NOISE MITIGATION STRATEGIES

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Technical Monitor: Tim Coats, Environmental Unit
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16. Abstract

Noise mitigation strategies involving both noise reduction at the source of transportation noise and at the receiver of transportation noise are reviewed. The following major sources of noise within a motor vehicle were considered: engine, intake, exhaust, cooling fan, transmission, and tire noise. Current research intended to address methods of reducing noise for each of these sources is discussed. It was found that vehicle manufacturer efforts in the U.S. to reduce vehicle noise is currently being motivated by marketplace demands for quiet vehicles. In addition to the potential noise reduction from specific components of the vehicle, it was found that the type of roadway pavement can have a significant effect on tire/road noise.

A key strategy for reducing transportation noise at the receiver of the noise is land use compatibility planning. Local agencies who have successfully implemented noise and land use compatibility planning programs were interviewed. These programs fall into two broad categories. The first category is land use compatibility brought about by zoning. In this category, land uses that are inherently compatible with transportation noise sources are located adjacent to the sources. The second category, referred to as proponent mitigated development, involves a process of mitigation needed to make the land use compatible with transportation noise through mitigation efforts funded by the proponent of the development. It was found that noise and land use compatibility programs were most beneficial to communities in the earlier stages of development whereas the use of a local noise ordinance was found to be more beneficial to communities that are more fully developed.

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"Noise Mitigation Strategies"

Noise Mitigation Strategies

by

Lloyd Herman
William Bowlby

Vanderbilt Engineering Center
for Transportation Operations and Research
Vanderbilt University
Box 96, Station B
Nashville, TN 37235

Technical Monitor
Tim Coats
Environmental Branch, Design Office
Washington State Department of Transportation

Prepared for

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DISCLAIMER

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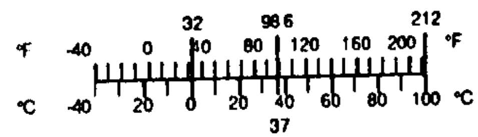
METRIC CONVERSION FACTORS

Approximate Conversion to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.54	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversion from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	sq. centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	sq. kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



n Data: Adm TRAC Adm: Metric

NOISE MITIGATION STRATEGIES

SUMMARY

This study focused on a review of noise mitigation strategies at both the receiver of a transportation noise source and the noise source itself.

Transportation noise control at the source involves strategies to reduce the noise emitted from vehicles. The major sources of noise are the engine, intake, exhaust, cooling fan, transmission, and tires. Strategies which are currently being studied to further reduce noise in each of these vehicle component areas are reviewed in this report.

While a number of strategies are discussed for each of the vehicle component areas, the strategies can be grouped into several categories. One type of strategy relies on additional equipment to reduce noise. Strategically placed resonators in the intake system or the use of add-on dampers for rotating parts of a vehicle such as crank shafts and drive shafts are examples of add-on equipment to reduce noise. A second type of strategy involves the redesign of the noisy component. In the case of tires, a redesign of an existing tread pattern may result in lower noise levels produced by the tire. In the same way, an improvement in the design of a muffler can result in reduced exhaust noise levels. A third category does not involve a change in design or the addition of auxiliary parts but rather focuses on the fit of mating parts within the vehicle. By reducing manufacturing tolerances such as those found in crank shaft bearings, or between gear teeth in transmission, the amplitude of vibrations can be reduced. The vibrations, which are structure borne initially, are radiated from the outer surface of these components as noise.

The marketplace provides the current motivation for U.S. manufacturers to reduce noise from motor vehicles. There is a perception that a quiet vehicle is a quality vehicle. As long as buyers hold this viewpoint, manufacturers will attempt to reduce noise levels even more. One potential exception to this trend is with tire noise. Noise reduction in this area could be limited should the market make a widespread move to tires with wider treads and smaller, stiffer sidewalls in the name of higher performance.

Noise and land use compatibility planning was the primary strategy studied under the category of noise control at the receiver. This focus was in contrast to a predecessor study for this work, which included a review of municipal noise ordinance strategies for

receiver noise control. Enforcement of a local noise ordinance, which is found in many communities, tends to be reactive in nature and is typically accomplished by the police department, noise control unit or the health department. It was found that the local noise ordinance is a complimentary strategy to noise and land use compatibility planning. The effectiveness of these two strategies depends on the level of community development. For communities in earlier stages of development, the land use compatibility strategy will have the greater effect. On the other hand, communities which are "built out" will rely mostly on the local noise ordinance.

In contrast to the enforcement of a local noise ordinance, a few local agencies have addressed transportation noise during planning. In these cases, the sources are not viewed as individual vehicles, for example, but as systems such as traffic, rail, and aviation. The goal of noise control at the planning level is to ensure that community development can proceed without incurring traffic noise impact. Enforcement of these plans generally involves the environmental planning department.

Noise and land use compatibility is the general term that has traditionally been used for the strategy to control noise at the receiver through the planning function. Two categories can be identified under this general concept. Different land uses can be compatible in terms of noise by their very nature (for example, an industrial plant adjacent to a highway). Other land uses can be made compatible by the design of the development, which may incorporate various methods of noise mitigation.

The first category typically deals with zoning laws. The second category might better be termed proponent noise mitigated development. This second method provides for incompatible land uses which are made compatible through abatement methods. The proponent of the development, be it a transportation facility or a residential area, is the one who must provide the abatement to make the land use compatible with the transportation noise. Both facets of land use compatibility are heavily dependent on the planning function. Further, it was found that the noise and land use compatibility strategy, while involving start up costs, can be maintained at a negligible cost to a local agency. The start up costs can be reduced for those local agencies located in states in which the state agency provides model noise and land use compatibility guidelines as well as technical assistance to local agencies. WSDOT can have a major, long-term effect on transportation noise in the State. The State Transportation Policy Plan delineated noise mitigation action strategies. And, while requirements for noise mitigation were deleted from the final Growth Strategies Act, the intent of the State Growth Strategies Commission and some legislators was to make environmental protection part of growth management. Noise control at the local level through land use planning and along existing roads has the potential to solve many of the state's noise problems.

The Phase I study, Comprehensive System-Level Noise Reduction Strategies [Bowlby et al 1991], recommended that WSDOT establish a funding category called "Environmental Mitigation and Enhancement Improvements," from which noise barriers for existing highways could be funded. Subsequent to the report, the federal ISTEA legislation of 1991 established the Transportation Enhancements Program. However, mitigation of existing highway noise was not listed as being eligible for funding. An effort to make it eligible passed the House as part of the Technical Corrections Bill for ISTEA, but died in the Senate due to the election recess. Some pro-environmental experts and planners opposed the action, worried that spending on noise abatement would threaten spending on other environmental areas.

A key finding of the Phase I report was that the demise of the USEPA noise program adversely affected state and local noise control programs. In 1991, an effort was made to reinstate program funding by Representatives Durbin and Schroeder. A fact-finding conference concluded that the legislation should not be simply a funding of the old office, but that improvements to the program should be included. Despite growing support for the Bill, Congress did not act on it for several reasons including Federal budget problems and the moratorium on new regulations that might inhibit growth. However the concept has merit. It is recommended that WSDOT support these efforts, including involving local Congressional representatives in providing support to Representatives Durbin or Schroeder.

This study also developed a framework for examining costs and benefits of the various strategies including looking at who pays, who benefits, what range in costs and benefits might be expected, and what are the cautions in using such data. There are difficulties--and, indeed, dangers--in trying to assign a "value" to every cost and benefit. There are just too many variables and case-by-case specifics that cloud interpretation of any given number. Nevertheless, this framework is one approach that WSDOT can use in sorting through the issues related to the various noise mitigation strategies.

CONCLUSIONS

SOURCE CONTROL

1. It is an oversimplification to assume that a given noise reduction strategy which is effective for one vehicle will necessarily be effective for a different vehicle.

2. Peak passby noise levels at highway speeds provide the vehicle noise information that is most important for transportation environmental noise assessment. Vehicle certification tests performed by vehicle manufacturers typically involve acceleration tests. These tests maximize the influence of engine, intake, drivetrain, and exhaust noise while minimizing the influence of tire noise.

3. The nature of noise reduction strategies employed by vehicle manufacturers is changing. To meet increasing demands for noise levels below those obtained by optimizing the design of components, researchers are studying the effect of improving the fit of components within a vehicle. For example, piston and cylinder tolerances when tightly controlled can reduce noise from piston slap. Similarly, crank shaft vibration, radiated as noise, can be reduced by more precise control of the machining and fitting of the main bearings.

4. Noise reduction strategies which depend on the fit of vehicle parts are expensive to implement and produce a temporary effect. Normal wear changes the fit and thus the amount of noise generated by the vehicle.

5. As manufacturers' attempt to address the demands for low noise vehicles increases, the problem of deterioration in noise performance will increase.

6. Strategies designed to reduce vehicle noise output are often in conflict with strategies designed to reduce vehicle energy consumption.

7. The marketplace is currently providing the necessary motivation for vehicle manufacturers to reduce vehicle noise levels. Additional legislation regarding vehicle noise levels is not justified at this time.

8. Trends in tire noise should be mentioned. An exception to conclusion number 7 could develop for tire noise. High performance tires designed with lower aspect ratios (sidewall height divided by tread width) tend to have larger tread contact patch areas and stiffer sidewalls, which result in increased noise levels. Should market demands cause a more widespread use of such tires, the noise emission levels from automobiles at higher speeds could be adversely affected.

RECEIVER CONTROL

1. Land use zoning, the first category of noise and land use compatibility planning, can be an effective, proactive means of noise control at the receiver for developing communities. However, this means of noise control has limited application for noise control in many communities in which the demand for incompatible land uses is disproportionately greater than compatible land uses in relation to the amount of land near a transportation noise source.

2. Proponent noise mitigated development is an effective, proactive means of controlling transportation noise at the receiver for developing communities.

3. Administrative costs for developing and maintaining programs for noise and land use compatibility planning are significant only during the start-up period for these programs.

4. Municipal noise control ordinances which focus on "nuisance noise sources" are complementary to noise and land use compatibility planning programs. The municipal noise control ordinances are the dominant means of noise control at the receiver for fully developed communities.

5. State technical advisors can provide needed support to counties and municipalities during both the development states and the operational states of noise control programs.

6. A state developed model noise and land use compatibility program can significantly reduce local agency program start-up costs and ensure consistency among local agencies in the state.

7. The building insulation strategy, consisting of various acoustical treatments to improve the noise reduction properties of buildings, can be an effective means of improving the interior sound environment, where other controls are not feasible or for land uses where outdoor activities are not an issue.

RECOMMENDATIONS

The following recommendations are summarized from the Implementation section of this report. While the recommendations are generally based on the findings of this Phase II study, the Phase I [Bowlby et al 1991] recommendations are foundational and in a number of instances integral to this study, as noted.

1. It is recommended that WSDOT support transportation noise control at the receiver for new development by promoting noise and land use compatibility planning at the state and local levels. The following two key elements from the recommendations listed in the Phase I report are included as part of this recommended support. First, WSDOT should assume a lead role in the development of noise barrier design specifications for residential developers. Second, WSDOT should assume a lead role in the testing and approval of proposed barrier materials and barrier systems.

2. It is recommended that WSDOT initiate the formation of a consortium within the state to produce a noise and land use compatibility planning guideline that could be adopted by local agencies.

3. It is recommended that WSDOT sponsor noise and land use compatibility planning workshops on control of transportation noise at the receiver. The workshops, which should include both information and working sessions, would be designed to support the process of implementing noise and land use compatibility planning at the state and local levels.

4. WSDOT should continue to support research of the implications of pavement type to road-tire noise.

5. It is recommended that WSDOT, allied with the Department of Community Development, follow and support any renewed efforts to fund the EPA Office of Noise Abatement and Control. This recommendation, based on the findings of

this study, is a reiteration of the recommendation to support the revival of an EPA noise program as given in the Phase I report. A revived EPA noise program related to both source control and land use compatibility, as well as expanded programs for noise control within the appropriate state agencies would provide technical and financial assistance to state and local programs, thus improving the noise environment.

6. It is recommended that WSDOT be aware of vehicle manufacturers' efforts to control vehicle noise. As long as the demand for quiet vehicles exists in the marketplace, no recommendation is made to pass legislation to force reduced noise levels in motor vehicles.

7. It is recommended that WSDOT monitor marketplace trends regarding automobile tire design. Should there develop a trend of increased use of tires that are inherently noisy due to wide tread designs, action to restrict the adverse effects of such widespread use may be required.

8. WSDOT should support noise research of the implications of alternative fuels to engine noise.

9. It is recommended that WSDOT continue to support the intention of the RCW 70.107 legislation. Further support should be given to update noise level standards and other rules in the legislation to be consistent with any noise and land use compatibility planning guidelines adopted in the future.

10. As recommended in the Phase I report, WSDOT should examine its level of staffing to ensure the capability to meet increased levels of effort to deal with several recommendations: a. responding to the action strategies for noise abatement in the 1991 State Transportation Policy Plan; b. inclusion of departmental noise experts in the regional transportation planning process, much along the lines of what is done with air quality; c. assuming the proactive role

recommended to responding to the interest generated in cities and counties as a result of the Growth Management and Growth Strategies acts; and d. implementing the recommendations for supporting the noise and land use compatibility strategies within the state as listed above. Expansion of activities beyond the current level of effort will require additional staff.

INTRODUCTION

THE PROBLEM

Interest in traffic noise abatement has been high among certain populations in the State of Washington. As the use of existing highways and streets in urban and suburban areas continues to grow, citizens will increasingly demand relief from this problem before even considering facility expansion to satisfy that traffic growth.

A research project was conducted by Vanderbilt University for WSDOT in 1990-91 titled Comprehensive System-Level Noise Reduction Strategies. (That project will be referred to as the "Phase I" study in this report.) The Phase I study examined the work done in traffic noise control over the past decade in a comprehensive manner to gain a perspective on the state-of-the-art and to recommend a course for future action. The results of that study included recommendations on where future efforts in WSDOT should be focused in terms of policy, legislation, implementation and research.

However, there remained a need to follow up on that work to take a more in-depth look at certain mitigation strategies, specifically vehicle noise reduction and community-based measures which could lead to specific implementation efforts by WSDOT, other Washington State agencies, and possibly the State Legislature.

BACKGROUND

Traffic noise analysis and control has traditionally been divided into three sections: source control, path control, and receiver control.

Source control efforts on a national level have focused on emission level regulations for newly manufactured vehicles (U.S. Environmental Protection Agency (EPA)) and on maximum allowable operating levels for motor carriers engaged in interstate commerce (U.S. Department of Transportation (USDOT)). State and local source control focused on enforcement of in-operation regulations, including state and local "nuisance" and "muffler" ordinances.

Path control efforts have concentrated on blocking the path by which the noise reaches the receiver. The focus has been the construction on the highway right-of-way of traffic noise barriers. By 1989, over 700 miles of noise barriers had been constructed in the U.S. by state transportation agencies. A useful reference on the subject on noise barrier design, construction maintenance, and programmatic issues is a National Cooperative Highway Research Program (NCHRP) synthesis published in 1992 [Bowlby, 1992].

Receiver control has traditionally been divided into two categories of items. The first includes administrative strategies such as zoning, building codes, subdivision laws, municipal ownership or control of land, and financial incentives for compatible use. The second category includes physical methods, such as site planning, sound insulation, and installation of barriers by private developers. Most of the strategies fall under the jurisdiction of local government. Federal research and development in the field was strong in the 1970s, but shifted to more of a maintenance effort in the 1980s as Administration priorities shifted. Some new FHWA research was funded but there was limited implementation of the results. In the 1980s, the EPA program, which also included a technical assistance program for state and local agencies, was phased out by the new Administration under the philosophy that noise control was a local problem not amenable to federal solutions.

However, interest in noise control remained high within many state DOTs and among many impacted citizens. The State of Washington saw the need to assess the state-of-the-art in traffic noise mitigation and where efforts should be focused in the future. The Phase I research project helped to satisfy those needs. Key literature was reviewed, and surveys conducted with state DOT noise analysts, and local environment noise control programs, and vehicle manufacturers. Areas of interest included abatement strategies, effective vehicle noise control, land use compatibility programs, and programmatic and administrative issues.

Findings of the Phase I study included:

1. the demand for noise abatement is increasing;

2. state DOTs need better sources of funds for retrofit ("Type II") noise barrier programs;

3. state and local noise control programs have suffered greatly since the end of the USEPA noise program in 1982;

4. truck manufacturers in the U.S. and Europe are successfully meeting the newly manufactured vehicle noise standards in their respective areas.

State of Washington initiatives were also examined in that study. Washington State DOT had included noise abatement as a priority area in its 1991 Transportation Policy Plan. The legislature had proposed a Growth Strategies Bill that called for comprehensive land use plan development (including noise control) by cities and counties. However, the final version of the bill did not include many of the important features of the earlier bill. Recommendations to Washington State DOT included the need for expanded staff, a dedicated source of funds for a phased retrofit abatement program and active involvement in implementation of the final Growth Strategies Act.

RESEARCH OBJECTIVES

A number of objectives guided the research for this study which builds upon the research conducted in Phase I.

A primary objective was to review the success of community measures to reduce the impact of transportation noise at the receiver. The main area of investigation for the community measures involved noise and land use compatibility planning strategies.

The second major thrust of this study was guided by the objective to review current strategies to reduce traffic noise at the source. Specifically, a review was to be made of strategies currently being researched by manufacturers to reduce noise for each major component of vehicle noise sources. Further, a review of the effort to reduce noise at the source in response to legislation was to be made.

An additional objective was to develop a comparison of the cost and benefit for systems-level abatement strategies. As research progressed, it became apparent that a comparison of the cost and benefit of strategies would not be valid. There is such a wide range in the cost of abatement type in terms of control of noise at the path as well as the number of people who benefit from such strategies. The same can be said for noise control at the receiver. Noise control strategies at the source involving specific design changes or modifications to vehicles result in widely varying affects on the overall noise level produced by given vehicles. In addition, the cost can vary from insignificant to very significant for a given strategy just depending on the vehicle and the design of the component being treated for noise reduction. A more useful alternative evolved in place of this latter objective. Specifically, a framework was to be developed which would provide key considerations necessary in considering the implications of choosing among alternative strategies for noise control at either the source, path, or receiver of the noise.

PROCEDURES

The information contained within this report was developed using a number of procedures. The discussion of noise and land use compatibility planning as well as local noise ordinance experience relied heavily on phone interviews with state and local agencies. Selection of the specific state and local agencies contacted for interviews was based largely on the results of surveys done under the Phase I project. In addition, some agencies were contacted as a result of an additional search to uncover those agencies with noise and compatible land use programs. Within local agencies, acoustical experts, and environmental planners, as well as consultants were contacted for interviews regarding local guidelines and procedures. Copies of both noise ordinances and noise land use compatibility guidelines were also reviewed. In addition, a trip was made to Ontario to interview in person a number of representatives from agencies involved in noise control from the provincial level to the city level.

Information on the reduction of noise at the source was gained through a number of sources. Information on the efforts to re-fund the EPA Office of Noise and Abatement Control was gained through contacts with Congressman Richard Durbin's office (Illinois) as well as noise experts associated with the symposium Combatting Noise in the '90's. This symposium was initiated by Congressman Durbin and organized by the American Speech-Language-Hearing Association.

The discussion of strategies to control noise from the major noise generating components of motor vehicles was based largely on a literature review of current research. In addition, researchers from vehicle and tire manufacturers were contacted to gain their perspective of noise reduction trends in motor vehicles.

SOURCE CONTROL

INTRODUCTION

This component of the three-part approach to transportation noise control represents the source, that is, the cars, trucks and other vehicles on the road. Significant strides to reduce vehicle noise have occurred since the early 1970s, both in the U.S. and Europe largely driven by government legislation and regulation. Legislation in Europe has led to more stringent noise levels required for U.S. vehicles. However, U.S. manufacturers continue efforts to reduce noise largely based on the competitive needs of the vehicle market in response to consumer demands for quieter vehicles. The need to compete in the European market is a further incentive for U.S. manufacturers to produce quiet vehicles.

The Phase I report for WSDOT, Comprehensive System-Level Noise Reduction Strategies, outlined the history of the U.S. and European legislation and regulations for reducing vehicle noise at the source. That report considered the major sources of vehicle noise and reviewed a number of strategies that are currently being used to reduce noise from these components. In addition, vehicle manufacturers were interviewed to gain insight in to their noise control programs, their level of staffing, current problems and future challenges.

The first objective of this study focusses directly on source control of traffic noise. Specifically, the research for this study explored the potential methods for each component of vehicle noise with emphasis on research that has been published since the "strategies" report. Vehicle noise has been divided into six noise producing components: engine, fan, intake, exhaust, transmission, and tires. While some workers in the field tend to use three categories--engine, exhaust, and tires--the use of the six components better reflects the usage in most of the current literature as well as being consistent with a National Cooperative Highway Research Project study (NCHRP Report 173) [Bolt, Beranek and Newman, 1976], which has been highly consulted by transportation professionals. That report contained a discussion of noise sources within motor vehicles, a description of models for predicting the noise levels for the noise components within the vehicle, and estimates of the noise reduction potential for these components. In the NCHRP report, five components were listed for automobiles. The category of transmission noise was not included for automobiles, but was recognized for trucks. However, in recent years, noise levels have been reduced to the point where transmission noise can no longer be considered negligible. The discussion of noise reduction strategies for each component of vehicle noise is considered in the following subsections.

ENGINE

Engine noise itself is a composite of many influencing factors. The complexity found in a specific engine is compounded by the variations found in engines of other designs. A common fallacy assumes that the causes of noise in one engine are in the same proportion in other engines. However, this assumption is not true even for engines produced by the same manufacturer. Further, the complexity is increased because of the relationship between structural vibration and noise output. This complexity can result in the measurement of a large portion of noise from one engine being contributed from the oil pan, for example, and in another engine of the same size, a much smaller percentage of the noise being contributed from the oil pan.

Many of the strategies discussed in the following sections pertain to improvements in the components being studied. However, the effect of the strategies on the noise emitted from the vehicle as a whole can vary for different vehicles. This variation is due to the interrelationship of vehicle components. For an example, the resonating frequency of an engine crank can combine with a newly designed drive line to produce a condition worse than what was experienced prior to the new drive line design. The original crankshaft design or the original drive line design might have actually been quieter when the two were coupled than in the second case. Therefore, not all findings from specific research efforts can be extrapolated to the overall vehicle noise performance.

In terms of categorizing the sources of engine noise and vibration as well as priorities for abatement, an emerging view of the problem is shown in Figure 1. As shown in this figure, specific sources can be identified within the moving parts of an engine. These sources act in terms of force and vibration generating components on the structural portions of the engine. The resulting vibration is transferred to the engine surface, which in turn radiates this energy in the form of noise to the

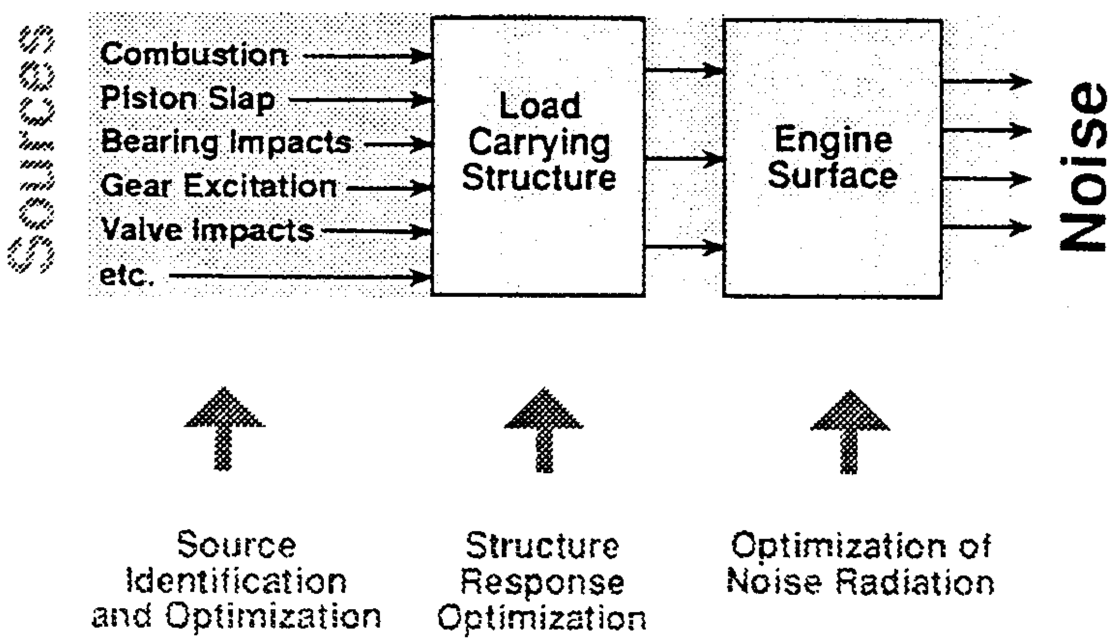


Figure 1. The noise generating process for engines; from Reference [Brandl, 1991]

environment. Such a view of the noise generating process also forms a structure for attacking the problem. The findings of recent research on the specific components producing noise excitation within the engine will be reviewed first.

Piston Slap

A long recognized source of internal engine noise is the presence of "piston slap". Recent studies have produced a more accurate and comprehensive description of the phenomena. A study by Vora and Ghosh [Vora and Ghosh, 1991], has provided the following information. Piston slap occurs when the travelling piston bounces from one side of the cylinder wall to the other. This bouncing can occur because of the need for clearance between the cylinder wall and the piston. The large load imposed upon the piston which fluctuates throughout the cycle, causes the movement of the piston within this clearance space.

Included in the phenomena of slap, which is often thought of as side-to-side movement, is also a tilting movement. This tilting movement occurs when the force on the top of the piston is not equally distributed with the result that the axis of the piston does not remain parallel with the axis of the cylinder bore. In effect, the top of the piston moves to one side of the cylinder bore and the skirt or bottom of the piston moves to the opposite side of the bore.

The study by Vora and Ghosh has produced experimental results to isolate a number of the mechanisms involved in the piston slap phenomena. It was found that the amount of piston slap varied according to engine load and engine speed. One potential solution derived from this research is the optimization of the wrist pin location. This location can be improved to better balance the forces acting on the piston and thus reduce the potential and severity for slap.

The piston itself as well as the connecting rod can affect the amount of noise within the engine. The mass of these reciprocating parts directly influences low order shaking forces in the engine [Albright and Staffeld, 1991]. No specific reduction in overall levels were attributed to the reduced mass of the reciprocating part by Albright and Staffeld.

Valve Train

Another engine component that has received attention for potential reduction in noise is the valve train. For some engines, as much as 55 percent of the engine noise is radiated from the upper one-third of the engine [Kalser et al., 1991].

There has been a trend in recent years toward production engines utilizing multi-valve combustion chambers. In the past, most vehicles have used two valves per cylinder, one intake and one exhaust. However, the automobile market has increasingly utilized four valves per cylinder, which results in a more complex valve train. In particular, tappet noise which results from that portion of the valve terrain that interfaces between the cam shaft lobe and the valve itself has been studied. By selecting different materials for the tappet, improvements have been realized.

In one study, aluminum alloy was used to increase the acoustic damping ratios for tappet noise. This technique was successful in reducing noise at low speeds [Kamiyama and Yasuhara, 1991]. High speed tappet noise has been reduced by redesigning the cam lobe profile to optimize the acceleration rates imposed upon the tappet.

In another study for certain engines where the cam forces showed high oscillation, a different strategy was utilized. Cam phasing in which adjacent lobes on the cam shaft were staggered in terms of their angular orientation by as much as 3 degrees, were found to reduce overall A-weighted engine levels by 2 to 2.5 dB at lower speeds and 1 dB at higher speeds. However, the phasing strategy used here in conjunction with an optimized cam lobe profile will not produce as dramatic results [Kalser et al., 1991]. This problem illustrates the fallacy of considering each strategy as an additive effect in terms of the overall result.

The strategy of rephasing the cam lobe fortunately has several side benefits. Improved valve timing accuracy is one of the benefits as well as improved durability of the valve train, cam shaft, and timing belt due to reducing peak forces and moments in the system.

Another strategy to reduce noise from the valve train has resulted in a redesign of rocker arm supports. Typically, engines have used stamped steel rocker arms supported by a spherical fulcrum. It was found that the friction from this support caused excitations which resulted in noise radiated from this area. Installation of a roller type fulcrum was found to reduce this friction and thus the noise from the friction induced excitations [Albright and Staffeld, 1991].

The study by Albright and Staffeld, in particular, has focussed on the results to be gained from noise reduction strategies that use existing technology [Albright and Staffeld, 1991]. In addition to the use of the roller fulcrum for the valve train as described above and the light-weight reciprocating parts (pistons and rods), a forged steel crank was compared with a cast iron crankshaft. The steel crankshaft was designed with a counterweight configuration from the one used with the cast iron crankshaft. As a result, the amplitude of the vibration generated was reduced compared to the cast iron crank shaft.

The rotation of a crankshaft in an operating engine results in bending of the crank shaft throughout the cycle. This bending results in vibrations which are finally transmitted as noise. In the Albright and Staffeld study, a bending damper was installed on the end of the crankshaft. The use of the damper reduced the flexural movement of the crankshaft allowing the use of tighter clearance on the main bearings. The tighter clearances in turn reduced the amount of "rumble" produced by the rotating crankshaft. The overall effect of this installation was to reduce the A-weighted sound level for the loaded power train by 1.5 dB at 3,000 rpm. The crankshaft is considered to be one of the major sources for vibration induced engine noise [Brandl, Wunsche, Gschveit, 1991]. One method of reducing vibration for the crankshaft is to stiffen the bearing support system. In the Albright study, the use of a system referred to as a full skirt girdle gave marginal improvement. By comparison, a one-piece bearing cap, also known as a beam bearing support, produced a 2.5 dB reduction in A-weighted sound level at low speeds (1,000 rpm). However, at higher speeds, this amount of reduction was not experienced.

An engine block of stiffer design was substituted for the standard production block in the Albright and Staffeld study. The increase stiffness of the block resulted in a 2 dB reduction in A-weighted sound levels at 3,000 rpm for a loaded drive train. Reduction of the engine clearances as a whole are considered to promote a quieter operating engine. However, reducing engine clearances is a difficult process. Production costs are increased due to the need for precisely controlled machining environments and fixtures used in positioning and prestressing components. In the Albright and Staffeld study, powder metal valve guides were used with reduced clearances in an effort to further reduce valve train noise. The individual effect of this step, however, was not measured.

Further reduction for the engine in the Albright and Staffeld study was achieved through the use of a oil pan which was modified with reinforcing ribs. The installation of this oil pan produced a 1.5 dB A-weighted reduction at 3,000 rpm. However, the ribbed oil pan could not be used with the one-piece bearing cap beam described above. Therefore, one or the other methods must be selected when this type of conflict occurs.

The stock rocker covers were exchanged for a ribbed rocker cover which used gasketing material to isolate the rocker cover from the engine head. This strategy produced an A-weighted level of 4-6 dB reduction in the noise emitted from the rocker covers. The engine under study was of a 1980s design. All of the modifications were considered to be current technology and cost effective. Table 1 shown below gives a summary of the noise reduction strategies and their effect on overall noise levels. The table indicates that some modifications produced no change or actually increased magnitudes. This study concluded that the resulting reduction in levels could serve as attainable "targets" for future production level design refinement. In another study, it was suggested that in a typical engine the oil pan and the block can radiate more than 50 percent of the total engine noise [Busch, Maurell and Meyer, 1991]. The authors described a scheme for predicting the effects of new block designs. In particular, open deck designs, which are used to take advantage of certain types of casting methods, were compared with closed deck designs. In addition, various bearing support designs were evaluated. While no specific noise level reductions were projected for various strategies, this study is typical of many which show the current commitment to explore engine redesign at a very fundamental level in light of noise reduction goals.

Currently, the most restrictive vehicle noise legislation exists in Europe. Figure 2 is a summary of the levels required by this legislation. Brandl has suggested the amount of noise reduction required to reach the 1996 European Economic Community (EEC) levels. The reference for classifying engines is the A-weighted sound level at 1 meter from the engine [Brandl et al., 1992]. It has been found that in order to meet

Table 1. Effect of Individual Modifications to Overall Engine Noise Levels. NVH refers to Noise, Vibration, Harshness. (Albright and Staffeld, 1991)

Hardware or Process Modification	Major NVH Advantages	Sound Power Change dBA RPM 1000	3000	Confidence Estimate
Forged Steel Internally Counterbalanced Crank	Lower mount vibration, Subjectively better in vehicles	+1.0	-1.0	2
Supercharged Block	Increased powertrain bending frequency	-0.8	-0.5	2
Bearing Beam	Lower mount vibration through speed range	-2.0	-0.2	1
Crankshaft Bending Damper	Lower mount vibration, Improved sound quality	0	-1.0	2
Lightweight Pistons Pins and Connecting Rods	Reduced low order shaking forces	0	0	3
Roller Fulcrums	Quieter valvetrain	-0.2	-0.1	1
Powder Metal Valve Guides With Tighter than Production Clearance	Better oil retention, NVH effects minimal	0	0	3
Quiet Fuel Injectors	Improved idle sound	-0.1	0	3
Ribbed and Vibration Isolated Rocker Covers	Suppress valvetrain noise	-0.3	-0.2	1
Production tight clearance and special machining operations to insure round crank and piston bores	Lower noise levels, Better sound quality,	-2.5	-0.8	3

Confidence Estimate
(1) Based on measurement, High confidence
(2) Extrapolated from measurement, Medium confidence
(3) Best judgement based on experience

Accelerated Pass-By Noise	Passenger Car	Van	Truck < 150 kW	Truck > 150 kW
EEC	77	79	83	84
Switzerland	75	77	82	84
Japan	78	78	83	83
Austria Low Noise Trucks	—	—	78	80
EEC 70/157 1996	74	76	79	80

Figure 2. Vehicle pass-by noise level requirements for Europe and Japan; from Reference [Brandl, 1991]

current EEC requirements an engine must meet a limit of 95-97 dB. In order to meet the 1996 limits, an engine with a lower noise limit of 93-95 dB will be required. This reduction required for engine noise assumes that all other vehicle noise sources are reduced by a proportional amount.

Brandl considers existing internal combustion engines, without special noise reducing features, to be incapable of meeting these requirements. The current average 1 meter A-weighted sound level is between 97 and 102 dB. Further, vehicle manufacturers have been forced to use noise reducing measures such as shielding or enclosures of the engine to meet current requirements. Therefore, meeting the future requirements will require more advanced technology.

Figure 3 gives a summary of the requirements that are needed to meet the future legislation. Note that the conventional strategies are shown on the left part of the figure and follow the concepts described above. As indicated in this figure, to reach the most stringent legislation requirements, new and unconventional concepts will have to be employed. This need is based on the observation that the application of part-by-part analyses (such as described above), can result in an engine with a 1 meter limit in the range of 95-98 dB. Again, this reduction is with current production and cost feasibilities as well as current technology. To reach the 93 dB level, then, will require the unconventional engine concepts.

The unconventional strategies envisioned by Brandl focus on the load carrying structure and the engine surface. Two major design concepts were described by Brandl [Brandl, 1991]. Since the lower end of the engine block which comprises the main bearings used to support the crankshaft are a major contributor of overall engine noise, design attention was focussed here. The proposed design involves the isolation of the main bearings. A material used to dampen and reduce the transmission of vibrations from the crankshaft and therefore the main bearings, is used between the main bearing support and the block. The second step, which involves the engine surface, is approached in this suggested design by using an outer engine structure. In effect, an inner engine structure and an outer engine structure type of design allow the possibility of introducing a damping medium or attachment method that interrupts the vibration transmission path.

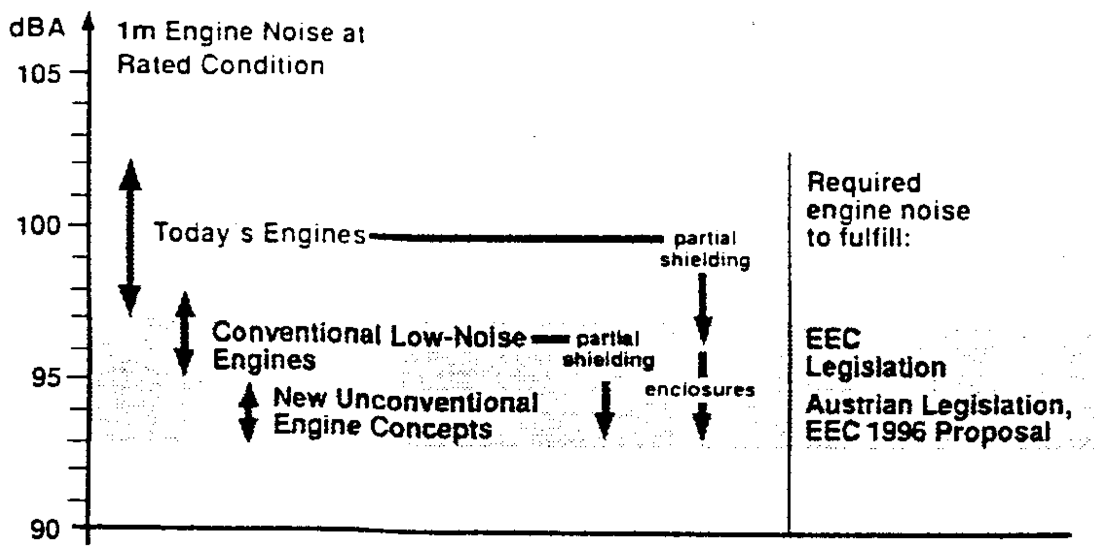


Figure 3. Reduction in engine noise levels to meet requirements of legislation; from Reference [Brandl, 1991]

Brandl sees the above strategies as necessary to meet the new requirements. Since shielding and enclosures have already been used up to this point, he does not see their benefit to be adequate to meet the new standards. He suggests that if the basic design of the engine can be improved to reach the standards, then the use of enclosures or shielding can be a backup for any engine that is marginal or for any future additional restrictions from legislation.

Noise reduction through the use of shields and enclosures has been evaluated in a study by Fingerhut and Feitzelmayer [Fingerhut and Feitzelmayer, 1989]. This study of one particular application of an enclosure on an automobile concluded that the enclosure was not effective. While noise was reduced, the increased heat confinement due to the enclosure had a number of negative results. Passenger discomfort was increased which resulted in increased use of the air conditioning system. This use resulted in poorer fuel economy, increased air pollution, and increased use of the cooling fan. The increased used of the cooling fan more than offset any noise reduction realized by the enclosure. This pessimistic view of enclosures is not shared by all researchers, however. While there are maintenance problems and cooling problems, enclosures have been used successfully in Europe to reach legislated noise reduction levels [Brandl, Wunsche, and Gschveit, 1991].

COOLING FAN NOISE

Early studies have shown cooling fan noise to be a significant problem. For trucks, noise levels from the fan were often comparable to those of the engine itself [Cummins, 1972], [International Harvester Company, 1973], [Johnston, GM, 1973]. In NCHRP Report 173, the components of cooling fan noise were described as steady blade forces, vortex shedding, inlet turbulence, and interference noise [NCHRP 173, 1976]. Since that report, researchers have continued to analyze cooling fan noise. A recent study by Cudina has explored the effects of rotor blade angle, rotor tip clearance, and axial clearance for cooling fans [Cudina et al., 1989]. Simultaneous measurements of pressure differentials for different fan blade configurations were compared based on resulting noise levels. Fan rotor blade angle has a significant effect on noise levels. It was found that some stock fans tested were able to reduce A-weighted sound levels by

1 dB while increasing efficiency by 2 to 5 percent. This study resulted in an optimum blade angle for the particular fan. It was found that tip clearance for the fan blade (the clearance between the tip of the fan blade and the stader housing surrounding the fan) affected noise levels. Increasing the rotor tip clearance dramatically deteriorated both the aerodynamic and noise characteristics of the cooling fan. On the other hand, the effect of the axial clearance between the fan and other vehicle components had a rather small effect on fan performance and noise levels.

In addition to optimizing the aerodynamic characteristics of fans, vehicle manufacturers have resorted to other strategies. Engine cooling does not require fan assist under all operating conditions. The need for fan operation depends on load and outdoor temperatures, as well as the air flow through the radiator. At cruising speed, air flow is generally high enough to provide sufficient cooling for most engines. Vehicle manufacturers have used thermostatically controlled or viscous controlled clutch type fans to reduce fuel consumption and noise levels. Therefore, under a highway operation, most light trucks and automobiles do not have significant levels of fan noise. Heavy trucks may have large contributions of fan noise depending on the type of fan used and whether it can be declutched or not.

INTAKE AIR NOISE

The mechanisms of intake air noise have been studied for many years. Historical attempts to reduce air intake noise have shown moderate success. However, intake air noise has not received much attention in recent times, where interest in reducing overall noise levels has been high. As other components of the engine have been designed to produce lower noise levels, the relatively minor noise source found in the intake system has become more noticeable. The challenge of noise reduction of motor vehicles includes both the time required for the application of existing technology and the technology itself. In many cases, the experimental work of reducing noise levels becomes a great burden to a manufacturer when trying to put a new design into production. Nishio and others have recently developed a system to reduce the development time for low noise air intake systems [Nishio, Kohama, and Kuroda, 1991]. A simulator was developed to evaluate intake noise at an early stage of engine development. In addition to shortening the lead time for intake design, several other advantages were realized. Historically, noise reduction in the intake system has often compromised volumetric efficiency of an engine. Reduced volumetric efficiency can result in increased fuel consumption and pollutant emissions that affect air quality as well as engine performance. The improved simulation technique described by Nishio and his colleagues allows the simultaneous pursuit of both goals.

Intake noise is generally made up of low-frequency sound, generally less than 600 Hz. The noise levels tend to be higher under conditions of high acceleration rates. Intake noise, therefore, has less impact at the roadside since most traffic noise occurs under cruise conditions. While somewhat less important under those conditions, intake noise is still present during passing and in stop-and-go traffic conditions.

The most successful strategies for reducing intake air noise involve the use of Helmholtz type resonators. The resonators are attached to the duct work between the air inlet and the engine. The resonators are installed perpendicular to the duct work and are generally frequency-specific. The dimensions on a resonator dictate the frequencies that will be attenuated. The new simulation methods, as discussed by Nishio, allow fine tuning of the resonator position, which is critical for noise reduction. In addition, this simulation technique makes it feasible to conduct studies in the reduction of wide band noise. In order to effectively reduce wide band noise, more than one resonator, each of different size, is often required.

The reduction in noise levels that result from the use of resonators is highly variable. The reduction can amount to as high as 30 dB at specific engine speeds and frequencies. However, the same resonator may produce no reduction at other engine speeds or at different frequencies. Therefore, it is not possible to provide a reduction in noise levels for this strategy for all engines and for all operating conditions. Nonetheless, it is important to note the success of the strategy in broad terms. Using current technology, intake air noise can be reduced to a level consistent with the other component noise sources in a motor vehicle.

EXHAUST NOISE

Unsilenced exhaust noise totally dominates over all other components of vehicle noise. Mufflers of various design have been standard equipment on internal combustion engines since their beginning. Historically, mufflers or exhaust silencers have been developed through a combination of art and science. Ultimately, a cut-and-try method was required to produce acceptable results. However, what was once considered acceptable performance in a muffler is no longer considered so in light of more recent requirements to lower overall vehicle noise levels. As a result, a great deal of effort is being expended to optimize principles of exhaust silencing that have been in use for years.

Mufflers generally have been classified as passive silencers. The units have no moving mechanical parts or electronic parts. They rely on several physical principles to attenuate noise. Expansion chambers are used to reflect unwanted noise back to the source. The abrupt change in area ratios for exhaust flow through the muffler cause the reflection to occur. Expansion chambers are particularly effective for low frequency noise. Mid-frequency range noise can be attenuated by using perforated sections within the silencer. The perforated section produces an inertance that coupled with the compliance of the surrounding cavity effectively attenuates sound. Exhaust noise typically shows a number of noise level peaks that are frequency-dependent. The mechanisms used to attenuate these peaks depend on principles of resonance. The application of these principles often produces strong attenuations which are also frequency-dependent. An example of this is shown in Figure 4.

For the case of the perforated muffler sections, the attenuation peaks can be shifted to higher frequencies either by increasing the number of holes in the perforated section or by reducing the cavity diameter [Morel, Morel, and Blaser, 1991]. Morel, Morel and Blaser have developed models to accurately predict the attenuation that can be expected under a variety of conditions. To accurately model exhaust noise, complex modeling techniques would need to be applied, which may achieve amplitudes above 140 dB. However, the researchers have demonstrated good performance of simpler models for the majority of applications.

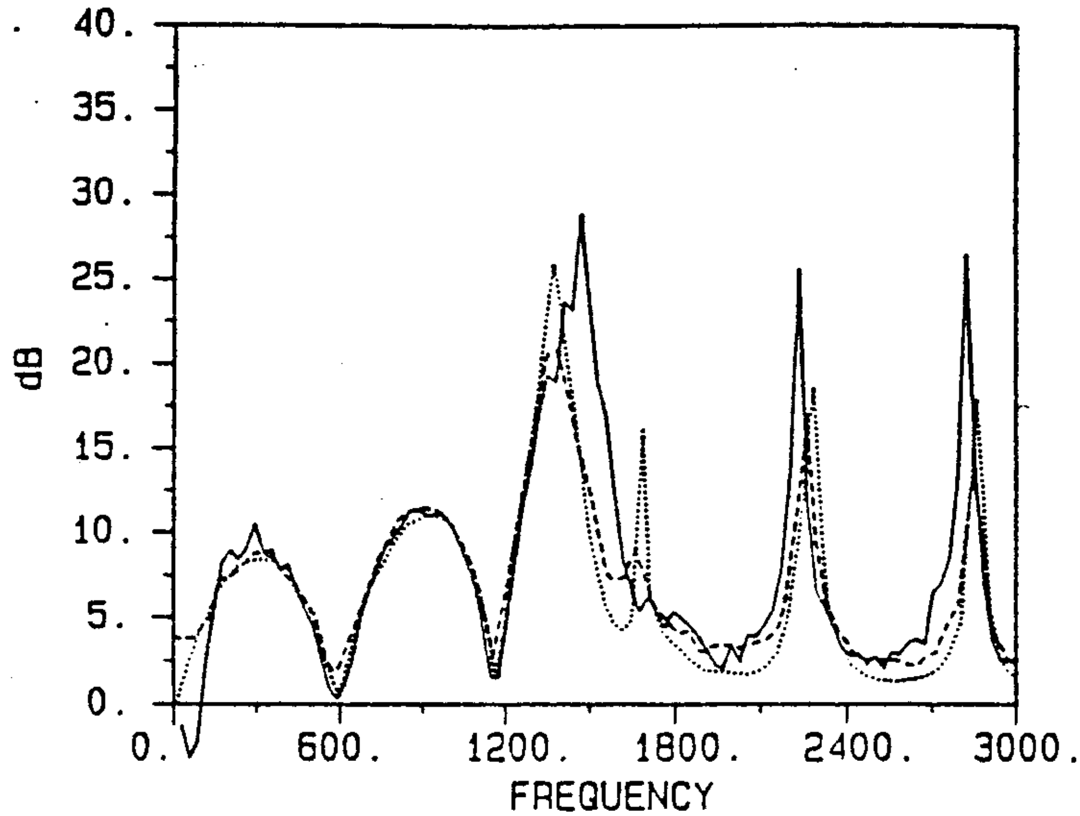


Figure 4. Frequency-dependent noise peaks for exhaust noise; from Reference [Morel, 1991]

The current trend to reduce noise in passive muffler systems is to optimize the ability of these systems to attenuate exhaust noise. However, there is a limit to the effectiveness of conventional muffler systems. Further, the principles used in attenuating exhaust noise in conventional systems have an adverse effect on engine performance. The flow of the exhaust gases through the system is met with resistance in the muffler. This resistance produces the pressure build-up in the system commonly known as back pressure. Back pressure can result in a build-up of heat in the exhaust system, which is already at high levels due to the presence of catalytic converters in most spark-ignition engines. Higher temperatures in the system can result in burnt valves for engines experiencing high restriction operating under heavy loads. Further, restrictive exhaust systems limit power output and correspondingly increase fuel consumption. As conventional exhaust systems have reached their practical limit, exhaust silencing research has turned to another method, known as active noise cancellation.

The principle of active noise cancellation has been understood for many years. A noise source has its own signature that is defined by the levels of noise found throughout the frequency. The signature also has a characteristic phase. Since the noise can be described by levels at the different frequency bands throughout the range, it follows that the noise can be reproduced by generating the same levels for the same frequencies. If one considers a simple wave, a sine wave for an example, it can be characterized by a frequency and an amplitude. Another wave of the same amplitude and frequency, but shifted out of phase by 180 degrees and superimposed, will cancel the original wave. This is the principle used in active noise cancellation. Though this principle has been understood for many years, it has only recently been feasible for practical applications. The advent of digital signal processing and high speed electronics has enabled designers to sample noise, construct the identical noise pattern, and then superimpose this pattern at the out of phase timing such that the original noise is attenuated through cancellation.

A recent study involving the application of an active noise cancellation system for exhaust noise has been successfully completed [Arnold, Frazer, and Hoge, 1991]. This study involved the use of a large Detroit Diesel 6 Victor-92TA industrial engine. The use of a diesel engine in this study is significant. Diesel engines as a whole are louder than spark ignition engines. This particular engine was tested in its unmuffled condition and produced sound levels approximately 20 dB higher than produced by automobile spark ignition engines. The engine studied was designed for a generator application. As such, the engine would normally operate at constant speed. It was determined that this would serve better as a first step in active noise muffler design before proceeding to a variable speed engine. The 6V-92TA is used in a number of applications. For example, it is probably the most common engine used in municipal buses.

The active noise system required a very high-powered noise generating equipment to cancel the exhaust noise from the diesel engine. It was also found that the directionality of high-frequency sound made it difficult to match with sound produced from the speakers in the test case. Further, these speakers could not be located in the exhaust stream. This problem only adversely affects noise cancellation for frequencies above approximately 500 Hz. In order to produce a system that reduced the levels both above and below 500 Hz a passive low-restriction, conventional muffler was used for the high-frequency noise. It should also be noted that only periodic noise which is generated by the repetitive firing of each cylinder in the engine can be reduced through the cancellation process. Other noise, such as that which is generated through turbulence in the system, is of a random nature and cannot be reduced through the cancellation process. After several phases of testing, Arnold, Frazer and Hoge have found encouraging results for the active noise cancellation system [Arnold, Frazer and Hoge, 1991]. The system, including the passive noise reduction element, reduced overall A-weighted noise levels from 5 to 13 dB compared to a conventional baffle passive muffler. Further, a significant improvement in fuel economy resulted from the lower exhaust flow restriction. Also, the study demonstrated the potential for reduced packaging size for the silencing system compared to conventional systems. This study also demonstrated that the active element in the system must be significantly more powerful than the units that might be used in light duty gasoline engine applications. Further, it was suggested that very high output diesel engines may produce sound at harmonics of the firing frequency. Should this indeed be the case, the aid of additional passive elements to assist attenuation of the exhaust sound below 500 Hz may also be required.

While this study has produced very encouraging results, it also demonstrates the complexity of the problem. More research is needed to demonstrate its effectiveness for broader applications, particularly variable speed engines found in highway vehicles.

Eghtesadi and Gardner have also applied active noise technology to an automotive exhaust system [Eghtesadi and Gardner, 1989]. The system used two 4.5-inch, low-frequency, high-temperature, acoustic transducers to generate the sound waves used in the cancellation process. The application used a GM 5.0 liter, 8-cylinder engine. The active noise muffler was attached to a 2.5-inch exhaust pipe. The transducers were capable of producing 115 dB sound pressure level in the frequency range of 30 Hz to 350 Hz. The system was powered by the on-board 12-volt electrical system. The test vehicle was mounted on a chassis dynamometer and operated at various engine speeds under load. The active noise system was designed to attenuate the periodic, repetitive pressure waves generated by the engine. The random components of the noise spectrum, which are produced by turbulence and other factors, could not be attenuated with the active noise system. To reduce the levels for these components, a low restriction resonator chamber was used in tandem with the active noise system.

Figure 5 shows four test configurations involved in the study. The "NCT OFF" was the levels measured without any noise attenuation. The "NCT ON" mode involved active noise attenuation only. The "STD.system" were the noise levels experienced with conventional passive muffler system installed as original equipment on the automobile. The curve "NCT ON plus resonator" represents the noise levels with the active noise system and the low flow resonator. The active noise cancellation system with the resonator successfully reduced levels over most of the operating range compared to the standard system. In addition, exhaust back pressure, which is produced by the restrictive construction used in passive elements found in conventional mufflers was reduced significantly. Figure 6 gives the comparison of back pressure for the systems tested at various flow rates.

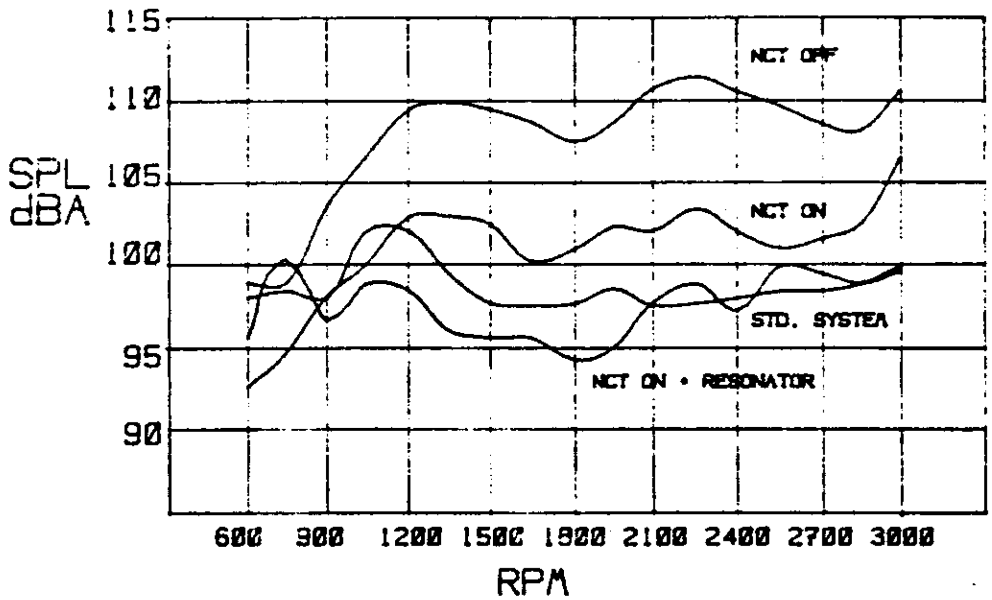


Figure 5. Exhaust noise levels for alternative exhaust systems; from Reference [Eghtesadi and Gardner, 1989]

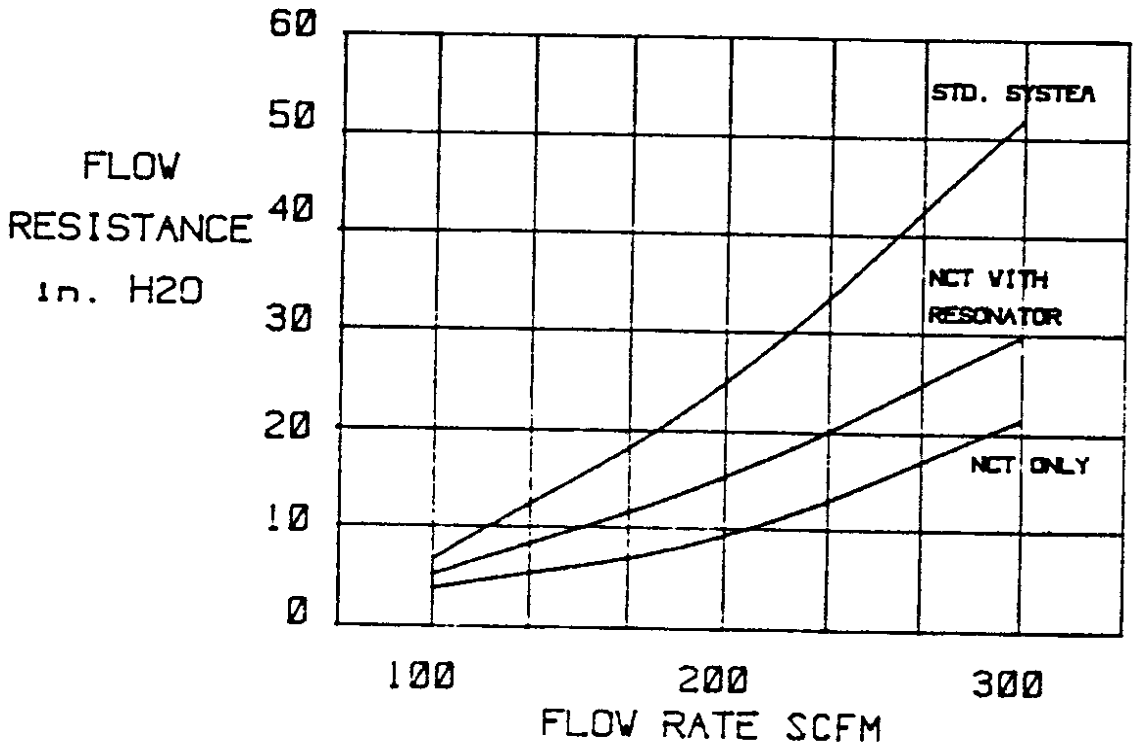


Figure 6. Exhaust back pressure for alternative exhaust systems; from Reference [Eghtesadi and Gardner, 1989]

TRANSMISSION NOISE

Truck transmission and differential gear noise have been recognized as significant component sources for a number of years. However, the transmission and differential noise in automobiles were considered inconsequential until recently [NCHRP 173]. The reason transmission noise is receiving increased interest in automotive applications is two fold. First, the process of reducing vehicle noise levels in the other components of the vehicle has brought the levels down to the point that the transmission noise is becoming a factor. Second, the effort to reduce fuel consumption in automobiles has resulted in reduced weights for drive line components as well as higher rotational speeds in many cases. The higher speeds are the result of operating smaller engines at higher rotational speeds through transmissions with larger gear ratios, as well as smaller tire diameters. The net effect of these changes is to place increased importance upon the gear noise.

A major source of gear noise is due to machining error. This produces the static transmission error which is most pronounced at the mesh frequency [Kahraman and Singh, 1989]. This mesh frequency is dependent on the ratio of the diameters of the two gears operating in mesh. The sources of error are small errors in the surface of a gear tooth or misalignment errors. These errors can produce the excitations that contribute to the large peaks typically found at the mesh frequency.

Another source of gear noise results from backlash. Backlash is the necessary clearance that is designed into the gear to prevent gears from binding and to provide space for lubricant [Spotts,1961]. Noise produced by the presence of backlash is most important under large dynamic loads [Kahraman and Singh, 1989]. Large fluctuating loads can cause the teeth to bounce back and forth in the clearance space thus producing the vibration that ultimately is radiated from the transmission case. For transmissions used in heavy trucks, the mesh frequency is typically between 700 and 1,000 Hz. For high point type gear sets which are found in drive axles, the major frequencies are between 300 and 800 Hz [Hirasaka and others, 1991]. Fingerhut and Feitzelmayer have emphasized the importance of designing such that the exciting frequencies in the gear meshing process do not coincide with drive shaft resonant frequencies [Fingerhut and Feitzelmayer, 1991].

This interrelationship of components is also true for the engine and drive line matching. Vibrations transmitted from the engine can be increased or reduced depending on the vibration characteristics of the drive line. This interrelationship can be dealt with more easily in automobiles. For truck drive lines, the components are specified by the customer. The customer specifies the transmission, drive axles, as well as the engine. Some models of transmissions are noisier than others. The drive line system as a whole then cannot be optimized for a particular application [Fingerhut and Feitzelmayer, 1991]. Fingerhut found in one study that an 8 dB range in noise levels occurred for the gear noise dependent on the gear selected. This noise was primarily radiated from the drive shaft. Fingerhut has experimented with dampened drive shafts and encapsulated drive shafts to reduce the amount of vibration and the noise resulting from the vibration.

Schwibinger has experimented with dampers installed on drive shafts [Schwibinger et al., 1991]. He has measured both torsional and bending vibrations which result from fluctuating forces in the engine and the cardan joints in the drive line. The type of dampers he used were dual mass dampers. The torsional dampers reduced torsional amplitudes by 60 percent compared to conventional dampers. The dual mass bending damper reduced resonant vibrations amplitude between 50 and 70 percent compared to conventional dampers.

Hirasaka has studied high point gear sets [Hirasaka et al., 1991]. He has suggested one solution to the interrelationship between the gear noise and the drive shaft interaction. This solution is to use a low torsional rigidity drive shaft. The effect of using such a drive shaft is shown in Figure 7.

Johnson and Hirami have conducted a thorough study of transmission noise [Johnson and Hirami, 1991]. They focussed on methods to locate the source of the gear noise as well as the causes the gear teeth interfaces. The impacts that occur between gear teeth at the input of the gear mesh appear to be a dominant cause of noise known as gear rattle in the transmission. A careful analysis was done to relate the magnitudes of the transmission noise with respect to the rotational position of the engine crankshaft.

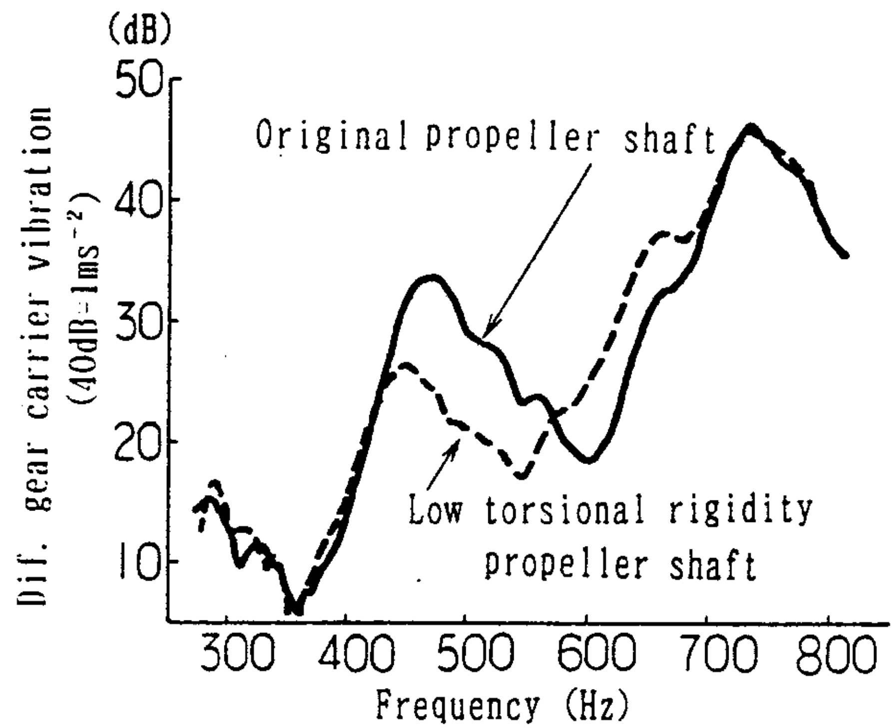


Figure 7. Effect of substituting a low torsional rigidity propeller shaft on gear vibration; from Reference [Hirasaka, 1991]

The studies reviewed above suggests several trends. Weight reduction trends in automotive design will make drive line noise reduction more difficult. The strategies used in the near future for drive line noise reduction will most likely include tighter manufacturing tolerances, optimization of the vibration characteristics between the various subcomponents of the drive line, and the use of effective dampers, and possible encapsulation of some components.

TIRE NOISE

Tire noise has been considered a significant component of vehicle noise for the last 20 years. As the noise contribution from other vehicle components has been reduced, tire noise has emerged as the dominant noise component at highway speeds as stated in the following.

> "Tire/road noise generated by modern vehicles already dominates over all others at a constant speed of 60 Km/h (40 mph) in high gear" [Reese and others, 1984].

In another paper it was stated:

> "Presently, 'quiet' tires produce noise levels about 8 dB(A) above a quiet or acoustically acceptable truck tractor" [Clapp and Eberhardt, 1984].

In spite of continued efforts to reduce tire noise, this component of vehicle noise still dominates. Further, there is a wide variation in the noise generated by tires. Tests on the same vehicle using tires of different manufacturer and design can produce a range in vehicle drive-by A-weighted sound levels of 10 dB [Sandberg, 1991] [Fingerhut and Feitzelmayer, 1991].

Mechanisms of Tire Noise Generation

Muthukrishnan suggests that the interaction between tread and sidewall properties affects tire noise significantly. That is, noise level depends on the tread and sidewall conditions taken together [Muthukrishnan, 1990].

The specific acoustical phenomena involved in the generation of tire noise is summarized as follows. The impact of the tire tread blocks or other elements of the tread upon the road surface induces vibrations caused by small deflections in the tread. This source of noise is referred to as the radial vibration mechanism.

A second mechanism is referred to as air resonant mechanism. There are three parts to this mechanism. The first mechanism is pipe resonance. It is thought that the grooves of the tire tread form an "air tube" in which standing waves can be present. Second, the volume of air in a cavity within the tire tread can act as a resonating spring in a Helmholz resonance fashion. The third type of air resonant mechanism has been referred to as pocket air-pumping. Air may be trapped in small cavities on the tire surface as the tire contacts the road surface. The air is compressed then expanded with such speed as to cause a large amount of turbulence and thus noise.

A third category of noise generation mechanism is referred to as adhesion mechanism. The adhesion mechanism is made up of two parts. The first part is a sticking or slipping motion between the tire and the road surface which produces tire vibrations. The second part of the adhesion mechanism occurs when the rubber sticks to and then is released from the road surface in a vertical fashion.

In addition to the three general mechanisms described above, there are other phenomena that may influence the amplitude of the noise generated. There may be a "horn effect" that is produced at the leading and trailing edges of the tire. The horn is formed by the curvature of the tire and the road surface and may cause an amplification of noise generated at the interface between the tire and the road surface in the directions fore and aft of the tire. On the other hand, the sound level may be reduced in the presence of a road surface that has sound-absorbing characteristics. In addition, the stiffness of the road may affect whether the sound is amplified or attenuated. The effect of stiffness has been referred to as the mechanical impedance effect. The radial vibration mechanism is thought to be limited to lower frequencies, generally below 1000 Hz, while the air resonant mechanism and the adhesion mechanism would tend to occur above 1000 Hz. This summary of tire noise generation mechanisms has been taken from [Sandberg, 1992a].

Nakajima has developed a rigorous method of tire noise modeling. He has concluded that side wall vibration is the main cause of truck and bus tire noise at low frequencies [Nakajima, 1992].

Operational Factors

New tires can be tested and rated for the potential contribution to noise levels on the highway. However, factors involved in the operation of the tires, which are beyond the control of the manufacturer, also have an influence on noise levels. In the early 1970s, it was observed that the noise level for tires changed as the tires experienced wear. Dougherty reported that as tires wore, in general the sound level increased until 25-50 percent wear had occurred. As tire wear continued, sound levels progressively decreased through the remainder of the tread life. Leasure and Bender suggested that the decrease in noise levels with increasing wear were explained in terms of tread design. Any air trapped in pockets on the tread would produce noise in the sealing/unsealing process. As wear progressed, less air was trapped within each pocket on the tread [Leasure and Bender, 1975].

It was also found that the road surface could affect different treads in different ways. That is, some road surfaces produced greater tire noise with one type of tread and less noise with another type of tread. Further, this effect could change as tire wear progressed [Leasure and Bender, 1975].

Mixed results have been reported on the effect of tire loading for the amount of tire noise generated. Leasure and Bender suggested that the sound level increased with load, particularly with loud tread types. There was not as much difference in sound levels under varying loads with rib type tires [Leasure and Bender, 1975]. On the other hand, Muthukrishnan reported that load changes did not effect noise levels significantly [Muthukrishnan, 1990].

Muthukrishnan also reported that changing tire pressure can increase or decrease sound levels depending on the load of the tire. In some cases, increasing the pressure would increase the noise level but only at low loaded conditions, see Figure 8. This interrelationship of pressure and load was also noted earlier by Corcoran [Corcoran, 1972].

Earlier research had indicated that the temperature of the tire and road surface had little effect on the noise level produced [Corcoran, 1972]. However, more recent information has indicated that there is a relationship between the temperature of the tire and road surface and the sound levels produced. Sandberg cites a Swedish study that

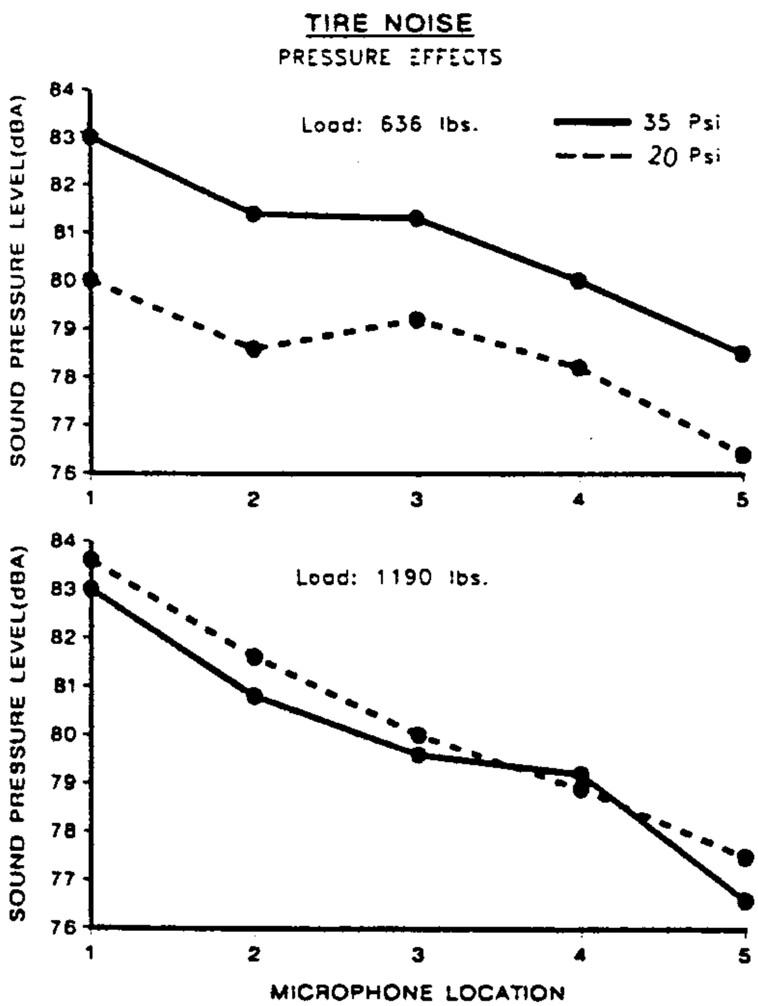


Figure 8. Effect of pressure on automobile tire noise; from Reference [Muthukrishnan, 1990]

concluded that A-weighted sound levels from the tire/road noise are reduced by approximately 1 dB/18° fahrenheit increase in temperature [Sandberg, 1991].

Thurman reported, in an earlier study, the effect of truck bed clearance on tire noise. The bottom of the truck bed was installed at two different heights above the tires. The study concluded that there was no significant difference due to this change in clearance [Thurman, 1974].

Design Factors

In an early study, Thurman distinguished between two types of tire noise. The first type of noise was referred to as background noise while the second type was referred to as tonal noise. The background noise was found to be independent of the tire design and generally produced levels 5-10 dB below tonal noise level. The tonal noise was found to depend upon the length of repeating tread patterns [Thurman, 1972].

Tread design for tires has been recognized as a significant factor in the noise produced by the tire. The main purpose of tread patterns in tires is to allow for water drainage. The theoretical lower limit then to tire tread noise would be the case of no tread or a smooth tire. Leasure and Bender used three categories of tread design. The category producing the highest noise level was termed the "pocket design". This design included many air spaces on the surface of the tread in which air could be trapped as it was compressed between the tire and the road surface. The second category was termed "cross bars". This name was given because of the orientation of large lugs in the tread located perpendicularly to the side walls. The third and quietest category was termed "rib". Ribbed tires were generally used on non-drive axles for heavy trucks.

Apart from the tread design itself, the consensus in the tire industry was that the tread pattern (described in terms of pitch lengths or tread element sequencing) must be produced on the surface of the tire in a random fashion. This randomness in repeating patterns is designed to broaden the frequency spectrum of the noise produced by the tread, thus lowering or eliminating tonal peaks [Leasure and Bender, 1975] [Oswald and Arambages. 1985].

Oswald and Arambages reported extensive experimental work with tread patterns. Patterns with various groove depths, groove angles, and groove shapes were tested for the impact on noise levels. It was found that forward-based grooves placed at an angle of approximately 45° produced lower noise levels than grooves at other angles. This, of course, required that tires be mounted on the vehicle in the correct direction in order to realize the benefits of lower noise levels. It was also found that the grooves should be relatively straight, not containing curves with abrupt directional changes. The groove should begin with a sharp point on the inside rather than a blunt beginning. Further, grooves of varying lengths on the tires were found to be beneficial in reducing noise levels. Lugs were tested at various angles and found that they should be at least 35° measured from the perpendicular to the side wall to produce the least amount of noise [Oswald and Arambages, 1985]. Ejsmont and others have confirmed the Oswald study and added that the groove length appears to affect the frequency of the resonance in the pipe and thus the tire noise produced [Ejsmont, 1984].

In a recent study sponsored by Washington State DOT, the influence of tire studs on tire/road noise was determined. Noise levels near the tire/road interface were measured for three tire types at 15 different roadway locations. The comparison of the same tires with and without studs indicated that the installation of studs produced an increase in noise levels from 2.2 dB to 4.2 dB [Chalupnik and Anderson 1992].

As a result of the many studies conducted to determine the effects of tire tread design on tire noise levels, models are now available for manufacturers to use in tread design. CAD programs for tire design can evaluate the effect of various tread patterns on noise levels very quickly [Walter, 1992].

Not only are tread pattern models becoming more accurate but progress has been made on modeling noise generated from the whole tire. Nakajima has developed a rigorous prediction model of tire noise using the boundary element method (BEM) and finite element modal analysis. With this BEM, a three-dimensional shape can be modeled by two-dimensional elements on the surface of the body. The system uses the tire geometry, the tread pattern sequences, and the modal characteristics of the tire to calculate the surface velocity at points around the tire. From the surface velocity, acoustic pressure and intensity can be predicted [Nakajima and others, 1992].

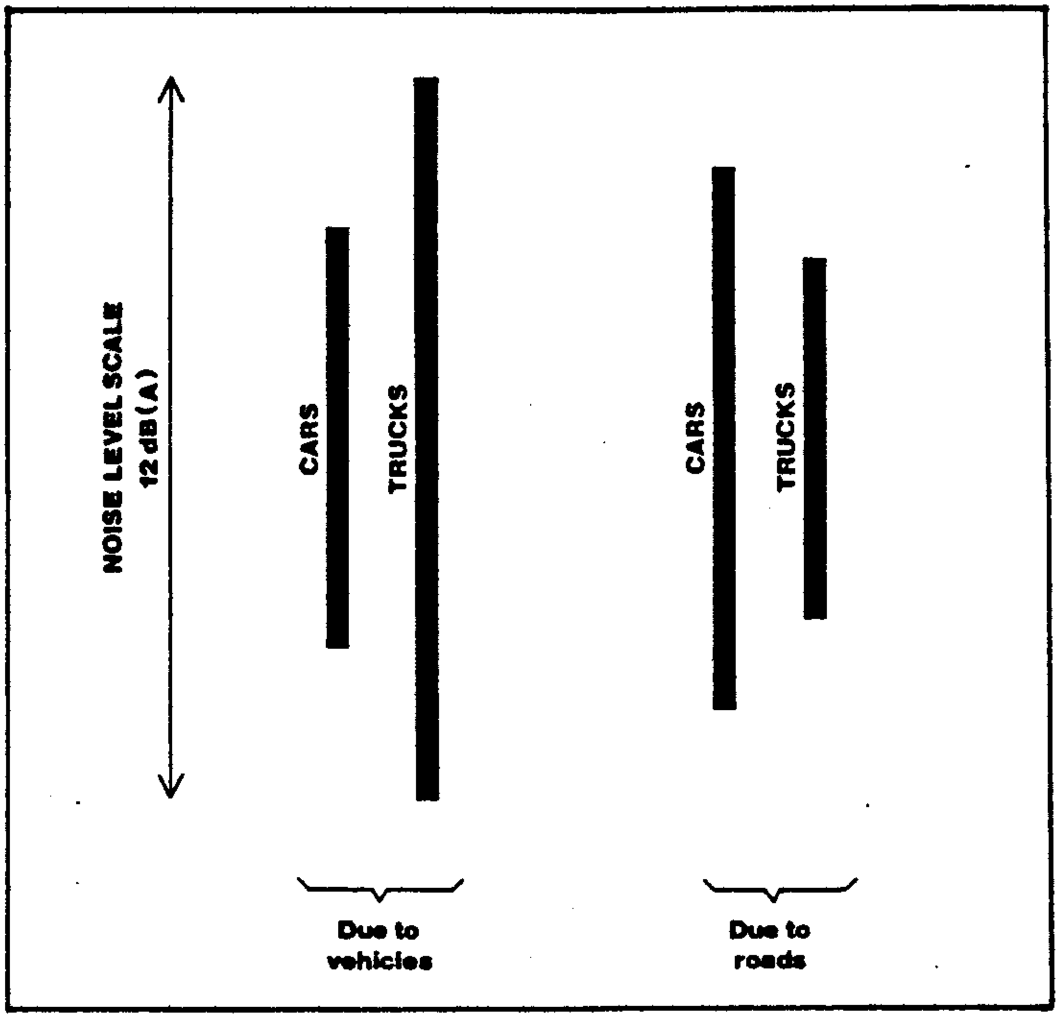
Road Surface Effects on Tire Noise

Earlier studies recognized the importance of road surface on tire noise. Both Thurman and Clapp found that for some tread types, rougher road surfaces produced lower noise levels than smooth road surface. However, for other tread types, the reverse was found to be true [Thurman, 1974] [Clapp and Eberhart, 1984]. Dougherty found that portland cement concrete surfaces produced louder noise levels for most tires than asphalt surfaces [Dougherty, 1972]. In tests conducted by Thurman, the portland cement concrete and the asphalt surfaces did not produce much difference in tire noise [Thurman, 1974]. On the other hand, Leasure and Bender concluded that the portland cement concrete typical of that used for interstate highway pavements, produces noise levels higher than those produced with asphalt [Leasure and Bender, 1975].

More recently, road surface differences have been conclusively shown to be of significance in the levels of tire noise produced. Sandberg has pointed out that the variation due to the road surface is almost as large as the variation found between individual vehicles. This spread in noise levels is illustrated in Figure 9. It should be noted that the variation in road surface types represented by the figure does not include portland cement concrete.

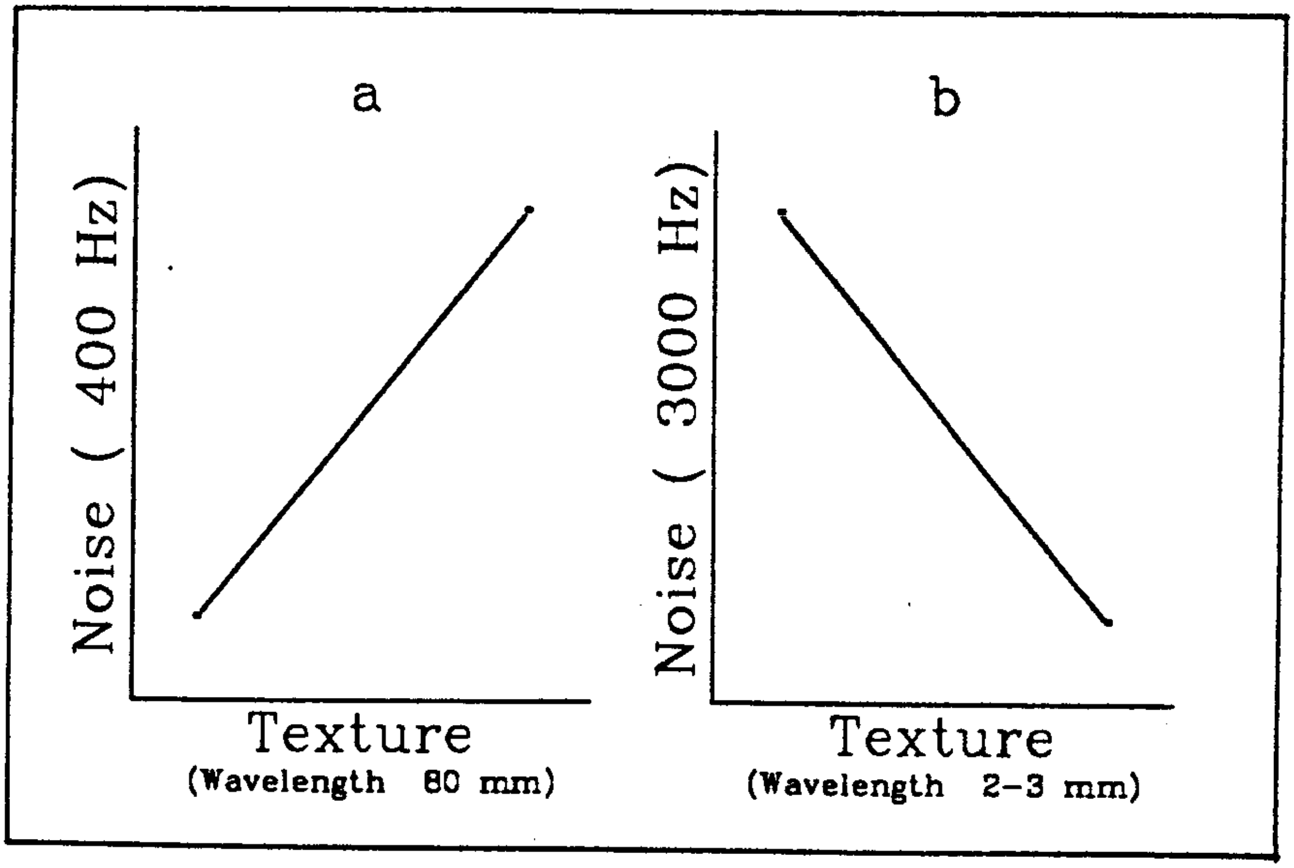
The large variation in road surfaces illustrated above does not include the effect of wet roads. Earlier studies reported mixed results on the effect of wet roads [Leasure and Bender, 1975]. However, more recent studies indicate that wet roads can produce an increase in A-weighted sound levels from 1-10 dB [Sandberg, 1992a].

Sandberg has investigated the properties of the road surface that affect the tire noise levels. For pavement surfaces other than open graded or drainage surfaces, the parameter which influences noise generation was found to be the macrotexture. The effect of this macrotexture is different for low frequencies compared to high frequencies. Figure 10 shows the relationship between texture of the surface for low frequency noise versus high frequency noise. The figure is based on the profile of the road surface texture. This profile was analyzed using a spectrum analyzer to categorize the wavelength components of the spectrum , similar to a spectrum analysis for sound waves. Tire-road noise emitted from a vehicle passby was found to correlate with texture as shown in the figure. For the long wavelength portions of the texture spectrum, the noise



Spread in traffic noise on different road surfaces and from individual vehicles, according to measurements at VTI 1982-88 in free-flowing traffic at about 70 km/h. Only dry, bituminous road surfaces are included. The bars indicate approx. the 5 to 95 percentiles, i.e. there are generally 5 % more extreme valuesat either end.

Figure 9. Comparison of variation in noise levels due to vehicle differences and road surface differences; from Reference [Sandberg, 1992a]



a. Noise at a low frequency (approx. 400 Hz) versus texture at a long wavelength (approx. 80 mm).
b. Noise at a high frequency (approx. 3 000 Hz) versus texture at a short wavelength (approx. 2-3 mm).

Figure 10. Illustration of the relationship between the frequency of tire/road noise and pavement texture; from Reference [Sandberg, 1992a]

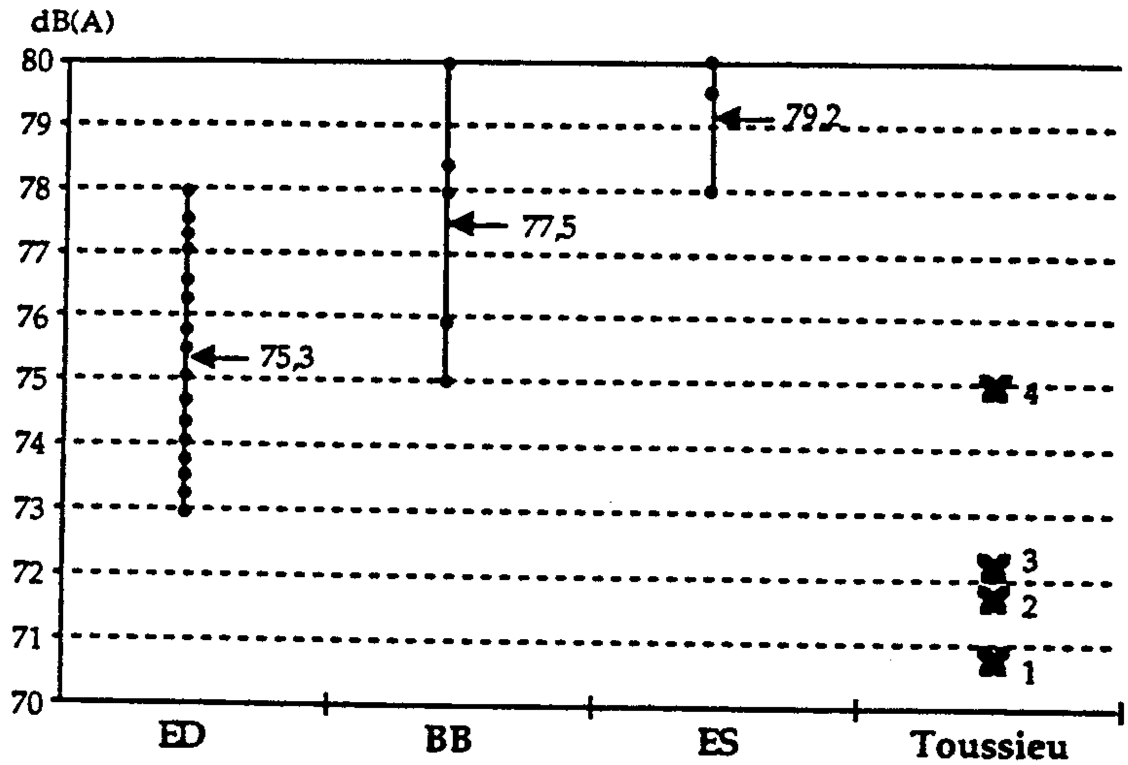
levels at low frequencies tended to increase with increasing texture wavelength (no values for noise levels are given since only trends are being shown in the figure). On the other hand, for the short wavelength portions of the texture spectrum, the noise levels at high frequencies tended to decrease with increasing texture wavelength. The overall noise levels for a given pavement would be composed of the sum of these two effects and may favor any one of them depending on the exact circumstances. Sandberg has also found that new asphalt produces less noise on the order of 1-2 dB compared to older asphalt. He has also found that portland cement concrete is definitely noisier than asphalt [Sandberg, 1992a].

Washington State DOT has sponsored a study to determine the influence of roadway aging on tire/road noise [Chalupnik and Anderson 1992]. Measurements of the levels of noise generated at the tire/road interface were made on 181 sections of a variety of asphalt and concrete compositions ranging in age from newly laid to 29 years.

The results of the study indicated that asphalt compositions produce the lowest noise levels when they are new. As the asphalt pavements age, noise levels increase throughout the service life of the pavement. Portland cement concrete compositions, on the other hand, produce relatively high noise levels when new. The higher levels were attributed to the use of a texturized surface composed of striations perpendicular to the roadway centerline. As this surface wears, noise levels are reduced to a minimum over a period of 8 to 12 years. As pavement aging continues, aggregate in the concrete begins to be exposed. Noise levels then begin to increase above these minimum levels.

Chalupnik and Anderson found that asphalt compositions produced tire/road noise levels approximately 3 dB lower than portland cement compositions when the pavements were new. However, the increase in noise levels experienced as the asphalt compositions aged, were matched with decreasing noise levels for the portland cement concrete compositions such that the measured noise levels were approximately equal at 6 to 8 years of age.

Porous surfaces or open graded surfaces have been shown to produce significant reduction in tire/road noise [Sandberg, 1992a] [Beaumont and Soulage, 1990]. Figure 11 illustrates the comparison of noise levels produced for different pavement types. The



Reduction of car pass-by noise levels at 90 km/h

ES= Chip seals (surface dressings)
BB= Dense asphalt concrete
ED= Porous asphalt concrete (single, normal layer)
Toussieu= Super-thick structures (400-520 mm)

Figure 11. Reduction in car pass-by noise levels at 90 km/h, ES = Chip seals, BB = Dense asphalt concrete, ED = Porous asphalt concrete, single layer, Toussieu = Super thick porous asphalt; from Reference [Sandberg, 1992a]

initial reduction in noise levels produced with the use of porous surfaces, however, is not maintained over the life of the pavement. This conclusion is based on the results of a four year experiment in Sweden which are shown in Table 2. The table provides both the L_{eq} and the $L_{max,}$ which is the peak passby level. The noise reduction for the L_{eq} is generally greater than for the L_{max}, since the L_{eq} measurement includes vehicle sound propagation over the "semi absorbent" road surface at long distances. The table indicates that as the porous asphalt pavement ages, the initial noise reduction benefits are gradually lost. This reduction in effectiveness has been attributed to the build-up of dirt in the pores of the pavement, thus reducing the sound-absorbing capabilities of the surface. It has been suggested that rubberized components used in the binders for bituminous surfaces could reduce noise levels. However, Sandberg finds no evidence of this from tests of rubberized binders. A strategy to reduce tire/road noise for portland cement concrete surfaces has been evaluated. This strategy involves the texture of the surface. Longitudinal lines in the surface rather than transverse lines tend to reduce noise levels. The longitudinal lines produced by dragging with burlap cloth at the time of placing the concrete having been found effective. For existing concrete surfaces, longitudinal grinding of grooves has also been shown to be effective. The reduction in tire/road noise for concrete surfaces with the longitudinal texture has been found to be on the order of 2 dB.

The importance of the road surface has also been studied for test tracks used by manufacturers to evaluate and certify noise reduction efforts for vehicle noise. In a study of European and Japanese test tracks, Sandberg has reported a large range in noise levels produced by the test surface for identical vehicle and tires tested [Sandberg, 1991]. Table 3 shows this range. The range for automobiles was 4.9 dB while the range for trucks was 2.8 dB. The significance of this data is apparent. Manufacturers expend large amounts of time and money to achieve noise reductions of 1 or 2 dB for vehicle noise. Depending which test track was used to evaluate the noise reduction effort, a greater reduction could result simply by changing test tracks. On the other hand, a vehicle certified at one test track might fail certification at another test track.

Table 2. Change in Effectiveness of Porous Asphalt Pavements Over Time (Sandberg, 1992a)

AGE OF SURFACE	NOISE REDUCTION	
	In L_{eq}	In L_{max}
0 years	5-7 dB(A)	6-7 dB(A)
2 years	4-5 dB(A)	2-3 dB(A)
4 years	1-2 dB(A)	0-1 dB(A)

Table 3. Variation in Noise Levels Produced by Different Test Tracks (Sandberg, 1991)

Test track No.	Texture depth	Absorption coefficient	Car noise in dB(A) Tire/road	Car noise in dB(A) ISO 362	Truck noise in dB(A) Tire/road	Truck noise in dB(A) ISO 362
1	0.50	0.05	66.7	73.0	68.5	83.9
2	0.42	0.05	66.3	72.8	67.7	84.0
3	0.51	0.05	65.2(2	71.5(2	-	-
4	0.50	0.05	65.3(3	72.7(3	-	-
5	0.57	0.05-0.10(1	66.0	72.5	67.9	83.7
6	0.69	0.10	66.0	72.0	68.7	83.7
7	0.71	0.14	65.3	71.7	68.0	82.1
8	0.57	0.13	64.2	71.3	65.7	82.8
9	0.43	0.19	63.0	70.5	66.4(4	81.7(4
10	0.48	0.20	61.8	70.3	66.4(4	82.8(4
Range for tracks 1-6	0.42--0.69	0.05--0.10	1.5	1.5	0.8	0.3
Range for tracks 1-10	0.42-0.72	0.05--0.20	4.9	2.7	2.8	2.2

Notes: 1) Estimated value. Will be measured in April 1991.
2) Values available only for one car and two tire types.
3) Values available only for one car and one tire type.
4) Values available only for one tire type.

Future Direction of Tire Noise Reduction Efforts

Legislation produced in the U.S. during the 1970s has eliminated the tires that produce extreme noise levels, most notably the suction cup design retreads. The driving force to produce new technology for reducing noise levels in the U.S. is the marketplace. Both automobile and truck drivers are demanding quieter vehicles. Tire manufacturers are under pressure from vehicle manufacturers to reduce the contribution of tire noise to the overall noise level experienced by the vehicle operator. It is expected that Europe will impose tire noise standards on manufacturers by the end of the decade [Sandberg, 1992b]. Ironically, it is also predicted that new tires will cause increase in noise levels for automobiles. This increase is projected because of the trend toward tires with a wider tread and thus a larger contact patch area. These tires are being marketed as low aspect ratio tires designed for improved road handling characteristics [Sandberg, 1991] [Sandberg, 1992b].

In addition to more use of porous asphalt type pavement, experimentation with high rubber composition surfaces is also under way in Europe. In one study on a Swedish roadway, a rubber surface composed of used tire chips was formed by bonding the chips. While there are many problems with this type of road surface, it is considered to hold a potential for reducing noise levels in urban areas.

Tread patterns have been optimized in most tire designs at this point. There is continued efforts to reduce rolling resistance and to increase the uniformity of the tire dimension. These efforts are intended to reduce vibrations which result in noise. In addition, tire manufacturers are looking for ways to mount tires on wheels that reduce the force transmitted to the wheel assembly. Various schemes such as a compliant rim with a solid tire have been suggested. The use of active noise attenuation, as described earlier for exhaust noise, is also considered by some researchers to have potential for attenuating tire noise for vehicle passengers [Walters, 1992].

ALTERNATIVE FUELS

The use of alternative fuels in internal combustion engines has emerged as another means to potentially reduce engine noise. Both the drivers and passengers in transit buses operating on compressed natural gas have reported the subjective impression that noise levels within the buses were lower than with diesel engine powered buses. These opinions regarding the lower noise levels came from two sources. In one case, the drivers and passengers were using buses manufactured by Orion in Ontario, Canada [Bigwood, 1992]. In the second case, the buses were operated by Pierce Transit in Tacoma and Pierce Counties. Both buses were using a Cummins L10 diesel engine that had been modified to operate on compressed natural gas.

The amount and nature of the noise reduction to be experienced with the use of alternative fuels is not known at this point. The subjective impression of reduced noise levels from alternative fuel of engines could be the result of a change in the noise spectrum for the engine, in addition to some reduction in overall levels.

Bus manufacturers have speculated that the engine noise differences between compressed natural gas and diesel fuel are due to two causes. A compressed natural gas engine is designed to operate at much lower compression ratios than engines fueled with diesel fuel. The lower compression ratios result in less vibrational forces being transmitted throughout the engine structure.

Secondly, the combustion characteristics of the natural gas combined with the lower compression ratios may eliminate the phenomenon of "diesel knock". The characteristic knock from diesel engines is a significant component in the overall noise emitted from these engines. Engines operated on methanol typically use higher compression ratios as those commonly found in diesel engines. However, the flame propagation characteristics of methanol within the combustion chamber are different than those found with diesel fuels. As a result, the "diesel knock" is not present in methanol fueled engines.

The use of alternative fueled engines has been motivated by air quality considerations and not the potential for reduction in noise emissions. Therefore, the noise reduction potential of these engines has yet to be studied. Noise levels produced by alternative fueled engines could potentially be a beneficial byproduct from efforts to reduce air pollution from internal combustion engines.

RECEIVER CONTROL

INTRODUCTION

Another key element of noise mitigation focuses on noise control at the receiver. Two general categories of receiver control are considered in this report. The first category deals heavily with zoning. In this category, administrative measures are taken to guide the development of land in such a way that the land use is compatible with existing noise sources. The second category deals with efforts to guide development in such a way that compatibility is achieved through noise mitigation. Both of these categories involve strategies that are proactive in their approach.

Efforts to control noise at the receiver are generally made at the local level. However, the most common form of local noise control involves enforcement of a local noise ordinance. This approach tends to be reactive in nature. These local ordinances are found in most communities. They typically deal with a wide range of noise sources including yelling, barking dogs, lawn mowers, and stationary sources such as air conditioners, chillers, exhaust fans and industrial sources. Enforcement of the local noise ordinance is typically accomplished by the police department, noise control unit or the health department. The enforcement of a local noise ordinance and the control of transportation noise converge at the common point of vehicle emissions. Typically, the noise ordinance requires the maintenance of vehicle noise levels throughout the operational life of the vehicle to be the same as at the time of manufacture. Inspections by noise enforcement officials include emission levels of automobiles and trucks.

In contrast to the enforcement of local noise ordinances, a few local agencies have addressed transportation noise at the planning level. In these cases, the sources are not viewed as individual vehicles, but as systems such as traffic, rail, and aviation. The goal of transportation noise control at the planning level is to ensure that community development can proceed without incurring traffic noise impacts. Enforcement of these plans generally involves the environmental planning department.

These two types of local noise control are complimentary. To ensure a satisfactory noise environment, both are needed. The emphasis given to each type of program can depend on the stage of community development. Those communities in the early stages of development will rely most heavily on the proactive planning for compatibility in noise control. On the other hand, those communities which are much farther along in their development will tend to emphasize the more reactive program found in the local noise ordinance.

The success of the noise ordinance enforced by the local noise control unit was studied in the project entitled "Comprehensive System Level Noise Reduction Strategies". On the other hand, this study focuses on the two categories of planning for receiver noise control in which transportation noise is emphasized.

This study has built upon the results of the previous study using additional information gained through contacts with local, state, and federal officials, as well as a number of consultants. As a result of this process, a number of communities were identified in which the receiver control through planning is used. In general, communities on the east coast, Canada and the west coast, primarily California, were found to have such programs.

Noise and land use compatibility is the general term that has traditionally been used for the strategy to control noise at the receiver through the planning function. As mentioned above, two categories can be easily identified under this general concept. Differing land uses can be compatible in terms of noise by their very nature. For example, an industrial plant is compatible with an adjacent highway because of the nature of activity and the noise environment within the plant. Other land uses can be made compatible through the design of the development which may incorporate various methods of noise mitigation. The first method typically deals with zoning laws. The second method might be better termed proponent noise mitigated development. Both facets of land use compatibility are heavily dependent on the planning function.

This report treats noise control at the receiver by considering each of these facets in general. A description of the role that state agencies as well as county and city agencies typically assume is then given. Each local agency listed in this report was treated as a case study. The results of interviews with personnel at each of the local agencies is given in each case study. In addition, a separate update is given on five communities which were part of a series of a USDOT case studies in the 1970s. These communities were contacted and a progress report on the success of their program. The many components of the programs instituted by the various local agencies have been compiled. An analysis of these components has resulted in a tabulated comparison of the key components of the programs studied. Finally, this report discusses the task of implementing such programs at both the state and local levels.

LAND-USE ZONING

The first category of noise and land use compatibility planning is land use zoning. The goal of this strategy is to create a pattern of development in which transportation noise sources and adjacent receivers are compatible. As an example, an industrial plant might be located near a highway. As a receiver, the industrial plant is compatible with the highway traffic noise source because of the noise environment and type of activity within the plant. In contrast, areas of outdoor living for residential developments are not compatible with traffic noise sources when located near them.

This strategy involves the process of determining the compatibility of various land uses with transportation noise and then defining and zoning those areas according to the types of development that can occur. In some cases, this process is accomplished by developing noise level contours for a community. These contours are based on measurements taken at various distances from transportation noise sources. The contours generated by these measurements then define the noise environment. The next step is to assign maximum noise levels compatible with a given land use.

In effect, the contour lines can, and often do, become policy lines. That is, a given land use is automatically restricted from certain areas because of the noise environment. As an example, airport noise contours define the boundaries where residential development may occur or may not occur. For other contours, industrial development may be allowed. Regardless of the specific process used, the goal of land use zoning is to prevent conflicts due to incompatibility between transportation noise sources and adjacent receivers. The strategy is preventative by nature and is designed to eliminate costly solutions to conflicts that result from unrestricted development. The responsibility for carrying out and enforcing this strategy rests with the local planning department. The strategy is not only designed to minimize total costs of noise mitigation, but is relatively inexpensive to administrate. In effect, land use zoning for noise compatibility simply incorporates another factor in the planning process, that of noise planning. The incremental cost of considering noise in the planning process is generally considered so small that it cannot be identified for most planning organizations.

In a recent GAO report on transportation noise [GAO, 1989, page 62], it was stated that the efforts of FHWA officials to encourage state and local government to control land use along highways have generally not been successful. While this assessment appears to be true in the general sense, the agencies studied in this report have generally been successful in their efforts to produce land use compatibility with transportation noise.

One of the NCHRP studies on traffic noise, documented in NCHRP Report 173 [Bolt, Beranek and Newman, 1976, 108-109], describes a number of land use strategies to reduce noise impacts. The study concludes that restricting the use of land bordering the right-of-way of transportation noise sources to unoccupied structures (such as warehouses) appears to be the most attractive alternative. Further, this attractiveness is especially true for communities in the earlier stages of their development. In contrast, unacceptable levels of economic investment would be required to acquire land and impose restrictions based on the noise environment in fully developed communities.

While the concept of land use zoning is straightforward and would seem easy to apply, particularly in the case of communities in early stages of development, it does have its limitations. A number of planning organizations suggested that this strategy can lead to "strip" development. These communities tend to have both a high level of demand for residential development and many miles of freeways within their communities. To zone the land areas along these highways as commercial or industrial would not only produce strip development but would provide an imbalance in demand and land availability. Usually, there simply is not enough commercial and industrial type land uses to occupy all the land near the transportation sources. Further, in the overall scheme of community planning, clustering of industrial or commercial land uses is being seen as more desirable than strip development. These communities prefer to use the second category of land use compatibility planning with transportation noise which is described in the following section.

PROPONENT NOISE MITIGATED DEVELOPMENT

Proponent noise mitigated development is a strategy intended to produce transportation noise and land use compatibility as part of project design. The development project can be either the transportation facility or the receiver of the transportation noise located near a transportation facility. Mitigation of the noise impact is accomplished through methods selected for each individual project. Examples of these methods are changes in highway alignment, construction of noise walls or berms, buffer zones, building orientation and insulation. Note that the effectiveness of strategies such as noise walls and berms was discussed in detail in the Phase I report under path control. The building insulation strategy, which falls under the category of receiver control, was considered in more detail in this present study.

As a basic tenet of this strategy, the proponent of the development bears the responsibility of noise abatement in order to achieve noise and land use compatibility. For a case in which the new development results in bringing a noise source to an existing development, for example, construction of a highway through a residential neighborhood, then the highway is the new development and the transportation agency is the proponent. In such a case, the transportation agency would fund the abatement project.

On the other hand, a residential developer may propose a development adjacent to either a planned or an existing highway facility. In this case, the residential developer is the proponent of the project. As such, he or she is required to assess the impact of noise on the future receivers and, if required, is responsible for noise abatement.

The environmental planning department is the key agency in this strategy as well as the land use zoning strategy described above. Impact criteria for noise affecting various land uses must be established. In addition, guidelines for acceptable abatement methods and design goals must be established. Control and enforcement of the entire process again rests with the planning department.

The proponent noise mitigation development strategy differs from land use zoning in that typically capital costs for abatement are required. As stated above, the responsibility for abatement lies with the proponent of the project and in all cases, the proponent must fund any required abatement. This method of cost allocation is often cited as being just. Ultimately, the users of the project pay for the noise abatement.

In the case of a transportation facility, the taxpayers using the facility pay for the abatement. In the case of a residential development, the homeowners protected by the abatement pay for it by the incremental cost associated with each home in the project. Additionally, the proponent is required to pay the costs of the study to analyze the need for abatement and to design the abatement feature. For a transportation facility, either in-house staff or consultants would do the studies, while residential developers would almost always hire consultants.

The administrative costs associated with maintaining such a program within the planning department are minimal. Satisfying the noise guidelines for any development is seen as simply another "check-off" item in the process of project approval. However, there are additional start up costs for such a program. These involve the costs for developing the program guidelines and establishing criteria, procedures, etc. Maintaining in-house staff in a public agency could be another cost. This staff would do the studies for transportation facility development, interface with consultants hired to do such work, provide technical advice to residential developers, and/or review or approve the studies done by consultants hired by residential developers.

As stated above, the strategy of building insulation was considered in this study as part of noise control at the receiver. This strategy is discussed in the following section.

BUILDING INSULATION

Building insulation is a method of receiver control designed to reduce interior noise levels. For certain land uses in which there is little or no outdoor activity, this strategy can be very effective. For those land uses such as residential use where outdoor activity is desirable, this strategy may still be used where adequate noise source or path control is not feasible. The goal for such situations is to preserve the quality of living as much as possible. If the noise environment is not acceptable outside, it can still be made acceptable inside.

To achieve the goal of reduced interior noise levels, the building must be altered to reduce the sound transmission through the structure. In some cases, the existing structure produces adequate noise reduction except during periods when windows are open to provide ventilation. A common solution in such cases is to install central air conditioning to eliminate the need for open windows.

In other cases, more extensive modifications are required. Windows and doors can be replaced with units that provide greater noise reduction. Other openings such as chimneys and exhaust openings may require redesign.

Since the building insulation strategy is often implemented near airports, two airport representatives were contacted to describe their experiences. These experiences, gained with homes near airports, provide an indication of the benefits that could be realized by applying this strategy to buildings near highways.

Seattle-Tacoma Airport (SEATAC)[1]

The SEATAC plan involves two types of sound insulation programs. These are dependent upon the noise contours in which the houses are located. The first designation is the "standard insulation area". This area is based on the contour interval of 65 dB to 70 dB LDN. The average house in this category requires $8,000 in construction costs to reach the noise reduction goal of 5 dB. This cost does not include replacement windows.

The standard insulation area receives storm windows, exterior doors, storm doors, attic insulation, and mechanical ventilation systems.

The second classification is the "neighborhood reinforcement area". This is based on the contour interval of 70 dB to 75 dB LDN. The average cost for insulating a home in this area is $18,000 to reach the noise reduction goal of 10 dB. Eight-thousand dollars of this cost is related to construction costs and the remainder is for replacement window material costs. While the cost averages $18,000 per house, the range can be from $3,000 to $40,000. The wide range is based upon the number of windows and the size of windows in the home. The policy will allow insulation of up to six rooms in a house; therefore, very large houses are not protected in all their rooms.

The "neighborhood reinforcement area," in addition to the items in the first area, receives replacement windows and some interior wall and ceiling treatments. Masonry-

[1]Based on telephone interview with Earl Munday, 6/29/92.

sided houses typically do not need wall treatments on the inside. Houses with cathedral ceilings typically need added treatment to the ceilings, whereas houses with attics do not need ceiling treatments.

Recently, wooden baffles have been installed inside the vent areas of some attics. However, there has been no testing done to determine if this has had an effect.

Overall, the design goals are 45 dB in the living areas, and 40 dB in the bedroom areas. In terms of the most gain in noise reduction, the priorities are windows first, doors second, and attic space third. Prior to acoustical treatment, older homes in this area, with standard construction, typically produce a 20-25 dB noise reduction. Newer homes which meet energy codes, include thermal windows, etc., typically produce a 25-30 dB reduction.

<u>Minneapolis</u>[2]

The Metropolitan Airports Commission in Minneapolis is beginning a pilot study of 150 homes for interior noise reduction. These homes are in the contours with the highest LDN's and qualify for home noise insulation. The actual amount of noise reduction is expected to vary for each home; however, the goal is a noise reduction well in excess of a 5 dB. Of these 150, the first group to be let for bid involves 64 homes. The homes within the highest level will have air conditioning systems so that the home can be maintained year around without open windows. The average estimated cost to treat these homes is $22,000.

The basic strategies are to use high STC rated acoustical window replacements, exterior door replacements, wall modifications, and air conditioning if required.

A demonstration house has been prepared at the airport. This house was bought by the airport and is located very close to one of the runways, in fact, it is actually in the clear zone. This house has been prepared with rooms which increase the transmission loss by 5, 10, and 15 dB. The one room that is rated at a 15 dB reduction has actually been measured to be over 20 dB reduction. This was achieved by adding

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[2]Based on telephone interview with Steve Vecchi, 6/30/92.

layers of sheetrock to the ceiling and walls along with acoustical windows and acoustical doors into the room.

STATE/PROVINCIAL AGENCY ROLES

While noise and land use compatibility are generally seen as strategies taking place at the local level, state agencies can also play a key role in the process of implementing such strategies. The two key functions carried out by the states are that of assuring uniformity of local guidelines and facilitating program start up for local agencies.

Uniformity among local agencies is desirable to prevent broad variations in regulations from one jurisdiction to the next. While each community is unique and may require special considerations, large scale differences in guidelines are not justifiable. The differences create an unreasonable burden on consultants, developers, and transportation agencies alike.

Uniformity is assured in most cases when the state agency develops a model guideline for noise and land use compatibility. Typically, the state will then require adoption of the model guideline either in its entire form or with added restrictions. While local agencies may choose not to have such a noise guideline, they do not have the option of developing a less restrictive guideline. In order to facilitate the process of model guideline adoption by local agencies, the state could consider grants to local agencies for this action.

State agencies can also facilitate program start up for local agencies in several ways. Providing a model noise guideline, as stated above, greatly reduces the cost and time involved in developing a program. In addition, technical assistance made available by the states to local agencies, can further reduce start up time. At the inception of a program, local agencies should consult with state agencies experienced with initiating local programs.

Often, local public agencies are limited in staff, budget and expertise to perform these tasks and must turn to higher levels of government for assistance. At the state level, these agencies are typically the Departments of Transportation or Environmental Protection. At the federal level, the agencies are the Federal Highway Administration, Federal Aviation Administration, Federal Railroad Administration or in the case of federally funded residential development involving federal funds for construction, construction loans or home mortgages, the Department of Housing and Urban Development.

LOCAL AGENCY ROLES

Local agencies must have a commitment to preventive measures in order for transportation noise and land use planning to be effective. Further, the commitment must be such that start-up costs are considered an acceptable investment in order to reap the benefit of the long-term gain from the program. The pressures of coping with rapid growth often cause local agencies to focus on the immediate problems of communities in the early stages of development. However, the effort required to initiate land use compatibility programs is of great worth in terms of elimination of future problems. Local agencies begin by considering available model guidelines produced at the state level. Special concerns of the local community can then be addressed by adding clauses to the model ordinance to tailor it to the specific needs of the local community.

Local agencies considered in this report fall in the categories of counties or cities. The programs can be identical for each agency. Typically, county agencies have jurisdiction over the unincorporated areas of the county. As a county develops, more and more of the land will become incorporated and fall under the jurisdiction of individual cities. As development progresses, the counties can continue to support the cities through technical support and use of noise measuring equipment. Counties play a key role in terms of the preventive nature of these strategies. If land use compatibility has not been achieved in the earlier stages of development, then additional problems will be present as communities are incorporated.

The cities are the most common user of land use compatibility methods. Seven cities are fully addressed in this study whereas four counties were investigated. The following case studies describe each state and local agency studied. A comparison of the local agency programs is given in Table 4 for reference.

Table 4. Characteristics of Local Agency Noise Compatibility Programs

	LOCAL AGENCIES										
	COUNTIES				MUNICIPALITIES						
CHARACTERISTICS	Montgomery MD	Howard MD	Orange CA	San Diego	Carlsbad	Cerritos	Fullerton	Irvine	Calgary	Saskatoon	Toronto
Environmental Planning Type											
Land Use Compatibility	Yes	No	Yes	Yes	NA	No	No	Yes	NA	No	No
Noise Mitigated Development	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transportation Noise:											
Air	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	*
Highway	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rail	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Criteria:											
Outdoor Noise Levels	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Indoor Noise Levels	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No+
Descriptor	DNL	DNL	CNEL	CNEL	CNEL	CNEL	CNEL	CNEL	LEQ(24)	DNL	LEQ(24)
Standards for Receivers											
Residential Out/In	55-65/45	65/45	65/45	60/45	60/45	55/45	60/45	65/45	60/	65/	55/+
Institutional Out/In			/45					65/45			/+
Indust./Commercial Out/In			/50-65			70/		/45-50			No
Off-Site Mitigation Req'ts	No		Yes	No	No	No	No	No	No	No	No
Noise Contours	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Policy Contours	Yes	No	Yes	NA	NA	NA	NA	Yes	No	No	Yes°
Agency Noise Abatement Methods											
Noise barriers											
Buffer zones	x	x	x	x		x	x	x	x	x	x
Building orientation	x	x	x	x		x					x
Building insulation	x	x	x	x			x	x			x
	x	x	x	x		x	x	x			x

* Federal
\+ Pending
° Provincial

STATE/PROVINCIAL AGENCY CASE STUDIES

In this category, three agencies were studied, one within the Province of Ontario, one within the State of California and one within the State of Minnesota.

Ontario, Canada[3]

Most of the noise guidelines in Ontario came out in the mid to late 1970s. Since then, amendments and refinements have been made. The Environmental Protection Act and the Environmental Assessment Act came out in 1975. The Environmental Protection Act was the empowering legislation that provided the basis for the noise bylaws, etc., to be developed.

On February 8, 1977, the Ontario Ministry of Housing and Ministry of Transportation and Communications (now the Ministry of Transportation) jointly released a policy statement regarding noise associated with major freeways. There was a lack of proper planning prior to this date allowing incompatibility between developments and noise sources. As a result, the Ministry of Transportation had to go into areas impacted by existing facilities with retrofit noise abatement to mitigate the noise impact ("Type II" projects in the language of the U.S. FHWA Noise Standards in 23 CFR 772). With the new legislation, the goal was to have proper planning such that these Type II programs were no longer necessary.

On May 29, 1979, the Ministry of Housing (now Ministry of Municipal Affairs) released its supplementary guidance for noise. This guidance is entitled "Guidelines on Noise and Residential Development Adjacent to Freeways". The guidelines are mostly aimed at new developments. According to the guidelines, "Planning principles should be adopted that minimize the chances of creating noise problem areas. Put simply, it

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[3]Much of the information in this section is the result of a February 11, 1992, meeting in Toronto on local government noise guidelines. Present were: Soren Pedersen, Ontario Ministry of Transportation; Chris Andrew, Coordinator-Noise Control, Environmental Policies and Systems Section, City of Toronto; W. Hugh Struthers, Transportation Department, The Municipality of Metropolitan Toronto; Vic Schroter, Noise Assessment and Systems Support Approvals Branch, Ontario Ministry of the Environment; and Chris Blaney, Environmental Planner-Acoustics, Ontario Ministry of Transportation.

means a proper place for every land use so that each use is compatible with the surroundings."

The guidelines further state that residential areas should normally be located away from freeways. Whenever possible, commercial, light industrial, recreational and agricultural uses should buffer residential areas from noisy freeway traffic. If residential areas must be located near a freeway, developments should include suitably-designed medium and high density residential buildings rather than low density single-family units. For the case of existing residential areas adjacent to freeways where noise is considered excessive, the guidelines provide for noise barriers to be built where feasible.

The sound level measurement descriptor considered for the purpose of this policy is the A-weighted 24-hour equivalent sound level, L_{eq}(24h), which is based on either the Average Annual Daily Traffic (AADT) or the Summer Average Daily Traffic (SADT), whichever is higher.

The overall objective is to have a residential L_{eq}(24h) of 55 dB or less in outdoor recreational areas. If the predicted sound levels in outdoor recreational areas are greater than 70 dB, development is prohibited. If the predicted sound levels in outdoor recreational areas are between 55 dB and 70 dB, development is made conditional upon requirements to mitigate the noise. Mitigation is carried out by the developer.

The goal of mitigation, therefore, is to reach an L_{eq}(24h) of 55 dB or less. If it is expected that the goal will not be reached, yet approval is to be granted, it is stipulated that perspective residents must be informed of the condition of the high noise conditions.

For the case where new residential developments are adjacent to proposed freeways, the requirements are somewhat different. The developer may be required to: (a) provide land at no cost to the local government for the construction of a noise barrier or (b) contribute to the cost of a barrier. In all cases where a proposed development is within 1 kilometer of the edge of a freeway right-of-way, the developer must make early contact with the Ministry of the Environment.

As a follow-up to the Ministry of Housing Guidelines, the Ministry of Transportation developed the Noise Assessment and Abatement Program. This program detailed the steps needed to implement the overall policy of February 8, 1977, and the subsequent guidelines. Included are detailed specifications to the municipalities for the construction of noise barriers.

Resulting from these efforts at the provincial level was the model bylaws for noise abatement. Of the over 700 municipalities in Ontario, most of them have adopted the bylaws in some form or other. The laws established on the local level must conform to or be more restrictive than the bylaws. The municipal or local governments have a choice to adopt either a qualitative or quantitative version of the model bylaws. The qualitative approach tends to be looser and allow more flexibility. Implementation of these qualitative guidelines does not require additional acoustical instrumentation or employment of additional acousticians. The actual adopting of the model bylaws by a municipality must meet with the approval of the Ontario Ministry of the Environment.

The bylaws themselves do not include planning models per se. They deal with noise guidelines only. Local planning requires that developers ensure that those within the development are not impacted. All new non-exempt sources of noise and vibration require permits through the Ministry of the Environment.

The bylaws do exempt a number of noise sources. These are aircraft noise, rail noise, and noise sources associated with emergency vehicles, etc. While the ordinances do restrict development that encroaches upon these sources, they do not restrict the sources themselves.

A difficulty arises for cases where residential development and industrial noise sources have encroached upon each other. This issue is exacerbated for situations where the problem existed prior to the establishment of the new guidelines. In these encroachment situations, more burden has typically been placed upon the developer. Again, land use planning is of key importance.

Where developers choose to locate near noise sources, they must provide appropriate noise mitigation. The "market" determines the type of development in many cases. The cost of noise mitigation must be allocated over the number of units. If cost effective, single-family dwellings may be a part of the development. Otherwise, two-family residences, apartments, or high-rise facilities might be built to increase the cost effectiveness of noise abatement. The goal is to ensure residences within these developments an environment free from noise impacts.

An example of this land use approach may be seen between Mississauga and Hopedale. Noise barriers have been built on both sides of the freeway to protect residential areas adjacent to the freeway. However, as soon as one crosses the boundary into the next city, there are no noise barriers. The reason is that the land use is entirely industrial on both sides of the freeway. This land use eliminates the problem and is a much better solution than building noise barriers.

As it is now, almost no developer would consider building near Ontario freeways. To do this would require a very deep lot for development and very little frontage. An example of a developer incurring a tremendous overhead can be seen on the west side of Toronto where the land area to be developed was located near the interchange for two freeways. A noise barrier, constructed by the developer, ranging from 5 to 6 meters high of approximately one mile in length, was required to protect the approximately 200 single-family dwellings in the development. The cost of this barrier was one million dollars. The developer then experienced difficulty because the homes did not sell as rapidly as was hoped.

The cost of maintaining this land use policy and the programs that it has fostered are not "all that high". In a sense, compliance is a check-off item for people that are already working in the planning department. Proposals and drawings of specifications are all reviewed as part of the general review for new development. The true cost are seen in increased prices for homes in the new development. However, the general population does not see an increase tax burden to pay for the noise mitigation.

Another legal possibility, is to have the Ministry of Transportation provide some funds while assessing new homeowners an amount to cover the construction of noise barriers for certain developments. While this is legally possible under certain provisions in the law, it has never been done. There are problems in attempting to provide abatement under this method. One question is determining how much the first row homeowners would be assessed as opposed to the second, third or fourth rows.

There is an abundance of government assistance at the provincial level that is available to the local governments. Both the Ministry of the Environment for Ontario and the Department of Transportation offer technical assistance to local governments.

Small local governments (population of 10,000 or less) generally have one by-law enforcement officer in the noise program.

For the case of a new roadway or reconstruction of an existing roadway by a public agency, an environmental assessment would typically be made. If a noise barrier is warranted, then it would be designed and constructed. Right now it takes in the neighborhood of 3 to 4 man years to maintain the public roads noise abatement program on the provincial level. This effort includes a management of 10 million dollar per year Type II program. In addition to the 10 million dollars, which is for barriers alone, there are other types of activities such as lowering roadways, changing alignment, and experimenting with lower noise pavements.

<u>California</u>[4]

The California Land Use and Planning Law requires that each community have a noise element as part of its general plan. This requirement forces local planners to consider noise in their communities; however, it does not require that they adopt a noise ordinance or produce land use compatibility guidelines. The Noise Element Guideline is part of the appendix of the General Plan Guidelines in the State of California. The guideline is used by communities and their consultants to develop the noise element as part of the community general plan. The guideline requires consideration of the major sources of noise, as well as development of Day-Night Level (DNL) contours. A model noise ordinance is also provided to communities as a service by the State. An individual community may choose to adopt, not adopt, or modify this model noise ordinance.

It is important that the local communities be involved in both the development and enforcement of their local noise ordinances. Communities can have very different noise sources. Some communities might have a lot of rail noise or air noise whereas others might be predominantly highway noise.

The Land Use Planning and Noise Compatibility Programs are more important to those communities that are in the process of developing. Communities which have been developed for some time receive less benefit from the Land Use Compatibility

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[4]Based on notes from telephone interview with Russell Dupree, State of California, 5/29/92.

Planning than from nuisance type noise ordinances. It is emphasized, however, that both guidelines really go hand-and-hand and are both valuable to any community.

No one community in California was cited as standing out among the others in its development of Land Use Planning Guidelines and activities. There is a lot of variation which is due to the noise sources and the problems particular to the specific location. Communities mentioned as having effective Land Use Compatibility Guidelines were Pleasanton, Sacramento and Concord (all of these are in northern California).

It is estimated that approximately half of the communities in California have adopted some kind of noise ordinance. Of those, approximately half of the ordinances are good ones. The problem with many of the noise ordinances is that they treat noise subjectively without any attempt to quantify noise levels and criteria for impacts.

Minnesota[5]

Minnesota, unlike most states in the U.S., has a state noise ordinance. This ordinance is binding on the entire state. However, local agencies can adopt or modify the noise ordinance. Any changes to the ordinance must be such as not to be interpreted as being more stringent. Should a local agency choose not to adopt the ordinance, the ordinance is in effect as it is written at the state level. There is some enforcement that is carried out on the state level. Also, training in the use of noise measuring equipment and other technical support is provided to local agencies who want to be involved in noise enforcement.

The Minnesota Pollution Control Agency (MPCA) was started in 1967. Authority to write state noise regulations was granted in 1971. Rules were finalized and went into effect in 1974. The state noise standard for residential require A-weighted $L_{10}(1h)$ maximum of 65 dB for daytime hours and 55 dB for nighttime hours. This time distinction has caused a problem with highway noise. Though nighttime hours are considered to be from 10:00 p.m. to 7:00 a.m., there is a large increase in traffic during the 6:00 a.m. to 7:00 a.m. hour. Since this increase makes it difficult to achieve the lower standard of 55 dB in residential areas, there is some thought to changing this hour

[5]Based on notes from conversation with Mr. Charlie Kennedy, Minnesota Pollution Control Agency, 6/9/92.

to be grouped with the daytime hours. Sometimes the A-weighted L_{50} level maximum of 60 dB is used for daytime hours and a 50 dB maximum is used during nighttime hours. This descriptor is typically used for facility noise referring to point sources such as factories or machinery, etc. in contrast to traffic noise.

As noted, the noise ordinance does not exempt traffic noise; however, there is a partial exemption for the case of highways where federal funds are involved. For such cases, FHWA Noise Abatement Criteria (NAC) given in 23 CFR 772 apply (an A-weighted L_{10}(1h) of 70 dB and an L_{eq}(1h) of 67 dB). Since the Minnesota State Noise Standards are more stringent than the FHWA NAC, this exemption is provided. If the FHWA NAC are met, the State of Minnesota is satisfied even though FHWA headquarters Office of Environmental Policy insists that the NAC are not design standards. Usually, Minn DOT attempts to not only meet FHWA NAC but also the Minnesota standards.

For the case of non-federally funded highway projects, Minn DOT comes under the Minnesota noise ordinance. A new construction or reconstruction project is reviewed for noise impacts by the Minnesota Pollution Control Agency. If impacts are predicted, abatement is required to meet the standards of the noise ordinance. For those cases where it may not be feasible to meet the standards, the state or local agency proposing the transportation facility must obtain a variance.

The USDOT case study of Minnesota made in the mid-1970s regarding noise and land use compatibility planning emphasized the key role played by Minn DOT. Currently, Minn DOT continues to review all proposed developments adjacent to state highways. However, this review is limited to an advisory role. Minn DOT makes suggestions for possible measures which could be implemented to reduce noise levels. While this process alerts local planners to potential problems, it does not ensure compliance with the Minn DOT recommendations.

Minn DOT has frequently asked for authority to do land use planning along their freeways and major arterials in Minnesota. The authority to do so has not yet been granted. Currently, there is no retrofit program for dealing with noise problems due to existing highways. This is in contrast to the 1970's when millions of dollars were spent on dozens of miles of retrofit barriers on existing highways, primarily in the Minneapolis-St. Paul area.

The state noise program coordinator is in the Air Quality Division of the Minnesota Pollution Control Agency. The noise coordinator deals with aircraft noise, as well as highway noise. Assisting the coordinator is a noise specialist who does field monitoring, noise measurements, and handles the technical aspects of the program. The noise group reviews all noise analysis done for new projects whether they are for residential developments or for transportation facilities proposed by Minn DOT.

The trend toward increased land use planning for highway noise compatibility is expanding in Minnesota. The trend seems to be occurring on a city-by-city basis. An example of a recent activity in this area took place for the City of Shakopee. State Highway 101 was an existing highway along which a new development had been proposed. In the review process, Minn DOT predicted that noise impacts from highway noise would affect the residential development. Since Minn DOT already had a permit for this transportation facility which was in operation, it was not required to mitigate the noise. However, Minn DOT provided noise abatement recommendations and suggested that approval for the new development be contingent upon the recommendations.

There are cases in which developments are approved without consideration of noise impacts or without regard for Minn DOT's recommendations. Residents suffer as a result. In general, Minn DOT and MPCA see the municipality as being responsible in these cases. However, it is the intention of the MPCA that a municipality either provide noise abatement or require developers to include abatement as part of the approval to develop the land. This requirement is not as clear-cut where other local agencies have defined their procedures; that is, the responsibility falling on the developers is not as clear-cut and is often shared with the municipality. The MPCA noise group encourages the communities to require that developers provide mitigation where it is required.

COUNTY AGENCY CASE STUDIES

Eleven local agencies were studied in detail, including both counties and cities. In addition, a review of four local programs, subjects of USDOT case studies in the

1970s is included. Three of the cities from those USDOT case studies received detailed study for this project. The remaining city, Lavonia, Michigan, is treated in less detail.

Montgomery County, Maryland[6]

A set of guidelines has been produced for Montgomery County to address transportation noise issues in all stages of planning. These guidelines are considered at the master plan level, zoning level, subdivision review, and site plan review. In addition to highway noise, the guidelines address air noise, and rail noise, since the county has an airport, transit ways, and railroads. County staff feels that in most local agencies there is a large void between the land use planning stage and the development review process that takes place at the time a new development is proposed.

Montgomery County has several different criteria for noise levels depending upon the area of the county. The criteria have been established as non-degradation levels. In other words, new development is controlled in such a way that the noise environment will not be degraded. This program has been in effect since 1983. The planning department in Montgomery County considers it a success in terms of its goal to have developers think along these guidelines by planning early for noise impacts.

The assumption has been made that industrial and commercial land uses are compatible with noise. Therefore, the noise guidelines only address residential land uses. Land uses that do not fit in the traditional residential, commercial, and industrial categories are taken on a case by case basis. Places of worship, as and example, would be addressed individually. Depending on the type of program and intended uses for the place of worship, different noise levels may be accepted.

A differential standard has been developed based on potential for abatement as well as land use characteristics. For example, the area of the county nearest Washington, D.C., inside the Washington Beltway, is a fully developed area with high density development. Ambient noise levels in this portion of the county are relatively high. Therefore, the standard for this area is the highest allowable consistent with a

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[6]Based on telephone interview with Mr. Steve Federline, Montgomery County, Maryland, 1/6/93

residential environment. The guideline for outdoor noise is an A-weighted Day-Night Level of 65 dB.

On the other hand, there are portions of the county which are much lower density. Approximately 15 miles from the Washington Beltway there is an area of land designated as agricultural reserve. This area has 25-acre lot size minimums. The requirement in this area is a DNL of 55 dB. This level of 55 dB is difficult to obtain, however, near highways.

A third category between these two extremes described above are those areas referred to as developing areas. The guidelines for noise levels in these areas is a DNL of 60 dB.

Once an impact area has been identified, a number of techniques are considered for noise reduction. A hierarchy of techniques is utilized, starting with those that are most cost effective. The first consideration is noise compatibility. Those land uses which are least sensitive to noise impacts are located closest to transportation noise sources where possible. For example, surface streets might be located near major highways, or municipal service facilities might be located near major noise sources. For mixed use development, parking lots might be located closer to the source than buildings. Also, commercial uses might be located near highways with residential uses located farther from highways. The land use compatibility approach is the first priority in Montgomery County.

Usually the potential impacts are not so great that the land use category must be changed when a new transportation facility is planned. For this case, mitigation is considered in order to reduce the impacts to an acceptable level. The first step in mitigation is site design. That is, using setbacks, building orientation, etc. to reduce the impact.

The second step involves the construction of barriers. Montgomery County has a goal of 5 dB reduction as a minimum for any noise abatement barrier. The first choice of Montgomery County for barriers is landscaped berms. Berms are favored for both aesthetics and life span. Berms seem to improve with age in contrast to walls, which deteriorate with age. Where land area is at a premium, the berm height may be reduced and a wall added. However, the walls are typically held to the 6 to 10 foot heights both for aesthetics and cost. The next level of mitigation in terms of priority would be a wall by itself (rather than one on the top of a berm). The biggest problem for residential noise abatement has been the second-story in town houses. One cannot build a barrier high enough that is aesthetically acceptable and cost efficient to shield these areas.

The last method of reducing noise is acoustical treatment. For those areas where a DNL of 65 dB cannot be achieved in the outdoor areas, the indoor areas are protected by increasing sound insulation in the building. The standard for indoor levels is a DNL of 45 dB.

Each step of the above methods must be addressed, if possible, before considering the next and less desirable step. All mitigation costs are absorbed by the developers.

The cost to administer the noise guidelines by the Environmental Planning Department has not been determined by the department. Noise is one of the many considerations given when reviewing land use plans; therefore, it consists of a very small portion of the overall budget.

Montgomery County has produced noise contours for the county. The contours are produced in the master planning stage where horizon year traffic levels are considered using the highway noise model with very generalized topographic inputs.

Land use compatibility zoning is done during the master planning stage. As one example, an area located near a highway source with high noise levels consisted of very small land parcels. Because of this, there was no way to produce adequate setbacks to reduce noise levels. Further, this area along the highway was on an exposed hillside making it even more difficult to install any kind of noise abatement. Therefore, the area was recommended for industrial land uses. In contrast, along the same highway, a large acreage area was proposed for residential development. This proposal was accepted because the topography provided some shielding and the development could be planned to produce clusters of houses with adequate setbacks to further reduce noise to guideline requirements.

Detailed noise analysis is done in the subdivision review phase. At this point, each lot is considered along with full information on topography, housing orientation and types of abatement possible for the given situation.

Montgomery County has not required any off site mitigation for large developments where the traffic generated by these developments may produce noise impacts on other roadways through existing neighborhoods.

Montgomery County has used owner notification for potentially high noise levels near the airport. Potential buyers will be notified that the property is subject to air traffic noise. This is done even for areas where it is predicted that the noise levels will be 55 dB (DNL) or lower. The reason is that as ambient levels become lower, any intruding noise will be more quickly perceived as an irritant. This owner notification policy is only being carried out in the vicinity of the airport and is not used near other transportation facilities.

Policy contours are generated in a few cases. One example was the example given above in which land use compatibility was carried out with small parcels on a hillside near a major highway facility. This is a very rare procedure, however.

There has been some disappointment in the effectiveness of acoustical fences which were constructed to reduce noise. The design used by some of the developers has not been adequate acoustically.

Located north of the Washington Beltway there is a development that has used multiple noise abatement methods to mitigate highway noise. These include a tall berm, setbacks as much as 150 feet, treed buffers, parking lots located between building and the highway, town houses faced away from the roadway, and the joining of garages and residential buildings in a town house development to produce a noise barrier.

County staff have not noticed a reduction in complaints or other verbal feedback from the public as a result of the noise reduction efforts. The reason given is that people do not really appreciate or are not aware of a lack of noise. If there is a noise problem, complaints are made. There is also the prevailing opinion that some people with noise problems do not complain in order to avoid "advertising" the fact that their house has a noise problem. Rather, they would choose to try to sell their property and move to a quieter area.

Some BEFORE and AFTER measurements have been conducted to determine the effectiveness of noise abatement measurements. These generally showed that the programs being used are successful.

Howard County, Maryland[7]

The noise program in Howard County, Maryland, was implemented in 1989. There were no start-up costs for this program in a formal budgeted sense. Members of the Public Works staff took on the program as extra work. Efforts to start the program involved research of what others were doing and understanding the traffic noise phenomenon.

The state provided assistance for approximately six months prior to implementation of the program. This assistance was in the form of paying the fees for a consultant who was hired for several test cases. In one case, a noise impact review was made for a planned development. This initial financial assistance and advice had a positive result. The development that was proposed ended up being a better development as a result. The houses were upgraded from no basement construction to basement houses. This was done in conjunction with the resulting noise berm design.

The guidelines are contained within the design manual for the Public Works Department. The legal authority that adopted these guidelines was the County Council. The guidelines, generally referred to as the Noise Design Requirement, apply to rail and highway noise sources. Aircraft noise is handled by the State Aviation Administration. The descriptor used for noise criteria is the A-weighted 24-hour equivalent level (DNL). The level used as a standard for impact is 65 dB. The standard for indoor noise is a DNL of 45 dB. The 65 dB exterior and 45 dB interior levels came from the HUD guidelines. The standards are also used as design goals where abatement is required.

The standard refers to the measurement of and prediction of noise levels in the "50-foot building curtilage" area. Regardless of how large a building lot may be, the outside area of activity is defined as 50 feet from any outside wall of the building. As further definition of the use of the 50-foot building curtilage, the following example was given. Should a house be built on a large lot, a portion of the lot might actually exceed the level for noise impact. However, the house must be located on the building lot in such a way that the 50 foot area around the house would be under the 65 dB level.

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[7]Based on telephone interview with Mr. Chuck Dammers, Howard County, Maryland, 5/11/92

Developers are allowed to use either STAMINA 2.0 or the HUD Nomograph method for noise analysis. They have found that the HUD Nomograph and STAMINA 2.0 give similar results for most roadway conditions. For a few cases where there is a substantial amount of truck traffic, they feel that STAMINA 2.0 is the preferred model.

The following guidelines are used to determine whether a noise impact analysis is required:

1. any portion of a planned subdivision that is within 500 feet of an existing or proposed principal or intermediate arterial requires a noise impact study;
2. any portion of a planned subdivision that is within 250 feet of a minor arterial (planned or existing) requires a noise impact study.

The county refrains from providing details on types of abatement that developers must use; however, berms are generally recommended. Other alternatives that have been used are reorienting buildings, leaving certain lots empty, and planting dense foliage plants where only a small amount of noise reduction is needed. Landscaping is required for any barriers that are built, in order to camouflage the barriers.

The exterior design goal of 65 dB is required regardless of the noise levels predicted. Where it is not feasible to meet the 65 dB level, abatement such as barriers may be augmented with added sound insulation to the houses to reach interior design goals.

Further, for those areas where the design goal may only be partially met, the plat for the subdivision must contain the label "noise sensitive area" for each lot affected.

The county has no retrofit barrier program. The county will construct abatement if it is required in conjunction with expansion or reconstruction projects. This has not occurred very much. In one example, the residents won a court case which resulted in the county paying damages to the residents in addition to providing abatement. Part of the damage was compensated for reduced visibility due to abatement measures.

Howard County receives 20-30 subdivision proposals per year. With this level of activity, the existing staff is able to incorporate the noise review along with their other duties.

Howard County has a high potential for residential development in the future. The total population of the county is between 250,000-300,000. The eastern portion of the county has been estimated to be at a 60 percent level of development. The western portion of the county, however, is still very rural. As a result of the level of development in the county, it is anticipated that the noise program will ultimately be very successful. Essentially all the new development that is predicted to take place will be free from transportation noise impacts.

The guidelines that have been implemented by Howard County have created quite an interest in neighboring counties. Most of the county citizens and those in the Planning and Public Works Department consider the implementation of these guidelines to be a success. Operating costs are insignificant since the guidelines are carried out as part of the plan review process for the subdivision portion of the planning in the county.

Orange County, California[8]

As noted earlier, the State of California has a General Plan which includes seven elements, such as fire, police, and noise, etc. The state requires each city or county to have their own version of these elements of the General Plan.

Environmental planning actions in Orange County are guided by both the noise element of its state-required General Plan, and its noise and land use compatibility manual. The noise element became effective in 1975, whereas the noise and land use compatibility manual was produced in 1984. This manual is intended for developers and others to prepare accurate noise reports.

The Environmental Management Agency of Orange County deals only with unincorporated areas within Orange County. Once an area becomes an incorporated city, the Agency no longer has jurisdiction and the city handles the proposals. The land use planning and the development guidelines used in Orange County include both aircraft and highway traffic as transportation noise sources that are regulated. Adjacent noise sources have an accumulative effect. For example, a proposed development near an airport would require more mitigation of any traffic noise that is present in order to keep the total noise, including that from the airport, from impacting residents. There is debate

[8]Based on telephone interviews with Karen Robertson, formerly of the Orange County Planning Commission and John Wayne Airport Noise Office, and Paul Wang of the Orange County Environmental Management Agency.

over the interpretation of the guidelines. Paul Wang, of the Environmental Management Agency, noted that the overall state requirements apply the criterion to any one intrusive element, such as a highway noise source. He does not believe that the criterion or the associated regulations were ever intended to mean the sum of two different sources, such as highway and aircraft noise.

The process for approving a new residential development is as follows. First, the developer or proponent of the development proposes to the planning group the development plans. The plans go to the environmental group for a CEQA (California Environmental Quality Act) Review. The agency's function is to review proposals from developers for noise impact. If warranted, conditions and stipulations are added to other requirements for plan approval to insure that the noise criteria have been met. The decision is then made whether to do an Environmental Impact Report (EIR) or the less rigorous environmental assessment (EA). Almost all developments require the Environmental Impact Report (EIR) process. Generally, any development more than 40 homes requires the EIR. Developers contract with local consultants to design abatement for noise-impacted areas. These consultants must be chosen from a list of 30-40 consultants that has been developed and approved by Orange County.

Following the study of potential noise impacts, any required conditions for approval are then placed on the developer's plans. These can include a wide range of conditions. For example, if the attenuation required results in a barrier over 5 to 6 feet high, a requirement for a berm (which would involve providing more land area) would be stipulated. Aesthetic considerations are the reason for berms and the 6 to 8 foot barrier height restriction. Also, a number of residential areas with views of the ocean have had the stipulation that glass barriers be used so that the view would not be obscured.

If the proposed development does not have noise impacts itself or minimal impacts, the land use may result in enough trips generated that other arterials will have increased volumes to the point that other residential areas could be impacted. The developer would be assessed a cost to contribute to noise mitigation in that area.

The noise descriptor used in Orange County is the A-weighted CNEL. All outdoor living areas in new developments in Orange County must comply with a CNEL of 65 dB or less (for all noise sources combined), and the interior spaces must meet a CNEL of 45 dB or less. An outdoor CNEL greater than 75 dB is considered "normally unacceptable". Above this level, no building permit would be issued. From 65 to 75 dB is considered "conditionally acceptable". In the "conditionally acceptable" range, mitigation is required to bring the levels to 65 dB.

A developer must be able to attenuate any of the noise sources to the point of reaching the design criterion. If this design criterion cannot be met, the development will not be permitted. There are no minimum insertion loss requirements for barriers constructed by the developers. However, any barriers built by the County have a goal of 5 dB insertion loss as a minimum.

It is clear that when a CNEL of 65 dB is reached near an airport that no building is allowed. However, proposed developments at the edge of this 65 dB CNEL are given permission to build, provided the CNEL can be maintained at or below 65 dB. When traffic noise is considered, the developer is unreasonably burdened to attenuate the traffic noise to such a low level that the total combined CNEL does not exceed 65 dB. Mr. Wang suggests that the aircraft noise should not be included at this point; rather, only the prediction of the highway noise and the corresponding attenuation needed to bring its CNEL down to 65 dB should be considered.

There is an arterial master plan that describes proposed lane increases from 4 to 6 lanes on arterials. This master plan is taken into account when a proposed development is being considered. As a result, the developers must often provide attenuation to meet required levels with the proposed arterial. Should a future reconstruction project take place that was not a part of the arterial master plan, Orange County will include abatement as part of the project.

Abatement methods used by the county include barriers and insulation to existing buildings. County money has been spent on private homes for insulation. This procedure has gotten a little awkward at times since the money is considered a gift of public funds to an individual. However, the County Council has ruled that this gift is an acceptable action.

There is a military base in the area which has been thoroughly studied for noise emission. As a result, contour lines were drawn representing the various areas of noise exposure. Following development of these contours, policy was written to convert the noise contours to policy lines. No development can occur within the boundaries of the established policy line. Permanent "aircraft noise impact area" warning signs have been installed at the boundaries of areas exceeding 65 dB CNEL due to aircraft noise.

Land use zoning that to prevent noise problems is somewhat limited. An example of limited land use zoning versus proponent mitigated development was given. Rancho Santa Margarita, a planned community in Orange County, will soon be an incorporated city.[9] It has a total residential population plan of 30,000. A future freeway (eastern transportation corridor) is planned through this city. As a result of proponent mitigated development, the homes currently being built along this proposed freeway have sound walls, sound-reducing windows, additional insulation, etc. This strategy was chosen rather than land use zoning since there is not enough industrial and commercial land use demand to form a buffered strip along the mileage of freeway that will exist. Further, the trend in planning is to stay away from strip commercial and industrial land development. Instead, the goal of planning is to provide centers of commercial and industrial activity. The concept of centers is seen as being efficient in terms of access to the centers and the cost of constructing them. For this particular community, the planned commercial and industrial areas will be located near a major interchange for the planned freeway.

In a few rare exceptions, the county has given the homeowner the option of having a noise wall built or receiving a one-time payment of money to compensate for the noise. If the homeowner accepts the payment, he must also sign an agreement that requires him to make the next homeowner aware the house may not be up to noise standards at the time it is sold.

Cited as an important contribution to the overall success of this program has been the decision to convert contour lines in certain areas to policy lines. As a result, there is not an annual fluctuation (i.e., update) of these lines nor is there constant litigation to challenge the lines. The overall effect is to remove the debate and exceptions regarding land use plans resulting in a large savings of time for everyone involved.

[9]Based on telephone interview with Fred Greve, Mestre-Greve Associates, 6/2/92.

The program has been a success in terms of its timing. Since the program went into effect prior to the huge residential building era in Orange County, most of the county has noise compatible land use.

No information is available regarding the cost to administer this program. It was noted that developer costs, including materials and consultants, are passed onto the housing buyer, which results in higher real estate taxes being paid to the County.

San Diego County, California[10]

The noise element for the County of San Diego includes a map with noise contours plotted for the county. For the contours with the highest noise levels, residential development is prohibited. This prohibition applies regardless of what techniques a developer may think could be used to bring the noise level down to the design goals for residential areas.

The County of San Diego has approved developer plans to mitigate transportation noise using a full-range of techniques such as walls, berms, insulation of houses, orientation and placement of buildings on the lots, etc. The noise abatement design goals for developers trying to meet outdoor levels is 60 dB CNEL (A-weighted). The interior residential levels are 45 dB CNEL.

The County of San Diego has built a few noise barriers where roadway improvements were being made. Alternative truck routes have been designated for the purpose of reducing noise in selected areas of the county. No homes have received insulation using San Diego County dollars.

For the case where a proposed development is judged to generate enough traffic to produce a noise impact for other residential areas, the developer must contribute funds toward the mitigation costs of the noise in those other areas.

CITY AGENCIES

Toronto, Ontario, Canada

The City of Toronto adopted a Noise Control Program in December, 1973. A

[10]Based on telephone interview with Alexander Segal, County of San Diego, 6/18/92.

key requirement of this program was that all aspects of future development and land use were to be evaluated in light of their impact on Toronto's sound environment.[11]

A Noise Control Branch was established to administer the noise program. The cost of establishing the Noise Control Branch was approximately $350,000 - $400,000. The approximate annual operating cost of $300,000 to $500,000 is required to administer the Noise Control Program at the Toronto Municipal level. Currently there are ten staff members in the Noise Control Branch. The responsibilities of this branch are listed as follows:

1. Enforcement of the city's noise By-Law
2. Processing citizen's complaints
3. Noise monitoring
4. Neighborhood surveys
5. Sound attenuation of city equipment
6. Public education programs
7. Maintenance of noise data bank
8. Noise impact statement evaluation
9. Monitoring of special events

In general, enforcement is carried out by both the Metropolitan Toronto Police Force and by the Noise Control Branch. The more technical portions of the By-Law are enforced by the Noise Control Branch while those sections which relate to noise produced sporadically which elicits complaints requiring immediate action are enforced by the police.

Some examples of the types of noises covered by the By-Laws are as follows: yelling, shouting of peddlers, animals, birds (i.e. pets), model airplanes and hobby equipment, radios and hi-fi's, horns, streetcar bells, vehicles out of repair or with faulty or no mufflers, power lawn mowers, etc. (snow blowers excluded), air conditioners, and other machines or stationary engine noises, public transit noises, garbage trucks, construction sites, and stock car racing.

In 1991, the City of Toronto received over 3,000 inquires or complaints of noise

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[11]City of Toronto Noise Control Program - Progress Report No. 2.

disturbance. The complaints led to five convictions. Since 1974, the dominant complaints involved animals (pets), accounting for 36% of all complaints. Most of these complaints involved barking dogs. Those complaints received which are covered by the bylaws are deferred to local police departments. Bylaw items include loud mufflers, noisy parties, loud music, etc. The police, however, put a low priority on enforcing the noise bylaws. Further, they do take a very conciliatory attitude in a lot of these disputes which tend to involve feuding of neighbors. The minimum fine for violation of the noise ordinance is $50 and the maximum fine is $1,000. In one case of a noisy party, the newspaper coverage of a large fine appeared to have had quite an impact on readers who realized the seriousness of noise ordinance enforcement in the city.

A major activity of the Noise Control Branch is the Noise Monitoring Program and Neighborhood Surveys. This program involves noise sampling at the intersections of a quarter mile grid system which has been superimposed on the city map. The noise statistics monitored for each site on the grid are L_{90}, L_{50}, L_{10}, as well as L_{eq} for a 24-hour period each year. Until recently, the number of monitoring points was 569. A period of 48 months was required to complete the monitoring of all 569 points. The number of points monitored has since been reduced to 240. This reduction in the number of points, along with the purchase of additional monitoring equipment, allows for a complete cycle of monitoring to be made for the city in one year.

Though not a part of the Noise Control Program, the City of Toronto has adopted noise and land use guidelines. Any applicants requesting an official plan change or rezoning must submit a Noise Impact Statement. This Impact Statement must describe: 1) impact of the development on the neighborhood, 2) impact of the neighborhood on the development, 3) impact of the development on itself.

Calgary, Alberta, Canada

The Transportation Department of the City of Calgary regulates traffic noise sources (major arterials and freeways) and rail noise (heavy rail and light rail). Residential noise receivers are considered; however, schools, hospitals, etc. are not included in this policy. The noise level standards apply to outdoor leisure areas. If this area is not well designated, then the alternative of 4.5 meters within the property line is used as the receiver position.

The design noise level is the A-weighted 24-hour equivalent noise level of 60 dB. Where noise abatement is required, the predicted attenuation must achieve this design noise level. Where noise barriers are constructed, a minimum of 5 dB reduction must be achieved, with a target of 10 dB. The policy also states that achievement of the design noise level must be technically, economically, and administratively feasible.

Impact analysis of noise sources is handled as follows. For an existing residential development, a survey (in response to a complaint or other means of calling the site to attention) is made by field measurements or predictions with a computer model. If warranted, a full impact analysis will be accomplished with the City of Calgary paying the cost. For the case of a proposed residential development near either an existing transportation corridor or a future one, the impact analysis is paid for by the developer. The analysis is then reviewed by the City of Calgary Transportation Department.

Implementation of measures to reduce noise impacts where required are handled according to guidelines for four different cases. These cases are characterized by the type of development, the type of noise source, the developer's responsibilities and the city's responsibilities.

1. Case I: Proposed Development, Existing Roadway. The residential development type for Case I is a proposed development (or redevelopment). The transportation noise source is an existing roadway or one that is imminent in its construction. Imminent is defined as a roadway that will be constructed within the next ten years. The design volumes for the roadways are based on the volumes predicted ten years into the future. The developer's responsibility is to propose an abatement method. The city's responsibility is to review and approve the abatement plans. The developer then must provide the approved abatement at the time of development.

2. Case II: Proposed Development, Proposed Roadway. For this case, the development is proposed as in Case I. However, the transportation noise source in this case is a future planned source. The timeframe here would be greater than

ten years into the future. The developers responsibility is to design the development with adequate provision to construct the needed abatement when required in the future. The city's responsibility is to actually construct the barrier, berm, etc., when it is needed in the future.

3. Case III: Existing Development, Existing Roadway to be Expanded. The type of development considered in Case III is an existing residential development. Also the transportation noise source is an existing one that is being expanded (for example, adding lanes to a roadway). In this case, the city will provide abatement to achieve the design noise level as a part of the construction project. This is not part of the retrofit program.

4. Case IV: Existing Development, Existing Roadway. The development for Case IV is an existing residential development. The transportation noise source is an existing one as well. For this case the retrofit program developed by the City of Calgary in 1985 outlines the responsibilities for the city. In essence, the city must investigate noise complaints. If a noise barrier is warranted, its cost, the number of people served and the noise reduction expected are all factored into a formula to arrive at a priority number.

Saskatoon, Saskatchewan, Canada[12]

The noise and land use compatibility program for Saskatoon was developed totally within the city. There were no guidelines or assistance from the provincial level. While there is a Ministry of the Environment for Saskatchewan, there is no noise control group or department, and very little funds are available. Also, no assistance or funding is available from the Department of Transportation for the Province of Saskatchewan.

The program for Saskatoon began in 1984 with an investigation of what other cities were doing in the area of noise control. Following the investigation, some guidelines were developed for the city. This investigation as well as the resulting

[12]Based on telephone interview with Mr. Tom Mercer, City of Saskatoon, 4/10/92.

guidelines focused on traffic noise rather than stationary sources such as air conditioning units, etc.

The descriptor used for the original guideline was the A-weighted 24-hour equivalent continuous level with a standard of 65 dB. This standard remains in use for two programs currently in effect in Saskatoon: the retrofit program and the new residential development program.

In 1990 another study was commissioned, which was completed in 1991. This study was more in depth, involved the purchase of some noise measuring equipment and led to the monitoring of a number of locations around the city. As a result of the research for this study, the DNL was selected as a noise descriptor, with the standard of 65 dB. Again, this criterion applied to both the retrofit and new development programs.

The retrofit plan has involved the listing of those areas qualifying for noise abatement based on a cost-benefit evaluation, and the various areas have been prioritized. Due to the location of receivers in Saskatoon, probably the worst noise situation for a receiver is approximately 75 dB. The worst highway traffic situation would be ADT of 40,000.

The first noise barrier in Saskatoon is currently under design. Assuming funds become available, the projected date for construction is in 1993 or 1994. Most of the sites on the retrofit list have been in existence in terms of the presence of the roadway and the receivers since the mid-1960s as a minimum. However, the first site for the barrier that is currently being designed is for a freeway that was built in 1983.

There is no Environmental Assessment procedure in Saskatchewan at this time; however, this is probably coming in the future. A developer must work with the city to design a subdivision plan. He generally would meet with the Planning Department; however, the plans would also go to engineering, school boards, parks, fire and police, etc. The policy end of the decision is made by the Municipal Planning Commission whereas technical issues go before the technical committee. Once the plan is approved on the city level, the approval must go to the provincial level, the Department of Urban Affairs.

For the case of a new residential area being built near an existing highway, the traffic would be counted and existing levels measured. Then a prediction would be made for a future year, the design year, and that result compared with the criterion. If the predicted level would be a DNL of 65 dB or less, nothing would be done. Probably nothing would be done up to a DNL of 70 dB. At 70 dB or greater, abatement would definitely be considered necessary.

If abatement were to be considered, the first step would be to determine the type of abatement, for example, berm or wall. For most existing situations, space limitations necessitate the use of a wall. The height of the wall would then be determined as well as the cost and the number of people served. This would lead to a cost-benefit ratio which would be a factor in the prioritizing of sites. Any noise barrier built in Saskatoon must achieve an insertion loss of at least 5 dB.

For new residential developments, the process is very similar. The design year would be selected according to when it would be expected that the residential area be fully developed. Measurements of existing traffic and existing noise levels would be made and future levels predicted. For the case of new development, regardless of the predicted noise level, the result with abatement must be a DNL of 65 dB or less. If the developer is unable to obtain 65 dB, the development will not be approved.

Where abatement is required, berms are typically preferred over walls. Part of the reason for this is the added buffer distance that berms create between the residential area and the roadway. The berm is placed such that the property line for the resident is at the top of the berm. The property owner then maintains his side of the berm while the city maintains the roadway side of the berm. A wall may or may not be built upon the berm depending on noise requirements and desire for privacy on the part of the residents or the aesthetic considerations of the development.

Where abatement is required for a future development, the developer must provide the land and construct the berm. While the developer contracts to have the berm constructed, all plans are reviewed first by the city. As traffic would increase, the final attenuation required would possibly entail the use of a wall on top of the berm. The costs for this are included in the prepaid service charges that a developer must pay which includes the cost of streets, sewerage, etc.

Right now, almost all the development in Saskatoon is on the periphery of the city. Traffic volumes are very light on these roadways, and in many cases, are not very heavy even with a 50 year projection. As a result, they are finding that by just constructing these berms along with the physical separation of the "buffer zone" that the barrier imposes, they are finding that the levels are low enough that a wall is not required and may not be required in the foreseeable future. Consequently many aesthetic type walls are being built on top of the berm rather than noise walls.

Carlsbad, California

Carlsbad has a noise element that is considered by some consultants to be one of the more stringent codes in southern California. At the time of this survey, however, no acoustical person was available in Carlsbad to discuss the program. The following information is based on a review of the noise policy.

Noise studies are required for all residential projects of five or more dwelling units within specified distances from the right-of-way for the main highways through the city. For an example, this distance is 2,000 feet from the right-of-way of Interstate 5. The local airport is also recognized as a dominant noise source and noise studies are required within its area of influence.

Developers must mitigate noise sources to a level of 60 dB CNEL maximum at the outdoor living areas for residences. This outdoor living area is defined as 5 feet inside the proposed property line at a 6 foot height above the finished grade. Interior noise levels must be mitigated to 45 dB CNEL with the windows closed. If any openings are provided, mechanical ventilation must also be provided. If the above standards cannot be met, the development is not to be approved unless the developer can demonstrate to the satisfaction of the Planning Commission that it is not feasible to comply with the standards. Further, to obtain approval under these circumstances, the interior noise levels must be reduced to 45 dB, and there must be overriding social and economic considerations which warrant approval of the development. In addition, all purchasers of the impacted property are to be notified in writing that the property they are purchasing is noise impacted and does not meet Carlsbad noise standards for residential property. In no case shall development be approved for areas that exceed 65 dB with mitigation.

The notification of purchasers of parcels and tracts of land is also required for those areas which are near existing or future transportation corridors. The notice to future purchasers indicates that noise impacts may be present from the proposed or existing corridor. This same procedure is carried out for residential projects within three miles of the local airport. In addition, notification signs must be posted at all sales and/or rental offices associated with any new development within the affected area of the local airport.

Fullerton, California[13]

The City of Fullerton was the first of the four cities chosen to be the subject of a series of USDOT case studies in the 1970s [USDOT, 1979]. Fullerton has chosen to use the A-weighted CNEL with a standard of 60 dB instead of the 65 dB value that is used by most other local agencies in southern California. The 65 dB was typically adopted by most of the other local agencies since the county used a CNEL of 65 dB. There is, however an "escape clause" in the Fullerton guidelines. If it is not feasible for a development to reach the CNEL of 60 dB, then up to 65 dB is permissible. However, under no circumstances can the predicted levels be above 65 dB.

The state requires a maximum interior level of 45 dB for multiple family dwellings. There is no state requirement for single-family dwellings. However, Fullerton, as well as many other local agencies in southern California, has adopted the 45 dB maximum level for single-family dwelling interiors also.

The standard applies to "useable outdoor living space". This definition is significant because some outdoor areas within the property are not considered useable. The front yard is one of these areas, and side yards also are generally not considered useable outdoor living areas. These non-useable areas may be above the maximum allowable standards referred to above. However, if a backyard living area meets the requirements, the guidelines are satisfied.

Because of this interpretation, it is possible that the orientation of a house on a lot may mean that the interior levels become critical in terms of the guidelines. That is, the interior levels might exceed the maximum allowable even though the outdoor useable

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[13]Based on telephone interview with Barry Eaton, Fullerton, California, 6/11/92.

space might be acceptable. Most consultants consider that an outdoor level of 60 dB will produce an indoor level of 45 dB with standard construction. Therefore, an outdoor level higher than 60 dB requires special construction techniques to maintain the required indoor level.

The city has a specification that all apartments and condominiums must have an outdoor patio or a deck. This presents a problem for developers, particularly with second-floor units. Generally, these decks must be facing away from the traffic source. Many times the second-story must have non-standard construction to achieve interior levels that are acceptable; whereas, the first-story may meet standards with standard construction. That is, a noise wall built to shield the outdoor living area would be shield the first floor but not the second floor.

Fullerton does not attempt to zone areas along freeways for industrial and commercial use on the basis of noise compatibility. This is not considered good land use planning since it promotes strip development for businesses.

Prior to the development of noise standards in Fullerton, the planning department received a lot of complaints from residents concerning traffic noise. Since this program has been in effect, they receive essentially no complaints from those residents living in developments constructed after the guidelines were in place. However, they still receive complaints from previous developments where noise remains a problem.

The administrative costs for the program are "minimal". Noise is just one element of the many considerations in the planning process, so it requires little additional time. Developers are familiar with the guidelines and consultants are experienced in carrying out the requirements, which facilitates the process.

While the guidelines and standards have been very satisfactory, there have been a few times when the commission has not remained strong in defending the guidelines against developers. Also, no sound measurements have been made in residential areas or developments to verify that the standards are being met.

Cerritos, California[14]

The City of Cerritos was the second of the four cities that were the subjects of a series of USDOT case studies in the 1970s [USDOT, 1979]. The noise ordinance for Cerritos requires an A-weighted CNEL of 55 dB in the area of outdoor living with 60 dB at the property line closest to the freeway. Interior levels of all residences are to be a maximum CNEL of 45 dB. Industrial levels at the property line are not to exceed a CNEL of 70 dB.

Cerritos originally considered zoning the land adjacent to freeways for commercial use. However, the number of miles of freeway through the city was so large that there was not enough commercial activity to use this much land. Further, commercial strip-type development, which noise-related zoning could result in, was not considered acceptable. Therefore, the conclusion reached was that residential development must occur adjacent to freeways. All new houses must meet interior sound level requirements.

When Cerritos made the decision to require mitigation of highway noise, it was also decided that a retrofit program was needed. The redevelopment agency funded the construction of buffer zones for residences near freeways. The total length was 25,000 linear feet of buffer for over five miles of freeway.

The buffer included a berm plus a masonry wall which was an additional 6-8 feet on top of the berm. The total height of the berm and wall averaged 22-24 feet. This height was chosen so that the top of the wall would be about 3-4 feet above the top of second-story windows in the houses. The city further convinced Caltrans to allow planting of climbing plants on the walls to eliminate the problem of graffiti. The cost of this retrofit noise abatement was between $200 and $325 per foot of freeway.

Acoustical windows were also installed in the houses as well as air conditioning and electrostatic filters to remove road dust. Charcoal filters were used to absorb pollutants from the air. To further control highway dust, a tree called "Cypress Lylandie" was planted on six foot centers. These trees, which grow 30-40 feet high, tend to have roots that grow straight down and do not interfere with foundations. The city has conducted some measurements to evaluate the effect of the noise mitigation

[14]Based on telephone interview with Mr. Ali Soliman, Cerritos, California, 6/11/92.

measures. Those houses that were measured prior to any mitigation typically had indoor levels of 48-53 dB. The houses after mitigation are well below 45 dB interior levels.

Arrangements were made with the California Department of Transportation (Caltrans) to allow encroachment of the buffer zone onto state right-of-way. Also, arrangements were made for the maintenance of this area of the buffer by Caltrans. Maintenance of the buffer zone on the residence side was assured by requiring residents to sign an agreement with the city. This agreement was then recorded on the lot deed such that future owners of the residence are bound by the agreement when they purchase the property. Part of the agreement was that the homeowner furnish the water for irrigating the buffer zone area. If a homeowner fails to do this, he is fined. There is little maintenance required of the homeowner in reality since most of the plantings were ice plants which only require water. The portion of the buffer zone that was on state right-of-way is maintained through an easement that the city has with the state. The city then adds another easement with the resident on top of the easement that the state has with the city to allow the resident to do maintenance.

The city continues to designate certain routes as truck routes. One example was a new industrial area that was located adjacent to an existing residential area. As a buffer, the city constructed a divided street between the industrial and residential areas. Further, a large setback was required for any buildings in the industrial area. Only automobile traffic was allowed to enter the industrial area from this divided street. An access road for truck traffic was placed at the back of the industrial area to allow trucks to have access to the buildings without driving on the residential street.

The success of the program is judged in part by the property values that have been maintained for houses adjacent to freeways. In many cases, the houses sell for more than the other houses in the subdivision because noise is not an issue and the additional buffer zone landscaping is appealing. The mitigation efforts have essentially eliminated the noise problem for residences.

Irvine, California[15]

The City of Irvine was the third of the four cities to be the subject of one of USDOT case studies in the 1970s [USDOT, 1979]. The City of Irvine has had a noise element as part of its general plan since the 1970s, as required by the State of California. Noise contour lines were developed for the entire city in the early 1980s. Since Irvine has highway, rail and aviation noise (there is one commercial and two military airports that impact the city), it has chosen to use the contour lines somewhat differently. The contour lines are actually converted to policy lines. Within certain contours, no development can occur. As the noise level decreases by each contour, various types of development become options for consideration. It is the land use element of the general plan that dictates the types of development that would be considered for different parts of the city. Irvine, in considering its land use element, considers the noise contours as a key part in the decision process. For example, there are several types of residential development, as well as commercial, institutional, industrial, and agricultural land uses which are recommended for consideration within the various contours.

The Planning Department will only consider proposed developments that are consistent with the land use recommendations. However, the development must be able to reach the standards established for noise levels for that type of development. Residential development is prohibited in contours with equal to or greater than 65 dB CNEL (A-weighted). Residential development must achieve a 45 dB interior CNEL with the windows closed (55 dB windows open). The developer is responsible for noise abatement required to achieve the standards listed in the noise element.

The city requires that a noise study be carried out for any proposed development prior to issuing the building permit. The typical process in Irvine involves the developer proposing a certain type of development in a specific location. The question must be answered as to whether there are noise impacts. If there are impacts, the developer must propose abatement to achieve the standards listed in the noise element. If the Planning Department approves the methods proposed by the developer, then the project can move forward in the planning process. This study, which is made by consultants in the area,

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[15]Based on telephone interview with Mr. Mike Balsamo and Mr. Dan Jung, Irvine, California, 6/12/92.

must identify all noise sources that impact the proposed development. In Irvine, these can be rail, highway, or aircraft noise sources. The study also must take into account projected traffic growth and induced growth due to the development. The increased traffic is first used in the prediction of levels which are then used in the abatement analysis.

While most sound walls in Irvine have been built either by developers or by Caltrans, the City of Irvine has built a few barriers. Irvine has also insulated some homes. Currently, there are a couple of projects involving overpasses where the city plans to install sound insulation (mostly in terms of acoustical windows) for houses impacted by this project.

Airport noise is a primary motivation for zoning certain areas as nonresidential. Since aircraft noise cannot be mitigated as easily as highway noise, residential development is not considered within high noise level contours produced by this mode.

A problem has occurred in Irvine with industrial and commercial noise standards. These standards, which apply to interior levels, are less strict than residential interior levels. Therefore, industrial and commercial developments have tended to be built in areas where the contours represent high levels from aircraft noise. Recently, however, there has been a desire to incorporate day care centers on the industrial and commercial properties. Day care centers, being an institutional land use, have an outdoor noise requirement as well for playgrounds. The location of the commercial developments is such that the standards cannot be met for the day care outdoor levels. Also, there is no way to abate the noise since most of it is from aircraft flyovers.

At one time Irvine had an environmental section which considered not only noise impacts but all environmental assessments. This section no longer exists and Irvine has no acoustical experts on staff; rather, they rely on consultants.

The cost to administer the compatibility program is minor for the city. It is just one step in many steps of the development process. Also, developer-paid fees offset the development process cost.

The Noise Control Program for Irvine has been judged as successful, based on the many noise measurements made throughout the city. Developments that were constructed since the noise ordinance was in effect (which comprise most of the city) have had no impacts from noise. In essence, all residential areas are experiencing an outdoor CNEL of 65 dB or less in Irvine. The few problem areas that do exist in the city were those sections constructed prior to the current noise element guidelines.

Lavonia, Michigan[16]

The City of Lavonia was the fourth city to be represented in the USDOT case studies [USDOT, 1979]. The solution to highway traffic noise for residential areas in Lavonia resulted from the implementation of a subdivision rule in the zoning ordinances. These provisions required the establishment of a greenbelt easement for all single-family subdivisions located adjacent to freeways or arterials. The greenbelt easement must be at least 30 feet in width. The purpose of the greenbelt is to reduce the visual and noise intrusion of the freeway for the residences located adjacent to the freeway. The greenbelt includes a berm as well as plantings to accomplish these goals. The original USDOT case history of Lavonia, described the Quakertown subdivision which made use of the greenbelt concept. The greenbelt not only created a buffer between the residences located adjacent to the freeway but actually enhanced the value of these lots to the point that the developer was able to sell them as "premium" lots. While there is no quantitative data regarding noise levels in this development, very few complaints have been reported to the planning commission in the years since the construction of the subdivision.

Two other minor developments have been constructed since the Quakertown subdivision. One development on the opposite side of the freeway involves approximately two dozen lots. The greenbelt was somewhat smaller than the one used for Quakertown due to constraints at that location. The other development along the freeway was also a small one in which the developer had planned a park between the freeway and the first row of residences. Again, the lack of complaints regarding noise has been the main criterion for judging the greenbelt concept to be a success.

[16]Based on telephone conversation with H. G. Shane, Lavonia, Michigan, 5/28/92.

LOCAL NOISE ORDINANCES

As described in the Phase I study, the most common form of local noise control involves enforcement of a local noise ordinance. Local noise ordinances are found in most communities and tend to be reactive in nature in contrast to noise and land use compatibility planning. These ordinances typically deal with a wide range of noise sources including noise from pets, lawn grooming equipment, and stationary sources such as air conditioners, exhaust fans, etc. Two noise control programs, administered by local agencies, were found to be exemplary. These were the county of Orange in California and the city of Boulder in Colorado. A number of local agencies interviewed in the course of this study have emphasized the complimentary nature of the noise ordinance along with land use and noise compatibility planning. Therefore, a summary of these two exemplary programs is included in this report.

Orange County, California[17]

The Orange County Noise Ordinance was established in the early 1970s to set limits for community noise in residential neighborhoods. As such, it regulated both the noise generated within the residential neighborhoods as well as any other sources such as industrial sources that might intrude into residential areas.

The Department of Environmental Health administers the ordinance. However, due to the demise of the EPA Office of Noise Abatement and Control in the early 1980s, as well as a budget crisis in Orange County, the program is now operating at a much reduced level. Although the position of Noise Specialist was eliminated in 1991, and Environmental Health supervisor is currently performing basic noise specialist duties at the present time.

The Environmental Health Department had contracts with 24 of 32 cities in Orange County up until 1991. These contracts were to answer complaints regarding noise in Orange County. Each city had a noise ordinance which was, in essence, the model county ordinance which each city adopted if the county was to be responsible for enforcing the noise ordinance.

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[17]Based on conversations with Alan Stroh of the Orange County, California Department of Environmental Health.

When budget problems caused the elimination of the Noise Specialist position, it was thought that the entire program would be eliminated. To eliminate the program, the noise ordinance needed to be rescinded. However, there was political pressure to maintain the noise ordinance, therefore, the department is still functioning but at a greatly reduced level. The county responsibilities include only the unincorporated areas of Orange County. Each of the incorporated cities must now do their own noise enforcement.

According to Orange County officials, many other local jurisdictions in the State of California and even outside of the state are experiencing the same problems. The lack of funding from the EPA, as well as the problem with municipal budgets, has ended many community noise enforcement programs as was described in the Phase I WSDOT study.

The original program in Orange County was started with EPA grant money to capitalize the program. This grant included the purchase of sound measuring equipment and a van. If the EPA office had continued to be functioning in the 1980s, another grant to purchase needed replacement equipment might have been available. In that case, the program could have continued, based on fees collected from each city in Orange County that had a contract with the Department of Health. Also to continue operating as before, the fees for the cities within the county would have had to been increased.

Currently, in the State of California, all noise programs must generate enough fees to offset their expenses, or else the programs are eliminated. The noise ordinance program manager is of the opinion that the noise ordinances are most efficiently enforced on a county level since only one agency needs to have the equipment and personnel to do the enforcement. The 32 cities are now faced with the decision whether to buy some amount of sound measuring equipment on their own as well as provide staffing to carry out the enforcement procedures.

Since the Health Department's responsibilities have been reduced to enforcement of the noise ordinance in only the unincorporated portions of Orange County, the workload has been greatly reduced. The Department is currently spending between 14% and 18% of one man year in noise ordinance enforcement. The staff is also minimizing the amount of time spent in the field monitoring. In place of this, they are spending more time on the phone answering complaints and dealing with problems.

Ironically, after all the cuts, approval was granted for purchase of a noise van and $16,000 worth of noise measuring equipment. As a result, the department will have the equipment that is desperately needed for replacing the old, failing equipment, but it no longer has an enforcement person knowledgeable in the field.

Boulder, Colorado[18]

In the late 1960s, the citizens of Boulder, a city of 85,000 population, wanted a quieter environment. As a result, a number of the citizens researched the issue of noise control for communities and suggested a noise ordinance. In 1970, the Boulder City Council passed the noise ordinance and allocated funds to provide a department to enforce the noise ordinance. One person was hired for this department to write letters to muffler shops, provide public information, and hire off-duty police officers. The off-duty officers drove the marked police car that was provided to the department. Sound level measurements were made at a complaint site by noise specialists. Initially, most of the efforts of the Noise Control Department were directed to enforcement of the laws against noisy mufflers.

In 1977, city-wide budget cuts hampered the activities of the Noise Control department. As a result, the Noise Enforcement Department requested that its staff be trained at the Police Academy to become commissioned officers. As a result of this request being granted, the noise enforcement officers are now uniformed, drive the marked police car, and write tickets for violations of the noise ordinance.

The noise ordinance states that from the hours of 7:00 a.m. until 11:00 p.m. the noise level from a given source shall not exceed 55 dB at the property line where the source is located. This A-weighted level is reduced to 50 dB during the nighttime hours of 11:00 p.m. to 7:00 a.m. Octave band levels are not considered since the noise enforcement officer must quickly assess the noise level at any given time in response to a complaint. The Day-Night Level descriptor is not used.

Not all complaints result in a violation. If a violation does occur, a warning may

[18]Based on telephone interview with Ms. Terry Steinborn, 5/12/92.

be given if it is a first time violation. Suggestions may be made regarding how the noise offender may reduce the noise level to his neighbors. If a repeat violation occurs, a summons to court may be issued. Court appearances can result in fines up to $300.

In the late 1970s, the department was also given responsibility for not only vehicular noise and vehicular smoke, but also trash, snow removal, pesticides, and other nuisances. The department then hired a second person and became known as the Environmental Enforcement Department.

The types of vehicles that are the object of violations has changed over the years. In the 1970s, the large V8-powered American cars with "glasspack" mufflers received many tickets. However, the trend has been away from these cars so that loud car mufflers are no longer much of a problem.

Motorcycle noise has also changed. Due to the EPA regulations for motorcycles, most new motorcycles meet the noise ordinance in Boulder. In the earlier years, the owners of Harley Davidson motorcycles, in particular, were often ticketed because of noisy mufflers. Now Harley Davidson motorcycles are less of a problem, and the owners of high-powered Japanese "racer" type motorcycles with "tuned exhausts" are receiving more tickets. The department also encounters off-road motorcycles being operated on the streets and thus violating the noise ordinance.

In 1977, it was common for 30 tickets to be issued within one shift. At that time it was estimated that ten percent of the cars did not comply with the Boulder noise ordinance. Today, it is common for the department to go an entire shift without writing one ticket for a noisy muffler. The number of cars failing the noise ordinance is estimated at 1 in 200 vehicles. In 1978, the department was given the responsibility for enforcing the ordinance for other nuisance type noise sources, particularly parties. The officers are on duty a number of nights during the week to answer complaints of noise from loud parties. This added responsibility is due to the reduced need for vehicle noise enforcement. Last year 2,000 complaints of noise sources such as parties were answered by the department.

During the 1970s when the EPA office was funding noise control programs, approximately 80% of the communities in Colorado developed some kind of noise ordinance. Typically the ordinance was enforced by the Police Department. Boulder and

Colorado Springs were the only cities to allocate an entire department for noise enforcement. Today, these two cities are the only cities in Colorado with an active noise program.

Two events were cited as leading to the demise of municipal noise enforcement in other Colorado communities. The first was the municipal budget crunch that occurred in the late 1970s and early 1980s. The second was the end of funding from the EPA. As priorities changed within the communities due to budget cuts, no money was allocated for training of noise enforcement officers. As new officers were gradually replacing those who had moved to other departments, funding was not available for noise enforcement training. This problem might have been averted if the EPA funding had remained. Without both municipal and EPA funding, noise enforcement was considered a low priority and something that the Police Department could handle.

There is now a resurgence of interest in noise control from many municipalities in Colorado. Boulder is being used as a resource to these communities since it maintained both its noise ordinance and its enforcement department. The department generally holds at least one training session per year for municipalities that desire to send trainees. Last year a relatively large seminar was held with a number of municipalities participating. For example, Aurora sent 15 planning people to become familiar with the noise ordinance and noise control. This community had specific concerns regarding noise from the new Denver International Airport.

Department staff attribute the success of the Boulder noise program to "a well-written noise ordinance, a separate department for enforcement which has the legal authority to write tickets, and a citizenry that is environmentally aware." The working relationship between the department and the citizens has been helped by frequent media attention to actions by the department. Since this publicity heightens awareness of the department's activities, the citizens who are interested in environmental issues are more supportive of the department and the program. The Noise Enforcement Department also reports once a year to the city council with a listing of the activities and accomplishments from the previous year.

It was suggested that there is an advantage to having a separate department for noise enforcement. The Police Department appreciates the second department because they can concentrate on those items that are typically of priority for them. The citizens like the separate Noise Department because they know that when they register a complaint it will be investigated in a timely manner. In other municipalities, such as Denver, the Police Department must handle noise complaints. However, it is a lower priority for them and many of the complaints go unanswered or require a long response time. As a result, many of the citizens do not bother registering a complaint. Noise complaints are typically handled in three to four minutes. The noise enforcement officers are so familiar with the city, the problem areas, and the noise ordinance that they know just what it takes to resolve the problem. As mentioned above, a complaint may result in a warning or issuing a ticket. Judgments are made by the noise enforcement officers regarding the level of penalty required. In general, a conciliatory approach is taken by the noise enforcement officers.

For communities without a separate noise department, the police are limited in their ability to carry out the requirements of the noise ordinance. They do not carry sound level meters. As a result, they must act upon a city ordinance for disruption which requires that the complainant sign the complaint. Many times those issuing a complaint prefer to be anonymous. The Noise Enforcement Department does not have this disadvantage since its staff carry sound level meters. The ordinance is enforced on the basis of the level of noise being produced. No signature is required for the complaint, and the identity of the one making the complaint is withheld.

The annual operating cost for the noise control program is $125,000. This amount covers salaries for two officers, a half time secretary position, and one patrol car.

Noise and land use issues are addressed by the Boulder planning department, which has guidelines based upon the type of roadway and/or the traffic volumes involved. There may be one or two developments a year that are flagged by this process for review regarding noise impact. A Development Review Committee includes a member of the Noise Enforcement Department for those developments with anticipated noise impacts. The Development Review Committee also includes members of the police, fire, utilities and other departments. The HUD Noise Guidebook is used in determining both the impact and what requirements developers must meet to mitigate the noise impacts.

While the Noise Guidebook is used, there are no formal guidelines incorporated in planning or the noise ordinance. The requirements could result in specifying the height of a wall or a berm as well as the construction type and the location of the berm or wall. A typical barrier might be a solid, double-faced wood fence. The barrier height is generally determined by ensuring that the top of the barrier breaks the line of sight for the path between the source and the receiver.

APPLICATIONS AND IMPLEMENTATION

The purpose of this research was to take an in-depth look at issues related to traffic noise control at the source and at the receiver and to provide WSDOT with information to assist in its decision-making on noise mitigation plans and programs. As such, this study is a follow-up to an earlier Phase I study titled Comprehensive System-Level Noise Reduction Strategies. The Phase I study focused largely on state DOT programs and activities, but also did a general analysis of source and receiver control issues. The Phase I study also examined activities in Washington State and made an extensive series of recommendations for implementation to WSDOT based on the findings.

This section of the current study will first summarize the key findings and recommendations of the Phase I study as they relate to source and receiver control. Then, new federal initiatives that relate to those recommendations will be discussed. Finally, this section will develop a framework for examining the costs and benefits of the various noise mitigation measures.

SUMMARY OF PHASE I FINDINGS AND RECOMMENDATIONS

As noted in the Phase I study, there are three key factors that must be in place if a state wishes to successfully mitigate its transportation noise problems:

1. the public must demand traffic noise mitigation;
2. the legislature must respond with laws conducive to noise mitigation; and
3. the administration must be committed to implementing the laws.

Even given the above, two other key factors must be kept in mind:

1. noise abatement must compete with other areas of environmental protection that the public, the legislature and the administration sometimes choose to be more important; and

2. demands, laws, choices and policies are useless without the resources to bring about action.

More legislation is needed and more administrative support is required in terms of staff and funds, or else the efforts will not succeed.

Federal, State and Local Programs

The Phase I study noted that because noise problems are geographically specific, one of the most appropriate control elements would be at the local level. In terms of transportation noise, a local government's main power lies in its ability to control land use and to require developers to mitigate noise levels to certain standards using any number of abatement measures. The one problem that may be encountered within local government is a lack of expertise. However, some state governments are prepared and equipped to provide the necessary expertise whenever needed. The federal government used to be able to provide a great deal of assistance through the EPA Office of Noise Abatement and Control (ONAC), but Administration cutbacks in 1982 closed that option.

The Phase I study found that elimination of the EPA noise program has had a serious, and often fatal, effect on state and local noise control programs in this country. The infrastructure of experience at all levels of government has largely been lost. Nonetheless, noise control remains an important issue. Local programs need financial assistance from state and/or federal programs, and state programs need federal assistance.

The history of federal noise control policy was reviewed in the Phase I study. Key milestones were:

1. In 1970, ONAC was established within EPA.

2. The Noise Control Act was passed in October 1972. According to this act, state and local authorities are primarily responsible for the control of noise; however, the federal government is responsible for major noise sources in commerce where uniformity is requested. Immediately following passage of the Noise Control Act,

the EPA began identifying and regulating major sources of noise, including medium and heavy trucks, buses and motorcycles.

3. The Quiet Communities Act of 1978 amended the Noise Control Act to emphasize assisting state and local governments. One aspect of the amendment required EPA to administer the Quiet Communities Program which provided for grants to state and local governments, the purchase of noise monitoring equipment for loan to state and local governments, and technical assistance in the development of state and local noise control programs. Another requirement put upon EPA was to provide assistance to state and local governments by preparing model legislation. The Each Communities Helps Others (ECHO) program arranges for loan of state and local noise experts to other communities to help establish noise control programs.

4. In 1982, the Reagan administration decided that noise control was a highly localized type of problem and that state and local efforts would exist at the state and local levels without further federal assistance. The Administration terminated EPA's noise program, beginning with a phase-out that put emphasis on transferring knowledge and experience to state and local governments. Nonetheless, the Noise Control Act remained in effect.

Since the ending of the program in 1982, EPA has had only a few people in the noise area, mostly to review environmental impact statements, as required by federal law. The Phase I study found that EPA is not enforcing its standards on newly manufactured medium and heavy trucks [U.S. EPA, 1987a], and motorcycles and motorcycle exhaust kits. EPA had also promulgated in-use motor carrier noise regulations that applied to trucks and buses engaged in interstate commerce [U.S. EPA, 1987b]. Enforcement of these regulations, delegated to FHWA, is not being done because of previously determined high compliance rates and other priorities. A key issue affecting source control is federal preemption. State and local agencies can only promulgate noise regulations for newly manufactured trucks and in-use interstate buses and trucks if their standards are identical to the federal ones. Several states and municipalities have passed such regulations. However, automobile and light truck noise is not regulated by EPA, and as a result, a number of states and cities have standards for these vehicles (typically, a value of 80 dB at 50 feet per an SAE acceleration test).

Despite the ending of the EPA program, concerns over noise control have remained. To study the issue, a General Accounting Office (GAO) investigation [U.S. GAO, 1989], was conducted in 1989, and a 1990 report commissioned by EPA [Soporowski, 1990], investigated the status of key state and local noise programs that existed prior to the closing of ONAC. The Phase I study reported that the major finding of these studies was that the closing of the EPA ONAC and the phase-out of the EPA noise program had a very major impact on state and local programs. These impacts were not anticipated by EPA when the decision to end the program was made. Only about 35 percent of the approximately 200 local noise control programs that were active during the 1970s remain active today, largely attributed to the loss in EPA funding and technical assistance. Only eight of the 20 state agencies with programs in the 1970's are still active. Few individuals remain heavily involved in the field at the state and local level. The report done for EPA concluded that the state and local programs were unable to remain strong after the discontinuation. That report called for a new federal program to provide technical assistance and technology transfer to these agencies. The report's conclusions were corroborated by the GAO investigation. The GAO concluded that the federal government needed to strongly consider expanding its efforts in several possible areas, including enforcement of current standards (with possible revision) and provision of technical assistance to local governments for land use control.

The GAO study also examined the FHWA role in noise control at the "receiver". While the FHWA cannot control land use planning directly, it encourages local authorities to regulate directly land use along highways so that either noise sensitive land uses are not present, or, if they are, that the noise impacts are minimized through planning, design and construction mitigation measures. However, the FHWA staff stated that it is very difficult to determine the progress of noise control through land use because of the complexity of the land development process. One major problem is the economic aspect, in that adjacent land becomes much more valuable when a highway is built so that highways built in undeveloped areas may soon be surrounded by development, some of which may certainly be noise sensitive. FHWA officials further noted that efforts with state and local authorities to institute land use control programs had generally not been very successful.

As part of the Phase I research for WSDOT, a survey was done of the state and local agencies that had reported to EPA that they still had a noise program in place. Six states and 35 municipalities responded. Most of the state respondents wanted to see an EPA program re-established, although one opposed such an action because that state felt that federal preemption led to lax standards. Twelve of the thirty-five municipal respondents noted that motor vehicle noise was a regulated source. Most of the ordinances dealt with source emission levels and properly functioning mufflers. Others dealt with land-use planning (avoiding noise-sensitive development in high noise areas or requiring noise mitigation). Most of the respondents indicated the ability to provide some service other than ordinance enforcement, although services were limited by the small staff.

The Phase I study did find that, currently, a number of state and local noise control programs do exist and are useful in reducing noise pollution. Although some programs, especially those in California, do address transportation noise, many do not. The most viable and widely-used transportation noise control available to the local governments is land and community planning. Local authorities are able to force developers to consider noise problems and to mitigate these problems in any number of ways if they wish to proceed with the development. In summary, it was found that while there are a number of examples of good state and local noise control programs, they are few and far between. The closing of the EPA Office of Noise Abatement and Control has hurt the state and local noise control efforts significantly.

Washington State Initiatives

The Phase I study noted that Washington State has seen a demand for traffic noise mitigation from the public. This public demand has resulted in state initiatives to address transportation noise through state legislation for motor vehicle noise sources and more recently, noise and land use compatibility planning.

The difference between noise ordinances and noise and land use compatibility planning guidelines has been emphasized in this report. While the focus of this study has been compatibility planning, the importance of a noise ordinance should not be minimized. In the State of Washington RCW 70.107, passed in 1974, provides for a state noise ordinance. This legislation, as a first priority, charged the Department of Ecology with the task of adopting motor vehicle noise performance standards (70.107.030 (5)). As such the RCW 70.107 legislation is a significant tool for noise control at the noise source in the State of Washington. It is recommended that WSDOT continue to support the intent of this legislation as well as the updating of any rules found to be inconsistent with future noise and land use compatibility guidelines.

Concerns over growth led the governor to create a Growth Strategies Commission. The state legislature passed a Growth Management Act [State of Washington, 1990]. A resultant Growth Strategies Bill [State of Washington, 1991a] was later amended to become the final Growth Strategies Act [State of Washington, 1991b] that call for the development of comprehensive land use plans by cities and counties experiencing rapid growth. WSDOT responded by making environmental protection, including transportation noise mitigation, as one of its top priorities in the 1991 State Transportation Policy Plan [WSDOT, 1991a]. WSDOT also embarked on a process called <u>Choices in Transportation for Washington's Environment</u> [WSDOT, 1991]. All of these activities were discussed in detail in the Phase I report. A summary of the key points of that discussion is presented below.

The <u>Choices</u> process focuses on five major areas, with consideration of transportation noise being part of the discussion on land use. WSDOT indicates that it will encourage local agencies to adopt noise compatible land use plans for undeveloped areas near highways, and will continue to install noise barriers to protect noise sensitive land uses along existing highways.

The Transportation Policy Plan grouped the environmental issues into eight areas, one of which was noise abatement. The Plan delineated four action strategies regarding noise impacts: (1) minimize noise impacts of new transportation system facilities; (2) require local land use plans to identify noise impacts and needed mitigation measures; and avoid future impacts through land uses and building code actions; (3) develop a program to mitigate noise impacts identified in local land use plans; and (4) support research on quiet alternative transportation modes.

The first strategy goes beyond normal federal-aid project requirements and includes projects without federal funding. The second strategy contains several essential items for a comprehensive, integrated noise abatement approach. The requirement that local and regional land use plans identify excessive noise impacts and the establishment of a pattern of land uses and building codes to minimize noise exposure are critical. A funding policy must be established, a funding program phased over several years must be developed, and finally, legislative or administrative action must be taken to make available the funds to abate the noise. The third strategy provides a tangible incentive to those local governments, but must have a funding mechanism that allows abatement of problems in a timely, dependable manner. The fourth strategy is aimed toward the noise consequences or benefits from other policy initiatives such as the improvement of air quality, the use of alternative fuels and the reduction of traffic congestion.

The 1991 Policy Plan also called for a strong regional transportation planning process with the various metropolitan planning organizations (MPOs) across the state. There is the potential in that process to minimize the noise/land use conflict in the development of region-wide transportation systems, as well as city/county comprehensive plan activities. Noise impact and noise mitigation could become important factors in assessing components of the regional transportation system plans.

The Growth Management Act of 1990 mandated a comprehensive land use planning process with environmental protection as a goal. It also expanded the MPO process beyond urbanized areas and required that regional transportation plans conform with land use plans. The Act permitted real estate excise taxes and impact fees to be imposed to help fund capital facilities improvements. It also called for state agencies to provide technical assistance and grants to the cities and counties for the development of their plans and subsequent implementation regulations. Important steps were made toward managing growth, but not enough was mandated explicitly on the subject of environmental protection.

The work of the Washington State Growth Strategies Commission [WSDOT, 1990] extended, refined, and further defined the provisions in the Growth Management

Act of 1990. The commission was much more proactive in its call for an Environmental Management element to be a part of each comprehensive plan so that the goal of protecting the environment and quality of life would be institutionalized into the process.

The resultant Growth Strategies Bill was a significant proposal with respect to environmental quality as it related to the development and implementation of the comprehensive plans by cities and counties. Control of noise from existing and planned transportation facilities was specifically mentioned as a component of these plans with the likely use of the WSDOT for assistance with transportation noise mitigation. However, the final Growth Strategies Act of 1991 was significantly different from the Bill and did not fully implement the recommendations of the Growth Strategies Commission, especially towards institutionalizing environmental management as part of the comprehensive land use planning process. Also, by deleting the requirement for consideration of noise mitigation in the comprehensive plan, the Growth Strategies Act neglected probably the best long-term measure to insure that the management of growth within the state would be done in a way to minimize noise impacts both <u>on</u> that growth and <u>due to</u> that growth.

Despite the deletion of this and many other items from the final Growth Strategies Act, the Phase I study concluded that the Act still provides an opportunity for long-term control of traffic noise through land use management and control. The Phase I study contained many relevant recommendations. First, WSDOT should work with the Department of Ecology on developing transportation facilities noise exposure standards. WSDOT also needs to be prepared to provide on-going technical assistance to cities and counties during plan development and implementation. Specifically, WSDOT can serve as a technical resource to developers and as a reviewer of noise mitigation plans. This role would ensure integration of developer-funded noise mitigation measures and state DOT noise control measures in terms of acoustical performance, integrity, and aesthetic quality.

The Department of Community Development was designated lead agency for implementing the Acts, but was directed to utilize staff of other state agencies for technical assistance, which could include "model land use ordinances, regional education and training programs, and information for local and regional inventories." WSDOT should take the initiative, especially in light of the noise "action strategies" in the State Transportation Policy Plan, to make noise compatible planning part of the comprehensive plans.

The Phase I study also noted that WSDOT must try to influence, or provide for some consistency, in developer-installed noise mitigation measures along transportation facilities. As was pointed out in the study, many miles of developer-built noise barriers in Toronto, Canada, were installed on private property along transportation facilities using an inferior concrete panel product. Soon thereafter, the concrete panels began to crumble and the responsibility may ultimately fall on the Ontario government to replace these barriers. WSDOT must take the lead in developing minimum materials or systems standards for privately built noise barriers, especially if the cities and counties start to include noise mitigation as part of their comprehensive plans. As part of that effort, WSDOT should develop the capability to test and approve such systems.

The lack of specific discussion of noise in the Growth Management Act and the Growth Strategies Act could result in noise mitigation being given a lesser priority, either by design or necessity, in times of tight funding. Thus, the Phase I study recommended that WSDOT work through the legislature for formal inclusion of an Environmental Management element and noise mitigation strategies in the comprehensive land use planning process.

The Phase I study concluded by noting that Washington State has declared as policy the mitigation of traffic noise. The state legislature has provided legislation for comprehensive land use plan development by cities and counties experiencing high growth. The legislation presents an opportunity for achieving the policy goal, but will require WSDOT to take the initiative since noise is not specifically mentioned in the legislation.

WSDOT is in a unique position to have a major, long-term effect on transportation noise in the State of Washington. The State Transportation Policy Plan delineates noise mitigation action strategies. While specific requirements for noise mitigation were deleted from the final Growth Strategies Act, the intents of the State Growth Strategies Commission and at least some members of the legislature were clear to make environmental protection an integral part of growth management. The opportunities are there in the current legislation, perhaps with some amendment regarding use of fees and taxes, to address transportation noise control at the local level through land use planning. Controlling transportation noise along existing state and federal-aid roads, which needs to be done at the state level, will require additional funding. Together, these two aspects of noise control at the receiver and along the path of the noise will control many of the state's existing and future noise problems.

In summary, key among the many individual recommendations in the Phase I research were the following:

1. WSDOT should have an active involvement in the implementation of the Growth Management and Strategies Acts, especially related to providing technical assistance to cities and counties in the development of their comprehensive land use plans and subsequent development regulations. The department should take a lead role in the development of noise barrier design specifications for residential developers and in the testing and approval of proposed barrier materials and systems;

2. WSDOT should support the revival of an EPA noise program, related to both land use compatibility and source control, and expanded programs for noise control within the appropriate state agencies.

3. WSDOT should carefully examine its level of staffing to be able to adequately deal with the action strategies for noise abatement in the 1991 State Transportation Policy Plan and to be proactive in responding to the interest generated in cities and counties during the debate over the Growth Management and Growth Strategies Acts; expansion of activities beyond the current level of effort will require additional staff.

4. WSDOT should move to include departmental noise experts in the regional transportation planning process, much along the lines of what is done with air quality.

NOISE MITIGATION AS A TRANSPORTATION ENHANCEMENT

One specific recommendation in the Phase I study was that WSDOT consider establishing a new category of highway improvement, namely "Environmental Mitigation and Enhancement Improvements." In principle and philosophy, such a category would be precisely in line with the 1991 Transportation Policy Plan, the 1989 FHWA Environmental Policy Statement, and the National Transportation Policy. A noise barrier retrofit program for existing highways could be funded from monies in this category.

Subsequent to the study, the federal Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) was signed into law and, among other things, established the Transportation Enhancements Program. However, noise abatement was not one of the items mentioned as eligible for funding through this program, despite its obvious role in environmental enhancement.

During the preparation of the technical corrections bill for ISTEA in the summer and fall of 1992, an effort was initiated by Representatives Clement of Tennessee and Mineta of California (current chair of the House Transportation Committee) to add Type II mitigation to the list of eligible enhancement activities. The goal was not to force states to spend these funds on noise abatement, but to give them flexibility to do so if desired. WSDOT was among the agencies contacted and asked to support this amendment. The amendment passed the full House after some clarification regarding Type I versus Type II projects, and was sent to the Senate. Unfortunately, the Senate recessed for the elections before acting on the entire Technical Corrections Bill and the noise abatement amendment (and hundreds of other technical corrections) was not passed.

The amendment was not without controversy, however. Somewhat surprisingly, the amendment was opposed by certain pro-environmental experts and the American Planning Association. These professionals saw spending on noise abatement as a threat on spending on other areas on environmental enhancement. It is a sad and telling commentary when different pro-environmental forces are at odds with each other because of competition over limited funds when both have the same ultimate goal--improvement of the environment and the quality of life. The answer, obviously, is that since citizens are demanding environmental protection, state and federal legislators need to respond by appropriate action. The support received for the noise abatement amendment in the

House (and in the Senate despite time having run out before action could be taken) should be viewed as a very positive sign of the potential for future support for noise abatement.

EFFORTS TO RESTORE AN EPA NOISE PROGRAM

A key finding, documented in the Phase I report was that the demise of the USEPA noise program adversely affected state and local noise control programs. In 1991, an effort was made to reinstate the USEPA program funding. As part of this current research project, the effort to reinstate funding of the USEPA program was investigated.

U.S. Representatives Richard Durbin of Illinois and Pat Schroeder of Colorado introduced a Bill in 1991 which called for funding of the EPA Office of Noise Abatement and Control at the 1970 level of $30 million per year. On October 28, 1991, Congressman Durbin asked the American Speech-Language-Hearing Association (ASHA) to coordinate a conference of professionals comprising nine working groups to discuss policy options and legislative needs. This conference took place December 17 and 18, 1991, in Rockville, Maryland.

The report of the ASHA conference along with recommendations was printed and distributed by Congressman Durbin's office in the Spring of 1992. This report, which was approximately 100 pages, contained a very wide range of recommendations. These recommendations were reviewed by Congressman Durbin's office to develop an overall strategy of sponsoring the Bill in 1992. The report from the conference described the general consensus from the individual workshops that the legislation should not be simply a funding of the old office, but that improvements to the program should be included.

While there was widespread support for the Bill from interested parties, a number of obstacles were present in 1992 which ultimately led to the failure of Congress to act upon this Bill. Nineteen ninety two was not a good year for legislation since it was both an election year and a short year for Congress. Federal budget problems caused Bills for increased funding to meet with resistance. An additional hindrance was President Bush's moratorium on all new regulations to review any regulations that might inhibit growth. It was considered by some that the noise legislation might fall into the category of tending to inhibit growth.

As a part of one of the Progress Reports for the current study, Noise Mitigation Strategies, several recommendations were made to WSDOT to support Congressman Durbin's Bill:

1. Provide a show of support along with specific input to Congressman Durbin's office during the critical period in the Spring of 1992.

2. Involve local Congressmen from the State of Washington through written support with copies of any letters sent to them being also sent to Congressman Durbin's office.

3. Provide copies of the report Comprehensive System-Level Noise Reduction Strategies to Congressman Durbin's office.

While efforts were made on the part of many to promote Congressman Durbin's Bill, the year ended without any action being taken by Congress to reinstate funding of the EPA Office of Noise Abatement and Control.

A NOISE MITIGATION COST/BENEFIT FRAMEWORK

One of the initial objectives of this study was to develop a matrix of costs and benefits for the variety of potential ways to reduce transportation noise impacts. A similar analysis had been done for the NCHRP 173 study in the mid-1970s, where calibrations were made to produce an Equivalent Uniform Annual Cost for each strategy. However, as the research progressed, it became obvious that while one could go through an arithmetic exercise to derive such numbers, the results might be meaningless or of little use. The reasons will be discussed below. As a result, it was decided that the more useful approach would be to try to develop a framework for examining costs and benefits of the various strategies. This framework would address: Who pays, who benefits, what range in costs and benefits must be expected, and what are the cautions in using such data.

The reasons for not trying to reduce all costs or benefits to single numbers were several. First, there can be a wide variation in costs for a given noise abatement strategy. As an example, the Phase I study showed noise barrier costs varied extensively throughout the country and even within a given state, depending on many factors: In one case in California, the data for two walls of similar height, length, materials and lateral location showed a 2:1 difference in cost. Those factors may include:

1. Which cost items a state included in its reporting of cost (materials, foundations, installation, engineering, safety, drainage, landscaping, traffic control for Type II projects, etc.)

2. How a noise barrier contractor constructed the bid and/or billed a job that included other items in addition to noise barriers.

3. The type of material.

4. The type of barrier system (especially, is it generic or proprietary?)

5. The contractor's prior experience in barrier projects (affecting the amount of risk or uncertainty he or she would try to cover in the bid).

6. The region of the country.

7. Soil conditions.

8. Whether a project was Type I or Type II, especially if traffic control or special structural accommodations were needed for Type II projects.

A second reason for not trying to reduce results down to single comparative cost numbers is the variation in who pays for the noise relief. Potential payers include: WSDOT (either fully or in terms of non-federal matching); more generally, the State of Washington; the cities and counties; the Federal government; all taxpayers; the citizens living near a project (either directly or through taxes); manufacturers of noise sources such as vehicles; consumers of those products; and stockholders of those products' companies.

What might be perceived by WSDOT as not being a cost to it, such as administering a land use compatibility program, might still be a cost to the state if the Department of Community Development was given the responsibility. The "savings" to WSDOT are actually no net gain to the State of Washington and its taxpayers.

The third reality in dealing with costs and benefits is the difficulty in deciding who benefits from a noise mitigation strategy, by how much they benefit and if that benefit is substantial enough to warrant being counted. An example is source control. In theory, if heavy truck emission levels were reduced by 5 dB, every citizen of the state could be said to benefit. But in reality, this benefit does not accrue to everyone. People live at different distances from transportation facilities and are exposed to different levels of truck noise. Different facilities carry different truck volumes; some may carry little or none, so that any potential reduction in levels is masked by noise from other sources, such as automobiles.

The actual amount of reduction in noise level from the individual source varies as well. As shown earlier in this report, a source control strategy dealing with any individual component such as engine casing, fan, transmission, etc., will affect different components differently. Engine casing optimization may reduce one engine's level by 3 dB, but affect another by less than one decibel. Also, the benefit to the wayside receiver of a reduction in a given component's noise is totally dependent on the relative level of that component to all of the other components on a vehicle. A 3 dB reduction in fan noise might not reduce wayside levels at all if tire or exhaust noise dominate. Yet, as tire and exhaust noise levels are reduced, the fan could become more of a dominant source and reductions in its level would affect total wayside level.

A second issue in source control benefits deals with the operating mode of the vehicle and will also affect component noise levels, and therefore, the benefits of any reduction. A 3 dB reduction in engine noise due to casing optimization might only occur during acceleration, and not during cruise. Or, exhaust noise reductions that reduce wayside levels might not be able to be detected at high speeds where tire noise dominates. Related to this last example is the fact that when the term noise level is used, what is actually being produced and heard is a spectrum of noise over a range of frequencies. The range varies, the car's response over the range varies and the shape of the spectrum varies. Broadband noise (relatively equal amounts of sound energy across the spectrum) is perceived differently from noise with energy concentrated in a narrower frequency ranges (described as "tonal"). Perception of tonal noise even depends on the particular frequencies in which the energy concentration occurs.

There is also a time-variation in the noise that could be variously categorized as continuous, intermittent, impulsive, etc. People's response to a noise often depends on this time-variation: impulsive or intermittent noises can be more disturbing than continuous noise at certain levels, while the opposite might be true at higher levels (the constant roar of traffic in a backyard adjacent to a freeway could be much more disturbing than intermittent truck passages, whereas for a person living several hundred feet from the road, the constant background "drone" of traffic might be less disturbing than individual passages with levels rising above that drone to interrupt concentration or conversation.

This discussion has pointed out some of the very real difficulties in addressing the subject of noise mitigation, especially in terms of comparing different strategies. Yet, despite those difficulties, analysts must analyze and decisionmakers must decide--what to study, what to fund, what to implement. The following framework is aimed at sorting out the various issues in a way that should help analysts and decisionmakers proceed with their tasks.

1. What is the strategy?

2. Who has an implementation role? What is that role?

3. Who pays for the noise mitigation, in what manner, and at what range in cost?

4. Who benefits from the mitigation, at what range of benefits, and under what circumstances?

Tables 5-7 present this framework in the following manner:

1.a. Strategies on the vehicle itself, as part of its manufacture, dealing with engine and driveline related noise generating components, and separately, with tires.

1.b. Strategies related to in-use mitigation of individual vehicle noise or traffic noise control through traffic management

2. Strategies controlling sound along its path, including pavement, noise barriers, roadway alignment and buffer zones; for noise barriers and buffer zones, separate categories are included for lead implementation roles by WSDOT, local government and developers.

3. Strategies at the receiver, including land use compatibility, sound insulation and relocating impacted dwellings.

The framework for assessing strategies listed above in items 1.a. and 1.b. is given in Table 5. The upper portion of the table pertains to those strategies described in 1.a. that are the reduction of vehicle noise produced by autos, medium and heavy trucks, buses and motorcycles.

The first row of cells in the table consider noise reduction for the major noise generating components of motor vehicles: intake, exhaust, cooling fan, engine and accessories, and the driveline. Tire noise is considered separately in the second row of table cells. This distinction of vehicle noise generating components is necessary since tire noise tends to dominate at high speeds, whereas the other vehicle noise generating components tend to dominate at lower speeds.

Table 5. Framework for Assessing Source Control

Strategy	Actions	Implementer	Who pays?	How do they pay?	Costs	Who benefits?	How much benefit?	Conditions on benefits
Reduction of new vehicle engine/drive-line noise	R&D, Mfg.	Manufacturer	Manufacturer	R&D, Mfg	Substantial	Residents near streets with speed limits below 35 mph	0-3 dB	1. Distance to road 2. Presence of traffic control devices (acceleration) 3. Traffic volume 4. Percent of other vehicle types 5. Background noise
	Pass Legislation	State Legislature	Customer	Purchase price	Variable, one-time			
	Possible enforce.	Washington State	Washington State	Start-up, annual	Minor			
	Tighten/pass legis.	U.S. Congress	U.S. EPA	Start-up, annual	Several million/yr			
	Develop Regs., Enforcement	U.S. EPA						
Reduction of tire noise	R&D, Mfg	Manufacturer	Manufacturer	R&D, Mfg	Substantial	Residents near roads with speed limits over 35 mph	0-3 dB	1. Distance to road 2. Traffic volume 3. Percent of other vehicle types 4. Background noise
	Pass legislation	State Legislature U.S. Congress	Customer	Purchase price	Variable, one-time			
			Washington State	Start-up, annual	Minor			
	Possible enforcement	Washington State U.S. EPA	U.S. EPA	Start-up, annual	Several million/yr			
In-use Limits: Low Speed Automobiles Medium trucks Heavy trucks Buses Motorcyles	U.S. Congress	Pass new or tighten current legislation	Local gov't	Start-up, annual	Substantial	Residents near streets with speed limits below 35 mph	0-3 dB	1. Distance to road 2. Presence of traffic control devices (acceleration) 3. Traffic volume 4. Percent of other vehicle types 5. Background noise
	U.S. EPA	Develop Regs.,Tech.Assist	Washington State	Start-up, annual	Moderate			
	FHWA	Enforcement	WSDOT	Start-up, annual	Moderate			
	Legislature	Pass legislation re preemption	U.S. EPA	Start-up, annual	Several million/yr			
	Washington State	Enforcement, Tech. Assist.	FHWA	Start-up, annual	Moderate			
	Local gov't	Enforcement	Violator	Per violation	$25-100/violation			
In-use Limits: High Speed Automobiles Medium trucks Heavy trucks Buses Motorcyles	U.S. Congress	Pass new or tighten current legislation	Local gov't	Start-up, annual	Substantial	Residents near roads with speed limits over 35 mph	0-3 dB	1. Distance to road 2. Traffic volume 3. Percent of other vehicle types 4. Background noise
	U.S. EPA	Develop Regs., Tech Assist	Washington State	Start-up, annual	Moderate			
	FHWA	Enforcement	WSDOT	Start-up, annual	Moderate			
	Legislature	Pass legislation re preemption	U.S. EPA	Start-up, annual	Several million/yr			
	Washington State	Enforcement, Tech. Assist.	FHWA	Start-up, annual	Moderate			
	Local gov't	Enforcement	Violator	Per violation	$25-100/violation			

Table 5. Framework for Assessing Source Control

Strategy	Actions	Implementer	Who pays?	How do they pay?	Costs	Who benefits?	How much benefit?	Conditions on benefits
In-use Limits: Stationary Automobiles Medium trucks Heavy trucks Buses Motorcyles	U.S. Congress	Pass new or tighten current legislation	Local gov't	Start-up, annual	Substantial	Residents near streets with speed limits below 35 mph	0-3 dB	1. Distance to road 2. Presence of traffic control devices (acceleration) 3. Traffic volume 4. Percent of other vehicle types 5. Background noise
	U.S. EPA	Develop Regs., Tech. Assist	Washington State	Start-up, annual	Moderate			
	FHWA	Enforcement	WSDOT	Start-up, annual	Moderate			
	Legislature	Pass legislation re preemption	U.S. EPA	Start-up, annual	Several million/yr			
	Washington State	Enforcement, Tech. Assist.	FHWA	Start-up, annual	Moderate			
	Local gov't	Enforcement	Violator	Per violation	$25-100/violation			
Traffic management: Vehicle prohibition or restriction	WSDOT	Project mitigation	WSDOT	Install & maintain	Low	Residents near streets, Residents near highways	0-5 dB	1. Distance to road 2. Traffic volume 3. Percent of trucks 4. Background noise 5. Could restrict interstate commerce 6. May shift noise/congestion problems to others
	Local gov't	Project mitigation, Enforcement	Taxpayer	State budget	Minor			
	Legislature	Pass legislation	Federal gov't	Federal-aid	Minor			
			U.S. taxpayer	Gas tax	Minor			
Traffic management: Speed reduction	WSDOT	Project mitigation	WSDOT	Install & maintain	Low	Residents near streets, Residents near highways	0-3 dB	1. Distance to road 2. Traffic volume 3. Background noise 4. Negative effects on capacity and traffic congestion
	Legislature	Project mitigation, Enforcement	Taxpayer	State budget	Minor			
	Local gov't	Pass legislation	Federal gov't	Federal-aid	Minor			
			U.S. taxpayer	Gas tax	Minor			

The second column of the table lists actions that can be taken to implement a given strategy. As an example, for the strategy "Reduction of new vehicle engine/driveline noise", a vehicle manufacturer may implement a research and development effort to reduce vehicle noise. The initial cost of this effort would be borne by the vehicle manufacturer. Generally, such an effort involves high costs, therefore, "substantial" is shown in the cost column . Those who most benefit from implementation of this strategy are residents near any roadway with speed limits below 35 mph. The benefits realized are variable as indicated by the 0-3 dB range. Further, the benefits vary due to the conditions listed in the last column. Washington State is listed as an implementer of enforcement of any legislation that might be passed to reduce vehicle noise. The costs, which involve start-up and annual maintenance costs for any enforcement program, are borne by the state and are considered relatively minor.

The lower portion of Table 5 lists strategies described in item 1b. above. These strategies consider vehicles that are in use. The strategies may focus on noise emission limits for in use vehicles or on traffic management measures to limit certain vehicle types from noise sensitive areas.

Table 6 and Table 7 present the framework for assessing path and receiver control strategies respectively. As with Table 5, alternative actions are listed for the noise control strategies considered. The implementer of such actions is given, as well as who pays for the action, how payment is made and the relative cost of the alternative. In addition, those who benefit from such action, the range of benefit in terms of noise reduction, and the conditions that affect the amount of benefit are given.

Tables 5, 6, and 7 are designed to be used together. For example, the strategy Reduction of New Vehicle Engine/Driveline Noise in Table 5 could be compared with the strategy Path control: Noise Barrier by WSDOT in Table 6 and Receiver Control: Proponent Mitigation Noise Barrier in Table 7. In all three cases, residents near roadways benefit: however, the amount of benefit varies. Further, The reduction of new vehicle noise can involve implementation efforts at the Federal as well as the state level, with substantial costs being first paid by the vehicle manufacturers. For the other two strategies the implementation efforts tend to be at the state or local level with the costs being paid through Federal and state funds for the noise barrier by WSDOT, or by the

Table 6. Framework for Assessing Path Control Strategies

Strategy	Actions	Implementer	Who pays?	How do they pay?	Costs	Who benefits?	How much benefit?	Conditions on benefits
Path control: Pavement	Project mitigation	WSDOT	WSDOT	R&D	High	Residents near roads with speed limits over 35 mph	3-5 dB	1. Least benefits if many trucks 2. Current pavement must be noisier 3. May degrade over time 4. May even help in low speed situations
			WSDOT	Install & maintain	Low (relative)			
			Taxpayer	State budget	Minor			
			Federal gov't	Federal-aid	Minor			
			U.S. taxpayer	Gas tax	Minor			
Path control: Noise barrier by WSDOT	Project mitigation.	WSDOT	WSDOT	Install & maintain	$12-30/sq.ft.	Residents near streets, Residents near highways	5-12 dB	1. Function of cross-section and barrier location 2. Decreasing benefit with distance from road 3. Traffic volume and truck mix 4. Background noise
	Pass resolution of support	Local gov't	Taxpayer	State budget	Few million/proj.			
			Federal gov't	Federal-aid	10%-20% share			
			U.S. taxpayer	Gas tax	Minor			
Path control: Noise barrier by Locality	Project mitigation	Local gov't	Local gov't	Install & maintain	$12-30/sq.ft.	Residents near streets, Residents near highways	5-12 dB	1. Function of cross-section and barrier location 2. Decreasing benefit with distance from road 3. Traffic volume and truck mix 4. Background noise
	Tech. Assist.	WSDOT	Taxpayer	Taxes	Variable			
			Affected resident	Assessment	Up to $1000s/res			
			WSDOT	Annual	Moderate if active			
Path control: Noise barrier by Developer	Project mitigation	Developer	Developer	Install & maintain	$12-30/sq.ft.	Residents near streets, Residents near highways	5-12 dB	1. Function of cross-section and barrier location 2. Decreasing benefit with distance from road 3. Traffic volume and truck mix 4. Background noise
	Review & approval		Affected resident	Purchase price	Up to $1000s/res.			
	Tech. Assist.	WSDOT	WSDOT	Annual	Moderate if active			
Path control: Road lids by WSDOT	Project mitigation.	WSDOT	WSDOT	Install & maintain	$1000s/linear ft	Residents near streets, Residents near highways	5-20 dB	1. Traffic volume and truck mix 2. Background noise
	Pass resolution of support	Local gov't	Taxpayer	State budget	Millions/proj.			
			Federal gov't	Federal-aid	10%-20% share			
			U.S. taxpayer	Gas tax	Moderate			

Table 6. Framework for Assessing Path Control Strategies

Strategy	Actions	Implementer	Who pays?	How do they pay?	Costs	Who benefits?	How much benefit?	Conditions on benefits
Path control: Vertical alignment	Project mitigation	WSDOT	WSDOT Taxpayer Federal gov't U.S. taxpayer	Design/construct State budget Federal-aid Gas tax	Variable depending on cut/fill costs	Residents near highways	3-8 dB	1. Function of depth of cut/height of fill 2. Position of houses relative to cut/fill 3. Traffic volume and truck mix 4. Background noise
Path control: Horizontal alignment	Project mitigation	WSDOT	WSDOT Taxpayer Federal gov't U.S. taxpayer	Design/construct State budget Federal-aid Gas tax	Variable depending on land cost, effects on design	Residents near highways	0-20 dB	1. Traffic volume and truck mix 2. Background noise
Path control: Buffer zone by WSDOT	Project mitigation	WSDOT	WSDOT Taxpayer Federal gov't U.S. taxpayer	Construct/maintain State budget Federal-aid Gas tax	Variable, depending on land cost	Residents near highways	0-5 dB	1. Distance to road 2. Traffic volume 3. Background noise
Path control: Buffer zone by Locality	Project mitigation Tech. Assist.	Local gov't WSDOT	Local gov't Taxpayer Affected resident	Construct/maintain Taxes Assessment	Variable, depending on land cost	Residents near streets, Residents near highways	0-5 dB	1. Distance to road 2. Traffic volume 3. Background noise
Path control: Buffer zone by Developer	Project mitigation Review & approval Tech. Assist.	Developer Local gov't WSDOT	Developer Affected resident WSDOT	Install & maintain Purchase price Washington State	Variable, depending on land cost	Residents near streets, Residents near highways	0-5 dB	1. Distance to road 2. Traffic volume 3. Background noise

Table 7. Framework for Assessing Receiver Control Strategies

Strategy	Actions	Implementer	Who pays?	How do they pay?	Costs	Who benefits?	How much benefit?	Conditions on benefits
Receiver Control: Land use compatibility Zoning	Develop & impl. program	Local gov't	Local gov't	Purchase price	Variable	Residents near roads	5-20 dB	1. Distance to road 2. Traffic volume 3. Background noise
	Tech. Assist.	WSDOT	WSDOT	Review & approval	Minor	Local Gov't WSDOT	No need for other mitigation	
				Tech. Assist.	Moderate if active			
Receiver Control: Proponent Noise Miti-gated Development	Develop & impl. program	Local gov't	Developer	Install & maintain	$12-30/sq.ft.	Residents near roads	5-12 dB	1. Distance to road 2. Traffic volume 3. Background noise
	Tech. Assist.	Developer	Affected resident	Purchase price	Variable	Local Gov't WSDOT	No need for other mitigation	
	Install & maintain	WSDOT	Local gov't	Review & approval	Minor			
			WSDOT	Tech. Assist.	Moderate if active			
Receiver Control: Building sound insulation	Develop & implement program	Local gov't	Developer	Install & maintain	$5-20K/res	Residents near roads	10-20 dB interior	1. No outdoors protection 2. Distance to road 3. Traffic volume
			Affected resident	Purchase price	$5-20K/res			
	Tech. Assist.	WSDOT	Local gov't	Review & approval	Minor			
	Install	Developer	WSDOT	Tech. Assist.	Minor			
Receiver Control: Relocation of impacted dwelling	Project mitigation	WSDOT	WSDOT	Cost to relocate	Several thousand	Affected resident	5-20 dB	1. Distance to road 2. Traffic volume 3. Background noise

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developer and those residents who directly benefit, for the case of a Proponent Mitigated Noise Barrier. Such a comparison process can result in support for strategies that are politically acceptable, produce maximum benefits and equitable distribution of costs.

In summary, Tables 5, 6, and 7 are not designed to produce a decision but to aid decision makers by organizing important factors to be considered when selecting trafficnoise reduction strategies. Further, the tables do not suggest a superior noise control strategy. Decisions reached after considering this framework will no doubt vary depending on circumstances surrounding a given application of the strategies.

As discussed above, there are difficulties--and, indeed, dangers--in trying to assign a "value" to every cell in the tables, especially in terms of costs and benefits. There are just too many variables and case-by-case specifics that cloud interpretation of any given number. Nevertheless, this framework is one approach that WSDOT can use in sorting through the issues related to the various noise mitigation strategies.

IMPLEMENTATION EFFORTS FOR WSDOT

Separate from the above framework, a number of particular implementation items have resulted from this research for consideration by WSDOT. These items are divided into the areas of source and receiver control. The subject of path control has been addressed in a recent WSDOT report [Cohn and Harris, 1993]. Table 8, a design matrix for special noise barrier applications, has been taken from the report.

Source Control

It is recommended that WSDOT assume several approaches to support transportation noise control at the source. Based on the findings of the Phase I study and the findings of the current study, which corroborate the Phase I results, the WSDOT should follow any efforts made by the U.S. Congress to reinstate funding of the EPA Office of Noise Abatement and Control (ONAC). It is recommended that WSDOT support any efforts to reinstate funding of ONAC.

It is fortunate that the goals of reducing transportation noise impact on the environment are consistent with the current trend of a demand for quiet vehicles as is

Table 8. Design Matrix for Special Noise Barrier Applications (Cohn and Harris, 1993)

Barrier Type	T-Top	Y-Top	Slanted Top	Absorptive Single	Absorptive Parallel
Height	>13'	>13'	>13'	All	>10'
Approx. Increased I.L. (dB)	1.5-2.0	1.0-1.5	0.0-0.5	0.0-2.0	2.0-3.0
Approx. Increased Cost (%)	10%	10-20%	10%	25%	20%
ADVANTAGES					
Reduced Height	✓	✓		✓	✓
Reduced Windloads	✓	✓		✓	
Smaller Foundation Requirements	✓	✓		✓	
Aesthetic Appearance	✓		✓		
DISADVANTAGES					
Debris Accumulation	✓	✓			
Drainage Problems	✓	✓			
Increased Foundation Requirements			✓		
Questionable Durability of Material				✓	
Periodic Maintenance	✓	✓		✓	✓

found in the marketplace. This has not always been the case. Those affected by transportation noise can benefit from the marketplace pressure on vehicle manufacturers to produce quieter vehicles. Therefore, legislation is not needed at this time to provide a motivation for vehicle manufacturers to produce quieter vehicles.

There is no way to know how long this marketplace trend will persist. WSDOT should continue to monitor the overall marketplace demand for quieter vehicles in order to be sensitive to any changes. Specifically, it is recommended that WSDOT be sensitive to any marketplace demand changes for certain tires. High performance tires, designed with wide tread which produces a large contact area, are inherently more noisy than narrow tires. Should this design become more widespread in its application on automobiles, the overall emission levels from automobiles at highway speeds may be adversely affected.

It is recommended that WSDOT support research to determine the potential noise reduction effects of alternative fueled engines. Noise reduction from alternative fuels potentially could be very significant. The results of such research could alter the thinking of vehicle manufacturers regarding noise control at the source.

This study has also highlighted another potential factor in noise control of the source. This is the effect of pavement type on tire/road noise. Apart from what has been done for WSDOT, there has been little research conducted in this country regarding the effect of roadway pavements on overall vehicle noise emissions. It is suggested that WSDOT continue to fund research in this area or support such research as part of a cooperative program. It is possible that benefits gained from selecting appropriate pavement types could overshadow efforts to reduce specific sources within the vehicle itself. In addition, quieter pavements could result in savings from noise barrier costs in applications where the height of barriers can be reduced because of lower tire/road noise emissions.

In addition, WSDOT should make every effort to ensure that the rules adopted under RCW 70.107 are consistent with any future noise and land use compatibility guidelines. Consistency between the noise ordinances supported by RCW 70.107 and any future noise and land use compatibility planning guidelines are needed for a balanced, two-pronged approach to noise control.

Receiver Control

The success of noise and compatible land use planning strategies in other parts of the country have direct application to the State of Washington. As noted earlier, these strategies have particular potential benefit to those communities which are in the earlier stages of their development. Since Washington State has many communities which are growing and developing, this is an opportune time to take advantage of these proven strategies. These strategies are proactive and preventative in nature; therefore, many problems in the future can be averted by pressing for implementation of such strategies now.

Strategies. The four strategies for noise control at the receiver strategies studied in this report are listed in Table 7 as follows: land use compatibility zoning, proponent noise mitigated development, building sound insulation, and building relocation. These strategies are briefly reviewed in the following paragraphs as background to the steps required for their implementation.

1. Land Use Compatibility Zoning. The goal of land use compatibility zoning is to promote land development in which land uses are compatible with the noise environment. To carry out this strategy the community noise environment must first be defined and acceptable noise levels must be determined for each potential land use. Once this information is available, the assignment of acceptable land uses for given areas can be made. For an example, an industrial land use category would carry a relatively high acceptable noise level limit. Therefore, industrial land uses could be planned for location near areas highly impacted by transportation noise sources. Under this strategy, land uses and the existing or planned noise environment for the community are matched.

One aspect of land use compatibility zoning also relates to proponent noise mitigated development discussed below. This method involves zoning large average lot sizes per dwelling for residential areas, and then planning individual lot sizes for a given development much smaller than the average size zoned. This excess land area is then used for the development of area buffer zones or green belts. In this manner, the buffer zones or green belts can be planned by a developer such to locate individual dwellings farther from the noise source.

2. Proponent Noise Mitigated Development. This strategy is seen by many to complement land use compatibility zoning. It is recognized that most, if not all communities will find an imbalance between the demand for land uses that are compatible with high transportation noise levels versus the land areas that are highly impacted by transportation noise. As a result of this imbalance, residential and other land uses requiring lower noise levels are often, out of necessity, placed near transportation noise sources. With the proponent noise mitigated development strategy, land uses are made compatible with the noise environment through mitigation. Under this strategy, the proponent of the development, be it a residential development or a transportation facility near a residential area, is responsible for noise mitigation. The methods used to mitigate transportation noise under this strategy include but are not limited to the following:

a. Buffer zones, setbacks, and green belts

   A residential developer who uses this strategy will seek to place areas of outdoor living and residential buildings as far from the transportation noise source as possible. By doing so, the sound levels experienced by residents will be lower due to the longer propagation path from the source to the receiver.

b. Building orientation and site layout

   The location of residential buildings, garages, parking lots, etc., can be planned to reduce the noise levels experienced by receivers. For example, the parking areas for a condominium development can be located near the transportation noise source thus producing a separation between the residential buildings and the transportation facility. For cases where parking is provided in long garages, the structure for the garage can also serve as a noise barrier. In addition, buildings can be oriented for less exposure to the direct path of propagation of the noise as well as to reduce reflections of the noise which tend to increase overall levels for the receiver.

c. Building design

The number and location of windows in a building can be considered to reduce interior noise levels. Also, the floor plan for residential buildings can be arranged to place utility rooms and workshop areas near the exterior walls of greatest incident noise levels. On the other hand, bedrooms can be located in a more protected part of the building, where they are less influenced by the transportation noise sources. Further, the layout of the building itself and the placement of outdoor living areas can be optimized along with the location of garages to further reduce noise levels in critical areas. Finally, the building elements can be chosen or constructed with several insulations in mind; see items 2g and 3 below for details.

d. Landscaped berms

Earth berms constructed as noise barriers between a noise source and the receiver are an effective means of mitigating noise impacts for a development. This method is particularly attractive in terms of both aesthetic and long term maintenance considerations.

e. Berm/wall combination

Another mitigation method is the construction of a noise barrier composed of an earth berm for the lower portion of the barrier which in turn supports a noise wall for the upper portion of the barrier. For areas of high predicted noise levels, the lot area required for a berm of sufficient height to abate the noise to an acceptable level may be too large. The combination of a berm and a wall allows the required area to be reduced while still maintaining some of the aesthetic qualities of the berm.

f. Wall

Where land area constraints are particularly high, a noise wall alone may be the only acceptable solution for reducing noise levels. One concept that gives the appearance of a berm in the space of a wall is the Evergreen system of stacked concrete cribs, filled with dirt, and then planted. This Swiss invention has been used on I-476 in Philadelphia.

g. Depressed roadways

This method of reducing noise levels for the receiver applies more to a Department of Transportation than to a residential developer. As the proponent of a new transportation facility, the Department of Transportation may elect to construct the roadway at a depressed grade relative to the development in order to achieve a measure of noise reduction for the receiver of the noise.

h. Money to compensate homeowners

For cases in which abatement is not feasible, in which no acceptable alternative to constructing a transportation noise source near homeowners can be found, the method of compensating homeowners has been used. One example of this strategy can be found in Howard County, Maryland. The state Department of Transportation has offered to buy as many as 24 condominiums near the proposed Route 100.

i. Acoustical treatments to buildings

For cases where the above methods of abating noise are not feasible, the noise environment can be protected in interior areas even if it cannot be protected in exterior areas. Use of this method requires the necessary steps to produce increased noise attenuation by the structure of the building. The attenuation due to the building itself can be enhanced through a number of means as described below in the strategy on building insulation.

3. Building Sound Insulation. This strategy of receiver noise control has been used extensively in areas of high noise levels due to airport operations. In addition, many departments of transportation have used this strategy along highways where noise barriers are not feasible. In particular, building sound insulation has been used most often for public or nonprofit buildings such as schools. While this strategy has most often been applied to existing buildings as a retrofit effort, it can be applied to new construction in noise impacted areas. For a specific building design, the interior noise levels can be improved by installing windows and doors that produce a higher noise transmission loss than standard components. In addition, openings such as chimneys, vents and fans can be redesigned to reduce noise infiltration. Increased ceiling insulation, dry wall thicknesses, reconstruction of walls, and addition of new facades are often used in more extreme cases to improve building attenuation. The installation of air conditioning or air circulation equipment is generally required in order to produce an acceptable interior comfort while keeping windows and other openings closed. The operating and maintenance costs of such equipment must be considered as costs to be borne by the building owner. However, sound insulation often provides thermal insulation benefits with resultant decreases in heating or cooling costs.

4. Relocation of Impacted Dwellings. This strategy of receiver noise control has been occasionally invoked where there are no other feasible methods of protecting the receiver from a transportation noise source. In effect, the receiver is moved away from the noise source. Generally a Department of Transportation has used this strategy where a new transportation noise source encroaches upon an existing building.

Implementation of Strategies. Implementation of the strategies summarized above requires action at both the state and local levels. The far reaching effects of establishing a noise and land use compatibility strategy for receiver noise control necessitates broad participation in the development of such a plan. State agencies involved in planning, community development, environmental issues, and transportation, along with their local counterparts will typically desire to provide input for such a program. At the heart of this plan is a noise and land use compatibility guideline that is adopted on the local level for use by planning agencies. Due to the broad participation required for such a program, the following recommended approach to guideline development is offered. For Washington State, this approach involves multi-agency participation based on the legislative foundation established in the Growth Management and Growth Strategies Acts. As outlined earlier in the section on Washington State Initiatives, the Growth Management Act charged the Department of Community Development with providing the technical assistance to local agencies with the assistance of agencies like WSDOT. In light of this act, it is suggested that the Department of Community Development take the lead in establishing noise and land use compatibility guidelines.

The program needed to establish noise and land use compatibility planning in the State of Washington would require three major components. The first component is a State-developed noise and land use compatibility planning guideline. The second component is a State Office of Technical Assistance to provide needed support to the local agencies who will enforce the program. The third component is the adoption of the guidelines by local agencies for use in their planning process. It is recommended that WSDOT promote the implementation of these strategies by being involved in all three components of the implementation. These are treated separately in the following three subsections.

1. Produce Noise and Land Use Compatibility Planning Guidelines. Guidelines produced at the state level will ensure consistency and uniformity throughout the state but require input from local agencies. It is recommended that WSDOT initiate the formation of a consortium within the state to produce a model noise guideline that could be adopted by local agencies within the state for use in noise and land use compatibility planning. Such activity is consistent with the provision within the Growth Strategies Act of 1991 as described in the Phase I report as follows:

> "In Summary, the Growth Strategies Act of 1991 did not fully implement the recommendations of the Washington State Growth Strategies Commission, especially as they apply towards institutionalizing environmental management as part of the comprehensive land use planning process. Also, by deleting the requirement for consideration of noise mitigation in the Land Use element of the comprehensive plan, the

Growth Strategies Act of 1991 has neglected probably the best long-term measure to insure that the management of growth within the State of Washington would be done in a way to minimize noise impacts both on that growth and due to that growth.

"However, the Act does not prevent or preclude WSDOT from encouraging noise mitigation as part of the Land Use element. The provisions on technical assistance and planning grants call for action by the Department of Community Development and other state agencies; WSDOT can and should take a leadership role by seeing that one focus of the technical assistance includes noise mitigation through land use strategies. Support for such a role may also be found in Section 16 on new fully contained communities, which notes that one criterion for approval of such communities is that environmental protection has been 'addressed and provided for.' Also, Section 17 on new master planned resorts notes that these resorts may only be authorized if on-site and off-site infrastructure impacts are fully considered and mitigated."

As described above, it would be most appropriate for the Department of Community Development to take the lead in this consortium. However, WSDOT could assume such a lead position in lieu of the Department of Community Development should circumstances warrant this action. Note that it is in the best interest of WSDOT to see such guidelines developed and implemented as the least costly (to WSDOT and the general taxpayer) method of minimizing future noise impacts. The development of the guidelines would require input from local agencies and other state agencies in order to consider the variety of characteristics found in communities in the State of Washington. Representatives from planning agencies in other states could be enlisted to supply additional expertise based on their experiences in guideline development. As a starting point for designing a model guideline, the following elements are recommended for consideration:

a. Adoption of guideline by local agencies: Is it mandatory or optional? If optional, what limitations should there be on any changes (i.e., more restrictive or less restrictive)?

b. Noise Impact Studies: Define cases where a noise impact study is required. For example, all development within a specified noise contour line. Define, review and approval process of noise study.

c. Community Noise Contours and noise prediction methodology requirements.

d. Policy Lines: Should noise contour lines be used for determining the need for a noise impact study or should they be used as policy lines for restricted development based on land use category?

e. Transportation noise sources to be addressed

f. Forecast/horizon year for noise impact studies

g. Traffic statistic to be used in noise predictions (example AADT or DHV)

h. Noise descriptor to be used in guideline criteria

i. Outdoor prediction/measurement locations

j. Outdoor standards (or criteria) for impact

k. Indoor standards (or criteria) for impact

l. Alternatives considered for cases where mitigation is not feasible

   - prohibit development
   - allow development, but require interior treatment? require issuance of "warnings": owner notification and notification to future purchasers of possible future impacts

m. Whether to assess developers for indirect noise impacts

n. Whether to recommend or prioritize abatement types such as:

   - buffer zones, set backs, green belts
   - building orientation, parking lot location

- review/approval process for abatement measures
- building design
- landscaped berm
- berm/wall combination
- wall
- acoustical treatments to buildings
- depress roadways
- money to compensate homeowner

o. Other issues:

- who maintains barriers/berms
- ROW: are easements required for maintenance?
- Review / approval process for abatement measures
- Provisions for post-implementation testing, corrections, penalties, etc.

2. State Office of Technical Assistance. It is recommended that WSDOT support the formation of an Office of Technical Assistance at the state level. This office could provide aid in terms of financial support for program startup as well as knowledge of how to implement noise and land use compatibility guidelines. In addition, technical assistance could be provided in terms of noise measurements, and acoustical understanding/training for local agencies.

In order to further support this component of the overall program, it is recommended that WSDOT make use of its experience with noise barrier designs, along with design experience from other states, to establish acceptable noise barrier designs that may then be adopted by local agencies. Such an effort will facilitate local agencies by allowing them to benefit by the experience WSDOT has gained with different types of noise barrier materials and designs. While the production of design standards by WSDOT would entail a significant effort, it is preventative in nature. Without such design standards, developers might install noise barriers that deteriorate rapidly, or that do not perform acceptably. Often, it is the DOT who must address such problems long after the developer is gone. By addressing this issue up front, WSDOT can avoid potential problems in the future.

In addition to noise barrier design, it is recommended that WSDOT monitor and test noise barrier systems and materials. As new and often proprietary materials or systems are introduced on the marketplace, WSDOT is in a good position to evaluate these products. The results of such evaluation could then be passed along to local agencies through the State Office of Technical Assistance, or WSDOT could add this information to its noise barrier standards.

3. Guideline Adoption by Local Agencies. The third component of implementation of noise and land use compatibility planning involves the adoption of guidelines for local use by local agencies. In order to do this, the local agencies must become aware of the significance of these strategies to their community development. It is recommended that WSDOT begin this process by distributing this report to all local agencies, both county and city, and to local planning departments. It is expected that as planners become more familiar with the success of the noise and land use compatibility planning strategies in other communities outside the State of Washington, they will be more receptive to implementing these strategies within the state.

Planning Workshops. WSDOT can support the local agency component of the implementation effort along with the other components by promoting a series of workshops to facilitate implementation of the program in the State of Washington. It is recommended that a workshop approach be considered for: the development of noise and land use compatibility guidelines, the duties of the State Office of Technical Assistance, and to facilitate the process of local agencies to adopt noise and land use compatibility guidelines into their planning process. In order to fully implement the land use compatibility planning process in the State of Washington, a series of workshops would be required. A suggested order to these workshops is as follows:

1. Noise and Land Use Compatibility Planning and Guidelines Workshop. It is recommended that WSDOT develop and sponsor a workshop for members of local planning organizations as well as participating agencies on the state level. This workshop should focus on the concepts involved in noise and land use compatibility planning. Information should be given on the strategies involved, the benefits to be realized and the costs that are entailed in such a program. Furthermore, the methods of implementation that have been successfully used by

other state and local agencies should be presented.

This workshop should also contain a component to address educational needs for workshop attendees in the area of noise fundamentals. The basic concepts of noise and noise control should be presented as well as information on noise prediction methods and barrier acoustical design tools in order to familiarize attendees with these concepts. It is recommended that outside experts who have participated in noise and land use compatibility planning be involved in these sessions as well as those who provide instruction in noise fundamentals.

A third component of this workshop would involve the participation of attendees in the discussion of the application of noise and land use compatibility planning guidelines to their individual communities. The comments and consensus developed from these discussions could be compiled for feedback to the guideline development phase of implementation.

2. Workshops to Develop a Model Guideline. A working group should be established to participate in a series of workshops for the development of a model guideline. These workshops should involve the presentation of possible elements along with sample guidelines used by agencies in other states or provinces. Outside technical resources again should be used to provide the necessary input to the working group. In addition, technical resources could be used to facilitate the process in order to lead to a consensus regarding the elements written into the model guideline. A second phase of this series of workshops would involve the establishment of a recommended political process for the adoption and approval of the model guideline at the state and especially the local level. Such a recommended process would aid local agencies in the process of adopting the guideline and reduce the overall startup time.

3. Workshop on Model Guideline Adoption and Implementation. This workshop would be for those participants present from state and local agencies in the first workshop. The focus of this workshop would be the steps necessary to implement noise and land use compatibility planning by the local agencies in light of the model guideline developed by the working group. This workshop would prepare attendees for the process

of implementation in their own communities. Necessary materials and background information plus a review of pertinent information provided in the first workshop would be provided to equip participants for the task of implementation.

SUMMARY

The suggested implementation of the findings from this study is designed to produce a balanced approach to reducing the impacts of transportation noise on the environment in the State of Washington. While the ultimate responsibility for noise control rests at the local level, the State of Washington can do much to facilitate the success of local programs. The provision of technical assistance and model guidelines is of critical importance to reducing start up costs and ensuring a measure of consistency throughout the State. In addition, the technical assistance allows special problems to be easily addressed without putting undue staffing requirements on local communities to provide acoustical expertise. State technical assistance is within both the spirit and the letter of the Growth Management Act and Growth Strategies Act. Noise compatible development is within the spirit of the Growth Strategies Commission's work prior to the Growth Strategies Act, as well as the WSDOT transportation environmental policy.

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