Determination of Reference Energy Mean Emission Level in Georgia

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ABSTRACT

In conducting any detailed noise impact analysis and subsequent barrier design, it is always desirable to calibrate the noise prediction model (STAMINA) with measured noise levels at the site in question. The model does not always yield noise levels acceptably close to those measured in the field, often for no apparent reason. It is suggested in this paper that the reference energy mean emission curves published by FHWA may cause the model to significantly overpredict noise levels in the vicinity of major highways. New emission data are offered and then used to compare the results of the noise prediction model with field measurements. This comparison reveals significantly closer agreement between the noise levels calculated by STAMINA, using the new emission curves, than was obtainable with the FHWA curves.

The presence of high noise levels adjacent to major highways continues to be a major problem to state transportation agencies throughout the United States. The primary mandate of these agencies is to provide the citizens of their respective states with a safe and efficient highway network. As a result, efforts to improve existing facilities and construct new facilities are causing significant increases in ambient noise levels in established residential areas. Many states are thus committing substantial sums of money to noise-abatement barriers in an attempt to minimize increases in existing noise levels along their highway systems.

Acoustic design of these noise barriers is accomplished through a computer model that calculates anticipated future noise levels and the insertion loss provided by a given barrier configuration. It is suggested in this paper that the state-of-the-art model may significantly overpredict expected noise levels for any given highway design. Although this may not pose a serious problem along an existing highway where present noise levels can be easily measured, a significant lack of confidence in the predicted noise levels could occur on a new location or project. A transportation agency will naturally be less likely to commit funds for noise abatement when the engineer cannot express a high level of confidence in his noise impact analysis.

PROBLEM STATEMENT

The author's past experience with STAMINA 1.0 and STAMINA 2.0 has indicated a tendency of the model to overpredict noise levels adjacent to Interstate highways. At first it was unclear if the error was related to the user's choice of the ground absorption (alpha) factor. Although there is ample evidence to support the use of 0.0 for acoustically reflective ground cover and 0.5 for absorptive cover, topographic characteristics vary from site to site; thus the choice of an alpha factor requires good judgement by the user based on prior experience. Even though this step does introduce a possible source of error for users not familiar with the model, experience should provide the necessary guidance in selecting the proper alpha factor.

Traffic volume and speeds are easily measured or can be closely estimated by an experienced observer, thus minimizing errors of this type. The calibration process should include noise measurements at a location free of terrain influence, thus eliminating any excess attenuation error. In short, the experienced user should be able to keep input data errors to a minimum, and expect the calculated noise levels from the model to agree closely with measured noise levels. If the calculated and measured noise levels do not agree within desired limits for the calibration sites, the user typically cannot find a logical explanation for the discrepancy.

Because the reference energy mean emission levels published by FHWA were gathered by the Four-State Noise Inventory (1) conducted in 1975, the question was raised on whether these data were valid for the state of Georgia. Accordingly, tests were begun to develop emission level curves for highway traffic in Georgia and then compare that data with the FHWA emission level curves. The results of that study are presented herein.

EMISSION LEVEL METHODOLOGY

The study was conducted in accordance with procedures established by FHWA (2). Only a brief discussion of the procedure will be presented here because a detailed description is available from the report.

All test sites were chosen to be level and free of extraneous terrain influence. The microphones were placed at 50 ft from the centerline of the near traffic lane, with a clear line of sight to the roadway and an unobscured arc of at least 150 degrees at the microphone. All roadways had a grade of less than 2 percent and consisted of dry, smooth asphalt or concrete pavement.

Measurement sites were chosen to minimize potential contamination of each sample by noise from other vehicles. This was done by choosing locations with wide, tree-covered medians, or locations with low traffic volumes. The sound level meter was carefully watched while the observer physically listened for interference from other vehicles. Careful application of this procedure ensured that these emission level samples were not contaminated by noise from other sources.

Wind speed, temperature, and humidity were checked at a local National Oceanic and Atmospheric Administration (NOAA) office to ensure that meteorological conditions were within acceptable limits for the time of the sample. It was assumed that humidity and temperature did not vary significantly at the measurement sites from that reported at the NOAA station, a reasonable assumption for middle Georgia during the summer months. Measurements were halted if the wind began gusting or if the constant wind speed was suspected of approaching 12 mph.

A Metrosonics db-602 Sound Level Analyzer was used to record the maximum A-weighted noise level from each vehicle passby. This equipment was field calibrated before and after each measurement session to ensure accuracy. The speed of each sample vehicle as it passed the microphone was measured with a hand-held radar unit, which was also calibrated before and after each measurement session.

Traffic was classified into three groups: (a) automobiles, which included light trucks with four tires; (b) medium trucks, which consisted of trucks with two axles and six tires; and (c) heavy trucks, which consisted of trucks with three or more axles and all tractor-trailer combinations. An estimated number of vehicles to be sampled from each classification was obtained from Figure 1 (2) for a desired confidence interval of ±1 dB(A) at a 95 percent confidence level. Samples were grouped into a speed range of ±3 mph, with midpoints ranging from 30 to 58 mph.

EMISSION LEVEL RESULTS

All samples greater than 48 mph were gathered on the Interstate highway system outside the Atlanta area. Because the vast majority of noise problems occur along this type of facility, it is significant to note that these routes are heavily used by interstate travelers. Thus the results of this study are influenced by traffic (all classifications) from states other than Georgia. The remaining samples of heavy and medium trucks were obtained from local roads in the vicinity of several interstate trucking terminals in south Atlanta. Consequently, the emission curves developed in this paper should be indicative of noise emissions from vehicles in other states as well.

The statistical tests used in the validation procedure all assume the data are normally distributed. In order for this assumption to be used with confidence, all the data for each vehicle classification were tested to determine if they were from a normal population. The tests for normality were accomplished by use of a statistical computing package (MINITAB) developed by the Statistics Department at Pennsylvania State University and modified for use on the DECsystem-10 at Vanderbilt University. A normal probability plot for each vehicle classification was produced (Figure 2). If the sample is from a normal population, the points on the plot will fall roughly on a straight line. As can be seen from Figure 2, all plots are reasonably straight. MINITAB also calculates a correlation coefficient that measures the straightness of each plot. Each set of data proved to be from a normal population based on a 95 percent level of confidence.

After the final number of samples of each vehicle classification was collected, the actual confidence interval for a 95 percent level of confidence (3) for each speed range within each vehicle classification was calculated according to the following equation:

$$\bar{x} - t_{0.025,n-1}/(S/\sqrt{n}) \leq \mu \leq \bar{x} + t_{0.025,n-1}(S/\sqrt{n}) \quad (1)$$

where

$\bar{x}$ = sample average emission level,
t = Student's t-test distribution,
s = sample standard deviation, and
n = actual number of samples.

The actual number of samples for each vehicle classification within each speed range is given in Table 1. Also included is the confidence interval as

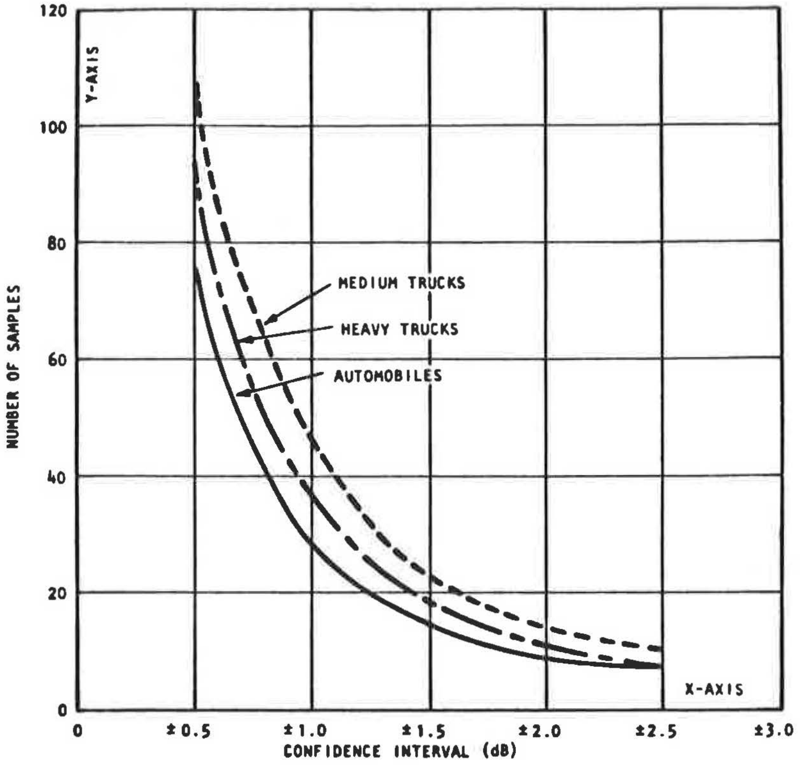

FIGURE 1 Estimated number of samples (2).

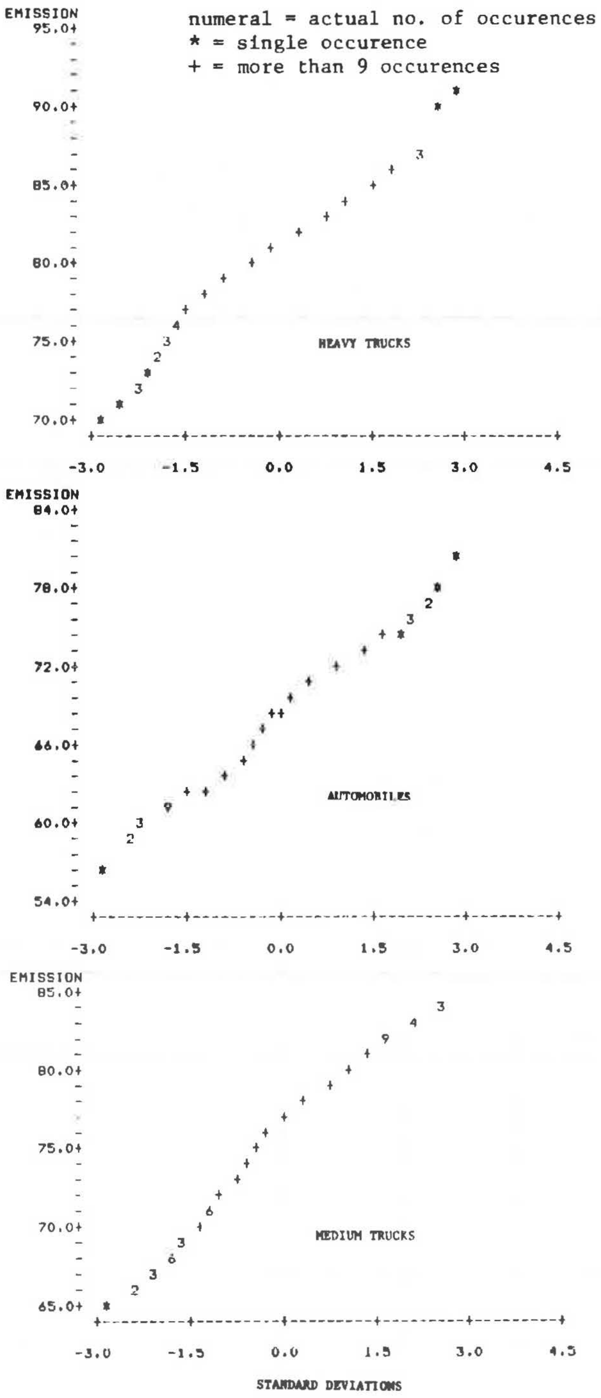

FIGURE 2 Normal distribution plot, all vehicle classifications.

calculated by Equation 1 for a 95 percent confidence level.

As illustrated by the data in Table 1, the larger the number of samples, the smaller the error limits. It is significant to note that because the vast majority of noise problems occur on facilities with high traffic speeds and volumes, all data at speeds greater than 40 mph were within the desired error limit of ±1.0 dB.

The reference energy emission level for each speed range within each vehicle classification was then calculated according to Equation 2:

$$(\overline{L_o})_{Ei} = (\overline{L_o})_i + 0.115\,(s)_i^2 \qquad (2)$$

where

$(\overline{L_o})_{Ei}$ = reference energy mean emission level for the ith vehicle class for a single speed range,
$(\overline{L_o})_i$ = arithmetic average sound level of the ith vehicle class for a single speed range, and
$(s)_i$ = sample standard deviation of the emission levels of the ith vehicle class for a single speed.

The arithmetic average sound level for the ith vehicle class $[(\overline{L_o})_i]$ is calculated according to Equation 3:

$$(\overline{L_o})_i = (1/n) \bullet \sum_{i=1}^{n} (\overline{L_o})_{ki} \qquad (3)$$

where $(L_o)_{ki}$ is the kth measured emission level for the ith class of vehicles for a single speed, and n is the number of measured emission levels for the ith class of vehicles for a single speed range. The sample standard deviation (s_i) of the ith vehicle class is calculated according to Equation 4:

$$(s)_i = \sqrt{[1/(n-1)] \sum_{k=1}^{n} [(L_o)_{ki} - (\overline{L_o})_i]^2} \qquad (4)$$

Once these calculations were completed, it was desired to find the mathematical equation that best described the relationship between the reference energy mean emission level and speed for each vehicle classification. This was accomplished through a regression analysis by the method of least squares. The values of the regression constants were obtained in this calculation, as well as the coefficient of determination (r^2). The value of r^2 will lie between 0 and 1 and will indicate how closely the equation fits the experimental data (the closer r^2 is to 1, the better the fit).

The data in Table 2 give the mean sound level, the standard deviation, and the reference energy mean emission level for each speed range and vehicle classification.

TABLE 1 Actual Number of Samples and Confidence Interval for 95 Percent Confidence Limit

Vehicle Class	Item	Speed Range (mph) 27-33	34-40	41-47	48-54	55-61
Automobiles	No. of samples	28	54	61	76	96
	Confidence interval (dB)	±1.0	±0.7	±0.7	±0.5	±0.4
Medium trucks	No. of samples	46	47	46	56	71
	Confidence interval (dB)	±1.2	±1.1	±0.8	±0.6	±0.6
Heavy trucks	No. of samples	38	65	58	60	78
	Confidence interval (dB)	±1.2	±0.8	±0.8	±0.7	±0.5

TABLE 2 Data Summary

Vehicle Class	Parameter	Emission Level as a Function of Speed [dB(A)] 27-33 mph	34-40 mph	41-47 mph	48-54 mph	55-61 mph
Automobiles	(L_o)	63.8	64.4	65.6	70.8	71.6
	s	2.64	2.69	2.63	2.35	2.03
	$(L_o)_E$	64.6	65.3	66.4	71.5	72.1
Medium trucks	(L_o)	73.3	73.3	76.9	77.8	78.5
	s	4.00	3.90	2.67	2.40	2.60
	$(L_o)_E$	75.1	75.0	77.7	78.5	79.2
Heavy trucks	(L_o)	80.7	80.8	81.1	81.1	81.6
	s	3.66	3.18	3.08	2.75	2.38
	$(L_o)_E$	82.3	81.9	82.2	81.9	82.2

The mean emission level from Table 2 was used with the midpoint of each speed range in a regression analysis to calculate the following equations, where V is vehicle speed in miles per hour:

Automobile: $(\overline{L_o})_E = 28.19 \text{ Log}(V) + 21.91$ dB(A) $(r^2 = 0.89)$ (5)

Medium truck: $(\overline{L_o})_E = 16.36 \text{ Log}(V) + 50.41$ dB(A) $(r^2 = 0.90)$ (6)

Heavy truck: $(\overline{L_o})_E = 81.1$ dB(A) (7)

Figure 3 is a graphic comparison of the data collected in Georgia with the FHWA emission level curves. There is a dramatic difference in the higher speed emission levels for both medium and heavy trucks, with relatively little change in the curve for automobiles. It is interesting to note that the emission level for heavy trucks is independent of speed, which is similar to the emission level applied to all trucks by NCHRP Report 117 (4) in 1971.

VALIDATION METHODOLOGY

STAMINA 2.0 was modified (5,6) by replacing the FHWA emission level curves with the curves defined in this paper, and a validation study was conducted in accordance with FHWA procedures (2). Four sites were chosen for this study.

Noise measurements were made with an equipment system provided by FHWA. The system consisted of a computer-controlled GenRad real-time analyzer modified to permit simultaneous A-weighted sampling from several microphones. GenRad 1962 0.5-in. electret microphones, powered by GenRad preamplifiers, send signals through shielded coaxial cables to a mobile laboratory. There the signal passes through Ithaco 451 amplifiers to an A-scale filtering modified GenRad 1925 multi-filter. The A-weighted signal is then sent to a GenRad 1926 rms detector, which, for this study, was set to sample the noise level eight times per second. These data are then sent through a Telecom 5141 interface to a Hewlett-Packard 2100S computer. The computer then analyzes the data and computes the L_{eq} at the desired location.

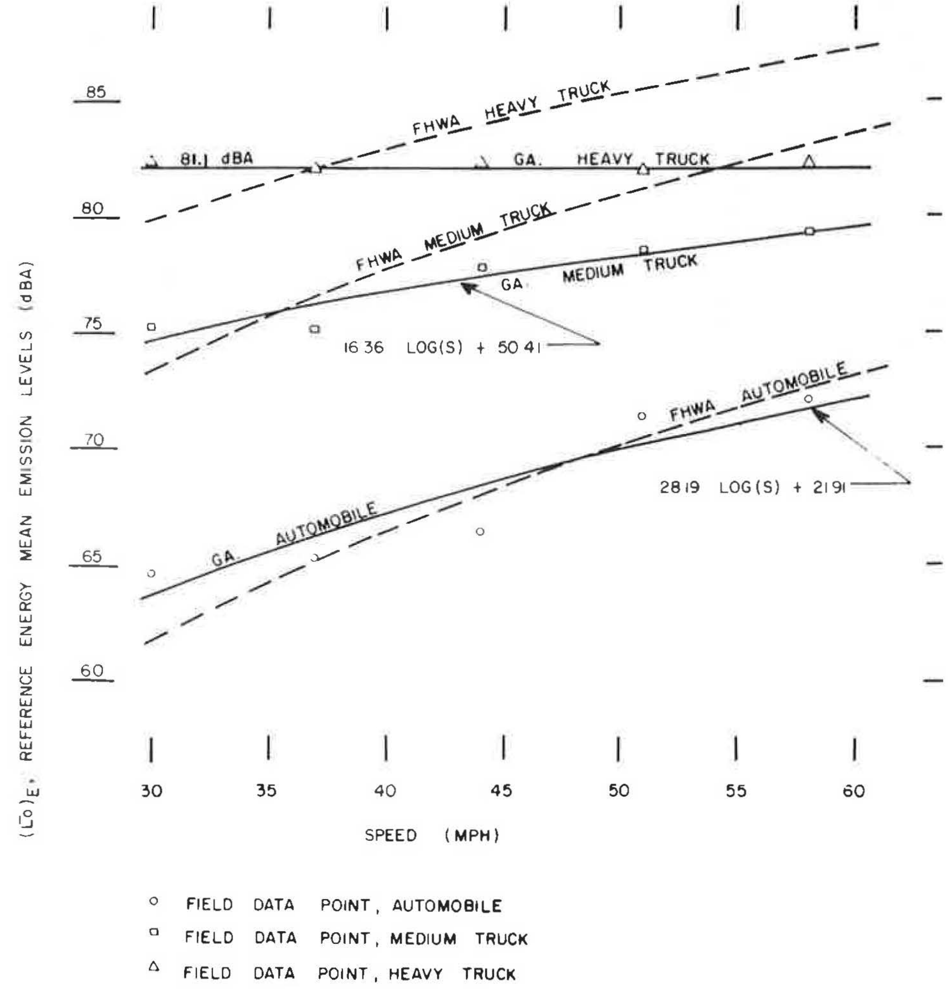

FIGURE 3 Reference vehicle sound emission levels.

Carefully controlled field measurements were then compared with STAMINA 2.0 output by first using the FHWA emission curves and then using the emission curves developed in this paper.

VALIDATION RESULTS

A comparison of the measured and calculated noise levels for each site is given in Table 3.

TABLE 3 Calculated Versus Measured Noise Levels

	L_{eq} [dB(A)]			Difference [dB(A)]	
Site	FHWA	Georgia	Measured	FHWA - Measured	Georgia - Measured
1	80.1	78.1	79.1	1.0	-1.0
	80.1	78.1	77.4	2.7	0.7
	80.1	78.1	78.7	1.4	-0.6
2	74.3	72.8	73.0	1.3	-0.2
	73.9	72.5	72.1	1.8	0.4
3	70.7	69.1	69.2	1.5	0.1
	71.0	67.6	68.0	3.0	-0.4
4	77.1	74.6	75.1	2.0	-0.5

As the data in Table 3 indicate, STAMINA 2.0 consistently overpredicts by 1 to 3 dB when using the FHWA emission curves. By using the same input data but with the Georgia emission curves, STAMINA predictions were all within the desired ±1.0 dB tolerance limit. The input data used in this comparison are given in Table 4.

It was then necessary to determine if the difference between measured and calculated noise levels was significant in either case. The Student's t-test for paired data was applied to the mean difference in measured and calculated noise levels (3) for both conditions. A mean difference of 1.84 dB(A) was obtained by using the FHWA data and -0.19 dB(A) was obtained by using the Georgia emission data. At a 95 percent level of confidence, there is a significant difference between the model results, using FHWA emission data, and measured noise levels at the modeled location. On the other hand, there was no significant difference between calculated and measured noise levels using the Georgia emission data.

CONCLUSIONS

The data presented in this paper suggest that the FHWA emission level data for medium and heavy trucks (1) may have changed over the years, or the data from that study may simply not be representative of the noise emission levels of the vehicles in states other than those sampled. Specifically, the following can be concluded.

1. The energy mean emission level for heavy trucks was found to be 81.1 dB(A), independent of speed. At 55 mph this is approximately 5.2 dB(A) lower than the speed-dependent value suggested by FHWA.
2. The energy mean emission level for medium trucks was found to be speed dependent. However, at 55 mph the Georgia emission level data produce a noise level 3.4 dB(A) lower than the FHWA emission level data.
3. At low speeds the Georgia emission level data are slightly higher than the FHWA emission level data for all three vehicle classifications.
4. Validation measurements at four sites indicate that calculated noise levels, using the Georgia emission level data, were not statistically different from measured noise levels at the modeled location at a 95 percent level of confidence. The same measurement data revealed a statistically significant difference in the calculated and measured noise levels using the FHWA emission data.

RECOMMENDATIONS

Atlanta is recognized as the major transportation hub in the southeast. As such, it is reasonable to state that the radial Interstate system through the city is well traveled by vehicles of all classifications from a large number of states. It therefore follows that the emission level data presented in this paper may also be representative of vehicles in other states as well.

It is suggested that other state transportation agencies may want to develop their own emission level data. An alternative would be for FHWA to develop regional emission level data based on measurements in a number of states in each region. This could be accomplished in a cooperative effort with

TABLE 4 STAMINA 2.0 Input Data Summary

	Automobiles		Medium Trucks		Heavy Trucks	
Location	No.	Speed (mph)	No.	Speed (mph)	No.	Speed (mph)
Site 1, all 3 runs						
I-285 NBL	4,518	58	178	57	203	57
I-285 SBL	5,094	61	200	56	229	58
Frontage Road	36	52	5	40	1	40
Site 2, run 1						
I-285 NBL	3,360	54	144	49	152	51
I-285 SBL	3,272	60	176	56	164	56
Site 2, run 2						
I-285 NBL	2,828	54	144	49	152	47
I-285 SBL	2,404	57	208	56	164	57
Site 3, run 1						
I-20 EBL	740	58	36	58	40	65
I-20 WBL	604	56	16	58	48	53
Frontage Road	76	45	1	30	4	41
Site 3, run 2						
I-20 EBL	564	62	24	59	36	59
I-20 WBL	528	58	60	59	72	59
Frontage Road	36	45	0	0	0	0
Site 4, run 1						
I-75 NBL	743	61	59	58	141	55
I-75 SBL	713	59	57	58	135	55

Note: NBL = northbound lane, SBL = southbound lane, EBL = eastbound lane, and WBL = westbound lane.

the state transportation agencies and would add reliability to the predictions of the model nationwide. Verification of the emission level data will not only give the user more confidence in his analysis, but it also has the potential for providing more cost-effective noise barrier designs.

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Rumble Strip Noise

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ABSTRACT

The Illinois Department of Transportation (IDOT) placed rumble strips near the north end of the Edens Expressway to alert drivers that they were approaching a signalized intersection. The intersection was a high-accident location, and previous safety measures were not significantly effective in lowering the number or severity of the accidents. Many complaints about noise were received from adjacent property owners after the strips were placed. When a berm that was placed between the residents and the strips did not reduce the complaints, IDOT requested assistance from the Demonstration Projects Division of FHWA to study berm effectiveness and rumble strip noise. Two types of strip construction were compared, the formed and the cut types. Several different configurations were also analyzed. Outside measurements were taken at three sites, and inside noise measurements were taken from the tractor of a semitrailer unit. Vibration measurements were taken from the steering column of the truck. The results indicated that the formed type of strip provided better driver perception than did the cut type at all speeds tested. Outside noise did not significantly vary with the different types and configurations of the rumble strips. The strips appear to have reduced the number and severity of accidents at the Edens Expressway location.

Rumble strips have been used by highway agencies as a safety feature to alert drivers to some impending change in the traffic flow (i.e., an upcoming toll booth on an expressway, and construction zones). Typically, the strips are used in conjunction with a visual stimuli, such as warning signs or lights. When the strips are crossed over, a driver feels the vibration and hears the noise. This causes the driver to become more alert and, on seeing the visual stimuli, to take the appropriate action.

The strips are usually made by cutting, or forming, transverse grooves or ridges in the pavement approximately 1 to 2 cm (0.5 to 1 in.) deep. The width, distance between, and the number of grooves (or ridges) vary. A set of grooves or ridges becomes a rumble strip. Typically, three strips are used with a length of untreated pavement in between each strip.

The Illinois Department of Transportation (IDOT) placed a set of rumble strips to warn drivers of the terminis of the Edens Expressway at Clavey Road in Highland Park. This intersection, which is signalized, has a high-accident history, the most severe being rear-end collisions. The abrupt change from a limited-access facility to a major arterial was the cause of these accidents. IDOT had tried several improvements to alleviate the problem, such as signs and warning lights. The effectiveness of these improvements has not been significant (1).

Public pressure became so great that rumble strips were placed to help warn the drivers of the upcoming signal. Immediately, complaints about noise from the rumble strips were received from the neighboring homeowners. IDOT attempted to reduce the noise from the rumble strips by constructing a 3.2-m