3. F.F. Rudder, D.F. Lam, and P. Chueng. User's Manual: FHWA Level 2 Highway Traffic Noise Prediction Model, STAMINA 1.0. Report FHWA-RD-78-138. FHWA, U.S. Department of Transportation, May 1979.
4. W. Bowlby et al., eds. Noise Barrier Cost Reduction Procedure, STAMINA 2.0/OPTIMA: User's Manual. Report FHWA-DP-58-1. FHWA, U.S. Department of Transportation, Aug. 1981.
5. F.F. Rudder. Engineering Guidelines for the Analysis of Traffic-Induced Vibration. Report FHWA-RD-78-166. FHWA, U.S. Department of Transportation, Feb. 1978.
6. D.T. Wright and R. Green. Human Sensitivity to Vibrations. Report 7. Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada, Feb. 1959.

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Examination of the Dependence of Diesel-Electric Locomotive Noise Emission on Speed, Rated Power, and Age

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ABSTRACT

A statistical analysis was conducted of an FRA data base of locomotive passby noise levels to determine the dependence of diesel-electric locomotive noise emission on speed, rated power, and age. Although a statistically significant dependence on locomotive speed was determined, the data set did not indicate a significant dependence on rated horsepower or age. Reasons for this finding are discussed.

Federal noise emission standards for moving locomotives in line-haul service limit the maximum A-weighted passby sound level at 100 ft to 96 dB for locomotives manufactured before December 31, 1979, and to 90 dB for locomotives manufactured after that date (40 CFR Part 201). Most existing locomotives meet this standard.

Recent efforts to improve fuel economy are leading the diesel-electric locomotive manufacturing industry to design diesel engines with higher rated power than is currently used. There is some concern that locomotives with such engines will not be able to meet the federal noise emission standard. At the time of the development of the noise emission standards, fuel economy was not an important issue.

In addition, there is concern that the noise emissions of a diesel-electric locomotive may increase as the unit ages. If this occurs, then a locomotive that just meets the standard when new may not meet the standard when older.

In order to put some of these concerns in perspective, a study was carried out to examine the dependence of diesel-electric locomotive noise emission on locomotive speed, rated power, and age.

SOUND LEVEL AS A FUNCTION OF SPEED

The data base used in this study was a computerized listing of locomotive passby sound levels measured by the Office of Safety of the FRA during the period from September 1978 to June 1981. It contained measurements of maximum A-weighted sound levels at 100 ft for 379 single- and multiple-locomotive passbys. Figure 1 shows the distribution of sound levels, which ranged from 69 to 97 dB (1).

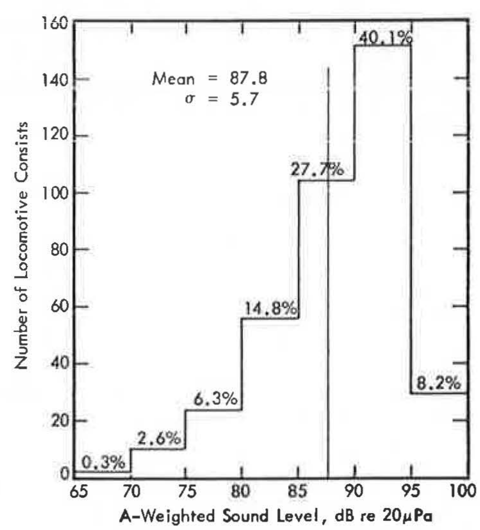

FIGURE 1 Distribution of sound levels for moving locomotive consists.

The data in Table 1 give the range, mean value, and standard deviation of these sound levels as a function of the number of units in the consist. The sound level does not increase with the number of units in the consist, as might be expected. However, note that many of the variables that affect noise emission, such as the power settings of the units, are unknown in these samples. These uncontrolled variables presumably play a more important role in determining the peak sound level than does the number of units.

TABLE 1 Range, Mean Value, and Standard Deviation of A-Weighted Sound Levels of Moving Locomotive Consists

Number of Units In Consist	Number of Samples	A-Weighted Sound Level At 100 Feet (dB re 20μPa)			
		Min.	Max.	Mean	σ
1	153	70	96	88.1	4.8
2	97	70	96	87.4	6.0
3	82	70	96	88.6	5.7
4	30	69	97	85.9	7.6
5	9	74	94	84.8	7.4
6	8	83	96	87.8	5.7
ANY	379	69	97	87.8	5.7

Figure 2 shows the relationship between the maximum A-weighted passby sound level (L_A) and the logarithm of the locomotive speed (V) for a 260-element subset of the FRA data base for which the locomotive speed was known. The corresponding linear regression curve, the standard error of estimate (σ), and the correlation coefficient (r) are also given. A correlation coefficient of +1 or -1 indicates an exact linear relationship between the two variables. A correlation coefficient of zero indicates that no relationship between the two variables exists.

Because the correlation coefficient indicated in the figure is an estimate (based on the 260 sets of measurements) of the actual correlation coefficient that would be found if an infinite number of sets of measurements could be examined, a statistical test must be used to judge whether it is reasonable to assume that the two variables are independent. One such test (2) compares the estimated correlation coefficient with a critical value, which is a function of both the number of sets of measurements and the degree of confidence desired. For 260 sets of measurements and a confidence level of 95 percent, Table A-30a in the work by Dixon and Massey (2) indicates the critical value of the correlation coefficient to be 0.12. Because the observed correlation coefficient of 0.520 exceeds this critical value, a statistically significant dependence of L_A on $\log_{10}V$ is indicated.

In examining Figure 2 note that the scatter of points about the regression line is quite large. Assuming this scatter to be normally distributed, 95 percent of the measurements lie within ±9.8 dB (2σ) of the regression line. Thus the measured points essentially occupy a 20-dB-wide band.

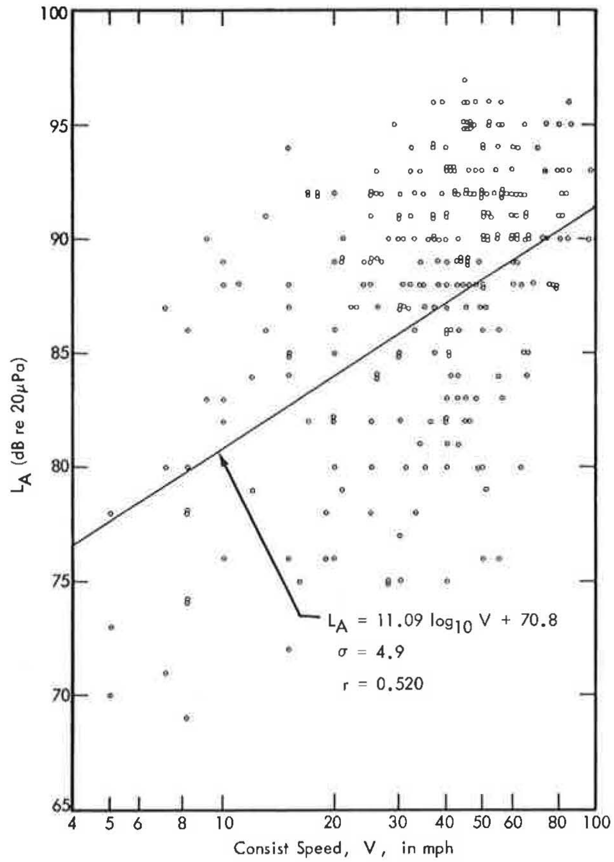

FIGURE 2 Maximum A-weighted sound level of locomotive consist passbys as a function of locomotive speed (V) (measurements at 100 ft).

SOUND LEVEL AS A FUNCTION OF RATED POWER AND AGE

To investigate the dependence of maximum passby sound level on rated power and age, a 40-element subset of the FRA data base was selected. It consisted of single locomotive passbys for which both locomotive speed and identification were known. The rated power and year of manufacture of each locomotive were obtained from the railroad company that owned the locomotive.

Linear regressions were carried out considering the passby sound level as a function of the two independent variables--rated power (P) and age (A)--and as a function of the two derived variables--$\log_{10}V$ and $\log_{10}P$. The correlation coefficient for each regression is given in Table 2.

TABLE 2 Correlation Coefficients of L_A with Locomotive Speed (V), Rated Power (P), and Age (A)

Independent Variable	Correlation Coefficient
P	0.23
A	-0.11
$\log_{10} V$	0.36
$\log_{10} P$	0.23

As described in the previous section, these correlation coefficients can be used to test for the independence of L_A on each of the dependent variables. For 40 sets of measurements and a confidence

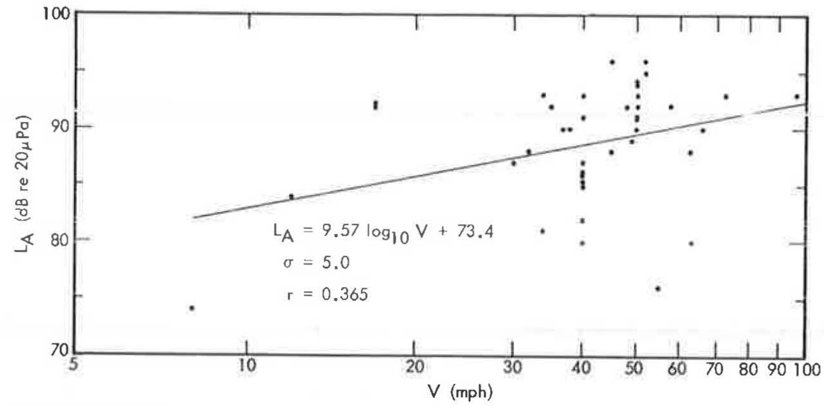

FIGURE 3 Maximum A-weighted sound level of single locomotive passbys as a function of locomotive speed (V) (measurements at 100 ft).

level of 95 percent, Table A-30a (2) indicates the critical value of the correlation coefficient to be 0.31. Applying this criterion to the values in Table 2, it is seen that, at the 95 percent confidence level, L_A is only dependent on the $\log_{10}V$ variable.

The linear regression of L_A with $\log_{10}V$ for the subset of single locomotive passbys is shown in Figure 3. The corresponding regression equation, the standard error of estimate (σ), and the correlation coefficient (r) for this subset of the data are also given. The dependence on $\log_{10}V$ is similar to that obtained in Figure 2 for the overall data base. The scatter of the data about the regression line is also similar.

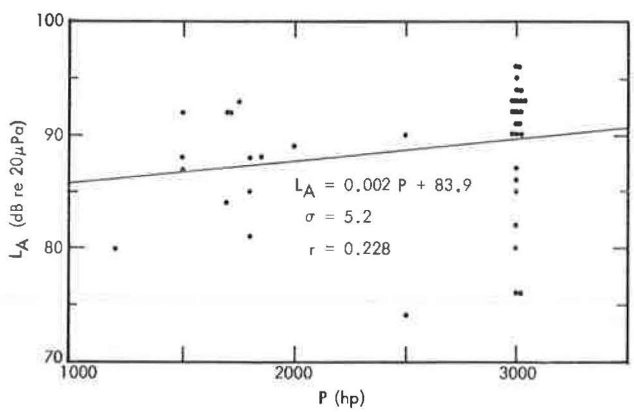

FIGURE 4 Maximum A-weighted sound level of single locomotive passbys as a function of rated power (P) (measurements at 100 ft).

Regressions of L_A with P and of L_A with A are shown in Figures 4 and 5, respectively. It is clear from the figures why dependence of the two variables cannot be statistically justified. The large scatter of data points coupled with the small slope of the regression curves cannot preclude a zero slope, which would indicate independence of the two variables.

Note that in Figure 5 the regression line indicates a decrease of passby sound level with increasing locomotive age. This is contrary to what might be expected; however, further examination of the data indicates a possible explanation. The correlation coefficient between rated power and locomotive age is 0.70, so that in this data set these two variables are not independent. Figure 6 shows the linear regression between these two variables. The older locomotives in this data set have lower rated power than do the newer locomotives. If indeed noise emission does increase with rated power, then it would be expected that this data set would indicate a decrease in passby level with age, because most of the older locomotives have lower rated power than the newer ones.

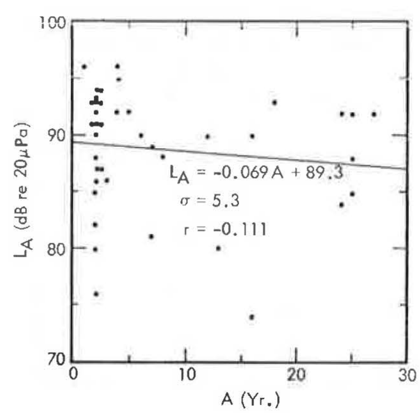

FIGURE 5 Maximum A-weighted sound level of single locomotive passbys as a function of locomotive age (A) (measurements at 100 ft).

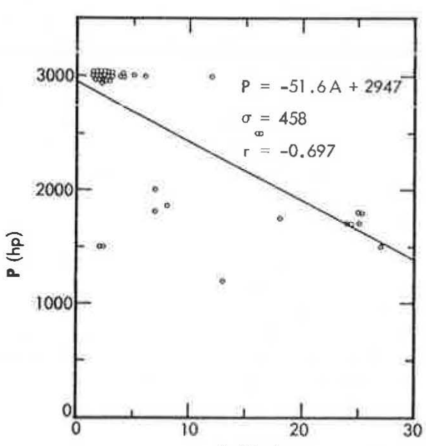

FIGURE 6 Linear regression of rated horsepower (P) with locomotive age (A) for subset of data used in this analysis.

These single-variable analyses ignore the fact that the sound level may be a function of several variables. To consider this case, a multiple linear regression was carried out by using $\log_{10}V$, P, and A as three independent variables. The results of this analysis are given in Table 3. Note that the multiple correlation coefficient (0.42) is larger than any of the values in Table 2, thus indicating a slightly better fit to the data.

TABLE 3 Multiple Linear Regression of L_A as a Function of the Logarithm of Speed, Rated Power, and Age

Regression Equation:

$$L_A = 10.15 \log_{10} V + 0.0022 P + 0.157 A + 65.6$$

Independent Variable	Regression Coefficient	Standard Error of Reg. Coefficient	t-Value
$\log_{10} V$	10.15	4.50	2.26
P	0.002	0.002	1.25
A	0.157	0.138	1.14

Multiple Correlation Coefficient: 0.42
Standard Error of Estimate: 5.0

In Table 3 the associated standard error and t-value for each regression coefficient are also given. The standard error is a measure of the uncertainty in the regression coefficient; the t-value is a related parameter that can be used to test the hypothesis that the fitted variable (L_A in this case) is independent of the indicated independent variable. By using a procedure similar to that which was described for correlation coefficients, the computed t-value for each independent variable is compared with a critical value that depends on the number of sets of measurements, the number of independent variables in the best-fit equation, and the degree of confidence desired (2). In this case Table A-5 (2) indicates the critical t-value at a 95 percent confidence level to be 2.02.

The data in Table 3 also indicate that only the $\log_{10}V$ variable has a t-value exceeding this critical value. Thus, as in the single-variable analysis, there is only statistical justification (at the 95 percent confidence level) for identifying $\log_{10}V$ as the variable on which L_A depends.

Even though there is no real statistical justification shown in this data base for assuming a dependence of L_A on rated power, it is interesting to note that the best-fit regression equations for P in both the single variable (Figure 4) and the multiple variable (Table 3) analyses indicate an increase in L_A of 0.2 dB with each 100 hp increase in rated power. The standard error in this regression coefficient is of comparable size; thus there is a 95 percent probability that the rate of change of L_A with P is between -0.2 and 0.6 dB per 100 hp.

CONCLUSIONS

A statistically significant dependence on locomotive speed of the maximum A-weighted sound level during a single locomotive passby has been found. No statistically significant dependence on rated power or age was found for the data set studied.

In interpreting these data, the analyst should be careful to avoid concluding that there is no dependence of locomotive sound level on rated power or on age. Rather, it is more correct to say that this data set has not indicated that there is such a dependence. Because of the necessity to consider only single locomotive passbys (most measured passbys are of multiple-locomotive consists), the data set is quite small. In addition, many variables that may affect the measured sound level, such as throttle setting, load, and the existence of turbocharging, were not considered in the regression. Finally, the normal unit-to-unit variation of sound level for the same locomotive model adds a certain amount of dispersion to the data.

For example, 15 of the 40 measurements in the data set were of different units of the same locomotive model. These 15 units were each rated at 3,000 hp and were each manufactured in 1979. The sound levels of seven of the units were measured while the locomotive was moving at 40 mph; that of seven others were measured at 50 mph. The standard deviation of the measurements at 40 mph was 4.6 dB, and that of the measurements at 50 mph was 1.6 dB. Such large variations in sound level for the same conditions of speed, rated power, and age are indicative of dependences on other unconsidered variables.

In order to further test the dependence of maximum A-weighted passby sound level on the rated power and age of the locomotive, it is necessary to obtain a data base of such sound levels in which throttle setting, load, and turbocharging are also accounted for, as well as speed, rated power, and age.

ACKNOWLEDGMENTS

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REFERENCES

1. E. Stusnick, M.L. Montroll, K.J. Plotkin, and V.K. Kohli. Handbook for the Measurement, Analysis, and Abatement of Railroad Noise. Report DOT/FRA/ORD-82/02-H. FRA, U.S. Department of Transportation, Jan. 1982. NTIS: PB 83-166173.
2. W.J. Dixon and F.J. Massey, Jr. Introduction to Statistical Analysis. McGraw-Hill, New York, 1957, pp. 196-200.

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