EFFECT OF MOTOR VEHICLE REGULATIONS ON HIGHWAY NOISE LEVELS

Ben H. Sharp
Wyle Laboratories

Technology to reduce motor vehicle noise is often expensive, more so as the noise levels become lower. Therefore, before a major national program of noise reduction is embarked on, several questions should be answered: What effect does vehicle noise reduction have on highway noise? Is this the most effective way of reducing highway noise? Which type of regulation is best? What can be expected from these regulations in the future? This paper will not provide the final answers to these questions even though answers must be found before vast sums of money are consumed in wasteful programs that do not benefit the community. This paper will examine the change in highway noise levels resulting from the introduction and enforcement of noise regulations in order to place the effectiveness of individual motor vehicle noise control into perspective.

HIGHWAY AND VEHICLE NOISE DESCRIPTORS

Highway noise is the summation of the noise produced by all vehicles operating on the highway. Although all vehicles contribute to this overall noise, the absolute, time-averaged noise levels are determined predominantly by the contributions from automobiles and trucks. Other vehicles, such as buses and motorcycles, do occasionally exhibit high noise levels, but their numbers are too few to significantly affect overall highway noise levels. The combination of the noise time history produced by each vehicle as it passes by a given point on the highway at random intervals gives rise to a fairly complex time history for the overall highway noise. To completely describe such a continual varying noise signal by means of a single number is difficult but necessary so that the noise levels at different highway locations can be compared and so that the effectiveness of noise regulations applied to individual vehicles can be assessed.

Various attempts have been made to characterize such noise signals, but only two of these have ever achieved almost universal usage. The first method represents the varying noise signal by means of a statistical distribution indicating the total amount of time that the continually varying noise level lies within. A slight modification of this method of presentation then allows a calculation to be made of the noise level that is exceeded for any given percentage of the time. The most common percentile level in use today is that which is exceeded 10 percent of the time and is denoted by the symbol L_{10}. This is the basic descriptor used in many highway noise models. The other method for characterizing varying highway noise levels involves a calculation of the average intensity of the signal over a given period of time. This descriptor, which is denoted by the symbol L_{eq}, represents the average energy level to which the nearby community is exposed and is thought by many to correlate better with annoyance than most of the other descriptors. The concept of the average energy level is the cornerstone in the calculation of the day-night level, L_{dn}, endorsed by the Environmental Protection Agency.

Even though the quantities L_{10} and L_{eq} are often calculated by completely different methods, they can of course both be determined from the same statistical distribution with time of the noise from the highway. It is therefore not surprising to find that, for many highway situations and under many traffic flow conditions, there is a simple relationship between the 2 quantities; in fact, they differ by about 2 to 3 dB when measured on the A-scale. More important, the introduction of any factor that reduces the overall highway noise level has the effect of reducing both the L_{10} and the L_{eq} values almost equally. Thus, for the purposes of this presentation, either descriptor could be used; but, since it is far easier to calculate highway noise levels by using the concept of average energy, this is the descriptor that will be used in the remaining sections.

If the traffic flow conditions remain unchanged, highway noise can be reduced 2 ways: (a) by the application of regulations limiting the noise produced by various vehicles and (b) by the erection of barriers alongside the highway. The effect of the latter measure is fairly easy to determine, the reduction in noise level being numerically equal to the attenuation provided by the barrier. The effect of introducing noise regulations is not quite so easy to determine. Since automobiles and trucks contribute different amounts to the overall average noise level, to assume that different regulations will be applied to these 2 types of vehicles is natural. Therefore, the effect of regulations on each vehicle class must be examined separately and then the results combined to determine the changes in overall highway noise. The overall reduction in highway noise levels will then be a complex function not only of the severity of the regulations applied but also of the traffic mix.

Regulations are stated in a way such that limits are placed on the allowable noise produced by the vehicles of the class in question. Just how many vehicles this affects depends on the statistical distribution of noise levels for vehicles within the class and on the severity of the regulation. To evaluate the effect of the regulation, therefore, requires that the statistical distribution of noise levels be defined for the vehicle class and then a single number be selected by which this distribution can be described. Figure 1 shows an idealized distribution of noise levels from a hypothetical vehicle class. One standard method for quantifying this distribution is to use the mean noise level. However, since the concept of average intensity or energy noise level is used to describe overall highway noise, the distribution of vehicle noise levels is characterized by means of the intensity average of the distribution as shown in Figure 1. Numerically the value of this descriptor is greater than the average noise level by an amount that is dependent on the standard deviation of the distribution. In this presentation

Figure 1. Hypothetical noise levels for a single vehicle class.

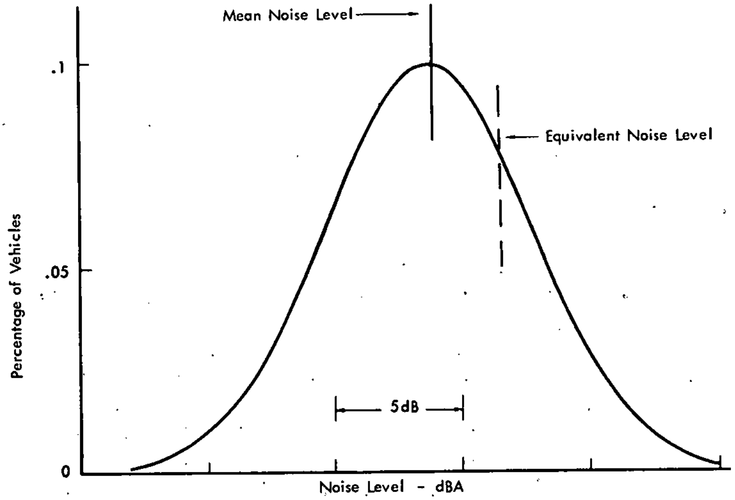


Figure 2. Effect of noise regulations on vehicle noise levels.

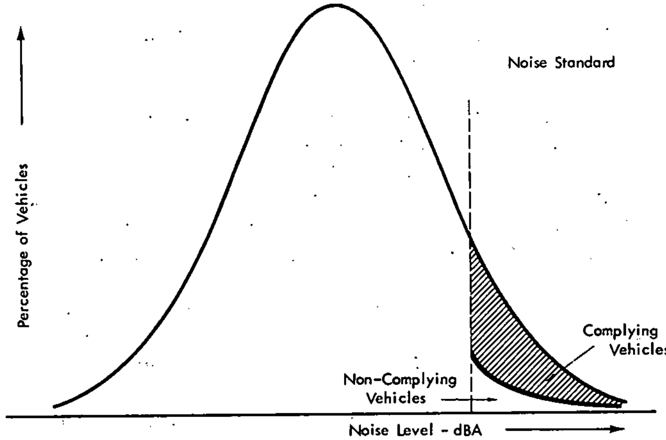
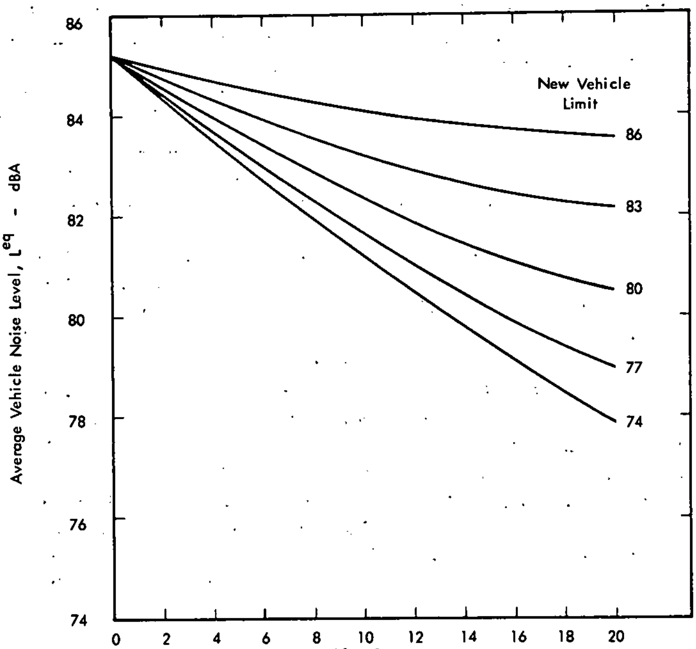


Figure 3. Decrease of L^{eq} with time for various new-vehicle standards.



this quantity will represent the average vehicle noise level and will be denoted by the symbol L^{eq}.

NOISE REGULATIONS AND VEHICLE NOISE DISTRIBUTIONS

The first objective is to determine the effect of motor vehicle noise regulations on L^{eq} for each vehicle class. In this context it is important to realize that regulations affect only those vehicles that would normally exceed the specified noise limits. Those vehicles producing levels lower than the limits are not affected. Consequently, there is no direct relation between the reduction in regulatory noise limits and the reduction in L^{eq} for any vehicle class.

There are, of course, 2 types of regulations related to the noise produced by motor vehicles. First, there is a limit imposed on the noise level produced by newly manufactured vehicles. In this regulation the increasing application of new and existing technology and redesign makes it possible to lower the regulatory limits according to a time schedule determined by the lead times involved in the design and manufacturing process. By itself this type of regulation is not sufficient because it allows an increase in noise levels once the vehicle is sold by the manufacturer. Second, there is a limit imposed on the amount of noise produced during the operation of the vehicle on the highway. Since this type of regulation applies to all vehicles on the highway, both new and old, the noise limit is usually higher than that for new vehicles unless there is a method of retrofitting existing vehicles at a reasonable cost. By itself, this type of regulation does not provide any necessity for new vehicles to be quieter than those already operating on the highway. Therefore, both types of regulations are necessary if vehicle noise is to be reduced in the most effective manner. Let us now examine the effect of these 2 types of regulations on individual vehicle noise distributions.

For the purposes of illustration, Figure 2 shows the distribution of the range of noise levels that would be measured alongside a highway from a large number of vehicles of a single class, for example, trucks or automobiles. It approximates the distribution for the national population of vehicles, excluding those influenced by local regulations. In the case of a new vehicle regulation, the vehicles manufactured after the effective date are limited to the noise level range below the noise standard. There will be no effect, of course, on any vehicle manufactured prior to this date. Those vehicles subject to the regulations that would normally have exhibited noise levels greater than the noise standard will now be distributed in the main portion of the distribution, except for those that do not comply. The exact way in which they are distributed is not known, and so, for the sake of convenience, the assumption will be made that they are distributed uniformly. Combining the modified distribution for the vehicles subject to the regulation with the distribution for the remaining vehicles that are not subject to the regulation in proportion to their numbers on the highway makes it possible to synthesize a completely new distribution for all vehicles on the highway.

The average noise level produced by these vehicles is shown in Figure 3 as a function of time after the effective date of the regulation (2). All curves in this figure start from an initial value of 85.3 dBA, which represents the L^{eq} of trucks as experienced on the highway today in states without motor vehicle noise regulations. Clearly, the reduction in the mean truck level for any given time after the effective date of the regulations depends on the value of the motor vehicle noise standard. However, the rate of decrease of the mean truck level is much less than one might at first expect. This is not surprising since each year only 10 percent of the vehicles on the highway are new and therefore affected by the regulations. Even a noise limit of 74 dBA if introduced this year would only reduce the mean truck noise level by slightly more than 4 dB in 10 years. Further extrapolation to longer time intervals undoubtedly introduces inaccuracies resulting from uncertainties in truck life cycles. The hypothetic use of the noise standards shown in Figure 3 does not suggest that they are technically or economically feasible with present-day technology. The sole purpose of Figure 3 is to demonstrate the long-term nature of the benefits provided by new-vehicle noise standards by themselves.

The effect of a regulation governing the noise produced during operation on the highway is also shown in Figure 2. In this case, both new and old vehicles are required to comply with the regulation, and those exceeding the noise standard will be modified and distributed in the main part of the distribution while a few violators remain at the higher noise levels. This type of regulation has an almost immediate effect of quieting the excessively noisy vehicles, and hence reducing the typical truck noise level will not be a function of time. The relation between L^{eq} and the value of the noise limit is shown in Figure 4. As would be expected, the reduction in L^{eq} is dependent on the rate of compliance, thus indicating the effectiveness of strict enforcement of any motor vehicle noise regulations. The magnitude of the reduction is also quite significant; however, the reduction in the value of the noise limit is severely limited by the availability of retrofit technology. Noise limits significantly less than 86 dBA for heavy trucks are not really considered feasible at this time. However, Figure 4 shows a potential effectiveness of operational regulations.

EFFECT OF MOTOR VEHICLE NOISE REGULATIONS

The effect of the 2 types of motor vehicle noise regulations can therefore be predicted by using the simple type of model discussed in the previous section. The verification of the prediction requires field measurements of vehicle noise distributions before and after the introduction of such regulations. A number of states have introduced noise regulations; California first introduced them in 1968. Unfortunately, few data exist on the noise levels from trucks operating in California prior to the introduction of the regulation. Those that do exist were obtained by the California Highway Patrol in 1965 from diesel trucks operating at high speed on the open highway (3). These measurements were taken at a distance of 25 ft (7.6 m) from the center of the lane in which the vehicle was traveling, and so a factor is required to correct the values to the more normal standard of 50 ft (15 m). A suitable correction factor appears to be 4 to 5 dB (4, 5). In addition, the measurements were taken with a hard ground surface between the microphone and the vehicle. To account for both factors, namely, distance and ground surface (6), a 6-dB correction factor has been subtracted from the levels as measured in 1965; the corresponding distribution of noise levels is shown in Figure 5. These original data do not contain information on the percentage of trucks in each axle classification, and the relative percentages are assumed to be the same as those considered typical in 1973. Under this assumption, noise levels from trucks measured in 1965 in California before the introduction of regulations are shown in Figure 5 to be very similar to levels measured in 1973 in states without regulations. This agreement tends to indicate that the typical noise levels produced by trucks have not changed significantly over the years in the absence of regulations. It is therefore possible to determine the effect of vehicle noise regulations by comparing the average truck noise levels in states without such regulations with those of trucks operating in California.

The effect of subsequent regulations in California between 1965 and 1973 (Table 1) is shown in Figure 6 and indicates that the average truck noise level has shifted downward by approximately 2 to 3 dB. The downward shift is evident at the higher noise levels, which receive the full impact of the regulations. The shift at the lower noise levels may represent a real effect or be due to differences in measurement sites. Many of the noisier trucks operating in nonregulated areas are equipped with poorly maintained exhaust systems and sometimes no mufflers at all. The addition of a muffler in these cases may well reduce the vehicle noise level below the standard level of 86 dBA in low-speed zones and hence also below 90 dBA in high-speed zones if the vehicle is equipped with quiet tires.

Figure 6 also shows an interesting comparison of noise levels in states with and without regulations and those in a state close to one with active enforcement (7). Regulations in California affect interstate trucks operating in Washington. This effect,

Figure 4. Effect on L^{eq} of various operating limits and degrees of compliance.

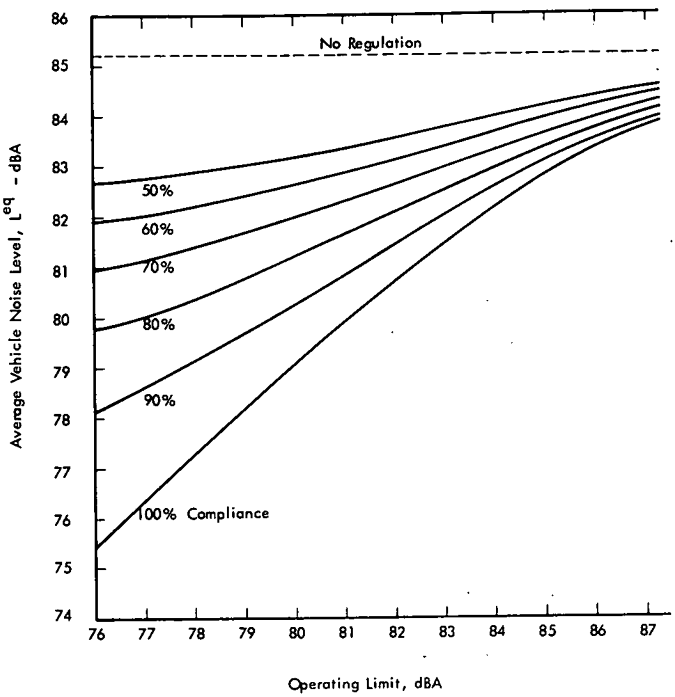


Figure 5. Overall noise levels of trucks operating in >35-mph (56 km/h) speed zones.

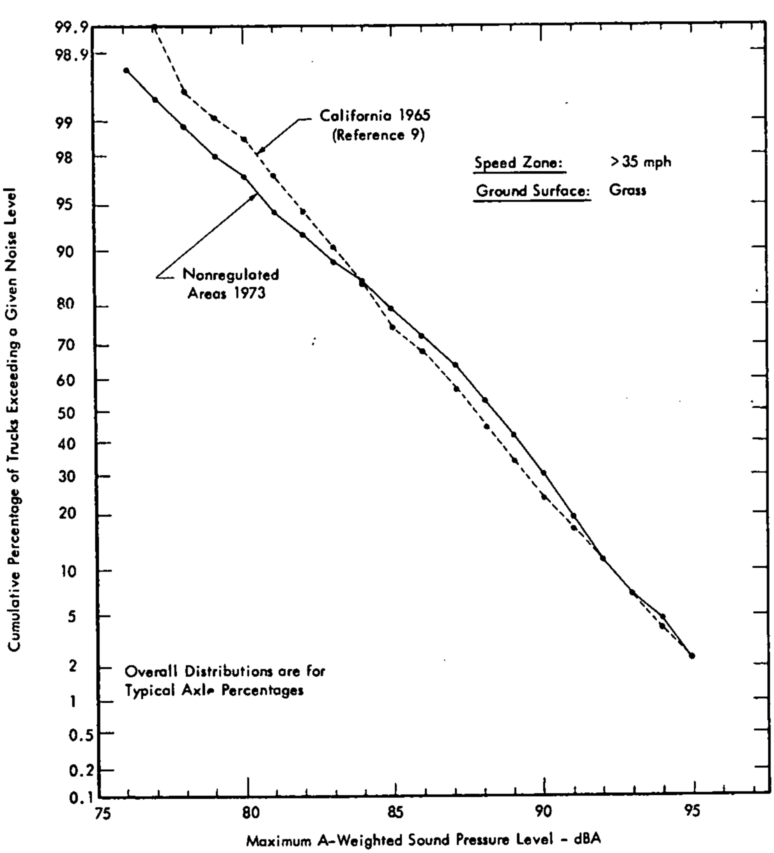
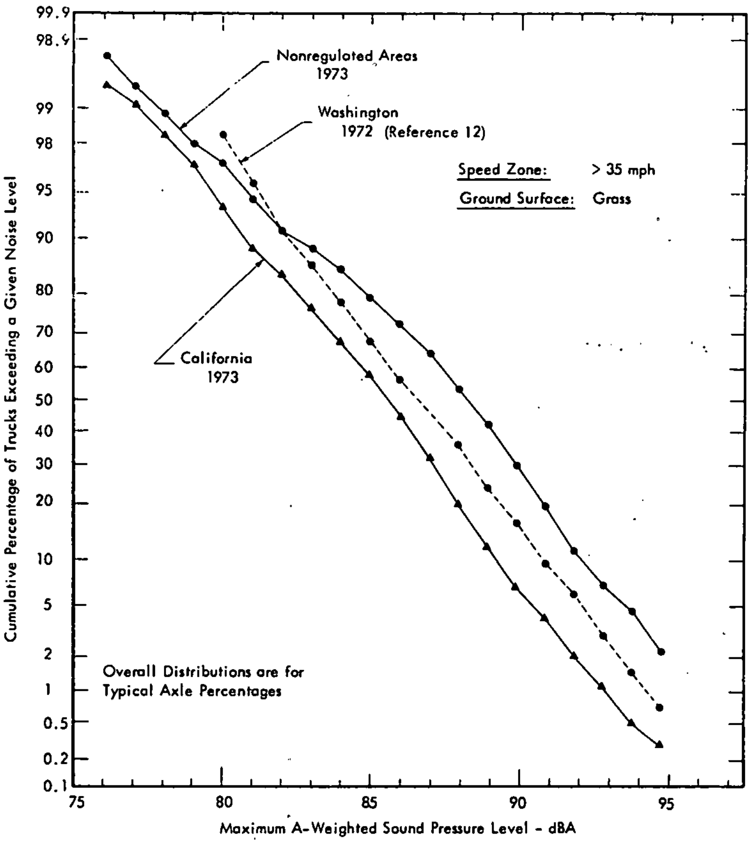


Table 1. Timetable for truck noise regulations in California.

Date	New Vehicles[a] (max dBA)	Vehicles in Operation (max dBA)	
		≤ 35 mph	> 35 mph
January 1968	88	88	92
January 1970	—	—	90
January 1973	86	86	90

[a]Measured according to a test procedure equivalent to SAE J 366b.

Figure 6. Overall noise levels of trucks operating in > 35-mph (56 km/h) speed zones after introduction of regulations.



which might be termed "regulation by influence," has an important application in the development of an effective national enforcement program in that the enforcement of noise regulations at a limited number of points can successfully reduce noise levels over a much wider area.

The effect of the regulations in California can also be examined by reviewing the change in noise levels when trucks travel at low speeds and produce noise predominantly by the propulsion system. Figure 7 shows noise levels for trucks measured in states without regulations in 1973 and those measured in California in the same year. A clear distinction between the 2 distributions, particularly at the higher noise levels, is evident. The difference at the 2 percent level is about 5 dB, an amount that is clearly distinguishable from any error in the measurement procedure. The measured reduction in L^{eq} of 2.8 dB agrees quite well with that of 2.3 dB predicted in the curves shown in Figure 4 for 90 percent compliance with an operational noise limit of 86 dBA. Similar measurements conducted in 1973 in Colorado show noise levels lying in between the others shown in Figure 7. The regulation in this state has been enforced neither so long nor so actively as has the corresponding one in California, and the noise levels would be expected to be slightly higher.

HIGHWAY NOISE REDUCTION

The effect of motor vehicle noise regulations on overall highway noise levels can now be determined by adding the noise contributions from the 2 vehicle classes, automobiles and trucks, in accordance with their relative numbers on the highway. The actual values of highway noise will, of course, depend on the volume of traffic. However, it is possible to postulate an "average vehicle" noise level, L^{eq}, that when modified by the total number of vehicles per hour will give the hourly value of the average highway noise level (2).

$$\overline{L^{eq}} = 10 \log_{10} \left[(1 - \alpha)\, 10^{L_c^{eq}/10} + \alpha 10^{L_t^{eq}/10} \right]$$

where L_c^{eq} and L_t^{eq} are the average noise levels for automobiles and trucks respectively, and α is the fraction of trucks. The effect on highway noise of reducing truck noise levels is shown in Figure 8 for 3 values of α and 2 values of the average noise level for automobiles. The curves apply to high-speed operation on highways. However, if the numerical values on the 2 axes and the parameter are all decreased by 4 dB, the curves then apply approximately to low-speed traffic, i.e., less than 35 mph.

The most noticeable reduction occurs for the case with the highest percentage of trucks. This is important because high truck percentages normally occur at night when communities are most sensitive to noise. For normal daytime traffic with 10 percent trucks, the reduction in the average truck level of 2 to 3 dB, as experienced in California as a result of noise regulations, provides a decrease of only about 1 dB in overall highway noise. The effect of reducing automobile noise levels increases as the average truck noise level decreases, but again is highly dependent on the truck percentage.

SUMMARY

The effect of motor vehicle noise regulations on overall highway noise has been assessed by means of a simple analytical model relating regulatory action to vehicle noise distributions. Field measurements of the effect of such regulations, although sparse, are in agreement with results predicted by the model. The following general conclusions can be drawn:

1. Motor vehicle regulations applied only to new vehicles form a rather long-term solution for highway noise reduction;

Figure 7. Overall noise levels of trucks accelerating in > 35-mph (56 km/h) speed zones after introduction of regulations.

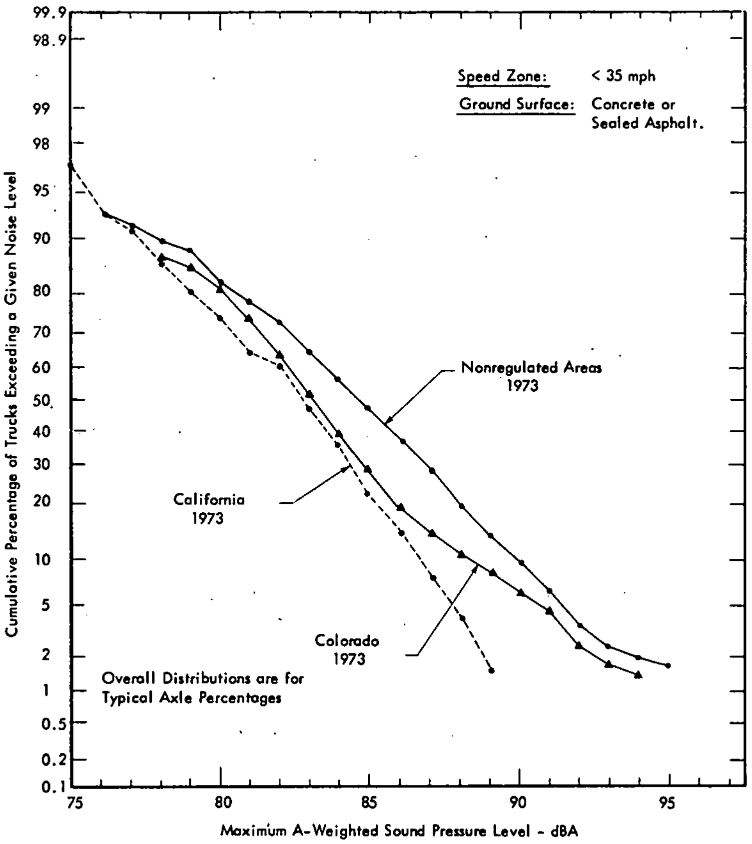
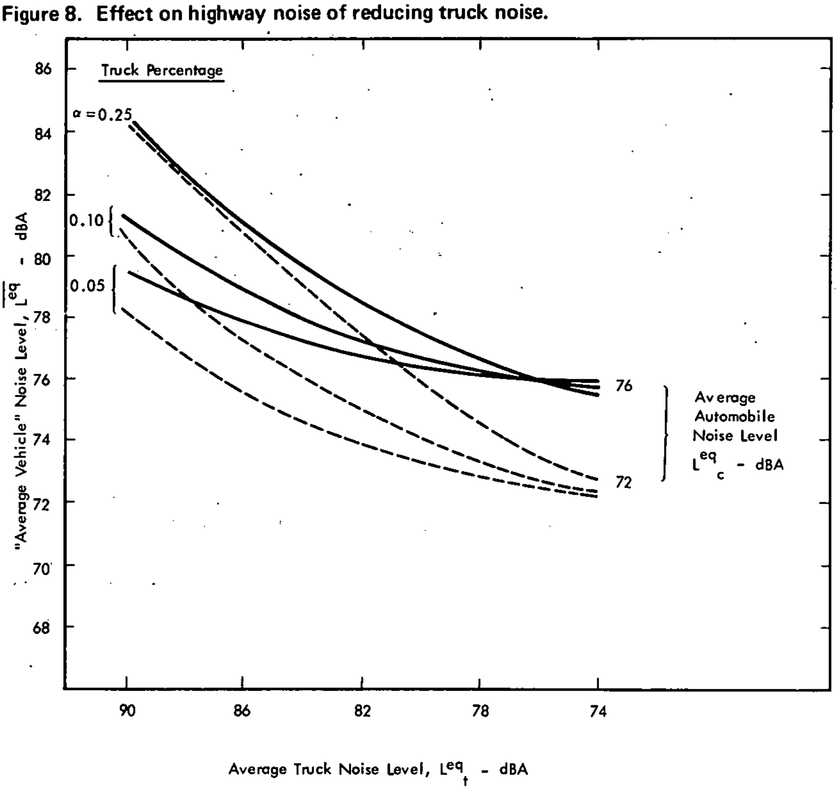


Figure 8. Effect on highway noise of reducing truck noise.



2. Motor vehicle regulations applied to all operating vehicles have an immediate impact on vehicle and highway noise levels;

3. The optimum reduction of vehicle noise levels requires a careful combination of both types of regulations; and

4. The largest reduction in vehicle noise levels results from the application of an operational type of regulation on a previously unregulated population of vehicles—further reduction becomes progressively more difficult and costly.

If one does not have curves showing the relative costs of reducing noise from trucks or automobiles or both, strategies for optimum highway noise abatement cannot be developed. However, an assessment of a number of schemes, as shown in Figure 8, provides information on the effectiveness of regulations in reducing highway noise and can be used to place the schemes in perspective with other methods, such as the erection of roadside barriers.

REFERENCES

1. Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Error. U.S. Environmental Protection Agency, Rept. 550/9-74-004, March 1974.
2. K. J. Plotkin. A Model for the Prediction of Highway Noise and Assessment of Strategies for Its Abatement Through Vehicle Noise Control. Wyle Laboratories, Report WR 74-5, Sept. 1974.
3. Use of Motor Vehicle Noise Measuring Instruments. California Highway Patrol, Sacramento, 1965.
4. B. H. Sharp. Research on Highway Noise Measurement Sites. Wyle Laboratories, El Segundo, Calif., Rept. WCR 72-1, March 1972.
5. Comments on Advanced Notice of Proposed Rule Making. New York State Department of Environmental Conservation, Motor Carrier Noise Emission Standards Docket ONAC 7202001 (EPA).
6. B. H. Sharp. A Survey of Truck Noise Levels and the Effect of Regulations. Wyle Laboratories, Rept. WR 74-8, Dec. 1974.
7. R. Foss. Vehicle Noise Study. Applied Physics Laboratory, Univ. of Washington, Final Report, June 1972.