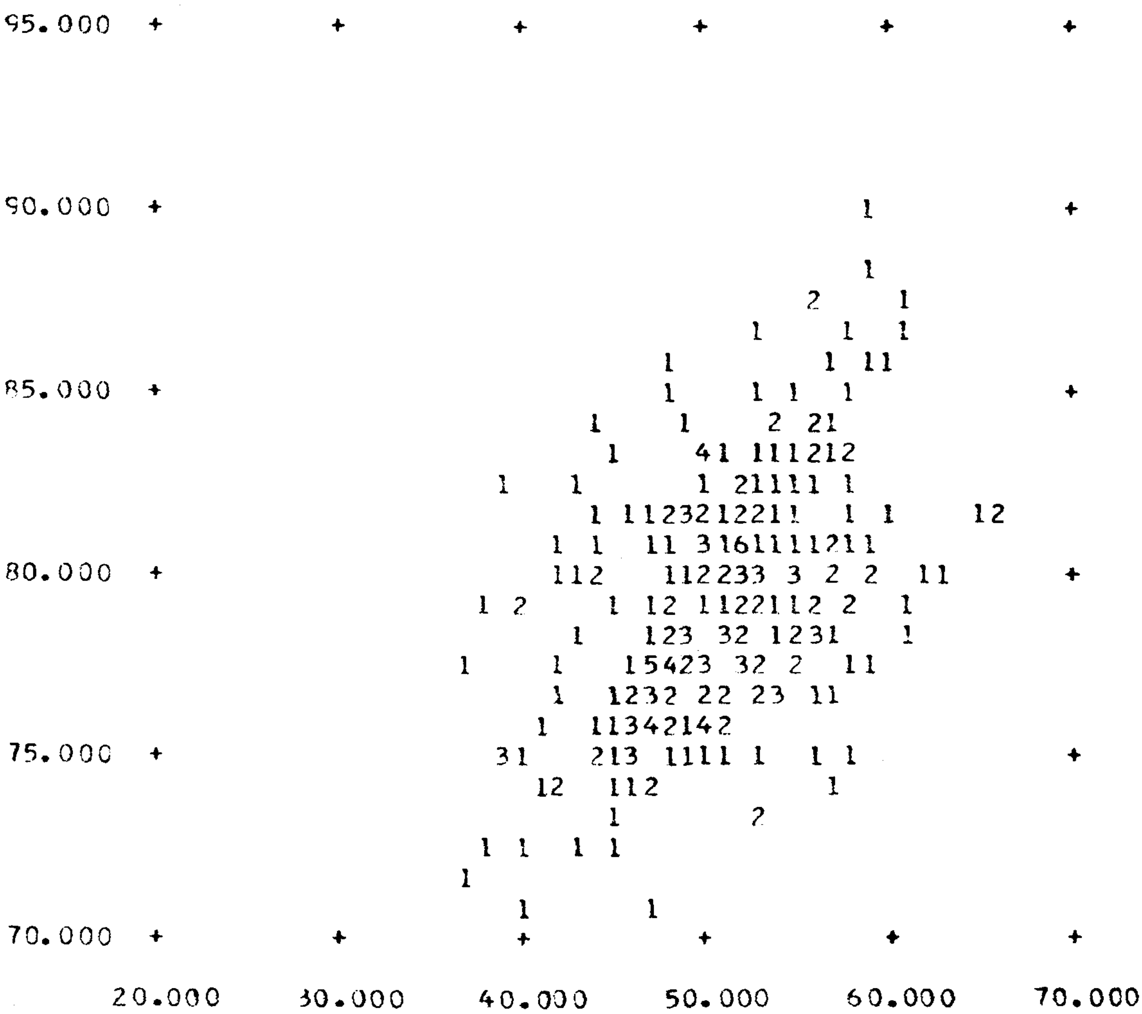
UPPER LIMIT	FREQUENCY	
78.558	1	X
80.117	5	XXXX
81.675	14	XXXXXXXXXX
83.233	45	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
84.792	47	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
86.350	69	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
87.908	53	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
89.467	25	XXXXXXXXXXXXXXXXXX
91.025	25	XXXXXXXXXXXXXXXXXX
92.583	14	XXXXXXXXXX
94.142	6	XXXX
95.700	3	XX

$(x'')^2 = 34.16$

$\chi^2_{.05}(25) = 37.7$

FIGURE 14-11.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 6(DOWNGRADE,NON-CONTROLLED ACCESS)
TRUCK TYPE 1(MEDIUM TRUCKS & BUSES)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

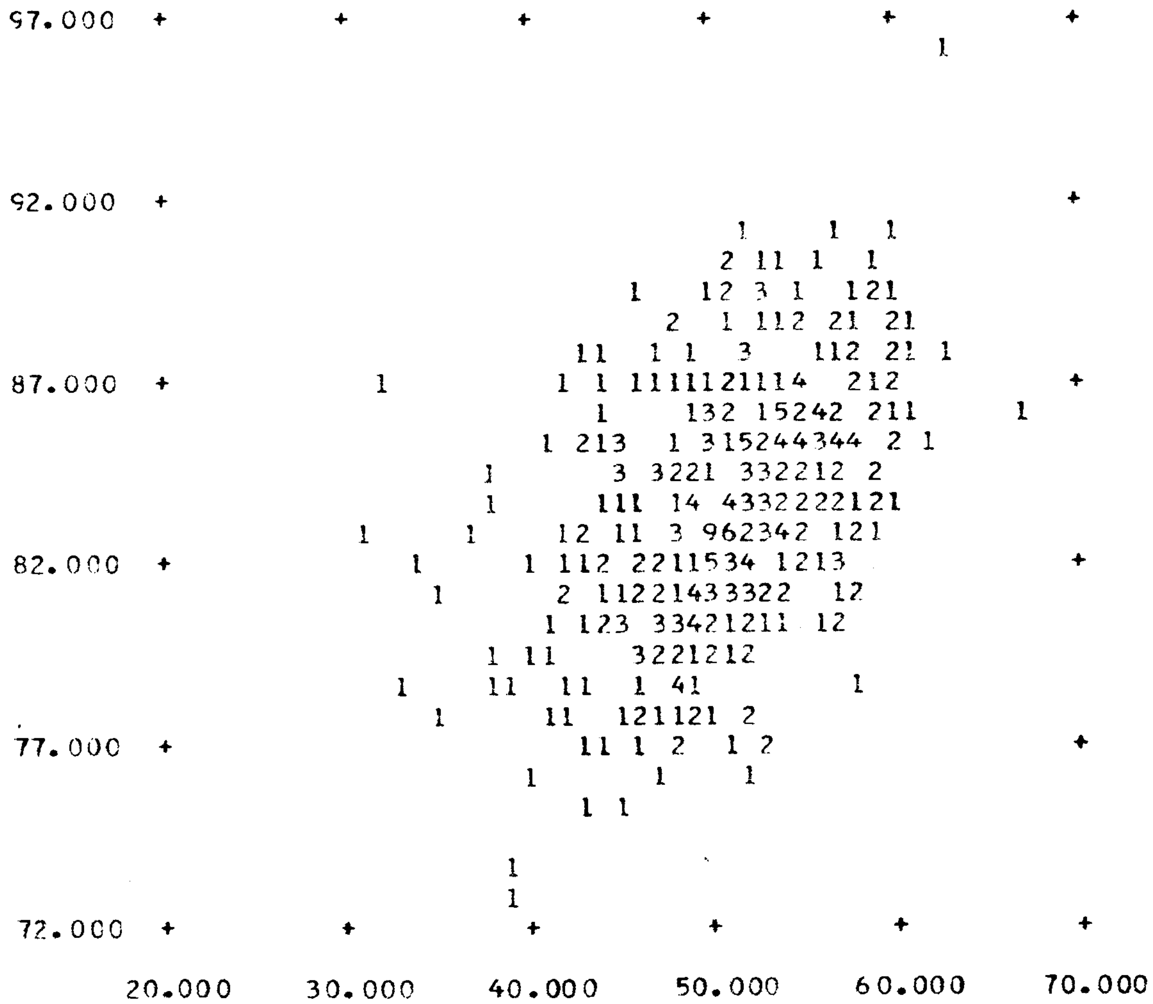
UPPER LIMIT	FREQUENCY	
72.400	4	XXXX
74.000	6	XXXXXX
75.600	28	XXXXXXXXXXXXXXXXXXXXXXXXXXXX
77.200	39	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
78.800	44	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
80.400	44	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
82.000	38	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
83.600	28	XXXXXXXXXXXXXXXXXXXXXXXXXXXX
85.200	12	XXXXXXXXXXXX
86.800	7	XXXXXXX
88.400	5	XXXXX
90.000	1	X

$(\chi'')^2 = 13.94$

$\chi^2_{.05}(12) = 21.0$

FIGURE 14-12.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 6(DOWNGRADE,NON-CONTROLLED ACCESS)
TRUCK TYPE 2(HEAVY TRUCKS)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

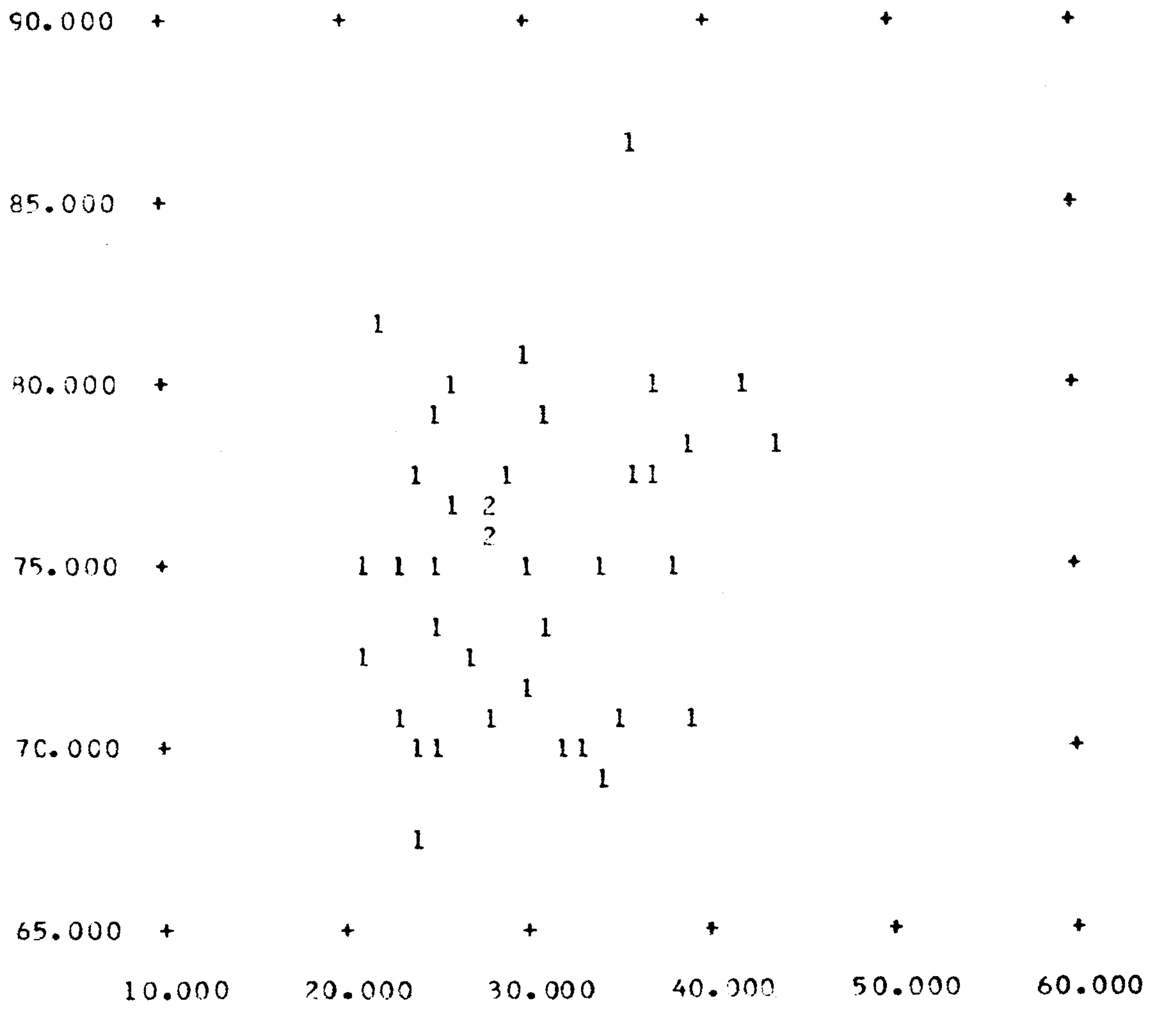
UPPER LIMIT	FREQUENCY	
74.950	2	X
76.900	7	XXXX
78.850	24	XXXXXXXXXXXXXXX
80.800	53	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
82.750	73	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
84.700	72	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
86.650	80	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
88.600	41	XXXXXXXXXXXXXXXXXXXXXXXXXXXX
90.550	25	XXXXXXXXXXXXXXXXX
92.500	3	XX
94.450	0	
96.400	1	X

$(x'')^2 = 30.39$

$\chi^2_{.05}(29) = 42.6$

FIGURE 14-13.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 7A(RAMPS,ACCELERATION)
TRUCK TYPE 1(MEDIUM TRUCKS & BUSES)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

UPPER LIMIT	FREQUENCY
69.258	2 XX
70.817	7 XXXXXXX
72.375	2 XX
73.933	4 XXXX
75.492	6 XXXXXX
77.050	5 XXXXX
78.608	6 XXXXXX
80.167	4 XXXX
81.725	2 XX
83.283	1 X
84.842	0
86.400	1 X

$(x'')^2 = 2.53$

$x^2_{.05}(3) = 7.81$

FIGURE 14-14.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 7A(RAMPS,ACCELERATION)
TRUCK TYPE 2(HEAVY TRUCKS)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)

```
  95.000  +         +         +         +         +         +


                         1          1

                               1
  90.000  +        1    1    1                              +
                      11        1
                      1       1 1
                     2   1
                      112   3 1   1       1
                     1111  111
  85.000  +          2 421211                               +
                       23 42 2   1  2 11
                     33 51321      1 1
                  1    4236244211  1112
             1       31322155221121 1
               111 124463621 211 11
  80.000  +  1      21 2445131111    1                      +
          1       1 3153 3331 311
                   122 24143112  1   1
                     11221211 1
                  1 2 3215 211 1        1
                   1 2 1  331 1
  75.000  +         12121 1                                 +
                          111
               1  1       1
                    1
                      1

  70.000  +         +         +         +         +         +

       10.000    20.000    30.000    40.000    50.000    60.000
```

HISTOGRAM OF OVERALL NOISE LEVEL

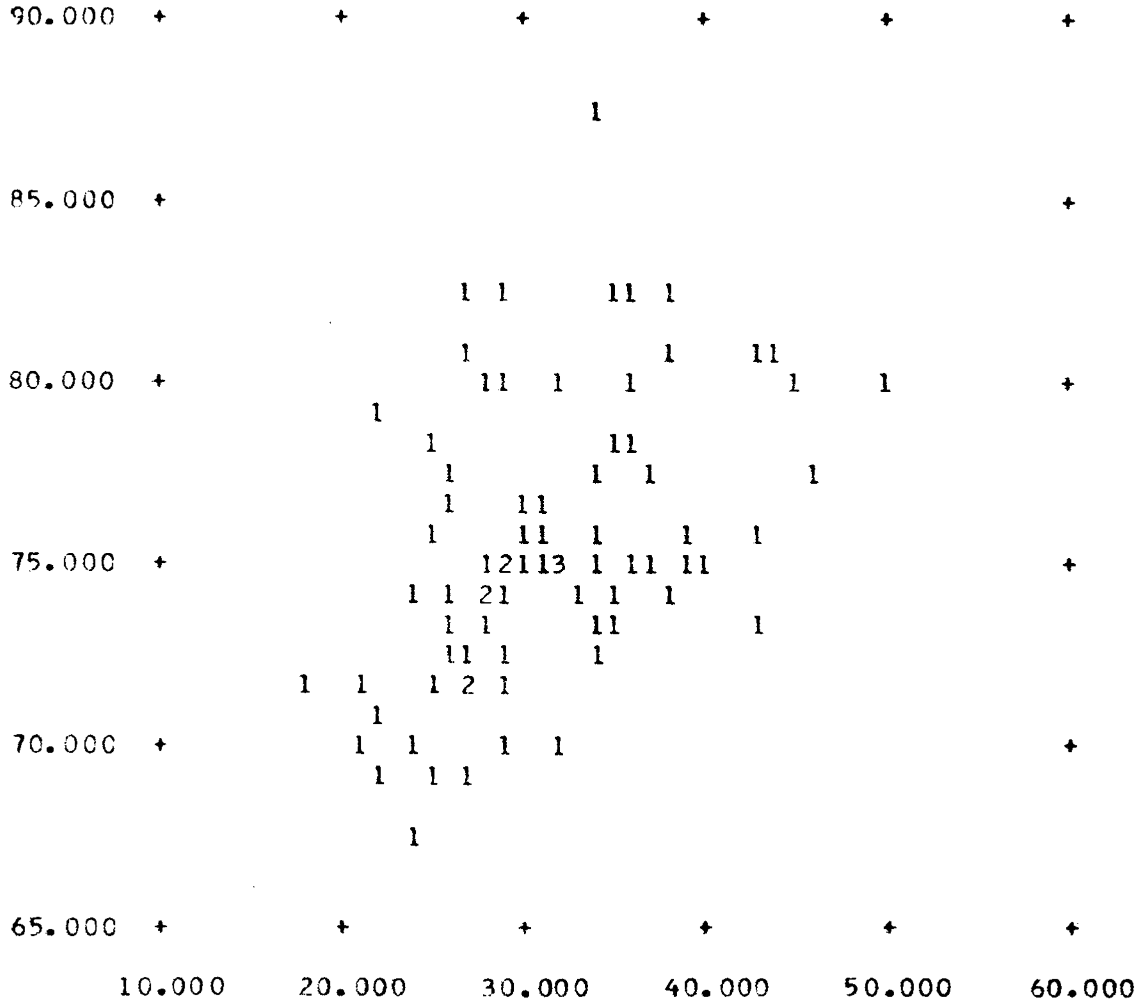
```
UPPER LIMIT     FREQUENCY
  73.167          2 X
  74.933          9 XXXXXX
  76.700         26 XXXXXXXXXXXXXXXXXX
  78.467         42 XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  80.233         54 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  82.000         72 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  83.767         63 XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
  85.533         31 XXXXXXXXXXXXXXXXXXXXXX
  87.300         17 XXXXXXXXXXXX
  89.067          7 XXXXX
  90.833          5 XXX
  92.600          3 XX
```

$(x'')^2 = 24.87$

$x^2_{.05}(28) = 41.3$

FIGURE 14-15.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 7B(RAMPS,NO ACCELERATION)
TRUCK TYPE 1(MEDIUM TRUCKS & BUSES)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

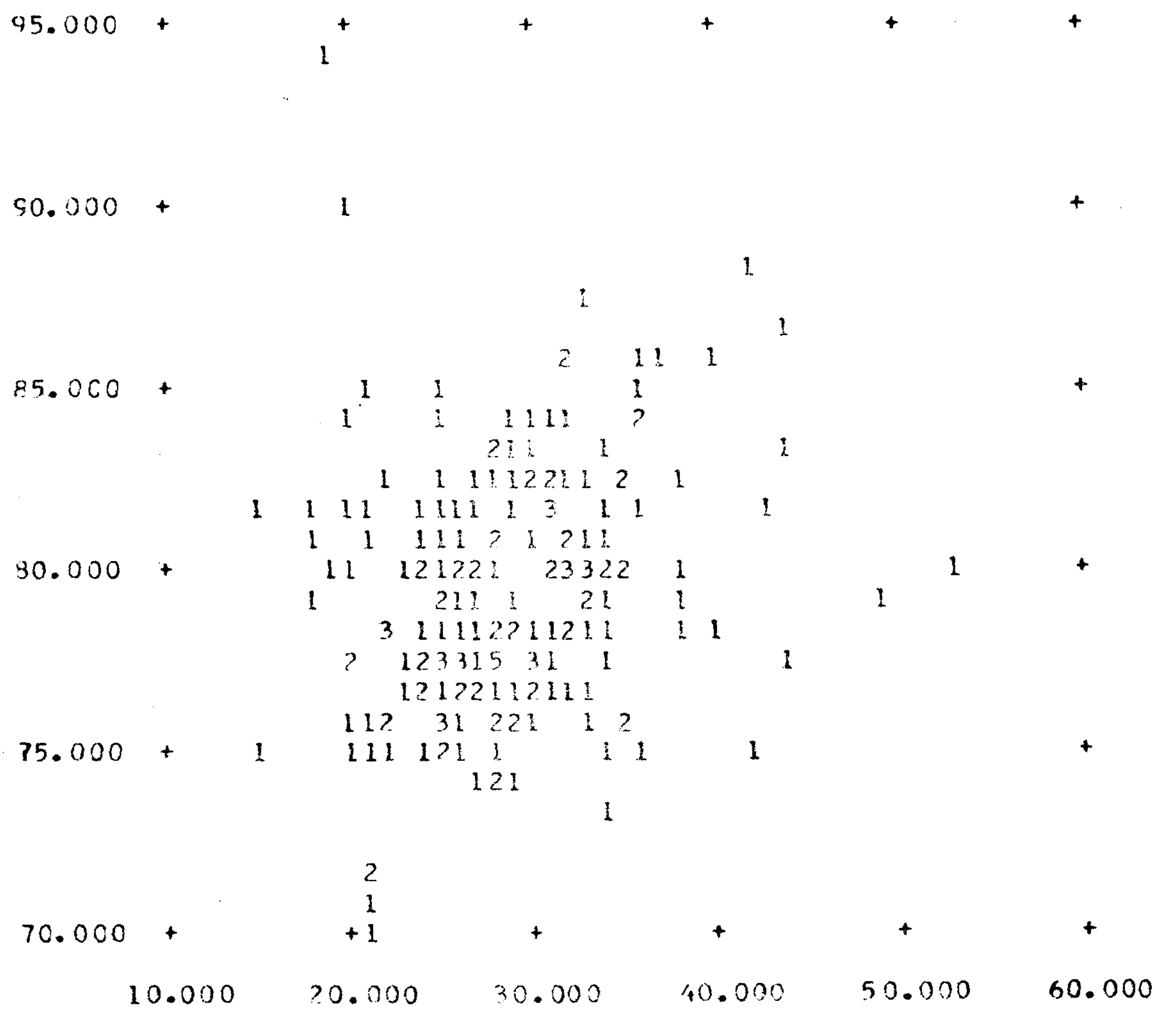
```
UPPER LIMIT     FREQUENCY
  69.242         3 XXX
  70.883         6 XXXXXX
  72.525        10 XXXXXXXXXX
  74.167         8 XXXXXXXX
  75.808        21 XXXXXXXXXXXXXXXXXXXXX
  77.450         9 XXXXXXXXX
  79.092         5 XXXXX
  80.733         8 XXXXXXXX
  82.375         5 XXXXX
  84.017         2 XX
  85.658         0
  87.300         1 X
```

$(x'')^2 = 15.95$

$x^2_{.05}(9) = 16.9$

FIGURE 14-16.
SCATTERPLOT AND HISTOGRAM OF OVERALL NOISE EMISSION LEVELS
ROADWAY 7B (RAMPS, NO ACCELERATION)
TRUCK TYPE 2 (HEAVY TRUCKS)

SCATTERPLOT OF OVERALL NOISE LEVEL IN DBA (Y) VS. SPEED IN MPH (X)



HISTOGRAM OF OVERALL NOISE LEVEL

UPPER LIMIT	FREQUENCY	
72.208	4	XXXX
74.217	3	XXX
76.225	30	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
78.233	47	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
80.242	42	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
82.250	38	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
84.258	21	XXXXXXXXXXXXXXXXXXXXX
86.267	8	XXXXXXXX
88.275	3	XXX
90.283	1	X
92.292	0	
94.300	1	X

$(x'')^2 = 13.01$

$x^2_{.05}(12) = 21.0$

50 feet (15.2m). In the scatterplots, a one digit number is used to indicate the number of data points that fall in an area. An asterisk indicates ten or more data points. Each figure also contains a histogram of overall emission level with associated Chi-square (x^2) statistics for a test of goodness-of-fit to a normal curve.

The scatterplots show considerable variation in the noise level data. In fact, for a particular speed, a variation in emission level of 10 dB is fairly common. Scatterplots for heavy trucks for Roadway Types 2 and 5 (upgrades) and 7A (ramps with acceleration) show little relationship between emission level and speed; while a relationship is much more obvious for Roadway Types 1 and 6 for medium trucks and buses, and Roadway Types 3 and 6 (downgrades) for heavy trucks. An examination of all the plots reveals that for this study, emission levels were on occasion greater than 95 dB but never above 100 dBA; occasionally below 70, but never below 65 dBA.

The scatterplots clearly indicate the range of truck speeds for which measurements of emission levels were obtained. The speed ranges for the various roadway types and truck types are shown in Table 7 on page 135.

Since the emission level prediction lines were developed from noise levels for trucks having speeds within these ranges, one should be careful when making noise predictions for speeds falling outside these ranges where the prediction lines are not well defined.

TABLE 7

RANGE OF SPEEDS

Miles per hour (kilometers per hour)

ROADWAY TYPE	TRUCK TYPE 1 (Medium Trucks and Buses)	TRUCK TYPE 2 (Heavy Trucks)
1 Controlled Access Level	28 - 64 (45 - 102)	38 - 68 (61 - 109)
2 Controlled Access Upgrade	25 - 64 (40 - 102)	18 - 66 (29 - 106)
3 Controlled Access Downgrade	37 - 69 (59 - 110)	35 - 73 (56 - 117)
4 Non-controlled Access Level	32 - 62 (51 - 99)	30 - 64 (48 - 102)
5 Non-controlled Access Upgrade	28 - 55 (45 - 88)	21 - 63 (34 - 101)
6 Non-controlled Access Downgrade	37 - 66 (59 - 106)	31 - 67 (50 - 107)
7A Ramps (Acceleration)	21 - 44 (34 - 70)	10 - 41 (16 - 66)
7B Ramps (Non-acceleration)	18 - 50 (29 - 80)	15 - 53 (24 - 85)

C. Normality of Noise Level Data - The histograms of overall noise emission level were included in Figures 14-1 to 14-16 in order to illustrate the shape of the frequency distributions. To the eye most of the distributions appear to be nearly normally distributed. In order to examine the normality of the data in a more rigorous manner, a computer program was written which utilized a Chi-square (x^2) goodness-of-fit test to evaluate how well the noise emission data fit a normal curve. Values of $(x'')^2$, a statistic determined for the distribution of noise levels, are compared to the value of the χ^2 distribution for the appropriate degrees of freedom and a 5% level of significance. If $(\chi'')^2$ is less than $\chi^2.05$ one can conclude that the noise data came from a distribution not greatly different from the particular normal distribution specified by the mean and standard deviation of the sample. Values of $(\chi'')^2$ and χ^2 are shown at the right hand side of each histogram. Results of the Chi-square goodness-of-fit tests indicated that except for the heavy truck data for Roadway Types 1 and 2 (controlled access, level and upgrade), all of the other noise data came from distributions approximately the same as the normal distributions specified in the tests.

Since the calculation of energy mean emission level, $\bar{L}_E$, by the prediction equation $\bar{L}_E = \bar{L}_0 + 0.115\sigma^2$ is based on the assumption of normally distributed data, the accuracy of this equation in regard to this study was examined at this point. In this equation $\bar{L}_0$ is the arithmetic mean emission level, and σ is the standard deviation of the noise data.

The equation will be evaluated based on the noise data for particular roadway type and truck type groups (e.g., Roadway Type 1, Truck Type 2). This data includes noise levels for all speeds encountered for a group, that is, speeds covering the ranges given in Table 7, page 135. Thus, here, $\bar{L}_0$ is not determined from a regression; it is simply the arithmetic mean of the emission levels of all vehicles in a particular roadway type and truck type group with no consideration given to speed. Hence, the accuracy of the energy mean level prediction equation was not evaluated for any specific speed or speed group.

The energy mean emission level calculated by the prediction equation (from here on, $P\overline{L}_E$) was compared to the directly calculated energy mean level $\overline{L}_E$. Direct calculation of the energy mean emission level means that $\overline{L}_E$ was determined by finding ten times the logarithm of the mean intensity level of all vehicles according to the equations:

$$\text{Energy Mean Emission Level} = \overline{L}_E = 10 \log (\overline{I}), \text{ and}$$

$$\text{Mean Intensity Level} = \overline{I} = \frac{1}{N} \sum_{i=1}^{k} f_i(10^{L_i/10})$$

$\overline{I}$ was calculated by grouping the noise emission levels into classes to form a frequency histogram. Thus, in the equation for $\overline{I}$, f_i = the frequency of class i, L_i = the sound level corresponding to the mid-point of class i, k = the number of classes, and N = the total number of individual truck noise emission level measurements.

Table 8, page 138, indicates the differences which occurred between directly calculated energy mean level, $\overline{L}_E$, and predicted energy mean level, $P\overline{L}_E$.

Table 8 indicates that in most cases $\overline{L}_E$ was higher than $P\overline{L}_E$. On the average, it was approximately 0.1 dB higher. The largest differences which occurred were 0.29 dB for medium trucks and buses on Roadway Type 5 (non-controlled access, upgrades), and 0.34 dB for heavy trucks on Roadway Type 7B (ramps with no acceleration). This would seem to indicate that at least for these noise data sets of large size and a wide range of speeds, the prediction equation for energy mean emission level is quite accurate.

TABLE 8

DIFFERENCE : $\bar{L}_E - P\bar{L}_E$ (dBA)

ROADWAY TYPE	TRUCK TYPE 1 (Medium Trucks and Buses)	TRUCK TYPE 2 (Heavy Trucks)
1 Controlled Access Level	0.13	0.02
2 Controlled Access Upgrade	0.00	0.10
3 Controlled Access Downgrade	-0.02	-0.04
4 Non-controlled Access Level	0.02	0.09
5 Non-controlled Access Upgrade	0.29	0.10
6 Non-controlled Access Downgrade	0.09	0.01
7A Ramps (Acceleration)	0.10	0.15
7B Ramps (Non-acceleration)	0.18	0.34

IMPLEMENTATION OF FINDINGS

The implementable product which has resulted from this study is a modification of the input truck noise levels for the Transportation Systems Center Noise Prediction Program, a modification which will make the noise levels used by the program more nearly reflect the truck noise levels presently occurring in the State of New Jersey. This modification will include changes to vehicle types (truck classifications), roadway types (upgrade and downgrade roadway sections), peak noise levels, their standard deviations and corresponding octave frequency spectra, noise level versus speed relationships, and vehicle source heights.

The findings of this study represent a modification of existing FHWA approved noise prediction methods and are thus subject to approval by the FHWA's Office of Environmental Policy before implementation. Assuming this approval is obtained, the proposed modifications will be incorporated into the TSC MOD-04 noise prediction computer program by NJDOT's Division of Data Processing. Once it is verified that this modified version of MOD-04 is operating properly, the findings of this study will be immediately implementable by operating personnel within NJDOT responsible for making traffic noise predictions.

This report, which discusses the work done on this study and provides the information required for implementation, will be presented to the operating agency. Meetings will be held between members of the Division of Research (responsible for this report) and operating personnel to review and clarify the findings of this study, thus aiding in their implementation.

Since the operating agency is presently using the TSC prediction program and has used it for several years, these meetings will deal primarily with the approved modifications. As a final step, after implementation has been begun, Research will continue to maintain close contact with operating personnel in order that any further difficulties arising in the use of the modified program can be resolved.

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APPENDIX A

DEVELOPMENT OF MEASUREMENT METHODOLOGY

This appendix contains a more detailed discussion of the development of the measurement methodology than was contained in the body of this report. The data collection procedures which are included in this appendix are slightly modified versions of the original procedures contained in the first interim report. The modifications resulted from field experience.

A measurement methodology was developed which insured the accurate collection of the noise level information needed to modify the reference emission level input to the TSC program. This information included the peak A-weighted noise level and frequency spectrum produced by the pass-by of an individual truck. Measurements were made at a distance of 50 feet (15.2m) from the center of the lane of travel. The measurement methodology also provided a procedure for the accurate collection of truck speed information and meteorological data.

The major steps in the development of the measurement methodology were (1) the definition and classification of trucks, (2) the establishment of a valid measurement criterion which provided a means of checking that an individual truck was isolated from other highway traffic to the extent that an accurate measurement of its noise level could be obtained, (3) the development of field procedures for noise, speed, and meteorological data collection, and (4) an examination, by statistical methods, of the relationship between the size of a random sample and the precision of a population estimate based on the results obtained for the sample.

Each of the above steps is discussed in the following sections.

Truck Definition and Classification

The definition of a truck was selected from [3] which contains federal noise standards and defines a truck as ... "any motor vehicle (including buses) having a gross vehicle weight greater than 10,000 pounds". This is a standard definition of a truck commonly used in studies dealing with noise levels.

Since for this study it was not possible to obtain the gross vehicle weights of trucks whose noise was measured, a different method of truck classification was chosen. It was decided to classify trucks in terms of axle configuration. Noise level data presented in terms of axle configuration is easily implementable within the state since traffic count information for New Jersey is also presented based on an axle classification system. Since axle configuration is strongly related to gross vehicle weight, this method of classification is also compatible with the truck definition stated earlier. Accordingly, any vehicle of greater than 10,000 pounds (4536 kg) gross vehicle weight generally corresponds in terms of axle configuration to any vehicle having at least two axles and six tires (dual rear wheels).

With this considered, it was decided to conduct noise level measurements for the following "truck" classifications with corresponding codes in parentheses:

(1) Two axle trucks with dual rear wheels (2/6)

(2) Two axle, dual rear wheeled truck tractors without semitrailers (2T)

(3) Three axle truck tractors without semitrailers (3T)

(4) Two axle buses with dual rear wheels (2B)

(5) Three axle buses (3B)

(6) Three axle, single unit body trucks (3)

(7) Four axle, single unit body trucks (4)

(8) Trucks with two axle tractors and one axle semitrailers (2-1)

(9) Trucks with two axle tractors and two axle semitrailers (2-2)

(10) Trucks with two axle tractors and three axle semitrailers (2-3)

(11) Trucks with three axle tractors and one axle semitrailers (3-1)

(12) Trucks with three axle tractors and two axle semitrailers (3-2)

(13) Trucks with three axle tractors and three axle semitrailers (3-3)

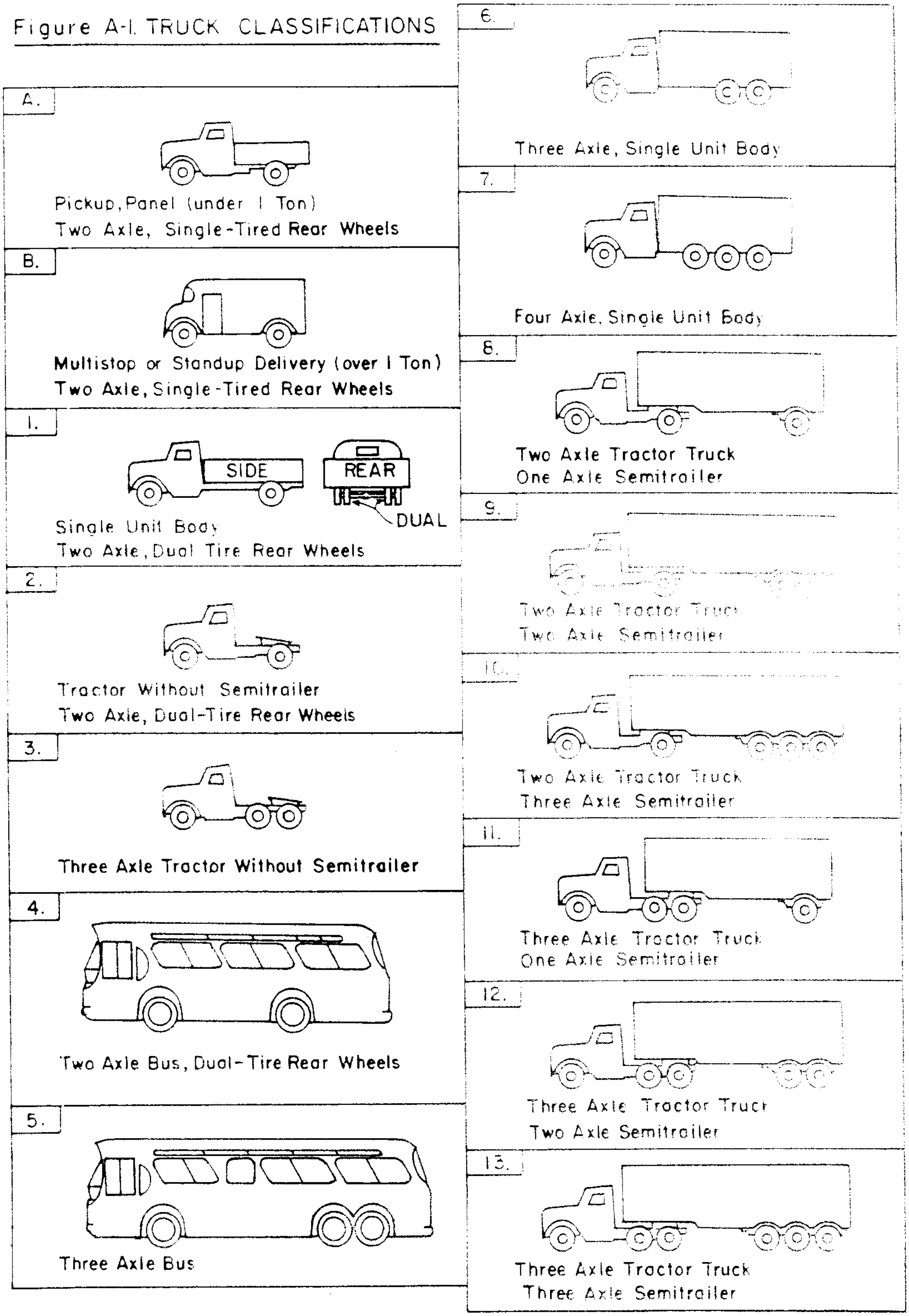
These classes of trucks are illustrated in Figure A-1, page 150, and are correspondingly labeled 1 to 13. Figure A-1 also shows Classes A & B, pickups and small standup delivery vans. Noise levels for vehicles in Classes A & B were not measured because the great majority of these vehicles are less than 10,000 pounds (4536 kg) in measured gross vehicle weight.

The dual rear wheeled, two axle trucks in Class 1 are the lightest trucks that were measured. They have measured gross vehicle weights which normally range from approximately 10,000 to 25,000 pounds (4536 to 11340 kg). Examples of dual rear wheeled, 2-axle trucks are small vans and flatbeds, utility trucks, and large delivery trucks.

Two and three axle tractors in Classes 2 and 3 are significant noise sources by themselves since engine and exhaust noise are a major part of the total noise produced by a truck. These tractors have weights ranging from about 8,000 to 15,000 pounds (3629 to 6804 kg) (not gross weight).

Examples of two axle, dual rear wheeled buses in Class 4 are city transit and school buses. Three axle buses in Class 5 are primarily commuter buses used for inter-city and interstate travel. The measured gross vehicle

Figure A-1. TRUCK CLASSIFICATIONS



NOTE: Body Types as shown are for sketch purposes only, and it is not intended to imply that they are the only body types encountered in these classifications.

weights of two and three axle buses range from approximately 20,000 to 35,000 pounds (9072 to 15876 kg).

The 3 or more axle trucks in Classes 6 to 13 include 3 and 4 axle single unit dump trucks and refuse trucks, and 3, 4, 5 and 6 axle tractor semi-trailers which are primarily either vans, tankers, or flatbeds. The measured gross vehicle weights for trucks in these classes range from about 20,000 to 80,000 pounds (9072 to 36288 kg).

Other studies [13, 14 & 15] have provided strong evidence that the noise produced by an individual truck is (1) to a certain degree, related to its measured gross weight, and (2) capable of varying by several decibels depending upon whether a truck is fully loaded or empty. With this in mind, Table A-1, page 152 has been included to provide some information about the truck weights which are encountered in New Jersey. It indicates the approximate distribution of truck weights within most of the classes of trucks listed on pages 148 & 149 and shown in Figure A-1, page 150. In Table A-1, Classes 1 and 2 are combined as well as Classes 3 and 6 due to the manner in which available data was presented. Data for Classes 4 and 5 (buses) were not available. The percentage of trucks within each weight range was based on the results of the 1977 New Jersey Loadometer Study in which the gross weights of trucks were measured at 27 locations throughout the state. The average weight of and the number of trucks sampled in each classification is also indicated. Data in the table may be useful to others who have truck weight information and wish to make comparisons.

A Valid Measurement

Since the noise produced by highway vehicles is summed at an observer, it was recognized that for a measurement of the noise produced by an individual

TABLE A-1.

TRUCK WEIGHT DISTRIBUTIONS BY PERCENT*

Measured Gross Weight Range (K lbs)**	Truck Classifications								
	1 & 2	3 & 6	7	8	9	10	11	12	13
	2 Axle 6 Tires Single	3 Axle Single	4 Axle Single	2-1 Tractor Trailer	2-2 Tractor Trailer	2-3 Tractor Trailer	3-1 Tractor Trailer	3-2 Tractor Trailer	3-3 Tractor Trailer
4-6 K	1.9%								
6-8	8.1								
8-10	11.5	0.2%							
10-12	12.9	0.5							
12-14	14.4	0.7			0.1%				
14-16	13.0	4.4		0.4%					
16-18	10.8	9.9		1.9	0.1				
18-20	8.4	7.1	3.6%	1.9	0.6			0.1%	
20-25	11.3	10.4	5.5	19.9	7.0	6.6%	17.6%	1.4	
25-30	5.1	18.0	18.2	26.4	17.3	13.1	23.5	7.2	
30-35	1.8	16.1	5.5	28.0	15.6	16.4	11.8	11.4	14.3%
35-40	0.6	10.6	1.8	13.0	17.3	13.1	11.8	9.1	14.3
40-45	0.1	6.2	10.9	6.5	13.1	1.6	17.6	7.5	
45-50	0.04	3.5	3.6	1.5	11.7		11.8	6.9	7.1
50-55		2.1	3.6		8.2	3.3	5.9	7.8	7.1
55-60		3.0	5.5	0.4	4.4	4.9		8.6	7.1
60-65		2.5	7.3		2.8	3.3		9.7	
65-70		3.0	5.5		1.1	8.2		8.1	
70-75		1.8	14.5		0.5	8.2		8.4	
75-80			5.5		0.1	13.1		7.2	21.4
80-85			3.6			3.3		4.1	
85-90			5.5			1.6		1.5	7.1
90-95						1.6		0.7	14.3
95-100						1.6		0.2	
100-105								0.04	
120K									7.1
Total %	100%	100%	100%	100%	100%	100%	100%	100%	100%
Average Weight (lbs)	15,193	32,391	51,555	30,192	38,983	51,516	34,853	53,750	65,893
Number in Sample	2,504	434	55	261	1,515	61	17	4,842	14

*Based on 1977 New Jersey Loadometer Study
**1 kilopound (Klb) = 0.45 metric tons (t)

truck to be accurate, interference must be minimized. Consequently, a criterion was established which insured that the presence of other vehicles on the highway did not significantly interfere with the noise measurement of the target vehicle. If a measurement met this criterion it was accepted as a valid measurement.

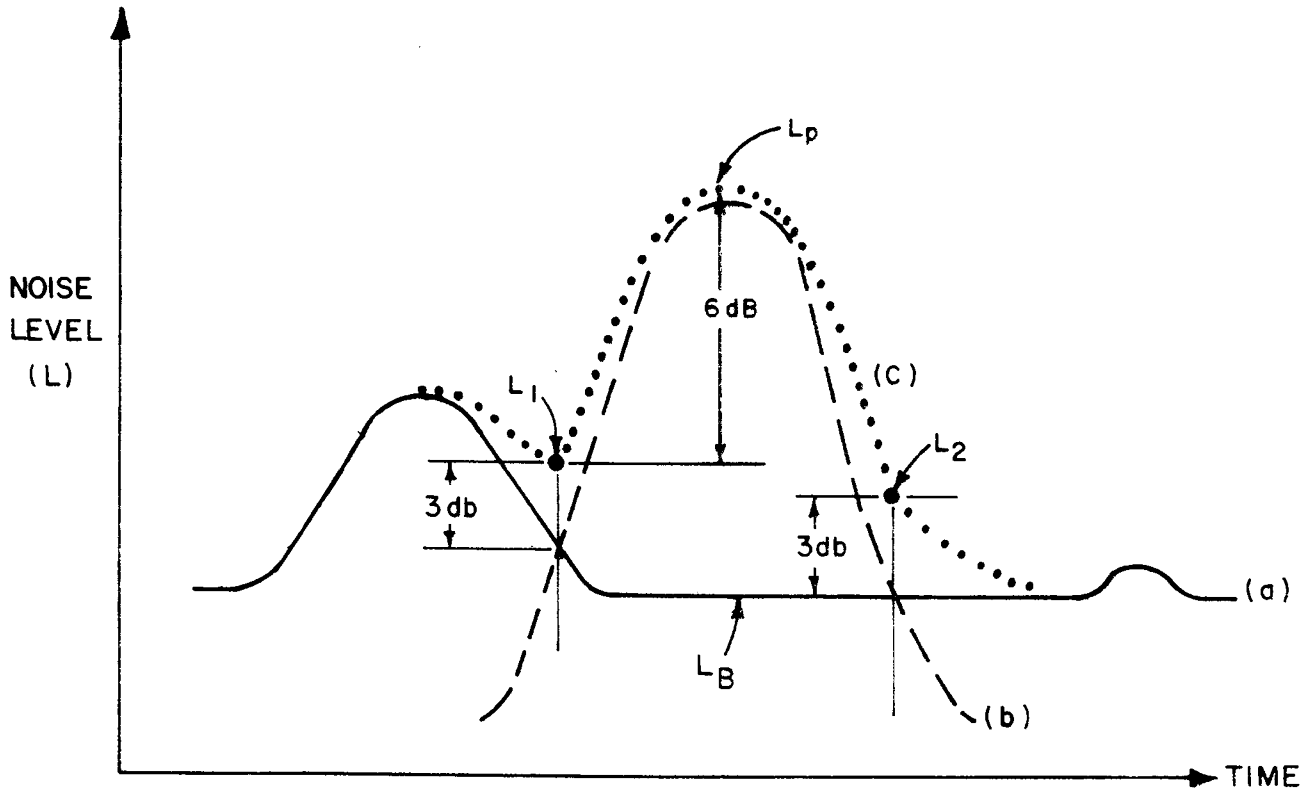
Initial efforts in developing the valid measurement criteria centered on the selection of a minimum vehicle spacing. When any vehicles are closer to the target vehicle than the minimum spacing, a measurement of the target vehicle's peak noise level would not be made since the error introduced by the presence of other vehicles would be significant (greater than 0.5 dB).

The concept of a minimum vehicle spacing was examined in some detail. Theoretical calculations were performed for two moving sound sources for a variety of different vehicle spacings, noise emission levels (reference 50 feet -15.2m), and spreading rates (sound decrease with doubling of distance). In all cases, the extent of the resulting error in the measurement of the peak level of the target vehicle was examined.

At about the same time, the ongoing literature search revealed another method for dealing with the influence of other vehicles. This method specified that for the measurement of the peak level of the target vehicle to be accurate to within 0.5 dB, at least a 6 dB rise and fall of the overall noise level about the peak level of the target vehicle must occur [16].

The reasoning behind this method is illustrated in Figure A-2, page 154. This figure is a typical time history of noise levels measured for vehicles on a roadway. The solid curve represents the background noise level, the total noise level produced by all vehicles passing the microphone site other than the target vehicle. The time history of the target vehicle alone is shown by the heavy dashed curve. The composite level is shown by the dotted

Figure A-2. RESULTANT NOISE LEVEL FROM A SERIES OF VEHICLES PASSING THROUGH A NOISE MEASUREMENT SITE



KEY:

Curve (a) – Time history of the noise level of vehicles other than the target vehicle.

Curve (b) – Time history of the noise level of the target vehicle.

Curve (c) – Composite of (a) and (b).

curve. At the point where the background noise level and the noise level of the target vehicle are equal, the composite is 3 dB higher. This 3 dB difference is indicated in Figure A-2.

Let the background noise level due to other vehicles be L_B at the instant the peak level, L_P, is produced by the target vehicle. The greater the difference between the peak level, L_P, of the target vehicle and the background noise level, L_B, the less is the error in measurement of the peak level. The rules of decibel addition require that the difference, $L_P - L_B$, must be greater than 9 dB for the presence of other vehicles to increase L_P by less than 0.5 dB. Thus, as illustrated in Figure A-2, if the difference between L_P and the level of both the preceding and following turning points (L_1 and L_2) of the composite level is greater than or equal to 6 dB, than $L_P - L_B$ is greater than or equal to 9 dB, and the influence of other vehicles on the measurement of the peak level will not have been significant (error in measurement ≤ 0.5 dB).

At this point, it was decided to further investigate the second method because it was as accurate as the first and more easily implementable. Moreover, verification of a measurement's validity could be done in the laboratory because the 6 dB rise and fall about the peak could be checked by examining a graphic level recorder trace produced from the playback of a recorded truck pass-by measurement. This method was checked against the theoretical calculations performed when considering the first method, and it was found to be in good agreement.

Since it was realized that specifying a greater than 6 dB rise and fall about the peak would yield even more accurate measurement of the target vehicle's peak noise, the possibility of specifying an 8 or 10 dB rise and fall was investigated. However, it was theorized that using an 8 or 10 dB rise and fall requirement did have a drawback. Such a requirement would unnecessarily increase the biasing of field measurements by making it much easier to obtain an acceptable measurement for a louder vehicle in an axle class than for a quieter vehicle in that same class. Thus mean peak levels calculated from acceptable measurements would be biased to the high side.

As an aid in the final determination of the rise and fall requirement, an actual field test was conducted. Approximately 100 truck pass-by measurements were made at a site located adjacent to an interstate highway (I-295, north of Trenton). The noise levels of all trucks passing the microphone position were tape recorded. The tape was played back and a graphic level recorder trace was produced. The trace was examined and mean peak levels were calculated for the different axle classes using peak levels which met 6, 8, and 10 dB rise and fall requirements, respectively.

The mean peak levels calculated in this manner were compared to the mean peak level calculated for a class by averaging the peak levels of all vehicles in that class. The mean peak level calculated from all vehicles in a class is, in itself, slightly high because some of the vehicles used in the calculation have had their peaks influenced upwards as a result of close vehicle spacing, but it is a good basis for comparison. The comparison provides an indication of the biasing introduced by the use of the three different rise and fall requirements. As expected, the 6 dB rise and fall requirement introduced the smallest biasing - for the worst case on the order of 0.5 dB too high. It was found, in fact, that switching to an 8 or 10 dB rise and fall requirement, increased the biasing error to such an extent that it outweighed any increase in peak level measurement accuracy that could be obtained.

It was finally decided to establish the following criterion for a valid measurement of peak truck pass-by noise:

> A measurement will be considered valid if the total sound level (as observed on a graphic level recorder trace) rises and falls at least 6 dB about the peak level.

In summary, this criterion was selected for the following reasons:

(1) measurement of a truck's peak noise level will be accurate to within approximately 0.5 dB.

(2) less biasing will be introduced by this requirement than by an 8 or 10 dB rise and fall requirement, and

(3) the validity of measurements can be verified in the laboratory.

Choosing less than a 6 dB rise and fall requirement was ruled out because such a criterion would most likely lead to errors of over 0.5 dB in peak level measurement.

Though a 6 dB rise and fall was selected for use as the valid measurement criterion, this rise and fall was found too difficult to accurately observe on a sound level meter when in the field. Thus, a vehicle spacing was selected for use in the field. The noise produced from the pass-by of an individual truck was recorded if the target truck was at least 100 feet (30.5 m) away from passenger cars and 250 feet (76.2 m) away from other trucks. These distances were selected so that most of the truck pass-bys that were recorded would be valid measurements when analyzed later on for the 6 dB rise and fall.

Data Collection Procedures

As part of developing the measurement methodology, field procedures were established for conducting noise level measurements and also for obtaining corresponding speed and meteorological information.

The noise data collection procedure takes into consideration the vehicle spacing requirements which were selected. It provides for the collection of accurate peak A-weighted noise levels, and corresponding frequency and truck description information. Tape recording of truck noise and truck description was decided upon primarily because it (1) provided a permanent record which could be reanalyzed if required, (2) eliminated the need to transport sophisticated data reduction equipment into the field on a daily basis thus protecting this equipment from damage, and (3) expedited the field operation thereby increasing the number of measurements per hour which could be obtained.

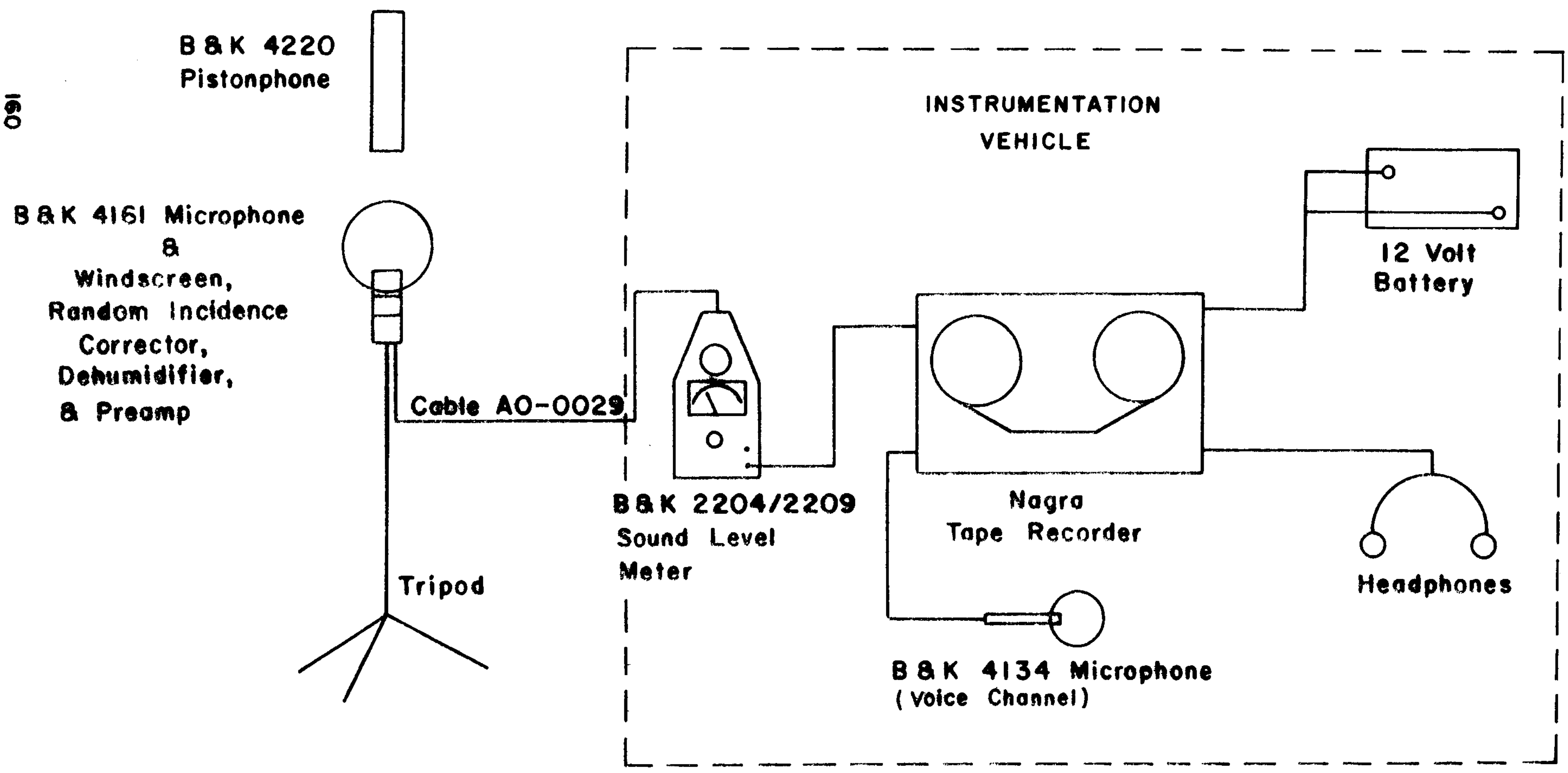
The data collection procedures are explained below. For a listing of the data collection equipment and a description of each piece see Appendix B, pages 166 - 170.

A. Noise Recording Procedure - At each of the measurement sites a microphone was placed away from the highway 50 feet (15.2 m) from the center of the nearest traffic lane. The microphone was a one-inch Bruel & Kjaer (B&K) free field, condenser microphone (Type 4161) equipped with a windscreen, random incidence corrector, dehumidifier, and preamplifier. The microphone was mounted on a tripod and set at a height of approximately 4 feet (1.2 m) above the ground. It pointed upwards in order that the vehicle noise reaching it struck the microphone at grazing incidence. Co-axial cable was run from the microphone to the instrument vehicle which was parked more than 100 feet (30.5 m) away and far enough from the edge of the highway so as not to influence traffic flow. At the vehicle the microphone cable was connected to a B&K precision sound level meter (Type 2204 or 2209) which was set on the A-scale. The A-weighted signal leaving the sound level meter was fed into one channel of a two channel Nagra tape recorder. The A-weighted noise produced by an individual truck pass-by was recorded on Channel 1 while at the same time a voice description of the truck was annotated on Channel 2. A 1/2-inch B&K pressure, condenser microphone (Type 4134) was used for recording on the voice channel. A pair of headphones for the tape recorder operator to monitor the recording and a 12-volt battery to power the tape recorder complete the basic recording set-up. The field recording set-up is shown in Figure A-3, page 160.

To qualify for measurement, a target truck had to be travelling in the nearest traffic lane (outside lane) and be at least 100 feet (30.5 m) away from passenger cars and 250 feet (76.2 m) away from other trucks travelling on the highway. When possible, the noise produced by every qualified truck was tape recorded thus providing a random sampling of the population. The tape recording was begun when the target truck was approximately 400 feet (121.9 m) from the measurement point (see Figure C-1 page 177). The first information recorded on the voice channel was the truck identification number. This was followed by the words "Ready" and "Set" which were recorded on tape the instant the front of the target truck passed the points 250 feet (76.2 m) and 100 feet (30.5 m) respectively, away from the measurement point. Next the word "Mark" was annotated* as the front of the truck passed the measurement point. The points 250 feet (76.2 m) and 100 feet (30.5 m) upstream of the measurement point as well as the measurement point itself were marked by small traffic cones placed along the highway. After the recording of "Mark"

*The annotation of these words was necessary in order to analyze the recording later on.

Figure A-3. NOISE RECORDING SYSTEM



the tape recorder was allowed to run at least an additional five seconds during which time the following truck description information was annotated:

- truck classification (see pages 148 and 149),
- truck type (van, tanker, dump, flatbed, etc.),
- exhaust configuration (vertical or horizontal),
- load condition (if possible),
- manufacturer (if possible),
- cab type (conventional or cab over engine), and
- vehicle speed (see below).

The recording system was fully calibrated (with cables in place) at the beginning of each period of measurement, each new reel of tape, approximately every two hours thereafter, at the end of each tape reel, and at the end of the measurement period. The B&K 124 dB calibrator was used.

Details of noise equipment settings, calibration times, etc. were entered onto log sheets.

B. Speed Recording Procedure - In conjunction with the recording of truck noise, the speeds of trucks for which noise levels were obtained were measured by an Electromatic Radar Speed Meter. Speed was measured as a truck was directly opposite the microphone position. The truck speed, as read off the meter, was recorded on magnetic tape to complete the truck description.

C. Meteorological Data Collection Procedure - Meteorological information was also taken while at the measurement site. Air temperature, humidity, barometric pressure, and wind speed and direction were measured following system calibration. Air temperature and humidity were measured by a Bendix electrically aspirated psychrometer; barometric pressure, by a barometer supplied with the B&K 124 dB calibrator; and wind speed and direction, by a Belfort wind measuring set. Wind speed and direction were remeasured whenever field personnel suspected the wind speed or direction had changed appreciably. Noise measurements were not made during periods of precipitation or when the average continuous or gust wind speed exceeded 12 mph (19.3 km/hr). No limits were placed on air temperature since normal temperature variation will not significantly effect sound propagation over the distances involved[16].

Meteorological information as indicated by the various instruments was entered on to log sheets.

Sample Size

The average peak noise levels determined for this study were presented as being typical of the entire population of New Jersey trucks. Since for obvious reasons, the entire population of trucks could not be measured, statements about the noise levels of the entire population were inferred from the noise level measurements made for a random sample of trucks from the population. Statistical methods specify the sample size required in order for a researcher to be highly confident that the results determined for the sample are typical of the entire population.

Accordingly, the approximate sample size required to estimate, to a precision of ± 1 decibel*, the mean peak noise level of the population of

*Confidence interval is the sample mean ± 1 decibel.

trucks of a particular class travelling on a particular type of roadway was determined.* An example of this type of population would be trucks with two axle tractors and two axle semitrailers travelling on controlled access highways of less than or equal to 2% grade.

This sample size was calculated according to established statistical procedures as explained below (see [17]).

The equation used was:

$$N = \left(\frac{(z_{1-\frac{1}{2}\alpha})\sigma}{d}\right)^2 \text{ where,}$$

N = sample size,

$z_{1-\frac{1}{2}\alpha}$ = standardized normal distribution statistic for confidence intervals at α level of significance,

σ = population standard deviation,

d = precision of the estimate of the population mean.

The following assumptions are made:

a) normally distributed population,

b) precision of the estimate of the population mean = $\pm$ 1 dB,

c) population standard deviation = 4,

d) a 95% confidence interval for the population mean (α error = 0.05, z = 1.96).

The precision of the estimate of the population mean was selected as $\pm$ 1 dB because this is comparable to the approximate accuracy of the combined noise recording and data reduction system. {Error in estimation from sampling is random in nature and differs from the upward biasing measurement error discussed earlier when a valid measurement criteria was considered (pages 151 - 157).} The population standard deviation of 4 was selected after considering the truck noise data for New Jersey and six

* For truck classes see page 148; roadway types, page 171.

other states contained in [18, 19]. It represents a worse case estimate based on an examination of the standard deviations of the peak noise levels measured in these states for classes of trucks travelling at various typical highway speeds (approximately 35-70 mi/hr, 56-112 km/hr).*

Substituting the assumed values into the equation yielded the results shown below.

$$\text{sample size} = \left(\frac{1.96 \times 4}{\pm 1}\right)^2 = 62 \text{ measurements}$$

Sixty-two individual truck noise measurements were thus considered the sample size for estimating, to a precision of ± 1 decibel, the mean for a population defined by a particular truck classification on a particular roadway type. For example, a sample of size 62 was required for estimating the mean noise level of the truck class two axle tractors and two axle trailers when travelling on controlled access highways of less than or equal to 2% grade. Thus, according to statistics, if more than 62 noise measurements of trucks having two axle tractors and two axle trailers were made on this type of roadway, than it can be stated with a high degree of confidence that the mean peak noise level determined from the sample was typical of the entire population. In other words, there was a 95% chance that the population mean peak noise level lay within ± 1 decibel of the mean peak noise level determined for the sample.

A sample size of 62 was only exceeded for several of the 13 specific truck classes -- notably, Classes 1, 6, 9 and 12 (see page 148) -- for which noise level measurements were taken since the trucks in some classes

* Actually, a standard deviation of 4 was a good choice for Roadway Types 1 - 6 because for these roadway types the highest standard deviation obtained in this study was 3.66 for particular truck classes for which more than 10 peak noise level measurements were obtained. For Roadway Types 7 & 8 (Ramps), however, standard deviations of peak noise levels were greater than 4 for several truck classes with a significant number of measurements.

make up a very small part of the New Jersey truck population. Thus, estimates of the population mean peak noise levels of some of the specific truck classes were not as precise as ±1 decibel.

To simplify the noise prediction process, specific truck classes were regrouped into several general truck classes. For this purpose, the sample mean peak noise levels of specific truck classes were compared by the use of a statistical test. Specific truck classes whose mean peak noise levels were not significantly different when statistically tested were grouped together. The statistical test which was used employed a Student t distribution to compare means of two independent samples. The test took into consideration the unequal sample sizes which occurred, as well as, the various precisions of the population mean peak level estimates.

After the specific truck classes were regrouped into general truck classes, the sample sizes of the general truck classes for Roadway Types 1 - 6 were larger than that required for estimating the population mean peak noise level to ±1 decibel precision. However, for one of the general truck classes for Roadway Type 7 (Ramps), the population mean peak noise level could not be estimated to within ±1 decibel precision because only 40 peak noise level measurements were obtained with a standard deviation of 4.1 .

The large data bases for most of the general classes now permitted the use of regressions of peak noise level versus speed which were developed using all of the data in a general truck class.

APPENDIX B

NOISE RECORDING EQUIPMENT AND ACCESSORIES

This appendix contains a description of the noise recording equipment which was used in the field to collect truck noise data. Descriptions of accessory equipment, which was used for recording of the voice channel, monitoring of the tape recording, and collection of speed and meteorological data are also given. A block diagram of the noise recording system is shown on page 160.

Recording Equipment List

.Bruel & Kjaer 4161 Microphone with
Random Incidence Corrector UA-0055
Dehumidifier UA-0310
Input Stage (preamplifier) ZC-0007
Windscreen UA-0207

.Bruel & Kjaer Microphone Cable AO-0029

.Bruel & Kjaer 2204 or 2209 Impulse Precision Sound Level Meter

.Nagra Tape Recorder IV-SJ

.Bruel & Kjaer 4220 Pistonphone

Accessory Equipment List

.Bruel & Kjaer 4134 Microphone (used for voice recording)

.Telex Headphones, Teleset HM-100

.Electromatic Radar Speed Meter - Model S-5

.Belfort Instrument Co. Wind Measuring Set - Cat. No. 6052

.Bendix Psychrometer Model 566-2

Equipment Description

B&K 4161 Microphone - This microphone is a one-inch condenser microphone with a normal incidence free field response which is linear from 1 to 2 Hz (-3dB) to 18 KHz (±1.5 dB). It consists of a microphone cartridge and a symmetrical protecting grid which screw together. The 4161 Microphone meets the requirements of the American National Standards Institute (ANSI) for laboratory standard type L microphones for free field use.

Random Incidence Corrector UA-0055 - The sensitivity of the 4161 Microphone above 3-4 KHz varies appreciably with angle of incidence. It is thus not suited, as is, to the realistic measurement of truck noise, which is composed of sound waves impinging on the microphone with variable angles of incidence. However, Microphone 4161 can be made practically omnidirectional up to 10 KHz by the use of Random Incidence Corrector UA-0055. This specially shaped device screws directly on to the microphone cartridge in place of the normal protecting grid and makes the microphone suitable for measurements in a diffuse field (truck noise).

Dehumidifer UA-0310 - This dehumidifier has been selected for use with Microphone 4161 since it has been shown that condenser microphones can be adversely affected by high levels of humidity. The back vented characteristic of Microphone 4161 allows it to be used with this dehumidifier. UA-0310 is mounted between the microphone and its preamplifier. It contains silica gel which effectively removes humidity from the air in the microphone.

Input Stage (Preamplifier) ZC-0007 - The 4161 Microphone is designed to be screwed on to the input of this preamplifier when the preamplifier is equipped with an adaptor. This preamplifier has a high input impedance which is required with B&K sound level meters 2204 and 2209 when a condenser microphone is used.

Windscreen UA-0207 - Because wind noise at lower wind velocities can interfere with outdoor noise measurements, a windscreen was used for wind noise attenuation. This windscreen is a round ball, 9 cm in diameter, composed of a specially prepared porous polyurethane sponge. It can attenuate wind noise at lower wind velocities by 10 to 12 dB.

Bruel & Kjaer AO-0029 Microphone Cable - This cable comes in 30 m lengths of 9 mm diameter. It is a multi-core shielded cable, supplied with a co-axial signal conductor and microphone connectors at both ends. Several lengths of cable can be used without significant signal distortion.

Bruel & Kjaer 2204 & 2209 Impulse Precision Sound Level Meters - The 2204 and 2209 are battery operated ANSI Type 1 sound level meters. They can also be used for vibration measurements. With a B&K 4161 Microphone equipped with random incidence corrector UA-0055, these sound level meters have a dynamic range of 15 dB(A) to 140 dB and a frequency range (±1dB) of 6 Hz (or 12Hz) to 12KHz. These instruments conform to IEC 179 for Precision Sound Level Meters, and to DIN 45633 parts 1 and 2. Both instruments contain A, B, C, and D weighting networks. 2204 and 2209 both have "Fast", "Slow", "Impulse", and "Impulse Hold" meter responses. The 2209 was developed from the 2204; its main additional feature is the ability to hold the "peak" value as well as the RMS value of a signal. Accordingly, the 2209 sound level meter has a "Peak Hold" meter response.

Nagra IV-SJ Tape Recorder - This tape recorder is portable, can be battery operated, and has a calibrated recording meter. It has four tape speeds, the highest being 15ips (38 cm/s) and uses 1/4" (6.35 mm) magnetic tape. Following are the manufacturers specifications: (All tests using 3M 223 tape, tape speed 7 1/2 ips (19 cm/s), and bias frequency 150 KHz)

- Frequency response, recording at 20 dB below maximum peak level	25Hz to 20 KHz (± 1.0 dB)
- Signal to noise ratio	60 dB (NAB-Linear)
- Third harmonic distortion at maximum peak level	1.5%
- Wow and flutter, unweighted RMS value in accordance with NAB Standard	± 0.08%

Bruel & Kjaer 4220 Pistonphone - The type 4220 is a small, battery operated, high level precision sound source which is used for direct calibration of sound measuring equipment. It generates a sound level of 124 dB ± 0.2 dB at 250 Hz when fitted to a B&K microphone. It fulfills the recommendations of the IEC on the calibration of precision sound level meters. The pistonphone has been individually calibrated and is supplied with a barometer which reads direct correction for changes in barometric pressure.

Bruel & Kjaer 4134 Microphone (Used for Voice Recording) - This microphone is a half inch condenser microphone designed for a linear pressure response up to 20 KHz (± 2 dB). It consists of a microphone cartridge and a protective grid. The microphone cartridge screws on to preamplifier 2619. The 4134 microphone fulfills the American Standard ANSI S1.12-1967 for type M laboratory standard microphones.

Telex Headphones, Teleset HM-100 - These headphones have an impedance of 2000 ohms and are properly matched for use with the Nagra tape recorder.

Electromatic Radar Speed Meter, Model S-5 - This unit, which can be powered by a 12 volt battery, measures the instantaneous speeds of moving vehicles to an accuracy of ± 2 miles per hour (3.2 km/hr). The speed meter operates between 0 and 100 miles per hour (161 km/hr). It has three range settings - short range (150 feet -45.7m), medium range (300 feet -91.4m), and long range (500 feet -152.4m). Calibration of the speed meter was checked with calibrated tuning forks.

Belfort Instrument Co. Wind Measuring Set. Cat. No. 6052 - This instrument gives a visual indication of wind direction through 360 degrees and of wind speed from 0 to 60 knots (111.1 km/hr). Wind direction can be resolved to within 1 degree; wind speed, to within one half a knot (0.93 km/hr).

Bendix Psychrometer, Model 566-2 - This unit is a portable, battery powered, electrically aspirated psychrometer which provides an indication of wet and dry bulb temperatures to an accuracy of 0.3 degrees Fahrenheit (0.17 degrees C). The wet and dry bulb temperatures are used to determine relative humidity.

APPENDIX C

SELECTION OF MEASUREMENT SITES

A detailed description of the measurement site selection process and the basic guidelines for selection is presented in this section. In addition, the physical site criteria selected to assure accurate noise level measurement are outlined. The measurement sites which were selected are listed and described in Tables D-1 to D-7 in Appendix D, pages 181 - 187.

Roadway Types

Measurement sites were selected for the following roadway types:

(1) Highways with control of access (roadways of grade less than or equal to 2%).

(2) Highways with control of access (roadways of greater than 2% upgrade).

(3) Highways with control of access (roadways of greater than 2% downgrade).

(4) Highways with non-controlled access (roadways of grade less than or equal to 2%).

(5) Highways with non-controlled access (roadways of greater than 2% upgrade).

(6) Highways with non-controlled access (roadways of greater than 2% downgrade).

(7) Ramps.

Highways were divided into controlled and non-controlled access because it was expected that different average speeds and operating conditions would occur for each of these types of highways. Noise level data obtained for Roadway Types 2, 3, 5, 6, and 7 expand the available truck noise data base because these types of roadways involve grades and acceleration. In addition, consideration of Roadway Type 7 (Ramps) provided noise levels for trucks operating at low speeds (less than 30 miles per hour (48 km/hr)).

Selection of Sites for Roadway Types 1-6

The objective of the site selection process with regard to these roadways was to select test sites from which noise measurements of a representative sample of the truck population in New Jersey could be collected. Since the NJDOT truck weighing stations were selected with basically the same objective in mind (obtaining a representative sampling of New Jersey trucks), it was decided to locate the noise measurement sites along roadways on which these truck weighing stations (loadometer stations) were located.

Over a period of several weeks, roadways on which the loadometer stations are located were visited. A list was drawn up of potential noise measurement sites satisfying the physical site criteria described on pages 175 - 179. From this list the final sites were selected with the primary guidelines being the following:

(1) Sites were selected from different areas of the state in an effort to maintain a geographical representation. Thus, sites

were selected along roads which handled traffic flows to the northern, southern, eastern and western portions of the state.

(2) Site locations were not selected where it was estimated there would be less than one accurate measurement of an individual truck passby in five minutes. Thus, very low and very high volume sites were not selected as final sites.

(3) For roadway types 2, 3, 5 and 6 (upgrades and downgrades), an effort was made to select sites of varied grade steepness and length.

As it turned out, guideline number (1) could not be followed very effectively for Roadway Types 2, 3, 5 and 6 since most of these roadways were located in the northern part of the state, the southern part having relatively flat terrain. Guidelines (2) and (3) took on greater importance for these types of roadways.

In addition to the sites selected in the manner described above, several sites were selected adjacent to recently constructed highways for which loadometer stations had not been set up. The selection of these additional sites was made because these highways obviously carried significant truck traffic.

Selection of Sites for Roadway Type 7

Measurement sites adjacent to ramps were selected in the following manner. Ramps were examined along the roads visited during the selection of the other types of sites. Those sites meeting the physical site criteria discussed on pages 175 - 179 were then listed. The final ramp sites were selected from this list based on the following guidelines:

(1) Sites were selected adjacent to ramps of different horizontal configurations (circular to straight) and having different roadway grades (flat, upgrade and downgrade).

(2) Sites were selected adjacent to ramps on which trucks were being driven under different operating conditions (constant speed operation, acceleration, etc.).

(3) Sites adjacent to ramps having a very high or a very low amount of truck traffic were not selected.

No effort was made to select ramps from different areas of the state.

List of Measurement Sites

In all, 38 original sites were selected. Six sites each were chosen for Roadway Types 1, 2 and 3; five sites each, for Roadway Types 4, 5, 6 and 7. The only reason selection was made in this manner was that more sites adjacent to Roadway Types 1, 2 and 3 met the physical site criteria than sites from other roadway types. See the first interim report for a list of these 38 original sites.

As it turned out, during the data acquisition phase of this project, measurements were not taken at original Sites 3, 15 and 26. No replacements were selected for these cancelled sites because a sufficient number of measurements were obtained for the roadway types these sites represented. However, two additional sites (Sites 36 and 37)* were selected for Roadway Type 7 because of the great range of truck operating conditions which were encountered at ramp sites.

*Updated site numbering

Thus, measurements were taken at 37 sites - the number of sites visited for Roadway Types 1 to 7 was 5, 6, 5, 5, 4, 5 and 7 respectively.

An updated list of sites at which noise level measurements were conducted is included in Tables D-1 to D-7, Appendix D, pages 181 - 187. The tables contain detailed site information. One table is presented for each roadway type. Sites have been renumbered as required.

Physical Site Criteria

All of the sites which were selected for this project were required to meet the site criteria described in this section. Criteria were established for sound reflecting obstacles in the measurement area and for the general physical features of a site. All of the sites which were selected qualify as "soft" sites (covered with grass or similar absorptive material) in accordance with the definition contained in [9].

A. Sound Reflecting Obstacles - Site criteria for sound reflecting obstacles were established to insure accurate noise level measurement at all sites. The criteria were necessary because some types of obstacles in the immediate vicinity of a noise recording microphone can cause errors in noise measurement due to their ability to reflect sound. If there are large sound reflecting surfaces nearby, the noise levels measured by a microphone will be high relative to those obtained under normal circumstances. Thus, the criteria outlined below limited the presence of obstacles at a measurement site in terms of their sound reflecting ability, size and distance from the microphone. These criteria allowed sites to be selected such that the effect of reflections from nearby obstacles was less than 0.5 dB [16]. The site criteria were formulated from the information contained in [16, 20, 21] and SAE Recommended Practice J366a, "Exterior Sound Levels for Heavy Trucks and Buses".

Following are the criteria governing sound reflecting obstacles:

(1) The measurement site must be a nearly level open area free of large sound reflecting surfaces such as barriers, signboards, buildings, walls, bridges, solid fences, earth embankments or parked vehicles.

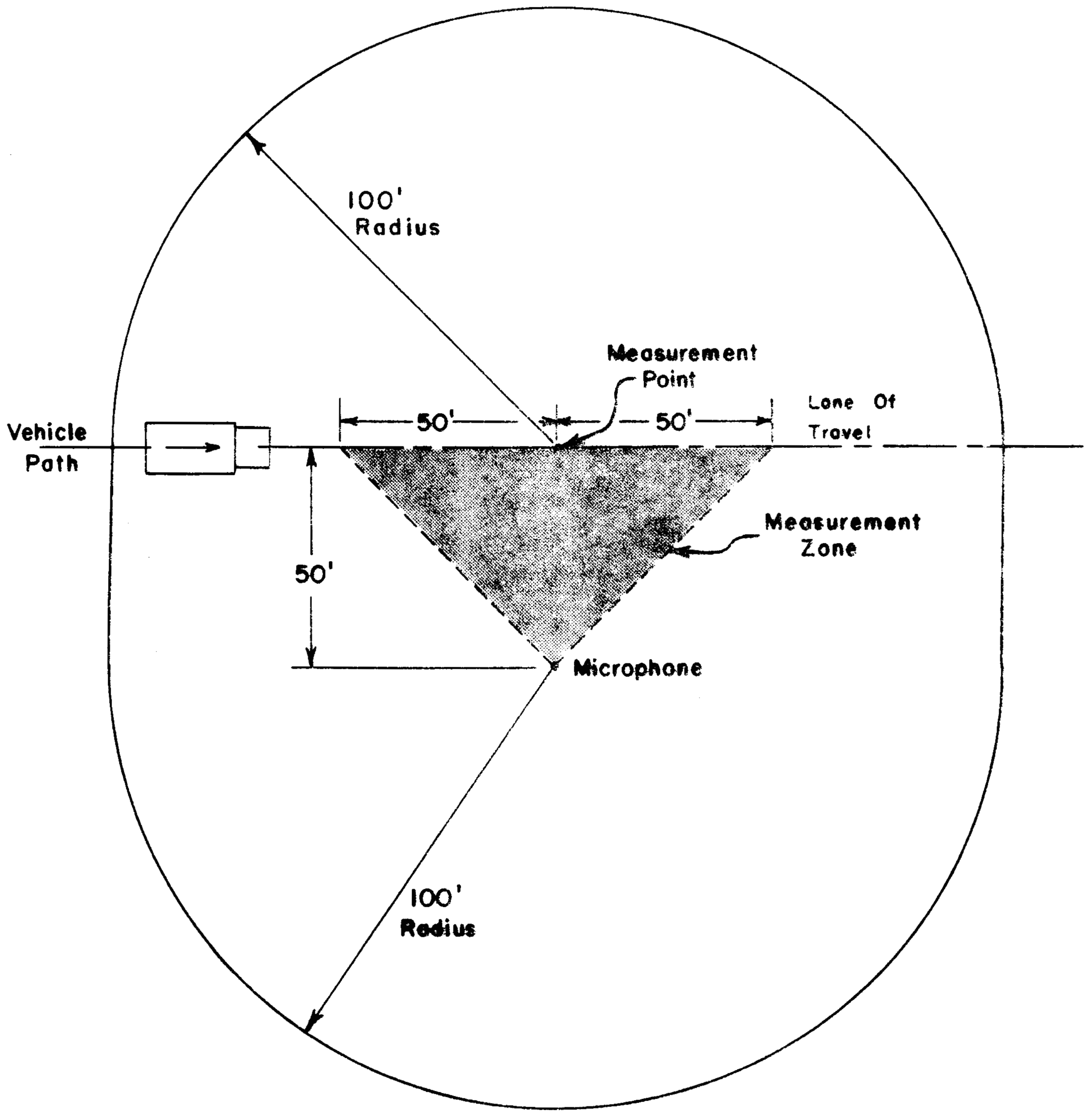
(2) The open area shall extend to at least a 100 foot (30.5 m) distance from both the microphone and the measurement point (the point of closest approach between the center line of the lane of travel and the microphone). See Figure C-1, page 177, for an illustration of a measurement site.

(3) The following stationary objects were not considered significant sound reflecting surfaces and were permitted within the measurement zone as well as within the rest of the measurement site. The measurement zone was defined as the triangular area between the microphone and the two points 50 feet (15.2 m) to each side of the measurement point (See Figure C-1).

- Solid objects less than 1 foot (0.3 m) in length, regardless of height, provided they are not located within 10 feet (3.05 m) of the microphone or vehicle path and,
- Solid objects less than 1 foot (0.3 m) in height, regardless of length, provided they are not located within 10 feet (3.05 m) of the microphone or vehicle path.

Figure C-1.

STANDARD MEASUREMENT SITE



50 ft. = 15.2 m

The types of objects described in the above included small trees and bushes, telephone and power poles, fire hydrants and rural mail boxes.

(4) The larger stationary objects described below were not considered significant sound reflecting surfaces when located within those areas of the measurement site outside of the measurement zone.

- A surface whose dimensions did not exceed 8 feet (2.44 m) in length (parallel to the vehicle path) and 2 feet (0.6 m) in height provided it is not located within 10 feet (3.05 m) of the microphone or vehicle path,
- A surface with less than a 45-degree slope above the horizontal,
- An elevated vertical surface or a surface sloping away from the microphone with the lower edge more than 15 feet (4.6 m) above the roadway and the space below the lower edge being open (e.g., an elevated sign),
- Chain-link or other open fencing, large trees, large bushes and hedges.

B. General Physical Characteristics - Additional criteria used in the selection of all measurement sites are outlined below. They were chosen to ensure accurate noise level measurement and to facilitate data collection.

(5) The microphone, which is located approximately 50 feet (15.2 m)

from the center of the outside traffic lane, should be placed on a surface whose elevation is within ± 3 feet (0.9 m) of the plane of the road surface.

(6) The pavement at the noise site should be Portland cement concrete or bituminous concrete and should be dry at the time of measurement.

(7) The surface of the ground within the measurement zone shall be free from standing water.

(8) There should be no more than 15 feet (4.6 m) of paved shoulder between the lane of travel and the microphone.

(9) There must be adequate visibility of oncoming trucks to allow for the identification of truck classifications.

(10) Measurement sites must be far enough away from traffic control devices and entrance and exit ramps so that freely flowing traffic conditions exist (this does not apply to ramp sites).

(11) The area in which the measurement site is located should be free of noise sources other than highway traffic.

APPENDIX D

LIST OF MEASUREMENT SITES

This appendix contains a list of the 37 sites at which noise measurements were conducted. These sites were selected according to the procedures and guidelines discussed under "Selection of Measurement Sites", pages 171 - 179. There are seven tables, each table lists the sites for one of the particular roadway types noted on page 171. Tables 1 to 6 contain location, highway description, site description, and traffic information for sites adjacent to controlled and non-controlled access highways with level, upgrade, and downgrade roadways. Table 7 provides information about the location of ramp sites, a description of each ramp, and a ramp's function.

Average annual daily traffic (AADT) figures presented in the tables are those determined for the nearest traffic counting station. The source was Straight Line Diagrams, New Jersey Department of Transportation, Division of Planning and Research, 1976. Truck percentages were estimated from data supplied by the Division of Comprehensive Transportation Planning, New Jersey Department of Transportation. Grade steepness is expressed as feet of roadway ascent or descent per 100 feet of horizontal roadway length. A "+" sign indicates an upgrade; a "-" sign, a downgrade. Grade length is the length of roadway from the beginning of the upgrade or downgrade to the measurement point. It was measured with the instrument vehicle's odometer. Microphone ground elevation is the ground elevation at the microphone position with respect to the elevation of the center of the near traffic lane.

TABLE D-1. MEASUREMENT SITES FOR ROADWAY TYPE 1

(CONTROLLED ACCESS HIGHWAYS, LESS THAN OR EQUAL TO 2% GRADE)

Site Number	Route (Direction)	N.J. Milepost	General Location	Highway Description	Traffic Information AADT	(% Trucks)	Grade Information Steepness (%)	Grade Information Length (mi)	Microphone Ground Elevation(ft)*	Pavement Type
1	I-78 (west)	4.0	5 miles east of Phillipsburg	4-lane rural freeway, a major east-west truck route	29,700	(30)	+0.4	-	-0.5	Portland Cement Concrete
2	I-95 (south)	4.6	5 miles north of Trenton	6-lane urban freeway, a high-way link between Route 1 and Pennsylvania	11,800	(15)	+0.53	-	+0.89	Bituminous Concrete
3	I-287 (north)	17.3	5 miles north of New Brunswick	6-lane urban freeway, a highway link between the N.J. Turnpike, Route 1, and westward routes	51,100	(20)	+0.15	-	-3.4	Portland Cement Concrete
4	I-295 (south)	16.6	10 miles south-west of Camden	4-lane rural freeway, a major north-south truck route	25,800	(30)	-0.47	-	-0.88	Portland Cement Concrete
5	55 (south)	22.0	5 miles south of Vineland	4-lane rural freeway, a lightly travelled 20 mile section in southern New Jersey	4,300	(35)	-0.31	-	-0.06	Bituminous Concrete

1 mile = 1.6 kilometers 1 foot = 0.305 meter

*Ground elevation at microphone position with respect to the center of the near traffic lane

TABLE D-2. MEASUREMENT SITES FOR ROADWAY TYPE 2

(CONTROLLED ACCESS HIGHWAYS, GREATER THAN 2% UPGRADE)

Site Number	Route (Direction)	N.J. Milepost	General Location	Highway Description	Traffic Information AADT	(% Trucks)	Grade Information Steepness (%)	Grade Information Length (mi)	Microphone Ground Elevation(ft)	Pavement Type
6	I-78 (west)	10.1	10 miles east of Phillipsburg	6-lane rural freeway	26,700	(30)	+3.95	1.4	+0.65	Portland Cement Concrete
7	I-80 (west)	9.1	10 miles northwest of Hackettstown	6-lane rural freeway	14,800	(25)	+2.92	0.2	-1.72	Portland Cement Concrete
8	I-78 (west)	27.9	5 miles north of Somerville	6-lane rural freeway	29,000	(30)	+3.02	0.25	+0.32	Portland Cement Concrete
9	I-95 (north)	1.0	5 miles northwest of Trenton	4-lane urban freeway	14,200	(15)	+2.33	0.75	+0.21	Bituminous Concrete
10	I-287 (south)	28.2	5 miles south of Morristown	4-lane urban freeway	18,400	(20)	+2.98	0.35	+1.02	Portland Cement Concrete
11	I-295 (north)	53.2	10 miles south of Trenton	6-lane rural freeway	20,600	(25)	+2.57	0.22	-0.82	Portland Cement Concrete

1 mile = 1.6 kilometers   1 foot = 0.305 meter

TABLE D-3. MEASUREMENT SITES FOR ROADWAY TYPE 3

(CONTROLLED ACCESS HIGHWAYS, GREATER THAN 2% DOWNGRADE)

Site Number	Route (Direction)	N.J. Milepost	General Location	Highway Description	Traffic Information AADT	(% Trucks)	Grade Information Steepness (%)	Grade Information Length (mi)	Microphone Ground Elevation(ft)	Pavement Type
12	I-78 (east)	19.6	2 miles east of Clinton	6-lane rural freeway. I-78 runs east-west, linking I-287 with Pennsylvania	21,500	(30)	-3.02	0.7	+0.05	Portland Cement Concrete
13	I-287 (north)	28.8	5 miles south of Morristown	4-lane rural freeway	18,400	(20)	-2.88	0.4	-2.89	Portland Cement Concrete
14	I-295 (north)	53.4	10 miles south of Trenton	6-lane rural freeway, runs north to south from Trenton to the Delaware border	20,600	(25)	-2.74	0.25	+1.32	Portland Cement Concrete
15	I-280 (west)	5.5	5 miles northwest of Orange	6-lane urban freeway running east to west	35,900	(10)	-3.86	0.5	-3.3	Portland Cement Concrete
16	I-78 (west)	27.2	5 miles northeast of Clinton	6-lane rural freeway	29,000	(30)	-2.35	0.28	-1.22	Portland Cement Concrete

1 mile = 1.6 kilometers 1 foot = 0.305 meter

TABLE D-4. MEASUREMENT SITES FOR ROADWAY TYPE 4

(NON-CONTROLLED ACCESS HIGHWAYS, LESS THAN OR EQUAL TO 2% GRADE)

Site Number	Route (Direction)	N.J. Milepost	General Location	Highway Description	Traffic Information AADT	Traffic Information (% Trucks)	Grade Information Steepness (%)	Grade Information Length (mi)	Microphone Ground Elevation (ft)	Pavement Type
17	33 (west)	19.1	10 miles east of Hightstown	4-lane rural divided highway, an east-west highway across the center of the state which runs through farming areas and can be used as a link between the N.J. Turnpike and the N.J. shore area.	11,500	(20)	-0.57	-	+0.84	Bituminous Concrete
18	22 (west)	26.8	10 miles northwest of Somerville	4-lane rural divided highway, a link between Somerville and Rte. 78.	15,900	(15)	+0.53	-	+1.62	Bituminous Concrete
19	46 (west)	54.2	5 miles southwest of Paterson	4-lane urban divided highway, a link between Metropolitan N.J. and westerly routes.	34,400	(15)	-0.68	-	-0.46	Portland Cement Concrete
20	130 (north)	74.4	10 miles south of New Brunswick	4-lane rural divided highway, a north-south route which passes through the center of the state.	13,500	(15)	+0.41	-	-0.13	Portland Cement Concrete
21	206 (south)	20.9	5 miles south of Mount Holly	2-lane rural undivided highway, a north-south route passing through farming areas in the middle of the southern part of the state.	7,200	(15)	-0.48	-	+0.91	Portland Cement Concrete

1 mile = 1.6 kilometers   1 foot = 0.305 meter

TABLE D-5. MEASUREMENT SITES FOR ROADWAY TYPE 5

(NON-CONTROLLED ACCESS HIGHWAYS, GREATER THAN 2% UPGRADE)

Site Number	Route (Direction)	N.J. Milepost	General Location	Highway Description	Traffic Information AADT	Traffic Information (% Trucks)	Grade Information Steepness (%)	Grade Information Length (mi)	Microphone Ground Elevation(ft)	Pavement Type
22	206 (north)	60.8	10 miles north of Princeton	2-lane rural undivided highway starts near Hammonton and ends at the Penna. border near the northern most tip of N.J. A north-south route.	11,700	(15)	+2.64	0.3	-1.47	Bituminous Concrete
23	70 (east)	14.6	15 miles east of Camden	2-lane rural undivided highway whose direction is east-west	10,500	(15)	+2.84	0.1*	-2.49	Bituminous Concrete
24	31 (north)	34.9	2 miles north of Clinton	2-lane rural undivided highway begins at Trenton and runs north-south to Rte. 46	12,100	(30)	+4.29	0.15	-0.77	Bituminous Concrete
25	31 (north)	30.4	2 miles south of Clinton	2-lane rural undivided highway	12,100	(30)	+4.14	0.15	-1.94	Bituminous Concrete

1 mile = 1.6 kilometers   1 foot = 0.305 meter

*Estimated

TABLE D-6. MEASUREMENT SITES FOR ROADWAY TYPE 6

(NON-CONTROLLED ACCESS HIGHWAYS, GREATER THAN 2% DOWNGRADE)

Site Number	Route (Direction)	N.J. Milepost	General Location	Highway Description	Traffic Information AADT	Traffic Information (% Trucks)	Grade Information Steepness (%)	Grade Information Length (mi)	Microphone Ground Elevation(ft)	Pavement Type
26	206 (south)	84.8	5 miles south of Chester	3-lane rural undivided highway	9,600	(15)	-4.99	0.55	-1.94	Portland Cement Concrete
27	22 (west)	23.5	5 miles east of Clinton	4-lane rural divided highway	13,900	(30)	-4.25	0.2	+1.13	Bituminous Concrete
28	46 (west)	23.1	2 miles east of Hackettstown	4-lane rural divided highway	12,500	(30)	-6.07	1.7	-2.16	Portland Cement Concrete
29	31 (north)	31.5	1 mile south of Clinton	2-lane rural undivided highway	12,100	(30)	-4.98	0.1	-1.92	Bituminous Concrete
30	31 (south)	34.8	2 miles north of Clinton	2-lane rural undivided highway	12,100	(30)	-4.32	0.25	-0.56	Bituminous Concrete

1 mile = 1.6 kilometers 1 foot = 0.305 meter

TABLE D-7. MEASUREMENT SITES FOR ROADWAY TYPE 7

(RAMPS)

Site Number	Routes	N.J. Milepost	General Location	Ramp Function	Ramp Description	Grade Information Steepness (%)	Grade Information Length (mi)	Microphone Ground Elevation (ft)	Pavement Type
31	I-78 & 173	6.8 (I-78)	5 miles east of Phillipsburg	Entrance ramp from Rte. 173 eastbound to I-78 westbound	Outer connecting ramp of a partial cloverleaf interchange, level roadway	+1.5	-	+0.5	Bituminous Concrete
32	I-295 & Berkley Road	18.6 (I-295)	10 miles south-west of Camden	Exit ramp from I-295 southbound to Berkley Road	Outer connecting ramp of a partial cloverleaf interchange, upgrade roadway	+4.53	-	-1.87	Bituminous Concrete
33	I-295 & 130	56.8 (I-295)	5 miles south of Trenton	Entrance ramp to I-295 southbound from Rte. 130 southbound	Inner loop ramp of a partial cloverleaf interchange, upgrade roadway	+2.83	-	-0.08	Bituminous Concrete
34	I-295 & Rising Sun Rd.	56.1 (I-295)	5 miles south of Trenton	Entrance ramp to I-295 southbound from Rising Sun Road	Diagonal ramp of a partial diamond interchange, downgrade roadway	-4.04	-	+0.74	Bituminous Concrete
35	130 & 22	74.1 (Rte. 130)	10 miles south of New Brunswick	Exit ramp from Rte. 130 southbound to Rte. 32 eastbound	Diagonal ramp of a partial diamond interchange, level roadway	+1.0	-	-1.59	Bituminous Concrete
36	I-295 & 130	56.7 (I-295)	5 miles south of Trenton	Exit ramp from I-295 northbound to Rte. 130 northbound	Outer connecting ramp of a partial cloverleaf interchange, level roadway	-1.2	-	+2.0*	Bituminous Concrete
37	18 & 34	18.9 (Rte. 18)	5 miles east of Freehold	Entrance ramp from Rte. 34 northbound to Rte. 18 northbound	Inner loop ramp of a partial cloverleaf interchange, downgrade roadway	-3.3	-	+0.5*	Bituminous Concrete

1 mile = 1.6 kilometers   1 foot = 0.305 meter

*Estimated

APPENDIX E

DATA REDUCTION PROCEDURE

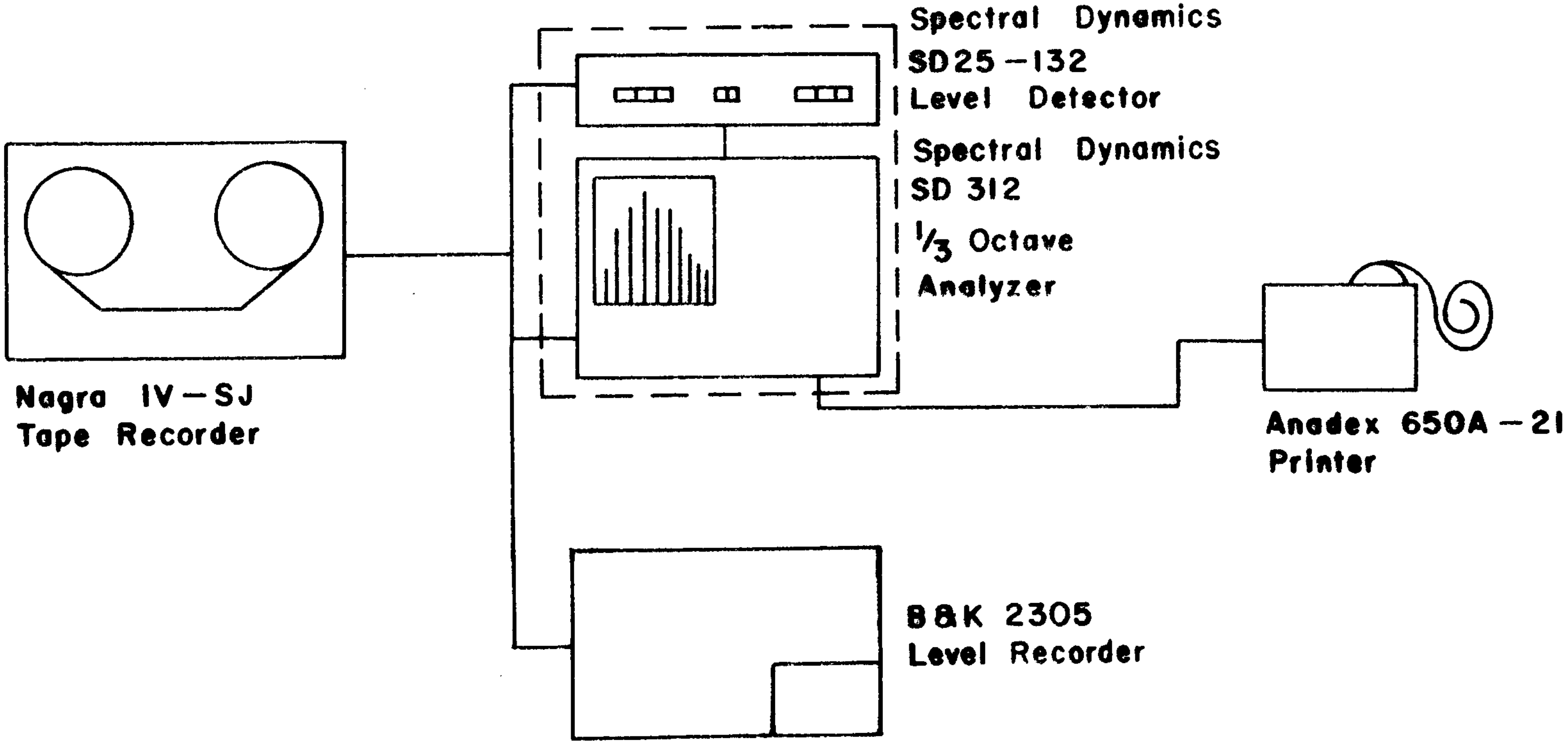
This section contains a detailed description of the data reduction procedure which was used to transform the truck noise data which was tape recorded at the measurement sites in to a more easily analyzed form.

Tape recorded field data was reduced in the laboratory and inputted to a computer file for storage. There were 4,967 truck noise measurements which were reduced; 4,536, which were inputted to the computer file. One channel of the tape recorded information was played back to obtain a description of each truck, the other, to obtain the A-weighted peak noise level of each truck pass-by and the 1/3 octave frequency spectrum at the peak level. A block diagram of the equipment used to reduce the taped information is shown in Figure E-1, page 189. A detailed description of each piece of equipment is given in Appendix F, pages 197 - 199.

Procedure for Reduction of Tape Recorded Information

The channel containing truck noise data was simultaneously played back into a Spectral Dynamics overall level detector, a Spectral Dynamics 1/3 octave real time analyzer, and a B&K graphic level recorder. The level detector continuously monitored the A-weighted overall noise level of the playback of a truck pass-by and detected when the level had reached its maximum. When this occurred, the level detector put the 1/3 octave analyzer, which had been continuously (in real time) analyzing the 1/3

Figure E-1. DATA REDUCTION SYSTEM



octave spectra of the noise signal, into a hold mode. In this mode, the 1/3 octave analyzer stopped analysis and held the last 1/3 octave spectrum and the corresponding peak level. This information was then fed to an Anadex strip chart printer which immediately listed the dBA level of every 1/3 octave filter as well as the A-weighted overall peak noise level. See Figure E-2, page 191 for an example of the printer output listing. After the printout cycle had been completed, the operator reset the overall level detector (thereby resetting the 1/3 octave analyzer by taking it out of the hold mode) and the system was ready to accept the pass-by noise signal for the next truck. The external speaker output at the rear of the 1/3 octave analyzer allowed continuous monitoring of the noise channel.

The B&K level recorder produced a graphical trace of instantaneous noise level versus time. See trace (a) in Figure E-3, page 194 for a typical example. The level recorder's potentiometer range was set to 25 decibels so that levels could be more accurately read from the graph.

The peak noise level which was read from the level recorder graph was considered to be the legitimate peak level for a truck pass-by for two reasons. First of all, when the level recorder writing speed was set to 100 mm/sec and the lower limiting frequency, to 20 Hz, the level recorder's averaging time was such that the peak level from the graph was approximately equal to the peak level obtained from a sound level meter set on "Fast" response. Secondly, the graphic level recorder demonstrated repeatability, that is, if a truck pass-by was replayed several times the peak noise level which was read from each graph was approximately the same.

030.0	20.0	Hz
030.0	25.0	Hz
032.6	31.5	Hz
035.6	40.0	Hz
047.3	50.0	Hz
051.9	63.0	Hz
056.9	80.0	Hz
054.2	100	Hz
057.1	125	Hz
065.9	160	Hz
075.9	200	Hz
083.0	250	Hz
074.8	315	Hz
068.9	400	Hz
075.0	500	Hz
071.4	630	Hz
071.1	800	Hz
072.3	1.00	KHz
071.1	1.25	KHz
069.6	1.60	KHz
066.6	2.00	KHz
065.3	2.50	KHz
064.7	3.15	KHz
059.7	4.00	KHz
057.3	5.00	KHz
052.8	6.30	KHz
051.4	8.00	KHz
047.1	10.0	KHz
038.7	12.5	KHz
030.0	16.0	KHz
030.0	20.0	KHz
086.1	00.0	KHz

Figure E-2. PRINTER OUTPUT.

The peak noise level measured by the 1/3 octave real time analyzer was not repeatable. It was found to vary more than 1/2 a decibel depending upon the settings of the level detector averaging time and sensitivity and the 1/3 octave analyzer averaging time, as well as, upon the exact time during the pass-by playback at which the level detector was reset.

In order to insure that the 1/3 octave levels obtained from real time analysis corresponded to those occurring at the peak level of the overall truck noise, it was required that the peak overall noise level obtained from real time analysis must be within ± 0.5 decibel of the peak level read from the level recorder graph. On occasion this necessitated the replaying of some truck pass-bys a number of times. In the process, detector and/or analyzer settings were changed, and/or the time of level detector reset was altered depending upon the shape of the level recorder graph. In almost all cases, however, the 1/2 decibel requirement was attained. For cases where it was not, the measurements from the pass-by in question were not included in further analysis.

The settings of the level detector and 1/3 octave analyzer which produced the most satisfactory results were a 0.2 second averaging time and a 2% sensitivity for the detector, and a 0.2 second averaging time for the analyzer. In general, the best time to reset the level detector was just after the word "Set" which was annotated on the voice channel of the tape as indicated in the measurement methodology, page 159. A sharp peak such as that illustrated in the level recorder graph (b) in Figure E-3, page 194, generally required faster averaging times on both the level detector and analyzer. Level recorder traces having many spikes, see graph (c) in Figure E-3, generally required that the level detector be reset just before the word "Mark" which in most cases occurred simultaneously with the peak noise level. In order to reset the level detector in this manner, it was often necessary to produce more than one level recorder graph for a particular truck pass-by. The second or succeeding graph was then observed to determine the exact instant to push the peak level detector reset button.

The level recorder graph was also used to decide on the validity of a particular truck noise measurement. This was done by checking the graph for at least a 6 dB rise and fall of the total sound level about the peak level as described on pages 153 - 157. Some examples of valid measurements by this 6 dB rise and fall criterion are illustrated in graphs (a, b, and c) on page 194; an invalid measurement, in graph (d).

For occasional graphs with unusual variations in noise level, the pass-by was replayed and the noise channel was carefully monitored with either headphones or a loudspeaker in an attempt to determine the reasons for the variations. Some of these variations occurred between the pass-by peak level and the 6 dB down points. Accordingly, if the variations could be satisfactorily explained, the measurement was accepted as valid; if they could not, the measurement was invalid.

Occasionally calibration tone irregularities were observed. Sometimes, irregularities occurred in a single calibration tone recording, while in other instances, there were significant differences in sound level between the tones recorded at the beginning and at the end of the

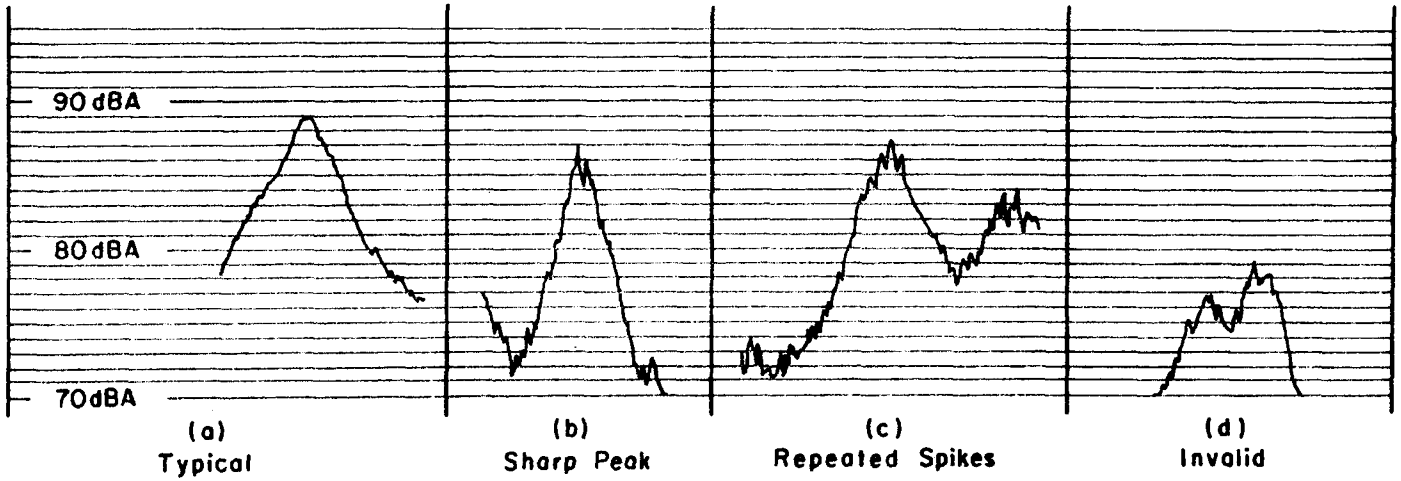


Figure E-3. LEVEL RECORDER GRAPHS

period of measurement. Normally, if irregularities in calibration tones of greater than 1/2 a decibel were noted, truck noise measurements taken for the corresponding period of measurement were considered invalid.

Truck noise measurements which were considered invalid were not included in further analysis. Of the 4,976 measurements which were reduced, 168 were invalid measurements because of failure to meet the 6 dB rise and fall valid measurement criterion on page 157; 258 were invalid due to calibration tone irregularities.

In order to obtain the truck identification number and the truck description information from the field tape recording, the tape was replayed and the voice channel was monitored. This information, which consisted of observation number, truck classification (see page 148), truck type (van, tanker, etc.), exhaust configuration, cab type, vehicle speed, and load condition and manufacturer (when possible), was transferred on to prepared forms.

Computer Data Storage

The data reduced in the lab was data coded and inputted to a computer file for storage. Later on, it would be analyzed through the use of the Department's computer facilities. Only information for valid truck noise measurements was inputted to the file - a total of 4,536 measurements in all.

The reduced tape data, which existed on various printouts and forms, and which consisted of roadway type, truck classification, truck description, peak noise level, speed, and frequency spectrum information, was transferred, in a standard format, on to data code sheets. The data on the code sheets was then keypunched onto computer cards, three cards per truck. The information on these cards was then inputted to the NJDOT's IBM 370/145 MOD3 computer and stored in a disk file.

A file maintenance program was written in Fortran IV. It edited the keypunched cards for errors, converted 1/3 octave frequency levels to octave levels, and updated an indexed sequential disk data file by sorting new truck records into the initial groups specified by a roadway type and axle classification. An example of an initial group would be Roadway Type 1, Truck Classification 9 (see pages 171 and 149). In addition, the file maintenance program created a backup tape when necessary. The creation of a backup tape was a precautionary measure taken so that the grouped data would not be lost if a disk failure occurred.

Thorough documentation of the file maintenance program and several other shorter programs, which were written expressly for this project, was not included in this report because these programs call unique NJDOT subprograms.

APPENDIX F

DATA REDUCTION EQUIPMENT AND ACCESSORIES

This appendix contains descriptions of the laboratory equipment which was used for reducing, to analyzable form, the large quantity of raw truck noise data which was collected in the field. Descriptions of accessory equipment are also given. A block diagram of the data reduction equipment is shown on page 189.

Data Reduction Equipment List

- Nagra Tape Recorder (IV-SJ)
- Spectral Dynamics SD25-132 Overall Level Detector
- Spectral Dynamics SD 312 Real Time 1/3 Octave Analyzer
- Bruel & Kjaer 2305 Level Recorder
- Anadex Model DP 650A-21 Digital Printer

Accessory Equipment List

- Telex Headphones, Teleset HM-100
- Bogen Public Address Amplifier, Model M120
- Bogen Sound Column, Model SCU 80

Equipment Descriptions

Nagra IV-SJ Tape Recorder - See Appendix B, page 169 for description.

Spectral Dynamics SD25-132 Overall Level Detector - When used with a real time analyzer, this unit permits holding the spectrum corresponding to the highest overall noise level reached by rapidly changing data. Both the detector time constant and the trigger threshold are adjustable. A trigger pulse from this unit places the real time analyzer in the hold mode.

Spectral Dynamics SD 312 Real Time 1/3 Octave Analyzer - This instrument analyzes and displays audio spectra in real time (essentially as they occur). It permits fast analyses of large amounts of acoustic data. Thirty-one 1/3 octave filters and one weighted overall channel is provided. A built-in CRT, which is updated twice per second, displays all 32 channels, and a digital readout of dB level and frequency is given. Frequency range is 20 Hz to 20 KHz. Dynamic range is 60 dB for each of the 1/3 octave channels. A, B, C and D weighting or flat response can be selected for all channels. The SD 312 has averaging times of 50 ms, 100 ms, 200 ms, .5, 1, 2, 4, 8, 16 and 32 seconds. Center frequency accuracy is ± 3%. Accuracy and repeatability are ± 1 dB over the top 50 dB range on display for a steady sine wave signal at the filter center frequency. An internal calibration signal is provided.

Bruel & Kjaer 2305 Level Recorder - The 2305 can accurately record the RMS, average, or peak level of AC signals in the frequency range from 2 Hz to 200 KHz. The recorded RMS value is accurate to within ± 0.5 dB for signals with crest factors of less than 5. DC signals can also be recorded.

Recordings can be made, as functions of time or frequency, by means of ink or preprinted recording paper or by means of a sapphire stylus on pressure sensitive paper. A synchronous motor is used for the paper drive, and, with gearing, provides 12 different paper speeds ranging from 0.0003 to 100 mm/sec. Writing speeds from 2 to 2000 mm/sec can be selected. The dynamic range of the recorder is adjustable by the use of interchangeable range potentiometers.

Anadex Model DP650A-21 Digital Printer - This printer is suitable for applications which require I. C. input logic levels for up to 21 columns and a minimum of interface control signals. Data input is 1, 2, 4, 8 binary code for each column. Print format is 21 columns; print rate, true 3 lines per second nominal, asynchronous, and 16 characters are available. Standard paper is single copy roll type of 3.5" (8.9 cm) nominal width.

Telex Headphones, Teleset HM-100 - See Appendix B, page 170 for description.

Bogen Public Address Amplifier, Model M120 - This amplifier was used to power the Model SCU 80 speaker cabinet. Power output is 120 watts at less than 3% distortion. Frequency response is 20 to 20,000 Hz ± 1 dB.

Bogen Sound Column, Model SCU80 - This model is a heavy duty wood cabinet which contains six 8-inch (20.3 cm) speakers. It provides a continuous output of 80 watts at 16 ohms input impedance. Frequency response is 50 - 15,000 Hz.

APPENDIX G

SUPPLEMENTAL FIGURES AND TABLES

Appendix G contains three tables and one figure.

Table G-1, page 201, presents the number of truck noise measurements obtained for Roadway Types 1 to 7 in terms of the thirteen original truck classifications. A brief inspection of this table indicates the following.

The truck mix varied considerably between controlled and non-controlled access roadways. For controlled access roadways (Types 1, 2 and 3), 63.0% of the measurements were taken for Truck Class 12 (trucks with three axle tractors and two axle semitrailers); while for non-controlled access roadways (Types 4, 5 and 6), about 40% of the measurements were taken for this truck class. In addition, for controlled access roadways, about 15% of the measurements were taken for Truck Class 1 (two axle trucks with dual tire rear wheels); for non-controlled access roadways, about 35%. Other significant differences occurred for Truck Class 6 (three axle single unit body trucks) and Truck Class 9 (trucks with two axle tractors and two axle semitrailers). Measurements for Truck Class 6 comprised 3.6% of the measurements for controlled access roadways; 8.5% of the measurements for non-controlled access roadways. Thirteen percent of the measurements for controlled access roadways were obtained for Truck Class 9: 8.7% for non-controlled access roadways.

TABLE G-1

NUMBER OF TRUCK NOISE MEASUREMENTS BY TRUCK CLASSIFICATION AND PERCENTAGE OF TOTAL*

Truck Class	Roadway Type 1	2	3	4	5	6	7	Total 1,2&3	Total 4,5&6	Total All
1-[2/6]**	118(16.5)	100(12.3)	122(16.2)	214(39.9)	120(27.7)	236(37.0)	112(17.3)	340(14.9)	570(35.5)	1022(22.5)
2-[2T]	2(0.3)	4(0.5)	6(0.8)	5(0.9)	2(0.5)	2(0.3)	3(0.5)	12(0.5)	9(0.6)	24(0.5)
3-[3T]	6(0.8)	3(0.4)	4(0.5)	3(0.6)	9(2.1)	6(0.9)	4(0.6)	13(0.6)	18(1.0)	35(0.8)
4-[2B]	6(0.8)	4(0.5)	3(0.4)	4(0.7)	4(0.9)	13(2.0)	3(0.5)	13(0.6)	21(1.3)	37(0.8)
5-[3B]	1(0.1)	1(0.1)	1(0.1)	1(0.2)	0(--)	5(0.8)	0(--)	3(0.1)	6(0.4)	9(0.2)
6-[3]	30(4.2)	21(2.6)	31(4.1)	56(10.4)	28(6.5)	53(8.3)	21(3.2)	82(3.6)	137(8.5)	240(5.3)
7-[4]	5(0.7)	4(0.5)	2(0.3)	0(--)	2(0.5)	5(0.8)	0(--)	11(0.5)	7(0.4)	18(0.4)
8-[2-1]	15(2.1)	15(1.8)	17(2.3)	14(2.6)	8(1.8)	13(2.0)	24(3.7)	47(2.1)	35(2.2)	106(2.3)
9-[2-2]	77(10.7)	109(13.4)	111(14.8)	42(7.8)	42(9.7)	56(8.8)	87(13.4)	297(13.0)	140(8.7)	524(11.6)
10-[2-3]	6(0.8)	11(1.4)	4(0.5)	3(0.6)	12(2.8)	4(0.6)	5(0.8)	21(0.9)	19(1.2)	45(1.0)
11-[3-1]	0(--)	2(0.2)	1(0.1)	0(--)	1(0.2)	0(--)	1(0.2)	3(0.1)	1(0.1)	5(0.1)
12-[3-2]	449(62.6)	539(66.2)	450(59.8)	192(35.8)	204(47.1)	244(38.3)	386(59.7)	1438(63.0)	640(39.9)	2464(54.3)
13-[3-3]	2(0.3)	1(0.1)	0(--)	2(0.4)	1(0.2)	0(--)	1(0.2)	3(0.1)	3(0.2)	7(0.2)
Total	717	814	752	536	433	637	647	2,283	1,606	4,536

*In parentheses
**Two axles, six tires, see page 148 for definition of truck classes.

Remembering that Truck Type 1, medium trucks and buses, includes Truck Classes 1, 2, 4 and 5, and that Truck Type 2, heavy trucks, includes Classes 3, 6, 7, 8, 9, 10, 11, 12 and 13, several other observations can be made. Considering all roadway types, nearly 94% of the measurements for medium trucks and buses were obtained for trucks in Class 1. Again considering all roadway types, about 70% of the measurements for heavy trucks were obtained for trucks in Class 12.

Table G-2, page 203 shows the mean peak noise levels for Roadway Types 1 to 6 for trucks in each of the thirteen classifications. The number of measurements from which the mean level was calculated are indicated in parentheses. A dash (-) indicates that less than two noise level measurements were obtained for a category. This table indicates that in most cases there is a significant difference between the mean peak noise levels of medium trucks and buses (Classes 1, 2, 4 and 5) and heavy trucks (Classes 3, 6, 7, 8, 9, 10, 11, 12 and 13) for a particular roadway type. It should be noted, however, that the sample size for many of the truck classes is very small.

Table G-3, page 204, lists prediction equations for energy mean emission level for speeds in terms of kilometers per hour. Equations are given for Truck Types 1 and 2, and Roadway Types 1-7.

Figure G-1, pages 205 - 208, is a sample output of the truck noise data processing computer program. It lists statistics associated with overall truck noise levels, frequency spectrum (8 octave bands), and regressions of overall and octave band levels versus the logarithm of speed for the original truck classifications outlined on pages 148 and 149. As noted, the processing program was capable of calculating these statistics for any regrouping of truck classes specified by the user.

TABLE G-2

MEAN PEAK NOISE LEVELS (dBA) BY TRUCK CLASSIFICATION*

Truck Class	Roadway Types					
	1	2	3	4	5	6
1 - [2/6]	82.40 (118)**	81.49 (100)	81.11 (122)	78.99 (214)	80.59 (120)	79.20 (236)
2 - [2T]	80.85 (2)	82.52 (4)	82.03 (6)	82.28 (5)	84.95 (2)	80.35 (2)
3 - [3T]	84.48 (6)	83.80 (3)	82.85 (4)	82.63 (3)	82.57 (9)	82.65 (6)
4 - [2B]	81.38 (6)	81.73 (4)	81.03 (3)	79.22 (4)	79.47 (4)	79.28 (13)
5 - [3B]	-	-	-	-	-	77.04 (5)
6 - [3]	85.96 (30)	87.47 (21)	84.45 (31)	83.66 (56)	85.57 (28)	84.20 (53)
7 - [4]	89.42 (5)	86.45 (4)	83.30 (2)	-	88.05 (2)	88.70 (5)
8 - [2-1]	84.67 (15)	86.00 (15)	83.85 (17)	81.59 (14)	82.99 (8)	81.23 (13)
9 - [2-2]	86.23 (77)	86.01 (109)	85.09 (111)	83.04 (42)	85.39 (42)	82.14 (56)
10 - [2-3]	87.27 (6)	88.28 (11)	85.82 (4)	81.13 (3)	87.97 (12)	80.73 (4)
11 - [3-1]	-	85.05 (2)	-	-	-	-
12 - [3-2]	87.03 (449)	85.44 (539)	86.44 (450)	84.07 (192)	86.21 (204)	83.72 (244)
13 - [3-3]	86.35 (2)	-	-	83.15 (2)	-	-

Truck Type 1 (Medium Trucks & Buses) = Classes 1, 2, 4 & 5

Truck Type 2 (Heavy Trucks) = Classes 3, 6, 7, 8, 9, 10, 11, 12 & 13

*Levels not adjusted for speed differences
**Sample size in parentheses

TABLE G-3

PREDICTION EQUATIONS FOR ENERGY MEAN EMISSION LEVEL, $(\bar{L}_0)_E$,
FOR SPEED (V) IN KILOMETERS PER HOUR

Roadway Type	Truck Type 1 (Medium Trucks & Buses)	Truck Type 2 (Heavy Trucks)
1	13.38 + 36.32 log V	50.04 + 19.28 log V
2	60.31 + 11.78 log V	73.18 + 7.46 log V
3	35.34 + 24.21 log V	23.70 + 32.22 log V
4	37.06 + 22.85 log V	44.69 + 21.00 log V
5	47.67 + 18.55 log V	80.39 + 3.63 log V
6	15.42 + 33.98 log V	26.56 + 30.42 log V
7A	60.69 + 9.82 log V	63.01 + 11.96 log V
7B	42.21 + 20.51 log V	67.97 + 7.71 log V

PEAK TRUCK NOISE LEVEL DISTRIBUTIONS

*GROUPS (535 TOTAL TRUCKS)

	1	2	3	4	5	6	7	8	9	10	11				
MEAN PEAK(DBA)	78.99	82.28	82.63	79.22	0.0	83.66	81.59	83.04	81.13	84.07	83.15	0.0	0.0	0.0	0.0
VARIANCE	11.57	25.46	3.58	6.67	0.0	8.13	6.46	7.08	37.86	9.81	0.04	0.0	0.0	0.0	0.0
STD. DEV.	3.40	5.05	1.89	2.58	0.0	2.85	2.54	2.66	6.15	3.13	0.21	0.0	0.0	0.0	0.0
L50	78.95	82.90	81.80	78.55	0.0	83.65	81.35	82.75	80.20	84.07	83.15	0.0	0.0	0.0	0.0
LEQ	80.32	84.30	82.92	79.76	0.0	84.52	82.30	83.90	83.86	85.32	83.15	0.0	0.0	0.0	0.0
PLEQ	80.32	85.21	83.05	79.99	0.0	84.60	82.33	83.85	85.49	85.20	83.16	0.0	0.0	0.0	0.0
TRUCK NUMBER	214	5	3	4	0	56	14	42	3	192	2	0	0	0	0
CHI SQUARE	12.79	12.79	12.79	12.79	0.0	21.31	21.31	2.29	2.29	5.53	5.53	0.0	0.0	0.0	0.0
DEGREES FREEDOM	11	11	11	11	0	5	5	2	2	10	10	0	0	0	0

PEAK VERSUS 10 LOG SPEED REGRESSIONS

*GROUPS (527 TOTAL TRUCKS)

	1	2	3	4	5	6	7	8	9	10	11				
MEAN PEAK(DBA)	78.99	82.28	0.0	79.22	0.0	83.66	81.59	83.04	0.0	84.07	0.0	0.0	0.0	0.0	0.0
MEAN 10 LOG SPEED	16.88	16.73	0.0	17.22	0.0	16.64	16.84	16.99	0.0	17.08	0.0	0.0	0.0	0.0	0.0
MEAN SPEED	49.02	48.40	0.0	52.75	0.0	46.68	48.57	50.38	0.0	51.33	0.0	0.0	0.0	0.0	0.0
STD. DEV. PEAK	3.40	5.05	0.0	2.58	0.0	2.85	2.54	2.66	0.0	3.13	0.0	0.0	0.0	0.0	0.0
STD. DEV. 10LOGSPD	0.494	1.156	0.0	0.241	0.0	0.695	0.489	0.524	0.0	0.462	0.0	0.0	0.0	0.0	0.0
STD. DEV. SPEED	5.40	11.87	0.0	2.99	0.0	7.10	5.43	5.91	0.0	5.29	0.0	0.0	0.0	0.0	0.0
CORRELATION	0.326	0.741	0.0	0.261	0.0	0.538	0.248	0.337	0.0	0.352	0.0	0.0	0.0	0.0	0.0
STD. ERROR EST.	3.22	3.91	0.0	3.05	0.0	2.43	2.56	2.54	0.0	2.94	0.0	0.0	0.0	0.0	0.0
F-TEST	25.16	3.65	0.0	0.15	0.0	22.04	0.79	5.11	0.0	26.88	0.0	0.0	0.0	0.0	0.0
PEAK(10LOG30)	74.27	75.94	0.0	86.06	0.0	79.54	78.92	79.24	0.0	78.56	0.0	0.0	0.0	0.0	0.0
PEAK(10LOG70)	82.52	87.84	0.0	75.77	0.0	87.67	83.67	85.53	0.0	87.35	0.0	0.0	0.0	0.0	0.0
TRUCK NUMBER	214	5	0	4	0	56	14	42	0	192	0	0	0	0	0

PEAK SPECTRUM WITH SPEED REGRESSION

*GROUPS (527 TOTAL TRUCKS)

	1	2	3	4	5	6	7	8	9	10	11				
RELATIVE PEAK	77.90	81.26	0.0	78.40	0.0	82.70	80.92	82.15	0.0	83.20	0.0	0.0	0.0	0.0	0.0
MEAN PEAK	78.99	82.28	82.63	79.22	0.0	83.66	81.59	83.04	81.13	84.07	83.15	0.0	0.0	0.0	0.0
MEAN OCTAVE(63)	55.91	62.38	0.0	53.29	0.0	61.44	58.42	60.68	0.0	60.98	0.0				
MEAN OCTAVE(125)	65.50	72.73	0.0	63.58	0.0	70.95	66.96	70.54	0.0	69.96	0.0				
MEAN OCTAVE(250)	71.16	72.64	0.0	72.08	0.0	76.13	73.78	74.72	0.0	74.90	0.0				
MEAN OCTAVE(500)	72.93	75.90	0.0	74.10	0.0	76.57	74.85	76.36	0.0	77.97	0.0				
MEAN OCTAVE(1000)	72.05	75.23	0.0	71.11	0.0	77.23	75.90	76.75	0.0	78.21	0.0				
MEAN OCTAVE(2000)	68.74	72.69	0.0	69.80	0.0	74.55	73.14	74.25	0.0	74.99	0.0				
MEAN OCTAVE(4000)	61.14	65.50	0.0	63.15	0.0	66.36	65.61	66.43	0.0	67.61	0.0				
MEAN OCTAVE(8000)	53.32	57.25	0.0	54.20	0.0	56.64	55.95	57.11	0.0	57.73	0.0				
STD DEV OCT(63)	4.80	6.53	0.0	4.70	0.0	8.00	5.75	6.62	0.0	6.44	0.0				
STD DEV OCT(125)	4.54	6.62	0.0	3.08	0.0	5.05	2.61	4.52	0.0	4.00	0.0				
STD DEV OCT(250)	4.82	5.87	0.0	5.05	0.0	3.76	3.10	4.02	0.0	3.89	0.0				
STD DEV OCT(500)	4.05	6.04	0.0	2.36	0.0	3.83	2.98	3.54	0.0	3.62	0.0				
STD DEV OCT(1000)	3.70	5.51	0.0	3.04	0.0	3.17	3.52	2.75	0.0	3.49	0.0				
STD DEV OCT(2000)	4.32	5.74	0.0	4.73	0.0	3.72	3.05	3.76	0.0	4.41	0.0				
STD DEV OCT(4000)	5.05	5.59	0.0	5.77	0.0	4.52	3.68	4.78	0.0	4.96	0.0				
STD DEV OCT(8000)	5.09	4.50	0.0	3.99	0.0	4.62	3.54	4.28	0.0	4.80	0.0				
TRUCK NUMBER	214	5	0	4	0	56	14	42	0	192	0				

*GROUP,	OCTAVE	SLOPE	INTERCEPT	STD.ERR	CORR.CO	LEQ(30)	LEQ(70)
1	OVERALL	2.24251	41.14456	3.22413	0.32573	75.46	83.72
1	63	0.79155	42.55474	4.79615	0.08148		
1	125	-0.28312	70.28290	4.54649	0.03083		
1	250	1.67252	42.93417	4.76307	0.17136		
1	500	3.00873	22.15247	3.77087	0.36755		
1	1000	2.43413	30.97274	3.50277	0.32547		
1	2000	2.40211	28.20284	4.16855	0.27447		
1	4000	1.99619	27.44704	4.96560	0.19529		
1	8000	1.93213	20.71682	5.00640	0.18776		
2	OVERALL	3.23342	28.17879	3.91462	0.74069	77.70	85.60
2	63	-2.37254	102.07944	6.84424	0.41991		
2	125	2.40810	32.43847	6.93557	0.42047		
2	250	2.18974	36.00511	6.11710	0.43111		
2	500	3.73176	13.45842	4.88902	0.71365		
2	1000	3.82997	11.14330	3.78067	0.80400		
2	2000	4.72014	-6.28639	2.07475	0.94982		
2	4000	4.41921	-8.44509	2.63299	0.91315		
2	8000	3.70655	-4.77133	1.57541	0.95285		