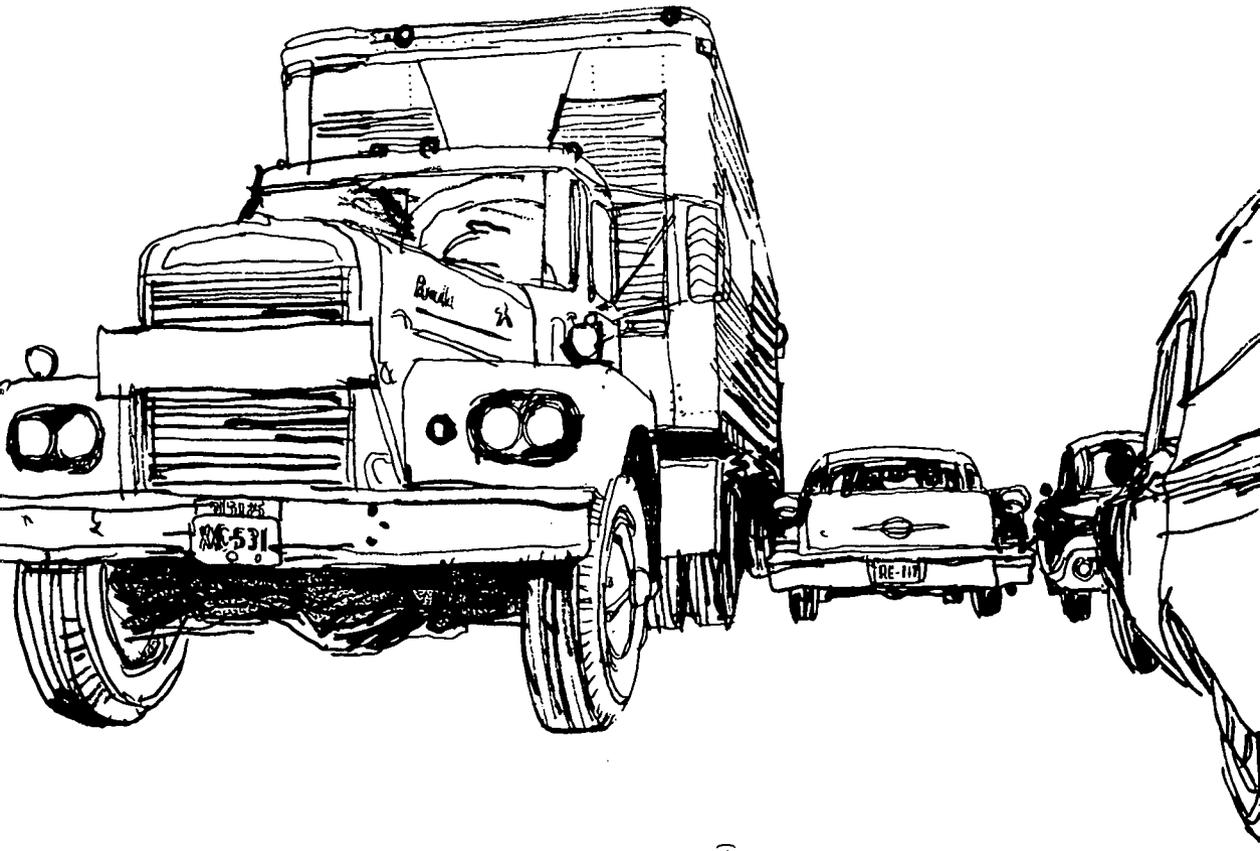


MOTOR VEHICLE NOISE CONTROL



1975

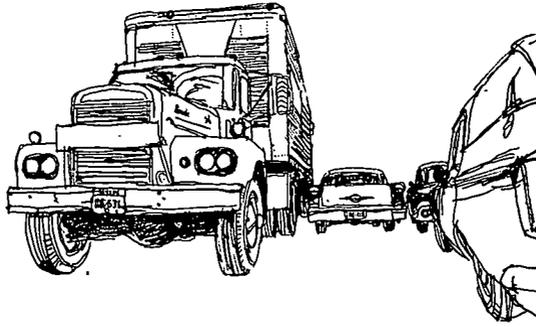
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MOTOR VEHICLE NOISE CONTROL

*proceedings of a workshop held December 10-11, 1974,
in Washington, D.C.*

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The members of the committee selected to organize the conference and to supervise the preparation of this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project.

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PREFACE

The Subcommittee on Transportation-Related Noise of the Transportation Environmental Review Process Committee (now the Committee on Transportation-Related Noise) sponsored a workshop on motor vehicle noise control at the National Academy of Sciences on December 10 and 11, 1974.

The purpose of the workshop was to evaluate the possibilities of motor vehicle noise reduction and the resultant impact on highway traffic noise. Medium and heavy trucks and motorcycles, which are the major sources of high-energy noise, were the primary discussion topics.

The following 4 topic areas were addressed during the workshop:

1. Motor vehicle noise sources and noise suppression possibilities,
2. Effects of motor vehicle noise reduction on overall traffic noise and timetable for and obstacles to source control,
3. Source control at federal, state, and local levels and assessment of effectiveness of controls, and
4. Case studies of state and local regulations.

The chairmen drafted summaries of the workshop discussions, which were then reviewed by members of the subcommittee. These summaries and the papers that were presented are contained in this Special Report.



INTRODUCTION

Michael Lash
Federal Highway Administration

Surveys consistently show that, of all the impacts of highways, noise disturbs the public the most. Many government agencies, including highway agencies, are now trying to solve this problem. Based on a requirement in the Federal-Aid Highway Act of 1970, all federal-aid projects must be examined with respect to noise impacts. If levels are found to exceed a given standard, an effort must be made to reduce the noise to acceptable levels. As a result of federal highway legislation passed in 1973, highway agencies must be concerned with reducing noise not only from new highway construction but also from existing highways. We have been at this for only a few years, but we have learned that the job is a staggering one, that the tools available through highway planning and design to reduce noise are few and limited in their effectiveness, and that the problem of highway noise must be attacked from several different directions if significant progress is to be achieved.

Some important lessons have been learned during the past few years about the control of highway traffic noise. Although federal law directs highway agencies to consider the problem of noise during the development of highway projects, they are generally limited to measures that can be taken during the planning and design phases of a highway project, and those measures do not always solve the noise problem. Substantial reductions in noise will require coordinated efforts to reduce sound at the source (the

motor vehicle), to control the use of land in the vicinity of the highway, and to include noise abatement measures in the planning and design of highways.

Even though most highway agencies do not have legal authority to exercise noise source control or land use control, they should become thoroughly informed on those controls and use their knowledge and influence to stimulate progress in these areas. Unless improvements are made in source control and land use control, noise abatement efforts by highway agencies will produce meager results at great public cost.

This does not mean that highway planners and designers can abandon their noise abatement efforts in the development of highway projects. On many freeway projects, noise reductions can be obtained by shifting the horizontal alignment, depressing the roadway, or constructing noise barriers. On other types of roadways, noise abatement may be possible through "soundproofing" public buildings. Traffic operation controls on vehicle types and hours of operation on selected roads and streets may also be feasible.

There are constraints, however, on using these solutions. Many times horizontal alignment cannot be shifted, particularly on existing roads that are to be improved. In other cases, important natural or man-made features govern the vertical alignment and prevent depression of the roadway. Noise barriers cannot or should not always be constructed, for example, when a noise barrier conflicts with safety, aesthetics, or local community desires. In addition, noise barriers are expensive. Continuous barriers on both sides of a road could cost as much as \$1 million per mile of roadway. Most significantly, noise barrier construction is physically possible only on freeways and expressways because 1,000 feet or more of uninterrupted length is required for significant abatement.

The highest payoff will likely come from source control. This is probably the only relief available to the multitude of people who occupy or use the noise-sensitive facilities adjacent to several hundred thousand miles of existing roads and streets.

The participants in the Workshop on Motor Vehicle Noise Control explored this proposition and evaluated what is being achieved and what can be achieved through source control techniques. The purposes of the workshop were to

1. Assist those concerned with highway traffic noise in developing a broader perspective on how the problem can be solved;
2. Specifically examine in some depth the present activities and state of progress on one direction of attack, namely, controlling noise at the source;
3. Appraise the extent of the overall traffic noise reduction that is possible and that can reasonably be expected to result from vehicle source control in the future; and
4. Identify and describe actions that can be taken by federal, state, and local governments and industry to control vehicle noise at the source.

SUMMARIES OF WORKSHOP SESSIONS

Motor Vehicle Noise Sources and Suppression

The first session established the extent to which motor vehicle noise contributes to total environmental noise. Highway vehicles were classified according to their noise emissions and the extent to which each participates in creating the overall noise on a roadway. Within each class of vehicles, the important noise sources in the vehicle and noise-control alternatives were identified. Consideration was given to several possible combinations and trade-offs provided by using both controls at the noise source and barriers to abate highway noise.

Three major urban noise studies clearly show that highway noise is a cause of annoyance both in this country and abroad. The geographic areas studied were subject to noise from highway vehicles and from aircraft. The degree of annoyance, however, was more significant with road noise than with aircraft noise. Noise developed as a result of on-the-road motor vehicles was uniformly found to be a matter of concern.

SOURCES OF MOTOR VEHICLE NOISE

Vehicular noise sources can be divided into at least 3 categories: automobiles, trucks, and motorcycles. There are on the nation's highways some 84 million automobiles, 17 million trucks, and 2 million motorcycles, but on the average a truck travels 4 times as many miles per year as an automobile, and that significantly affects the degree to which a given automobile or truck contributes

to highway noise.

Surveys show that automobiles traveling at speeds lower than 35 mph (56 km/h) emit the least noise; trucks operating at speeds higher than 35 mph emit the most noise; and motorcycles operating at low and high speeds, automobiles operating at speeds above 35 mph, and trucks operating at speeds below 35 mph are in between. The survey indicates that noise levels generated by automobiles and trucks increase with speed, although not to the same extent, and that trucks produce A-weighted sound pressure levels that are 19 dB or more higher than those produced by automobiles. Thus, given the combination of total vehicle-miles per vehicle per year and the significantly higher noise levels of trucks as opposed to automobiles, one can conclude that the enhancement of the environment in areas adjacent to roadways will require the reduction of truck noise.

TRUCK NOISE

The mechanisms for producing sound are either speed independent or speed dependent. Of the speed-independent sources, the engine-exhaust system, which includes the exhaust-pipe outlet and the vibrating exhaust pipe, is often the major source of noise, especially when the vehicle speed is less than 45 mph (72 km/h). The air-intake or induction system, the cooling system, and engine and power train mechanical vibrations are also noise sources. These noise sources are relatively independent of vehicle speed but are related to engine speed, which, because of the usual presence of a large array of gears, is confined to a narrow range. An additional factor is the location of these sources above the ground. Exhaust noise is generally taken to originate at some 12 ft (3.5 m) for a vertical exhaust stack, and engine and fan noise generally originates at about 4 or 5 ft (1.3 m).

Abatement Possibilities

The technical possibilities for abatement of all of these sources of noise on new vehicles, independent of cost considerations, are good. Technology is currently available to provide overall reductions on the order of 10 to 15 dBA. These noise level reductions are achieved by a combination of more effective muffler systems, clutched fan engine-cooling systems, muffled air-induction systems, and enclosed engine and transmission. The use of the clutched fan in the engine-cooling system allows the fan to operate only when required by the engine operating temperature (usually less than 10 percent of the engine time) and results in a savings of some 20 hp (15 kW).

Tire Noise

The major component of noise related to vehicle speed is that caused by the interaction of the vehicle tire with the road surface. If the number of tires on a single vehicle is 18 or more, tire noise may actually be the dominant noise at vehicle speeds above 45 mph (72 km/h). Increasing with vehicle speed, tire noise is related to tread design and condition as well as to road surface conditions. Tests have shown that crossbar tires (commonly found on the drive axles of trucks and trailer axles) are significantly more noisy than are rib tires (found on the front wheels of trucks and usually on all 4 automobile wheels). Significant reductions of tire-generated noise occur when rib tires are used in place of crossbar tires. The selection of tires for use on vehicles for the purpose of noise control must, of course, be subject to considerations of safety.

Available Technology for Reducing Truck Noise

Technology exists to produce trucks whose noise levels at 50 ft (15 m) from exhaust, cooling, air intake, and mechanical sources are on the order of magnitude of 78 dBA. Tire noise is the limiting factor; at highway speeds, tire noise often will be greater than all other noise. However, reduction of the speed-independent noises, especially the exhaust noise, is an extremely important consideration. For example, the reduction of exhaust noise, which originates some 12 ft (3.5 m) above the road surface, reduces the overall effective noise source height of the truck. Hence, the truck noise that remains is more readily attenuated by the terrain or buildings adjacent to a roadway or through the use of sound barriers.

With regard to existing trucks in operation, the most effective and feasible alternatives for noise abatement include the installation of effective engine-exhaust muffling systems and shielding and the use of quieter tires such as rib tires. The feasibility of modifications such as engine enclosures or clutch cooling fans varies with the individual vehicle. The reduction of noise on existing vehicles can have substantial effects, especially the lowering of the effective source height through the reduction of engine-exhaust noise levels.

AUTOMOBILE NOISE

Surveys show that, under most operating conditions, well-maintained automobiles have noise emission levels some 10 to 15 dBA lower than those of trucks. In addition, the noise levels generated by automobiles are dependent on the speed of the vehicle and consist mainly of tire noise, exhaust noise, and engine noise. At highway speeds, the tires are often the dominant source of noise. The technology exists for control of engine and exhaust noise under normal operating conditions.

MOTORCYCLE NOISE

Although present in relatively small numbers, the motorcycle is a major source of noise in urban areas. The noise levels of motorcycles are between those of automobiles and trucks and are speed dependent. The major components include the engine-exhaust system, the air-intake system, and engine mechanical vibrations. Because of the light loading and subsequent small road-surface contact areas, tire noise is generally not a problem unless off-the-road tires are being used.

Perhaps the major problem with regard to motorcycle noise is related to the manner in which the machines are maintained and operated. The love of the sound of power provokes many operators to drive these vehicles in a manner that creates excessive noise, for example, performing rapid, high-power accelerations. In addition, the intentional modification of engine-exhaust muffling systems by vehicle owners to enhance the sound of the exhaust accounts for a considerable amount of the loud and unnecessary noise generated by motorcycles.

Certain problems exist in terms of enclosing the small air-cooled engines of motorcycles for the purpose of noise control. Motorcycle manufacturers generally agree that reductions in motorcycle noise emission levels on the order of 15 dBA can be achieved by 1983.

CONCLUSION

Identifying the sources of vehicular noise along the roadways and the technical alternatives to controlling the noise at the source allows us to understand the regulations necessary for implementing the available and economically feasible abatement techniques. Because of the mixture of vehicles, regulation, inspection, and enforcement programs are required for both new and old vehicles if advantage is to be taken of the

amount of noise abatement potential that is available through control of noise at the source. Because vehicle types themselves are different and within any given group certain aspects of the noise emission problem are more amenable to solution than others, programs for regulating the emission of vehicular noise at the source must also reflect these factors.

The identification of the vehicular noise source and the abatement possibilities provides the opportunity to evaluate the effects that reducing the noise of individual vehicles has on abating highway noise by other means. The reduction, for example, of truck engine exhaust by 10 or 15 dBA through the use of improved muffling systems will have a significant effect on the height requirements of roadside noise barriers and hence on the cost of such barrier systems for noise control. This benefit arises even though the overall noise emission level of the truck might not be significantly reduced (possibly 3 or 4 dBA).

Reduction of Motor Vehicle Noise at the Source

An objective of this session was to explore the extent to which the following can be determined:

1. The effect that noise reductions in specific categories of motor vehicles have on overall traffic noise levels, and
2. A timetable for the reduction of motor vehicle noise levels.

EFFECT OF NOISE REDUCTION ON A TRAFFIC STREAM

When the noise levels of the individual vehicles in a traffic stream have been reduced, what is the effect on the total noise of a traffic stream? On the basis of the analysis of data from California and certain other states, the following conclusions were reached.

1. The regulation of new-vehicle noise levels will not have an immediate effect on reducing traffic stream noise because only part of the vehicle population will be affected, i.e., the 10 percent of the population that represents new vehicles in any given year.
2. The regulation method that will have the most immediate effect is establishing noise standards to apply to the entire existing vehicle population. The most significant drops in traffic stream noise level will occur on highways with a high percentage of large commercial vehicles.
3. Existing operational regulations have reduced the number of excessively noisy vehicles relatively easily. Further reductions, however, will be progressively more difficult because of costs and technology.
4. Assessing the relative effectiveness of highway design versus vehicle noise-reduction measures will require study of the economic and technologic feasibility of each. However, vital as it may be, source control alone will not entirely solve the traffic stream noise problem.

TIMETABLE FOR SOURCE CONTROL

Although noise control of the automobile and motorcycle is needed, the principal high-

way noise problem is the heavy truck and it is to that vehicle that present efforts should be directed.

This topic entailed considerably more conflict of opinion and findings and therefore is more difficult to summarize. It was explored by experts from the city of Chicago, state of California, General Motors Corporation, Society of Automotive Engineers, and the U.S. Environmental Protection Agency. These engineer-administrators attempted to assist in what proved to be a currently impossible task: to predict the time schedule under which specific vehicle noise levels will be achieved in the future.

The schedule of decreasing allowable noise levels to be enacted into law was begun in California in 1968 and in Chicago in 1971. The federal government and other state and local governments have adopted or are adopting similar schedules. Whether these schedules will be met remains to be seen. Their early successes are predictable in that the earliest scheduled reductions could be achieved by certain relatively easy changes on new vehicles and primarily by muffler maintenance on older vehicles. But now that those early reductions are accomplished, the later scheduled reductions are encountering obstacles. This appears to be the pattern that can be expected with any vehicle noise-reduction schedules: early success and then increasingly difficult obstacles to achieving further reductions. Moreover, federal motor vehicle noise regulations will also influence local schedules and thus increase the probability of meeting those schedules.

OBSTACLES TO VEHICLE NOISE CONTROL

The principal obstacles to vehicle noise control include costs, technology, methods to reduce tire noise, nationwide uniformity and coordination in regulation, enforcement lead times required for noise abatement through regulation, and a cost-benefit measure to indicate the advantages of the source control approach.

If allowance is made for necessary lead times and production engineering, technology appears to be available to achieve significant decreases in the noise levels of new vehicles and in those already in the traffic stream. The cost of applying the technology is, however, still under debate. The decision requires weighing the effects of nonimplementation on the public's purse, health, and welfare versus the effects of implementation on costs to industry and the public.

To support and facilitate regulation, research is needed to better define the interaction of vehicle tires and roadway surfaces. For vehicles traveling above some minimal speed, perhaps 35 mph (56 km/h), the tire-roadway interface is the most significant noise source and at the same time the least understood. Vehicle noise-abatement efforts, however, should not be delayed or lessened until a way is found to reduce tire noise. Most of the highway-vehicle noise impact in this country occurs at relatively low speeds in high-population-density urban areas where tire noise is not a serious problem.

The discussions during this session identified 2 important needs that state and local governments should address.

1. The source control efforts of the federal government will not have a lasting effect unless there are complementary state and local government regulations and enforcements. The quiet that is required by new-vehicle regulation will quickly deteriorate without operational regulations. The interstate motor carrier regulations will monitor only a fraction of motor vehicles. State and local regulation is the only means of controlling the remainder.

2. As the noise emission levels for new vehicles are reduced, state and local government operational regulations need to be comparably reduced (for corresponding vehicle model years) so that advances made in new-vehicle manufacture are not lost through lax vehicle maintenance or deliberate vehicle modification.

There are valid and compelling reasons for seeking nationwide uniformity in traffic

noise regulations and in enforcement of those regulations. A great variety of standards would place a heavy burden on the vehicle operator and the manufacturer and add confusion and uncertainty to enforcement operations. At the same time, some state and local government officials want federal regulations that permit flexibility to meet unique state and local conditions.

The importance of acquiring uniformity of standards and regulation must not be a cause of undue delay in obtaining such standards and enforcement. Accomplishing significant vehicle noise abatement is a long-term undertaking, for reasons discussed earlier, that should be initiated as soon as reasonably possible.

Control of Motor Vehicle Noise at the Source

The purpose of this session was to identify and analyze the critical elements needed to accomplish an effective source-control program. Speakers during this session provided specific information in the following areas:

1. Interstate enforcement;
2. Integration of federal, state, and local programs;
3. In-use and new-product source-control strategies; and
4. Community benefit from noise source control.

ENFORCEMENT

The enforcement strategy of a noise emission-control program is a critical element and should be oriented toward minimizing the practical problems that may arise during field application. The U.S. Bureau of Motor Carrier Safety (BMCS), for example, in carrying out its responsibilities to enforce the federal noise emission standards for interstate motor carriers, uses the stationary test procedure defined in the standard. This approach fits in well with BMCS's current safety inspection program conducted at highway weighing stations and optimizes the use of its 123 inspectors in carrying out their added noise-measurement responsibilities. As a result, noise enforcement at the federal level beyond the weigh station will be extremely limited, which emphasizes the important enforcement role that states will need to play if the program is to be effective nationally.

An information and education program that explains to the vehicle user and the public how, when, and why noise-control enforcement will take place is another important element of an enforcement program. This can be accomplished through posters, public presentations, training meetings, courtesy measurement programs, and preliminary warning-ticket programs.

In some cases an enforcement program may also include suggestions to potential violators for quieting their vehicles. An example of this is BMCS's simplified noise-problem identification procedure, which uses a standard sound-level meter fitted with an inexpensive plastic funnel to directionally locate noise sources inside truck cabs. This procedure is demonstrated in a slide presentation package that is shown to truck operators on request.

FEDERAL, STATE, AND LOCAL PROGRAMS

Technical assistance to state and local programs is available through several programs.

These include

1. Model noise-control legislation that was recently developed jointly by the Council of State Governments and the U.S. Environmental Protection Agency (EPA);
2. Regional workshops sponsored by EPA to provide training and assistance in establishing and operating state or local noise-control programs; and
3. Cooperative noise-reduction programs jointly sponsored by BMCS and EPA to assist in the implementation of the Federal Motor Carrier Noise Control Regulation.

Also under way at EPA is an extensive nationwide nonoccupational noise survey, the results of which may be useful to state and local jurisdictions interested in noise-control programs.

IN-USE AND NEW-PRODUCT STRATEGIES

Assessing the effectiveness of in-use versus new-product regulations over time leads directly to the need to understand truck population dynamics. This is particularly important in estimating the time lag for new products that are manufactured after a set time to begin to dominate numerically the total in-use population of products. Such a model, using medium and heavy-duty trucks, has been developed and was presented in detail at the session. The principal conclusion from this analysis indicates that the population of trucks in existence when a new truck regulation is promulgated will dominate the total truck population for as many as 20 years.

COMMUNITY BENEFIT FROM SOURCE CONTROL

A method for assessing the effect of a change in environmental noise on public health and welfare was summarized. In addition, as an example of the application of this method, a first approximation to quantify the impact of the federal interstate motor carrier regulation and proposed new-truck regulation was presented. Results indicate that regulations being promulgated to date will greatly reduce the traffic-noise impact on the national population. If community noise levels identified by EPA are to be achieved, further reduction of automobile and light-truck noise levels should be required, although this might not be sufficient.

CONCLUSIONS

Workshop discussion centered primarily on enforcement program consideration. Among these were

1. The need for education of the court system on noise enforcement to reduce the number of court-rejected noise cases, and
2. The importance of noninstrument enforcement through visual inspection and issuance of equipment-correction citations (97 percent of California's citations are of this type).

A major finding of the session was the need to investigate ways of providing monetary incentives to state and local jurisdictions for noise source-control programs since these programs appear to be more cost effective than sound-barrier programs in many cases.

State and Local Regulations

In the previous 3 sessions, we gained knowledge on source levels and source-control technology and accumulated ingredients for a timetable of vehicle noise reduction. These timetable ingredients include technological constraints, a large list of "foreseeable" obstacles (especially those pertaining to enforcement), and the necessary cost-benefit balance. We still, however, have no "road map" for a state program to control vehicle noise. Missing is the administrative framework. A state agency knows where it is now in its own state efforts. It can see the goal at the end of the trip. And it has in rough form some tools for the trip: a timetable of limits and the technical enforcement procedures. But it is missing the administrative road map. And on this map there will be many routes to the goal, each requiring a decision tailored to each state's uniqueness. State agencies need guidelines for deciding the direction they should take.

In this session, we suggested such a road map of administrative decisions and presented 3 case histories of noise-control programs in Florida, New Jersey, and Maryland to illustrate different routes toward the goal of vehicle noise control. These programs and those in California and Chicago show how each route is tailored to the uniqueness of each individual jurisdiction.

ADMINISTRATIVE DECISIONS

The administrative plan and the resulting enforcement program must be workable (enforceable), technologically and economically feasible, and effective in reducing community noise.

One area of concern is the administrative decisions required. Briefly, these decisions involve (a) enabling legislation, especially the amount of detail required and the balance between administrative and legislative decision-making; (b) balance among state agency roles in the program as affected by agency desires, staff skills, budgets, and existing administrative habits; (c) enforcement thoroughness on certification of sites, inspectors, and instruments; (d) enforcement balances such as in-use versus new-product enforcement, noise limits for all vehicles versus noise limits for heavy trucks only, enforcement along freeways versus enforcement in urban areas also, moving tests versus stationary tests, and disposition by trial versus disposition through administrative procedures; and (e) coordination with local and federal jurisdictions, with the state legislature, and with programs to build roadside noise barriers.

Case History 1: Florida

Florida's program on vehicle noise control is administered through the Florida Department of Pollution Control, which has a low operating budget. Warnings are now issued; full enforcement will begin July 1, 1975. Florida extensively borrowed experience and research from other jurisdictions and solicited the help of various local universities. The program incorporated a thorough training program and public awareness campaign, including participation of the Motor Vehicle Manufacturers Association. The administrative framework allows an effective source-path-receiver balance toward community noise reduction on a cost-effective basis.

Case History 2: New Jersey Turnpike

The administrative experience of the New Jersey Turnpike Authority in vehicle noise control, especially experience of common interest to state jurisdictions, was presented in this case study. Full enforcement began on the turnpike October 1, 1974.

The turnpike had a full program of information dissemination, including the enforcement training of State Police and Division of Motor Vehicle personnel. The turnpike received timely certification advice from legal counsel on sites and microphone placement and advice on choice of instrumentation.

Case History 3: Maryland

Maryland's program was developed by the Department of Transportation and is administered under the Department of Health and Mental Hygiene. Because of budget limits, enforcement will not begin until early 1976. Key ingredients to success are proper timing and the interaction with other state agencies and key state legislators. In Maryland, interagency coordination was stressed both in the planning and in the program operation, especially since parallel planning efforts existed in other state agencies and these efforts were thought insufficient by the transportation department. Preparation was thorough and was valuable in defending the administrative plan against changes proposed by legislative committees.

ENFORCEMENT PROGRAMS

In several states, noise limits for in-use vehicles are more stringent than the limits those same vehicles had to meet when new. Is this reasonable or feasible? On the one hand, some off-the-shelf equipment now exists for retrofitting older trucks, and some believe the retrofit trend will continue. With the retrofit equipment, in-use vehicle noise levels may be lower than new-product levels. Motor vehicle industry representatives, however, strongly believe that costs will preclude this.

Is a nontampering provision feasible for vehicles manufactured before noise certification, as some states imply by their regulations? In other words, if we do not know the noise output when the vehicle is new, how can we legislate against the operator's increasing the noise output by tampering with the original equipment? California has had success on 2 fronts. Officers can often tell by visual inspection whether equipment has been modified. Especially for motorcycles, this inspection alone enforces against tampering. California officers also collect data on many vehicles that are nominally identical and determine a distribution of source levels for such vehicles. They suspect that tampering has occurred when a vehicle passes that is far noisier than the norm. For vehicles that are noise certified, all participants seem to agree that the tampering provisions can be enforced in a straightforward way.

ROLE OF THE JUDICIARY

In California, most judges have insufficient time for noise concerns. The California Highway Patrol has asked the judges how they wish citations written to ease the judicial process; cooperation was thereby increased. Low fines seem to help. In addition, a large number of violations are now considered misdemeanors, which are not tried by jury. In Chicago, the judges rotate, the traffic courts are jammed, and the judicial response is highly variable. Improvement is slowly occurring. In Florida, training of enforcement officers included a full-day session on court preparation. The same educational process is planned for the future for state and local government officers. All state attorneys were subsequently contacted, and full support is expected. The New Jersey Turnpike invited municipal judges for a day's briefing, but had dismal response. The prosecutors will be chosen from Turnpike staff, specially deputized, because of budget cutbacks in the state Attorney General's Office. In Maryland, liaison is planned with judges and prosecuting attorneys.

VEHICLE NOISE SOURCES AND NOISE-SUPPRESSION POTENTIAL

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U.S. Department of Transportation

Table 1 gives the origins of noises that disturb people in their homes. Highway noises are cited as being annoying by 20 to 30 percent of the people. The London survey sample (1) was drawn from more than 400 sites uniformly distributed but generally located away from aircraft noise. The Chicago and Minneapolis-St. Paul survey samples (2) were drawn from a cross section of the cities and included sonic boom complainants. Surveys in the 4 eastern and 4 western cities (3) included people who were within an area subject to substantial amounts of airport noise. Certain obvious differences, therefore, appear among the transportation categories, particularly the amount of dissatisfaction directed toward aircraft operations. Significantly lower annoyance due to aircraft is shown by the London data than by the other data; and, not too surprisingly, higher annoyance levels are shown by communities near airports than by communities in the sonic boom cross-sectional survey.

Table 2 gives some vehicle population and use statistics. Since each vehicle is a noise source, the sheer number of motor vehicles and the magnitude of vehicle-miles per year tend to explain some of the public outcry about traffic noise. More than 84 million automobiles, 17 million trucks, and 2 million motorcycles interject a continual stream of noise into residential areas. Data in this table also indicate the increasing use of highway vehicles within the urban community; 1985 projections indicate almost a

Table 1. Percentage of people annoyed by and sources of residential noise.

Noise Source	London ^a	Chicago ^a	Chicago ^b	Minneapolis-St. Paul ^a	4 Western Cities ^b	4 Eastern Cities ^b
Aircraft	9	37	40	33	39	62
Road traffic	36	36	26	29	24	33
Trains	5	7	7	3	3	3
Bells, alarms, and sirens	3	8	6	15	14	17
Industrial and construction	7	3	2	6	2	6
Other people (children)	19 (8)	33 (18)	32 (13)	32 (13)	26 (14)	20 (9)
Pets and animals	3	10	8	13	13	15
Number surveyed	1,400	1,064	872	901	3,590	3,217

^aCity cross section.^bAirport environs.

Table 2. Population and use of mobile noise sources in United States.

Source	1968		1985	
	Number in Use	Use	Number in Use	Use
Automobiles	84,000,000	9,000 miles/vehicle/yr (55 percent urban)	130,000,000	9,000 miles/vehicle/yr (65 percent urban)
Trucks	17,000,000	12,000 miles/vehicle/yr (40 percent urban)	28,000,000	12,000 miles/vehicle/yr (50 percent urban)
Buses	350,000			
Motorcycles	2,000,000		9,000,000	
Tractors and construction equipment	2,000,000			
Aircraft	150,000	80,000,000 operations	317,000	430,000,000 operations
Commercial	2,900			
General aviation	120,000			
Military	30,000			
Trains				
Locomotives	29,000			
Cars	1,800,000			
Boats				
Outboard motors	7,000,000			
Pleasure boats	4,000,000			
Ships and towboats	5,000			

Note: 1 mile = 1.6 km.

Table 3. Miles traveled by motor trucks.

Truck	Year Registered	Trucks Registered	Miles Traveled	Average Miles Per Vehicle
Single-unit	1965	14,008,000	140,117,000,000	10,003
	1966	14,694,000	140,893,000,000	9,588
	1967	15,363,000	147,450,000,000	9,598
	1968	16,124,000	158,938,000,000	9,857
	1969	16,942,000	167,241,000,000	9,871
Combinations	1965	787,000	31,319,000,000	39,759
	1966	823,000	33,012,000,000	40,112
	1967	830,000	35,006,000,000	42,176
	1968	871,000	37,713,000,000	43,299
	1969	929,000	39,439,000,000	42,453
Total	1965	14,795,000	171,436,000,000	11,587
	1966	15,517,000	173,905,000,000	11,207
	1967	16,193,000	182,456,000,000	11,268
	1968	16,995,000	196,651,000,000	11,571
	1969	17,871,000	206,680,000,000	11,565

Note: 1 mile = 1.6 km.

doubling of urban vehicle-miles compared to 1968. One could presume that this means only a 3-dB increase in the highway noise level (which is almost imperceptible). The projected increase, however, will result from increases in the number of miles of high-speed roadway travel and possibly an increase in average vehicle speed. That combination will produce more than the nominal 3-dB increase in noise level in communities now exposed and will expose many new communities not now subjected to significant highway noise.

Table 3 gives the miles traveled and the number of trucks registered each year between 1965 and 1969. Although combination trucks represent a small portion of the total highway population of vehicles, the number of miles they travel each year is significant; each vehicle operates on the average 42,000 miles (67 200 km) per year. This has implications in terms of the alternatives to reduce the noise generated by these heavy vehicles.

Figure 1 shows the average speed of highway vehicles and the percentage of those exceeding 50 mph (80 km/h). Both continually increased between 1942 and 1968. Recently, fuel shortages have caused nationwide reductions in highway speed limits so that the gradual increase in average vehicle speeds has been temporarily reversed. Indications are, however, that average speeds are again climbing.

The average age of motor trucks in the United States must also be considered in noise-abatement strategies. Figure 2 shows that a great number of motor trucks are 5 to 10 years old. More than 25 percent of all trucks are older than 10 years.

The range of problems one encounters in categorizing highway noise sources is shown by Figure 3 (4). Two things are immediately evident: (a) As speeds increase, the noise levels generated by automobiles and trucks increase and (b) trucks produce higher sound levels than automobiles do. Figure 3 also shows that the ranges of sound levels generated by these vehicles overlap when the noisiest in one category is compared to the quietest in the next category. That is, the noisiest 10 percent of automobiles generated as much noise on streets as did the quietest 30 percent of motorcycles or trucks at speeds of 35 mph (56 km/h) or less. In general, however, trucks are the dominant noise source on highways.

TRUCK NOISE

Figure 4 shows the noise sources of a heavy-duty diesel tractor trailer. Figure 5 shows sound levels of the major noise sources measured 50 ft (15 m) to the side of the vehicle. Two levels are shown for tire noise because of the speed dependence of this source. This type of presentation is possible for diesel trucks because of the insensitivity of the first 4 noise sources to vehicle speed. They are dependent on engine speed (rpm), but the large array of gear ratios provided in most diesel trucks results in a narrow range of engine speed during typical operations.

Engine noise produced by the rapid pressure rise in the combustion chambers of such engines is radiated by the vibrations of the engine block and attached fixtures. A sound level of 78 dBA has been attributed to the engine and mechanical combustion noise sources.

Exhaust noise is engine noise radiated from the exhaust pipe outlet and vibration noise of the pipes and mufflers. A level of 85 dBA is shown to represent typical exhaust noise.

Engine air intake or induction noise is created by the pulsating column of air moving into the engine and, in many cases, includes noise of mechanically driven or exhaust turbine-driven supercharges. A relatively low level of 75 dBA is generated by the induction process.

The engine cooling fan moves large quantities of air through the radiator with a very restricted downstream flow condition and generates high noise levels. Fan noise, 82 dBA, is second only to engine exhaust noise.

Tires generate a noise level of 75 dBA at a speed of 35 mph (56 km/h) or less and 95 dBA at highway speeds.

Adding all sources gives a total truck noise level of 88 dBA at speeds less than

Figure 1. Speed trends on main rural highways by vehicle type.

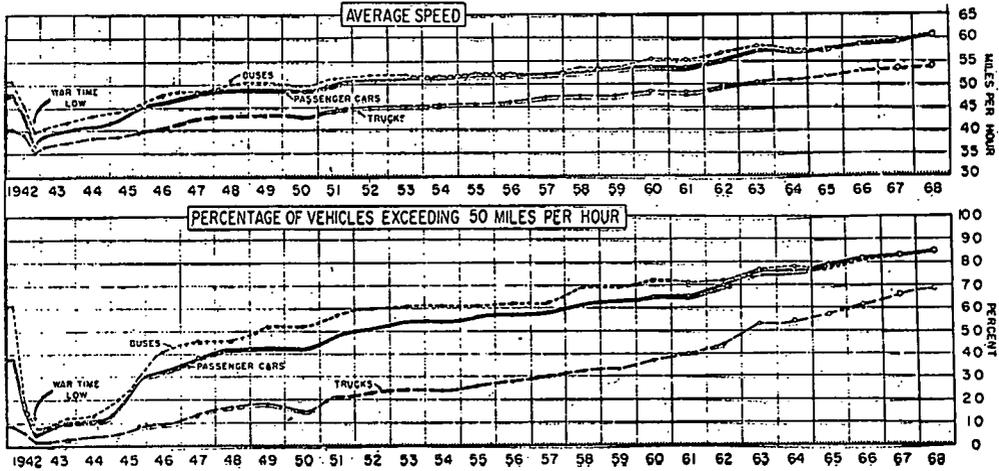


Figure 2. Motor trucks in use by age groups.

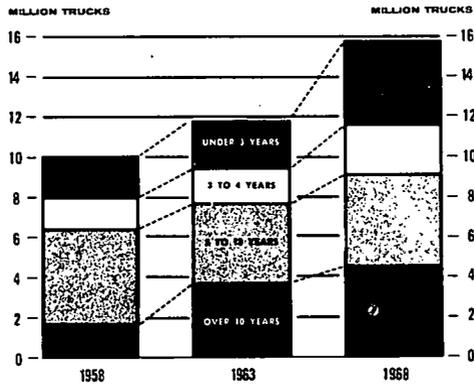


Figure 3. Results of 1971 California noise survey.

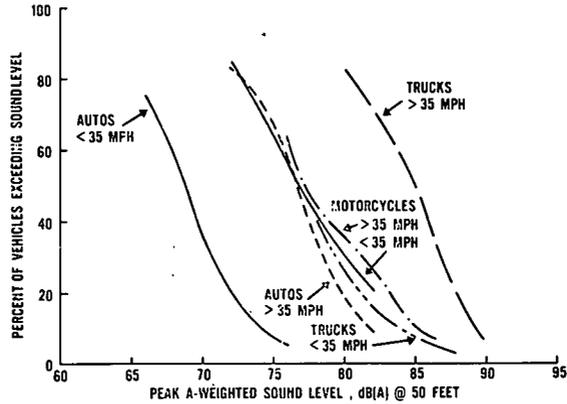


Figure 4. Truck noise sources.

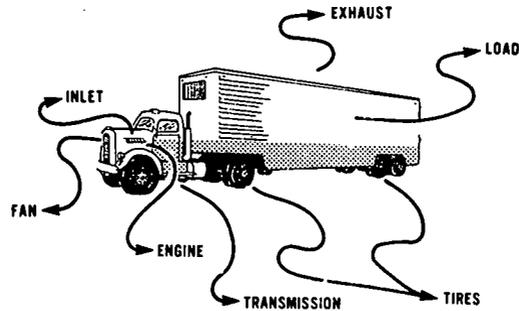


Figure 5. Diesel truck noise sources.

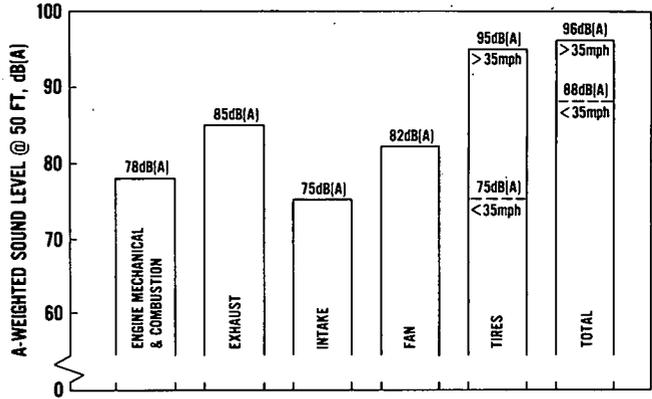


Figure 6. Effect of speed on truck tire noise.

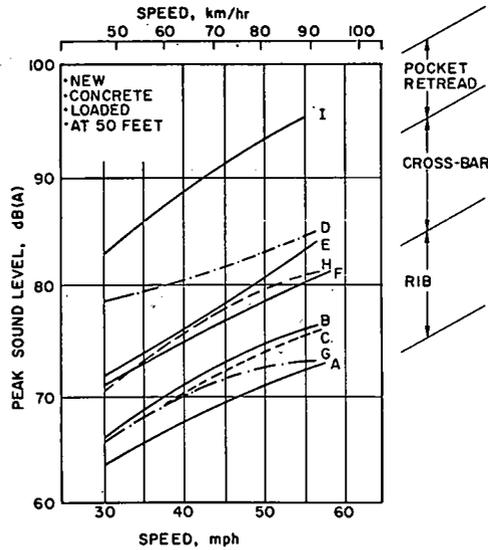
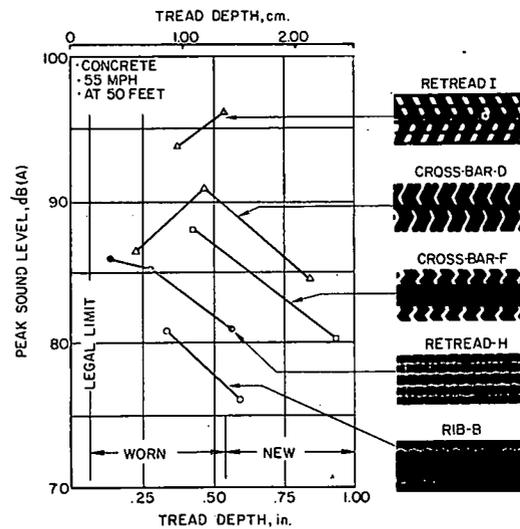


Figure 7. Effect of wear on truck tire noise.



35 mph (56 km/h) and 96 dBA at highway speeds. These data would apply to a relatively modern truck design that is in compliance with voluntary industry standards and noise regulations of various states and localities. Half of the large trucks today, however, have either inadequate muffling or no muffling at all, and that makes exhaust noise for normally aspirated engines (not turbocharged) considerably higher than that shown on this figure.

The problem is obvious: to reduce the noise level of these loud vehicles. Suppose a hypothetical truck has a completely silent exhaust. That is, the noise level of 85 dBA shown in Figure 5 for exhaust noise is reduced to zero. In this case, the highway noise level of the truck is diminished by approximately $\frac{1}{2}$ dB, clearly imperceptible to a roadside observer. Complete elimination of the exhaust noise would, however, benefit the urban dweller (where vehicles typically operate at low speed generating lower tire noise) by reducing the total vehicle noise from 88 dBA to 85 dBA. Such a small reduction of 3 dB in the urban environment, however, is not a significant improvement because trucks are 8 dB louder than automobiles on the average. It is evident, therefore, that a concerted attack on all sources of noise emanating from these heavy trucks must be made simultaneously to reduce the noise level to values that are sought by legislators and expected by residents of communities adjacent to the highways.

Truck Tire Noise

Results of research of the U.S. Department of Transportation are presented. Nine distinctly different tread patterns, which represent the more popular tires used by industry today, were tested. Figure 6 shows truck tire noise levels as a function of speed for a variety of new truck tires operating on a concrete, semipolished surface, loaded to typical state load limits. Sound levels measured at the 50-ft (15-m) side-line position are presented as the peak A-weighted sound level. Four test tires were mounted on the drive axle of a single-drive-axle flatbed truck, which in turn coasted past the microphone with the engine turned off and clutch disengaged. Sound levels shown, therefore, are those generated solely by the tires of the vehicle. Test tire A was the quietest of all commercially available tires and was used on the steering axle for all tests. Rib tires were significantly quieter than cross-bar tires, which in turn were significantly quieter than certain pocket retread tires. Variation of sound level as a function of speed and tire type is clearly shown in Figure 6.

Figure 7 shows the effect of tread wear on sound levels. The data points at the extreme right indicate the tread depth of each tire when it is new or newly recapped. As the tire wears, the tread depth decreases and the sound level increases for all tires with the exception of the pocket retread I. The decrease in sound level resulting from wear of retread I is believed to be directly related to the decreased volume of the suction cup cavities. These cavities are indicated by the white areas in the patch print. As the tread wears, this cavity volume is reduced and the sound level decreases, for the cavity suction is the most significant noise generator for this tread pattern. Also the question of vibration input to the noise generation process must be considered. The increased tread element stiffness resulting from tire wear enters into the equation in some as yet undetermined fashion.

Figure 8 shows the effects of axle loading on the noise generated by 4 test tires. Two-point curves are drawn representing the empty vehicle and the typical state axle limit of 17,000 lb (7650 kg). Significant variations in sound level are generated by changing this one variable at a constant vehicle speed of 55 mph (87 km/h).

Figure 9 shows the effects of road surface on the sound level of a variety of new and worn truck tires. The road surface descriptors have been arbitrarily spaced across the abscissa, for it is not known what critical surface variable controls the noise levels produced. The suction-cup tires become significantly quieter on rough surfaces where the tread pockets cannot seal to the road surface effectively. Cross-bar tires are relatively insensitive to road surface, but rib tire noise increases as road roughness increases. The road roughness increases the vibration forcing function

Figure 8. Effect of axle loading on truck tire noise.

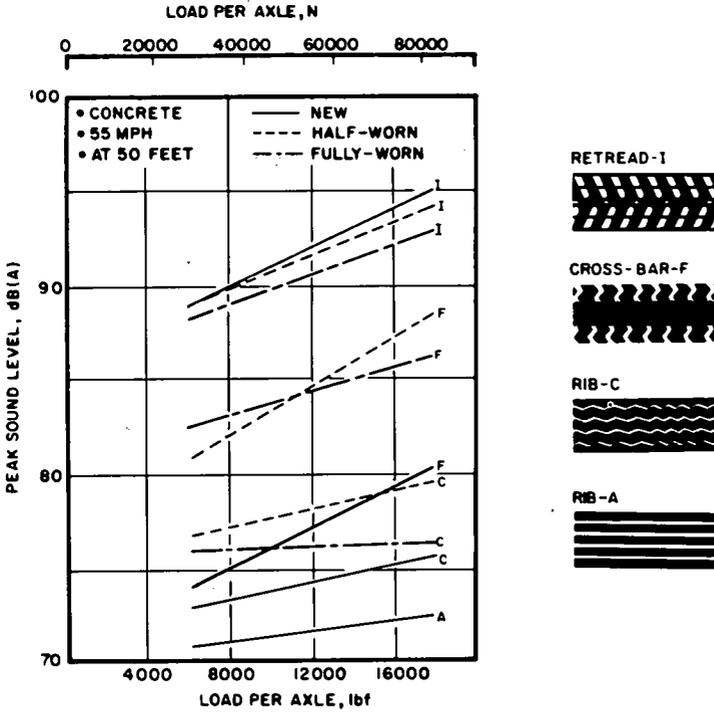
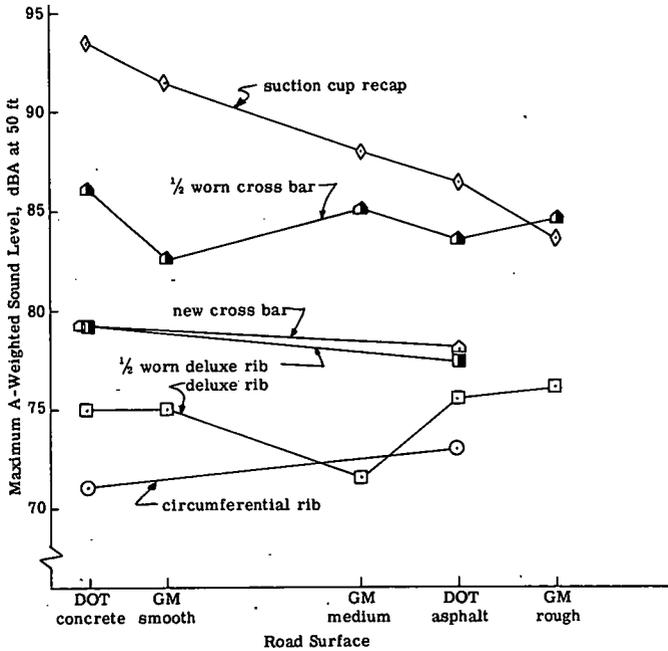


Figure 9. Effect of road surface on truck tire noise.



for rib tires, but the tread elements of the cross-bar tires simply overpower the comparatively small-scale road surface features of the range of roads tested.

Figure 10 shows a narrow-band analysis of the sounds generated by a truck tire at 50 mph (80 km/h). A fundamental tone at 360 Hz is a dominant portion of the spectrum, and a harmonic is indicated at 720 Hz. In between, broad-band noise is generated by the smaller tread elements and road surface texture.

Diesel truck noise sources excluding tires are shown in Figure 11. This shows important sources of noise for speeds below 35 mph. The dashed lines indicate what is possible with the application of known technology for retrofitting present production vehicles. A 10-dB improvement in exhaust noise and a 5-dB reduction in intake noise through the application of improved muffler and air cleaner combinations and 6- to 7-dB improvement in fan noise are believed possible on present vehicles without significantly degrading the performance or economics of the vehicle. The total noise level, therefore, of 81 dBA at 50 ft (15 m) under maximum acceleration conditions is achievable and has been demonstrated under research by the federal transportation department.

Truck Intake and Exhaust Noise

Figure 12 shows the exhaust noise at 50 ft (15 m) for a variety of 2- and 4-stroke diesel engines as a function of engine rpm. The unmuffled engine generates a cacophony of sounds reaching ear-shattering proportions. A typical range of muffling extends from 20 to 30 dB, which reduces the judged loudness of the muffled sounds to a fourth to an eighth of the unmuffled sounds. Apparently, a significant option is available for noise reduction by simply reducing the engine speeds. Unfortunately, the typical diesel engine generates its maximum horsepower (wattage) at higher engine speeds, and all of the horsepower is required to operate the truck and maintain the flow of traffic on the highway.

Figure 13 shows the sound level reduction that can be achieved as a function of ratio of muffler diameter to exhaust pipe diameter. The lower curve denotes the basic volume attenuation achieved by the expansion chamber effect of a properly placed muffler in an exhaust system. The upper curve indicates the improvement that can be made by placing the proper elements in the volume of the muffler. This is the "black art" of the muffler acoustician. Present mufflers range from 20- to 30-dB attenuation with ratios of muffler diameter to tube diameter of 2 to 3. Adding length to the present diameter ratio will increase the attenuation as indicated on the right, and increasing muffler diameter will continue to provide further increases in muffler attenuation.

Of paramount importance in muffling exhaust systems of diesel trucks is the back pressure of the exhaust system (from exhaust manifold to ambient pressure). Manufacturers' engine warranties are specific on the point that installation of engines requires that low back pressures at the manifold not be exceeded. In addition to the engine warranty problem, power is significantly degraded by increased back pressure. Engine valve deterioration is also attributed to excessive back pressure. Therefore, the problem is to develop mufflers that have low back pressure, are acoustically effective, meet present weight and space limitations of diesel trucks and buses, and cost only reasonably more than the present mufflers.

The right ordinate in Figure 13 indicates the degree of efficiency of present muffler technology in terms of the percentage of sound power emanating from the engine that is attenuated by the muffler in achieving 20 to 40 dB of sound reduction as indicated on the left ordinate. Forty decibels, for example, requires 99.99 percent of the sound to be attenuated by the muffler. This efficiency has been demonstrated, and only packaging technology and regulation are required to bring it into practice. The basic parameters also apply for the intake induction muffler. Most trucks have an efficient air cleaner on the induction side of the engine, which happily provides a fair degree of muffling. However, in the balanced noise reduction approach that must be taken, additional muffling must be designed into the induction system and, particularly, in turbocharged and supercharged diesel engines, where significantly higher induction

Figure 10. Narrow-band analysis of truck tire noise.

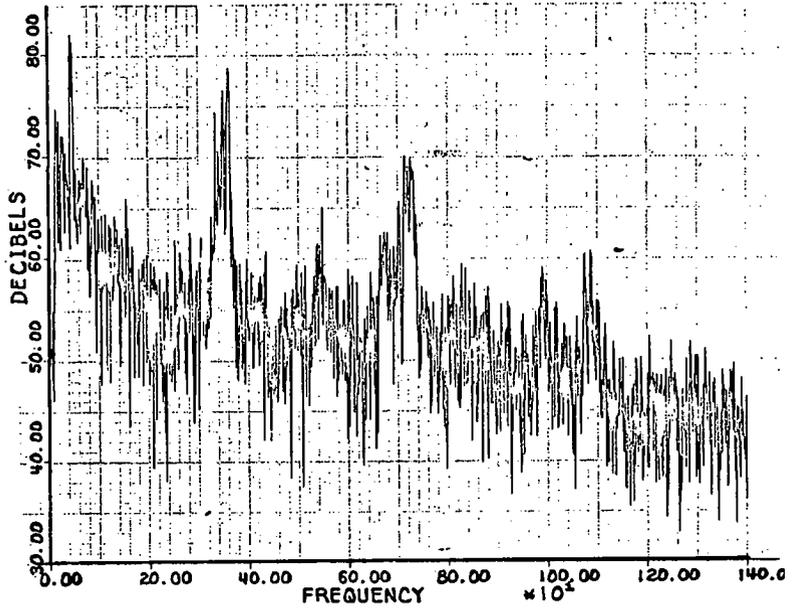


Figure 11. Diesel truck noise sources, excluding tires.

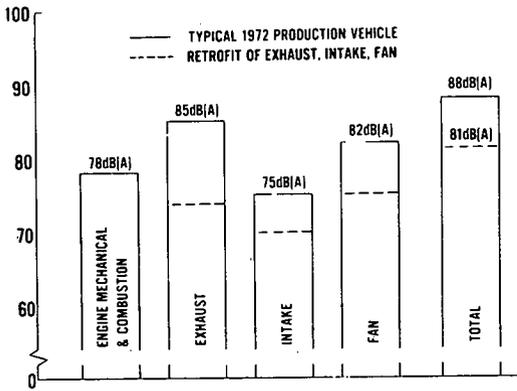


Figure 12. Diesel engine exhaust noise.

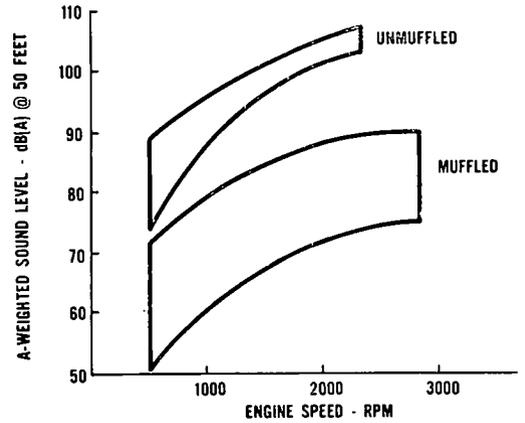


Figure 13. Intake and exhaust muffler effectiveness.

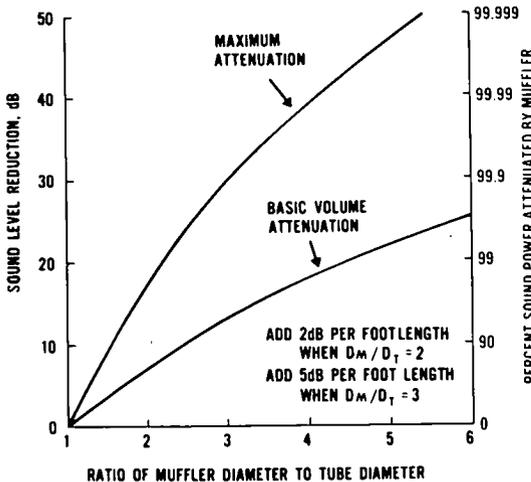
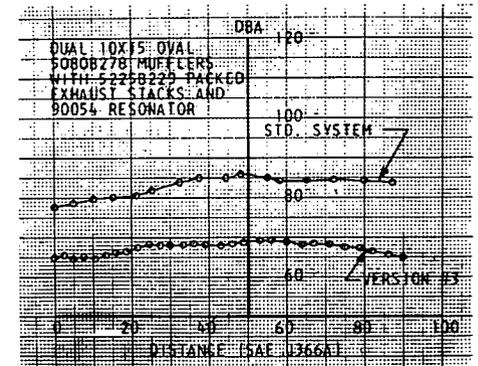


Figure 14. Truck noise with and without muffler and exhaust stack silencer.



noise levels are generated.

Several factors are particularly important in considering the balanced reduction of heavy-duty diesel truck noise. One is the low frequency of the exhaust noise that propagates more efficiently than the higher frequency noise and that couples more efficiently with structures and provides, therefore, secondary radiation such as dish rattling. Of perhaps greater importance, typical diesel exhaust and induction stacks are located 10 to 13 ft (3.5 m) above the road. This is an important factor in the application of highway noise barriers, which would have to be very high to be effective in handling these components of the overall truck noise. All of the other truck noise sources emanate relatively near the road surface so that low barriers that are aesthetically acceptable and less costly can be used. The source height must be taken into account and given some special attention in a balanced noise-reduction scheme.

Given below are the components of exhaust system noise for 1 bank of a Detroit diesel 8V71 engine on an International truck with full load at 2,100 rpm with the microphone at 50 ft (15 m).

<u>Noise Source</u>	<u>dBA</u>
Muffler shell	72
Discharge	80.4
Pipe and leak	78.6
Overall exhaust system	83.0

Figure 14 shows the sound level measured during the SAE maximum acceleration test as the vehicle passed by the microphone with all sources silent except the standard exhaust system. The peak sound level is 86 dBA and relates to the figures above since the V-8 engine has dual exhaust or a doubling of the components. Figure 14 also shows the sound level of the same truck after dual 10x15 oval mufflers with exhaust stack silencers were installed. Just past the closest point of the microphone, the sound level of the exhaust system peaks to 69 dBA, some 16 dB lower than the standard installation.

Figure 15 shows the oval muffler, which was used in tests in the transportation department project to reduce the exhaust noise level. This is a change from a straight-through muffler to a double-rack system with a 10x15 oval configuration. The flow is diverted twice through resonator chambers. In addition, stack silencers are used at the pipe terminants.

Truck Cooling-System Noise

American trucks have been productive in large measure because of efficient cooling systems. The fan must move large volumes of air through the radiator to achieve the cooling. The typical cooling fan is a stamped sheet-metal, riveted subassembly, driven by a belt directly coupled to the engine. Until recently, little attention has been given to the noise of the cooling system.

Sound generated by fans varies principally with tip speeds, as shown in Figure 16. Decreasing fan tip speeds by increasing the number of blades and reducing rotational velocity or diameter are the directions to proceed in reducing fan noise. Aerodynamic shaping of fan blades and closer shrouding of tips are other ways to reduce fan noise level. Separating the fan from the engine block and removing obstacles in the fan air stream also have to be considered in fan noise reduction. Much more research is required to understand fan noise.

Figure 17 shows the increases in cooling, air flow, and noise when fan-to-radiator distances are increased. Each of these parameters reaches a maximum at some point and decreases beyond that point. The parameters do not necessarily reach their maximum values at the same point, but most important the cooling increases at a greater rate than air flow does because of the better distribution of air across the core. Optimum fan-to-radiator distance on the tests conducted in this program range

Figure 15. Oval muffler.

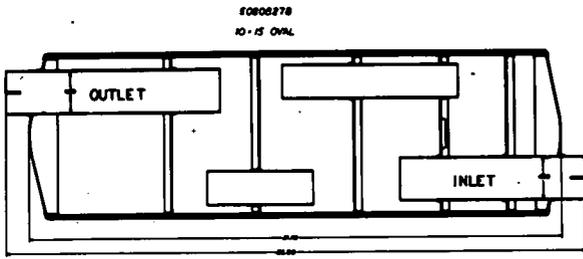


Figure 16. Effect of speed on fan noise.

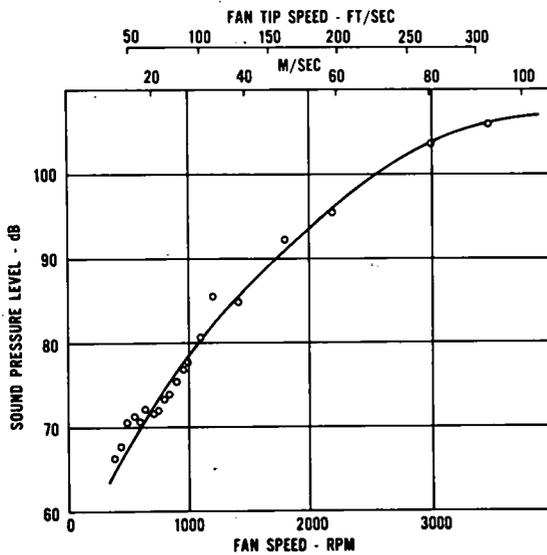


Figure 19. Diffusers for fan discharge.

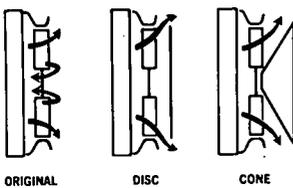


Figure 20. Noise factor for various radiator arrangements.

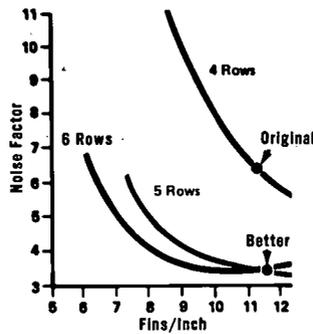


Figure 17. Effect of fan-to-radiator distance.

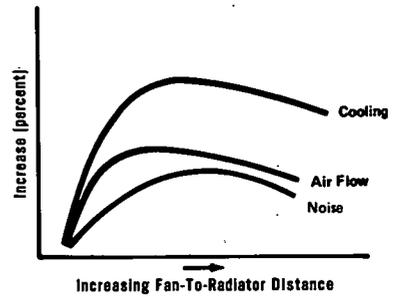
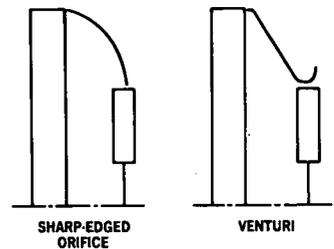


Figure 18. Shroud shape and transition.



from 4 to 8 in. (10 to 20 cm). Noise reduction is achieved by optimizing cooling and fan-to-radiator clearance. The shroud shape and the fan position within the shroud are then considered.

The original shroud found on most trucks today most closely resembles the sharp-edged orifices shown on the left in Figure 18. The shroud shown on the right offers significant increases in performance and reduction in fan noise by reducing tip speed while maintaining constant cooling.

Previous research has indicated that a disk diffuser placed at the proper location behind the fan, as shown in the center of Figure 19, increases the air flow and reduces the horsepower (wattage) requirements of the fan. The effects appear to be a reduction in the recirculation losses near the fan hub, as shown in Figure 19 on the left. Improved designs take on the appearance of a mixed-flow fan, that is, one that combines axial and radial discharge. Theory indicates that a mixed-flow design has the best efficiency for the flow rates and pressure differences normally experienced in truck applications. This is particularly important in the design of engine or engine enclosures to produce quiet trucks. Such noise-reduction items block the nominal radiator air-flow passages and indicate the desirability of diverting the flow to seek discharge passages under the wheel wells or under the engine.

One final area of investigation involves the radiator itself. Figure 20 shows the noise factor for various radiator core arrangements. Noise factor is proportional to total air flow through the radiator times the square of the pressure; that is proportional to the general cooling system noise. The abscissa is the number of fins per inch, and the data are plotted on the basis of equal heat rejection from the radiator. If we compare the original design point, for the 4-row radiator, to the better points for 5- and 6-row radiators, we can see that the noise factor, or air flow times pressure squared, is reduced significantly. Thus, the air flow times pressure squared across the radiator is translated into reduction requirements for the fan so that the fan can be made smaller or made to turn slower. This is the area where the noise reduction is achieved.

A new trend in diesel truck design is toward increased radiator size and thermostatically controlled fans that rotate only a small portion of the time as needed and thus greatly reduce overall vehicle noise. The advanced design practices noted above that will lead to lower fan noise generation must be applied, nevertheless, to abate this source of noise during the periods of fan operation.

These combinations in new technology can immediately alter present production vehicles to achieve levels of approximately 81 dBA at 50 ft (15 m) under maximum acceleration conditions. This was indicated earlier in Figure 11. However, more stringent requirements have already been scheduled in various states and cities, and the Noise Control Act of 1972 adds pressure for still further reductions in truck noise levels in order that trucks may indeed approach the sound levels typical of automobiles. A more difficult goal of 75 dBA is proposed by the U.S. Department of Transportation. To achieve such a reduced sound level will require progressive application of the existing technology in the exhaust, intake, and fan areas.

Truck Engine Noise

Research in Great Britain, supported by several American engine manufacturers, indicates that future engine designs may indeed provide lower inherent mechanical and combustion noise levels. Until this new technology can be incorporated in engine designs, an alternative approach must be taken.

Figure 21 shows a concept of such an alternative approach to fundamental engine redesign; it is engine and transmission encapsulation and is noted by the heavy lines around the engine. Consideration has to be given to apertures for air discharge so that the engine is cooled. These apertures are also used for noise discharge. The maintainability of encapsulated engines is an important feature, and innovative mechanical design will be required to achieve acceptance by the trucking industry. Within the truck noise demonstration program of the U.S. Department of Transportation, truck

Figure 21. Engine-transmission enclosure.

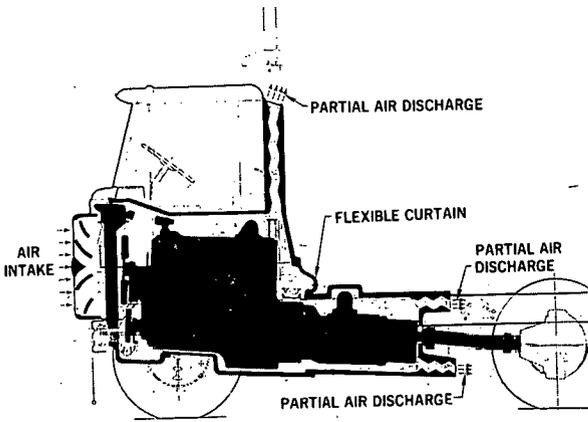


Figure 22. Diesel truck pull-away and highway noise.

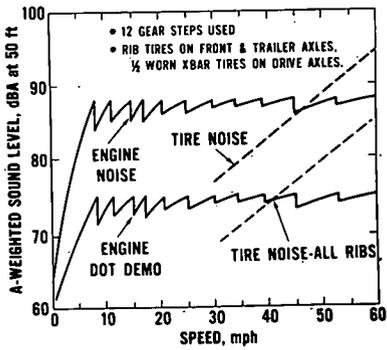
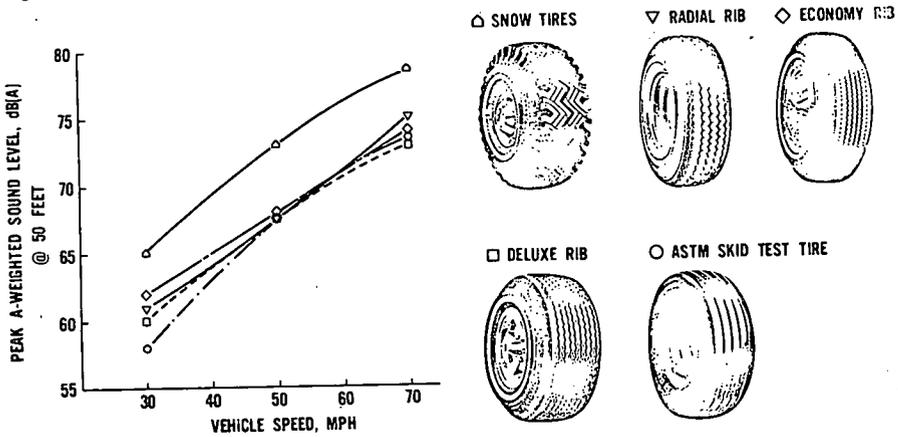


Figure 23. Passenger-car tire noise.



manufacturers have been looking at inspection panel damping, soft engine mounting, and other ways to reduce engine combustion and mechanical noise. A final option is encapsulation of the type shown in Figure 21. These manufacturers have taken on the challenging task of reducing overall vehicle noise levels to 75 dBA and have explored the practicality of whole engine and transmission enclosures as potential means to reduce the general mechanical clatter of an engine to levels required to achieve that goal.

Figure 22 shows what happens today when a heavy-duty diesel truck pulls away from a stop and accelerates to highway speeds. The engine noise shown as the jagged line indicates that the engine operates within several hundred rpm of its governed speed, and most of the vehicle speed control is maintained through the selection of appropriate gear steps during the acceleration. This tire noise becomes dominant at about 45 mph (72 km/h) and exceeds the engine noise level from speeds above 45 mph. If, as an option, the half-worn cross-bar tires are removed from the axles of the tractor and replaced with new rib tires, the noise would not be dominant until speeds exceed 60 mph (96 km/h).

If the goals of the noise-reduction demonstration project of the U.S. Department of Transportation are achieved, the engine noise levels will have been reduced substantially, as shown by the lower jagged line in Figure 22. Tire noise then is the dominant source at quite low speeds. Application of new-truck engine noise technology forces a significant requirement on the tire manufacturers to evolve technological solutions to bring tire noise levels into line with engine noise levels.

PASSENGER-CAR NOISE

In 1970, the U.S. Department of Transportation sponsored a pilot measurement program of passenger-car tire noise levels on a new section of Interstate 95 north of Washington, D.C. A 4-door sedan and a variety of test tires were used, and coast-by noise measurements were made with the engine shut off and transmission in neutral. The results of this experiment are shown in Figure 23. The quietest commercial tire, which has no sipes and only 4 circumferential grooves, is the ASTM skid test tire. The sound level produced by the skid test tire was slightly lower at 30 mph (48 km/h) but merged with the sound levels of deluxe rib, economy rib, and radial tires at higher speeds. Typical snow tires mounted on the rear axle and ASTM tires on the front of the same sedan, however, increased the sound level 5 dBA. These tires in this project were new and, if the trends established in the truck tire tests carry over to the passenger-car tires, sound levels will tend to increase as the tires are worn. The noisy snow tires were still below the sound level generated by more than 80 percent of the trucks at freeway speeds in the California survey.

MOTORCYCLE NOISE

Motorcycle noise, as shown in Figure 3, falls generally between automobile and truck noise. Not much information exists on motorcycle noise levels, but it is clear that exhaust noise is a dominant feature of motorcycles, followed closely by intake, engine, and chain noise. Noise levels for motorcycles, sports cars, and passenger cars shown in Figure 24 generally agree with those found on a much broader sampling by the California Highway Patrol but also indicate the general lack of exhaust muffling in the low-frequency range that accounts for the throaty roar of motorcycles. A similar low-frequency dominance is seen for sports cars.

Figure 25 shows still another investigator's findings of the broad range of noise levels emanating from motorcycles. Subsource contributions of component sources of motorcycle noise for the limited number of bikes tested are also shown. Exhaust noise exceeds the intake contribution, engine mechanical noise is a close third, and tire noise level is the least contributor because of the light loading on the tires.

One of the major problems with motorcycles is the "love affair" that the drivers seem to have with the sound of power. The sound of power can be enhanced by

Figure 24. Range of octave band noise levels at 25 ft (8 m) for passenger cars, sports cars, and motorcycles at 65 mph (105 km/h).

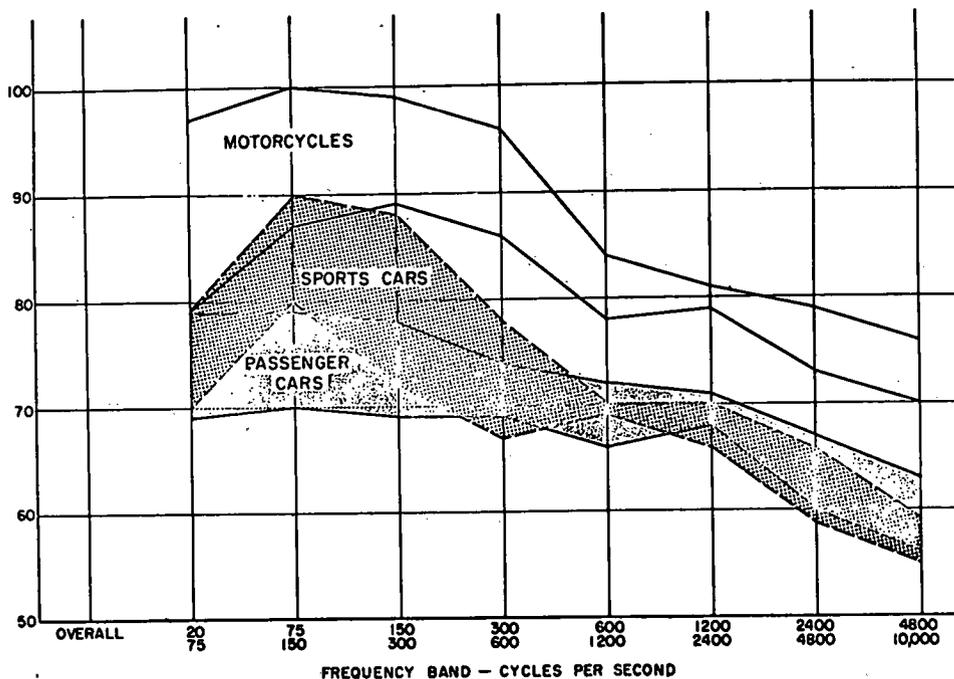
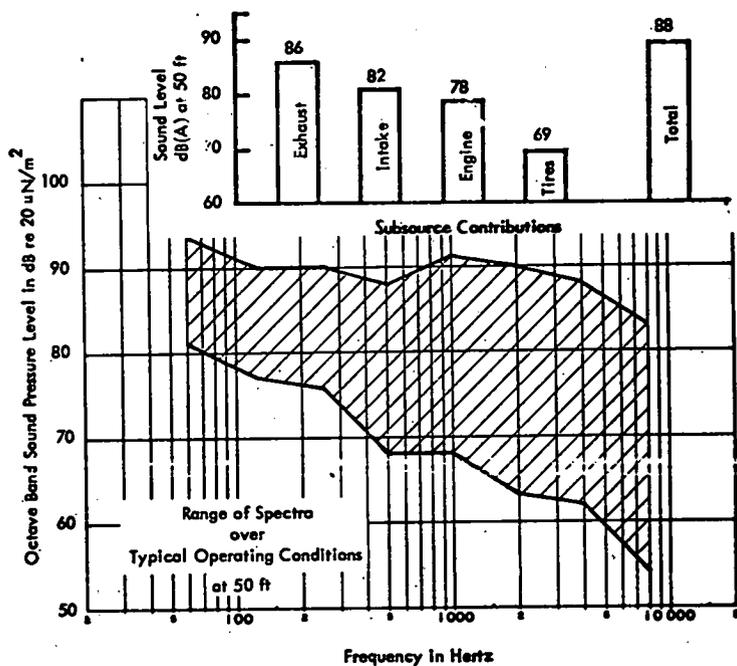


Figure 25. Motorcycle noise levels.



modifying the muffler, as shown in Figure 26. The noise level measured under maximum acceleration conditions for a variety of motorcycles is plotted as a function of engine displacement in cubic inches. The lower line indicates the general trend with standard production mufflers, which many cyclists prefer. These tests were performed by the Ontario Ministry of Transportation and Communications in 1967 (5). The specific test procedures were the International Standards Organization recommendation 362, which prescribes a sideline measurement distance of 25 ft (8 m). The measured data have been extrapolated to an equivalent 50-ft (15-m) sideline level for consistency with the other vehicle sound levels. For motorcycles, the approximate difference in 25- and 50-ft levels is 6 dB as shown on the shifted ordinate.

Figure 26 shows that the smaller bikes are considerably quieter than the largest U.S.-manufactured motorcycles. With modified exhaust systems, however, the smaller bikes can produce high sound levels. Further reduction of exhaust noise from motorcycles is possible; however, intake and engine noise is close to the noise levels emanating from standard exhaust mufflers. The application of engine enclosures for these small air-cooled engines presents a number of problems not encountered with the water-cooled automobile and truck engines. Notwithstanding these problems, industry members of the President's National Industrial Pollution Control Council suggested that the present voluntary maximum noise level standards of industry for bikes with engines greater than 240-cm³ displacement could be reduced as follows (6):

<u>Year</u>	<u>Feet</u>	<u>dBA</u>
1971	50	92
1973	50	90
1978	50	86
1983	50	77

Comparable recommended maximum sound levels for bikes under 240 cm³ displacement are 2 to 3 dB lower.

NOISE CERTIFICATION LEVELS

Table 4 gives a summary of California's new code for motor vehicle noise certification levels. It contrasts the motorcycle manufacturer's suggested achievable goals and the levels expected by regulatory agencies. Trucks are certificated for maximum vehicle noise equal to or less than 86 dBA measured at 50 ft (15 m) to the side of the centerline of the vehicle path. On January 1, 1975, this level dropped to 83 dBA and will drop to 70 dBA by January 1, 1988. Automobiles are certificated at levels only 2 dBA lower than those for the trucks. This surprisingly small difference illustrates the problem of automobile certification noise levels relative to operational noise levels.

SOUND PROPAGATION

Figure 27 shows how sound propagates away from a single vehicle. For simplicity, we assume that the noise is generated at the center of this source and that it is a point source. At relatively short distances away, this approximation is reasonable. The hemispheric nature of the propagation then dictates that the sound level is reduced by 6 dB for each doubling of distance away from the source. That is to say, a measurement of 90 dB at 50 ft (15 m) to the side of a passing vehicle would be 84 dB at 100 ft (30 m) to the side of that same passing vehicle.

Figure 27 also shows the way sound is propagated from an array of sources such as 2 trucks or many trucks and automobiles. In this case, the spreading is not hemispherical but hemicylindrical. The geometry dictates that, for each doubling of distance away from the source, the sound level will be reduced by 3 dB.

Figure 26. Maximum noise levels of motorcycles in acceleration test.

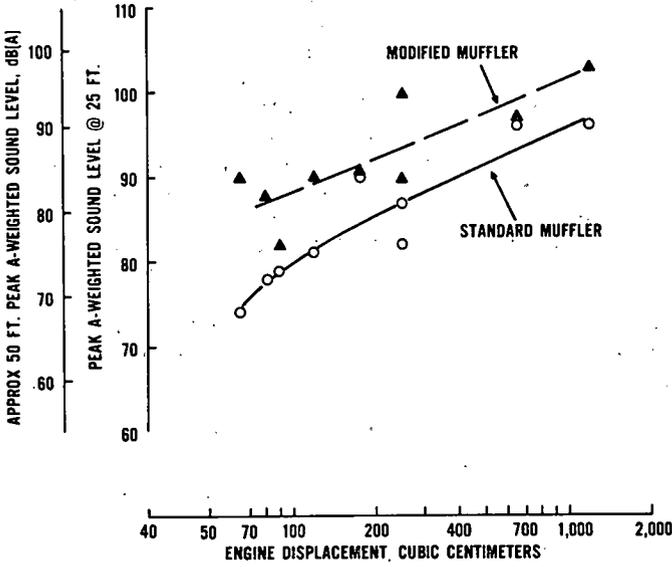


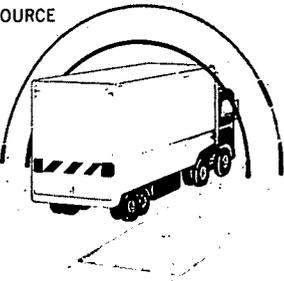
Table 4. California motor vehicle noise certification levels at 50 ft (15 m).

Vehicle	Noise (dBA) by Date of Manufacture				
	1967 to 1973	1972 to 1975	1974 to 1978	1977 to 1988	1987
Trucks	88	86	83	80	70
Automobiles	86	84	80	75	70
Motorcycles	88	86	80	75	70
Snowmobiles		82 ^a			

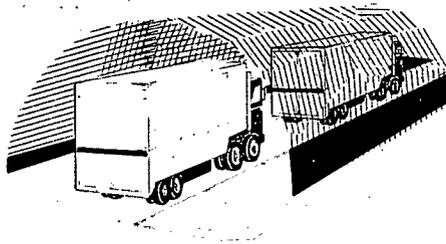
^aEnforcement agency and means not specified.

Figure 27. Sound propagation.

POINT SOURCE



LINE SOURCE



Of course, other things are to be considered in the propagation of sound either with point source or line source. One of the things that cause problems in predicting noise levels is the ground cover adjacent to highways, which will tend to attenuate the sound by 2 to 3 dB. However, one should not count on vegetation, even dense rows of bushes and trees, to provide much more than 2 to 3 dB unless broad areas of dense growth are present.

ATMOSPHERIC ATTENUATION

At significant distances away from the highway, substantial high-frequency content of the sound will be attenuated because of the absorption of the atmosphere. The high frequencies are attenuated as much as 30 dB/1,000 ft (300 m) over the predominant low frequencies of highway noise, which are barely affected by this phenomenon. Atmospheric attenuation is a function of temperature and humidity. Winds and temperature gradients can cause refraction of sound or curving of the sound rays, which will cause either reinforcement or reduction of noise.

TRAFFIC NOISE

Figure 28 shows one procedure for predicting the sound level emanating from a busy highway. Estimated is the sound level exceeded 50 percent of the time at a point 100 ft (30 m) from the side of the highway. The lowest line is the sound level generated by automobiles only traveling at 50 mph (80 km/h). As the percentage of trucks is increased in the traffic, the sound level increases. For example, if there are 100 vehicles per mile of roadway, automobiles alone would generate a median sound level of 69 dBA at 100 ft (30 m). Increasing the percentage of trucks from 0 to 20 percent raises the sound level from 69 to 75 dBA. This amounts to quadrupling the number of automobile sound sources if addition is on a simple energy basis, i.e., 20 trucks equals 320 automobiles or 1 truck equals 16 automobiles.

Another way to look at this is to consider a constant sound level of 69 dBA and ascertain what relative reduction in vehicle density is required as the number of trucks is increased. In this case we start with 100 vehicles per mile of roadway at 69 dBA. For passenger cars only and with 20 percent trucks, we have 69 dBA with 20 vehicles per mile of roadway. This comparison leads one to say that 4 trucks (20 percent of 20 vehicles per mile of roadway) plus 16 automobiles generates the same noise level as 100 automobiles.

HIGHWAY NOISE BARRIERS

Placing noise barriers along highways is another method for reducing vehicular traffic noise levels. Such barriers can be effective in reducing highway noise, and the higher the barrier the better (Table 5). The data do not fully indicate the direct relation between noise barriers and vehicle (especially truck) noise reduction. Noise emanates from trucks from several locations—exhaust stack, engine enclosure (casing radiation, cooling fan), and tires. Table 6 gives the complementary relation between barriers and truck noise reduction. If a typical truck is modified for quiet operation so that the exhaust noise is reduced by 15 dB and the engine noise by 10 dB, the total noise level at 100 ft (30 m) becomes 76.5 dBA, a reduction of 5.5 dB. Instead of quieting the truck, assume that an 8-ft (2.4-m) barrier is erected 25 ft (7.6 m) from the edge of the roadway. This barrier provides little noise reduction for the 12-ft (3.6-m) high exhaust noise, but substantial reductions for the engine and tire noises. The resultant noise level at 100 ft (30 m) is 78.5 dBA, a reduction of 3.5 dB. Now assume that both actions are taken together: The truck is quieted, and an 8-ft (2.4-m) barrier is erected. The resultant noise level at 100 ft (30 m) is 67 dBA, a total reduction of 15 dB.

Figure 28. Mean noise level estimates of mixed traffic.

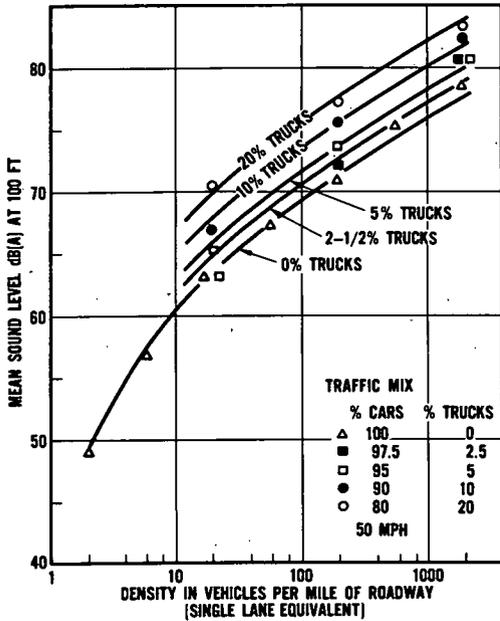


Table 5. Effect of noise-abatement measures on highway noise.

Number of Lanes	Noise Abatement Measure	Noise (dBA) by Distance From Edge				
		100 ft (30 m)	125 ft (38 m)	200 ft (60 m)	300 ft (90 m)	400 ft (1200 m)
6	None	78	77	74	71	69
	Landscaping, 100 ft	73	72	69	66	64
	Barrier, 6 ft	67	66	64	61	58
	Barrier, 12 ft	63	62	60	56	54
	Depressed roadway, 10 ft	73	72	69	64	61
8	None	80	79	75	72	70
	Landscaping, 100 ft	75	74	70	67	65
	Barrier, 6 ft	70	69	66	63	51
	Barrier, 12 ft	65	65	64	61	55
	Depressed roadway, 10 ft	75	74	68	65	62

Note: Traffic consists of 11,000 vehicles per hour and includes 5 percent trucks. Speeds are 53 mph (85 km/h).

Table 6. Relation of quieting truck and using roadside barriers to reduce truck noise.

Truck-Barrier Combination	dBA at 50 ft (15 m)			Total dBA at 100 ft (30 m)
	Exhaust ^a	Engine ^b	Tires ^c	
Typical truck	86	81	82	82
Typical truck quieted	71	71	82	76.5
Typical truck and 8-ft (2.4-m) barrier ^d	84	82	80	78.5
Typical truck quieted and 8-ft (2.4-m) barrier	69	62	70	67
Typical truck and 12-ft (3.6-m) barrier ^d	81	69	68	75.5
Typical truck quieted and 12-ft (3.6-m) barrier	66	59	68	64.5

^aAt a height of 12 ft (4 m) above roadway.

^bAt roadway.

^cAt a height of 5 ft (1.5 m) above roadway.

^dAt 25 ft (7.6 m) from edge of roadway.

Noise reduction in the vehicle will not by itself sufficiently reduce noise along highways and streets. Effective use of rights-of-way and land use controls along rights-of-way must also be undertaken.

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EFFECT OF MOTOR VEHICLE REGULATIONS ON HIGHWAY NOISE LEVELS

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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.

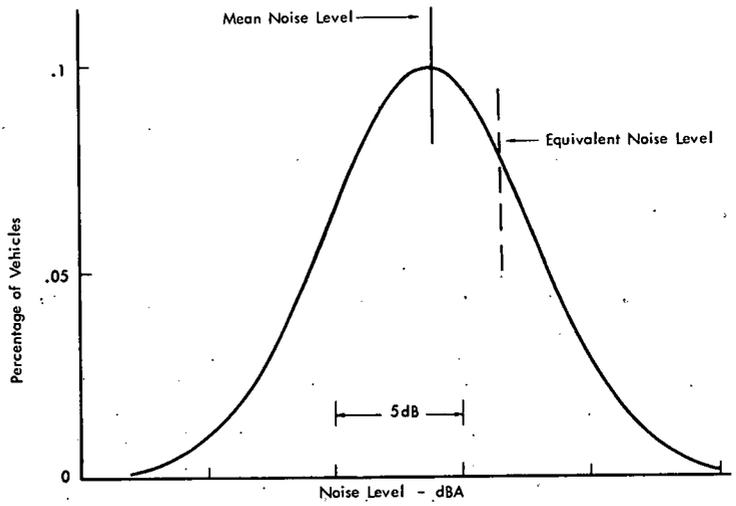


Figure 2. Effect of noise regulations on vehicle noise levels.

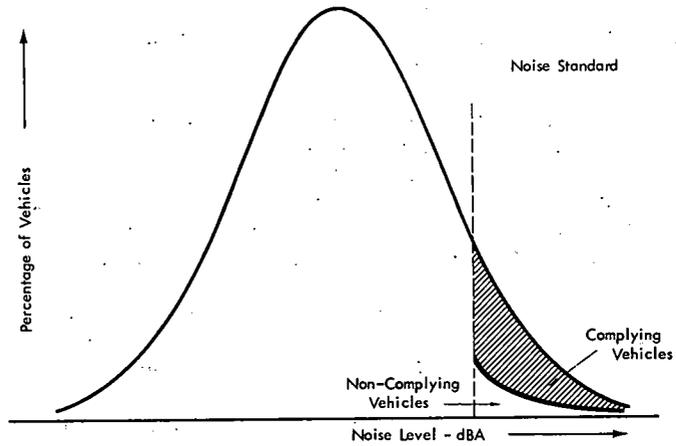
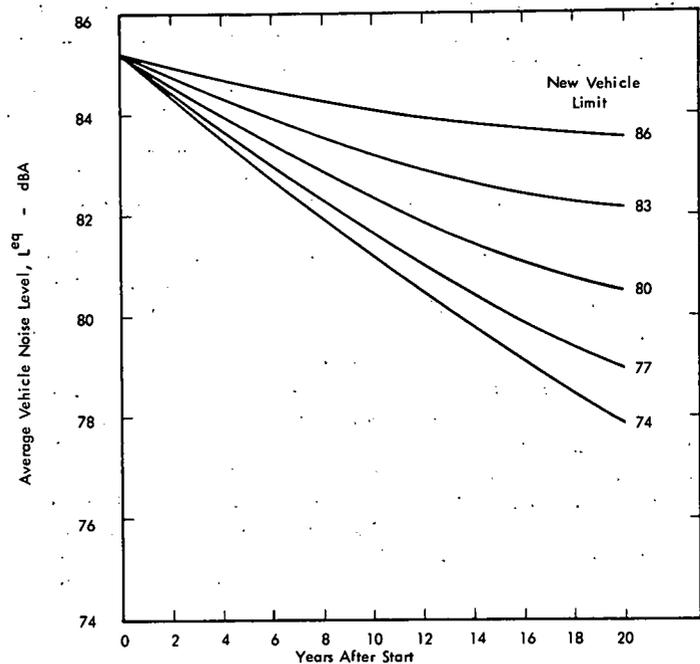


Figure 3. Decrease of L^{eq} with time for various new vehicle standards.



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

NOISE REGULATIONS AND VEHICLE NOISE DISTRIBUTIONS

The first objective is to determine the effect of motor vehicle noise regulations on L^a 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^a 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^a 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 hypothetical 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^a and the value of the noise limit is shown in Figure 4. As would be expected, the reduction in L^a 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.

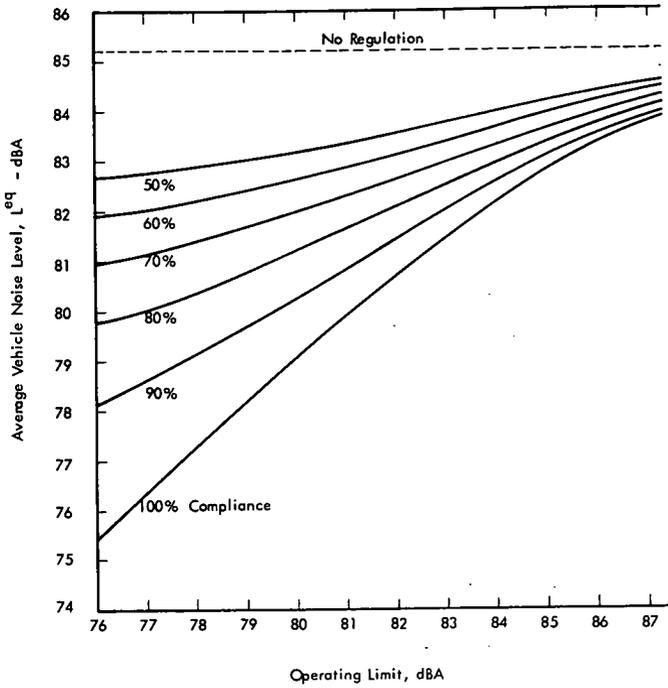


Figure 5. Overall noise levels of trucks operating in >35-mph (56 km/h) speed zones.

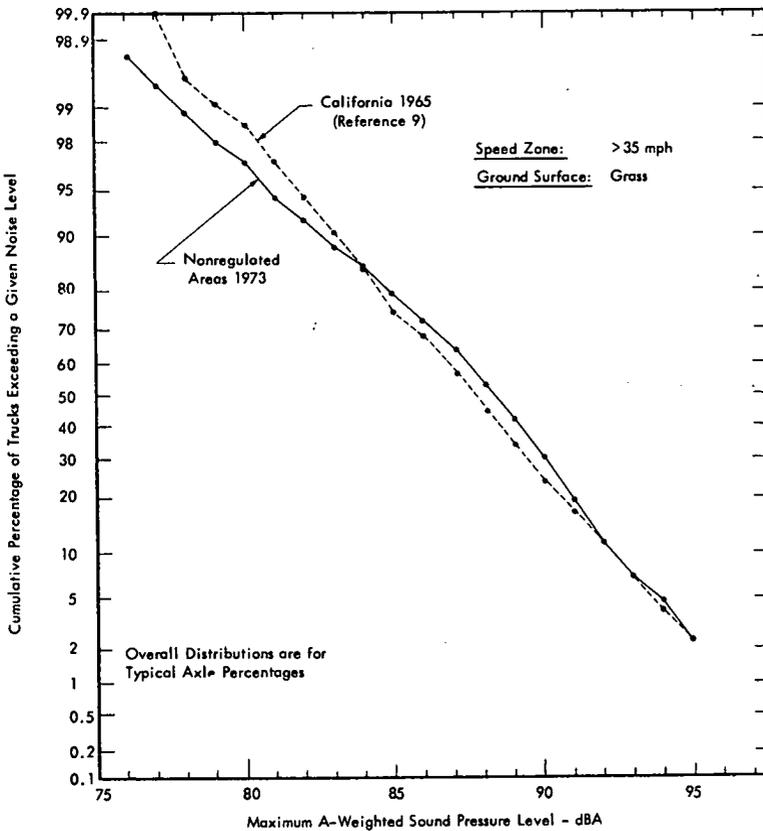
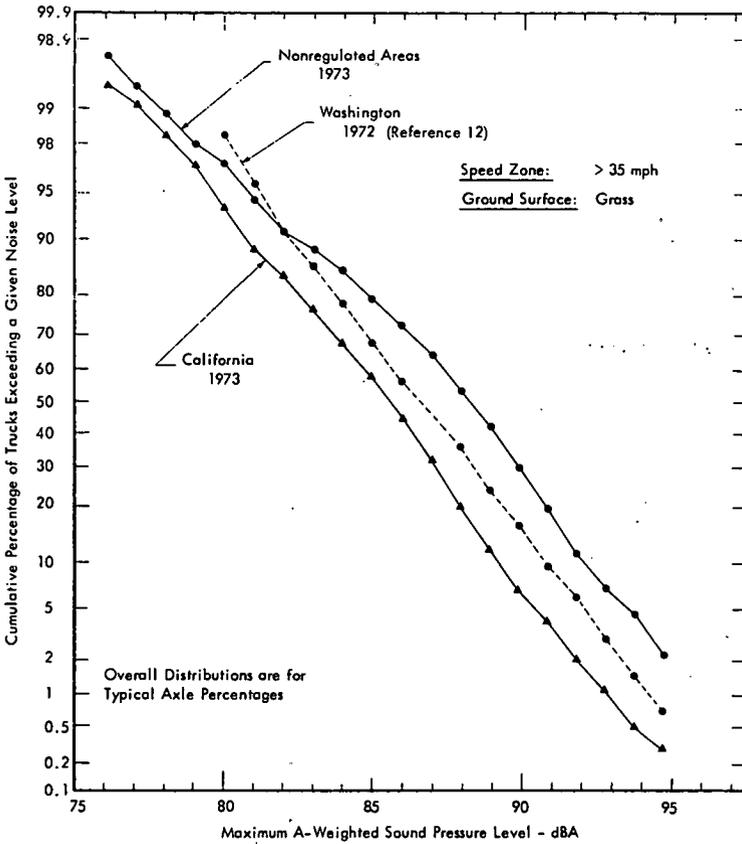


Table 1. Timetable for truck noise regulations in California.

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

^aMeasured 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).

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

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.

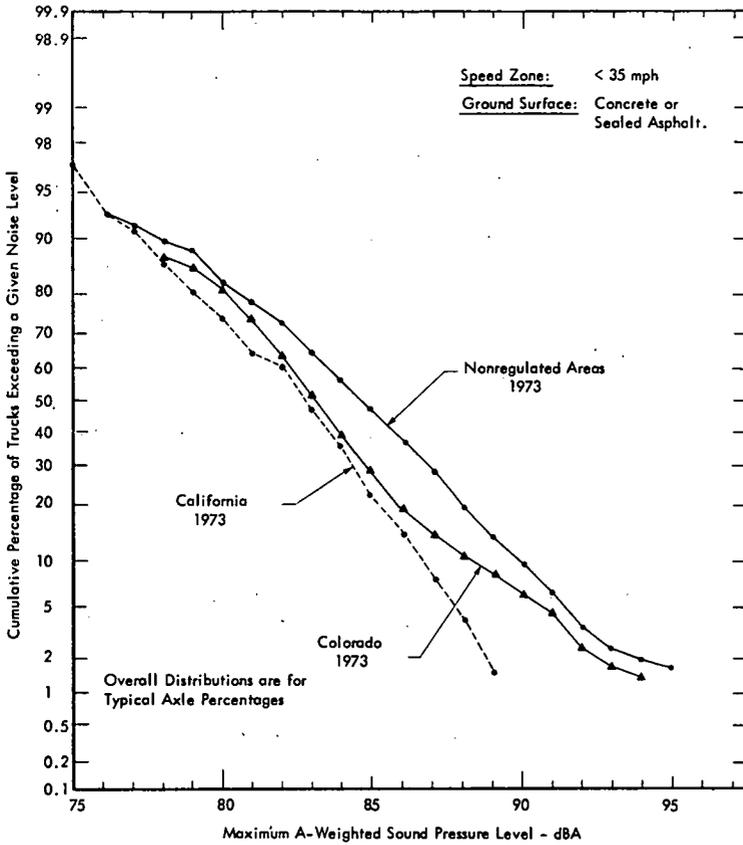
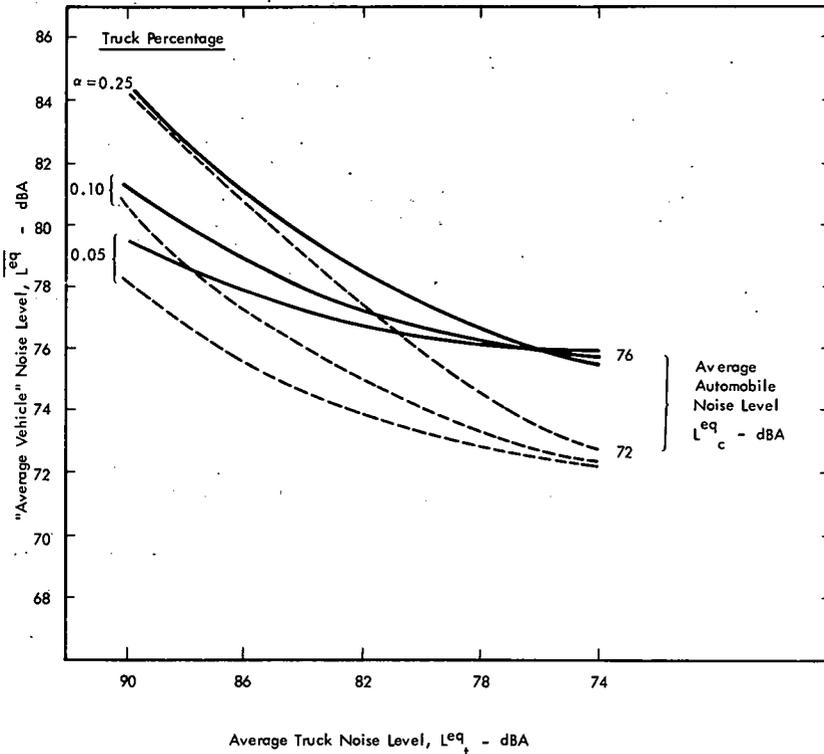


Figure 8. Effect on highway noise of reducing truck noise.



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.

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TIMETABLE AND OBSTACLES FOR SOURCE CONTROL IN THE CITY OF CHICAGO

H. W. Poston

Chicago Department of Environmental Control

The Chicago Noise Ordinance became effective July 1, 1971. The ordinance deals with all noise problems, but this paper discusses only motor vehicle noise.

Studies that we made throughout Chicago show that motor vehicles create high noise levels. Noise levels during a 24-hour period at the intersection of State and Madison streets stay above 60 dBA until the early morning hours, when the amount of vehicle traffic decreases, and decrease to 56 dBA at 3:00 a.m. Noise levels measured on the tenth floor of the Palmer House Hotel in the Loop were above 64 dBA until the early morning hours and decreased to 58 dBA at 1:00 a.m. One of the noisiest places in Chicago is near the elevated Calumet Skyway, which links the Indiana toll road with the Chicago expressway system. When large trucks roll over this expressway at high speeds at night, the noise levels are extremely disturbing.

The ordinance provides noise standards for new vehicles and for operating vehicles on city streets. Furthermore, we have requirements that prohibit the modification of vehicles to bypass noise control devices or the idling of large trucks for longer than 2 minutes and that specify noise levels for off-the-road vehicles such as snowmobiles and dune buggies and for vehicles not subject to registration.

The ordinance adopted on March 10, 1971, provides for a step reduction in noise levels from 92 dBA for motorcycles, 88 dBA for vehicles of 8,000 lb (454 kg) or more, and

86 dBA for cars and other motor vehicles on July 1, 1971, downward in 4 increments to 75 dBA for all vehicles by January 1, 1980. Each manufacturer selling vehicles in Chicago must certify in writing that they comply with these levels. This program has been successful and even resulted in General Motors taking several models off the Chicago market in a recent year.

During a typical month, our vehicle noise enforcement teams issued 210 summonses and 34 verbal warnings for violations that exceeded the ordinance by 3 dB. Out of 64 cases on the court call, 51 showed proof of compliance, 10 cases were continued, and 3 warrants were issued. We are greatly encouraged by the positive attitude shown by motorists in correcting these problems. In October 1974, 50 percent of the tickets issued for violations were for vehicular noise alone. More than 1 million vehicles are registered in Chicago, and many thousands more enter the city from the suburbs. We therefore need additional test sites, increased manpower, and continued local jurisdiction, for we are only scratching the surface of this problem.

For moving vehicles, we used 2 vehicle pass-by teams, each consisting of 2 inspectors and a police officer (Illinois statutes do not give inspectors power to halt moving vehicles). The measurement procedure is based on standards and recommended practices established by the Society of Automotive Engineers.

We find, unfortunately, that there is a lack of appreciation by the judiciary for the seriousness of vehicle noise as an urban menace. Few of the tickets issued result in fines because it is felt that loss of a day of work is sufficient punishment for a violator and a noise violation appears to be not so significant as a moving violation, some of which result in property damage or personal injury.

The control of motorcycle noise is the most difficult vehicle enforcement problem we have encountered. Apprehension of motorcyclists is very difficult because they operate largely during weekends and at night and they can weave through heavy traffic to escape apprehension. In addition, a motorcyclist can remove or reinsert muffler baffles in a matter of 15 minutes. The cyclist is frequently a type of individual who enjoys creating a lot of noise since noise is equated with power and also attracts attention. We are initiating studies to determine a successful approach to this elusive noise problem. Consideration is being given to amending the noise ordinance to prohibit the sale of modification equipment in the city of Chicago. Coincidentally, the Illinois Pollution Control Board is in the process of passing such a regulation. The passage of such a regulation in Chicago and not in the state would negate its benefits, for the owner would only have to go to one of the close-in suburbs to have a vehicle modified. Such an authority will act to greatly reduce the number of noise-modified vehicles operating in the urban environment.

The problem of emergency vehicles creating excessive noise is under consideration by our noise control personnel. An ordinance specifying maximum noise levels permissible, similar in scope to that proposed in New York City, is being considered. Our department has recently sent a letter to all independent ambulance services requesting them to caution drivers about improper or unnecessary use of sirens.

I am concerned about the recent trend of the federal government to preempt local ordinances in requiring certification of noise levels for new vehicles. I feel that local governments may have unique problems for which there is not sufficient awareness in Washington. For example, the federal government has proposed regulations establishing noise emission standards for new medium and heavy trucks. Chicago already has a vehicle certification program for new trucks that provides a 75-dBA limit for vehicles manufactured after January 1, 1980. The proposed federal regulations set the 75-dBA limit for January 1, 1983, thus allowing 3 more years for compliance. Federal standards for light trucks, passenger cars, and motorcycles are also under consideration by the U.S. Environmental Protection Agency.

Shortage of inspectors and police, lack of adequate test sites, attitude of some of the judiciary toward enforcement, and federal preemption make it more difficult for a local regulatory agency to have an effective noise-abatement program. Chicago welcomes testimony from organizations and other public agencies to support local noise standards for new vehicles. Federal standards are needed, but should not supersede more stringent local ordinances that are imposed to rectify local problems.

TIMETABLE FOR VEHICLE NOISE REDUCTION

Warren M. Heath
California Highway Patrol

The present California schedule of reduced noise levels for new passenger cars, motorcycles, trucks, and buses had its origins in a 1967 addition to the California Vehicle Code (1). That law established the first sound-level standards for new motor vehicles and was applicable to vehicles manufactured after January 1, 1968.

The new limits were a compromise between what was desired by the author of the bill and what was economically practical at the time. Under specified wide-open-throttle acceleration tests from initial speeds of 30 mph (48 km/h) or lower, limits were set at 88 dBA for trucks and buses, 86 dBA for passenger cars and pickups, and 92 dBA for motorcycles (with a limit of 88 dBA required after January 1, 1970). In a meeting prior to committee hearings on the bill, the author, the California Highway Patrol, and representatives of the vehicle manufacturers agreed to these numbers to the extent that they would allow the feasibility of metered noise enforcement to be demonstrated.

By 1970, the California legislature had become environmentally conscious in many areas and in that year adopted a resolution directing the state Department of Health to appoint an advisory committee on noise. The resolution stated that "some of the blame for the disorientation and frustration of today's urban life can be placed on the high noise levels that act as subliminal irritants, and, in addition to these mental symptoms, definite and measurable hearing loss has been found among those who work or play under

noisy conditions." It requested that a report be prepared "on the subject of noise including the noise from industrial equipment, construction, motor vehicles, boats, aircraft, home appliances, electric motors, combustion engines, and any other noise-producing objects, identifying the sources of noise pollution, and recommending means of controlling the harmful effects of noise, including recommending standards of noise level emissions." Quite an assignment to be accomplished within a 5-month deadline by a voluntary advisory committee that was not then in existence!

The committee appointed by the Department of Health consisted of 20 members from various public organizations, private firms, and associations. The deadline for preparing the report was so short that there was time for only 3 monthly meetings of the full committee and no time for research or literature review. The information and recommendations included in the final report came from the knowledge, opinions, and feelings of the individual members.

The first meeting began with a discussion of the full range of noise problems and their effects. It ended with the drafting of tables of sound measured at the hearer's ears relating to (a) noise levels at which various harmful effects occur, (b) levels that people want, (c) levels that people will accept without undue complaint, and (d) estimated community response to noise at various levels above the acceptable levels. The tables included levels for locations ranging from industrial zones to wilderness areas.

It was obvious that there was not enough time for the committee to recommend either limits or methods of source control for a large number of products as different as kitchen garbage disposals and supersonic aircraft. Thereafter, its effort was concentrated on making specific recommendations concerning transportation noise. Vehicle noise and aircraft noise caused the most complaints throughout the state. More important, in each of these areas, state departments were already working on the problems and were actively enforcing the limited standards that were then in effect. It was felt that more benefit could be obtained in the short time available by enhancing programs already in operation rather than by attempting to establish a catalog of noise limits on items that would require legislative enactment of new programs.

The committee eventually adopted 13 recommendations: 1 applied to the establishment of an office of noise abatement at the state level; 2 applied to aircraft noise; 1 recommended a 75-dBA occupational noise exposure level mandatory for all industry by January 1, 1980; 6 applied to motor vehicle noise; 1 applied to freeway barriers and design features; 1 recommended that state agencies require noise control on equipment that they purchase or that is used in construction of state projects; and 1 requested that the advisory committee on noise be continued (2).

Since the emphasis of this paper is on vehicle noise, only the committee recommendations pertaining to that subject will be discussed.

NEW-VEHICLE NOISE LIMITS

After much somewhat unfruitful discussion on the wide-ranging subjects of vehicle noise, its measurement, and its control, the advisory committee decided its most effective procedure would be to develop a recommended schedule of noise reduction during a period of several years. In the past, different sessions of the legislature seemed to have differing attitudes toward vehicle noise reduction and the amount of noise reduction that was economically feasible. Vehicle manufacturers were faced each year with the threat of new legislation and had no lead time to do necessary research and make changes in the design and production of their vehicles.

A schedule recommended in 1970 to project decreasing levels in coming years would meet 3 objectives: (a) establish an eventual limit that was low enough to practically eliminate public annoyance and complaints, (b) allow sufficient lead time so manufacturers could design and tool up to meet production deadlines, and (c) allow the legislature to consider in an orderly manner any needs that may arise for future revisions of the timetable. Table 1 gives the schedule that was finally adopted by the committee (with far from unanimous agreement).

Table 1. Timetable for noise reduction of new vehicles.

Year	Trucks and Buses (dBA)	Passenger Cars, Pickups, and Motor-Driven Cycles (dBA)	Motorcycles (dBA)
1970	88	86	88
1973	86	84	86
1975	83	80	80
1978	80	75	75
1988	70	70	70

Note: Noise was measured at 50 ft (15 m) from the centerline of the vehicle.

The levels shown for 1970 and 1973 were already in the Vehicle Code at the time the advisory committee met. The 1973 values had been adopted in 1969 to give manufacturers 3 years to reach the new limits. The proposed 1975 date for further lowering the limits was intended to give new-vehicle manufacturers 3 years from the 1971 session of the legislature to bring their vehicles into compliance.

With respect to trucks, 83 dBA was proposed on the basis of what could be done by using knowledge already avail-

able without a massive increase in cost to quiet the larger vehicles. The committee recognized that this limit would require a substantial reduction in exhaust system noise on heavy diesel-powered vehicles, quieting of intake noise and fan noise, and provision of some sound-absorbing enclosures on certain models.

The 1975 passenger car limit of 80 dBA was based on information that many of the car models already complied with an 80-dBA performance and the belief that the louder models should be reduced to that level. It was also thought that by 1975 new motorcycles should be quieted to the same level as new passenger cars instead of being as loud as trucks, as previously permitted.

The 1978 level of 80 dBA for trucks was proposed as a limit that was considered to be possible with available knowledge but that will require extensive changes in the vehicle and engine. A lead time of 7 years will probably be required, and major increases in manufacturing costs will have to be passed on to the truck operators in the form of higher prices.

The committee recognized the desirability of coordinating the noise-reduction schedule with a proposed timetable for air pollution emission standards for diesel trucks, because both affect engine design. Such coordination was not accomplished, but later modifications in the emission standards seemed to make it less essential.

The 1988 requirement of 70 dBA for all classes of new vehicles was a conjectural one that had little support among most of the members of the committee. It was included because it seemed to be an acceptable limit below which further quieting of vehicles would not be necessary to eliminate general complaints. Information was not available to indicate that far in advance whether it would be an acceptably low limit for the public and whether it would be economically feasible for manufacturers. The 70-dBA limit was not technically feasible with the then-current types of trucks, tires, and engines, but it would allow manufacturers a lead time of at least 16 years to attempt to meet that goal.

The foregoing proposals applied only to the maximum noise produced by a single motor vehicle from an initial speed of 30 mph (48 km/h) or less. Vehicles that met these limits under the low-speed, wide-open-throttle acceleration test would not necessarily be this quiet on the highway. The enforcement limit for open highways would need to be greater because the new-vehicle tests do not include tire and other operational noises that occur at higher speeds, nor do they include the additional noise produced by tires and running gears of trailers and semitrailers.

The recommended schedule of new-vehicle noise reduction was enacted into law in 1971 and has already proved to be more effective than anticipated. It has resulted in the quieting of new vehicles sold not only in California but in many instances across the country. It has also served as a point of departure for other states, the federal government, and some cities in developing their own new-vehicle noise requirements.

The schedule has given manufacturers the opportunity to present their cases before the legislature in instances where they thought the timetable could not be met. Motorcycle manufacturers successfully obtained legislation in 1974 to raise the proposed 80-dBA limit for 1975 to 83 dBA, thereby keeping cycles at the same loudness level as trucks instead of quieting them to the passenger car level. The truck manufacturers

at the same session sought legislation to postpone the 83-dBA limit for 2 years because the difficulties in bringing a few of their louder models down to this level would result in discontinuing their sales in California. That legislation did not pass, and, at the time of this writing, the limit remains at 83 dBA for trucks sold in California after January 1, 1975.

HIGHWAY NOISE LIMITS

Quieting new vehicles in itself will not effectively reduce highway noise unless quiet limits on vehicles in use are enforced. An attempt was made by the committee to set a highway noise-reduction schedule similar to that for new vehicles. However, such a long-term proposal would have been even more of a guess than that for the new-vehicle standards. No information was then available on the practicality of bringing older vehicles into conformance with substantially lower standards in future years. The committee limited itself to making the one-step proposal given in Table 2 beyond the already scheduled 1973 limits in the Vehicle Code.

The proposed 1975 reductions in the limits for trucks were at that time thought to require no basic redesign of the older trucks or engines but only the use of the best available mufflers and quiet-running tires. Obtaining the reduction was recognized to be far more difficult for diesel truck operators than for operators of other classes of trucks.

Truck operators were having difficulties in obtaining mufflers to meet the 88- and 90-dBA limits, principally because of lack of communication among the dealers, the service shops, the original truck manufacturers, and the muffler manufacturers. The California Highway Patrol, in following up on the outcome of muffler violations, was told by older truck owners that 2 or 3 replacements had to be made before they stopped receiving noise-limit violation notices. The industry was not prepared for servicing older vehicles with muffler systems that were adequate to meet the then-current limit.

The highway noise limits recommended by the committee were not enacted into law, as was the new-vehicle noise schedule. There was no assurance that owners would be able to obtain equipment at reasonable cost to further quiet their vehicles. The results of a 1965 study conducted by the California Highway Patrol indicated that the proposed 1975 limits would have been exceeded by 38 percent of the diesel trucks at speeds greater than 35 mph (56 km/h), a violation figure that appeared to be unacceptably high to the author of the other noise bills.

Not yet developed is a practical means of applying lower highway limits to vehicles manufactured after 1974, so the quieter new vehicles cannot be modified to produce as much noise as the current operational limits. Any legislation on this subject will apparently need to include a 2-level arrangement to keep newer vehicles properly muffled while allowing relief for older vehicles that cannot economically be quieted to lower levels.

Table 2. Timetable for noise reduction of in-use vehicles.

Year	Trucks and Buses (dBA)		Passenger Cars, Pickups, and Motor-Driven Cycles (dBA)		Motorcycles (dBA)	
	<35 mph*	>35 mph	<35 mph	>35 mph	<35 mph	>35 mph
1970	88	90	76	82	82	86
1973	86	90	76	82	82	86
1975	83	86	74	78	74	78

Note: Noise was measured at 50 ft (15 m) from the center of the lane of travel.

*56 km/h.

HEAVY TRUCK CLASSIFICATION

The committee's recommendations continued in effect the gross-vehicle-weight rating (GVWR) of 6,000 lb (2770 kg) that was the dividing point between light trucks and heavy trucks. This figure originated in 1967 when a survey made by the California Highway Patrol of pickup trucks manufactured before that date indicated a substantial proportion of $\frac{3}{4}$ -ton (680-kg) pickups were rated at less than 6,000-lb GVWR. Since then, various federal safety regulations, a public interest in improved styling, comfort and accessories, and stronger components for carrying heavy camper bodies have resulted in most of these vehicles now being heavier than the 6,000-lb limit.

Some of the 4-wheel-drive vehicles that used to be in the lightweight jeep category, minivans that used to be in the Volkswagen bus category, and medium-sized pickups now exceed the 6,000-lb limit. California law should now be changed to adopt the 10,000-lb (4534-kg) division point contained in the Environmental Protection Agency standards applying to noise from motor carrier vehicles engaged in interstate commerce.

NEW URBAN TRANSIT BUS LIMITS

Several members of the committee were quite concerned about the high level of noise emitted by city buses when they accelerated from an intersection or bus stop under full power. They proposed an additional new-vehicle limit that would apply to city transit buses. Measurements would be taken with a microphone at a distance of 15 ft (4.6 m) from the centerline of the vehicle. Readings would be taken as the vehicle accelerated from a standing stop; the distance from the starting point to the point at which the rear of the bus passed the microphone has yet to be established.

The suggested new-vehicle limits for this test at 15 ft were the same as those for the trucks and buses under the 50-ft test. No data were available to support the proposed numbers, and this recommendation did not find its way into legislation.

CERTIFIED TIRES

The committee realized that quieting traffic noise on open highways would not result simply from continually lowering the noise of new vehicles accelerating under full power. At fast speeds, high noise levels still persisted even when engine and exhaust noises had been substantially reduced.

A number of tests by passenger car manufacturers showed that cars at high speeds gave much the same sound-level readings whether their engines were operating or not. The noise from these cars was principally produced by the tires on the road. Truck manufacturers also found the same situation to be true. Quieting the exhaust and power plant noise of a new truck to levels below the 1978 levels would not have any effect on the total noise produced by a combination of vehicles at legal highway speeds (although it would quiet low-speed operation).

The next major step in noise reduction was eliminating noisy tires. At that time, an operator who was cited for excessive noise due to loud tires had no way to determine which tires on the market could be used to correct the violation. Truck operators needed a list of tires that were certified by the manufacturer as being below certain noise-level limits both when new and when well-worn.

As a result of the committee's recommendation, legislation was enacted requiring the California Highway Patrol to adopt regulations setting noise standards for pneumatic tires. These standards were to be the lowest level of noise consistent with economic and technological feasibility and with public safety. The law specifies that the U.S. Department of Transportation must be considered before independent standards are developed for tire noise. Tire noise standards have not yet been adopted because the federal transportation department has not published (as of 1974) a report of its tire noise study.

CERTIFIED MUFFLERS

Considerable committee discussion was devoted to the observation that truck operators in particular and other operators in general could not know with reasonable certainty whether a particular replacement muffler would quiet a vehicle to within the highway operation limits. Many members expressed a desire for the state Department of Health to publish a list of certified mufflers similar to the present lists of approved lighting equipment. Other members of the committee, including representatives of the health department, were concerned that such a program as then conceived would be so unwieldy as not to be enforceable. The approving and listing of mufflers for every combination of vehicle model, engine type, and exhaust pipe configuration appeared to be a monumental task.

Despite the potential problems, legislation was enacted and funds were appropriated for the health department to conduct a study of the most feasible method of certifying exhaust systems. This study was done under a contract awarded to McDonnell Douglas Astronautics Company (3). Stationary vehicle test procedures were suggested as a simplified method of manufacturers' certifying the contents of their exhaust system catalogs.

An informal advance notice of proposed regulations based on the report was mailed to major organizations. Extensive comments received on the informal proposal and a considerable amount of test data were presented. This information resulted in a revised official notice that has been mailed to the industry and interested parties for formal comment.

INSPECTION OF MUFFLER RETAIL OUTLETS

The committee believed that muffler retail outlets should be inspected in the same manner as lighting equipment outlets to prohibit the sale of illegal mufflers that are designed to increase noise output of a vehicle. The new law on exhaust system certification, in conjunction with certain laws that were already in existence, will allow this to be done.

The proposed exhaust system certification regulations will require exhaust systems and their major components listed in any catalog to be certified by the manufacturer as meeting the noise limits for the particular vehicles for which they are listed. When the certification program becomes operational, the officers who inspect retail outlets throughout the state for illegal automotive equipment will include mufflers on their list of items to be checked.

MUFFLER CERTIFICATION STATIONS

The development and licensing of official muffler certification stations similar to the present official stations for lamps, brakes, and air pollution control devices on vehicles were suggested. It was proposed that the health department develop instrumentation and test procedures for such stations so that a vehicle that is cited for exhaust noise can have the violation cleared by a test at an official station in a similar manner as for headlamp-aim violations.

This recommendation was adopted in legislation requiring the department to establish regulations for licensed exhaust-system certification stations. Proposals for stationary tests to be conducted at licensed stations were included in the McDonnell Douglas report (3). These proposals, as modified by the department, have been sent out for comment in a notice of proposed regulations.

DYNAMOMETER TESTING

The committee informally suggested that the health department consider installing

chassis dynamometers at each of the on-highway truck inspection facilities for measuring the noise output of trucks under full power. This recommendation was not implemented because such an operation would be quite expensive in terms of land, equipment, and personnel for the number of violations that might be detected. It also had other problems, such as tire noise on the dynamometer rolls and slippage between the tires and rolls under full load.

The EPA noise limits that were recently adopted for motor carriers engaged in interstate commerce appear to be a more feasible type of stationary test. The EPA standard establishes a limit of 88 dBA at 50 ft (15 m) for trucks equipped with governors when the accelerator is rapidly opened and held open until the engine reaches the governed rpm. It has been included in the proposed California regulations for certified exhaust systems and licensed muffler stations.

The advisory committee also suggested, prior to the idea of a stationary test, that moving-vehicle testing facilities be set up at the local highway patrol offices. The intent was that any road patrol officer who apprehended a vehicle that appeared to be excessively loud could require the driver to take it to a highway patrol office for a noise test using a sound-level meter.

This suggestion was not entirely practical because of land and personnel costs and the excessive travel distances for motorists. Part of it will become effective when muffler stations are licensed and authority is obtained for passenger vehicle inspection teams to take sound-level readings on exhaust systems when the vehicle is stationary.

HIGHWAY MEASUREMENT SITES

The committee encouraged the health department to proceed as rapidly as possible with a study on easing the restrictions on highway measurement sites. At that time, the test procedures specified 100 ft (30 m) of clear area around the microphone and around the portion of the roadway on which vehicles were being measured. The requirement for large, clear, open areas was so restrictive that it was difficult to find test sites except on major highways. Enforcement on most city streets was not possible because of the proximity of buildings.

The study was conducted by Wyle Laboratories under contract to the health department (4). Regulations allowing for sound-level reading corrections based on variations in test distance from the center of the roadway to the microphone and on the presence of reflecting buildings and other objects within 10 ft (3 m) of the microphone were subsequently adopted.

INCREASE IN NOISE TEAMS

When the committee was reviewing vehicle noise enforcement, the health department had 6 noise teams in the field working half-time. These teams could not cover all locations that had obvious noise problems. Doubling the number of noise teams was informally recommended. The following year the teams that were operating only half-time were assigned to full-time enforcement. Every year since, the department has budgeted for an increase in the noise-enforcement teams but has not been successful in obtaining additional person-hours.

LOCAL NOISE ENFORCEMENT

A further informal recommendation was that local law enforcement agencies establish noise-enforcement programs. With few exceptions, most police departments understandably consider vehicle noise enforcement to be an incidental function subordinate to traffic safety. Noise violators are not sought out but are apprehended only when an outstandingly loud vehicle happens to be encountered.

In most cases, exasperating noise in residential areas occurs sporadically and in locations where the use of meters is not feasible because the violators who go out of their way to make noise temporarily avoid operating where the meters are. Officers who are informed of noise problems and who observe the defects can more effectively apprehend these violators under current muffler statutes. Suitable backing from the courts is also required.

Although there is no statewide control over the operation of local enforcement agencies, the health department has assisted some in training their officers in the use of sound-level meters. It has also encouraged individual police departments to increase noise enforcement by all officers assigned to traffic duty. The highway patrol has expanded its enforcement in this manner by a substantial amount in recent years. In fact, 97 percent of the department's exhaust-system enforcement actions are taken as a result of eye and ear observations and not by meter readings. During times when one member is off duty, an instrument is being repaired, or the wind is too high, even the noise teams disperse to problem residential areas or locations around schools where enforcement by ear has been quite effective.

TESTS FOR MAXIMUM NOISE

The committee recognized that the test procedures for new vehicles in effect at that time did not measure the maximum possible noise that the vehicles could produce. The only exception was the procedure for trucks; however, even in this case, a particular condition of operation was found that would emit slightly more noise than the standard procedure. The committee consequently recommended that the new-vehicle tests be conducted in such a manner as to produce maximum noise.

As a result of the recommendation, some minor changes have been made in the regulations, such as now requiring cars with 5-speed transmissions to comply with the new-vehicle noise limits in first gear as well as in second gear. The health department has also participated in work of the Vehicle Sound Level Committee of the Society of Automotive Engineers in developing tests to measure the maximum acceleration noise from passenger cars and from motorcycles.

It has not been possible to adopt these procedures as administrative regulations without some legislative increase in the Vehicle Code limits. Those limits were based on the current methods that produce less than maximum noise for many vehicles. Also, the vehicle manufacturers are concerned that such procedures would allow a low-powered vehicle that requires most of its power, and consequently maximum noise, during cruise conditions to be louder on the highway than a high-powered vehicle that uses only a portion of its power for cruising.

ABOLISHMENT OF ADVISORY COMMITTEE

Perhaps the best way to end this paper is with the statement that the legislature rejected the recommendation that the advisory committee be continued in existence. Unlike other similar committees, it accomplished its major purpose in a short time and then disbanded. Seven of its recommendations were partially or fully enacted into law. Despite some major disagreements among members of the committee and the cursory way in which some of the recommendations were developed, the committee's report had a substantial influence on new noise legislation for motor vehicles.

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NOISE CONTROL FOR MOTOR VEHICLES: HOW FAR SHOULD WE GO?

Donald R. Whitney
General Motors Corporation

The Federal Noise Control Act of 1972 requires the identification of major noise sources. Under Section 18, noise emission standards for motor carriers engaged in interstate commerce were promulgated on October 29, 1974. Under Section 17, noise emission standards for railroads in interstate commerce were published July 3, 1974. As a requirement of Section 6, the Environmental Protection Agency published proposed standards for new medium and heavy trucks on October 30, 1974.

General Motors has been involved in noise control programs concerning both interior and exterior vehicle noise for more than 35 years. Control of interior sound is necessary to satisfy GM customers, and control of exterior sound is necessary to satisfy the community.

General Motors believes a federal noise control act was needed to achieve uniformity of standards across the nation through preemption of state and local regulations. Without federal preemption, the multiplicity of levels, test procedures, and compliance requirements that were being proliferated at an increasing rate by state and local governments would place a prohibitive burden on the manufacturer and add confusion to the work of the enforcing agencies.

Further, differing state and local requirements for motor vehicles meld into confusion as a result of travel, transfer, and resale of products among communities. Federal preemption will eliminate the chaos with respect to dBA values. Included within the federal

regulation should be a compliance enforcement program that ensures equal treatment for all.

We have determined that passenger cars and light trucks under 10,000 lb (4540 kg) frequently contribute significant amounts of sound energy when they are not well maintained or when they are intentionally modified to be noisy. Passenger cars and light trucks manufactured during 1973 and 1974 and in good repair typically produce sound levels in the following ranges when they are operated in the modes listed:

<u>Operating Mode</u>	<u>Range (dBA)</u>
SAE J986a pass by	78 to 85
Normal city acceleration	62 to 74
40-mph (64-km/h) cruise	64 to 70
55-mph (88-km/h) cruise	68 to 75
70-mph (113-km/h) cruise	73 to 80

The SAE standard J986a test results represent near maximum power-plant noise of these vehicles. However, the levels emitted during normal operation are considerably lower. An investigation carried out by General Motors indicates that wide-open-throttle operation, and thus maximum power-plant noise, occurs less than 1 percent of the time. We have recently determined that sound levels of normal city acceleration for new light vehicles will be reduced somewhat when the wide-open-throttle sound level is reduced to 80 dBA beginning with 1975 production.

We wish to emphasize that newly manufactured vehicles are now performing in the community at acceptably low sound levels. Therefore, to consider a further reduction of the noise level standard that is associated with a 1 percent mode of operation of light vehicles is absolutely unnecessary. Additional regulations should not be imposed on the manufacturer in a misguided effort to reduce community sound levels. Rather, necessary regulations and enforcement programs should be adopted to ensure that users are held responsible for the operation and maintenance or modification of their vehicles. This approach will accomplish the most good with the least overall expenditure.

If the new passenger cars and light trucks are not the major cause of motor vehicle noise, then what is? The recently promulgated regulation for interstate motor carriers, which will become effective October 1975, established a limit of 86 dBA at 50 ft (15 m) from the lane of travel for speeds less than 35 mph (56 km/h) for vehicles weighing more than 10,000 lb (4540 kg) GVWR.

Even though the interstate motor carrier regulation is generally interpreted to include all trucks moving and handling goods in interstate commerce, probably only those vehicles operating on major highways will be inspected by the Bureau of Motor Carrier Safety. Therefore, a large segment of trucks used in urban areas (or intrastate) will probably escape federal enforcement. It is believed that these vehicles tend to be older and less well maintained. At the same time many of them are operated in densely populated areas and may expose the public to many times the noise energy of similar but well-controlled trucks. Allowing high noise-energy-producing vehicles to continue to operate in densely populated areas does not meet the objective of the interstate motor carrier regulation.

This regulation will not be an effective means of noise control unless all states adopt regulations that are identical to the interstate motor carrier regulation. This must be done to allow enforcement by local law officers, for the critical factor in accomplishing the first big reduction in highway transportation noise is effective enforcement. Uniform action in this area should be encouraged.

What should be the goal for quiet trucks? First, we must determine what community sound level is acceptable from the standpoint of the effects on the people and then determine what portion of the noise exposure is associated with trucks. Some of the current community noise models employed to evaluate potential progress in community noise reduction assume that all trucks already comply with the new interstate motor carrier regulation (86 dBA). When this condition is actually attained, we may

well have achieved a significant reduction in the ambient levels and the annoyance caused by the loudest vehicles in communities.

One fundamental but extremely important point that must be understood is that, when designing a vehicle to meet a regulated level, a manufacturer must establish a design margin sufficiently below that standard to assure that vehicles will comply. In so doing, the mean sound level of the vehicles produced to comply with a regulated standard will be some 2 to 3 dB below that standard. Thus, new vehicles produced to comply with a regulated level of 86 dBA will have a mean level in the range of 83 to 84 dBA, and new vehicles produced to comply with a regulated level of 83 dBA will have a mean level in the range of 80 to 81 dBA.

The vehicle manufacturer has little control over the other major highway noise source, namely, the interaction of the tires with the road. Of course, there are noisy tires and quiet tires, and proper selection will eliminate the worst offenders. However, tires perform many functions related to vehicle control and safety, and those must not be overlooked in determining the selection of quiet tires. There is a floor or minimum tire sound level that is speed dependent and essentially determined by a smooth tread or blank tire. Many designs of acceptable tires produce noise levels within about 5 dBA of the tire noise floor. A 5-dBA range from the tire noise floor should be used as a starting point for a performance guideline in future noise considerations. Barring a technical advance that we do not now foresee, tire noise will continue to establish a noise level floor while vehicles are operating at highway speeds. These levels are quite predictable based on the traffic volume, the kinds of vehicles, the sound levels of those vehicles, the traffic mix, and vehicle speed.

The motor vehicle industry is in the process of evaluating the federally proposed regulation on new medium and heavy trucks. To evaluate the ability and time required for industry to comply with a new regulation, we must define where we are now and where we will have to be when the new regulation is in effect. The preamble to the proposed regulation defines available technology in part as "technology applications that have been demonstrated to be feasible, as a prototype product upon which production manufacturing may be based." Such a demonstration on 1 or 2 trucks does not by any stretch of reason constitute evidence that the design is fit to be engineered into mass production. Hundreds of basic vehicle configurations need to be designed and extensively tested for performance, safety, reliability, and durability. Let me illustrate a few of the considerations.

1. The use of a specific muffler with a specific engine can have widely varying results depending on the relative locations, lengths, and diameters of pipes. One cannot simply specify that muffler 32 be used with engine D and guarantee the resultant sound level of the exhaust system.

2. Cooling systems must be designed to be adequate for the maximum demand condition even though that condition may seldom occur in the operation of any given truck. For trucks that require engine side-shielding and underpans to meet noise regulations, cooling becomes increasingly difficult. Since maximum cooling capability is required only a small percentage of operating time, a thermostatically controlled fan clutch can be used with attendant noise reduction and economy of operation when the fan is declutched. The fuel savings available in addition to the noise benefits will most certainly increase the use of clutch-controlled fans. During normal testing of the truck under the SAE standard J366b, the thermostatically controlled fan will not be in operation.

3. Engine-radiated noise becomes the dominant noise on many trucks after the exhaust, fan, and intake noises are sufficiently quieted to meet a regulated level of 83 dBA. Engine shielding presents a major problem of redesign when it must be integrated into existing configurations. Shielding in turn affects cooling, durability, and maintainability.

The cost of all aspects of obtaining products that are acceptable under the proposed new truck standards must be weighed against the benefits received. When we attempt

to quantify the benefits, we must consider the degree of reduction of noise and the number of people who are benefited. Benefit has been measured in terms of freedom from interference, freedom from annoyance, and improvement of the quality of life. The quantitative transfer functions by which we can relate these positive effects to economic values are difficult to derive at best and are subject to individual opinion. The costs are much more apparent. One of the considerations of cost during the remainder of this decade must be that noise control of vehicles contributes nothing to the productivity of the vehicles and with few exceptions contributes nothing to the productivity of the surrounding community. Adding cost to a product without increasing its productivity contributes to the inflationary trend. In the current economic climate, the value of reduced noise levels must be considered carefully. We should reserve the decision relative to the proposed federal levels of 80 and 75 dBA until the effectiveness of the regulation at 83 dBA including enforcement can be evaluated.

The strategy to be implemented for noise control should be considered not solely on the basis of whether new vehicles can be manufactured to these limits but also on an assessment of all of the effects including the reduction of the average energy level of overall highway noise, L_{eq} , and the day-night level, L_{dn} , and the effect of the single older loud vehicle on the affected population.

With that background and philosophy, let us now consider the following statements.

1. The cost of trucks per dB reduction in sound level rises rapidly as the mean level is decreased below 80 dBA.
2. In terms of the number of people exposed to various sound levels and the degree of reduction of that exposure, the benefit per dB reduction diminishes as the sound of the vehicles perceived by the listeners approaches the background levels established by tires and other ambient noise.
3. Therefore, the cost-benefit ratio, which is a function of both of the above effects, increases rapidly as the noise level of trucks is reduced below the range of 80 to 81 dBA, which would be the mean sound level corresponding to a regulated level of 83 dBA.
4. The following statements place in perspective the benefit of attaining mean levels in the range of 80 dBA for maximum noise of new-truck power plants.
 - a. New trucks will be mixed in with existing trucks, which have noise levels that range more than 10 dBA higher, such that 1 newly manufactured truck will emit only a tenth of the energy output of 1 old poorly controlled truck.
 - b. The interstate motor carrier regulations can only affect that fraction of the operating medium and heavy trucks that come under the surveillance of the Bureau of Motor Carrier Safety.
 - c. The eventual adoption by all states of identical regulations will permit enforcement nationwide so that a uniform level of 86 dBA may be achieved.
 - d. But these levels will be achieved only if vigorous enforcement policies are implemented with instruments and personnel.
 - e. If we are successful in bringing these trucks to 86 dBA, truck power-plant noise will be materially reduced. And the manufactured trucks with a mean sound level near 80 dBA will emit only about a fourth of the energy of those older trucks. Therefore, as the numbers of new trucks increase, the community noise level resulting from trucks will decrease materially.
5. Considerations relative to reducing power-plant noise of trucks should take into account the technology and attainable levels of tire noise. Power-plant noise in the 80-dBA range is dominated by tire noise at highway speeds for a typical 5-axle truck fitted with rib tires except for the cross-bar tires on the drive axles.
6. Adding cost without substantial benefit to both the customer and the community should be viewed cautiously, especially in an inflationary period.

Is it logical and cost-effective to assign to trucks a regulated noise level lower than 83 dBA? At this time, we think not!

STANDARDS DEVELOPMENT AS A FACTOR IN MOTOR VEHICLE NOISE ABATEMENT

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General Motors Proving Ground

The groups who write standards are certainly a factor in the process of vehicle noise reduction through control of the source in that the standards establish measurement and evaluation techniques and also the basis for technical communication.

According to the Society of Automotive Engineers, the definition of a standard is, "The documentation of sound, established, broadly accepted engineering practices." As such, it may take the form of a test procedure or performance requirements. If we consider standards pertaining to product noise and examine them in the context of the Noise Control Act of 1972, these standards (and any resulting regulations) must take into account health and welfare (which is to say, established criteria), available technology, and also the cost of control and its effectiveness.

The use of the term standard implies that there is a consensus of concerned parties, so perhaps we need to identify these concerned parties. They may be groups having rather limited or special interests: environmentalists, trade association members, research academicians, or perhaps just someone who has an ax to grind. On the other hand, they may be a standards writing group that has a broad-base of participants and national and international representation. In these, I would include SAE, the American National Standards Institute (ANSI), and the International Organization for Standardization (ISO).

Who should establish standards? If they

are test procedures, I think that industry and also the professional technical community must be involved to a great extent. If they are performance requirements, I think those same groups must be involved and also socioeconomists and representatives of the public at large, for then we get into the political process.

In the area of politics, we must be mindful of which role we are playing. The problem becomes one of mutual trust, depending on each participant staying within the scope or bounds of his or her expertise. Should participants step out of the accepted roles, their motives may become suspect. The industry, which produces in this case, and the public, which uses, can be more adversely affected by standards that are arbitrarily drafted by government, which regulates, than by those that are established by a technically competent and broadly based group. This latter group is, of course, obligated to provide the rationale, the supporting data, and any other pertinent information to ensure that the decisions reached are not arbitrary.

Another small problem involves those who act outside the standards process, changing a little here or a little there, so that in application standards are not truly standards after all.

The administrator of the Environmental Protection Agency, in a 1974 address to the National Conference on Standards for Environmental Improvement, said: "Standards making is a comprehensive process, yet the final result is rarely the consensus of interest parties. . . . With industry codes, compliance is voluntary, and consensus is probably the more appropriate method. But consensus does not lend itself to timely action, and when compliance is required by law, there is nearly always a deadline to be met. . . . [Industry help is desirable, but] on an arm's length basis [to prevent public suspicion that the agency has] knuckled under to private interest."

There are several points of interest in that quotation. One appropriate to this discussion is the question of timeliness or the response time of the standards system. How fast can the standards system respond under a given set of circumstances?

Fortunately, many standards already exist for measurement of motor vehicle sound levels. These are primary SAE standards; some have been approved by ANSI. At one time, they were used for product development and evaluation. Now they are the basis for regulation, and in some instances consensus has tended to evaporate (or perhaps sublimate, for we have seen little boiling). Regulators, whoever they may be (the user from the regulatory standpoint), must recognize these test methods for what they are and how they relate, or do not relate, to the problem at hand. Test-site measurements of maximum sound level may not be an indicator of levels experienced in community situations, nor do the requirements for these measurements at a test site necessarily apply to roadside monitoring, for example.

Timing really depends on the support given by employers. Industry, government, educational institutes, or whoever is funding those developing standards determine the timetable. The emphasis in industry now seems to be toward the trade-association approach, which I think has less consensus because of its narrow defined interest. In the present political climate, this may be much more practical and expedient. At the same time, I see a trend to broader consensus through the national and international standards activity. Many affected industries and the government are supporting these activities when the business involves international trade.

Recognition of standards development in the private sector as a potential resource is beginning to be evidenced by some governmental activities. Working relations are being established between the European Economic Community or Common Market and various ISO technical committees concerned with development of standards in specific areas such as noise. The intent behind this is to use international consensus standards wherever possible to promote trade without technical barriers. In this country, exploratory effort toward cooperation between ANSI and the Occupational Safety and Health Administration, and also ANSI and EPA, in development of standards has been reported.

In summary, there may be several obstacles in the development and implementation of standards pertinent to motor vehicle noise reduction, perhaps caused by a lack of trust among the participants in the process. However, timing need not be much of a factor. If standards groups are given a voice and a chance to participate, I think they

can be a productive and timely partner in the abatement of traffic noise and vehicle noise.

ACKNOWLEDGMENT

The opinions expressed in this paper are those of the author and do not necessarily represent a position of either the Society of Automotive Engineers or the General Motors Corporation.

BALANCING CONCERNS IN THE DEVELOPMENT OF REGULATORY NOISE CONTROL

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The development of noise-control regulations is a careful balancing of a wide range of concerns to approach as closely as possible an optimum solution. Final decisions, of course, are based on trade-offs and compromises of alternative approaches. The challenge in this process is to provide management decision-makers with accurate and complete factual information on all reasonable alternatives.

Trade-off analysis in 3 major areas is required in the development of noise-control regulations: assessment of the impact on health and welfare as a result of noise reduction, assessment of the availability of technology, and assessment of costs resulting from the application of the required technology.

HEALTH AND WELFARE

When a criterion for assessment of health and welfare impact has been determined, the relative importance of different noise sources can be assessed so that regulatory development priorities can be selected. Figure 1 shows the relative impact of 4 general sources of noise on people within the United States. This figure shows that on a national basis (a) freeway traffic creates a high noise level for a relatively small number of people and (b) urban traffic noise, though not so high in sound level as some freeway traffic noise, impacts nearly 20 times as many people.

A regulatory strategy based on these observations would incorporate controls

Figure 1. Impact of general noise sources on people.

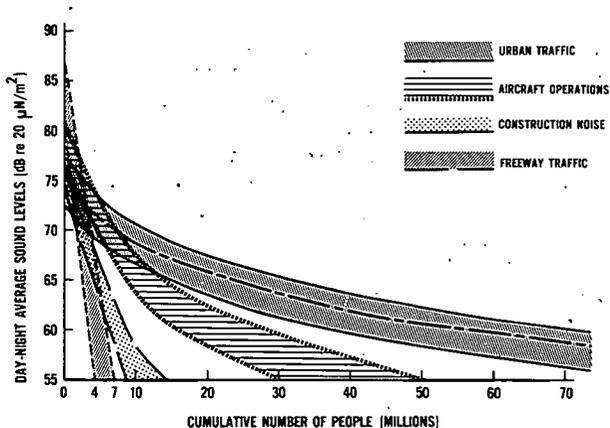


Figure 2. Effect of combined truck noise-control regulations.

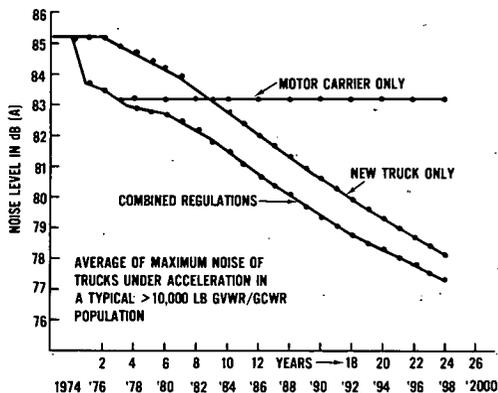
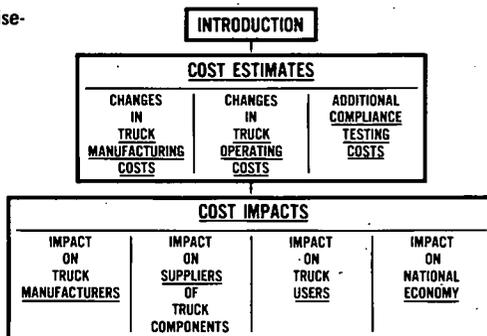


Figure 3. Economic consequences of truck noise-control regulations.



immediately to reduce the noisiest vehicles operating on freeways and thus provide some near-term relief for those who are currently severely impacted by freeway noise. The development of a time-phased control program to reduce urban traffic noise in a systematic manner would also be important.

The assessment of health and welfare impact should be considered in context with the scope of each individual regulatory situation. For example, the health and welfare impact analysis for a state or local noise-control regulation could entail considerations much different from those of a national noise-control regulation. The major noise sources and the desired levels of individual noise sources may be quite different. A local community that has a major rail line through it is a case in point. Although on a national or state level railroads may not be a major source of noise, in this particular local community railroad operations could be the highest noise source. If this is the case, a priority effort would be oriented toward abating railroad-related noise. This could be brought about by negotiations with the railroad company to reroute traffic, to lower speeds within the jurisdictional limits of the locality, or to plant and erect barriers to reduce the transmission of sound to the surrounding community.

Another health and welfare impact consideration is the time-phasing effect of standards to lower environmental noise levels. When the product being regulated has a long service life, lowering the new-product noise standard to a low noise-emission level may have little or no impact on actual health and welfare benefits to the community for a long period of time. In such a situation, the cost-effective approach of new-product noise regulation should be considered in conjunction with in-use product controls in order to effect health and welfare benefits to the community in a shorter time period. Two recent regulatory actions by the Environmental Protection Agency are good examples of regulatory time phasing, as shown in Figure 2. The relation between the interstate motor carrier noise-control regulation and the newly manufactured medium- and heavy-duty truck noise-control regulation illustrates the importance of noise control on the in-use fleet and the importance of increasingly more stringent regulations on newly manufactured trucks in order to achieve lower environmental noise levels. The combined regulations reduce noise exposure significantly more than either regulation does separately.

AVAILABLE TECHNOLOGY

An available-technology assessment should address the narrow area of what technology is available regardless of its state of development or cost to quiet noise emissions from a particular product. After this assessment is completed, cost, health, and welfare considerations can then be balanced with available technology to determine the regulatory level.

The assessment of available technology for reducing many sources of noise can best be done by examining control technology for individual component sources. Parametric studies to identify the major component sources of noise and available noise-control techniques for those sources have been used in the development of quieter trucks. The major sources of truck noise are the engine, air intake, fan, exhaust, and tires. The assessment must include not only the effect of individual noise sources but also the integrated effects of component sources in creating the overall truck sound level. Also important in assessing the availability of technology are the lead time requirements of the impacted industry to make the necessary changes in production capacity and facilities in order to comply with a proposed regulation. This requires consideration of development time, testing time, time to obtain components, and production lead time.

Defining and assessing available technology for noise control include consideration of acceptable noise measurement methods for use in determining compliance with a particular product regulation. The measurement methodology used to define and enforce a noise standard determines to a large degree the stringency of the numerical standard and should be considered as a part of the general area of technology assessment. An accurate repeatable test for measuring noise emissions is required to test

products for conformity to the specified standard. Such a methodology theoretically is the result of careful scientific assessment of the validity and accuracy of the measurement procedure in reproducing precisely the characteristics of the noise that the product emitted. However, from a practical enforcement standpoint, the need for simplicity in order to meet the varied enforcement situations often results in compromises in time and accuracy requirements to achieve an effective measurement procedure for the particular product application.

COSTS

In many fields of environmental regulation the current cost of pollution is being borne by the public. This cost may be reflected by increased mortality rates, increased medical bills, or increased maintenance costs of private property. Environmental regulation is intended to redistribute the cost of pollution to those responsible for producing it and to do so in as equitable a fashion as possible. The public will continue to pay a portion of the cost of pollution but a more equitable one.

A complete cost-impact analysis of a regulatory action includes the consideration of costs of more impacts than those of the principal manufacturing industry of the product under regulation (Fig. 3). It includes impacts on subcomponent suppliers to the major manufacturers, on users, and on the national economy. For example, the initial cost of new hardware, such as engine enclosures or thermostatically controlled fans, must be added to the potential increase in maintenance and operating costs throughout the useful life of the truck. Also the cost of potential early retirement of the truck due to regulatory requirements for maintaining newly manufactured noise-emission characteristics throughout its useful life must be considered.

Particular attention should be given in a cost analysis to the impact of regulatory action on small businesses or firms that manufacture the product under regulation. Often the effect of regulation on this segment of the impacted industry can be severe.

SUMMARY

The evolution of noise-control regulations is an intricate process based on the information provided in the general areas of health and welfare, available technology, and cost analysis. If the data are accurate and are presented in a manner that allows for a comparison of all reasonable alternatives, management will be provided with the tools to make sound assessments and reach proper conclusions.

ENFORCEMENT OF CONTROL OF INTERSTATE MOTOR CARRIER NOISE: A FEDERAL PERSPECTIVE

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The U.S. Bureau of Motor Carrier Safety promulgates and enforces a series of regulations designed to increase the safety of interstate commercial vehicle transportation. This bureau is responsible for the administration of the Federal Motor Carrier Safety Regulations and that part of the Hazardous Materials Regulations that concerns highway transportation of certain dangerous or potentially dangerous commodities.

In 1970, the bureau began making rules that would lead to a limitation on the noise level within the cabs of commercial vehicles (1). This was brought about because of the concern that high noise levels could cause driver fatigue and, in the long run, degrade hearing acuity, thus affecting the safe operation of the vehicle. Further investigation revealed little evidence that noise levels in the range experienced by truckers would cause sufficient fatigue to measurably affect the safe operation of commercial vehicles. However, there was no doubt that exposure to noise levels in excess of those specified by the Occupational Safety and Health Administration (90 dBA for an 8-hour exposure) would in the long run affect the driver's hearing.

Substantial tests were conducted to correlate a fast and easy interior noise test of the noise exposure the driver was likely to sustain during as much as a 10-hour driving period without rest. Subsequently, a final rule setting a limit of 90 dBA (only coincidentally the same number set by OSHA for an 8-hour exposure) was set in late 1973.

The test is performed with the sound-level meter held 6 in. (15 cm) from the driver's right ear while the stationary vehicle is operated at wide-open throttle in neutral against the engine speed governor. The standard went into effect on October 1, 1974, and covered vehicles built after that date. Older vehicles are required to meet this maximum noise standard by April 1, 1975.

Under the authority of the Noise Control Act of 1972, the Secretary of Transportation must be consulted before publication of any standards concerning motor carrier noise emissions (exterior noise standards). In addition, after the publication of such standards by the Environmental Protection Agency, the secretary must promulgate regulations to ensure compliance with all standards promulgated by EPA and must carry out those regulations through the use of safety enforcement powers under the Interstate Commerce and Department of Transportation acts. The part of the Interstate Commerce Act that refers to motor carriers (Part II) is the primary responsibility (within the Department of Transportation) of the Bureau of Motor Carrier Safety, and that bureau was therefore delegated the exterior noise enforcement authority. The bureau has been deeply involved in working with EPA on the Interstate Motor Carrier Standards, which were published October 29, 1974.

By mutual agreement between the transportation department and EPA, an effective date of October 15, 1975, was set for the new EPA standard. We believe this provides adequate time for the rule-making procedure leading to the publication of enforcement standards.

ENFORCEMENT PROCEDURES

The enforcement procedures used by the Bureau of Motor Carrier Safety represent a long-standing and well-reasoned method of ensuring compliance with both Federal Motor Carrier Safety Regulations and the Hazardous Materials Regulations of the U.S. Department of Transportation. The enforcement of both interior and exterior noise standards will fit into the present compliance activities so that resources can be best used for all responsibilities.

The bureau employs approximately 123 safety investigators and 27 other professionals (regional directors, regional hazardous materials and accident investigation specialists) in 9 regions throughout the country. They are responsible for the safety compliance of approximately 160,000 motor carrier operators, ranging in size from single-vehicle operators to operators of large fleets such as United Parcel Service, Leaseaway, and Consolidated Freightways.

To effectively enforce both safety and noise standards, we continue to stress education and voluntary compliance. Safety investigators are available to assist any motor carrier, trade organization, union, or other group in setting up safety programs and to provide information concerning the federal safety regulations.

The bureau encourages state authorities to adopt the Federal Motor Carrier Safety Regulations and assists them in both training and enforcement. We hope that cooperative programs of the bureau and the EPA will be effective in convincing states and localities to adopt the new Motor Carrier Noise Regulations and make them effective locally. We expect that a large percentage of the enforcement of these regulations will be done by state and local authorities.

The field staff conducts a well-organized enforcement program. Safety surveys at the carrier's place of business reveal inadequate safety practices, record-keeping violations, and thus lax safety compliance by the carrier. Random road checks allow us to inspect vehicles and, if necessary, to put them "out of service" on the spot. These road checks are our leads to noncomplying carriers.

Most of our interior and exterior noise checks are made on the highways. Figure 1 shows a typical road check site. A weigh station or other large area on the side of the road is usually chosen. Because they do not have authority to stop motor vehicles, the safety investigators work together with state authorities much of the time.

The investigator usually selects a vehicle that appears not to be well maintained, for all vehicles cannot be inspected. After the truck has been weighed, the safety

Figure 1. Road check site.

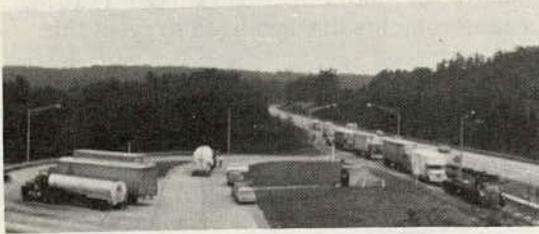


Figure 2. Noise-detection device.

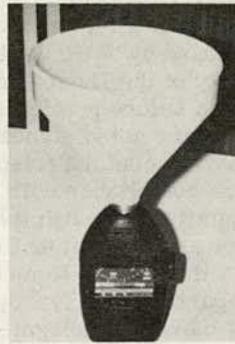


Figure 3. Insulation placed under truck cab.



Figure 4. Installation of acoustic headliner.



Table 1. Interior noise levels of trucks tested in 1973.

Testing Agency	Sound Level (dBA)	Number of Trucks	Percentage of Trucks
Bureau of Motor Carrier Safety	≤90	61	79
	91-92	9	12
	>92	7	9
Leaseway	≤90	76	43
	91-92	36	20
	>92	67	37
Bureau, Leaseway, AIRCO, and New York Motor Truck Association	≤90	194	57
	91-92	53	16
	>92	92	27

investigator asks the driver to pull aside for a safety inspection. At this point the safety investigator checks the driver's papers, including log sheets, medical certificate, and shipping papers. The entire vehicle is then checked from front to rear—brakes, lights, fifth wheel, air and electrical hoses, wheels, tires, suspension, and other safety accessories.

Both an interior and a stationary exterior noise check are included as part of this safety inspection procedure. Of course, we will have to be sure that we have an adequate site for noise measurement before we begin. If 2 safety investigators are available, they can check both interior and exterior noise simultaneously, for the procedures are nearly identical for stationary tests. The addition of the noise check should not be particularly time-consuming, except setting up the proper site at the beginning of the day and ensuring that each vehicle is properly situated within the site when the check is made.

The safety investigators will be prepared to do pass-by inspections also. But, since they do not have the power to stop vehicles, pass-by tests are expected to be a small portion of the overall total. They will, of course, conduct tests in response to complaints from drivers or citizens. And they will perform the visual tire and exhaust system checks set forth by EPA as part of the normal vehicle inspection procedure.

During the inspection, the safety investigator fills out a form listing the defects found. Violations of the interior and exterior noise regulations are recorded on this form in the same manner as any other violation. Violations of the Federal Motor Carrier Safety Regulations and the Hazardous Materials Regulations are criminal, not civil offenses. The bureau has the authority to assess civil forfeitures to carriers for the absence of required documents, false documents, and certain other record-keeping violations, but equipment violations, such as those found in road checks, must generally be brought to criminal court. Penalties for violations of Federal Motor Carrier Safety Regulations range from \$100 to \$500 per count for the first count, and \$200 to \$500 for additional counts; each day of a continuing violation is a separate offense.

The penalty provisions of the Noise Control Act of 1972 provide for a maximum fine of \$25,000 per count, with no minimum specified. Here, too, violations are considered to be criminal offenses:

As a practical matter, we have generally found it neither equitable to the carrier nor worthwhile to the government to ask the U.S. Department of Justice to prosecute a carrier for one violation. Before enforcement action is initiated by the bureau, a pattern of violations is documented. We prosecute carriers who have shown that they are not willing or able to abide by the regulations. This is an important matter to consider in the enforcement of both interior and exterior motor carrier noise standards by the federal government. In most cases, the carrier will receive a copy of the MCS-63 form and be required to make necessary repairs to the vehicle, including control of noise, within 15 days. In only a few cases will court action likely be initiated, and then only after a pattern of violations is found. State and local authorities that adopt the federal regulations can complement our efforts not only by inspecting far more vehicles than our limited field staff can but also by issuing citations, which may be more helpful as a reminder to the carrier in the short run than federal inspectors are.

NOISE INSPECTIONS TO DATE

By the end of 1974, the Bureau of Motor Carrier Safety had issued approximately 100 type 2 sound-level meters and calibrators to its field staff. Although not every safety investigator had a meter as yet, enough were available to undertake some sampling of interior noise. Since the standard is only in effect for new trucks at this time, we initiated a program of providing complementary noise checks of older vehicles until the standard took effect April 1, 1975. Not only did these early noise checks provide data but they also provided the carrier with advance information on how his trucks were doing before noise levels higher than 90 dBA became a violation of the federal regulations.

Interior noise checks by the bureau of 233 trucks during October 1974 revealed that the interior noise levels were 90 dBA or lower for 209 or 90 percent of the vehicles, between 91 and 92 dBA for 17 or 7 percent, and higher than 92 dBA for 7 or 3 percent. This low percentage of potential violations is interesting in view of the concern being shown by the motor carrier industry about the supposed large number of trucks that would need to be modified to meet the requirements. Results of tests made in 1973 by the bureau, Leaseway, Airco, and the New York Motor Truck Association showed that 57 percent clearly passed the test (Table 1). A further study of those data indicated that the poor showing was primarily due to the large amount of data from the Leaseway Corporation, which showed only 43 percent of its vehicles clearly passing and 37 percent in clear violation. The bureau data showed 79 percent of the vehicles passing and only 9 percent in clear violation, which is reasonably close to the 1974 data.

PUBLICITY CONCERNING MOTOR CARRIER NOISE STANDARDS

As indicated earlier, the Bureau of Motor Carrier Safety relies in large part on a program of voluntary compliance by motor carriers. And this requires getting information to all motor carriers and others concerned with safe highway movements of commercial vehicles. The bureau undertakes information dissemination within its limited budget. Press releases are published on all rule-making actions. Personnel are made available to speak before industry groups whenever possible. The field staff spends much of its time meeting with and educating interested groups. The trade press is also quick to pick up regulatory efforts of wide interest, such as noise-related work.

The Bureau of Motor Carrier Safety is planning to cooperate with the Environmental Protection Agency in publicizing the Interstate Motor Carrier Noise Emission Standards and Enforcement Regulations.

The bureau has just completed a slide presentation for use by its field staff, trade organizations, and others to help carriers get started in quieting truck cab interior noise. Many professional organizations, of course, offer the industry valuable service in this area, but many carriers will try to do the work themselves. The presentation shows a relatively simple way of locating noise sources within the truck cab and gives some suggestions on how to go about quieting them with readily available materials and a little common sense.

Figure 2 shows the noise detection device, which consists of a sound-level meter that is given a directional response by the addition of an ordinary funnel over the microphone. A sound-level meter that meets at least ANSI type 2 requirements can be used both for locating noise sources and for making the interior and exterior noise tests. A less expensive meter is perfectly acceptable for locating interior noise sources but may not be accurate enough to ensure the carrier that the vehicle complies with the federal standards. The bureau borrowed the idea of the funnel from Stemco Manufacturing Company.

The truck used in making the slides for the presentation is a 17-year-old tractor with more than 700,000 miles (1 120 000 km) on it. The initial interior reading was 93 dBA. The noise-locating device was moved about the cab, near possible sources of noise, until substantial increases in noise level were found. We found it to work best when it was set on the 100 to 110-dBA range and when the engine was set at maximum governed speed in neutral and the doors were closed as set forth in the regulations. The meter and funnel can indicate relatively quickly which of the potential noise sources let the noise into the cab. In the truck tested, we found that holes around the pedal linkages did not serve as noise sources. The sealing area around the shift lever at the top of the "doghouse" was one area where sound was pouring into the cab. It was initially sealed with a sandwich made of fiberglass insulating material and dense, open-cell urethane foam. The fiberglass was used for fire resistance. Figure 3 shows the installation of the sandwich under the cab and also shows that a more professional job could be done by removing a rubber mat and putting the

sandwich, or a specially treated fire-resistant dense foam, in place of the jute backing originally installed.

This installation failed to reduce the noise level to 90 dBA or lower. An opening in the right side of the doghouse, used to check oil, was located as a noise source and sealed. A search around the cab led to the C-pillars behind the driver, where the meter read about 5 dBA higher than in the surrounding area. A dense foam sheet was then applied to the C-pillars. The next noise source found was the roof itself, which was resonating sound in the same manner as the C-pillars. An acoustic headliner was installed underneath the standard fiberboard headliner (Fig. 4). Available waffled open-cell carpet backing was used. The truck was then quieted to the required 90 dBA.

This slide presentation should be helpful to the industry in giving some idea of how to go about a program of checking and quieting present equipment. This procedure may be helpful for gross noise sources, but professional assistance may be more prudent for large fleet operators, particularly if the fleet consists of a mix of vehicle makes and models.

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NOISE CONTROL STRATEGIES FOR NEW AND IN-USE TRUCKS

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The task of achieving control of the noise output of trucks is a systems problem of rather large dimensions. Appropriate noise regulations must be formulated and promulgated, and then suitable enforcement techniques must be applied. The process is still in the formative stage, but it appears that at some future date, through the cooperation of federal, state, and local agencies, a comprehensive system for control of in-use truck noise will evolve and will include periodic inspection, highway surveillance (covering intervals between inspections), and use of truck weighing stations. In addition there will be an adequate system of factory inspection that will control the noise emissions of newly manufactured trucks.

Devising and setting in place this system are crucial to the success of the truck noise-control program. However, this is not the problem addressed in this paper. This paper assumes that such a system is in existence and examines its effect on the number of trucks within various noise categories. A model of truck population dynamics is described. The associated analytical techniques are outlined, and the method is applied to an idealization of a practical situation. A few tentative conclusions are drawn from this analysis.

MODEL DESCRIPTION

The truck population is divided into mutually exclusive classes, m . These could be, for

example, the trucks present in the truck population at the start of a regulation, those manufactured after the first stage of the regulation, or those manufactured after the second stage of the regulation. Each of these classes, say, the i th class, is associated with a rate of new-truck input (q_i , trucks manufactured per year) and a rate of truck retirement (Q_i , trucks retired per year per n_o of population). This input-output relation causes the truck population in the i th class to vary with time. We assume that this is a continuous process and develop the equations describing it in the following section. The model is shown in Figure 1.

ANALYSIS OF MODEL

In a short interval of time, dt , the change in truck population in the i th class, dN_i , is given by $q_i dt$, the number of new trucks injected into the population, less $(N_i/n_o)Q_i dt$, the number of trucks retired. That is,

$$dN_i = q_i dt - \frac{N_i}{n_o} Q_i dt \quad (1)$$

which yields the first-order linear differential equation

$$\frac{dN_i}{dt} + \left(\frac{Q_i}{n_o}\right)N_i = q_i \quad (2)$$

where

$N_i(t)$ = number of trucks of the i th type in the population at time t ;

$Q_i(t)$ = rate of retirement of the i th class of trucks at time t and given as trucks per n_o of population retired per year, where n_o is usually taken as 1,000; and

$q_i(t)$ = rate of injection of new trucks of i th type into population and given as number of new-truck manufacturers per year, computed at time t .

The total population $N(t)$ is given by

$$N(t) = \sum_{i=1}^m N_i(t) \quad (3)$$

General solutions for Eq. 2 are readily attainable even when q_i and Q_i are any prescribed functions of time, that is, when manufacturing rates and retirement rates are not constant. Future work is planned employing time-varying q_i and Q_i but the present paper assumes that they are constant.

Two types of solutions are obtained from Eq. 2: growth and decay. For the growth functions, q_i is not 0; for the decay functions, $q_i = 0$. Both functions are exponential. However, the growth functions are increasing functions of time and approach an asymptotic value as time approaches infinity. On the other hand, the decay functions are decreasing functions of time and start from some initial value and approach 0 as time approaches infinity. These are

$$N_i(t) = \frac{n_o q_i}{Q_i} - \left[\frac{n_o q_i}{Q_i} - N_i(T_{ia}) \right] \cdot e^{-\frac{Q_i}{n_o}(t - T_{ia})} \quad (4)$$

for the growth function and

$$N_i(t) = N_i(T_{ib}) \cdot e^{-\frac{Q_i}{n_o}(t - T_{ib})} \quad (5)$$

for the decay function. Growth starts when $t = T_{ia}$; decay starts when $t = T_{ib}$. The character of the growth and decay curves is shown qualitatively in Figure 2.

Figure 1. Dynamic truck population model.

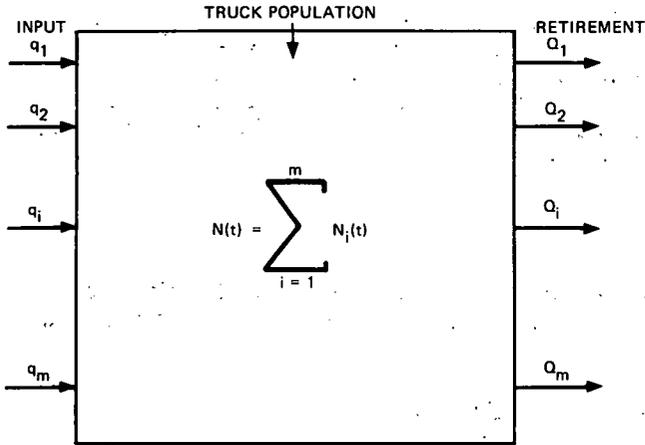


Figure 2. Growth and decay of truck populations.

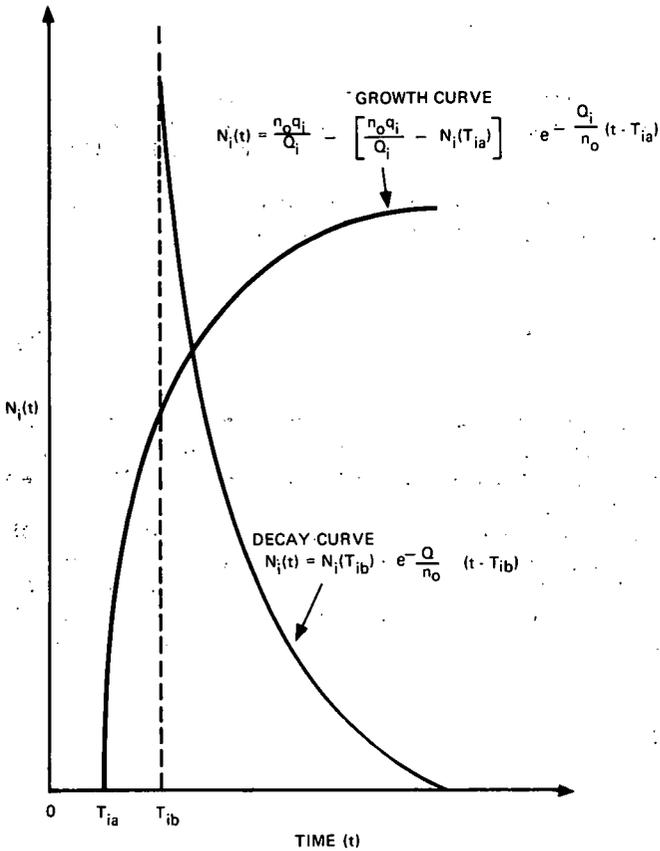


Figure 3. Proposed new-truck noise regulation.

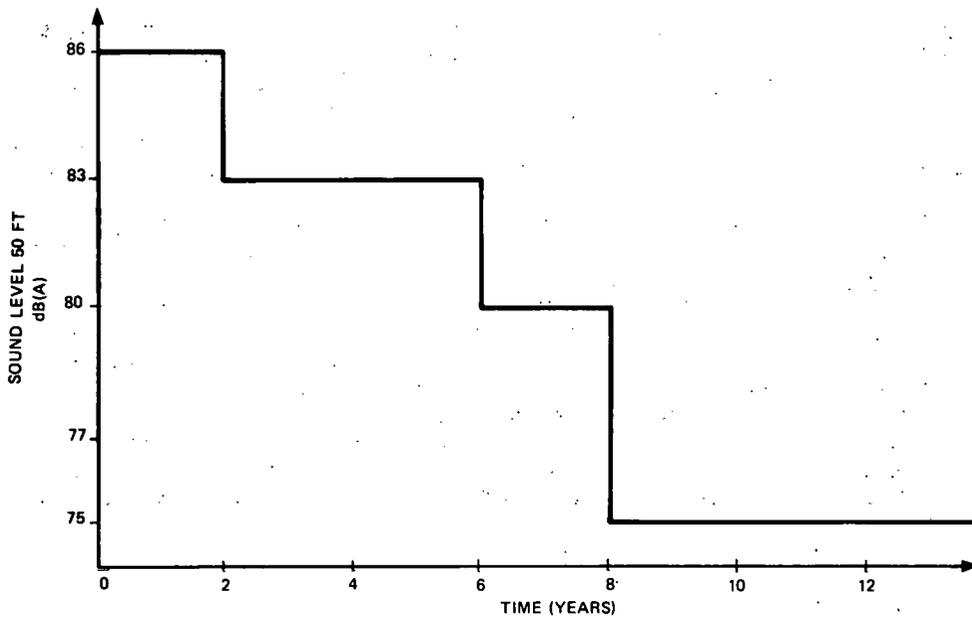
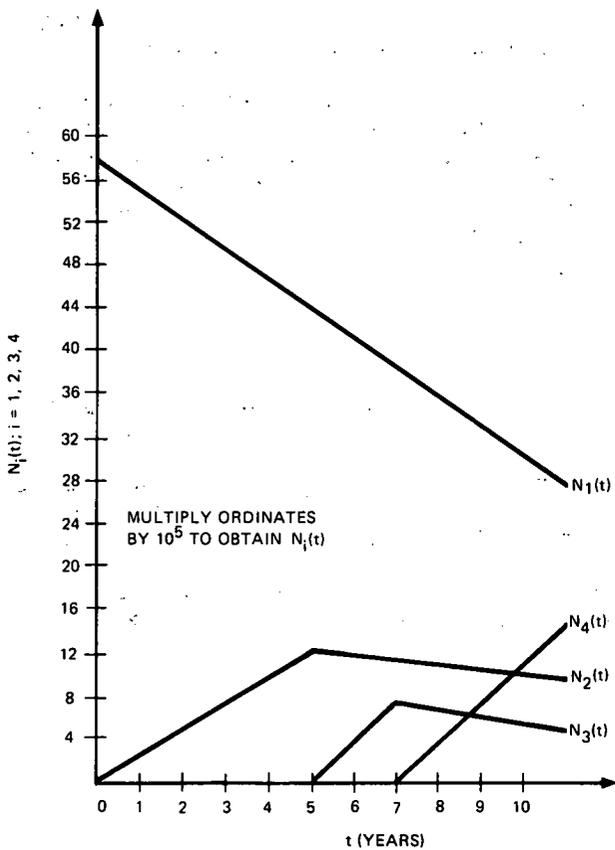


Figure 4. Truck population versus time.



APPLICATION TO PROPOSED NEW-TRUCK REGULATION

The formulas given above are applied to the truck populations, which are expected to be associated with the recent interstate motor carrier regulation and the proposed new-truck regulation. The trucks covered by these regulations are medium and heavy trucks having a gross vehicle weight rating of 10,000 lb (4500 kg) or greater. The results are approximations because data for an accurate calculation are not available. However, the character of the results is correct even though the numbers are not precise.

Figure 3 shows the proposed new-truck regulation schedule. When the regulation is formally announced, a sizable truck population will be in existence. This is labeled as an 86-dBA population. This is the motor carrier allowed level and was selected for that reason. However, for the purposes of this analysis, the number is only a label, and the value of the number does not enter into the calculation. The same is true of all the other levels shown in Figure 3; i.e., they are only labels. The schedule shows that 2 years after the announcement the new-truck level will drop to 83 dBA. During the next 4 years, 83-dBA trucks will be manufactured and injected into the truck population. At the end of this period, the new-truck level will drop to 80 dBA and stay there for 2 years. Finally, the new-truck level will reach 75 dBA and stay permanently at that value. The following numerical values were employed in the analysis:

<u>Item</u>	<u>Value</u>
Initial truck population	$N_1(0) = 5.7 \times 10^6$
Annual rate of truck production	$q_2 = q_3 = q_4 = 4.0 \times 10^5$
Annual retirement rate of trucks	$Q_1, Q_2, Q_3, Q_4 = 71.9/\text{thousand/year}$
Truck retirement basis number	$n_0 = 1,000$

Figure 4 shows the time history of each of the populations defined above, starting 2 years after the announcement of the regulation, i.e., at the time the 83-dBA trucks start to be manufactured.

The $N_1(t)$ curve (86 dBA) starts at about 5.7 million and decays steadily with time. However, because it has such a large initial value, it dominates the other populations for a long time. The $N_2(t)$ curve shows that the 83-dBA population increases steadily for 4 years and then decays. The $N_3(t)$ curve shows that the 80-dBA population increases for 2 years and then decays. Finally, the 75-dBA population is given by the $N_4(t)$ curve, which steadily increases and approaches an asymptotic value of 5.6×10^6 , which is not shown on the curve.

SUMMARY

1. A technique for calculating truck populations has been developed. It is applicable to a rather wide variety of cases, including variable truck manufacturing rates and variable truck retirement rates.
2. The technique has been applied to an approximate model of the interstate motor carrier regulation and the proposed new-truck regulation and indicates that the population of trucks in use when the new-truck regulation is promulgated will dominate the total truck population for many years thereafter.
3. The work reported here is a first installment. Further work using variable manufacturing and retirement rates as well as a more refined estimate of the initial truck population will be undertaken.

EVALUATION OF THE EFFECTS OF MOTOR VEHICLE NOISE REGULATIONS ON POPULATION

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The purpose of this paper is (a) to present a conceptual method for quantifying the effects of a change in environmental noise on public health and welfare and (b) to present, as an example of the application of this method, a first approximation to quantifying the impact of motor vehicle noise regulations. The methodology was developed in conjunction with developing a design guide for highway noise in a project sponsored by the National Cooperative Highway Research Program (1).

Within the context of this paper and in accordance with the World Health Organization definition, health and welfare include personal comfort and well-being as well as the absence of clinical symptoms. Furthermore, the approach taken in this paper is statistical; that is, emphasis is placed on the average response of groups of people to noise, where average response is a combination of factors such as speech interference, sleep interference, desire for a quiet environment, and the ability to use TV, telephone, and radio satisfactorily. The measure of the response is expressed in terms of the magnitude of the population that would be expected to express in a social survey a high degree of annoyance as a result of the activity interference produced by a specific exposure level. Experience indicates that individual responses may differ quite significantly from averaged group

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responses; however, these responses cannot be accounted for at the present time.

ENVIRONMENTAL NOISE MEASURES

In these analyses, use was made of 2 measures proposed by the Environmental Protection Agency for describing environmental noise and its cumulative effects on people (2, 3).

1. The equivalent A-weighted sound level in decibels, L_{eq} , is defined as

$$L_{eq} = 10 \log_{10} \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} 10^{L_A(t)/10} dt \right] \quad (1)$$

where $t_2 - t_1$ is the interval of time over which the levels are examined, and L_A is the A-weighted sound pressure level, expressed in decibels.

2. The day-night sound level in decibels, L_{dn} , is defined as

$$L_{dn} = 10 \log_{10} \frac{1}{24} \left\{ 15 \left[10^{L_d/10} \right] + 9 \left[10^{(L_n+10)/10} \right] \right\} \quad (2)$$

where L_d is the L_{eq} obtained between 7 a.m. and 10 p.m., and L_n is the L_{eq} obtained between 10 p.m. and 7 a.m. the next morning. L_{dn} is in effect the weighted equivalent level for a 24-hour period; the weighting is applied to nighttime noise events to account for the increased awareness of people associated with the drop in background noise at night.

When environmental noise exposures are assessed in areas such as schools, offices, and other occupational settings where occupancy is shorter than 24 hours, L_{eq} is used and averaged over an appropriate time period. When environmental noise exposures are assessed in areas such as residences and hospitals where people are expected to be present for prolonged periods of time, L_{dn} is used.

METHODS FOR QUANTIFYING POPULATION IMPACT

In the evaluation of the effect of a proposed action on public health, the goal is to relate the anticipated change in environmental noise to the change in the size of the population at risk and the severity of the risk. Thus, the process involves a series of steps:

1. Quantification of the original environmental noise exposure,
2. Quantification of the impact of the original environmental noise on the population in terms of both the severity of the impact and the size of the population,
3. Quantification of the environmental noise exposure following the implementation of the action, and
4. Quantification of the population impact following the action.

The methods for quantifying the acoustical environment will vary greatly depending on the nature of the noise system under consideration, for different predictive models are necessary for predicting noise levels at different sites such as airports, highways, and construction sites. However, once noise exposures have been estimated, the method used for assessing the effects of the noise on the population remains constant no matter what the noise sources are. The reason for this is that the average reaction of groups of people to noise exposure is considered to be relatively stable and predictable, as has been documented in several EPA reports (2, 3, 4).

In the following analysis it is assumed that, if the environmental noise exposure is either below or at the level identified by EPA as protective of public health, then the

impact of the noise is so negligible as to have 0 percent impact on public health. The problem of defining an upper boundary for impact is somewhat more difficult. Nevertheless, the EPA documents do provide useful information for deriving what may constitute a severe impact on public health and welfare as will be seen in the next paragraphs. However, the conclusions derived are tentative and will require refinements as more research data become available.

The data on community reaction and annoyance (3, Appendix D) reveal that on the average the expected community reaction to an identifiable source of intruding noise changes from none to vigorous when the day-night sound level increases from approximately 55 to 75 dBA (Fig. 1). Furthermore, the results of sociological surveys, which are usually stated in terms of the percentage of people who express a high degree of annoyance due to noise in their environments, reveal that this change of 20 dBA (from an L_{dn} of 55 to 75 dBA) results in an increase of approximately 40 percent in the number of people highly annoyed and that within that range the relation between the number of highly annoyed people and the exposure level is linear as shown in Figure 2. Thus, a change of 20 dBA appears to be a reasonable value to associate with a change from 0 to 100 percent impact. For environmental noise levels that range from 0 to 20 dBA above the EPA criterion, it is hypothesized that "impact" varies linearly with level. Thus, a 10-dBA excess represents a 50 percent impact and a 5-dBA excess represents a 25 percent impact.

For convenience of calculations, these percentages can be expressed as fractional impact in accordance with the following formula (1, Appendix D):

$$FI = 0.05 (L - L_c) \quad \text{for } L > L_c \quad (3)$$

$$FI = 0 \quad \text{for } L \leq L_c \quad (4)$$

where L is the environmental noise level, and L_c is the criterion level identified by EPA as protective of public health and welfare for the situation under evaluation.

In the previous paragraphs the impact assessment was considered in terms of the general adverse reaction of people to noise in residential areas. This response includes, among other things, considerations of the masking of speech by noise. Situations exist, however, in which the impact produced by a noise system may be better assessed by direct evaluation of the degree of speech interference associated with a given voice level. This would occur, for example, when an assessment is made of the impact of noise exposure on people in schools, offices, and similar spaces.

EPA has identified the level that will provide an adequate environment for speech communication indoors as an equivalent level of 45 dBA. A noise having this level should provide on the average a 100 percent speech intelligibility for all types of material and would have a calculated articulation index of 1.0. For a constant voice level, the intelligibility of sentences (first presentation to listeners) drops to 90 percent when the noise level increases above this value by about 18 dBA and to 50 percent when the level increases by approximately 24 dBA. The intelligibility of sentences known to the listener drops to 90 percent when the level increases by approximately 22 dBA and to 50 percent when the level increases 26 dBA. Since normal conversation contains a mixture of both types of material, some new and some familiar, it is reasonable to conclude that, when the noise level increases by about 20 dBA above the EPA criterion for indoor speech communication, the intelligibility of conversational speech starts to deteriorate rapidly with each increment of noise. Certainly, communication can be maintained by raising the voice level when noise intrudes; however, in an ideal environment one should not have to increase the voice level above that which is comfortable for normal and easy communication. For this reason a level that exceeds the EPA criterion for indoor speech by 20 dBA or more can be considered to have such a severe effect on speech intelligibility as to constitute a 100 percent impact, particularly if allowances are made for people, such as children and foreigners, whose language skills are not so well developed as those of adult English speakers.

The appropriate L_c to be used in computing the FI for various situations can be obtained from Table 1, which gives a summary of the levels identified by EPA as

Figure 1. Community reaction to intensive noise as a function of normalized outdoor day-night sound level of intruding noise.

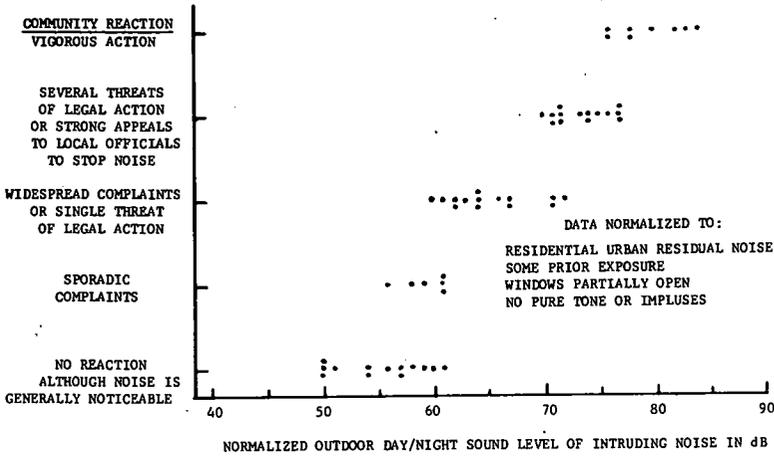


Figure 2. British and U.S. survey results of people annoyed by noise in residential areas.

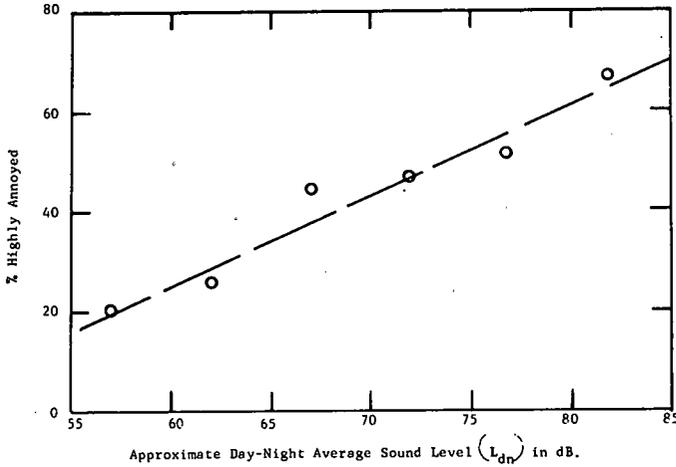


Table 1. Criteria for noise impact analysis.

Areas	Measure	Level* (dBA)
Residential		
Outdoors	L_{dn}	55
Indoors	L_{dn}	45
Indoor spaces such as schools, offices, and churches	L_{eq}	45

*Derived from the levels proposed by EPA as protective of public health and welfare.

protective of public health. The L_{eq} given in the table for indoor spaces may be translated to an outdoor level by using a sound reduction appropriate to the type of structure under consideration.

A measure of the incremental impact of a given noise environment can be obtained by multiplying the number of people exposed by the fractional impact associated with a given level of exposure as follows:

$$\Delta P_{eq} = (FI)(P) \quad (5)$$

where P_{eq} is a measure of the impact and is numerically equal to the equivalent number of people that have a fractional impact of unity, FI is the fractional impact for the level, and P is the number of people exposed to the noise.

When the total impact of a complex noise environment is evaluated, it is convenient for calculation purposes to subdivide the geographical area impacted into sub-areas, each with its own fractional impact, FI_i , and subpopulation, P_i . The total impact can then be obtained by the following formula:

$$P_{eq} = \sum_{i=1}^n P_i FI_i \quad (6)$$

where FI_i is the fractional impact associated with the i th level, P_i is the population associated with the i th level, and n is the number of subareas.

The procedure outlined above is repeated twice: first to assess the effects on the population produced by an existing noise environment and second to assess the impact after the noise environment has been modified by a proposed action. A useful measure in determining the effect of a regulation on the population at risk is the percentage reduction, Δ , which is calculated by the following expression:

$$\Delta = 100 \frac{P_{eqB} - P_{eqA}}{P_{eqB}} \quad (7)$$

where P_{eqB} is the total impact on the population prior to the change and P_{eqA} is the total impact on the population following the change.

APPLICATION OF IMPACT METHODOLOGY TO REGULATION OF MOTOR VEHICLES

In the remaining portion of this paper an application of the concepts described above is summarized. Specifically, the methodology has been applied in an attempt to quantify the health benefits that may result from regulating motor vehicle noise. A series of steps has been taken by various governmental authorities to curb noise from motor vehicles. These include federal regulations that apply to motor vehicles now in interstate commerce. These specify that no vehicles will operate at sound levels exceeding 90 and 86 dBA, at 50 ft (15 m), on highways and urban streets respectively. In addition, various state and city regulations coming into effect during the 1975 model year will force an estimated 4-dBA reduction in the noise produced by automobiles and an estimated 4-dBA reduction by 1980 for medium trucks (5). Proposed regulations by EPA for noise emission from new trucks specify that no vehicles weighing more than 10,000 lb (4 500 kg) will exceed, under specified test procedures, the following sound pressure levels at 50 ft:

<u>Date</u>	<u>dBA</u>
January 1977	83
January 1981	80
January 1983	75

In the analyses summarized below, to assess the effects of the various regulations for highway and urban traffic conditions separately was found to be more convenient. In the case of highways, the following assumptions were made.

1. Traffic moves at a constant speed of 55 mph (88 km/h) on level ground.
2. Noisy tires are forced out of use by increasingly stringent regulations, thus lowering the levels due to tires to 77 dBA (5).
3. The typical highway has 6 lanes of traffic and accommodates during peak hours a traffic flow of 7,200 vehicles per hour.
4. The typical mix of vehicles is 10 percent trucks and 90 percent automobiles.
5. The population living within 1 mile (1.6 km) of urban freeways is homogeneously distributed and has a density similar to that of the average population density in urban areas reported by the Bureau of the Census in 1970, that is, 5,000 people per 1 mile² (2.6 km²). Since there are 8,000 miles (12 800 km) of urban freeways in the nation, the total population living within 1 mile (1.6 km) of a highway is estimated to be equal to 40 million.
6. For the purpose of calculating attenuation of highway noise, the typical house is on a lot 100 ft (30 m) long and 50 ft (15 m) wide and the first one is 70 ft (21 m) away from the nearest lane of traffic.

In the case of urban traffic, excluding freeways, it was assumed that the average speed of traffic is 27 mph (43 km/h) and that the mixture of vehicles is 1 percent heavy trucks, 6 percent medium trucks, and 93 percent automobiles. The population distribution assumed is that provided in an EPA study (7).

In computations of the noise levels produced by traffic at various points throughout an area adjacent to a highway, extensive use was made of the predictive model developed by Kugler, Commins, and Piersol (8). This model allows for predicting the noise levels expressed in terms of L_{dn} at various points from the highway from a knowledge of the equivalent level produced by a defined mix of vehicles for the design hour of the highway. From these computations, various L_{dn} contours may be determined around the typical highway in convenient increments, and then the population living within each contour can be estimated and assigned an exposure level midway between successive L_{dn} increments. Such computations were carried out to determine the impact of motor vehicle noise on the 1974 U.S. population. The results of these computations are given in Table 2. For the national population, a significantly greater problem is created by urban traffic than by highway traffic.

Noise reductions (relative to 1974 levels) as a function of time were computed to assess the effects of various regulations. In these analyses, it was assumed that trucks remain in the fleet for 8 years and then decrease linearly at a rate of 11 percent per year to a residual level of 10 percent after 16 years (9). The results of these computations are given in Table 3 for both highway and city streets.

Because the calculations involved in the determination of the effects of the various noise level reductions on the population are rather involved, a detailed summary of the various computations is given in Table 4 for 1 level of noise reduction and 1 traffic condition. However, similar analyses were made for all the noise level reductions given in Table 3. The results of these computations are given in Table 5 in which the figures reported represent, as a function of time, the number of people who will experience an exposure level corresponding to a fractional impact equal to unity. From the results obtained, the percentage reduction in the equivalent population as a function of time was estimated relative to 1974 levels. The results of these computations are also given in Table 5.

The percentage reduction in equivalent population exposed to traffic noise is slightly greater for highways than for urban streets. This result reflects the fact that most regulatory actions proposed thus far affect mainly the population of heavy trucks and that most people live in areas where automobiles and medium and light trucks are the main noise sources. To achieve an additional significant reduction in impact will require further regulations of medium and light trucks as well as of automobiles. If an additional 6-dBA reduction were required for each of these vehicles, the day-night

Table 2. Impact produced by traffic noise.

L_{dn}	Highway Traffic			Urban Traffic*		
	P_i (in millions)	FI_i	P_{eq} (in millions)	P_i (in millions)	FI_i	P_{eq} (in millions)
85 to 80	0.28	1.375	0.39	0.1	1.375	0.1
80 to 75	0.40	1.125	0.45	1.2	1.125	1.4
75 to 70	0.64	0.875	0.56	5.6	0.875	4.9
70 to 65	0.88	0.625	0.55	17.4	0.625	10.9
65 to 60	1.40	0.375	0.53	34.7	0.375	13.0
60 to 55	2.00	0.125	0.25	34.4	0.125	4.3
Total			2.73			34.6

*Excluding freeways.

Table 3. Reduction in day-night sound level relative to 1974 values.

Year	Highway Traffic Noise (dBA)		Urban Traffic Noise (dBA)	
	Local Government and Motor Carrier Regulations	New-Truck Emission Standards	Local Government and Motor Carrier Regulations	New-Truck Emission Standards
1977	2.4	2.4	0.7	0.3
1981	2.4	3.6	1.2	1.2
1983	2.4	5.0	1.4	2.1
1991	2.4	8.4	2.0	4.9
1993	2.4	8.6	2.0	5.0

Table 4. Determination of change in impact with 2.4-dBA reduction in day-night sound level on highways relative to 1974 levels.

L_{dn}	d^a	Δd^b	P_i (in millions)	FI_i	P_{eq} (in millions)
85 to 80	0.018	0.006	0.23	1.375	0.32
80 to 75	0.026	0.008	0.32	1.125	0.36
75 to 70	0.039	0.013	0.52	0.875	0.46
70 to 65	0.057	0.018	0.72	0.625	0.45
65 to 60	0.083	0.026	1.04	0.375	0.39
60 to 55	0.122	0.039	1.56	0.125	0.19
Total					2.2

Note: Percentage reduction in $P_{eq} = 100 \frac{(2.73 - 2.2)}{2.73} = 22$.

^aDistance in miles between the highway and an area exposed to a given L_{dn} level.

^bDistance separating successive L_{dn} contours.

Table 5. Number of people, P_{eq} , experiencing noise exposure from vehicular traffic at a fractional impact equal to unity.

Year	Highway Traffic Noise		Urban Traffic Noise	
	Local Government and Motor Carrier Regulations	New-Truck Emission Standards	Local Government and Motor Carrier Regulations	New-Truck Emission Standards
Estimated P_{eq} (in millions)				
1974	2.7	2.7	34.6	34.6
1977	2.1	2.1	31.5	31.5
1981	2.1	1.8	29.4	28.0
1983	2.1	1.6	28.4	25.6
1991	2.1	1.1	26.0	15.9
1993	2.1	1.0	26.0	14.9
Reduction in P_{eq} (percent)				
1977	22	22	9	22
1981	22	33	15	19
1983	22	41	18	26
1991	22	59	25	54
1993	22	63	25	55

sound level resulting from urban traffic would be reduced by an estimated 5.3 dBA from the levels anticipated in 1993. This decrease in level would reduce the estimated equivalent number of impacted people at a fractional impact equal to unity to a total of 5 million, a reduction of more than 85 percent from the 1974 base-line condition.

ACKNOWLEDGMENTS

The author wishes to express her grateful appreciation to William J. Galloway for the many discussions and the assistance with computations throughout the course of this study.

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A STATUS REPORT ON THE FLORIDA MOTOR VEHICLE NOISE CONTROL PLAN

Jesse O. Borthwick
Florida Department of Pollution Control

Florida's noise control program began in 1971, when the Florida legislature amended the statutory responsibilities of the Florida Department of Pollution Control (FDPC) to cover noise as well as air and water pollution. However, because of severe statewide budgetary limitations, funds were not provided to support noise control activities at that time.

In early 1972 the Florida Department of Transportation (FDOT), anticipating noise study requirements of the Federal Highway Administration (FHWA), began to research and develop methods of investigating present and future highway traffic noise levels. However, no funds were available specifically for noise control activities until July 1972, when \$36,000 was authorized for FDPC to hire 1 staff engineer and to obtain contractual services. During the next fiscal year, funding was increased to \$62,000.

Recognizing the increasing legislative and public interest in noise control, FDPC designed and implemented a unique low-cost support system involving Florida's academic community. Under the system the Florida Board of Pollution Control approved contracts with the 5 state universities for basically the following services:

1. Provide encouragement and technical support to individual municipalities throughout Florida in the development of comprehensive effective local noise control programs;
2. Conduct research and development activities necessary to support the establishment of an overall noise control program for

the state;

3. Act as expert witness on behalf of FDPC at legislative and public hearings; and
4. Coordinate and conduct training programs at the state, regional, and local levels for governmental officials with interests in and responsibilities for noise control.

The universities were located in 5 geographic regions as follows:

<u>University</u>	<u>Region</u>
University of West Florida, Pensacola	Northwest
University of Florida, Gainesville	Northeast
Florida Technical University, Orlando	Central
University of South Florida, Tampa	West central and southwest
Florida Atlantic University, Boca Raton, and Florida International University, Miami	Southeast

Funding for the 1974 fiscal year noise control activities was increased to \$88,000, mainly because staff positions were increased to three. However, the major increase in state noise control funding accompanied the establishment of a motor vehicle noise enforcement section within the Florida Highway Patrol (FHP), and that will be discussed further in a subsequent section. Figure 1 shows the organizational structure of full-time noise control support personnel.

NOISE CONTROL PROGRAM RESPONSIBILITIES

The Noise Control Section of the FDPC has as its key responsibility the development of a comprehensive statewide program for the prevention, control, and abatement of all excessive and unnecessary noise. Figure 2 shows a noise identification system that the section has developed. In fulfilling its responsibilities, the section conducts research, develops plans, enforces noise laws, coordinates with other agencies and groups, and provides for the dissemination of pertinent information.

NOISE CONTROL LEGISLATION BEFORE 1974

Since the onset of the noise program, the legislature has been primarily concerned with motor vehicle noise. In 1972 the legislature passed a law that required the establishment of a maximum decibel level by FDPC for motor vehicle exhaust systems and further directed that it be enforced by FHP through the state's official motor vehicle inspection stations.

In 1973, 2 noise control bills were filed for consideration: a senate bill that basically adopted the Chicago noise ordinance for Florida and a house bill that called for the use of vegetative noise barriers for the control of highway noise. Both failed to pass.

The attitude of the Florida legislature has definitely changed with respect to noise. In the 1971 session, the senate chamber rang with laughter as one senator joked about little decibels flying about the chamber. However, in 1974 the atmosphere was quite different as will be shown in a later section.

MOTOR VEHICLE NOISE CONTROL PLAN

From the beginning of the noise program development, transportation noise control has been recognized and treated as the highest priority area. Fifty percent of all noise complaints in Florida at the state and local levels are related to motor vehicles.

Figure 1. Organization of the noise program.

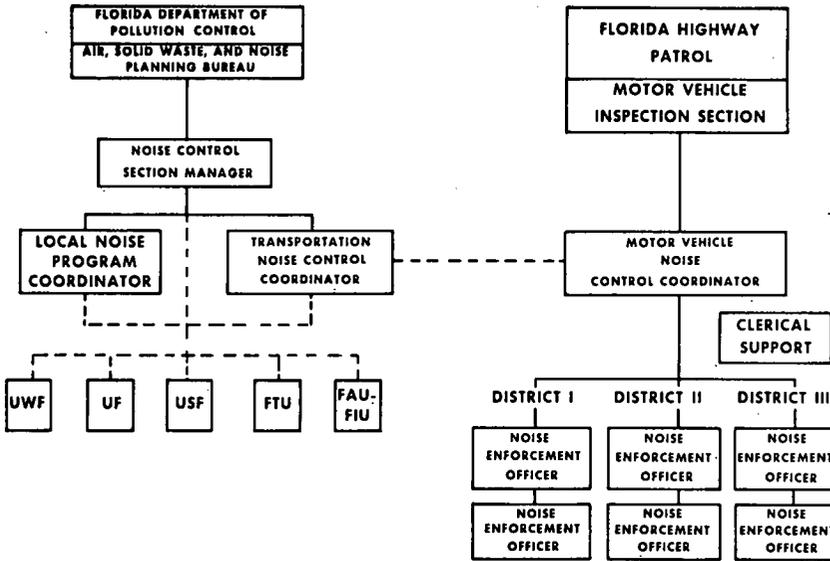
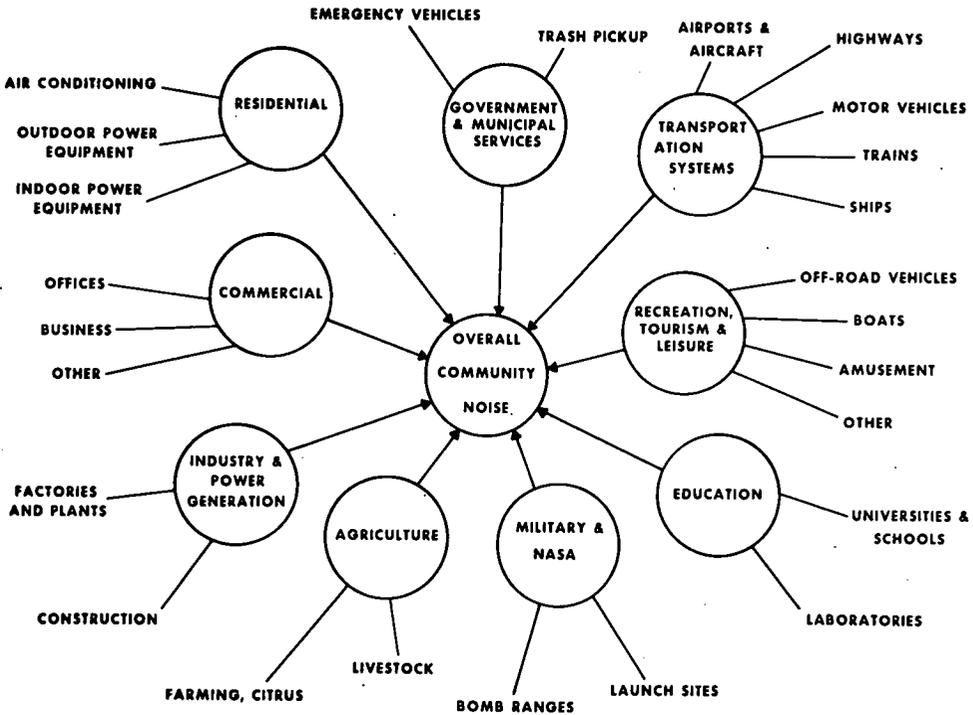


Figure 2. Noise identification system.



The noise control program manager spent approximately 60 percent of his time during the second half of 1972 and 1973 working with FDOT and FHP on the research and development of an in-station noise test procedure as called for by 1972 law. During the summer of 1973, 3 representatives from FHP and 2 from FDOT attended a course sponsored by the U.S. Department of Transportation on vehicle noise enforcement. The information gained from this course and the lack of success in developing a cost-effective means of stationary vehicle testing led to the development of an over-all motor vehicle noise control plan.

The plan, which has recently been updated, consists of the 3 alternative control approaches shown in Figure 3. These approaches, source control, path control, and receiver control, are each then broken down into alternative control strategies (Figs. 4, 5, and 6). FDPC recognizes that source control is the most effective approach, but strongly feels that all 3 approaches are necessary to achieve a practical and meaningful reduction in noise levels generated by motor vehicles.

At the end of 1973 the only part of the plan that had been implemented was a visual check in the inspection stations to determine whether exhaust systems were in working order. FDPC and FHP were receiving more and more pressure to establish a quantitative noise test procedure for in-station use. Both agencies agreed that, even if a test could be developed that would accurately identify noisy motor vehicles, the cost of retrofitting more than 1,400 Florida stations and equipping and training the necessary personnel would be prohibitive, especially since the legislature failed to provide any funds for research and development related to or for implementation of the 1972 noise law. Furthermore, both agencies knew that the effectiveness of this control would be severely limited because of the "put-the-muffler-back-on" and "get-the-thing-fixed" syndrome related to the annual vehicle inspection. Florida needed a more comprehensive control.

NOISE CONTROL LEGISLATION IN 1974

In the 1974 session of the Florida legislature, 3 bills directly related to noise control were introduced: a bill that would limit motor vehicles to one horn or warning device with a sound emitting capability no greater than the vehicle manufacturer's original equipment (failed); a bill that directed FDOT to incorporate in the construction of state highways both artificial and natural means of abating highway noise (passed both houses); and a bill that was related to motor vehicle noise prevention and control (passed with only minor amendments). This latter bill, sponsored by Representative Betty Easley and Senator John Vogt, is discussed in the following sections.

HISTORY OF VOGT-EASLEY BILL

In early January 1974 FDPC was requested by Representative Easley of Clearwater to provide technical assistance in the drafting of a motor vehicle noise control bill. A preliminary meeting was attended by Representative Easley and representatives from FDPC, FHP, and FDOT. It was decided that FDPC would coordinate the drafting of a motor vehicle noise control bill; the California Vehicle Code and the Chicago Noise Ordinance would be used as models. It was also suggested that Senator Vogt of Cocoa Beach, who in 1973 sponsored an unsuccessful noise control bill similar to the Chicago Noise Ordinance, be invited to join in the development of a bill concerning motor vehicle noise alone.

A second meeting was held in Orlando on February 15, 1974, attended by Representative Easley and Senator Vogt and representatives of FDPC, FHP, University of South Florida, Florida Technological University, a local pollution control department, and Bolt Beranek and Newman (BBN), at that time under contract to FDPC to research and develop a static vehicle noise test. A preliminary draft bill presented by FDPC was discussed and revised, and a strategy was developed for introducing companion bills in each house of the legislature and for identifying support requirements for the

Figure 3. Alternative approaches to motor vehicle noise control.

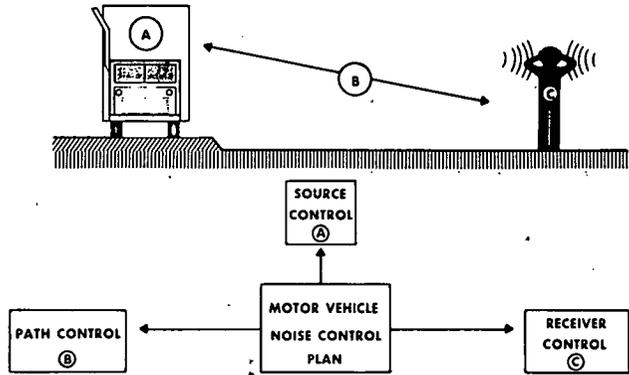


Figure 4. Noise source control strategies.

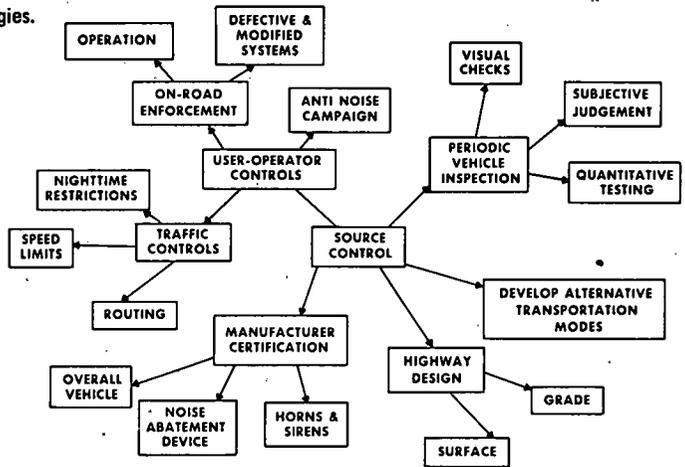


Figure 5. Noise path control strategies.

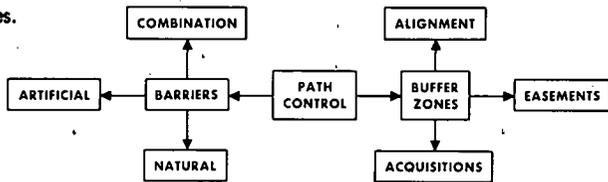
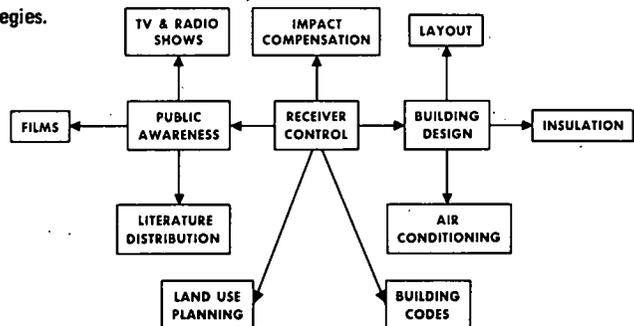


Figure 6. Noise receiver control strategies.



bill, such as resolutions of support, documentation on the effectiveness of the bill and its compatibility with existing and anticipated federal, state, and local noise control legislation, and expert witnesses for backup.

On February 19, 1974, the Florida Board of Pollution Control extended an existing agreement held with BBN to act as an advisor to the state; evaluate and refine the draft bill in such a manner as to maintain its original intent; document the bill, that is, explain its purpose and compatibility with existing and anticipated federal, state, and local regulations; and provide expert testimony at legislative hearings on technical aspects of the bill.

A final review and organizational meeting was held in Tallahassee on April 3, 1974, the day after the legislature convened. Attending the meeting were Representative Easley and staff, Senator Vogt and staff, and representatives of FDPC and FHP. The final draft of the noise bill was reviewed and accepted. The funding requirements for the proposed program were presented by FHP and FDPC. The program would establish 1 new FDPC position at a cost of \$17,000 and 8 new FHP positions—1 sergeant, 6 troopers, and 1 clerk—at a cost of \$185,000. FDPC and FHP joined in requesting that the bill be killed if funding provisions were eliminated or severely limited. Representative Easley also announced that Representative Ted Randell had agreed to co-sponsor the house companion bill. The sponsors of the bill held a press conference on April 10, 1974, to announce the filing of their companion bills and to explain the purpose and content.

CONTENT OF VOGT-EASLEY BILL

The bill, which was entitled Florida Motor Vehicle Noise Prevention and Control Act of 1974, essentially amended 3 existing chapters of Florida Law as shown in Figure 7.

1. Chapter 403, Environmental Control, was amended to include section 403.414, which provides definitions, prohibits the sale of new motor vehicles that produce a maximum sound level in excess of specified limits, requires the establishment of test procedures for determining compliance, requires certificates of compliance, prohibits the sale of mufflers or other noise abatement devices that increase the noise above that of the motor vehicle as originally manufactured, and provides for uniformity of its provisions throughout the state.

2. Chapter 316, State Uniform Traffic Code, was amended to include section 316.293, which provides definitions, prohibits the operation of motor vehicles that produce a sound level in excess of specified limits, provides for the establishment of measurement procedures for enforcement, prohibits the modification of motor vehicles to increase their noise above that emitted by the vehicle as originally manufactured and prohibits the operation of a vehicle so modified, and provides for exempt vehicles.

3. Chapter 320, Motor Vehicle Registration, was amended to include section 320.834, which prohibits the registration of the new motor vehicle for which certification of compliance with new motor vehicle noise limits has not been made.

The bill further provided for a joint study by FDPC and FHP on the effectiveness of the act and set October 1, 1974, as the effective date.

In summary, the bill required that new motor vehicles be manufactured to operate quietly and that individuals maintain their vehicles so as to ensure the continuance of the original sound level. It prohibits the modification of any noise abatement device that would increase the overall sound level of the vehicle. Finally, the bill outlawed the sale of noise abatement equipment replacement components that when installed as directed would increase the overall sound level.

LEGISLATIVE ACTION ON VOGT-EASLEY BILL

After being introduced in the respective houses, House Bill 3365 and its companion

Figure 7. Florida Motor Vehicle Noise Prevention and Control Act of 1974.

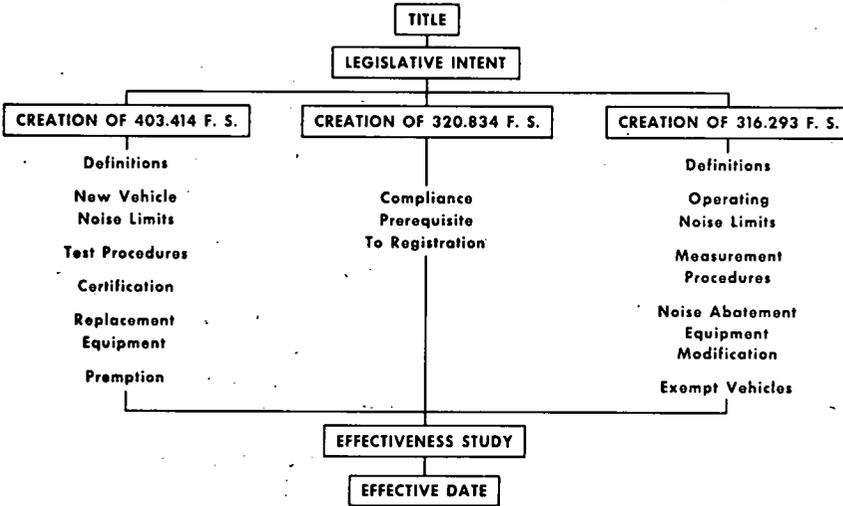
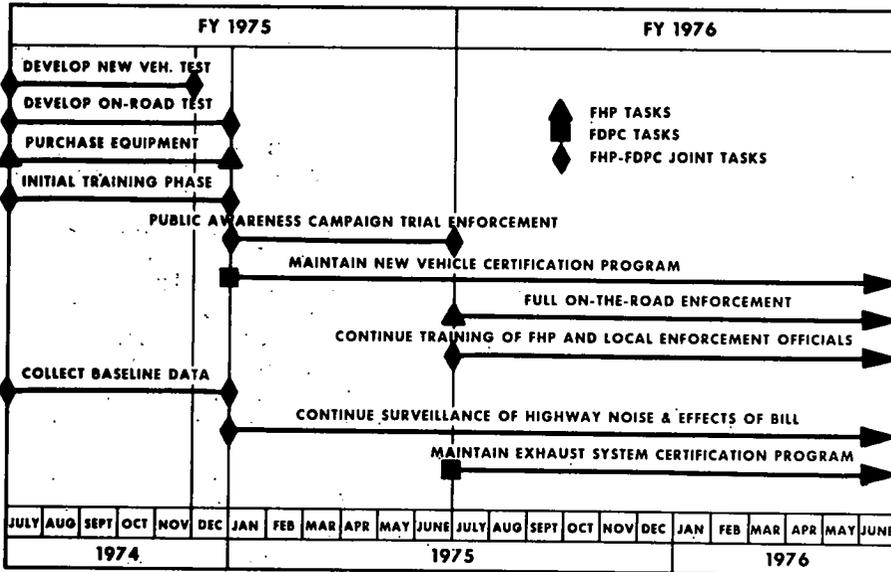


Figure 8. Program implementation of noise act.



Senate Bill 278 were referred to committees for technical review and fiscal impact investigation. The following major amendments were successfully made during the legislative review process.

1. The House Environmental Protection Committee insisted on adding to the newly created section 403.414 a subsection that would require the provisions to be uniform throughout the state, thus preempting any local efforts to implement manufacturers' noise limit requirements that differed from those in the state law. A similar requirement already exists within chapter 316; therefore, the provisions of newly created section 316.293 are likewise preemptive.

2. As a result of strong pressure exerted by representatives of major motor vehicle manufacturers, the sound-level limit was increased from 80 to 83 dBA for motorcycles manufactured between January 1, 1975, and December 31, 1977, and from 75 to 78 dBA for those manufactured after January 1, 1978. Also, the last change date in the timetable was postponed a year in all 3 vehicle categories, and the operating noise limits timetable in section 316.293 was adjusted to maintain consistency between the 2 sets of sound level limits. An amendment also exempted any motor vehicle not required to be licensed under the provisions of chapter 320.

3. The list of vehicles exempt from the provisions of newly created section 316.293 was extended to include motor vehicles engaged in a sanctioned professional or amateur competitive sports event; motor vehicles engaged in a manufacturer's engineering, design, or equipment test; and construction or agricultural equipment either on the job site or traveling on highways.

The bill passed both houses and became the Motor Vehicle Noise Prevention and Control Act of 1974.

IMPLEMENTATION PLAN FOR THE ACT

FDPC has developed in cooperation with FHP a program for implementing the provisions of the act. Program phasing considerations and a breakdown of FDPC and FHP task requirements are shown in Figure 8.

Although the act was not to take effect until October 1, 1974, some efforts were started in June 1974 to collect base-line data on individual vehicle noise levels and to monitor overall highway traffic noise. A more detailed study of individual vehicle noise levels was conducted from October 1, 1974, to December 1, 1974, by FDPC noise staff and its 5 consultant universities, each collecting detailed information on 1,000 vehicles under a wide range of operation conditions for a total of 6,000 data points. A continued surveillance of both individual vehicle levels and overall highway noise levels will be maintained throughout program implementation to monitor its effectiveness.

Appropriations requested for the implementation of the act were approved by the legislature and during the fall of 1974 the positions were filled. The 6 troopers were put through an 80-hour training course designed by FDPC and FHP on the fundamentals of sound and the enforcement of the act. Shortly after the training session, the troopers contacted the state attorneys to brief them on the new program and to answer questions.

A new FDPC Rule on Test Procedures to be used for determining compliance with the law was developed by both agencies and promulgated by the Florida Board of Pollution Control at a public hearing on November 20, 1974. These procedures closely parallel the test procedures established by CHP and are, as the law requires, in strict conformance with the recognized standard procedures of the Society of Automotive Engineers.

FHP began a trial on-road enforcement program on December 1, 1974, and plans to go to full-fledged enforcement sometime in 1975. FDPC requested manufacturer certification of new vehicles by letter on November 20, 1974; the actual certification program was not implemented until January 1, 1975. Both agencies are working on a

strong public awareness campaign including press releases and public speaking engagements, and FDOT has designed road signs that might be used at some future date to alert travelers as they enter the state.

Since the on-road enforcement program is set up as a section under chapter 316, Florida's Uniform Traffic Code, local law enforcement officials are required to become involved in the enforcement. However, as required by the new rule on vehicle sound measurement, all officials involved in enforcement will have to be trained and certified by FDPC and FHP. A training program is currently being developed for local law enforcement officials and will probably be implemented in 1975.

The final phase of program implementation will involve the development of an exhaust system certification program as required by the act. This program is scheduled to begin on July 1, 1975.

HIGHWAY NOISE ABATEMENT ACT

As mentioned earlier, another bill was passed in the 1974 session of the Florida legislature that essentially directs FDOT to

1. Use noise control methods in the construction of state highways, especially where they abut residential development;
2. Consider both artificial and natural means of highway noise abatement, emphasizing the uses of vegetation for both physical reduction and psychological screening;
3. Expend the maximum amount of federal matching funds available for highway noise control;
4. Consult and cooperate with the Division of Forestry and FDPC in the study and use of noise control strategies; and
5. Report to the legislature prior to the 1975 regular session.

Although this act is not so comprehensive as the noise control and prevention act, it clearly expresses the legislature's desire for FDOT to accept a more responsible role in controlling motor vehicle noise.

SUMMARY

The recently enacted motor vehicle noise control legislation has established a means of implementing a number of high-priority control strategies within the motor vehicle noise control plan. The implementation of the act is continuing with visual checks of exhaust systems during periodic vehicle inspection, and FDPC is continuing its research in the area of quantitative static testing. The act established a means of implementing additional source control strategies, which can be classified as user-operator controls and manufacturer controls. The noise abatement act primarily directed the implementation of barrier-oriented control strategies. However, if strictly interpreted, it could be considered a directive to implement all alternative noise control strategies, for it speaks to the use of "noise control methods." Unfortunately, the only control strategies directly funded are those that were created by the noise control and prevention act, and even those funds are limited in terms of supporting a statewide program.

VEHICLE NOISE CONTROL PROGRAM OF THE NEW JERSEY TURNPIKE AUTHORITY

John G. Kunna
New Jersey Turnpike Authority

The New Jersey Turnpike is located in a key corridor in the northeast United States. Its 120 miles (193 km) connect the southwest and northeast corners of the state and carry traffic in and out of the New York City area from and to all points south and, via the Pennsylvania Turnpike, from and to all points west.

In 1974, the New Jersey Turnpike was traveled by approximately 105 million vehicles including approximately 16 million trucks carrying nearly 128 million tons (116 000 Mg) of goods and supplies. One out of every 364 vehicle-miles (572 vehicle-kilometers) traveled in the United States is traveled on the New Jersey Turnpike.

The Turnpike Authority is an agency of the state, responsible to the governor. The enabling legislation, which created the Turnpike Authority in 1948, permits the authority to make and enforce traffic regulations to control vehicles operating on the turnpike. To the extent practicable, the regulations are to be consistent with the state's Motor Vehicle Code.

The turnpike passes through approximately 40 municipalities. Traffic growth caused the authority to widen the northern 25 miles (40 km) of the turnpike from 6 to 12 lanes. While the authority has tried to provide an efficient transportation facility within New Jersey, states adjacent to the turnpike have complained about the noise emanating from turnpike traffic. Originally, the authority adopted the position that it was the responsibility of the state legislature to deal with noise. In more recent years, the accentuated

concern for the environment, the establishment of environmental protection agencies, and the need to prepare environmental impact statements for the authority's ongoing expansion programs made it increasingly apparent that the Turnpike Authority itself had to do something about traffic noise.

STARTING THE PROGRAM

In early 1973, the authority became aware that the U.S. Environmental Protection Agency was to adopt vehicle noise emission regulations. In addition, the New Jersey Noise Control Act of 1971 provided that the state Department of Environmental Protection promulgate requirements for the control of noise for motor vehicles. The involvement of these agencies in the control of vehicle noise raised the question of what the Turnpike Authority should do.

After a period of time, it became obvious that the EPA regulation would not be promulgated soon enough to serve the authority's immediate timetable. In addition, the state Department of Environmental Protection had no immediate plans for a vehicle noise emission regulation. Enforcement by either of these agencies or other agencies that might be assigned the enforcement responsibility was uncertain. Therefore, in June 1973, the authority engaged a consultant to prepare noise emission regulations.

REGULATIONS

It was understood that the proposed EPA regulation preempted all other regulations pertaining to interstate carriers. So that it would not have to revise regulations at a future date and would be able to benefit from all studies made by the Environmental Protection Agency, the authority decided that its regulations would be identical to the proposed EPA regulations for heavy trucks without regard to whether they were engaged in interstate commerce. This distinction would be of no significance to the turnpike and would avoid the problem of authority personnel trying to determine which trucks were engaged in interstate commerce and which were not. But the authority wanted to control noise from all vehicles and, therefore, decided to adopt lower limits for light trucks, passenger cars, and motorcycles.

Because of a serious concern about a long-term solution to the problem of noise from ever-increasing traffic, the authority adopted stricter regulations for future years based on the best information available on future technology.

PUBLIC RELATIONS

The Commission of the Turnpike Authority adopted the noise regulations on March 26, 1974. The consultants had prepared a background document that incorporated data collected by other agencies but related exclusively to turnpike traffic. The authority invited municipal officials and the press to attend a noise measurement demonstration program. Both press and television reporters were interested in this program and gave major coverage in New York newspapers and on Philadelphia television stations. Many local newspapers also printed stories. Members of the New Jersey Motor Truck Association were invited to attend special meetings at which the regulations were explained and questions were answered.

In June 1974, a public hearing was held on the proposed noise regulations. Based on the position papers and the testimony presented, we concluded that the proposed regulation would be workable. Subsequently, on July 23, 1974, the authority adopted, in its final form, the vehicle noise emission regulation. All necessary requirements of the New Jersey Administrative Code were followed. In deference to some of the arguments presented by the Motor Truck Association, the stationary test and visual inspection tests were to become effective on January 1, 1975, and the pass-by test to

become effective October 1, 1974.

During August and September, the authority conducted a relatively extensive program to inform truckers whether their trucks were too noisy. On several occasions, arrangements were made to have trucks pass by the noise measurement site where officials of the Motor Truck Association were present at the microphone locations. There were also conferences at which the data collected during this period were made available to the officials of the Motor Truck Association.

A high percentage of tank trucks seemed to be in violation of the regulation, and the authority conducted special tests for tank trucks. First a stationary test was performed, and sources of noise from the vehicle were analyzed. Results revealed that two of the large truck companies that operated tank trucks on the turnpike were using certain tires that, when they were about 30 percent worn, imitated the effect of a "pocket" retread. We have been working with the New Jersey Motor Truck Association in correcting this problem.

The authority also decided that it would be to the benefit of the trucking industry to have a manually operated display sign that would tell drivers their noise level readings. One day a week was set aside for operation of the sign, and the trucking association informed drivers that appointments could be made at specific hours.

TRAINING AND ENFORCEMENT

A state police troop is assigned exclusively to the turnpike to enforce traffic regulations. An important decision for the authority was defining the role the state police were to play in enforcing the noise regulations.

The state police were included in all discussions during the development of the regulations and also in the training program. The state police also assisted the authority in the decision on the course of action with regard to identification of the source of excessive vehicle noise. On the heavily traveled turnpike, which does not offer wide areas for checking vehicles, identification of the source was deemed to be a hazardous job. Therefore, the authority agreed only to advise truckers of the possible sources of unwanted noise.

Because of the special training required, the limited staff (2 teams) of noise enforcement personnel, and the frequent turnover of state police officers assigned to the turnpike, the authority decided that equipment operators should be civilian employees of the Traffic Engineering Department inasmuch as the state police work through the Traffic Engineering Department, which is responsible for vehicle operations on the road. Therefore, the Traffic Engineering Department has full responsibility for the enforcement program. The state police are in radio contact with equipment operators, intercept the vehicle in violation, and issue the summonses.

For comfort of the operator throughout the year, a van was purchased that was fitted with an office desk and that allowed the operator to have a full view of the road. Because the van constituted a sound-reflecting surface that would have required site correction factors, a 120-ft (36.6-m) extension cable was used. To our knowledge, extension cables longer than 60 ft (18.3 m) had not been used before for enforcement of vehicle noise regulations.

The consultant conducted the first training program and certified the equipment operators and the state police involved in the initial enforcement effort of the program. In the future, we expect authority personnel to conduct training classes, except for the class on acoustics. State police officers attended the training program and, in addition, an officer of the state Division of Motor Vehicles was also invited to attend. At the conclusion of the course, certificates were presented to 9 graduates.

JUDICIAL CONSIDERATIONS

The authority wants to set a minimum fine for noise emission violators, but the statutes governing fines for traffic violations on the turnpike do not now permit this. The

minimum fine is determined by the municipal courts; the maximum allowable fine is \$200. The authority is trying to change the regulations pertaining to fines.

The authority invites municipal judges to witness noise measurement procedures, but the response so far has been minimal. To date, the courts have not established clear policies on how ticketed violators are to be handled.

Since the state police are represented by the Office of the Attorney General, a deputy attorney general is assigned to this vehicle noise emission regulation program for representation in court.

SITE SELECTION AND INSTRUMENTATION

The sites were selected by members of the Traffic Engineering Department, the Engineering Department, the state police, and the consultant. The Traffic Engineering Department is responsible for safety on the road and required that the van be located 30 ft (15 m) beyond the edge of the pavement or behind the guardrail. The state police were concerned about the position of their intercept vehicle and the distance available for the intercept vehicle to pull over a violating vehicle. A representative of the Engineering Department and the consultant inspected the sites so that they could certify on a site plan the nature of the engineering features and the sound-reflecting surfaces within the sound measurement site.

For each site, a monument was located at the microphone location to eliminate the need for the operators to make measurements at the site each time they set up the equipment and thus to eliminate a potential source of error. According to legal counsel and the state police, a certified site is of immense aid in the defense of any violation of a summons in court.

The authority relied on the consultant's expertise in the selection of the noise measurement equipment. Although the regulation requires only that the instrument meet specifications of the American National Standards Institute for sound level meters, the authority decided to invest in the best instruments available and thus acquired a precision sound level meter. We thought that the courts, knowing that we were using the best instruments available, would be more favorably disposed to ruling in favor of the enforcement action.

REMAINING PROBLEMS

Although the New Jersey Motor Truck Association has not undertaken any formal action at this time in contesting the noise regulation, it continues to indicate dissatisfaction with various aspects of it. Precisely what can be done with regard to the tire problem experienced by some tank trucks is unclear at this time. The Motor Truck Association has also focused a lot of attention on construction vehicles and the noise that they make; however, no material has been presented that indicates that these vehicles cannot be quieted.

The program funding is still a problem in these times of economic uncertainties. What the authority does on the turnpike has a major effect in adjoining states. Others are receiving the benefits of our efforts, for which we are pleased, but the program requires more than just positive action by the New Jersey Turnpike Authority. We hope that neighboring jurisdictions will soon adopt and enforce noise regulations.

DEVELOPMENT OF A PROGRAM TO CONTROL MOTOR VEHICLE NOISE IN MARYLAND

Frederick Gottemoeller
Maryland Department of Transportation

The Maryland legislature meets in annual 90-day sessions, beginning early in January. Almost all legislative business is conducted during those periods. The development of new legislative programs is therefore tied to this annual cycle.

The starting point for our efforts in noise control was a series of bills to regulate aviation noise. They were introduced in the late 1960s and early 1970s by Senator Alfred Lipin whose district in Anne Arundel County includes the Baltimore-Washington International Airport. Environmental noise is a matter of some concern to his constituency. The bills were not adequate to deal with the complex field of aviation noise and, in general, were unenforceable. The Maryland Department of Transportation felt that controlling aviation noise was a worthwhile goal and suggested to Senator Lipin that he withdraw his bill in the 1972 session and substitute a resolution directing the department to make a study and submit suitable legislative proposals to the 1973 session. He agreed to do so, and the resolution passed.

The Maryland Department of Transportation was formed in the 1971 legislative session and began operation in July 1971. The agency brought together the State Roads Commission, the Baltimore Metropolitan Transit Authority, the Maryland Port Authority, the State Aviation Administration, which at the time was primarily a regulatory and licensing body but which was shortly to become owner of the Baltimore-Washington International Airport, and the Department of Motor Vehicles,

which is responsible for licensing, registration, safety inspections, and other matters relating to motor vehicles. The goals of the new department included making efficient and effective use of all of the modes of transportation and reducing the environmental impact of transportation. Therefore, the department felt that noise of other transportation modes should be considered in the study. The Maryland Highway Administration had been active since the late 1960s in developing highway noise barriers, including several in advance of federal requirements, but the ratio of reduction gained to barrier cost was discouraging. Source control appeared to be a more effective means, so the study was expanded to include all transportation noise.

The decision was reinforced by the opening during the same period of I-95 from the Baltimore Beltway to the Washington Beltway. This event suddenly exposed a whole new group of people to the noise of a major highway. The natural result was a series of letters and complaints to legislators and to the department.

We advised those who wrote, particularly legislators, of our progress as we went along. One of the legislators went as the governor's representative to a motor vehicle noise course sponsored by the U.S. Department of Transportation in California in 1973. His interest carried over to the 1974 session of the General Assembly, where he was a strong supporter of our legislative proposals.

Senator Lipin's resolution became effective in July 1972. In September we organized an interagency advisory committee, composed of representatives of all agencies that had an interest in noise control: the Motor Vehicle, Highway, Transit, and Aviation administrations in the Department of Transportation, the State Police in the Department of Public Safety and Correction, the Department of Health and Mental Hygiene, the Department of Natural Resources, the Department of State Planning, and the Assistant Attorney General assigned to the Department of Transportation.

The next step was to design the study and to engage an acoustical consultant to perform the study. The study design, which was developed with the help of the interagency advisory committee, included these major reports:

1. A background report to bring all decision-makers to a common level of understanding of the transportation noise problem and to include the status of existing noise control legislation, both in Maryland and elsewhere, surveys of the transportation noise problem in Maryland, and documentation of the state of the art of transportation noise control;
2. A working report to present the major alternatives for noise control legislation and the advantages and disadvantages of each; and
3. A final report to be a plain-language version of the legislation for use in explaining the proposal to legislators and potential supporters.

Contracting difficulties delayed the start of the study until January 1973, and the schedule to produce a legislative proposal was revised to the 1974 session. The background report was published in May 1973. It established that transportation noise, and in particular motor vehicle noise, determines the ambient noise level in most parts of Maryland. The report also showed a generally favorable view of noise control by public officials at both the local and state levels, but little existing legislation or technical resources that could be drawn on. The state's exhaust system law was not seriously enforced because of its vagueness. Furthermore, mufflers were not required on trucks, and many trucks were sold in Maryland without mufflers. In fact, Maryland has the honor of having the loudest single truck ever measured by the study consultant: 104 dBA at 50 ft (15 m) on I-95 north of Baltimore.

While we were working on the background report, another noise control effort was launched, which had the effect of making our carefully drawn study design suddenly obsolete. Environmental groups were successful in 1972 and 1973 in raising noise control as an issue in Montgomery County, a suburb of Washington, D.C., and in Baltimore City. Local ordinances were proposed and passed in Baltimore City. Supporters of these measures quickly realized that action at the local level would be insufficient to deal with transportation noise, particularly from motor vehicles. So a number of noise control bills were introduced in the 1973 General Assembly by

legislators from Baltimore City and Montgomery County. Interest quickly focused on a bill by Senator Newton Steers of Montgomery County.

The Steers bill basically amended the existing air pollution law to include noise. The bill was a step forward in the sense that it established noise control as a function of state government and established an administrative mechanism for developing regulations. However, it suffered from some serious defects that limited its effect in controlling transportation noise. The methods of measurement and enforcement were unchanged from those provided for air pollution; that is, a \$10,000 civil penalty was the only tool available for enforcement. The responsibility of noise control was left to the Department of Health and Mental Hygiene, which has neither the resources nor the technical background for the task in the transportation field. Finally, the legislature added a provision that all regulations had to be approved by the legislature before taking effect.

On balance, we felt that the state could be better off to wait for the more carefully studied noise control program that we intended to present in 1974. Therefore, we recommended to the legislature that they defer the Steers bill. This put us in the unfortunate position of appearing to criticize a concept that we in fact favored. It also reinforced the suspicions of those who thought that the real goal of our noise control study was to weaken or delay environmental noise control in Maryland.

There are always those who think that setting a transportation agency to monitor transportation noise is like setting a fox to guard the chickens. Unfortunately, the evidence of experience is on their side. Those of us in transportation wanted to believe that our good will and sincerity would counter those views; at least, that is what I used to think. I now think that those views are inevitable and that the only way to deal with them is to set up some other agency, preferably an environmental agency, to be the watchdog. Only in this way can the credibility and the effectiveness of the program be maintained.

In any case, the passage of the Steers bill sealed the decision for us in Maryland. Once given the responsibility for noise control, the Department of Health and Mental Hygiene was understandably reluctant to give it up. Thus, we had hardly issued our background report when the whole legal and administrative framework we were working in changed. Fortunately, our contract and our consultant were flexible enough to adapt to the changed circumstances, so we plunged ahead.

The working report was recast to present 3 alternative reactions to the new bill:

1. Leave the responsibility of noise control with the Department of Health and Mental Hygiene;
2. Attempt to administratively reinterpret existing transportation department laws in the light of the Steers bill to develop an enforceable noise control program (for example, regulations adopted by the Department of Health and Mental Hygiene might be established that would provide quantitative definitions of "excessive noise" under the existing exhaust system law); and
3. Rewrite the Steers bill to include a strong transportation noise control element that involved several state agencies in addition to the health and mental hygiene department.

These possibilities were presented to the interagency advisory committee, which unanimously chose the third alternative in September 1973. This recommendation was presented to the Secretary of Transportation, who concurred.

Clearly the Steers bill would have to be much broader than the transportation noise control bill envisioned in the original contract. The Department of Natural Resources asked that sections on recreational vehicles and motor boats be included. As finally written, the bill included sections on stationary sources, control, recreational vehicles and motorboats, state purchasing and contracting, and motor vehicles and aviation.

It was also clear that the rewrite must contain the basic substance and, as much as possible, the exact wording of the Steers bill. This established the Department of Health and Mental Hygiene as the overall coordinator of the state's noise control

program and the final authority on environmental noise standards. Two basic strategies were adopted.

1. The noise control program would be a joint effort involving several state departments in the areas in which they were most qualified; the Department of Health and Mental Hygiene would provide overall coordination. As a corollary, the bill would build on existing sections of the code and existing enforcement methods insofar as possible. In the final version, 6 chapters of the Maryland Code would require amendments. A permanent Interagency Noise Control Committee, under the chairmanship of the health and mental hygiene department, would be established to coordinate the state's activities and report to the legislature annually.

2. The proposal would be an enabling act, allowing state agencies to promulgate and enforce sound-level limits in accordance with overall policies contained in the bill and environmental noise standards to be established by the Department of Health and Mental Hygiene. Policy guidelines would include reasonable cost, availability of technology, and safety of flight.

Under this basic scheme, the promulgation of motor vehicle sound-level limits was to be assigned to the Motor Vehicle Administration of the Department of Transportation. Enforcement was to be done jointly by the Motor Vehicle Administration and the State Police. This approach paralleled an existing section of the motor vehicle code dealing with safety equipment, to which the noise provisions were merely appended. The motor vehicle section includes regulation-writing authority for motor vehicles in use, new motor vehicles, and after-market replacement equipment.

In mid-October we explained our strategy to Senator Steers. Once he was satisfied that we were sincerely attempting to strengthen his bill and that its major features would be preserved, he was willing to lend his support to the proposal.

We were not so fortunate with the Department of Health and Mental Hygiene. Defining exactly how its role would change from that envisioned in the Steers bill proved to be the most difficult aspect of the drafting job. A 3-month period of interagency negotiation was required. The final issue was who would have the final approval of transportation sound-level limits. We proposed a consulting relation with the Department of Health and Mental Hygiene. Representatives of that proposed that transportation sound-level limits be submitted to them for approval and promulgation. Finally, a secretarial-level meeting was arranged between the 2 departments that resulted in an agreement that transportation sound-level limits would be promulgated by the Secretary of Transportation with the "endorsement" of the Secretary of Health and Mental Hygiene.

We presented the proposal to Governor Mandel with a request that he make it part of his administration program. Only a few bills are placed in this program each year. Once included, the bills are handled by the governor's own legislative staff, and their prospects are much improved. The governor agreed to support the bill, and on this basis the bill was presented to the legislature.

In the first hearing, the Senate committee was not overly receptive. Most of the support was qualified; changes and delays were requested. The committee chairman agreed to appoint a subcommittee, whose membership included Senator Steers, to mark up the bill. During the subcommittee sessions, about a dozen changes were made in the bill. All of our background work paid off, for we were able to give immediate answers on the effects of the bill and to judge whether to accept or reject changes. In the process, we were able to convince the subcommittee members and gain the acceptance of the critics.

The most serious issue was legislative review and approval of sound-level limits. Industry groups were concerned that the state agencies would be unreasonable in setting those limits and wanted to amend the bill to include approval by the legislature of all regulations. We argued that the policy guidelines on the bill were sufficient safeguard. The compromise finally reached was to delay the enforcement date of the bill to July 1975. This would allow the industry groups to bring any unfair regulations to the attention of the 1975 legislative session. With this and other changes, the bill

passed the Senate.

On the house side, a subcommittee was also formed. However, here there was a new issue for us: the effect of the bill on agriculture. At this point it was too late to consider further changes, so our goal was to convince the subcommittee to support the bill. We could not convince the farmers. The bill cleared committee, but a major amendment to exempt agriculture was offered on the floor. It failed by a tie vote, and, by the margin of 1 vote, we have a noise control program in Maryland.

The law went into effect in July 1974. We moved immediately to get budget amendments and new positions in the various agencies to implement the law. Because of the concern expressed in the house hearings, we are careful to include the Department of Agriculture in our implementation efforts.

Our basic schedule is to prepare regulations during early 1975, and simultaneously to obtain personnel and needed equipment. Training and public information programs are to be done during late spring, and enforcement is to begin in July.

In the Department of Transportation, we were able to move money and positions from elsewhere within the department. We developed a follow-up contract with our consultant to assist in developing the regulations and enforcement programs. Vehicle in-use regulations were published on October 30, 1974, and a public hearing was held January 8. The regulations are similar to federal and California standards. New-vehicle standards were published December 11, 1974, and a hearing was held February 18.

Other agencies have not been so successful. The State Police agency was turned down on its request for 12 additional troopers for noise work, and the Department of Health and Mental Hygiene was also refused a special request for additional funds. The earliest that additional help will be available for these agencies will likely be in the budget for the 1976 fiscal year, which begins July 1, 1975. Although this is the earliest that noise enforcement can begin, we had hoped to have the required personnel recruited and trained by that time. If that becomes the earliest that new personnel is available for training, serious enforcement will probably not begin until early 1976. Here the issue of timing is raised again. When we started in 1972, the state's economic situation was much different, and budget support did not appear to be a problem. Now, budget support is a major issue.

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