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POTENTIAL NOISE REDUCTION FROM - AND THE COST OF - STATE AND LOCAL IN-USE MOTOR VEHICLE EXHAUST NOISE ENFORCEMENT PROGRAMS

Demonstration and Evaluation Branch
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INTRODUCTION

The Demonstration and Evaluation Branch of the State and Local Programs Division, Office of Noise Abatement and Control conducted a program to evaluate (1) the noise reduction and benefits that may accrue from State/Local motor vehicle exhaust noise control and (2) the cost of various enforcement schemes to achieve the control.

The thrust of the program is best described by the following hypothetical scenario and attendant questions:

Scenario: The police department in a community has received 20 phone calls from irate citizens complaining of a noisy vehicle that has awakened in the middle of the night.

Questions: (1) What can be done to control the number of complaints?

(2) How much will it cost?

The report summarizes the various study areas and presents results of the analyses that relate to the questions. The report is divided into the following sections:

Section 1: The Problem

Section 2: Motor Vehicle Exhaust Systems and Their Degradation In-Use

Section 3: Analytical Procedures to Quantify the Effectiveness of Motor Vehicle Exhaust Noise Control

Section 4: State/Local In-Use Exhaust Noise Enforcement

Section 5: Potential Noise Reduction from State and Local In-Use Motor Vehicle Noise Enforcement

Section 6: The Cost of State/Local Motor Vehicle Noise Control.

Section 7: References

SUMMARY

The results of the study and analyses performed indicate that on-the-street enforcement can reduce ambient traffic noise and mitigrate the number of potential intrusive events (which lead to complaints) due to vehicles with faulty exhaust systems. Using the State of Florida enforcement statistics, in the 1976 to 1980 time frame, it is estimated that ambient traffic noise levels have been reduced by 1.7 dB overall and the potential daily intrusive events reduced by over 4,000 occurrences per day for all vehicle types.

Of several ways to perform on-the-street enforcement of vehicles with faulty exhausts, the use of the human ear to detect - and human eyesight to confirm, appears to be the most cost effective method. Greater effectiveness of the ear as a detector over the meter has been demonstrated.

The cost of enforcement has been shown to vary with community size, ranging from about \$ .03 per person for communities of 2 million and greater persons, to about \$ .50 per person for communities of 5 to 25 thousand people. Thus, as a first approximation, a community of 25,000 people could provide on-the-street motor vehicle enforcement for \$12,500, whereas a city of 7,000,000 could provide on-the-street enforcement for \$200,000. In the case of Florida, a 4,000 per day reduction in potential intrusive events has been achieved with an annual noise enforcement budget of around \$200,000.

Summary

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Section 1: THE PROBLEM

Studies have shown motor vehicles to be a major source of outdoor noise in urban residential areas. It is estimated that almost half of the people living in communities throughout the U.S. are exposed to urban traffic noise that affect their daily activity in a variety of ways. Motor vehicle noise is known to disturb/interfere with conversation, sleep and relaxation, as well as cause fatigue, irritability and insomnia in some persons. In view of the varied affects, control of motor vehicle noise, which accomplishes reduced levels of noise and/or reduced numbers of vehicles producing objectionable noise, will provide varying types/degrees of relief to the exposed populus from the intrusive events.

Traffic noise consists of the superposition of noise generated by motor vehicle themselves as an overall source and the interaction of the vehicle tire with the roadway. At speeds below 35 miles per hour (approximately), traffic noise is dominated by noise generated by the vehicles themselves from mechanical, aerodymanic and combustion process phenomena. It is not until speeds in excess of 35 miles per hour (approximately) are reached that noise due to tire/roadway interaction become prominent and dominate the traffic noise spectrum. Since motor vehicle speeds in urban areas typically are less than 35 miles per hour, relief from traffic noise that interferes with human activity most accrue from reduction and/or control of noise created by the vehicles themselves.

Stuides conducted to identify and characterize motor vehicle noise show that engine exhaust noise dominates the sources of vehicle noise. This is shown in Figure 1-1 where the sources and relative levels of motorcycles, automobiles and trucks are shown.[1] The vehicles were tested with mufflers in place. Had the vehicles been tested without mufflers the level of exhaust noise would be shown to be dramatically higher. When situations arise where the exhaust noise muffling components degrade, or are degraded, engine exhaust noise escalates to levels that mask the noise contributions from other vehicle sources; the vehicles are then readily identified by the raucous nature of their sound. It is vehicles in this condition that elevates annoyance to the highest degree.

Information and data for communities throughout the U.S. show that as high as 15.3 percent of motorcycles, 7.4 percent of light vehicles (private automobiles and trucks) and 5.4 percent of medium/heavy trucks have inadequate exhaust noise muffling systems in the form of either modified, poor quality, deteriorated or no mufflers.[2] Vehicles with modified or without mufflers are most likely the result of persons knowingly and willfully causing alterations to produce more vehicle noise or to produce greater overall engine performance.* Vehicles with poor quality or deteriorated mufflers more likely arise from the caustic effects of climatic/road conditions; e.g., rusting and corrosion by salt. For whatever reasons vehicles have inadequate muffling systems, it remains that become engine exhaust noise clearly dominates the vehicle noise spectrum at low speeds, maintenance of an adequate muffler system must be the focus of in-use control measures if motor vehicle noise is to be controlled.

The environmental benefit that can be derived from the control of the number of vehicles with degraded exhaust noise muffling system components depends on atleast three factors:

*Engine exhaust mufflers create some engine back pressure. This increases the work the engine must expend to push the exhaust gases out of the exhaust port with the net result being a degradation in overall engine performance.

(1) The level of excess exhaust noise caused by the inadequacy,

(2) the number of vehicles possessing an inadequate muffling system and,

(3) the reduction in the number of vehicles with inadequate muffling systems through in-use control measures.

The fruition of factor (3) in practice leads to lower levels of excess motor vehicle noise, as well as, fewer numbers of intrusive events related thereto.

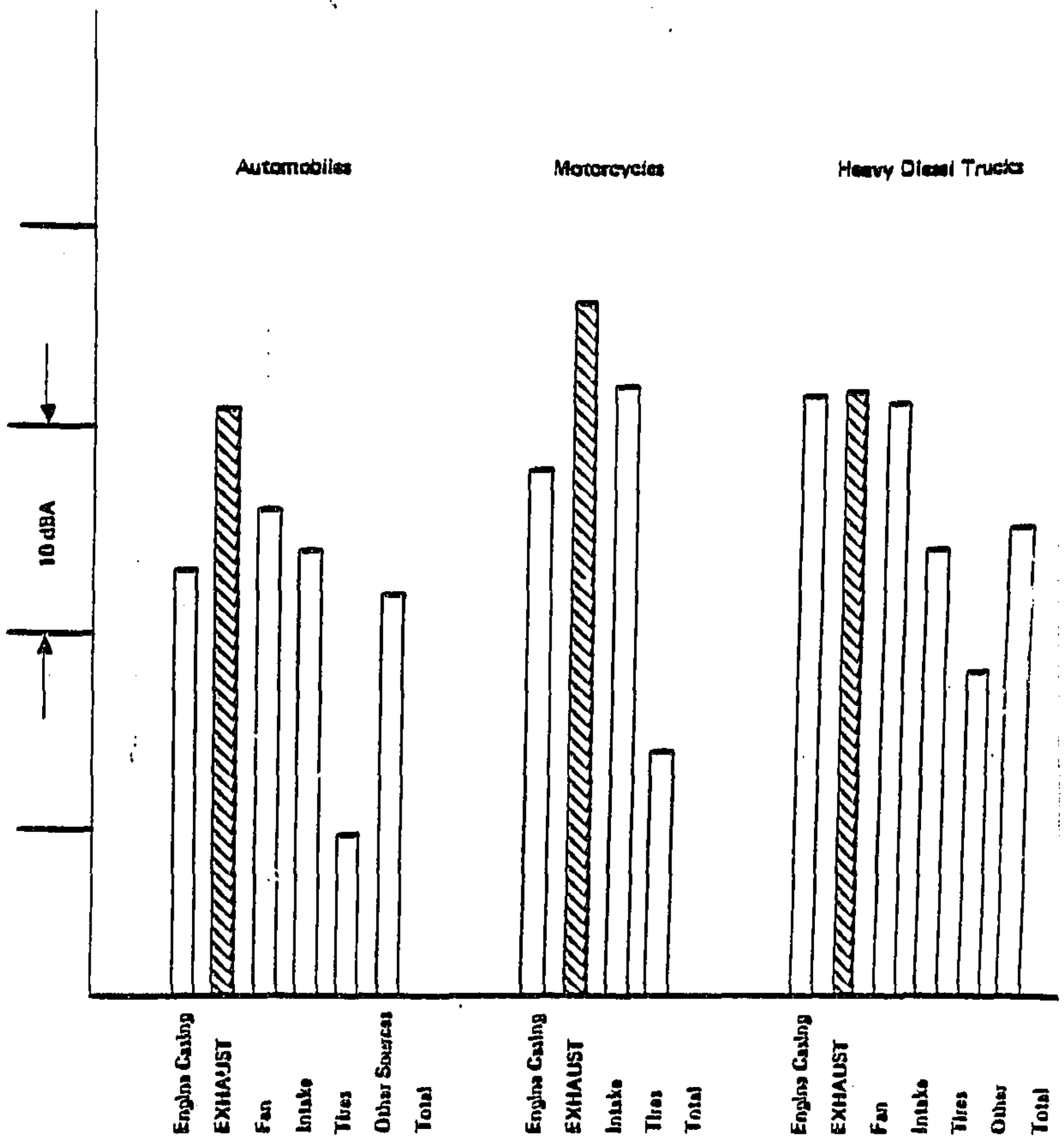


Figure 1-1:Motor Vehicle Noise Sources and Relative Noise Levels

Section 2: MOTOR VEHICLE\EXHAUST SYSTEMS AND THEIR DEGRADATION IN-USE

Motor Vehicle Exhaust Systems

Motor vehicle exhaust systems are comprised of three or four major components (1) pipe system, (2) muffler, (3) resonator (a second muffling device which complements the primary muffling device i.e., the muffler) and (4) catalytic converter (in most vehicles). Figure 2-1 shows where the components are positioned in a typical exhaust system. Usually a defect of any of the components causes motor vehicle noise to escalate. However, because the muffler is designed to reduce noise generated during the engine combustion process, where high levels of noise are generated, it is the key element in controlling motor vehicle.

Mufflers are designed to absorb engine noise using one of three basic design concepts:

- Dissipative
- Reactive
- Combination dissipative/reactive.

Figure 2-2 shows these basic designs and indicates their typical attenuation capability. The dissipative muffler is packed with sound absorbing material and relies the material to absorb engine noise. The dissipative muffler provides for engine noise attenuation over a wide noise frequency range.

The reactive muffler is comprised on chambers (in the direction of noise propagation) and/or noise flow path disruptions e.g., bends. Noise reduction is accomplished by causing some of the acoustic energy in the exhaust noise field to be used (up) to excite the air in the air chambers and/or by causing a loss in the energy at the flow path discontinuity; i.e., at the bend(s) some acoustic energy is reflected back toward the engine leaving that which travels toward the exit port to be less intensive. Reactive mufflers provide noise attenuation over a limited frequency range, but can be tuned (designed) to provide for maximum noise reduction at engine noise frequencies containing the major portions of the acoustic energy. Because the dissipative muffler is subject to rapid acoustical degradation due to clogging/contamination by liquids, most motor vehicle mufflers tend to be of the reactive type.

The combination reactive-dissipative muffler provides for engine noise attenuation over a wide frequency range with special emphasis (by design) on those frequencies containing major portions of the acoustic energy. The combined reactive-dissipative muffler suffers from the clogging/continuation problems of the purely dissipative muffler.

<u>Exhaust System Lifespan</u>

Many factors influence the effective operating life of a muffler including:

- Exhaust system design
- Materials used in construction
- Operating temperature
- Exhaust gas volume and flow
- Vehicle operator driving patterns
- Road salt

Due to the wide variation among these factors there is no single design life for a muffler; however, the cost of materials, which comprise 75% of the cost of a muffler, is very much a prime consideration in muffler design.

Automotive mufflers are constructed from cold rolled, galvanized, aluminized and stainless steel depending (1) upon the manufacturer, (2) whether the muffler is original equipment or replacement and (3) the temperature to which components are subjected.

Two recent trends, the use of catalytic converters and lead free gas, have altered muffler design with attendant positive and negative affects on muffler life. On the negative side, the catalytic converter raises exhaust gas temperatures to 1100 - 1200° Fahrenheit. At these higher temperatures a sulfuric acid mist (aerosol) and nitric acid are produced which can cause increased corrosion within the muffler. On the positive side, the elimination of the lead in gasoline has eliminated lead oxide compounds which tend to reduce the effectiveness of mufflers by coating the internal surfaces of the muffler.

Road salt is considered a major factor in muffler wear. One manufacturer suggested this externally caused rusting is more important than the internal rusting especially at joints and hangers. Once a hanger fails i.e., rusts away, the muffler will dangle and may be dragged along the road causing almost immediate and irreparable damage.

Dissipative and combination reactive/dissipative muffler designs incorporate fiberglass packing with the muffler in order to absorb the sound. The glass packing deteriorates quickly if exposed to temperatures above 700 - 900° Fahrenheit. It is not common that after three to six months little or no material remains in the muffler.

It is difficult to assign a life to a motor vehicle muffler because of the strong dependence of life on use or place of use. Table 2-1 summarizes estimates of the service life of automobiles and trucks made by various manufacturers. In the main, exhaust systems probably start to fail after two years (approximately) of motor vehicle service.

Motor Vehicle Exhaust System Degradation

Initial efforts to obtain data on the level of degradation in automobiles, trucks and motorcycles exhaust system focussed on the open literature. The search revealed minimal quality data.

Automobiles

To obtain first hand quality data, tests were conducted on automobiles* in three geographical areas (1) Washington, D.C. (2) Chicago, Illinois and (3) Albuquerque, New Mexico. These areas were selected to provide data representative of degradation in a wet/harsh climate (Chicago), in a dry arid climate (Albuquerque) and in a cross between the two (Washington).

The testing consisted of measuring the noise level before and after vehicle repair at a muffler repair facility. Visual inspections of the degraded exhaust

*Testing was limited to automobiles because of monetary constraints and the rationale that these vehicles represent the greatest portion of traffic.

system components revealed the types of defects listed below; the defects have been categorized as major or minor depending on their influence on the level of excess noise:

Major Defects

- no muffler
- holes in muffler
- holes in leadpipe
- faulty installation

Minor Defects

- no tailpipe
- broken tailpipe
- holes in midpipe
- loose clamps

Generally, minor defects cause up to a 3 dB escalaion in vehicle noise whereas the major defects cause as much as 29 dB escalation.

Washington Tests[3]

Forty-five vehicles were tested before and after repair at a muffler repair facility. The tests results are summarized below:

Vehicle Type	Number	Defect Major (dB)	Defect Minor (dB)
8 cylinder	24	11	1
6 cylinder	8	11	1
4 cylinder	13	10	3
all types	45	11	3

Chicago Tests[4]

Data were obtained for 316 vehicles. The results of the testing are as follows:

Vehicle Type	Number	Defect Major dB	Defect Minor dB
8 cylinder	181	11	3
6 cylinder	77	13	3
4 cylinder	58	12	4
all types	316	12	3

Alburquerque Tests[5]

One hundred six vehicles were tested. A summary of the test results are listed below.

Vehicle Type	Number	Defects Major dB	Defects Minor dB
8 cylinder	62	12	3
6 cylinder	14	15	2
4 cylinder	30	11	3
all types	106	13	3

Though the test results show some difference in the levels of excess noise between the 3 test areas, it appears that on average, major and minor defects produce the same order of magnitude increases in noise regardless of geographical area. For excess noise analysis purposes, the data of the three areas are averaged with the following results:

Vehicle Type	Defect Major (dB)	Defect Minor (dB)
all	12	3

Motorcycle

Excess noise data for motorcycles caused by degraded exhaust system components has been obtained from available literature.[6] Table 2-2 lists shows the levels measured for a motorcycle with various muffler configurations. Listed below are noise levels for each configuration relative to the motorcycle with a new muffler. These relative noise levels are defined as excess motorcycle noise.

Motorcycle Type	Defect Major (dB)	Defect Minor (dB)
all	13	4

Trucks

Excess medium/heavy truck noise levels for degraded exhaust muffling components was obtained from available literature.[7] Levels of the order of 7, dB to 14 dB excess noise results from vehicles with degraded muffling systems. Listed below are estimated noise levels caused by degraded truck mufflers.

Truck Type	Defect Major (dB)	Defect Minor (dB)
all	14	7

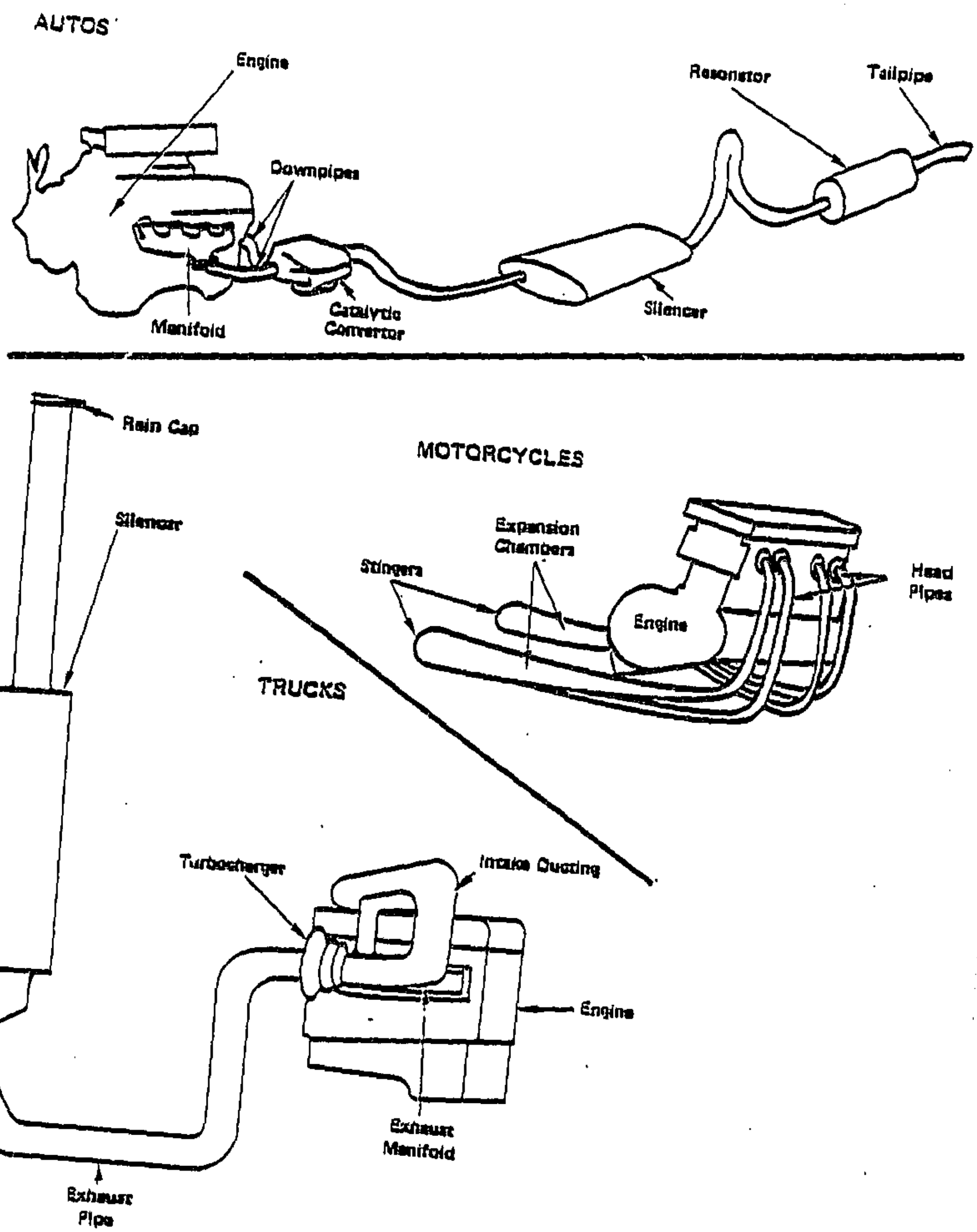


Figure 2-1: Typical Motor Vehicle Exhaust Systems

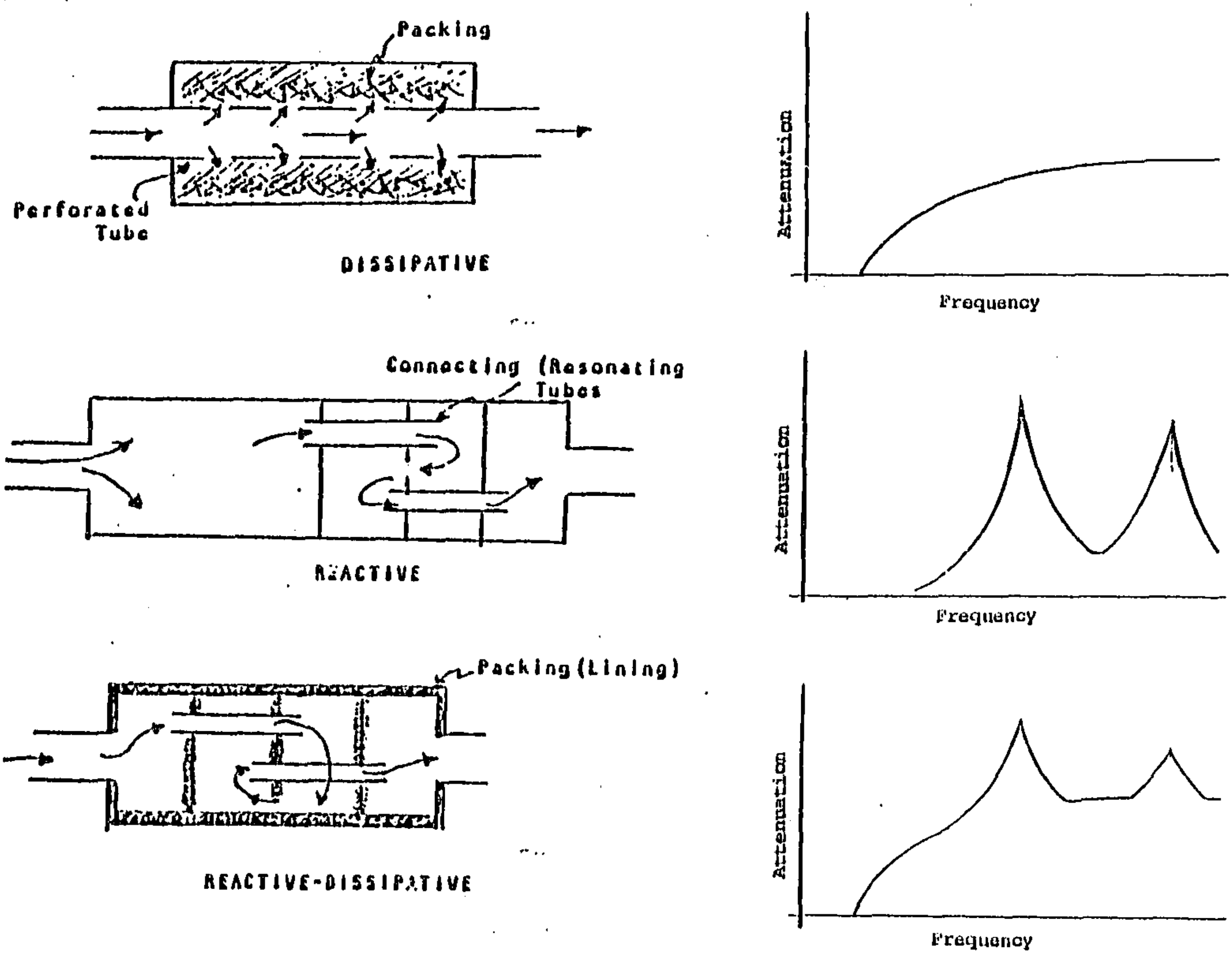


Figure 2-2: Muffler Types and Typical Attenuation

Table 2-1

Estimates of Motor Vehicle Exhaust System Service Life

Source	Vehicle Type	Muffler Type	Condition	Estimated Service Life years or mileage
Arvin Industries	automobiles	original	average	4-5
Arvin Industries	automobiles	original	harsh climate	3-4
Midas International	automobiles	original	average	2.5
Midas International	automobiles	original	harsh climate	2.3
Midas International	automobiles	replacement	average	2.7
General Motors	light trucks	original	average	2.0
Ford	light trucks	original	average	27,000
Donaldson Co.	medium gas trucks	original	average	20,000 - 60,000
Donaldson Co.	heavy diesel trucks	original	average	100,000

Table 2-2

Excess Motorcycle Noise Due to Various Muffler Configurations

Exhaust Configuration	Acceleration* Level, dB
no muffler	98
badly rusted muffler	84
new MCM stock muffler	85
modified MCM muffler	97
new muffler**	88
new Honda muffler	84

* measurements made 50 feet from the vehicle during acceleration passby, SAE J331A procedure.

** unknown brand

Proportion of Defective Vehicles

Data presented in the previous chapter shows that the level of noise degradation due to a defective muffler is 3-7 dB for minor defects and 12-14 dB for major defects. The remaining important data point is the proportion of such defective vehicles which are likely to be found on urban roadways. To determine this data was collected in Plainsboro, New Jersey in which noise measurements were combined with aural identification and visual inspections. The proportion of traffic having defectively muffled vehicles from this study is reported below.

	Proportion Defective Vehicles (Plainsboro)
Auto	1%
Trucks	9%
Motor Cycles	10%

The New Jersey study adds to existing data from other locations on the percent of defective automobiles.

	Automobiles Proportion Defective
Kansas City	12%
Birmingham	8%
Eugene	4%
Trotwood	10%

Modes of Operation

Tests presented above show excess exhaust noise using stationary test. It is therefore logical to ask whether stationary tests provide an accurate description of the excess noise typically experienced in a community, and, from an enforcement point of view, whether stationary tests adequately descriminate between defective and non-defective vehicles.

To answer these questions, comparisons were made between the results of stationary tests and tests under other operating modes. The results show that the excess noise from the stationary mode is, on an overage, slightly higher, but that there is non-systematic variation between modes. That is, one defective muffler may show greater excess noise on acceleration than cruise, but the opposite may be true of another. Among all modes considered, however, the stationary tests are the most descriminating between defective and non-defective muffler systems.

	Stationary 75% RPM	35 MPH Cruise	Acceleration	Deceleration
		Auto		
Defective				
63 ford, poor muffler	98		77	76
63 ford, very poor muf.	104		73	79
63 ford, glass pack	96		79	76
63 ford, burned out glass pack	102		77	70
MEAN	100		77	77
Non-Defective				
63 ford, new muffler	84		68	66
66 Chevy II	81		59	-
69 Mustang	104		84	79
70 Porsche 914	88		-	-
MEAN	89		70	73
Excess	11		7	4
		Motor Cycle		
Defective				
74 Honda-no muffler	116	75	98	-
74 Honda-modified muf.	101	68	85	-
74 Honda-rusted muf.	102	75	84	-
MEAN	106	76	89	
Non-Defective				
74 Honda-Honda stock muffler	98	74	84	-
76 Honda-Honda stock	93	72	79	-
MEAN	96	73	82	
Excess	10	0	7	

Section 3: ANALYTICAL PROCEDURES TO QUANITFY THE EFFECTIVENESS MOTOR VEHICLE EXHAUST NOISE CONTROL

Analytical Procedure to Calculate Excess Noise

Given that excess traffic noise results from degraded components of a motor vehicles exhaust system, the question of "how much excess" logically follows. To answer the question requires knowledge of the extensiveness (how many) and severity (how noisy) of motor vehicle exhaust system degradation. Insight into the trend(s) to expect is obtained by addressing the range of noise escalations due to degraded motor vehicle systems and the percentage of a traffic population exhibiting the escalation. Figure 3-1 shows the family of curves that result when the percentage of motor vehicles ranges go from 0 to 100% for various degradation (noise escalation) values. By entering the abscissa at some % inadequacy and selecting the appropriate degradation value, the level of excess traffic noise may be read off the ordinate. For instance, if 20% of the motor vehicles in traffic stream had degraded exhaust muffler systems which caused the vehicles to be 10 dB noisier than normal, the overall level of traffic noise would increase by 4.5 dB.

The trends of Figure 3-1 can also be used to show the effectiveness of a State/local program in controlling motor vehicle exhaust noise. Figure 3-2 has been prepared to show this. In the example of Figure 3-2, if A% of the motor vehicles in a traffic flow stream have degraded exhaust muffling systems that cause C dB increase in vehicle noise and if a State/local program reduced (through compliance with an exhaust system code) the percentage of vehicles with degraded exhaust system (A to B in the figure), a resulting decrease in excess traffic noise would result (C to D in the figure).

Recognizing that traffic noise, in the main, consists of contributions primarily from autos/light trucks, motorcycles and medium/heavy trucks and that the escalation (excess noise) of vehicle noise may differ by vehicle type and by degradation level, a finer approximation of excess traffic noise is obtained by considering (1) traffic mix in terms of auto/light trucks, motorcycles and medium/-heavy trucks, and (2) the percentages of the degraded exhaust muffling components and the noise escalation related thereto.

The table below shows the type and kind of data used to refine estimates of excess traffic noise.

	Degraded Exhaust System Percent		Excess Noise Level dB	Traffic Mix Percent
VEHICLE TYPE	major defects	minor defects		
Auto/light truck	*	*	***	**
Motorcycle	*	*	***	**
Med./Hvy truck **	*	*	***	

*Varies by State/locality; major defects = defective muffler; minor defects = modified or inadequate muffler

**Site specific

***Major and minor defects

Analytic Procedure to Calculate Potential Intrusive Events

Given that motor vehicles with degraded exhaust noise muffler components produce intrusive events that are disruptive in a variety of activities e.g., sleep, communication, it can be expected that the number of such events will decline as the number of vehicles with degraded systems decreases. Estimates of this decline may be calculated in a manner similar to that employed to evaluate excess vehicle noise using the assumption that, in the count of Average Daily Traffic (ADT), potential intrusive events exist when motor vehicles with degraded exhaust system components operate on roadways. Under the hypothesis that not all modes of vehicle operation e.g., idle, produce noise of an intrusive nature (intrusive event), it is necessary to accommodate vehicle operating conditions in the analysis. This is accomplished bv multiplying that ADT flow by the percentage of time vehicles are in an intrusive model of operation. Thus, the intrusive event analysis employs data related to urban place size; roadway type; percentage vehicle mix in traffic flow and the percentage of time vehicles are in a particular operating mode.

If 100% of vehicles (in a particular urban place size, on a particular roadway) had degraded exhaust noise muffling components, the potential number of intrusive events is the product of the ADT and percent time in the modes of operation causing the intrusion. If the percentage of degraded vehicles is known, the potential number of intrusive events is the product of ADT, percent time in the intrusive mode of operation and percent of vehicles degraded. The improvement or reduction in the potential intrusive events, due to fewer vehicles with degraded exhaust noise muffling components, is the difference in the potential intrusive ADT events before and after the reduction. This notion is shown in Figure 3-3 for automobiles/light trucks, in an urban place size of 200 thousand to 500 thousand people. Referring to Figure 5, if 13% of the auto/light trucks in an urban place size of 200K - 500K people have a degraded exhaust system, and if through some enforcement action this percentage is reduced by 60%, that is to 5.3%, then a 403 per day reduction in potential intrusive events would be expected.

Analytic Procedure to Calculate Level Weighted Population

Level Weighted Population (LWP) expresses both the extent and the severity of a noise impact. The extent of impact refers to the number of people who are adversely affected, while the severity represents the degree to which each person is affected. LWP provides a simple, single number which may be used to show the subjective effectiveness of reduced noise levels.

Figure 3–4 is a pictorial representation of the LWP concept. The circle is a noise source which emits noise to a populated area represented by the figures. The various partial amounts of shading represent various degrees of partial impact by the noise. Note that those people closest to the noise source are more severely threatened. The partial impacts are then summed to give the LWP. In this example, 6 people who are adversely affected by the noise (partially shaded) results in an LWP of 2 (totally shaded). If through some enforcement action, reduced noise levels caused an LWP of 1, then a 50% reduction in impact would be realized.

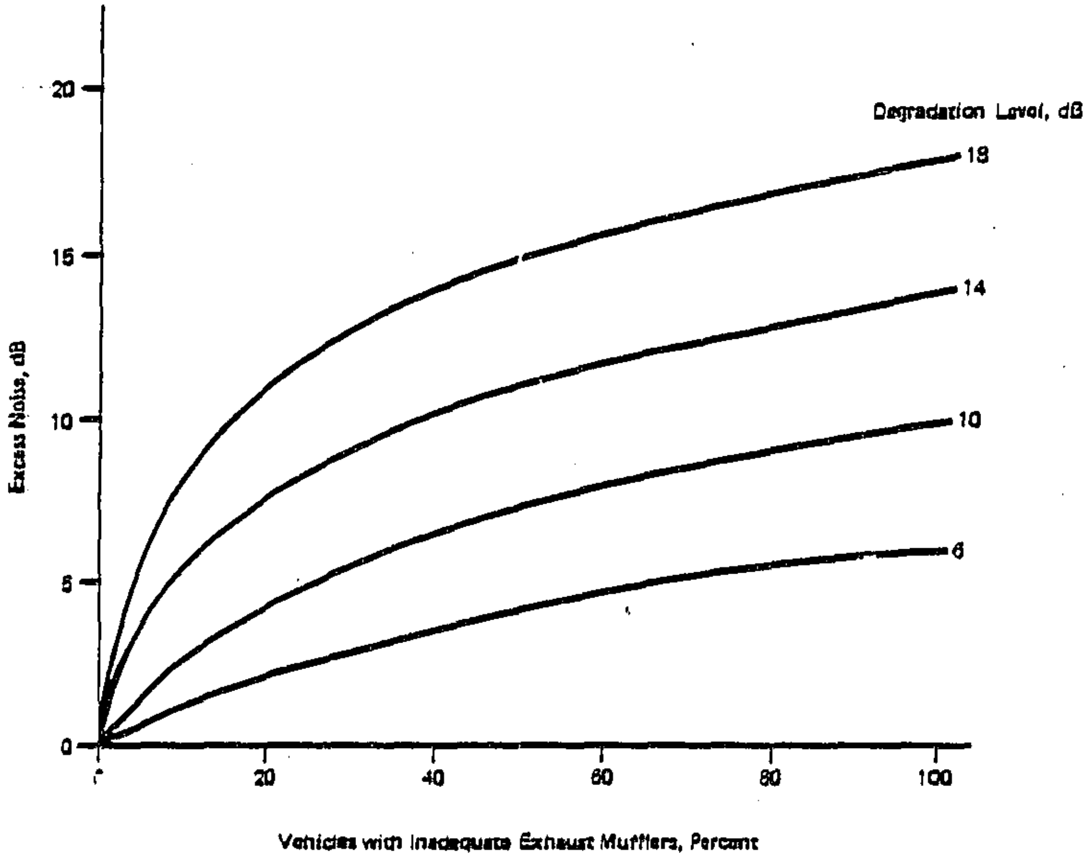


Figure 3-1: Excess Traffic Noise as a Function of the Percent of Motor Vehicles Having Degraded Exhaust Noise Muffling Components

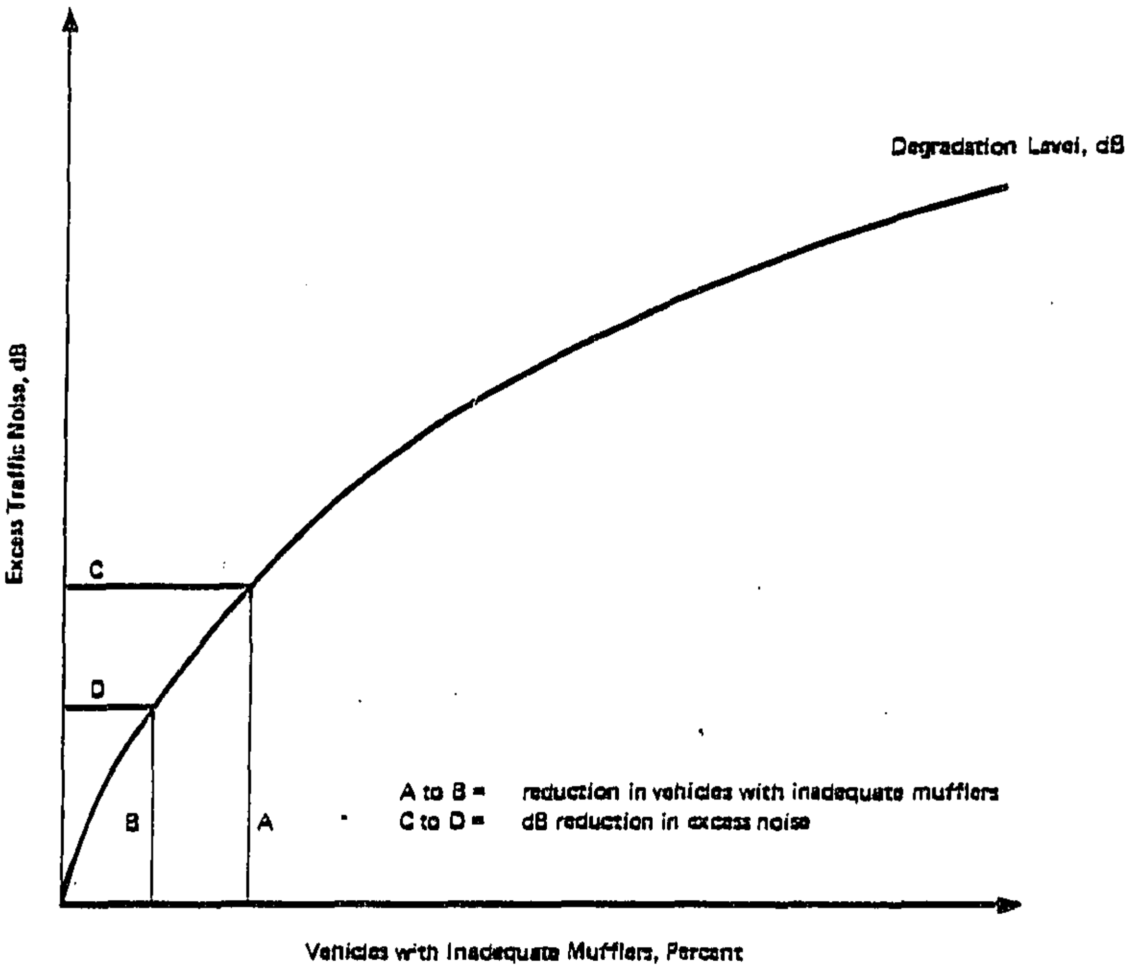


Figure 3-2: Example of the Decrease in Excess Traffic Noise Resulting a Reduction in Motor Vehicles Having Degraded Exhaust Noise Muffling Components

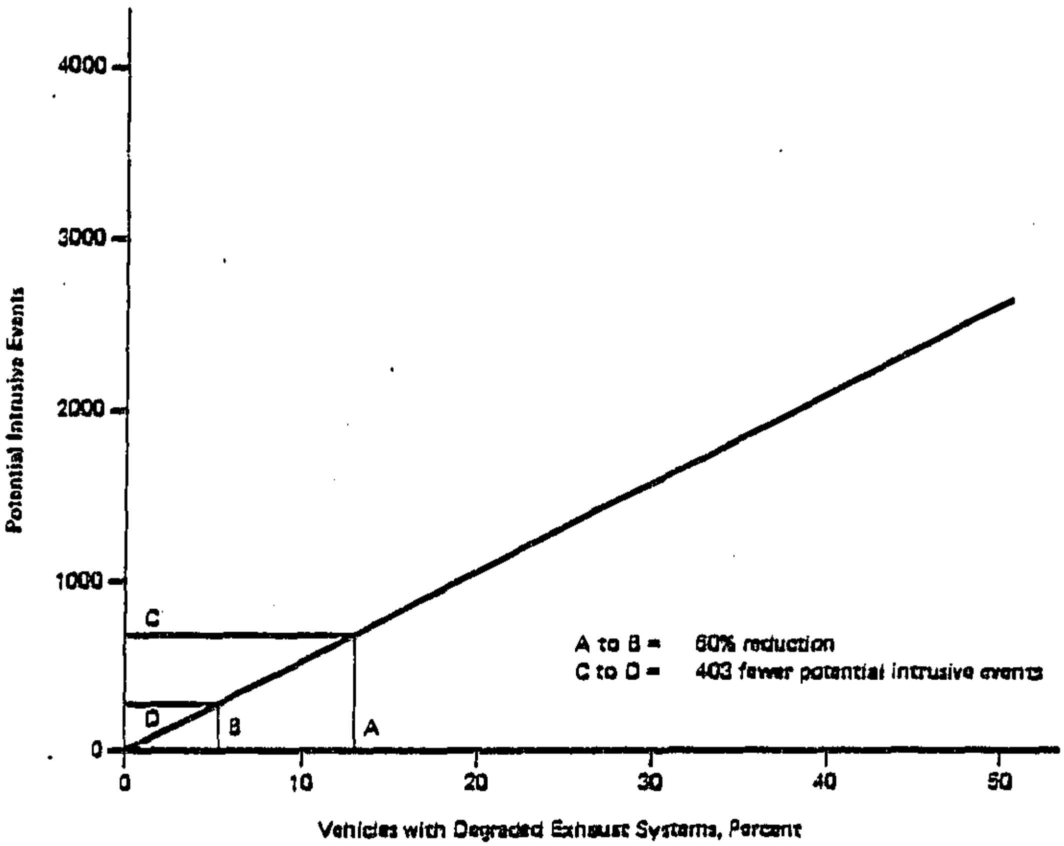
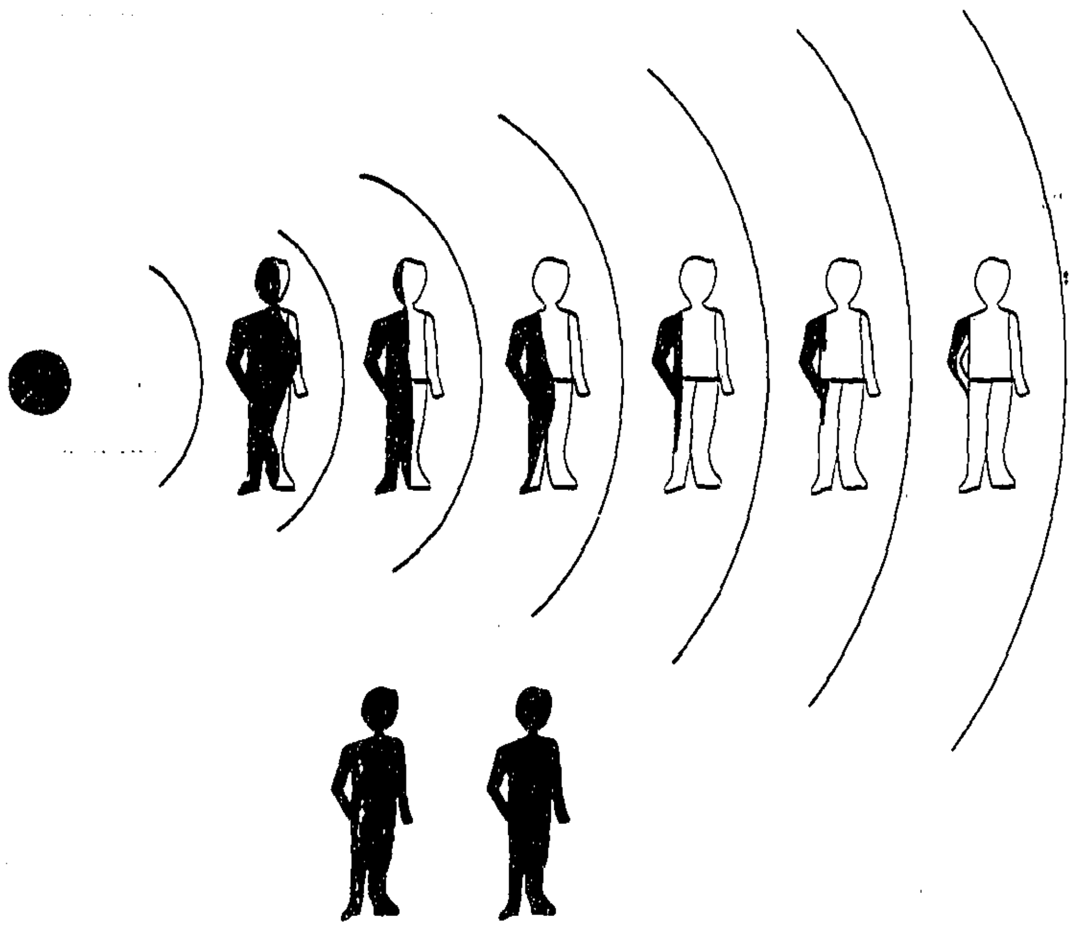


Figure 3-3: Example of Reduced Potential Intrusive Event Analysis



The circle is a noise source which emits noise to a populated area represented by the figures. The various amounts of shading represent various degrees of partial impact by the noise. Note that people closest to the noise source are more impacted. The partial impacts are summed to give the LWP. In this example 6 people who are adversely affected by the noise (partially shaded) results in an LWP of 2 (totally shaded).

Figure 3-4: LWP Concept

Thus, the analytic procedure for identifying impact according to LWP analysis is to to superimpose on a population distribution around a roadway noise level generated from that roadway, and then generate the total persons fully impacted by the proportional analysis above. The percentage reduction in LWP attributable to a motor vehicle noise enforcement program results from a reduction in noise levels, (and therefor people impacted) around that roadway.

For example, we have seen how the excess noise methodology can be used to determine the noise reduction that would be achieved from a noise control program which was succesful in reducing the proportion of defective vehicles by some amount. It is instructive to show what this might mean in terms of reduction in LWP. To perform this analysis, some consensus average of the proportion of defective vehicles was assumed as being representative, as follows:

	Proportion Defective (Consensus)
Autos	7%
Trucks	10%
MC	12%

To this a proportional reduction in the number defective vehicles of 15%, 40% and 29% was assumed based on available evidence from, the Quiet Communities Program and from NANCO data sources. National averages of the population distributions around major roadways were also assumed. The analysis indicates that a 10% reduction of noise impact, as measured by the Level Weighted Population (LWP) may be considered typical. This is useful when making comparisons with, say, regulations, though the value of LWP analysis is of questionable use to state and local officials.

Section 4: STATE/LOCAL IN-USE EXHAUST NOISE ENFORCEMENT

A necessary prerequisite to State/local in-use motor vehicle exhaust noise enforcement is a noise regulation. The threat of punitive action as a finality provides the incentive for operators of noisy vehicles to repair/maintain the acoustical integrity of their vehicles. Figure 4-1 shows a universal motor vehicle noise enforcement scheme. The overall scheme is comprised of an in-use vehicle passby screening element for "on-street" noise evaluations and a test station element for "off-street" vehicle noise evaluations. Each of the elements may exist alone or be combined to serve as the enforcement scheme for the control of vehicle exhaust noise. The "on-street" scheme requires some form of direct police participation to enforce the vehicle noise code. The test station scheme, with periodic inspection, needs no direct police participation; police involvement would occur "on the street."

In-Use Screening Element

In-use screening may be accomplished by subjective means using the human ear or objectively using electronic means. The intent behind either means is to initially identify vehicles suspected of having inadequate exhaust noise mufflers by the excessive or unusual noise levels. Once a vehicle has been identified as producing an undesirable or unusual sound, subsequent curbside checks may be performed to corroborate or refute the excessive noise suspicion. At this point the motorist may be either given a lecture, warned or cited for failure to comply with the motor vehicle code. Listed below are possible "on-street" enforcement schemes.

In-Use Screening Enforcement Schemes

A. Aural screen plus curbside visual inspection

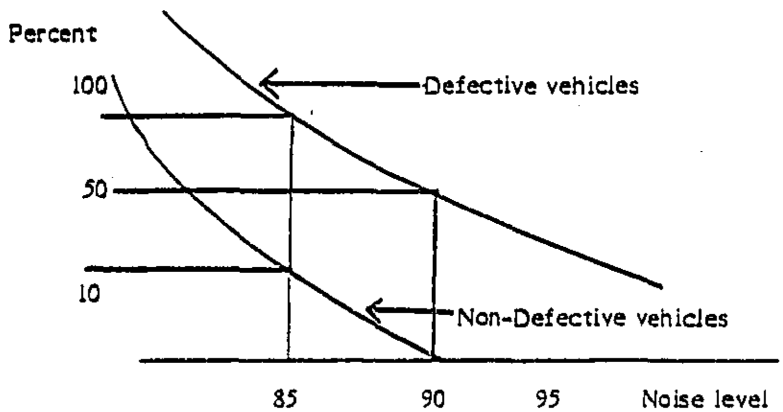
B. Aural screen plus curbside visual inspection and meter test

C. Meter screen plus curbside visual inspection

D. Meter screen plus curbisde visual inspection and meter test

E. Meter screen as part as routine radar surveillance

The traditional noise enforcement schemes employ instrumentation under a passby test criteria. This form of enforcement involves a serious dilemma in which the deire to minimize the citation of vehicles with good mufflers, runs counter to the desire to maximize the citation of vehicles with defective mufflers. For example, if the cumulative noise distributions of defective and non-defective vehicle populations is represented below, a criteria level of 90 dB would insue that no non-defective vehicle was incorrectly cited, but would only identify 50% of vehicles with defective mufflers. Lowering the criteria level to say 85 dB would improve the proportion of defective vehicles cited, but only at a cost of incorrectly identifying a large proportion of non-defective vehicles.



Fortunately, there are alternatives to the traditional approach which have been tested. These tests show that aural screening gives police the greatest flexibility in that an officer can be observing traffic (as opposed to observing a meter) as he/she listens for vehicles with degraded exhaust systems.

Based upon a Demonstration/Evaluation conducted by the State of New Jersey,[11] police officers trained to listen for vehicles with deteriorated exhaust noise muffling components were far superior to instrumentation used to detect loud vehicles. The New Jersey data show that instrumentation successfully identified only about 20% of the vehicles with deteriorated muffling systems. The reason for this is that "bad" muffling systems do not necessarily produce higher levels of noise, as would be detected by a meter, but always produce sounds alien (unusual) to ambient traffic noise, and hence are easily detected by the ear. The use of aural screening, on the other hand, succeeded in identifying approximately 80% of vehicles with defective mufflers. Thus, it would appear that a motor vehicle noise enforcement program intending to control noise from deteriorated muffling systems must rely on the human ear rather than on instrumentation. For vehicle codes which state* "Every motor vehicle subject to registration shall at all times be equipped with an adequate muffler in constant operation and properly maintained to present any excessive or unusual noise ...", the human ear to detect - and human eyesight to confirm - appears to be all that is necessary to enforce the noise control ordinance.

*Township of Plainsboro, New Jersey

Enforcement scenarios that would integrate noise control with speed control, enables an officer to observe radar speed readings and to listen for noise. The "pick-up" officer could be alerted to curb the motorist for speeding and/or a possible noise violation.

Test Station Element

Vehicle test stations may be used to provide for periodic inspections of a motor vehicle's exhaust noise muffling system. The stations may be an air pollution test station, safety check station, or exist alone for noise testing. The test station provides a controlled environment, free from adverse meteorological/ambient noise conditions, where visual and noise meter tests may be performed with alacrity. As such, motor vehicles could be certified to meet vehicle exhaust system noise emission criteria and bear a label or sticker. stating same, for some finite period of time.

On localities where air quality (Inspection and Maintenance) testing or safety checks are made, noise testing could be integrated into the air program. Where it is not politically expedient to require mandatory noise testing, the existing I/M or safety stations could participate in a driver referral program. In the referral program, police officers direct ticketed persons to the I/M station to certify their auto has been repaired. In the voluntary testing program, motorists could travel to the I/M station for a free test to check whether their vehicle is in compliance with the appropriate noise code. No citation would be issued for a failure discovered during the voluntary testing.

Combined In-Use and Test Station Evaluation

In-use screening and test station evaluations may be combined to provide an enforcement scheme whereby motor vehicles initially culled from the traffic flow are diverted/directed to a test station for noise inspection under controlled conditions. Such action may be a matter of routine or pursued when roadside measurements or observations reveal that a vehicle is marginally within compliance with a motor vehicle noise code. Vehicle certification or recertification may be accomplished through this combined scheme.

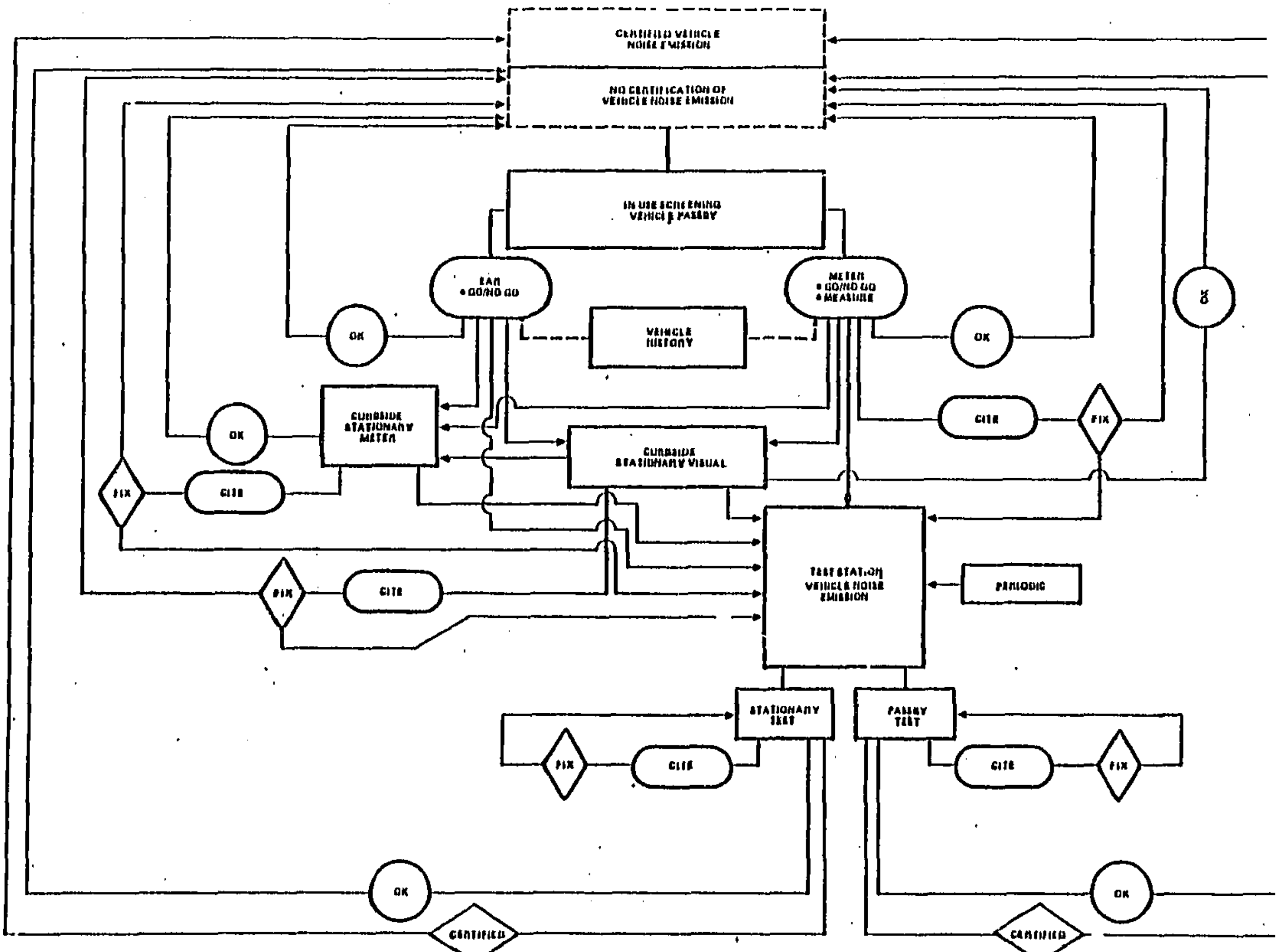


Figure 4-1: - Universal Motor Vehicle Noise Enforcement Scheme

Section 5: POTENTIAL NOISE REDUCTION FROM STATE AND LOCAL IN-USE MOTOR VEHICLE NOISE ENFORCEMENT

By applying available data/information to the methodologies of Section 3, it is possible to quantify the effectiveness of motor vehicle noise enforcement programs to show their effectiveness. Data from the State of Florida is used to show the effectiveness of one such mature program.

State of Florida

The state of Florida has been actively enforcing motor vehicle noise codes since 1975. They use a meter screen followed by a visual inspection of the muffling system. Table 5-1 lists the total man hours expended in their noise control effort for the years 1975 to 1980, inclusive. This activity has resulted in the statistics regarding the number of medium/heavy trucks, automobiles/light trucks and motorcycles; travelling over, at and below 35 miles per hour in violation of their noise code. The statistics are presented in Table 5-2, 5-3, 5-4, 5-5, 5-6 and 5-7 for the years 1975 to 1980, vehicles weighing 10,000 lbs and greater, (medium/heavy trucks) vehicles weighing less than 10,000 lbs. (automobiles/light trucks) and motorcycles. Since noise associated with tire/roadway interaction does not become prominent until vehicle speeds in excess of 35 mph are attained, it is inferred that the number of violations identified in Tables 5-2 through 5-7 for speeds at or less than 35 mph, are vehicle generated. Further, since the combustion process creates the highest noise levels of any of the vehicle noise sources, it is inferred that all, or very great preponderance, of violations are the direct result of degraded exhaust noise muffling components. Accordingly, use of the statistics at or below 35 mph provide a good first approximation of effectiveness of the State of Florida program in controlling motor vehicle exhaust noise.

Using Tables 5-2 through 5-7, the traffic mix and the percentage of vehicles having inadequate/modified or defection exhaust noise muffling components are calculated and are shown below.

Percentage Degraded Exhaust System

	Inadequate/Modified Percentage	Defective Percentage	Traffic Mix Percentage
Auto/Light Trucks	66.5	33.5	77.7
Motorcycles	87.4	12.6	5.7
Med./Heavy Trucks	83.5	16.5	16.6

The data (of Tables 5-2 through 5-7) are also used to show the trends in motor vehicle enforcement since the inception of the Florida program. Figure 5-1 summarizes enforcement statistics.* By comparing the statistics for the years 1976 and 1980, by vehicle type, the following is observed with regard to reduced vehicle noise code violations:

Percentage Reduction in Violations of the Florida Noise Code

Automobiles/Light Trucks	Motorcycles	Medium/Heavy Trucks
47.1	48.5	50.6

*(The year 1975 has been omitted from the table by reason that 1975 was a start-up year and the years 1976 through 1980 provide better statistics for a mature program.)

Reductions in excess motor vehicle noise, number of potential intrusive events and Level Weighted Population are calculated by applying the statistics listed above to the methodologies discussed in Section 2.

Excess Noise

It is estimated that the following reductions in traffic noise have resulted as the direct result of vehicle exhaust noise enforcement in Florida.

Reduction in Excess Noise

Automobiles/Light Trucks	Motorcycles	Medium/Heavy Trucks
-1.4 dB	-2.5 dB	-2.5 dB

These individual reductions are estimated to have caused a 1.7 dB overall reduction in excess traffic noise.

Potential Intrusive Events

The table that follows shows estimated reductions in the number of potential instrusive events. Focusing on automobile/light trucks, potential sleep awakenings, speech interferences or general annoyances has been reduced by over 2000 incidences per day along major arterial roadways in Florida.

Estimated Reduction in Potential Intrusive Events Per Day

Roadway Type	Automoible/Light Truck	Motorcycle	Medium/Heavy Truck
Major Arterial	2183	49	214
Minor Arterial	933	32	107
Collector	379	13	44
Local	119	5	5

Level Weight Population

When considered in light of the reduction in the extent and severity of noise, the Florida program is estimated to have caused the following reduction in LWP.

Reduction in LWP, Percent
Roadway Type

Major Arterial	Minor Arterial	Collector	Local
1	7	9	11

Table 5-1

Annual Motor Vehicle Enforcement
Expended by the State of Florida, Manhours

	Year					
	1975	1976	1977	1978	1979	1980
Travel	2078	1527	1722.5	2075.5	1519	2211
Office	683	381	588	537.5	446	589
Enforcement With Meter	1977	2131.5	2977.5	3238	3074	4663
Other Noise Enforcement	1669	1066.5	1967	753	531	452
Court Time	69	86	82	199	106	111
Training	797	215	236	330	423	252
Total	7275	5407	7543	7133	6099	8278

Table 5-2

Partial Florida Highway Patrol Noise Enforcement
Report for 1975
Enforcement Statistics for Speeds 35 MPH or Less

	Vehicle Type		
	10,000 Lbs. or more	Less than 10,000 Lbs.	Motorcycles
Vehicles Measured	4,666	17,152	448
Vehicles with Violations (contacted)	1,003	1,726	155
Vehicles with Violations (not contacted)	638	1,212	106
Exhaust Stysems			
Modified	38	803	47
Defective	217	484	18
Inadequate	535	54	52

Table 5-3

Partial Florida Highway Patrol Noise Enforcement
Report for 1976
Enforcement Statistics for Speeds 35 MPH or Less

	Vehicle Type		
	10,000 Lbs. or more	Less than 10,000 Lbs.	Motorcycles
Vehicles Measured	6,854	19,885	855
Vehicles with Violations (contacted)	1,376	3,097	230
Vehicles with Violations (not contacted)	886	2,307	130
Exhaust Stysems			
Modified	60	1,148	102
Defective	295	818	33
Inadequate	857	87	72

Table 5-4

Partial Florida Highway Patrol Noise Enforcement
Report for 1977
Enforcement Statistics for Speeds 35 MPH or Less

	Vehicle Type		
	10,000 Lbs. or more	Less than 10,000 Lbs.	Motorcycles
Vehicles Measured	10,211	34,180	1,354
Vehicles with Violations (contacted)	1,912	4,782	344
Vehicles with Violations (not contacted)	1,253	3,542	199
Exhaust Stysems			
Modified	7	2,602	170
Defective	375	1,346	34
Inadequate	1,474	83	135

Table 5- 5

Partial Florida Highway Patrol Noise Enforcement
Report for 1978
Enforcement Statistics for Speeds 35 MPH or Less

	Vehicle Type		
	10,000 Lbs. or more	Less than 10,000 Lbs.	Motorcycles
Vehicles Measured	13,695	52,273	2,750
Vehicles with Violations (contacted)	2,185	7,192	592
Vehicles with Violations (not contacted)	1,616	5,617	426
Exhaust Stysems			
Modified	73	4,143	428
Defective	553	2,090	86
Inadequate	1,409	105	22

Table 5-6

Partial Florida Highway Patrol Noise Enforcement
Report for 1979
Enforcement Statistics for Speeds 35 MPH or Less

	Vehicle Type		
	10,000 Lbs. or more	Less than 10,000 Lbs.	Motorcycles
Vehicles Measured	13,309	79,135	4,594
Vehicles with Violations (contacted)	1,759	10,152	889
Vehicles with Violations (not contacted)	1,365	9,074	568
Exhaust Stysems			
Modified	15	5,032	675
Defective	342	3,169	93
Inadequate	1,271	98	27

Table 5-7

Partial Florida Highway Patrol Noise Enforcement
Report for 1980
Enforcement Statistics for Speeds 35 MPH or Less

	Vehicle Type		
	10,000 Lbs. or more	Less than 10,000 Lbs.	Motorcycles
Vehicles Measured	17,793	102,157	7, 491
Vehicles with Violations (contacted)	2,207	13,687	1,242
Vehicles with Violations (not contacted)	1,692	11,055	908
Exhaust Stysems			
Modified	36	7,517	968
Defective	348	3,848	145
Inadequate	1,728	131	35

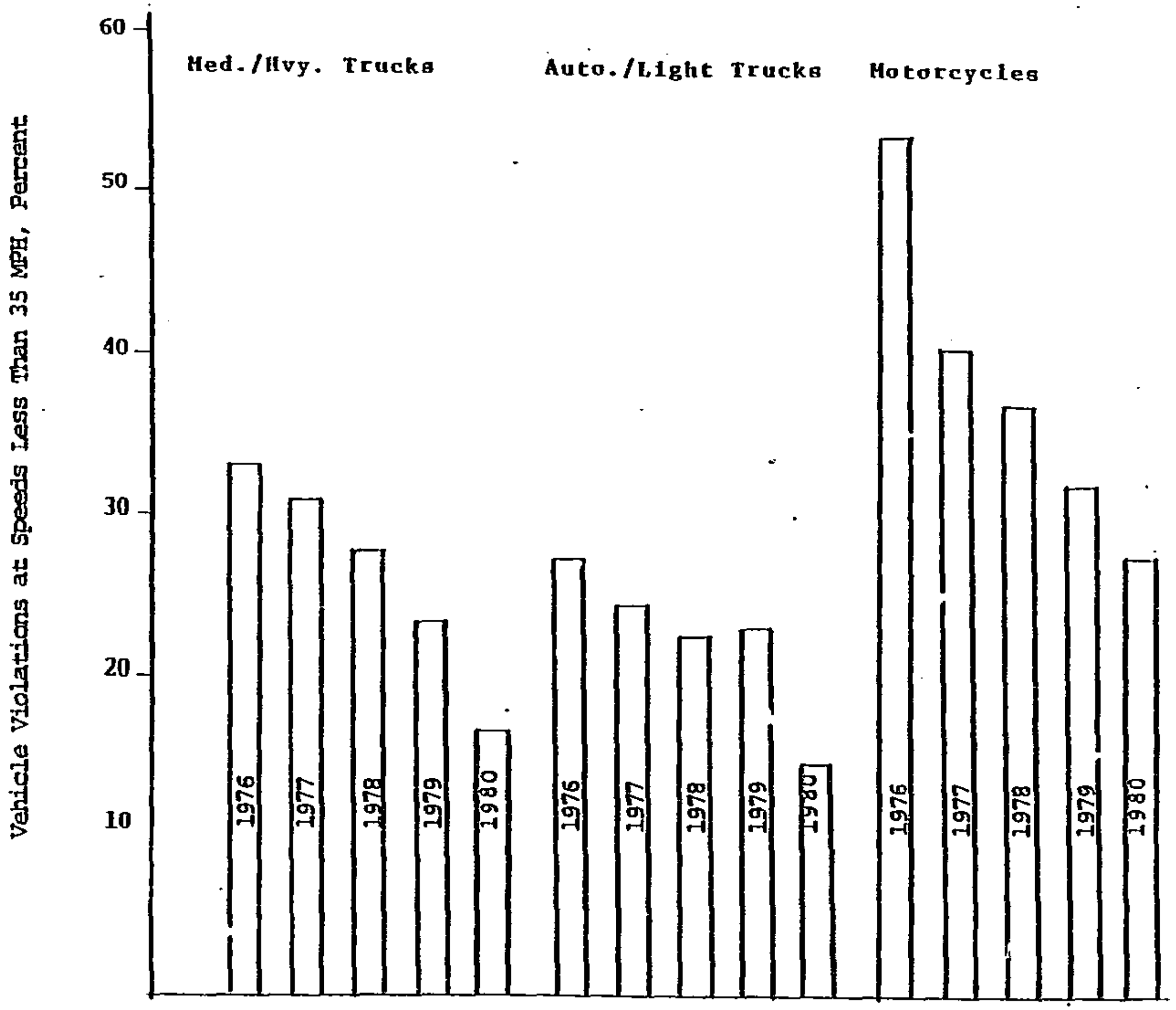


Figure 5-1: Effectiveness of Florida Motor Vehicle Noise Control

Section 6: THE COST OF STATE/LOCAL MOTOR VEHICLE EXHAUST NOISE CONTROL

Cost Effectiveness

A framework for evaluating the cost effectiveness of state and local motor vehicle noise control programs is fully derived in the appendix. This analysis shows that the absolute cost effectiveness (i.e., cost per citation of defective vehicle), will vary with respect to factors which are unique to a community and/or roadway (e.g., traffic volume, and percent defective vehicles) and factors which are specific to the method of enforcement (e.g., citation time and accuracy). This allows a community to collect minimal data and actually calculate the cost per citation of defective vehicles under various enforcement schemes. They can decide, based on the analysis in the previous chapter concerning the noise reduction and reduction in intrusive events, how much they would desire to budget for noise control.

Ofcourse, one need not know the actual cost per citation in order to rank order various enforcement schemes. Relative cost effectivenesss of the five identified enforcement schemes have therefore been identified, based on educated assumptions concerning the relative number of citations per hour of the various schemes presented. The analysis shows that scenarios employing the least amount of equipment tend to be more cost effective.

Cost

The cost of a State/local motor vehicle exhaust noise control program is related to the population of the political jurisdiction served by the police activity. A place the size of, say, 2 million persons is likely to have at least 4-6 police officers surveilling noise, whereas, a community of 25,000 people is likely to have 1-2 officers involved. To estimate the program costs, the budget[8] of the ten areas, listed below, was reviewed and a plot made of the cost per person. The plot of enforcement cost per person is shown by Figure 6-1.

Area	Population	Budget
Bloomington, Minnesota	79,000	$ 26,000
Boulder, Colorado	85,000	39,000
State of California	22,000,000	610,000
Colorado Springs, Colorado	300,000	67,000
Eugene, Oregon	100,000	65,000
State of Florida	7,000,000	200,000
State of Maryland	4,000,000	158,000
State of Oregon	2,250,000	204,000
Salt Lake City, Utah	180,000	167,000
San Francisco, California	675,000	80,000

Enforcement cost by population place size may be calculated as the product of the incremental cost of Figure 6-1 and the population. Using the average population for the typical place sizes identified in the National Roadway Traffic Noise Exposure Model (NRTNEM),[9] the following, estimated annual cost of a motor vehicle exhaust noise program is derived.

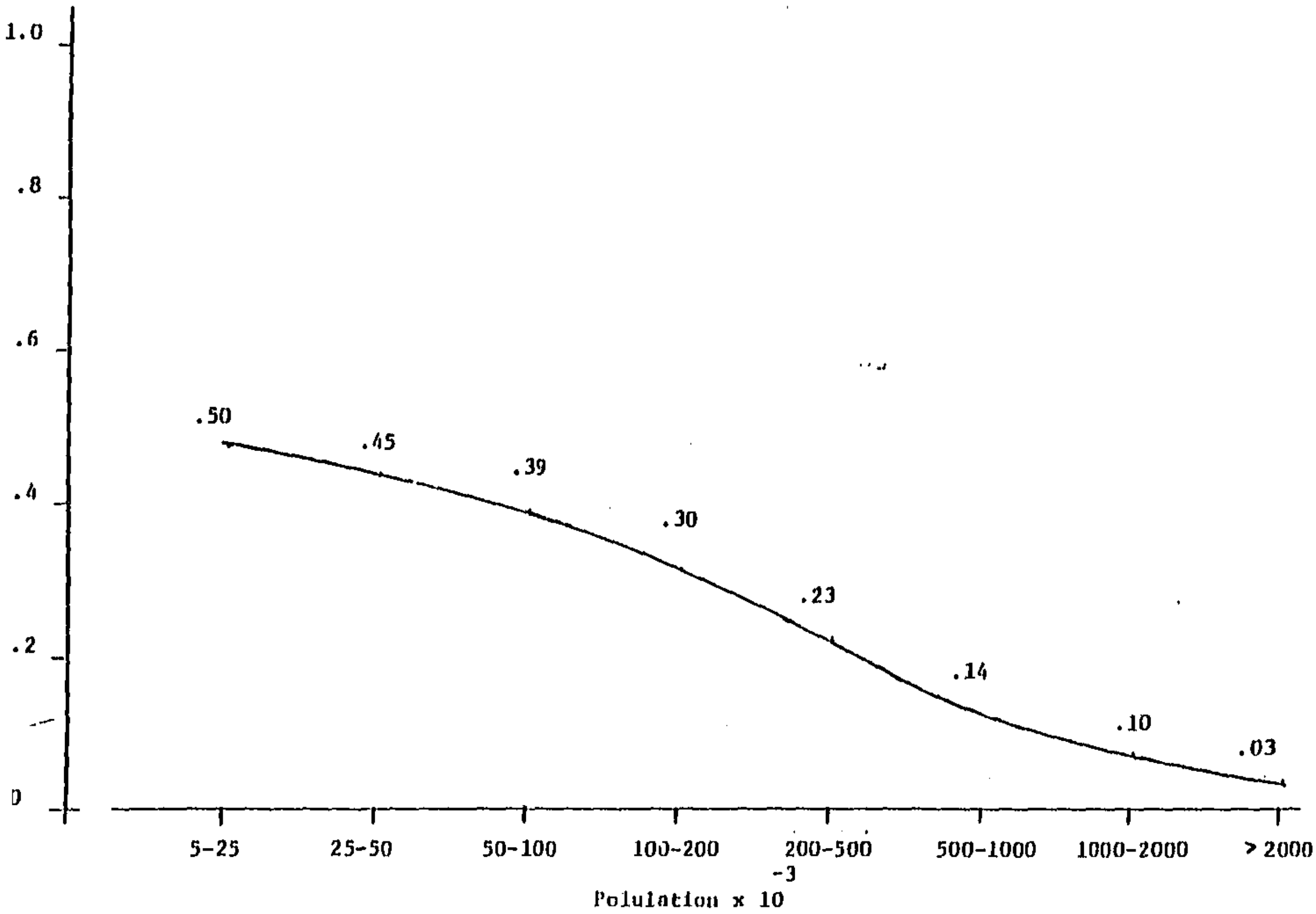
Place Size, Population	Annual Cost, $
2 M	300,000
1 - 2 M	150,000
500K - 1 M	105,000
200K - 500K	81,000
100 - 200K	45,000
50 - 100K	29,000
25 - 50K	16,900
5 - 25K	7,500

To arrive at the cost of various enforcement schemes, the values above are scaled by the relative cost[10] of each enforcement scheme. Inasmuch as current in-use enforcement practices usually employ a scheme of meter screening plus visual inspection, the costs are relative to that scheme.

Enforcement Scheme	Relative Cost
Aural screening plus curbside visual inspection	0.727
Aural screening plus curbside visual inspection and curbside meter test.	1.371
Meter screening plus curbside visual inspection	1.000
Meter screening plus curbside visual inspection and curbside meter test	1.371
Meter screening coupled with routine radar surveillance	1.008
Test station stationary test, exclusive of land/building cost	P/2 x .69 P = population

Table 6-1 lists the estimated costs of various motor vehicle exhaust noise enforcement schemes. The results show that the notion of an initial screening by the human ear, followed by a curbside visual inspection of the vehicle exhaust system is the least costly of the pass-by evaluations. As shown by the New Jersey program (Section 4), the initial screen by the ear is also more effective in identifying vehicles with deteriorated exhaust systems. Accordingly, for a motor vehicle program focusing on exhaust noise control, it appears that the pass-by aural plus the curbside visual is the most cost effective option for use by State/local governments.

Excluding the cost of land/building noise checks at test stations, appears to be the least costly of all motor vehicle exhaust noise control schemes. However, without on-street enforcement, exhaust systems that deteriorate in-between inspections cycles are likely to impact a community. Thus, in the spirit of true effectiveness, some on-street enforcement would be necessary. This then would raise the cost of enforcement above the aural/visual option.


1.0
.8
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5-25
25-50
50-100
100-200
200-500
500-1000
1000-2000
> 2000
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Table 6-1

ESTIMATED ANNUAL COST OF MOTOR VEHICLE EXHAUST NOISE ENFORCEMENT BY PLACE SIZE AND TYPE OF ENFORCEMENT

Place size	In-Use Pass By Enforcement Scheme* A	B	C	D	E	Test Station F
> 2M	$219,000	$411,429	$300,000	$411,429	$302,449	$138,000
1M - 2M	109,500	205,714	150,000	205,714	151,224	103,500
500K - 1M	76,650	144,000	105,000	144,000	105,857	51,750
200K - 500K	59,130	111,085	81,000	111,085	81,661	24,150
100K - 200K	49,431	61,714	45,000	67,714	45,367	10,350
50K - 100K	29,534	40,457	29,300	40,457	29,146	5,175
25K - 50K	16,919	23,177	16,900	23,177	17,038	2,587
5K - 25K	7,508	10,285	7,500	10,286	7,561	1,035

*A Aural screening plus curbside visual inspection

B Aural screening plus curbside visual and curbside meter test

C Meter screening plus curbside visual inspection

D Meter screening plus curbside visual inspection and curbside meter test

E Meter screening coupled with routine radar surveillance

F Test station stationary test, exclusive of land/building cost

Section 7: REFERENCES

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APPENDIX

Analytic Procedure for Assessing
the Cost and Benefits of
Alternative Noise Enforcement
Methods

The purpose of this appendix is to lay out the analytic framework through which the costs and benefits of alternative noise enforcement senarios can be evaluated with respect to local conditions and the level of enforcement. This will enable realistic evaluation and decision concerning the most cost/effective enforcement procedure and the most cost effective level of enforcement for any given locale. The analytic framework presented is kept simple and straight forward to facilitate its usefulness. Finally, an example is presented based on assumed conditions to demonstrate its applicability.

Analytic Framework

The analytic framework for assessing costs and benefits is dictated by measures of performance for state and local motor vehicle noise programs. As such, the performance of a motor vehicle noise program is directly proportional to the reduction in number (proportion) of vehicles with defective exhaust systems.

Costs per se are not meaningful unless compared to some unit of output (i.e., noise reduction). As previously described, it is operationally useful to relate noise reduction to the reduced number of defective vehicles. It is necessary therefore to compare each enforcement scenario in terms of its cost per defective vehicle cited, provided that each cited vehicle is repaired. In the scenarios discussed, the cost includes those elements necessary to insure compliance.

Analysis

The cost effectiveness of any given scenario is measured by the cost per citation of that scenario. The cost per citation depends on the cost per hour of enforcement and the number of citations per hour. Very simply -

$$\text{Cost/Citation} = \frac{\text{Cost/hour}}{\text{Citations/hour}} \qquad (1)$$

Generally, there are two types of cost, labor cost and equipment cost.

$$C_t = w + e \qquad (2)$$

C_t = total cost per hour of enforcement

w = (wage rate) labor cost per hour of enforcement.

e = equipment cost per hour

While labor cost is applied only to hours of labor expended on enforcement, equipment cost must be amortized over its full useful life including those times when not in use.

The number of citations per hour is the inverse of the time it takes per citation. Thus, a scenario that consumes 20 minutes per citation is capable of 3 citations per hour.

Thus, (3)

$$\text{Citations/hour} = \frac{60}{T_t}$$

T_t = total time in minutes required per citation.

The time consumed per citation is made up of two factors: (1) time required to identify a defective vehicle and (2) time required to inspect and cite that vehicle. Thus-

Total Time = Time for Identification + Time for Citation

$$T_t = T_i + T_c \qquad (4)$$

T_t = total time

T_i = time for identification

T_c = time for citation

Identification Time (T_i)

The time required to identify a defective vehicle by an enforcement officer on the side of the road depends on how frequently such vehicles pass by. For example, on a road on which 10 defective vehicles pass per hour (one every 6 minutes), an officer, just completing an inspection on one vehicle, would have to wait up to 6 minutes, before the next defective vehicle passes. The actual average time he would have to wait (delay time) would be some proportion of the average time between defective vehicles. Thus, identification time is taken to be, on average, "b" proportion of the time between defective vehicle passbys.

$$T_i = b\,(60/f_d) \qquad (5)$$

T_i = identification time in minutes

f_d = frequency (vehicles per hour) of defective vehicle passbys

60 = 60 minutes per hour.

b = delay time factor (some proportion between 0 and 1).

The frequency of defective vehicle passbys per hour, itself, depends on the average hourly traffic flow on the roadway in question, and the proportion of defective vehicles in that flow. Thus -

$$f_d \quad = \quad (AHT)(P_d)$$

AHT = average hourly traffic in vehicles per hour.

Pd = Percent deffective vehicles.

Substituting into (5) yields (6)

$$T_i \quad = \quad \frac{60\ b}{(AHT)(Pd)}$$

This relationship is important because waiting time is dead time in terms of noise enforcement. The longer the waiting time, the lower is the number of vehicles that can be cited in a given time period. It is clear then that the efficiency of any noise enforcement officer decreases on roads with low traffic volume, and in situations with low proportion of defective vehicles. This element of efficiency is a directly measurable quantity and will naturally vary from locality to locality depending on these two factors.

<u>Citation Time</u> (T_c)

Citation time is simply the time required to inspect and cite a vehicle once identified. This time is important because it directly affects the number of vehicles an officer can cite during each hour of enforcement. Thus, if it requires 10 minutes per vehicle, the maximum number of vehicle citations an officer is capable of would be 6, assuming no identification (waiting) time between vehicles. Citation time is unique to the enforcement scenario, and should not vary from community to community. Therefore, information on citation time (time for inspection) for each scenario is easily collected through simple experimentation.

Citations Per Hour

Citations per hour are now easily derived from the above.

$$\text{Citations/hour} = \frac{60}{T_t} = \frac{60}{T_i + T_c} \tag{7}$$

$$= \frac{60}{60\ b/((AHT)(P_d) + T_c)}$$

Citations per hour need now be adjusted for the failure rate associated with the use of a particular technique. While some techniques may have a shorter citation time, and in that sense, be more efficient, they may also have a higher failure rate (less accurate) so that some of the citations will not be valid. Therefore, citations per hour must be adjusted by the failure rate (proportion of inaccurate citation), unique to a given scenario.

$$\text{True Citations/hour} = \frac{60}{T_t}\ (1-a) = \frac{60(1-a)}{T_i + T_c} \tag{8}$$

$$= \frac{60\ (1-a)}{60\ b/((AHT)(P_d) + T_c)}$$

Using (1) and (7), cost per citation then becomes - (9)

$$\text{Cost/Citation} = \frac{(w+e)\ (60\ b)\ /\ ((AHT)(P_d) + T_c)}{60(1-a)}$$

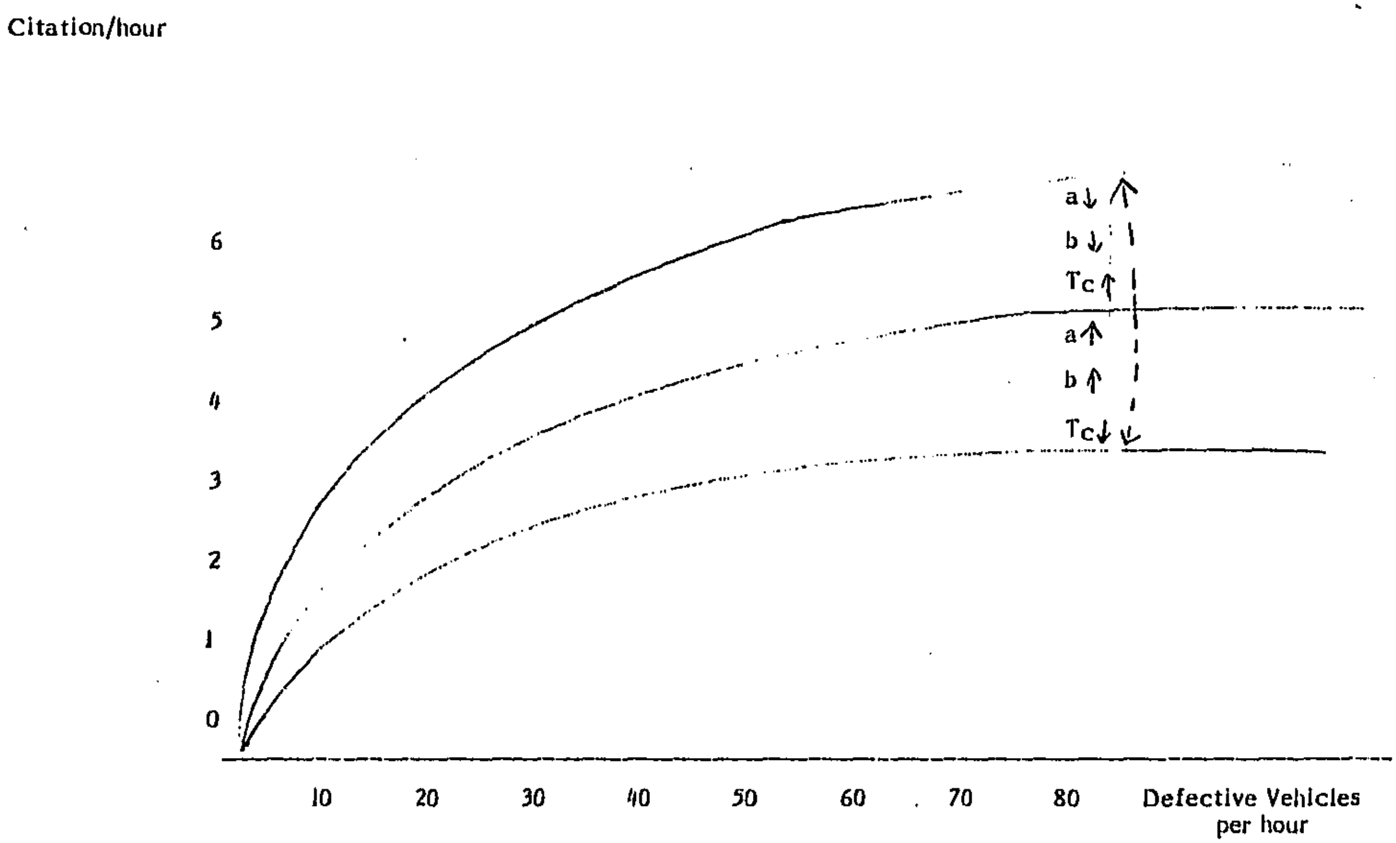
The above represents the analytical framework for collecting and analyzing data on the cost effectiveness of various enforcement techniques. It is useful that its derivation separately deals with the independent issues associated with both cost and efficiency (time) dimensions. It highlights those factors which are unique to the community (e.g., traffic volume) or roadway (e.g., proportion of defective vehicles), and those which are unique to the enforcement procedure (e.g., citation time, and failure rate). Further, despite its apparent complexity, the algebraic computation is easily reduced to simple dimensions.

For example, the following chart presents equation 9 as a family of curves showing how citations/hour is related to Average Hourly Traffic flow (AHT), percent defective vehicles (Pd), citation time (Tc), failure rate (a), and the delay time factor (b). When such curves (one for each scenario) are developed, a local community, knowing the traffic flow and percent defective vehicles can determine its citations/hour for each scenario. It need then simply apply normal wage rate and equipment cost rates as described to determine the cost per citation for each scenario in question.

I & M Stations

The formulation presented above has the capacity to accommodate both on the road scenarios, inspection station scenarios, or combinations. For inspection station enforcement, the vehicles inspected per hour, replaces the average hourly traffic (AHT) in the analysis. All other variables are the same.

EQUATION 9



Citations Per Hour as Determined
By Defective Flow (AHT)(P_d)
and Citation Time (Tc).