California Vehicle Noise Emission Levels

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ABSTRACT

The Federal Aid Highway Program Manual (FHPM) 7-7-3 directs state highway agencies to analyze traffic noise impacts and abatement measures for federal and federal-aid highways. The directive requires noise prediction methods to be consistent with Federal Highway Administration (FHWA) RD-77-108 procedures, using either national reference energy mean emission levels as a function of speed or reference energy mean emission levels determined by methodologies described in the FHWA report Sound Procedures for Measuring Highway Noise (FHWA-DP-45-1R). The California Department of Transportation recognized the need for developing California vehicle noise reference energy mean emission levels. Criteria, methods, and analyses used to develop these emission levels are presented in this paper. More than 3,000 noise measurements were made of automobiles, medium trucks, and heavy trucks as defined in the FHWA report FHWA Highway Traffic Noise Prediction Model (FHWA-RD-77-108). The measurements, taken at 16 sites in California, included vehicles traveling at constant speeds from less than 25 mph to greater than 65 mph on level roads. Microphones were set up at 25-, 50-, and 100-ft distances and at heights of 5 and 10 ft. The results show automobile levels 0.8 to 1.0 dBA higher than national levels at 31 and 62 mph respectively (the current range of speeds for national levels). Medium and heavy trucks were less than 0.5 to about 3 dBA lower than national levels at 31 and 62 mph. Further analyses indicated that at 50 ft the effects of terrain type, wind speeds of 12 mph or less, and wind direction could be ignored without introducing errors of more than 1 dBA. The study also indicated that the three vehicle groups adequately represented the California vehicle population and that geographical differences could be ignored.

The noise abatement procedures for federal and federal-aid highway projects are governed by the Federal Aid Highway Program Manual (FHPM) 7-7-3 (1). This directive requires state highway agencies to determine and analyze expected traffic noise impacts and alternative noise abatement measures for mitigating these impacts.

As part of the traffic noise impact analysis under FHPM 7-7-3, prediction of future traffic noise is required. Any prediction method may be used to satisfy this requirement if it generally meets the following two conditions:

1. Consistency with the FHWA highway traffic noise prediction model [FHWA RD-77-108 (2)].
2. The prediction method uses either the national reference energy mean emission levels as a function of speed (1,2) or reference energy mean emission levels determined by the methodology described in the FHWA report Sound Procedures for Measuring Highway Noise [FHWA-DP-45-1R (3)].

Since 1978, the California Department of Transportation (Caltrans) has used the national reference energy mean emission levels as a function of speed. These noise emission levels were based on FHWA's Update of TSC Highway Traffic Noise Prediction Code [FHWA RD-77-19 (4)] (automobiles), and Statistical Analysis of FHWA Traffic Noise Data [RD-78-64 (5)], which presented statistical analyses on truck data gathered in the 1975 four-state noise inventory (6). Aside from California not being among the four states, it is reasonable to assume that vehicle noise emission levels may have changed since 1975. New truck noise emissions regulations have changed and compact energy-efficient automobiles have become more popular since the first energy crisis in 1973-1974. The need for a California vehicle noise emission study was therefore recognized.

A 1981 barrier evaluations study by the Office of Transportation Laboratory at Caltrans (7), which compared before-and-after barrier measured noise levels with those predicted by FHWA methods [FHWA-RD-77-108 (2)], concluded that the latter methods tended to predict values that were an average of 3 to 4 dBA higher than those measured at 11 barrier sites throughout California. The study recommended further investigation to examine the validity of using the national emission levels in California. The recommendation was followed up, and the results are presented in this paper.

The primary objective of this study was to develop California vehicle noise reference energy mean emission levels within a speed range of 25 to 65 mph for use in California highway noise studies complying with the FHPM 7-7-3 requirements. The methods and criteria used to accomplish the primary objective are consistent with FHWA-DP-45-1R (3) and FHWA-OEP/HEV-78-1 (8).

There were also some secondary objectives in this study:

- Verification of the inference from the four-state study that vehicles in California can be categorized into three acoustic source groups to represent the state's entire vehicle population without introducing significant errors in noise predictions.
- Examination of the effects of hard and soft site characteristics on noise emission levels measured at the reference distance of 50 ft.
- Examination of geographical differences in vehicle emission levels for two regions in California, designated as Northern California and Southern California.

• Examination of the effect of wind on emission level measurements.

A total of 16 sites were selected for this study, 8 in Northern California and 8 in Southern California. Each vehicle group was about equally represented in the northern and southern portions of the state.

The number of vehicles measured was 3,045. Because of stringent contamination control and other rejection criteria, 2,734 events were actually used to determine emission levels. Of these, 46.2 percent were automobiles, 11.6 percent were medium trucks, and 42.2 percent were heavy trucks [as defined in FHWA-RD-77-108 (2)]. Reference energy mean emission levels that were speed dependent were developed for each of the three vehicle groups for constant speeds from 25 mph to 65 mph on level roads.

The secondary objectives were attained by measurements using up to 5 microphones at distances ranging from 25 to 100 ft from the centerline of vehicle travel and at heights of 5 ft and 10 ft.

No frequency spectra were measured, nor was any attempt made to verify vehicle noise centroid heights as reported in FHWA-RD-77-108 (2). Also, no comparisons of effects of pavement types were made; rather, such comparisons should be the subject of a separate research project. Pavements at all sites conformed to requirements set by FHWA-DP-45-1R (3) and FHWA-OEP/HEV-78-1 (8).

INSTRUMENTATION

All sound level meters (SLMs) used in this study met the requirements of Type I precision SLM per the 1983 Specification for Sound Level Meters (S1.4) of the American National Standards Institute. The SLMs were connected to a data logger specifically designed for the California Transportation Laboratory.

The data logger has 16 channels that may be selectively activated to receive up to 16 D.C. output signals from SLMs. These signals are then converted by the data logger's microprocessor into continuous, time-varying noise signals that are digitally displayed and updated at short time intervals depending on the slow or fast response settings. The data logger has two mode settings: standby and sampling. In the sampling mode, the data logger stores one sample per activated channel per second in the microprocessor. The stored values are used at the end of each sampling period to derive noise descriptors and statistical values. At the end of each noise measurement period, the data logger prints out the channel number, date, site number, time sampling began, time sampling ended, number of samples lost (due to editing during measurement), L_{eq}, L_{10}, L_{50}, a histogram of noise levels versus percent frequency, standard deviations, skewness, and kurtosis, for each channel.

The data logger also has the capability of measuring maximum noise levels in either the standby or sampling mode while a peak button is pressed. When the button is released, the maximum noise level received by each channel while the peak button was depressed is printed with the date, site number, time, and elapsed time of a single event. The data logger was used in this mode during the California vehicle noise emission levels study.

Figure 1 shows the noise instrumentation, typical setup, and site cross-section criteria. All instruments were field calibrated as a system before and after each measuring period in addition to the semiannual calibrations by the Transportation Laboratory, which has facilities and instruments for performing SLM calibrations using two laboratory standard microphones calibrated every 6 months by the National Bureau of Standards in Washington, D.C. Wind speeds and directions were measured with a portable anemometer mounted on a 7-ft high standard. Vehicle speeds were measured with a radar gun.

SITES

The physical criteria for sites used in this study were in conformance with emission level site criteria set forth by FHWA OEP/HEV-78-1 (8) and FHWA-DP-45-1R (3). Cross-sectional and layout criteria are shown

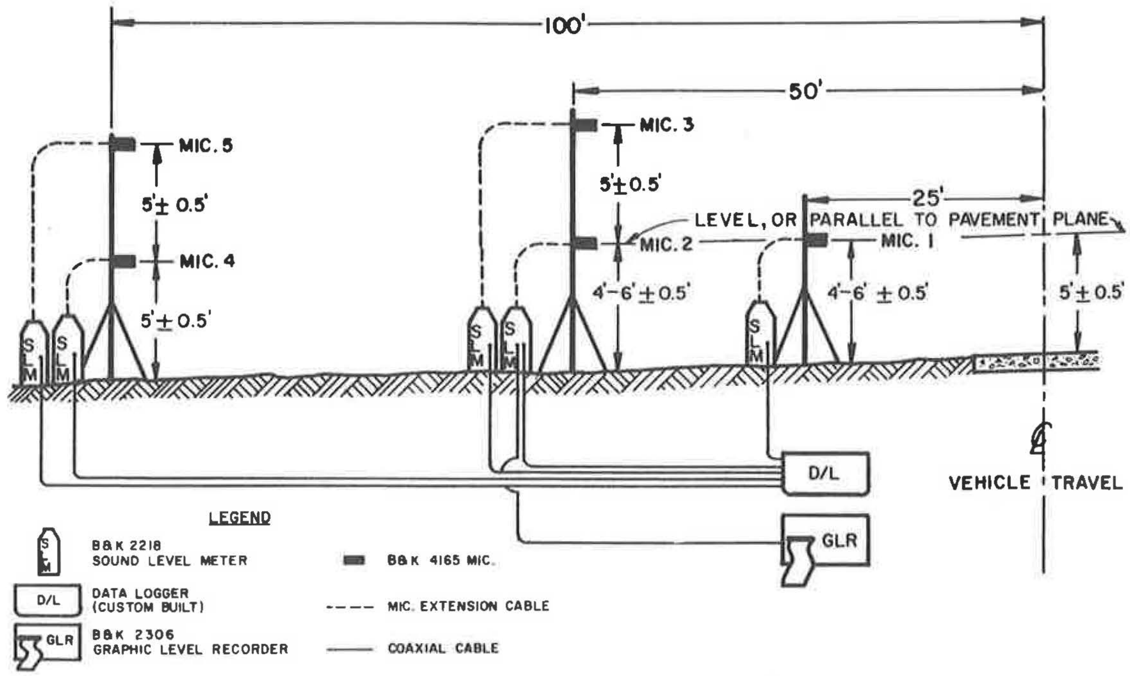


FIGURE 1 Noise instrumentation, typical setup, and site cross-section criteria.

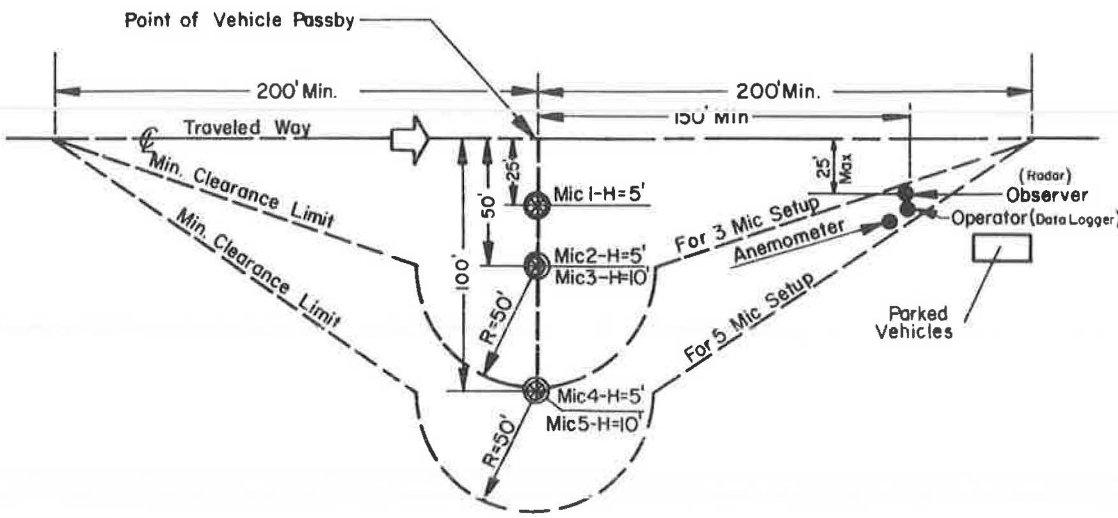


FIGURE 2 Typical site layout and microphone locations.

in Figures 1 and 2. In addition to these criteria, the following two general requirements were strived for during the site selection process:

1. Adequate representation of hard and soft sites as defined in FHWA RD-77-108 (2). Of the 16 sites used in this study, 5 were considered hard sites and 11 were considered soft.
2. Adequate geographical and speed representations. Because of California's diversity in traffic, it was opted to take fewer samples at many sites rather than many samples at few sites. In California, the FHWA highway traffic noise prediction model is used predominantly with higher speed traffic in urban and suburban regions. Adequate high-speed representation of automobiles and heavy trucks was obtained by sampling near high-population densities of the state as well as near Interstate highways (Figure 3).

FIGURE 3 Site locations.

Nineteen sites (Nos. 1-19) were selected originally. For various reasons, two sites (Nos. 4 and 13) were later rejected and one (No. 8) was never measured due to adverse weather conditions. To avoid confusion and maintain correlation with the original data, the remaining sites were not renumbered.

FIELD MEASUREMENTS

General Approach

Field measurements consisted of three operations: (a) vehicle identification and speed measurements, (b) A-weighted noise measurements, and (c) meteorological measurements. The first operation was performed by a vehicle observer, and the last two operations by an instrument operator. All measurement procedures and criteria reported in this section were consistent with FHWA-OEP/HEV-78-1 (8) and FHWA-DP-45-1R (3).

Where space and other conditions permitted the use of five microphones and SLMs, the typical microphone setup shown in Figure 1 was used to measure highest noise levels of individual vehicles. These were assumed to occur when vehicles crossed the point closest to the microphones.

Nine sites (Nos. 1, 2, 5, 7, 11, 12, 15, 16, 17) had the typical setup, shown in Figure 1, although site 5 had an exception. At this site, Microphones 4 and 5 were located 75 ft from the centerline of traveled way instead of the typical 100 ft. At each of the seven remaining sites, the terrain did not allow a setup of five microphones, so a setup of three microphones was used. Except for the elimination of Microphones 4 and 5, the microphone location criteria and numbering convention for three microphone setups were identical to those shown in Figure 1. Sites 3, 6, 9, 10, 14, 18, and 19 had a three-microphone configuration.

Quality Control Criteria for Events

An event was defined as the set of noise, vehicle, and meteorological measurements during a vehicle passby. Each of the measured components comprising an event was evaluated for acceptance or rejection according to five objective and subjective criteria: noise measurements, vehicles, meteorological criteria, number of events accepted and rejected, and sample size. Each of these criteria will be discussed further.

Noise Measurements

Significant contamination of noise measurements by extraneous noise sources was avoided by using three contamination control strategies: (a) selecting vehicles that were adequately separated from other vehicles, (b) analyzing the graphic level recorder (GLR) trace for compliance with valid-peak criteria, and (c) audiovisual observation by the radar observer and instrument operator.

Vehicle separation criteria were developed from two common scenarios, which are shown in Figures 4 and 5. Figure 4 shows two vehicles with equal noise strengths and a background noise level (L_B) of 10 dBA below the vehicles' noise emission levels (L_O) measured 50 ft from the point of passby. The two vehicles are separated by a minimum distance so that the highest observed noise level includes no more than 0.5 dBA contamination when Vehicle 1 crosses the point of passby. Because of the symmetrical relationship between the two noise sources, the same contamination is present when Vehicle 2 crosses the point of passby. A GLR documenting the events would produce a trace similar to the solid line in Figure 4, depicting the sum of L_i Vehicle 1 + L_i Vehicle 2 + L_B. This scenario approximates the passing of two automobiles without the presence of trucks and may also be applied conservatively to the passing of two trucks. The minimum distance of 308 ft between the vehicles provides a criterion of separation when two vehicles of equal noise source are involved.

Because of uncertainties in actual background levels and because there were usually more than two vehicles in the vicinity, the minimum distance criterion between the measured vehicle and any other vehicle of approximately equal source was set at 400 ft. A traffic cone placed 400 ft ahead of the point of passby aided the observer in estimating the minimum distance criterion in the field.

The second scenario, shown in Figure 5, involves two vehicles of unequal source strength. In this scenario, the noise source of one vehicle is 10 dBA higher than that of the other vehicle. The background noise is assumed to be 10 dBA below the lower noise source. This scenario approximates that of measuring the noise emission level of an automobile while a truck is approaching. In this case, the minimum vehicle separation should be 985 ft, or approximately 1,000 ft, to avoid contamination of more than 0.5 dBA.

The observer in the field had to estimate the 1,000-ft distance when the second scenario applied. Usually, this did not present a problem. Most automobile measurements were taken when there were not trucks in sight. In the cases when trucks were pres-

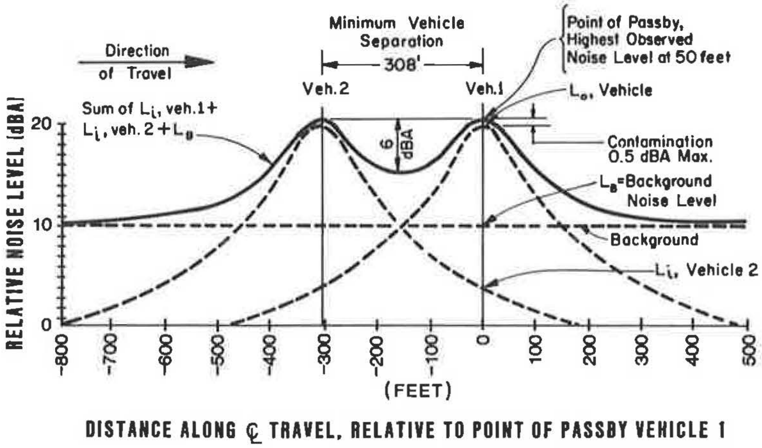


FIGURE 4 Minimum separation between two vehicles–equal noise sources.

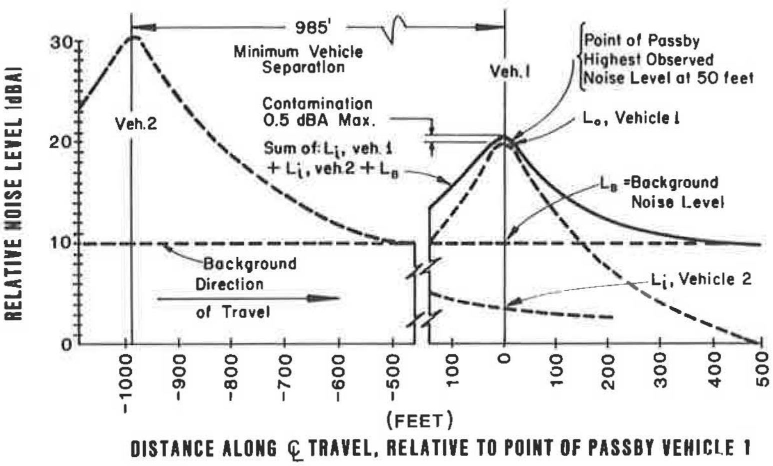


FIGURE 5 Minimum separation between two vehicles–unequal noise sources.

ent, the observer and instrument operators made independent judgments about the measurement quality. Because of probable presence of considerable ground attenuation and some atmospheric attenuation over a 1,000-ft distance (not included in the criterion calculation), this criterion was probably conservative.

Finally, a short discussion about the reverse of Scenario 2 (Figure 5) should be included. In this scenario, the louder vehicle is measured and the quieter vehicle is in the vicinity. If the difference between the sources is 10 dBA or greater, no separation should be necessary when 2 vehicles are involved. However, when the louder source is surrounded by several quieter sources, contamination may still occur. No criteria were set to cover this situation, but in general, trucks were not measured when surrounded by more than two or three automobiles in the immediate vicinity. In most cases, trucks selected for measurement were adequately separated from automobiles so that few judgments were necessary.

Valid-peak criteria were developed to help determine whether background noise contributed to the highest observed noise level of each event (vehicle passby). These criteria were based on a GLR trace of the event, recorded 50 ft from the centerline of vehicle travel at a microphone height of 5 ft (Reference Microphone 2 location).

To limit contamination to less than 0.5 dBA, the background noise levels should be at least 10 dBA lower than the highest observed value, which would have been a convenient criterion to use. However, a previous study by the New Jersey Department of Transportation (9) suggests that accepting only peaks of 10 dBA or greater would introduce a bias toward noisier vehicles. This would be true especially if background noise were relatively high. The New Jersey study used a rise-and-fall criterion of 6 dBA to prevent this bias, at the risk of slightly contaminating the measurement. For this reason, the California study used the same 6-dBA rise-and-fall criterion for acceptance. In this study, a rise and fall of 6 to 9 dBA was coded as an event of Quality 1; a rise and fall of 10 dBA or greater was coded as an event of Quality 2. Figure 6 shows the relationships between valid-peak criteria, event quality codes, and resulting maximum contamination.

The final audiovisual contamination control strategy consisted of an on-the-spot judgment by the vehicle observer or instrument operator, or both, to determine the quality of an event. In these instances, judgments were made using ears and eyes. Common examples included: sudden rises in background noise during measurements due to aircraft, nearby construction, or sporadic traffic on nearby frontage roads or ramps. When these rapid background noise increases coincided with vehicle passby measurements, they sometimes blended in with GLR traces, showing a valid peak. Contamination would have gone undetected except for the alertness of the observers during measurements.

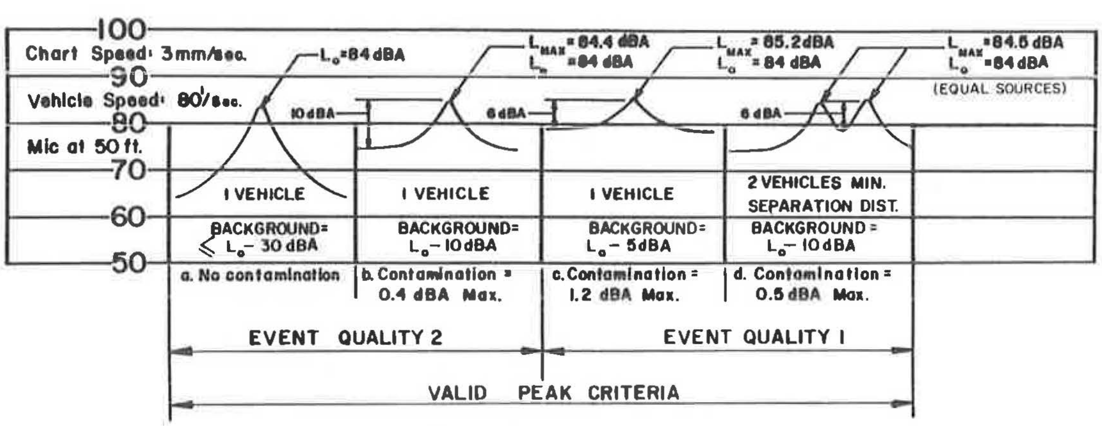
Vehicles

The three vehicle groups discussed in FHWA-RD-77-108 (2)--automobiles, medium trucks, and heavy trucks--were also used throughout this study. However, to confirm that vehicles can be placed in these three acoustic source groups, vehicles were identified in greater detail than were the FHWA groups. Automobiles were divided into compact and standard categories, a division that was made subjectively in the field by the observer. Heavy trucks were categorized by number of axles. The subdivisions resulted in eight vehicle types, which are given in Table 1.

All events were identified in the field and recorded with the passby speeds in mph. The speeds were measured with a radar gun by the observer, beginning at a point approximately 400 ft ahead of the point of passby and ending just beyond the point of passby. The speed at the point of passby was recorded. If the speed changed more than 3 mph in the 400-ft distance, the vehicle was assumed to be accelerating or decelerating and the event was rejected. Because of its position, the radar gun was usually not noticed by the drivers until after the point of passby, and thus few let up on the throttle.

Meteorological Criteria

One of the secondary objectives of this project was to attempt to isolate the effects of wind on vehicle noise emission measurements and noise measurements in general. FHWA-OEP/HEV-78-1 (8) and FHWA-DP-45-1R (3) do not recommend taking noise measurements when



NOTES: • L_o = Vehicle Noise Emission Level.
• L_{MAX} = Highest Observed Noise Level.
• Contamination = $L_{MAX} - L_o$
• When L_{MAX} − Background Level <6dBA, Event Was Rejected. (Event Quality 0)

FIGURE 6 Valid-peak criteria, event quality codes, and maximum contamination.

TABLE 1 Vehicle Types

Vehicle Type	Designation	Definition-Description	FHWA-RD-77-108 Designation (2)
0	Compact automobile	Four cylinders; otherwise same as FHWA automobiles	Automobile
1	Standard automobile	Six or eight cylinders; otherwise same as FHWA automobiles	Automobile
2	Medium truck	Same as FHWA medium trucks; includes two-axle, six-tire buses	Medium truck
3	Three-axle truck	Three axles; otherwise same as FHWA heavy trucks	Heavy truck
4	Four-axle truck	Four axles; otherwise same as FHWA heavy trucks	Heavy truck
5	Five-axle truck	Five axles; otherwise same as FHWA heavy trucks	Heavy truck
6	Trucks with more than five axles	More than five axles; otherwise same as FHWA heavy trucks	Heavy truck
7	Miscellaneous	Vehicles not covered under Types 0-6; example: motorcycles	NA

wind speeds exceed 12 mph. All measurements in this study were made at wind speeds below 10 knots (11.5 mph).

Wind speeds and direction were measured with a Belfort anemometer set on top of a standard at a height of 7 ft near the instrument operator and observer at a distance of approximately 25 ft from the centerline of the nearest roadway. The measurements were taken between measured events and during gaps in traffic to avoid turbulence from passing vehicles. Wind speeds were measured to the nearest 1 knot and then grouped into three wind speed classes, as follows:

Wind Speed Class	Range (knots)	Range (mph)	Center Speed (mph)
0	0-2.5	0-3	0
3	2.5-5.5	3-6	4.5
6	5.5-10	6-12	9

The center speed was later used to compute cross-wind components 90 degrees to the roadway. These were then categorized as follows: 6 to 12 mph, 3 to 6 mph, -3 to +3 mph, -6 to -3 mph, and -12 to -6 mph. A positive wind blew from source to receiver, and a negative wind from receiver to source. Other important environment criteria were the 90 percent or greater relative humidity and wet pavement. No measurements were attempted under either condition.

Number of Events Accepted and Rejected

The event data were recorded on four different types of charts and sheets: (a) GLR chart (vehicle trace at reference distance), (b) vehicle observation sheet (vehicle identification and speed), (c) data-logger printout (maximum observed noise levels at each microphone), and (d) environmental and site data sheet (meteorological data). Data from each of these sources were coded with either an event Quality 1 (accepted) or 0 (rejected). GLR data was coded either 2, 1 (accepted), or 0 (rejected), as discussed previously. Thus, each event had four quality codes. Events with at least one 0 code were called Quality 0 events and were rejected, for example, 1011. Events with all quality 1 (1111) were designated Quality 1 events and accepted for emission levels only. Events with a GLR quality 2 (2111) were designated Quality 2 events. Of the 3,045 events measured at the reference microphone (Microphone 2), 2,426 (79.7 percent) were Quality 2, 308 (10.1 percent) were Quality 1, and 311 (10.2 percent) were Quality 0 (rejected).

Sample Size

The minimum required sample size for each vehicle group was first estimated from methods described in FHWA-OEP/HEV-78-1 (8) for a 95 percent confidence interval of ±1 dBA around the mean of each speed class. Table 2 gives the speed classes that were designed for this purpose.

TABLE 2 Ranges of Speed Classes

Speed Class	Speed Range (mph)	Speeds to Nearest 1 mph
0	<24.50	<25
1	24.50-28.49	25-28
2	28.50-32.49	29-32
3	32.50-36.49	33-36
4	36.50-40.49	37-40
5	40.50-44.49	41-44
6	44.50-48.49	45-48
7	48.50-52.49	49-52
8	52.50-56.49	53-56
9	56.50-60.49	57-60
10	60.50-64.49	61-64
11	>64.49	>64

After data had been collected in each speed class, the minimum required data for the confidence interval of ±1 dBA was calculated from

$$n = \left\{[(t_{\alpha/2;n-1}) \cdot (S)]/d\right\}^2 \qquad (1)$$

where

$t_{\alpha/2;n-1}$ = the amount of sample standard deviations associated with (1.00 - α) · 100 percent confidence level and n - 1 degrees of freedom,
α = significance level (= 0.05),
S = the sample standard deviation,
d = (1. 00 - α) x 100 percent confidence interval (= ±1 dBA).

Tables 3 and 4 give the number of points sampled, minimum number of points required, mean speed, mean energy noise levels, mean noise levels, and standard deviations for each speed class. The statistics are shown for the 50-ft reference microphone (Microphone 2) only. The total number of events sampled and accepted was 2,734, and consisted of the following

TABLE 3 Low-Speed Data by Vehicle Group

Data by Speed Class	Automobiles	Medium Trucks	Heavy Trucks
Class 0 (less than 25 mph)			
No. of points sampled	3	1	3
Minimum number of points required	535	0	345
Mean speed (mph)	23.00	22.00	21.00
Mean energy noise level (dBA)	60.55	63.30	76.68
Mean noise level (dBA)	58.20	63.30	75.57
Standard deviation mean dBA	5.37	0.00	4.32
Class 1 (25 to 28 mph)			
No. of points sampled	6	7	18
Minimum number of points required	113	178	50
Mean speed (mph)	27.33	27.43	27.11
Mean energy noise level (dBA)	63.90	74.37	79.45
Mean noise level (dBA)	62.25	72.03	78.20
Standard deviation mean dBA	4.13	5.46	3.35
Class 2 (29 to 32 mph)			
No. of points sampled	21	8	37
Minimum number of points required	25	45	49
Mean speed (mph)	30.57	30.50	30.54
Mean energy noise level (dBA)	63.44	74.48	80.55
Mean noise level (dBA)	62.75	73.61	78.59
Standard deviation mean dBA	2.40	2.85	3.49
Class 3 (33 to 36 mph)			
No. of points sampled	46	20	40
Minimum number of points required	37	50	32
Mean speed (mph)	34.59	34.10	34.80
Mean energy noise level (dBA)	64.95	76.02	79.49
Mean noise level (dBA)	63.69	74.63	78.57
Standard deviation mean dBA	3.03	3.38	2.83
Class 4 (37 to 40 mph)			
No. of points sampled	33	15	34
Minimum number of points required	39	48	22
Mean speed (mph)	38.45	38.67	38.53
Mean energy noise level (dBA)	66.86	76.73	80.89
Mean noise level (dBA)	65.68	75.58	80.22
Standard deviation mean dBA	3.11	3.23	2.33
Class 5 (41 to 44 mph)			
No. of points sampled	88	16	48
Minimum number of points required	34	31	20
Mean speed (mph)	42.65	42.38	43.06
Mean energy noise level (dBA)	68.00	76.25	81.74
Mean noise level (dBA)	66.70	75.50	81.17
Standard deviation mean dBA	2.93	2.62	2.26

vehicles: 1,263 automobiles, 317 medium trucks, and 1,154 heavy trucks. For automobiles and heavy trucks, sufficient amounts of data were gathered in all speed classes from 32 to 64 mph (except for automobiles in the 37 to 40 mph range, of which there were slightly fewer than the minimum number required). For medium trucks, the minimum amount of samples required was reached for all speed classes above 48 mph. Because of the deficiency in data at lower speeds and to cover the desired range of 25 to 65 mph, curve-fitting methods were employed with 95 percent confidence intervals for the prediction equation.

Use of this curve-fitting method should be restricted to normally (Gaussian) distributed data in each speed class for each vehicle group. Although this constraint was never tested on the data in this project, previous unpublished Caltrans studies suggest that at constant speeds, vehicle noise approaches a normal distribution.

ANALYSES AND RESULTS

Emission Levels by Vehicle Types

Reference energy mean emission curves as a function of speed were developed for all vehicle types shown in Table 1 except for Types 6 and 7. Type 6 was not included because only one event was observed; Type 7 vehicles (motorcycles and miscellaneous) were also very scarce.

The energy mean emission curves were expressed as

$$LOE_{(i)} = A + 0.115(Sy)^2 + B \log (\text{speed,mph}) \qquad (2)$$

where

$LOE_{(i)}$ = energy mean emission level for vehicle type i,
A = constant in the regression equation,
Sy = standard error of y(dBA) on log X (speed, mph), and
B = slope in the regression equation.

Figure 7 shows a comparison of compact versus standard automobile mean emission curves. The curves indicate that compact automobile (four-cylinder) emission levels are between 1.2 dBA (at 25 mph) and 1.5 dBA (at 65 mph) lower than standard automobiles (six or eight cylinders). The reasons for this difference are unclear, but it is suspected that the compact car fleet consists of later model cars with better mufflers than the standard car fleet. The difference, however, is not significant enough to warrant separate emission curves. Instead, compact and standard curves were combined.

Figure 8 shows comparisons of curves for three-, four-, and five-axled trucks. Because of close agreement between the curves for heavy trucks, one combined curve was used to represent them. [This study therefore concurs with the original FHWA findings that all vehicles can be categorized in three acoustic source groups (2).]

TABLE 4 High-Speed Data by Vehicle Group

Data by Speed Class	Automobiles	Medium Trucks	Heavy Trucks
Class 6 (45 to 48 mph)			
No. of points sampled	92	19	77
Minimum number of points required	34	59	25
Mean speed (mph)	46.66	46.32	46.22
Mean energy noise level (dBA)	69.34	75.96	82.10
Mean noise level (dBA)	68.36	74.95	81.26
Standard deviation mean dBA	2.90	3.66	2.50
Class 7 (49 to 52 mph)			
No. of points sampled	117	32	106
Minimum number of points required	36	23	27
Mean speed (mph)	50.73	50.69	50.97
Mean energy noise level (dBA)	72.68	78.48	82.64
Mean noise level (dBA)	71.21	77.85	81.74
Standard deviation mean dBA	3.01	2.42	2.62
Class 8 (53 to 56 mph)			
No. of points sampled	258	69	233
Minimum number of points required	28	29	31
Mean speed (mph)	54.57	54.58	54.60
Mean energy noise level (dBA)	72.99	78.98	83.49
Mean noise level (dBA)	72.09	78.11	82.51
Standard deviation mean dBA	2.64	2.71	2.79
Class 9 (57 to 60 mph)			
No. of points sampled	272	78	300
Minimum number of points required	31	23	21
Mean speed (mph)	58.53	58.45	58.60
Mean energy noise level (dBA)	74.03	80.78	83.99
Mean noise level (dBA)	73.04	80.11	83.34
Standard deviation mean dBA	2.79	2.37	2.27
Class 10 (61 to 64 mph)			
No. of points sampled	220	44	212
Minimum number of points required	27	24	23
Mean speed (mph)	62.35	62.07	62.12
Mean energy noise level (dBA)	74.85	81.74	85.21
Mean noise level (dBA)	73.91	81.02	84.44
Standard deviation mean dBA	2.62	2.46	2.40
Class 11 (more than 64 mph)			
No. of points sampled	107	8	46
Minimum number of points required	35	8	85
Mean speed (mph)	67.79	67.38	66.76
Mean energy noise level (dBA)	76.07	81.24	87.20
Mean noise level (dBA)	74.91	81.10	85.39
Standard deviation mean dBA	2.94	1.21	4.60

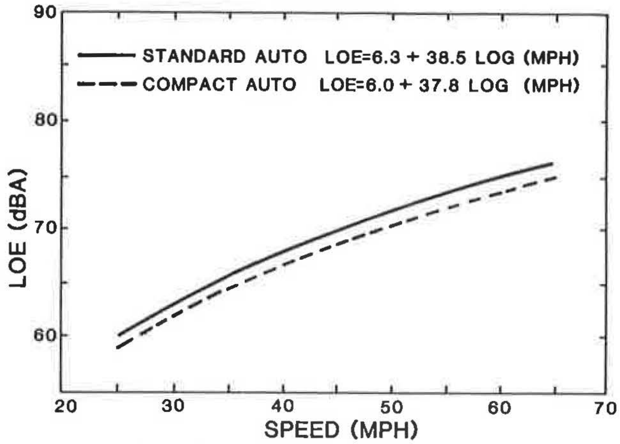


FIGURE 7 Comparison of compact versus standard energy mean regression lines.

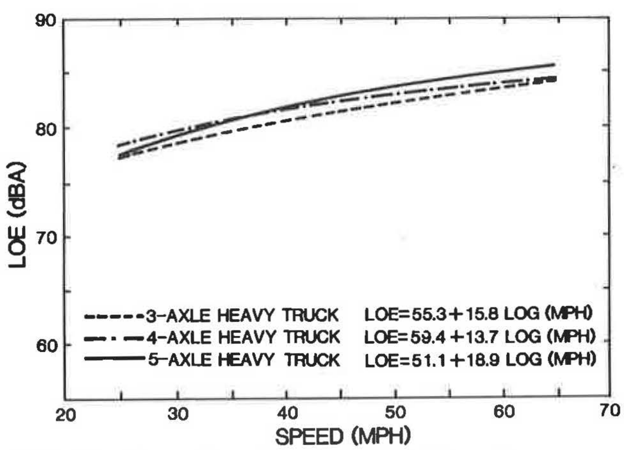


FIGURE 8 Comparison of three-, four-, and five-axle energy mean regression lines.

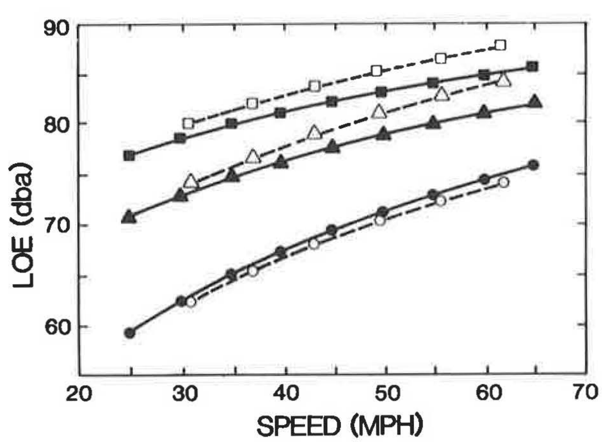
Figure 9 shows a comparison of energy mean emission levels for automobiles, medium trucks, and heavy trucks in the California study with the same three vehicle groups reported in FHWA-RD-77-108 (2). The California automobile curve is from 0.7 dBA (at 25 mph) to 1.0 dBA (at 65 mph) higher than the FHWA automobile curve (projected up to 65 mph and down to 25 mph). The California medium-truck curve is from 0.3 dBA higher (at 25 mph) to 3.2 dBA lower (at 65 mph) than the FHWA medium-truck curve. Approximately the same is true for the California heavy-truck curve, which is from 0.7 dBA lower (at 25 mph) to 3.1 dBA lower (at 65 mph) than the projected FHWA heavy-truck curve.

The emission levels for the three vehicle groups were also plotted by energy mean noise levels for each speed class at 50 ft. Although these plots deviated up to about 3 dBA from the regression lines for automobiles and medium trucks, the differences were not statistically significant (Student's t-test, $\alpha = 0.05$). The heavy-truck plot, however, showed statistically significant deviations of 1.4 and 1.7 dBA above the regression line for speed classes 25 to 28 mph and 29 to 32 mph, respectively (see Figure 10), deviations that may have been caused by increased noise levels in lower gears. Because of the importance of heavy-truck noise emission levels in predicting highway noise and designing noise barriers, further refinements in the curve appeared justified.

Figure 11 shows the California vehicle noise reference energy mean emission levels, including the modified curve for heavy trucks. These curves are recommended for use with traffic noise prediction models in California.

Hard Versus Soft Sites

There are several problems in comparing emission levels measured at one group of sites with those from another group: (a) vehicle populations may be different, (b) meteorological conditions are probably not the same, and (c) the speed distributions are likely to be different. These problems were reduced, if not eliminated, by normalizing the 50-ft



	○ ● AUTOS	△▲ MEDIUM TRUCKS	□■ HEAVY TRUCKS
---○--- FHWA	LOE=5.5+38.1 LOG(MPH)	LOE=23.4+33.9 LOG (MPH)	LOE=43.6+24.6 LOG(MPH)
—●— CALIFORNIA	LOE=5.2+38.8 LOG(MPH) No. of observations: 1263 Std.error y on LOGx: 2.81 r^2=0.56; r=0.75	LOE=35.3+25.6 LOG (MPH) No. of observations: 317 Std. error y on LOGx: 2.83 r^2=0.42; r=0.65	LOE=50.4+19.2 LOG (MPH) No. of observations: 1154 Std. error y on LOGx: 2.68 r^2=0.29; r=0.53

FIGURE 9 Comparison of California versus FHWA energy mean regression lines.

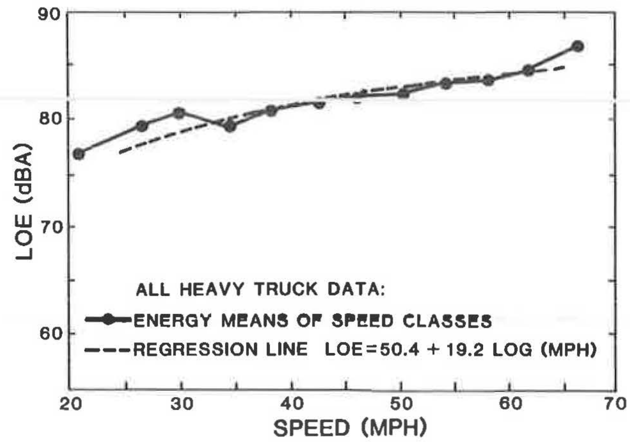


FIGURE 10 Comparison by energy means of speed classes and energy mean regression line for heavy-truck data plots.

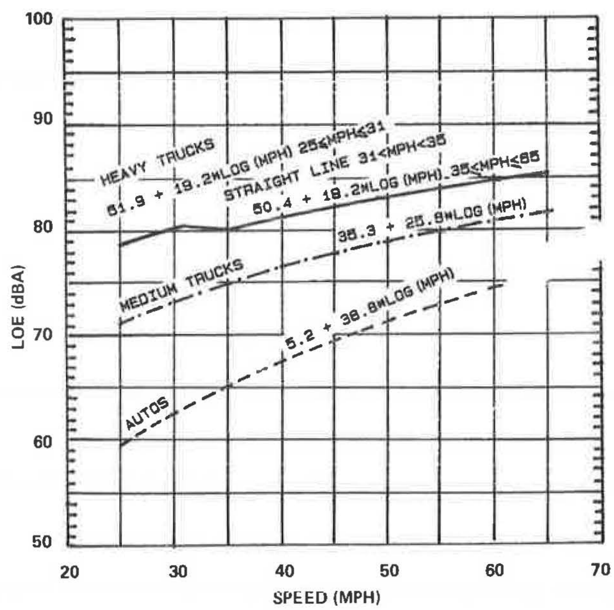


FIGURE 11 California reference energy mean emission levels.

microphones of soft sites to those of hard sites. This was accomplished by setting the 25-ft microphones equal and correcting up the 50-ft microphones. The underlying assumptions were that site and meteorological effects were negligible near the source. Remaining differences could then be attributed to differences in vehicle populations. The normalizing process eliminated these differences. Variations in speed distributions were eliminated by comparing only those speed classes with sufficient data to assure 95 percent confidence intervals of ±1 dBA around the means.

Table 5 shows that for all vehicle groups and speed classes tested with a statistical t-test (10), the effects on measured noise levels caused by hard or soft site characteristics were significant at the 50-ft reference distance at a height of 5 ft. These differences (maximum 2 dBA) appeared to decrease with increasing source heights, but appeared to be insensitive to speed.

In reality, there are few true hard sites, whereas variations in soft sites are almost endless. It is therefore impractical to have separate emission levels for hard sites and soft sites. It appears that site characteristics will, in most cases, affect noise predictions by no more than 0.8 dBA when using the California emission curves.

Geographical Differences

Table 6 shows a comparison of emission levels measured at 25 ft for Northern California and Southern California by vehicle group and speed classes with sufficient data to ensure a 95 percent confidence interval of ±1 dBA. As was discussed previously, at 25 ft the site and environmental effects could be eliminated. In general, automobiles and medium trucks did not appear to be significantly different. In the heavy-truck group, however, Northern California trucks were up to about 2 dBA noisier. The differences were statistically significant (t-test, $\alpha = 0.05$). Between 49 and 64 mph, the average difference was slightly greater than 1 dBA. Using the California heavy-truck emission curve would probably result in maximum errors of 0.5 dBA due to geographic differences. Separate curves for Northern California and Southern California would therefore not be justified or practical.

Effects of Wind

The effects of wind on measured noise levels were examined at 50 ft and 100 ft. After crosswind com-

TABLE 5 Comparison of Vehicle Emission Levels for Hard Sites Versus Soft Sites

	Energy Mean (dBA)								
Vehicle Type	Speed Class (mph)	Hard Sites— 50 ft ($\overline{X}$)	Normalized[a] Soft Sites— 50 ft ($\overline{Y}$)	Difference in dBA ($\overline{X}$-$\overline{Y}$)	Standard Deviation (S_x)	No. of Observations (N_x)	Standard Deviation (S_y)	No. of Observations (N_y)	t-test (α = 0.05 significant)
Automobiles	53-56	74.2	72.2	2.0	2.9	84	2.3	174	Yes
	57-60	74.8	72.8	2.0	3.3	96	2.4	176	Yes
	61-64	76.1	74.1	2.0	3.5	71	2.0	149	Yes
Medium trucks	57-60	82.1	80.2	1.9	2.0	23	2.2	55	Yes
Heavy trucks	49-52	82.9	81.3	1.6	2.5	46	2.7	60	Yes
	53-56	83.9	82.5	1.4	2.9	101	2.7	132	Yes
	57-60	84.8	83.1	1.7	2.4	123	2.1	177	Yes
	61-64	85.7	84.1	1.6	2.3	81	2.4	131	Yes

Note: Speed classes with sufficient data only.

[a]Normalized: 25-ft microphone of soft sites was set equal to 25-ft microphone of hard sites and 50-ft microphone was corrected with same correction.

TABLE 6 Comparison of Vehicle Emission Levels for Northern California and Southern California

Vehicle Type	Speed Class (mph)	Energy Mean (dBA) Northern California Sites—25 ft ($\bar{X}$)	Southern California Sites—25 ft ($\bar{Y}$)	Difference in dBA ($\bar{X}$-$\bar{Y}$)	Standard Deviation (S_x)	No. of Observations (N_x)	Standard Deviation (S_y)	No. of Observations (N_y)	t-test (α = 0.05 significant)
Automobiles	45-48	76.7	75.4	1.3	2.2	2.9	45	47	Yes
	53-56	79.5	79.5	0	2.3	2.7	160	90	No
	57-60	80.5	80.7	-0.2	2.4	3.2	129	134	No
	61-64	81.5	81.2	0.3	2.3	3.1	96	119	No
	>64	83.4	82.3	1.1	2.8	3.2	41	62	No
Medium trucks	53-56	85.6	84.7	0.9	2.1	3.1	33	34	No
	57-60	87.6	86.9	0.7	2.5	2.2	31	46	No
Heavy trucks	49-52	89.5	87.4	2.1	2.7	2.4	63	41	Yes
	53-56	90.1	88.9	1.2	2.5	2.7	111	114	Yes
	57-60	90.8	89.7	1.1	2.3	2.1	119	178	Yes
	61-64	91.4	91.5	-0.1	2.1	2.6	68	142	No

Note: Speed classes with sufficient data only.

ponents (90 degrees to the roadway) had been calculated and categorized as previously discussed, associated noise data at 50 ft and 100 ft were normalized using the 25-ft microphone data. Wind effects at 25 ft were judged to be small and therefore neglected. Tables 7 and 8 give comparisons of opposite crosswinds at 50 ft, first using all sites (Table 7), then using soft sites only (Table 8). Table 9 shows the comparison using data from all five microphone sites at 100 ft.

Wind effects were expected to be greatest for soft sites, longer distances, and lower noise sources. As the tables indicate, however, no significant changes could be detected at 50 ft. At 100 ft, there was a significant difference in the automobile data when opposite winds between negative and positive wind speeds of 6 to 12 mph were compared.

SUMMARY

The California vehicle noise reference energy emission levels are 0.7 to 1.0 dBA higher for automobiles, 0.3 higher to 3.2 dBA lower for medium trucks, and from 0.8 dBA higher (at 25 mph, after refinement) to 3.1 dBA lower (at 65 mph) than FHWA (2) emission levels (projected down to 25 mph and up to 65 mph). For average traffic mixes and at-grade highways, noise predictions made with California emission levels will be about 2 dBA lower than those made with the FHWA levels. The FHWA categorization of vehicle noise sources into three groups appears to also be valid for use in California. Although there are significant differences of up to 2 dBA in noise levels at 50 ft for hard sites and soft sites, the California curve will cause maximum errors of no more than about 0.8 dBA due to site characteristics. Similarly, geographic differences will cause maximum deviations of 0.5 dBA. The effects of wind speed and direction on noise measurements at 50 ft may be ignored if wind speeds are 12 mph or less. The current practice of increasing truck emission levels to 87 dBA for speeds below 31 mph (2) is contradicted by the data in this study for constant speeds from 25 mph to 31 mph.

TABLE 7 Comparison of Wind: +6 mph to +12 mph Versus -6 mph to -12 mph at All Sites, 50 ft (Microphone 2)

Vehicle Type	Speed Class (mph)	Energy Mean (dBA) Wind: +6 mph to +12 mph ($\bar{X}$)	Wind: -12 mph to -6 mph[a] ($\bar{Y}$)	Difference in dBA ($\bar{X}$-$\bar{Y}$)	Standard Deviation (S_x)	No. of Observations (N_x)	Standard Deviation (S_y)	No. of Observations (N_y)	t-test (α = 0.05 significant)
Automobiles	All	74.1	73.9	0.2	4.4	24	4.7	124	No
Medium trucks	All	83.3	84.7	-1.4	1.3	3	4.0	26	No
Heavy trucks	All	83.9	84.3	-0.4	2.3	48	3.5	52	No

[a]25-ft microphone for -6 mph to -12 mph was set equal to 25-ft microphone for +6 mph to +12 mph and 50 ft microphone was corrected with same correction.

TABLE 8 Comparison of Wind: +6 mph to +12 mph Versus -6 mph to -12 mph at Soft Sites, 50 ft (Microphone 2)

Vehicle Type	Speed Class (mph)	Energy Mean (dBA) Wind: +6 mph to +12 mph ($\bar{X}$)	Wind: -12 mph to -6 mph[a] ($\bar{Y}$)	Difference in dBA ($\bar{X}$-$\bar{Y}$)	Standard Deviation (S_x)	No. of Observations (N_x)	Standard Deviation (S_y)	No. of Observations (N_y)	t-test (α = 0.05 significant)
Automobiles	All	69.3	69.6	-0.3	1.1	7	2.5	48	No
Medium trucks[b]	All	76.5	77.0	-0.5	3.7	29	3.1	7	No
Heavy trucks	All	81.1	81.4	-0.3	2.5	7	4.4	7	No

[a]25-ft microphone for -6 mph to -12 mph was set equal to 25-ft microphone for +6 mph to +12 mph and 50-ft microphone was corrected with same correction.
[b]Because of insufficient data, +3 mph to +6 mph was used for medium trucks.

TABLE 9 Comparison of Wind: +6 mph to +12 mph Versus -6 mph to -12 mph at Sites with Five Microphones, 100 ft (Microphone 4)

		Energy Mean (dBA)							
Vehicle Type	Speed Class (mph)	Wind: +6 mph to +12 mph ($\bar{X}$)	Wind: -12 mph to -6 mph[a] ($\bar{Y}$)	Difference in dBA ($\bar{X}$-$\bar{Y}$)	Standard Deviation (S_x)	No. of Observations (N_x)	Standard Deviation (S_y)	No. of Observations (N_y)	t-test (α = 0.05 significant)
Automobiles	All	68.4	65.0	3.4	3.5	17	2.5	48	Yes
Medium trucks	All	76.7	75.4	1.3	1.2	3	3.6	7	No
Heavy trucks	All	77.9	77.8	0.1	2.1	41	4.7	7	No

[a]Set 25-ft microphone for -6 mph to -12 mph equal to 25-ft microphone for +6 mph to +12 mph and corrected 100-ft microphone with same correction.

ACKNOWLEDGMENT

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