COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT, KENTUCKY 40601

CHARLES PRYOR, JR.
COMMISSIONER OF HIGHWAYS

April 11, 1972

ADDRESS REPLY TO:
DEPARTMENT OF HIGHWAYS
DIVISION OF RESEARCH
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LEXINGTON, KENTUCKY 40508
TELEPHONE 606-254-4475

H.3.24

Memorandum to: J. R. Harbison
State Highway Engineer
Chairman, Research Committee

Subject: Research Report No. 322, "Noise Abatement: A Review of Literature"; and Proposal

Complaints concerning traffic noise and possibly seismic vibrations emanating from highways would probably have been adjudicated on the basis of common law doctrines pertaining to "nuisances", "common enemy", and "power of relief" were it not for recent legislation and regulations directed toward protection of the total environment. In effect, "freedom from noise" has been added to the clean water, clean air, clean earth policies. Surely each of those policies are founded on public sentiment.

There have been a few instances where the Department has yielded relief because of traffic noise. Now safeguarding regulations seem inevitable.

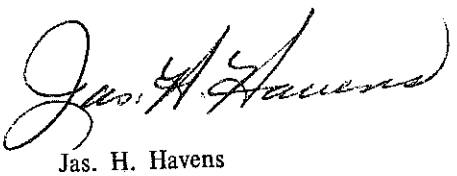
In the past, this Division has not presumed to pioneer in noise research but has been dutifully watchful toward developments elsewhere. We have procured a basic noise meter and have been cooperating with the Design Division in their more immediate efforts to bring measurements and abatement possibilities into consideration at the design stages.

The formal, research proposal attached hereto is intended to consolidate our more casual efforts of the past into a timely study implementation of regulations. The work thus far has not involved federal participation. Regardless of whether or not participation will be sought, critical review and comments on the proposal are invited.

The report submitted herewith is probably best described as "soft work"; it is a brief review of literature and is included here in support of the proposal. The first part was written by Diana Deen, R. C. Deen's daughter, for a high-school assignment. It appeared to bring forward certain items of information not found in highway literature.

The report has been prepared for limited distribution only.

Respectfully submitted,



Jas. H. Havens
Director of Research

JHH:dw
attachments
cc's: W. B. Drake
J. T. Anderson
G. F. Kemper
C. G. Grayson
J. W. Spurrier
John Witt
G. F. Vansant
E. B. Gaither
J. W. Fehr
L. F. Cohn

PROPOSAL

FOR

RESEARCH STUDY

I. IDENTIFICATION

A. Title of Study	Highway Traffic Noise
B. Proposer	Kentucky Department of Highways State Office Building Frankfort, Kentucky 40601
C. Research Agency	Division of Research
D. Responsible Principal	James H. Havens Director of Research 533 South Limestone Lexington, Kentucky 40508
E. Co-Principals	Kenneth R. Agent Research Engineer Associate
	Ben Carr Research Engineer Associate

II. PROBLEM STATEMENT

Increased noise levels on todays highways have clearly indicated that the design and routing of new highways must consider the impact of added noise upon the environment. Procedures have been developed for the prediction of traffic noise levels, and these procedures will be applied in highway design. There is a need to verify and, if necessary, to modify procedures and assumtions involved by utilizing on-site noise level measurements and comparing them to predicted values. Roadside acoustic barriers have been suggested as a means to shield the surrounding environment at critical locations from excessive traffic noise. Effectiveness and feasibility of such barriers needs to be demonstrated.

III. BACKGROUND AND SIGNIFICANCE OF WORK

Traffic noise, while recognized in the past as a nuisance by those subjected to it, has reached alarming levels in some urban areas and is considered a major pollutant of the environment. Increased traffic volume and construction of high speed highways within densely populated areas in particular has aroused public concern and even indignation. The rural dweller as well has shown increased concern in the disruptive effects to his environment as result of locating major highways nearby. The highway engineer, therefore, is called upon to consider the consequences of added noise upon the community in the design, location, and construction of highways while satisfying the needs and demands for improved transportation facilities.

Highway-generated traffic noise emanates primarily from vehicle engine exhausts and the tire-pavement interaction. Under normal operating conditions, the car generates as much noise from the tire-pavement interface as from the engine exhaust. Large diesel trucks are much noisier than cars and even with maxium muffling would be expected to produce significantly higher noise levels than cars at the same road speed due to the larger contact areas under the tire. Noise produced in the tire-pavement interface is speed dependent and varies with pavement texture. Course-textured pavements are noisier than smooth pavements. The noise level at a particular highway site depends on the traffic speed, composition of trucks, traffic density, roadway characteristics (e.g. grade, intersections, elevated or depressed roadway), noise attenuation barriers such as trees and shrubs, and distance from the traffic streams.

Abatement and control of traffic noise within an environment involves the direct control of noise emitted by individual vehicles, traffic routing and highway design. The highway engineer is primarily concerned with the last two categories since he can exert some degree of control. However, highways attract residential and other developments around them and in time may cause noise problems.

Several design guide procedures have been developed in an attempt to predict noise levels at points near a highway from information on traffic characteristics and roadway geometrics. Design guides identify the roadway and traffic parameters and the expected contribution to noise level from each parameter by simple application of charts and tables. The prediction procedure can be computerized and, thus, plots of noise level contours can be prepared automatically.

The following publications describe studies which are related to the problem area:

1. Apps, D. C.; "Cars, Trucks, and Tractors as Noise Sources," Noise as a Public Health Hazard, February 1969.
2. Gallowey, W. J.; Clark, W. E.; and Kerrick, J. S.; Highway Noise-Measurement, Simulation, and Mixed Reactions, National Cooperative Highway Research Program Report No. 78, Highway Research Board, 1969.
3. Gordan, C. G.; Gallaway, W. J.; Kugler, B. A.; and Nelson, D. L.; Highway Noise--A Design Guide for Highway Engineers, National Cooperative Highway Research Program Report No. 117, Highway Research Board, 1971.
4. Paullin, R. L.; "Transportation Noise Control," 49th Annual Meeting, Highway Research Board, January 12-16, 1970.
5. "Pollution of Michigan Urban Atmospheres by Highway--Generated Noise," Michigan Department of State Highways February 1970.
6. Swanson, H. A.; "Motor Vehicle Noise Research and Legislation," Traffic Engineering, July 1971.
7. Young, M. F. and Woods, D. L.; "Threshold Noise Levels," Texas Transportation Institute, December 1970.

IV. OBJECTIVE OF THE STUDY

To verify the Department's noise prediction procedure presently in use and to determine the effectiveness and feasibility of roadside acoustic barriers in reducing noise levels.

V. IMPLEMENTATION

The findings of this study will be used to verify and, if appropriate, to suggest modification of procedures in order to improve noise level predictions. Knowledge of the effectiveness of acoustical barriers will facilitate the design and location of such barriers at critical areas on highways.

VI. WORK PLAN

With the aide of a sound level meter and recorder, continuous noise level measurements will be obtained at sites with varying roadway configurations and characteristics and under varying traffic conditions. From these, the L_{50} and L_{10} noise levels will be calculated and compared to the predicted values. In the event of significant discrepancy, various parameters associated with a given highway site will be analized and more accurate prediction models will be derived. However, major emphasis will be placed upon validation of the assigned weighting factors associated with each parameter considered in the prediction model. Extensive collection of noise level readings of individual vehicles operating under various roadway conditions on several catagories of roads will be required.

Several highway construction sites will be studied, especially in urban areas. Noise level measurements will be initiated prior to construction to establish existing background noise levels. During construction, readings will be taken to ascertain the impact of construction upon the environment. After the highway is opened to traffic, further monitoring will be performed.

Sites will be selected at critical locations, or locations suitable for investigative work, and noise measurements will be obtained before and after erection of experimental acoustic barriers to study their performance. Guidelines will be prepared as to the utilization of such barriers and their design requirements.

VII. STAFFING PLAN

Research Engineer Associate (1)	50%
Research Engineer Associate (1)	25%
Engineer Aides (2)	20%

VIII. LEVEL OF EFFORT

It is anticipated that three years will be required to successfully complete the efforts described in the work plan. The following level of effort will be expended in the intermediate phases of the overall plan:

Obtain L_{50} and L_{10} values under various roadway conditions	20 months-27%
Monitoring of individual vehicles	12 months-16%
Monitoring of construction sites	18 months-24%
Field testing of acoustic barriers	14 months-19%
Data analysis and reporting	10 months-14%

IX. FACILITIES AVAILABLE

The Division of Research is housed in a large laboratory and office building designed to accommodate personnel and equipment. An electronics workshop is available for maintenance and repairs of instrumentation and equipment required in the study. The Division of Research is well equipped with calculators and other office and reproduction equipment. The University of Kentucky's IBM computer and consultation services are also available. A sound level meter and a sound level recorder have recently been purchased for use in traffic noise studies.

X. SUPPORTING DATA

A review of literature in the area of noise pollution and abatement was recently completed by the Division. A large number of readings of noise levels of individual vehicles have been obtained.

The following studies in the general area of traffic and safety have been conducted by the Kentucky Department of Highways:

1. Agent, K. R. and Deen, D. R.; "Noise Pollution and Control - A Review of Literature," 1972.
2. Lynch, R. L.; "Analysis of Traffic Loads on Bridges", 1968.
3. Garner, G. R.; "Accidents at Median Crossovers", 1969.
4. Hughes, R. D. and Garner, G. R.; "Grooving Pavement Centerlines for Lane Demarcation", 1969.

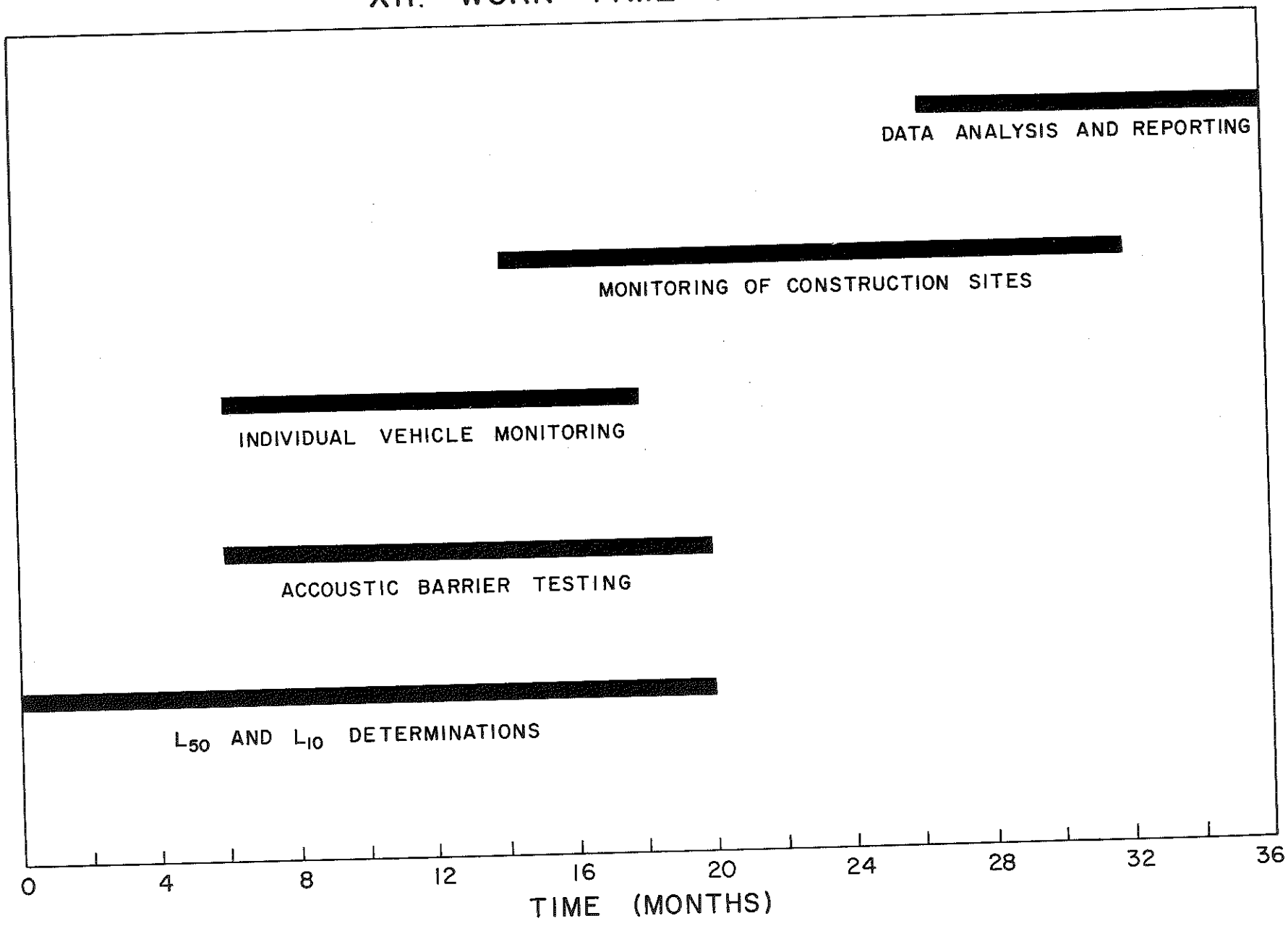
XI. WORK TIME SCHEDULE

(See Attachment)

XII. BUDGET ESTIMATE

	FY 1973	FY 1974	FY 1975	TOTAL
1. Personel	$13,000	$14,000	$10,000	$37,000
2. Non-Expendable Equipment	0	0	0	0
3. Consumable Supplies	500	1,000	500	2,000
4. Travel and Subsistence	500	1,000	500	2,000
5. Other Expenses	0	0	0	0
	$14,000	$16,000	$11,000	$41,000

XII. WORK TIME SCHEDULE



Research Report
322

NOISE POLLUTION AND ABATEMENT

A Review of Literature

KYP-72-24, HPR-1(7), Part III

by

K. R. Agent
Research Engineer Assistant

and
D. R. Deen

Division of Research
DEPARTMENT OF HIGHWAYS
Commonwealth of Kentucky

February 1972

INTRODUCTION

Cities are faced with increasing noise pollution from more trucks, aircraft, motorcycles, automobiles, and new kinds of powered equipment. With noise already a serious problem along freeways and near airports, expanding air and surface vehicular traffic will extend noise pollution over entire communities unless it is controlled. It is this noise from aircraft and automobiles which is a primary concern, not only because of its widespread effects today and for tomorrow, but because it is not too late to control it without severe economic disruption. A key question is whether governmental units have the will and the organizational capability to accomplish the following *(5)*:

*Enact laws limiting noise emission in the urban environment,

*License the sale of products presently or potentially noisy,

*Establish legal responsibility for noise emission,

*Create an office within municipal government to take the lead locally in the abatement and prevention of noise pollution,

*Require mandatory notice to home-buyers when their dwelling is in an existing or potential area of noise pollution.

*Develop acoustical insulation standards for new apartments throughout the city, and new single-family houses in designated areas,

*Employ an Environmental Air Traffic Controller to monitor air traffic routes over the city and control overhead aircraft noise,

*Equip ground patrol vehicles with sound meters to monitor ground noise,

*Install sound-recording equipment at airports and elsewhere to monitor air traffic noise,

*Plan municipal facilities so they maintain acceptable noise emission,

*Consider noise in subdivision, land use, and city planning,

*Establish a purchasing policy requiring bidders to meet noise standards,

*Establish a system for gathering and analyzing noise information,

*Adopt new and stricter limits for noise emission in urban and regional environments,

*Urge manufacturers to produce products with low noise emission.

NOISE POLLUTION

Sound can be defined as a mechanical disturbance or an oscillation in pressure, stress, particle displacement, and particle velocity propagated in an elastic medium of such character as to be capable of exciting the sensation of hearing *(15)*. Noise is sound that is obnoxious. The word is derived from the Latin roots nausea, meaning sickness, and noxia, meaning harm *(2)*. Both accurately describe the effects of noise.

Noise, at last, is being recognized as a major pollution. It is often referred to as the "New Pollutant;" but in fact, it is one of the oldest. Two thousand years ago, Horace complained about the noise that harrassed the man of letters in the Eternal City *(5)*. Noise bothered Julius Caesar so much that he banned chariot driving at night. In 1851, Arthur Schopenhauer wrote about the *"disgraceful... truly infernal"* cracking of whips in German streets *(18)*. English law (Act of 1864) allowed a householder to send away street musicians, and to this day they are required to keep moving. James Sully, writing on civilization and noise in 1878, discussed the legal aspects of noise control. He assured us that it was possible to restrain noise as a nuisance, and cites a case in which the plaintiff obtained an injunction to restrain the ringing of bells at unseasonable hours in a chapel near his dwelling *(5)*. In a study published in October 1955, **Fortune** reported *"a rising tide of noise [in] U. S. streets, factories, homes, and skies"* and asserted that Americans *"have decided that noise should be abated."* The optimism was unwarranted. Today the level of everyday noise to which the average American is exposed is more than twice what it was in 1955, and the level continues to mount *(18)*.

Although a few individuals have fought against noise for centuries, noise pollution has only recently come to the attention of the public. Scientific research has shown that noise may affect one's health in subtle ways -- both physiologically and psychologically. Dr. Samuel Rosen, clinical professor of otology (the science of the ear) at Mount Sinai School of Medicine and consulting ear surgeon at Mount Sinai Hospital in New York City, feels that unexpected or unwanted noises cause certain physical reactions -- the pupils dilate, skin pales, mucous membranes dry, there are intestinal spasms, and the adrenals explode secretions. The biological organism is disturbed *(8)*. Loud noise also can increase body tensions which in turn affect the blood pressure, the functions of the heart and the nervous system. Dr. Rosen believes that the millions of city dwellers with heart disease, high blood pressure and emotional illnesses need protection from the stresses of noise *(2)*. Rest, relaxation and peaceful sleep are necessary to all, especially to those already tense or ill. Innumerable noises invade the daily lives of great masses of people, yet nobody becomes indifferent to them. Even though such noise is not likely to damage the hearing, it does inflict stress, tension, and sometimes intolerable nervous strain. People become irritable,

unsociable, and more quarrelsome at work and at home. There seems to be little doubt that noise pollution is a health hazard *(3)*.

Dr. Alexander Cohen, director of the National Noise Study, a Public Health Service research program headquartered in Cincinnati, contends *(17)* that loud and continual noises not only damage the ears and cause hearing loss but also produce physiologic side effects, such as the narrowing of blood vessels near the surface of the body. Even loud conversation is enough to affect the nervous system and therefore provoke constrictions in a large part of the blood circulation system. Dr. Cohen confirms that hearing loss rises in proportion to noise levels and time of exposure *(7)*.

Dr. John D. Dougherty of the Harvard School of Public Health and Dr. Oliver I. Welsh, chief of the Audiology Unit of the Veterans Administration Outpatient Clinic in Boston, made a study of the loss of hearing in high frequencies. They observed that many noise levels encountered in the community exceed standards found injurious in industry *(3)*.

The human ear has three major divisions. The outer ear is the fleshy shell and ear canal at the side of the head. Originally this shell was designed to gather sounds but lost that function evolutionarily eons ago. Dividing the outer and middle ear is the pear-gray eardrum which is shaped not like a drum but like the cone of a tiny loudspeaker. Connected to it from behind is a chain of three tiny bones called the ossicles. They do more than transmit sound to the inner ear. When the sound listened to is weak, they can amplify sound thirty times; or, thanks to two tiny muscles connected to them, can lower the efficiency of their transmission of sound when it is too loud. The muscles do this in an important reflex action, on command from the brain, a few hundredths of a second after a loud noise is heard. This acoustic reflex automatically protects the inner ear much like the narrowing of the iris protects the retina of the eye from too much light.

Snail-like in shape, and filled with a liquid which closely resembles sea water, the cochlea, or inner ear, is located deep inside the protective temple bones in the skull. Sound waves transmitted by the eardrum and middle ear create waves in this liquid; these waves, in turn, cause tiny and sensitive hair cells (cilia) to be thrust against an overhanging ledge. This action triggers the electrical impulses that travel along nerves to the hearing centers of the brain.

There are about 23,500 cilia in a cochlea, arranged so that those at the front, or the outermost point of the cochlea, sense the highest frequencies, while those at the innermost peak of the spiral sense the lowest frequencies. Consequently, there is persistent wear in the small area where the high-frequency sounds impinge; this area wears out first. Also there is marked tissue change in the hair cells during noise exposure *(6)*.

According to Dr. Dougherty, the hair cells can regenerate themselves after noise exposure; but long-term exposure is likely to cause complete destruction. Dr. Dougherty has noticed increasing deafness in the general population. "There is incriminating evidence that community noise levels are causing hearing loss," he says. Even the average kitchen is guilty, he believes; the whirring and whining of kitchen machines is too loud for comfort and health. Also on Dr. Dougherty's guilty list in the rising decibel count are autos, trucks, buses, subways, power lawn mowers, and outboard motors. Sirens and police whistles, too, are dangerous to hearing, he asserts, because they affect the sensitive high frequency range *(6)*.

A more exceptional type of hearing damage, called acoustic trauma or blast trauma, is caused when a sudden burst of noise, such as gunfire, ruptures the eardrum or disrupts the chain of small bones that transmits the sound within the ear to the auditory nerve. Explosive noise may also affect the inner ear, producing cochlear damage and permanent nerve deafness *(15)*. Sonic booms are able to induce the typical startle reaction, similar to acoustic trauma, in human beings. Prolonged exposure to these sonic booms can result in health hazards, including deafness, cardiovascular, glandular, and respiratory malfunctions *(8)*.

At a recent meeting of the American Association for the Advancement of Science, it was asserted by Dr. Lester W. Sontag that the human fetus may be damaged by noise pollution, either directly by such violent noise as sonic booms, or indirectly by the mother's psycho-physiological reaction to excessive noise *(15)*. Experiments in Sweden have shown that the body of a fetus responds involuntarily to even moderate noises of 50 decibels by increasing the rate of its heartbeat. Noise also makes the fetus move around and kick. Other experiments at the University of Georgia and at the Fels Research Institute indicate that noise as a stress may induce developmental abnormalities in the fetus. This would be especially true of violent noises like the sonic boom *(3)*.

Psychiatrists and psychologists have recently noted the connection between excessive undesired noise and mental disorders. Drs. Rosen and Knudsen suggest that loss of hearing may in fact be the least serious impairment to the human organism caused by noise pollution. Both point out that one no longer has to work in a boiler factory to suffer noise-induced psychological and physiological damage. Day and night most of us are exposed to a general racket. These noises are now being recognized as a major factor in the celebrated tensions of modern living. Dr. Knudsen calls the total effect of the background roar of modern life "decibel

fatigue," and says that millions of Americans suffer from it. Dr. Rosen believes that medical science will one day recognize an entire "noise syndrome" -- a family of symptoms related to unwanted or unexpected noises *(15)*.

Noise profoundly affects the heart and blood vessels. Guinea pigs exposed to brief periods of above-normal, but supposedly tolerable, noise have developed swollen inside-the-ear membranes, and vital inner ear hair cells have been destroyed. Under prolonged noise exposure, rats have turned homosexual *(3)*. Noise also increases the level of cholesterol in the blood and raises blood pressure. Even moderate noises cause small blood vessels in the body to constrict and impede blood flow. This vaso-constrictive reflex is the body's automatic way of responding to the stress of noise. It occurs even in sleep. Dr. Gerd Jansen of Essen, Germany, measured vaso-constriction in the fingers of sleeping subjects when he played recorded noises at only 55 decibels, the level of nearby traffic. He found the effect even when the noise exposure lasted only a fraction of a second; but the blood vessels took minutes to reopen. He concluded that night sounds such as that of traffic, heard while we sleep, might endanger the health of our heart and arteries *(3)*. Even when the sleeping area is quiet, a person may be kept awake by a ringing sensation in the ears, called tinnitus, which may have been caused by exposure to excessive noise several hours earlier. Adequate sleep is a physiological necessity, and noises which prevent sleep can be said to be prejudicial to physical health. Victims may also develop psychotic symptoms because their dreams are interrupted *(15)*.

Other experiments, conducted by Dr. Jansen and at the University of Southampton in England, show that noises, even mild ones, make the pupils of the eye dilate. This can help explain why watchmakers, surgeons, and others who do close work are so bothered by noise: it affects their eyes so that they are constantly changing focus. This can cause eyestrain and headaches *(3)*.

"Sound" may damage the body and mind even though it cannot be heard. Studies have been started by the French National Centre for Scientific Research in Marseilles concerning infrasound. Infrasound has a pitch or frequency of below 30 cycles per second and is thus inaudible to the human ear, but is still capable of harming the human organism. Persons affected by infrasound experience physiological effects similar to those caused by low-frequency mechanical vibration. Vertigo and nausea are attributed to the excitation of the semi-circular canals, and infrasound may also cause resonances of internal organs producing intense irritation, visual disturbances, and interference with intellectual activity *(15)*.

At the other end of the frequency scale are the ultrasounds which are also inaudible to the human ear but which may have other serious effects on the human organism. In an extensive survey of the auditory and subjective effects of industrial ultrasonic sources made in 1967, it was found that unpleasant subjective effects, including headache, nausea, tinnitus, and fatigue were experienced by some persons and that temporary threshold-shift occurred. It is rumored that the latest exotic weapon for military use in Vietnam uses a type of ultrahigh, ultraloud sound. This weapon is a siren capable of emitting 200 decibels -- a sound intense enough to literally "boil" the inner ear *(15)*.

How harmful our civilization's noises are is well illustrated by the studies of a primitive people in Africa who live in an eerily quiet environment of 35 decibels. These people are the Mabaans of Southeast Sudan. Mabaans have incredibly sensitive hearing, even when they are very old. (The old Mabaans do not have hardening of the arteries or high blood pressure, but this might be due to their low-fat diet.) Other researchers found the same was true among the primitive Todas who live in their very quiet pastoral area of India. Furthermore, when Mabaans move to noisy Khartoum, their hearing abilities decrease and their incidence of heart diseases increases *(3)*.

Besides its biological and physiological effects, noise also has important physical effects. Take the Comet, England's and the world's first jet airliner. It was noise, in the form of acoustic fatigue, which grounded these planes in 1954. Noise generated through the fuselage caused tiny cracks in the metal, which grew until the fuselage split open, and because of pressurization, exploded. Acoustical fatigue is an important concern of aerospace engineers. Part of the testing of airplane and rocket components is to determine the effect noise will have on them *(3)*.

The sonic boom is a special kind of noise which, because it is explosive in nature, is particularly damaging. Serious damage connected with sonic booms has been observed and reported in the Canyon de Chelly National Monument in Arizona, Bryce Canyon in Utah, Mesa Verde National Park in Colorado, and elsewhere. At the Canyon de Chelly, an ancient Indian dwelling was demolished when a large portion of an overhanging clift fell following a sonic boom. Rare sandstone formations in Bryce Canyon have been severely damaged *(15)*. A rockfall of 66,000 tons occurred in 1968 in Mesa Verde National Park after the passage of two jet planes traveling at supersonic speeds *(8)*. A rock slide from a canyon wall of the Navajo National Monument in Arizona has recently been reported. In the Death Valley National Monument (California and Nevada), 323 sonic booms were counted in a six-month period ending in February 1968, with 68 of these considered to be serious enough to cause weakening and demolition of

geologic features *(15)*. Sonic booms also cause much hidden damage, especially to private homes. This was pointed out by Harvey H. Hubbard, head of the Acoustic Branch of the National Aeronautics and Space Administration. He explained that under the shock of a sonic boom a house is first moved laterally by the initial positive loading on the front surface. Then there is an inward force from all directions followed by an outward force. Finally, the house is moved laterally because of the negative pressures acting on the back surface *(3)*.

The effects of noise can largely be alleviated or prevented -- and should be. Frank Kirschner, director of engineering of the Soundcoat Company, a Brooklyn firm whose rapid growth exemplifies the rising technological interest in quiet, does not believe that machines are naturally noisy, nor is noise an inescapable price of progress. Machines can be designed to be quiet, often with a careful selection of the materials. When Stradivarius was making his violins, he would go out in the winter when the woods were dry and the sap had gone from the trees. Tapping the trees with a hammer, he would mark his selections. In late spring, he would return to cut the trees when the sap had risen, binding the fibers together. Kirschner believes that is the sort of concern for materials the modern engineer should possess *(2)*.

Proper construction techniques can make walls effective barriers to noise. The use of weather stripping to insure a tight fit of doors and windows can help to combat noise pollution. Also helpful are resilent mounting under appliances, cushioning material between plumbing connections, and an acoustical ceiling. Walls can also be made into effective sound absorbers if they are covered with sound-deadening board *(16)*.

Far better than blocking noise is preventing noise. This means that a "Think Quiet" movement has to pervade all of our technology. There are some signs of a beginning with the quiet steel garbage can developed by a Bethlehem Steel Corporation noise-control engineer at the suggestion of Citizens for a Quieter City; the can makes a thud instead of a clang when dropped. There are designs for quiet vacuum cleaners and quieter power motors *(3)*. An inaudible motor has been designed for use in front-line combat vehicles *(2)*. And new bulldozers have been made quieter by the addition of exhaust mufflers and sound-absorbing side panels *(7)*.

Noise that is not or cannot be eliminated often can be contained. The Labor Department established a health code in May 1969 in which 90 decibels was set as the loudest continuous noise a workman should endure in an eight-hour day; the higher the decibel count, the less the exposure time. Companies that do not comply to the code could be barred from bidding on government contracts worth $10,000 or more. Noise levels can be reduced at the source by noise and shock absorbers or by requiring workers to wear earplugs or earmuffs and exposing them to shorter periods of high-level noise. West Point-Pepperell, Inc. chairman Joseph L. Lanier says the company's voluntary earplug-earmuff program is being expanded to include workers in all areas where noise is excessive. J. C. Radcliff, supervisor of industrial safety at Ford Motor Company, says fewer than 50 percent of the eligible employees take advantage of the voluntary program. At Ford's forging plant in Canton, Ohio, the decibel count can reach 120. After Ford's 61-day strike in the fall of 1967, a returning worker commented, "For the first time in my life I've been hearing the birds in the morning." In trying to lower the decibel count in their factories, General Motors vents air-powered tools far from the ear of the operator instead of in his face. Ford is using acoustical-tile isolation booths to protect workers in high noise areas, such as where scrap metal is baled. J. H. Botsford, noise-control engineer for Bethlehem Steel Corporation, says that the company's purchasing agent began setting stricter noise-level standards four years ago for bulldozers, shovels, cranes, and rock drills *(7)*.

Although some individuals and industries have lowered the noise levels, government action has been slow. The first high court decision that favored persons attacked by the noise of low-flying airplanes approaching nearby airports was U.S. vs Causby [328 U.S. 256 (1946)]. Mr. Causby, a chicken farmer whose land was near the runway of a World War II air base, alleged that Air Force planes had tresspassed under the theory of "ad coelum" (to the sky), meaning that Mr. Causby's real property extended vertically as well as horizontally. The court agreed. In 1962 the U.S. Supreme Court again ruled in favor of a private citizen in Griggs vs County of Allegheny [363 U.S. 84 (1962)] when it told the operator of the Pittsburgh, Pennsylvania, airport to buy and use its own land for the approaches of low-flying jets and not to invade the airspace above private property such as that of Mr. Griggs *(3)*.

In 1948 an American court of law was first to recognize the right to quiet of individuals as workers. A New York Court of Appeals decision favored a worker named Matthew Slawinski who had lost a good measure of his hearing because of the noise of the machinery he had worked with for years. Previous industrial deafness cases had awarded compensation to workers who had lost hearing in on-the-job explosions, but his was the first for hearing loss due to long-standing noise pollution at work. The principle was nailed down firmly three years later, in 1951, when the Wisconsin Industrial Commission awarded a claim to Albert Wojik for loss of hearing due to noise at his forge job. This decision

was upheld by the Wisconsin Supreme Court *(3)*.

Because many states react to these decisions with various legislation, Dr. Meyer Fox, a Milwaukee physician, and Ralph Gintz, director of Workmen's Compensation for Wisconsin, (in 1963 and again in 1969) surveyed the United States and Canada to determine changes that had occurred. They found that the trend is for greater coverage of occupational hearing loss. But seven states still did not compensate for hearing loss from noise unless that loss is total in one or both ears. The states are Illinois, Ohio, Pennsylvania, Michigan, Rhode Island, Massachusetts, and Texas *(3)*.

Several states have regulations requiring employers to hold factory noise to certain decibel levels. The federal government established a regulation in 1969 requiring contractors to meet noise limits of 90 decibels at the work place, given near-continuous eight-hour-a-day exposure. The United States lags far behind the Soviet Union, Sweden, Austria, Finland, and Brazil. These nations all have laws regulating the amount of noise to which any worker can be exposed *(3)*.

As for building construction, the Federal Housing Administration has issued a recommendation (F.H.A. No. 2600) that considerably influences the designs of its mortgaged buildings. This specifies quiet construction techniques and maximum allowable decibels. But these are only advisory. Again, other countries -- Canada, Britain, and West Germany -- are ahead with national building codes *(3)*.

The United States also lags because it has no national anti-noise legislation. Britain has a Noise Abatement Act, passed in 1966, that allows any citizen to initiate legal action against any noisemaker. France has a 1966 law against noisemakers. Many American cities have some anti-noise ordinances, but usually their enforcement is weak or nonexistent. An exception is Memphis. Intent on keeping its reputation as The Quiet City, it enforces its ordinances stringently. Memphis awards prizes for anti-noise essays and ideas, honors Silent Citizens who do things like muffle their power mowers, and annually arrests 1,000 horn-honkers (usually visitors who do not know any better) *(3)*.

City ordinances and state and federal legislation need to be specific about the decibel levels to which noise must be reduced. This means that police and other enforcement personnel will need training in the use of noise meters and similar instruments. California and New York have laws against motor vehicle noise which are decibel specific. Likewise, Chicago has a zoning ordinance which specifies decibel levels for noise spewed into the general community environment by industry. The maximum is 79 decibels as measured at the boundary of the zone. Such zoning laws can be very effective in separating the noise of airports and factories from homes, schools, hospitals and other peaceful quarters. Usually, though, airports and some factories are outside city limits and can impose their noise from a separate governmental jurisdiction. When such is the case, a superauthority is needed *(3)*.

Perhaps what is needed is a whole set of anti-noise laws which follow the concept proposed by a well-known British economist -- that all citizens have violable "amenity rights." These, explained Professor Ezra J. Mishan of the London School of Economics and Political Science, are the rights to peace and quiet, to privacy and clean air. Now, he said, the noise created by airlines, factories, motor vehicles, among others, is limited only by what authorities believe the people will put up with. And they put up with more and more as they become accustomed to the noise -- or think they do *(3)*.

Dr. Vern O. Knudsen, a physicist, a founder of the Acoustical Society of America and former Chancellor of the University of California, did not overstate the problems of today's noise when he said: "NOISE IS A SLOW AGENT OF DEATH" *(15)*.

HIGHWAY NOISE

As traffic on highways continues to increase, the problem of traffic noise increases and relief is sought. Studies in several major American and European cities have shown that, despite the noise produced by aircraft, surface traffic, which includes automobiles, buses, trucks, and motorcycles, is the predominant and most widespread source of noise. It has been shown *(2)* that noise levels in certain areas were increasing at the rate of 1 decibel (db) per year, a result of increasing traffic flow.

An instrument called a sound level meter is commonly used to measure noise (sound) level; and the noise level is expressed in decibels (db). The decibel is a dimensionless unit -- the logarithm of the ratio of a measured quantity of sound to a reference quantity of sound *(3)*. Usually, this reference value is a sound pressure of 0.0002 microbars, corresponding to "0 decibels". This reference of 0 decibels is the threshold of hearing.

Sound pressure is the fluctuation of air pressure above or below atmospheric pressure which is caused by disturbances in the air; disturbances in the air are known as sound. Typical conditions on the scale of noise levels are shown in Figure 1. For example, the noise level of normal conversational speech at three feet is 60 db, and the noise level of a jet takeoff at two hundred feet is 120 db. A difference of 6 decibels means that one sound pressure is twice another. If one sound is ten times another, the decibel difference is 20 *(5)*.

The sound level meter has three "weighting"

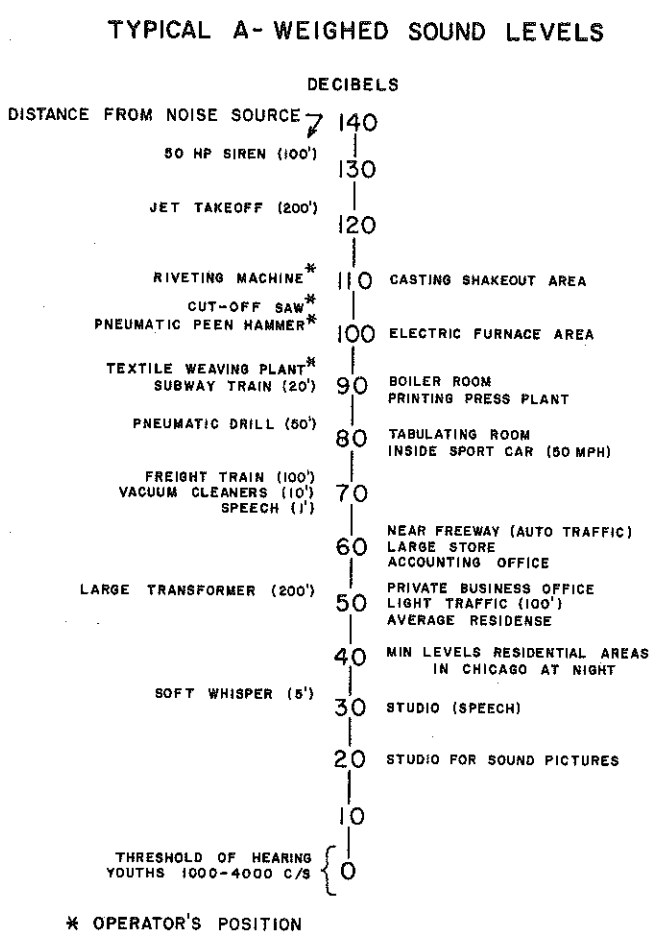


Figure 1.

networks to measure sound pressure levels. These weighting networks, designated as A, B, and C (as shown in Figure 2), allow for the fact that the apparent loudness attributed to sound varies not only with pressure but also with frequency *(5)*. The A network is used in most studies, and readings made using that network are indicated as dBA. The A network has been shown to be as statistically reliable as the best psychologically derived measures as a predictor of human responses to vehicle noise. The A network places more emphasis on higher frequencies and is supposed to have a frequency response roughly comparable to the inverse of the frequency response of the human ear at low levels of sound excitation *(4)*.

Other descriptors have been used in noise prediction and measurement. The descriptor used by the US Department of Transportation for aircraft noise certification is the effective perceived noise level, EPNL, a measure purporting to rate noisiness rather than loudness. The Society of Automotive Engineers (SAE) uses the sone as its descriptor. The sone unit of loudness, a psychological measure, is arbitrarily tied to the physical scale by letting a 1000 Hz (cycles per second) signal of 40 db sound pressure level be a loudness of one sone *(7)*. The SAE has established an advisory new-vehicle noise specification of 125 sones (84 dBA) measured at 50 feet, under maximum noise-producing test conditions *(1)*. The maximum noise levels for airplane noise certification have been established by the Federal Aviation Administration. They vary with airplane takeoff weight and are measured at 3.5 n.m. (nautical miles) from the start of takeoff roll, 1.0 n.m. from the runway threshold on landing, and 0.25 n.m. and 0.35 n.m. to the side of the runway on takeoff. The highest levels, which are constant for weights above 600,000 pounds, are 108 EPNdB, approximately 95 dBA, for all three measurement points. Another measure which has been used is the Speech Interference Level (SIL), a measure of noise bearing a direct relationship to the masking of speech *(4)*. A measure of loudness level using the phon has also been used. This is a measure of strength of sound and is derived from the sound pressure level of a 1000 Hz tone giving an average judgement by normal observers of being equally loud. However, the A-weighted sound level (dBA) has remained the most commonly used in motor vehicle noise studies *(4, 5, 9)*.

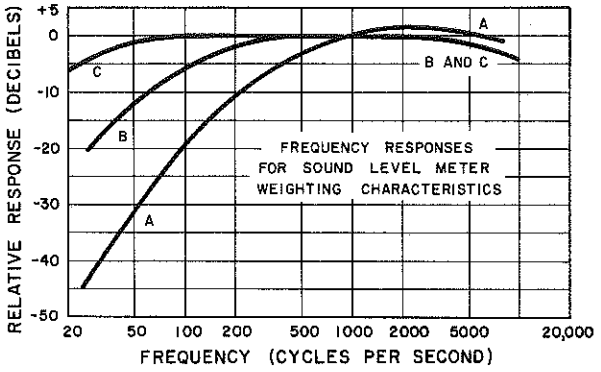


Figure 2.

Three general principles of control that may be applied to the traffic noise problem have evolved. One is direct control of noise of an individual vehicle. A second concerns traffic routing, such as bypassing through traffic around populated areas. The third considers the impact highway design itself has upon

traffic noise, such as the effects of elevated or depressed freeways.

Efforts to directly control noise level of trucks have been unsuccessful; the loudness of trucks may go above the 125 sone limit. Specifications for direct control of vehicles are advisory rather than mandatory, apply to new vehicle design and not to operation, and therefore do not cover vehicle maintenance of such items as mufflers and tires.

Noises from vehicles are primarily attributable to engine exhaust and tire-roadway interaction. Major variables to be considered are average speed, number of lanes, density and composition of traffic, load on the engine (acceleration, grades), and distance from the measuring site. The most important single variable affecting noise level is traffic density.

A major source of automobile noise, particularly at high speeds, is the interaction of tire tread with the road surface *(5)*. Tire noise increases markedly with speed. It has been shown that the average noise level from freely flowing passenger vehicle traffic varies approximately with the third power of the average traffic speed *(4)*. The pavement texture is an important factor affecting passenger car noise levels. Lower noise levels are associated with the smoother surfaces. Maximum acceleration conditions for automobiles produce noise levels in the order of 6 dBA above those for cruise conditions.

The primary source of highway noise, based on complaints, is heavy trucks *(10)*. Noise levels measured a given distance from the roadway vary more from truck to truck than from car to car due to greater variability in truck designs and muffling practices. For large diesel trucks, the principal noise source is the engine and exhaust system, tire-roadway interactions being less prominent. As a comparison, it would take 30 passenger cars, having noise levels of 67 dBA, to produce as high a noise level as one truck at 82 dBA. There is a difference of about 2 dBA between trucks on a 3 to 5 percent up-grade and on a level roadway. Acceleration of trucks on level roadways produce noise levels about 5 dBA higher than those for cruise conditions. Because of the predominance of engine and exhaust noise over tire-roadway noise, the effect of speed is minimized. Trucks tend to operate at nominally constant rpm and engine and exhaust noise do not vary appreciably with vehicle speed under level roadway cruise conditions. There is no significant relationship between road surface characteristics and noise from trucks *(4)*.

Motorcycles and sport cars are often cited as prime offenders of noise restrictions, probably due to a low standard of muffling. Light trucks are similar to passenger cars, except for the tendency for the muffling to become less effective in later years. Large gasoline-powered trucks, such as dump trucks and concrete trucks, are thought to have noise levels somewhat below those of diesel trucks. Buses seem to be well muffled and maintained so as to have relatively low noise levels.

Attempts have been made to predict noise levels near a highway based on information relative to traffic and roadway characteristics. A computer simulation may be used for that purpose. The dBA means and standard deviations obtained from simulated conditions have been approximately the same as measured values as shown in Figure 3. The simulation results showed that increases

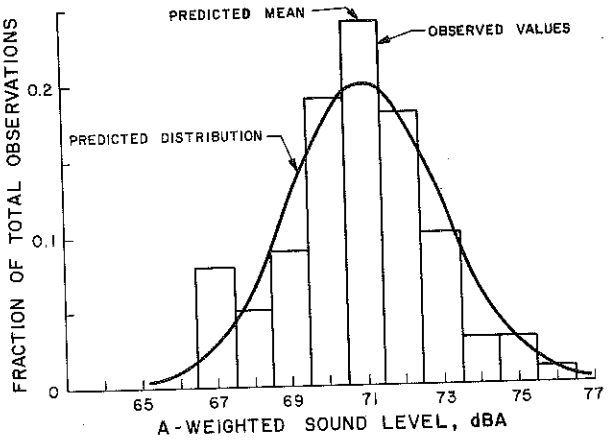


Figure 3.

in total vehicle flow increase the average noise levels and reduce the fluctuations in noise levels. For traffic volumes in excess of about 1,000 vehicles per hour at a fixed average speed, noise levels varied almost linearly with total vehicle flow. Also, increased distance between the observation point and roadway decreased the fluctuations around the average noise level. Noise from multilane highways may be simulated by using total volume flow on a single pseudo-lane located at the geometric mean distance from an observer determined by the distance from the observer to the nearest and farthest lane. A simplified analytical form for the simulation model may be used for passenger cars on a level highway having traffic flows above 1,000 vehicles per hour. The mean noise level in dBA is given by:

$$L = 10 \log_{10} q - 10 \log_{10} d + 20 \log_{10} V + 20$$

in which

q = traffic volume in vehicles per hour,
d = distance to the pseudo-lane in feet, and
V = average traffic speed in miles per hour.

The effects of adding trucks to the vehicle mix is given in Table 1.

Another method of noise prediction is presented in a design guide *(5)* which identifies all variables in terms of roadway parameters. These parameters are identified for each traffic situation, and by means of a simple "cookbook" procedure, they may be transformed into noise level estimates through the use of charts and tables. The parameters are classified as either traffic parameters, roadways characteristics, or observer characteristics. Traffic parameters are vehicle volume, vehicle mix, and average speed. Roadway characteristics are pavement width, vertical configuration, flow characteristics, and surface characteristics. Observer characteristics refer to the observer size, element size, shielding, and observer's relative height. The roadway is first separated into elements with constant characteristics, and after quantifying the parameters, noise levels are calculated for each of the elements and combined to give an overall noise level.

TABLE 1
EFFECTS OF ADDING TRUCKS TO VEHICLE MIX

PERCENT OF TRUCKS IN TRAFFIC	ADDITIONAL dBA
0	0
2.5	1
5	2
10	4
20	8

Noise contours rather than single point noise level estimates are desirable. Computer programs may be used wherein a design guide or some other noise prediction model could be digitalized and the ultimate output of the program would be calculated noise levels for ground positions on a mesh or grid system for which noise contours could be drawn.

Traffic noise levels decrease with distance from the roadway (a line source) at the rate of about 3 decibels for each doubling of distance *(4,5)*. When considering an individual vehicle (a point source), the noise level decreases at the rate of 6 decibels for each doubling of distance. Therefore, very significant changes in distance from the highway are required to produce a marked reduction in highway noise. Distance is not a very effective means of noise control.

When a highway is elevated above grade or depressed below grade, a degree of shielding is introduced into the propagation path between the noise sources and observer. Some studies *(4)* have shown that, at close distances to the highway (approximately 100 feet), both depressed and elevated roadways decrease the noise level about 12 decibels. When the distance from the roadway is increased to 500 feet, the elevated configuration becomes relatively ineffective while the performance of the depressed highway is even better than at 100 feet. At 500 feet, the elevated roadway was about 3 decibels quieter than the grade-level situation while the depressed roadway was approximately 15 decibels quieter.

The frequency spectrum of traffic noise is altered when shielding is introduced. Shielding is more effective at high frequencies than at low frequencies, and a shielded highway sounds less "hissy" than an unshielded road.

Roadside acoustic barriers provide a further means of shielding noise from the observer. The acoustic barrier, however, may be expensive because it must be impervious to sound and sufficiently long to subtend a large angle of the observation position and high enough to provide the required degree of attenuation.

Investigations have been made relative to the effectiveness of roadside plantings *(5)*. Planting ground cover on highway slopes has virtually no influence on propagated traffic noise. Trees or hedge planted along a highway have little effect unless the vegetation is deep. A design value of 5 decibel noise reduction for every 100 feet of planting (depth) may be used if the trees are at least 15 feet tall and sufficiently dense so that no visual path between them exists. A large number of trees would have to be planted in order to reduce noise levels. In general, the influence of vegetation on man's response to traffic noise is psychological.

A design value of up to 10 decibels reduction may be used when there are multiple rows of intervening buildings and structures such as houses or apartments.

Many factors are involved in the manner in which individuals react to the noise environment. The effects of noise on people could be classified as either subjective effects of annoyance, nuisance, and dissatisfaction; interference with activities such as speech, sleep, and learning; and psychological effects such as startle or hearing loss. Response of people to highway noise is psychological rather than physical since the individual must be subjected to high noise levels for extended periods of time to sustain physical damage to the auditory system. To illustrate, 6 percent of people will suffer a hearing impairment if they are exposed to a noise level of 85 dBA, 40 hours per week, for 20 years *(10)*. Such levels over an extended period of time are virtually unknown in highway situations. However, noise does not have to reach this level to be annoying. Figure 4 indicates the approximate sound pressure levels at which noise becomes annoying or objectionable.

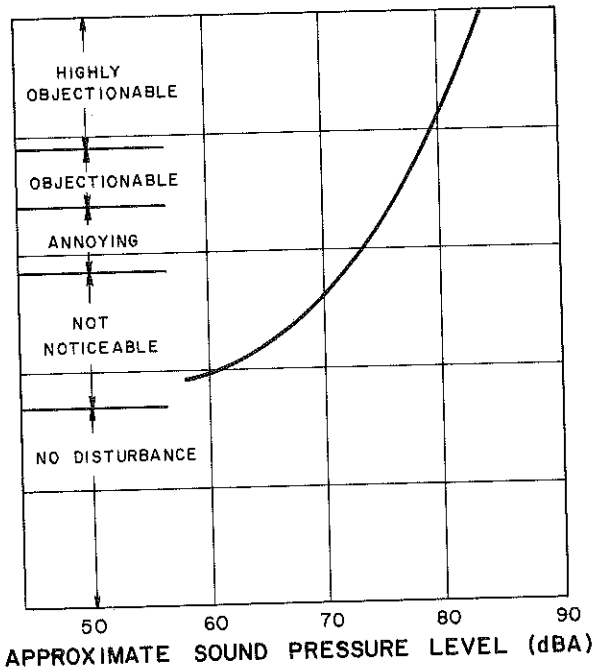


Figure 4.

Certain conclusions may be deduced from laboratory and social survey studies *(5)*. First, interference with television viewing is the predominant complaint against traffic noise. Interference with sleep is also an often cited complaint. Both a measure of the time-average noise level and measures of the magnitude and rate of occurrences of peak noise levels are important in describing peoples' response to traffic noise. It has been shown that the number of complaints are not directly related to the magnitude of noise. The perceived annoyance of freeway noise is a poor measure for the prediction of expressed annoyance. Most expressed annoyances may be explained by attitudes towards living near a freeway and by selected personal characteristics of respondents *(4)*.

Higher socio-economic groups are most annoyed with traffic noise, even when that noise is minimal. People living in expensive homes complain almost as much about depressed real estate values as they do about noise, while people living in modest areas, even though these areas are noisier, complain less about noise; some are even pleased that the depressed real estate values enable them to buy a home in that area.

Speed and convenience, especially convenience to leisure activities, appear to be related to noise annoyance. If the highway provides speed and convenience, there are fewer complaints.

Attractiveness of the highway is an important attribute in decreasing noise annoyance. Features related directly to judged attractiveness include distance to highway, lack of visual dominance of the highway, and presence of intervening features. Features related to judged intrusiveness of the highway include lack of landscaping, high noise level, and years of exposure to the highway.

There have been many attempts at setting noise limits for vehicles, including those by the Society of Automotive Engineers and the FAA. The people of Bermuda have eliminated their problem with noisy motorcycles. All motorcycles were tested before licensing; the sound level can not exceed 93 decibels. Each motorcycle's noise output was measured while the unit was running on rollers at 20 mph. The state of New York has defined excessive noise as anything above 88 dBA (plus 2 dBA tolerance) measured at 50 feet (plus or minus 2 feet) from the centerline of traffic at speeds less than 35 mph. The state of California has one of the most comprehensive laws. At distances of 50 feet from the center of the lane of travel, a vehicle with a gross weight of 6,000 pounds or more must adhere to the limit of 88 dBA at 35 mph or less and 92 dBA at speeds in excess of 35 mph. For any other vehicle, the limit is 82 dBA at 35 mph or less and 86 dBA for speeds above 35 mph *(4)*. There have also been suggestions concerning separate requirements for night travel *(10)*.

The ambient noise level, or background noise, also should be considered when recommending maximum noise levels. That is to say, the recommended noise level should not be less than existing background noise. The ambient noise level in urban areas is approximately 60 dBA during the day and 50 dBA during the night.

Several difficulties arise in establishing and enforcing maximum noise limits. It is a problem to show that measured noise is attributable to a specific vehicle in a traffic stream. High cost of purchasing instruments, setting up measuring stations, and training officers in the new techniques present problems. Low conviction rates, compared with man-hours expended and restrictions placed on officers in making the measurements, act as deterrent to enforcement. Lack of uniformity from one jurisdiction to another, resulting in an automobile being in violation of the law in one place and not in another, further complicates the situation.

In recent years, significant research has been done on the subject of noise pollution involving surface traffic and a great deal has been learned. Much remains to be done. As the volume of traffic becomes larger, noise levels will increase unless solutions are found and applied to some of today's problems.

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