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

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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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 airborne 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. In contrast to the enforcement of a local noise ordinance relied upon by most communities, 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.

Two categories of noise and land use compatibility planning are identified. 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.

Included in this study was a follow up of the Phase I findings in the areas of efforts to fund the USEPA Office of Noise Abatement and Control and needs for a funding category called "Environmental Mitigation and Enhancement Improvements" in the State of Washington.

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.

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, noise generated from vibrating crank shafts 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 monitored. 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 noncompatible 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 barriers 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. 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 under the philosophy that noise control was a local problem.

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 objective of the second phase of this study was 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 framework 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 a number of representatives from agencies involved in noise control from the provincial level to the city level.

Information for 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 '90s. 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 quieter vehicles.

DISCUSSION

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.

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.

Many of the strategies reviewed in the technical report for this study 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. Therefore, not all findings from specific research efforts can be extrapolated to the overall vehicle noise performance.

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.

The mechanisms of intake air noise have been studied for many years. Air filter housings have been designed to reduce intake air noise to an acceptable level for a long time. As a result, 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.

Intake noise is generally made up of low-frequency sound, generally less than 600 Hz. Using current technology, intake air noise can be reduced to a level consistent with the other component noise sources in a motor vehicle.

The current trend to reduce noise exhaust systems is to optimize the ability of muffler systems to attenuate exhaust noise. However, there is a limit to the effectiveness of conventional muffler systems. As conventional exhaust systems have reached their practical limit, exhaust silencing research has turned to another method, known as active noise cancellation.

Though the principle of active noise cancellation has been understood for many years, it has only recently been feasible for practical applications. More research is needed to demonstrate its effectiveness for broad applications, particularly variable speed engines found in highway vehicles.

Truck transmission and differential gear noise have been recognized as significant component sources for a number of years. 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, optimizing of the vibration characteristics between the various subcomponents of the drive line, and the use of effective dampers and possibly encapsulation of some components.

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. In spite of continued efforts to reduce tire noise, this component of vehicle noise is still dominant. 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].

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.

In a recent study sponsored by Washington State DOT, the influence of tire studs on tire/road noise was determined. 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].

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 [Sandberg, 1992a].

Washington State DOT has sponsored a study to determine the influence of roadway aging on tire/road noise [Chalupnik and Anderson 1992]. 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. 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]. The initial reduction in noise levels produced with the use of porous surfaces, however, is not maintained over the life of the pavement. 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 [Sandberg, 1992a]. 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 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]. In addition to more use of porous asphalt type pavement, experimentation with high rubber composition surfaces is also under way in Europe. 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.

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. Any reduction in noise levels produced by alternative fueled engines could potentially be a beneficial byproduct from efforts to reduce air pollution.

RECEIVER CONTROL

INTRODUCTION

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 motor vehicle noise plus a wide range of other 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.

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.

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.

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. In some cases, this process is accomplished by developing noise level contours for a community. 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. 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.

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.

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.

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.

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. 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.

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.

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.

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.

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. In addition, technical assistance made available by the states to local agencies, can further reduce start up time. As each local agency chooses to develop a program, the state brings to bear the experience of its involvement with start up programs of local programs already instituted. 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.

The study examined programs in three state or provincial agencies: Ontario, Canada, California and Minnesota.

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.

The eleven local agencies (four counties, seven cities) listed below were studied in detail. In addition, a review was made of the four local programs that were subjects of USDOT case studies done in the 1970s.

Montgomery County, Maryland
Howard County, Maryland
Orange County, California

San Diego County, California

Toronto, Ontario, Canada

Calgary, Alberta, Canada

Saskatoon, Saskatchewan, Canada

Carlsbad, California

Fullerton, California

Cerritos, California

Irvine, California

Table 1 is a summary of the noise and land use compatibility programs for the local agencies listed above.

LOCAL NOISE ORDINANCES

As described in the Phase I study, the most common form of local noise control involved enforcement of a local noise ordinance. These local ordinances are found in most communities and tend to be reactive in nature in contrast to noise and land use compatibility planning. Two noise control programs, administered by local agencies, were found to be exemplary and are reviewed in the technical report. These were the county of Orange in California and the city of Boulder in Colorado.

Table 1. Characteristics of Local Agency Noise Compatibility Programs

CHARACTERISTICS	LOCAL AGENCIES: COUNTIES: Montgomery MD	Howard MD	Orange CA	San Diego	MUNICIPALITIES: 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	LDN	LDN	CNEL	CNEL	CNEL	CNEL	CNEL	CNEL	LEQ(24)	LDN	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			/+
Insdust. Comm. 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	x	x	x	x		x	x	x	x	x	x
Buffer zones	x	x	x	x		x					x
Building orientation	x	x	x	x			x	x			x
Building insulation	x	x	x	x		x	x	x			x

* Federal
\+ Pending
° Provincial

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 decisionmaking on noise mitigation plans and programs.

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." 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 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. The amendment passed the full House. Unfortunately, the Senate recessed for the elections before acting on the entire Technical Corrections Bill and the noise abatement amendment was not passed.

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. 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.

A NOISE MITIGATION COST/BENEFIT FRAMEWORK

The discussion in the technical report 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 2-4 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 2. The upper portion of the table pertains to those strategies described in 1.a which 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.

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 (i.e., who pays) for 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

Table 2. Framework for Assessing Source Control Strategies

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. Pass Legislation Possible enforce. Tighten/pass legis. Develop Regs., Enforcement	Manufacturer State Legislature Washington State U.S. Congress U.S. EPA	Manufacturer Customer Washington State U.S. EPA	R&D, Mfg Purchase price Start-up, annual Start-up, annual	Substantial Variable, one-time Minor Several million/yr	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
Reduction of tire noise	R&D, Mfg Pass legislation Possible enforcement	Manufacturer State Legislature U.S. Congress Washington State U.S. EPA	Manufacturer Customer Washington State U.S. EPA	R&D, Mfg Purchase price Start-up, annual Start-up, annual	Substantial Variable, one-time Minor Several million/yr	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
In-use Limits: Low Speed Automobiles Medium trucks Heavy trucks Buses Motorcyles	U.S. Congress U.S. EPA FHWA Legislature Washington State Local gov't	Pass new or tighten current legislation Develop Regs.,Tech.Assist Enforcement Pass legislation re preemption Enforcement, Tech. Assist. Enforcement	Local gov't Washington State WSDOT U.S. EPA FHWA Violator	Start-up, annual Start-up, annual Start-up, annual Start-up, annual Start-up, annual Per violation	Substantial Moderate Moderate Several million/yr Moderate $25-100/violation	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
In-use Limits: High Speed Automobiles Medium trucks Heavy trucks Buses Motorcyles	U.S. Congress U.S. EPA FHWA Legislature Washington State Local gov't	Pass new or tighten current legislation Develop Regs., Tech Assist Enforcement Pass legislation re preemption Enforcement, Tech. Assist. Enforcement	Local gov't Washington State WSDOT U.S. EPA FHWA Violator	Start-up, annual Start-up, annual Start-up, annual Start-up, annual Start-up, annual Per violation	Substantial Moderate Moderate Several million/yr Moderate $25-100/violation	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

Table 2. Framework for Assessing Source Control Strategies

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			

Table 3. 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 WSDOT Taxpayer Federal gov't U.S. taxpayer	R&D Install & maintain State budget Federal-aid Gas tax	High Low (relative) Minor Minor Minor	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
Path control: Noise barrier by WSDOT	Project mitigation. Pass resolution of support	WSDOT Local gov't	WSDOT Taxpayer Federal gov't U.S. taxpayer	Install & maintain State budget Federal-aid Gas tax	$12-30/sq.ft. Few million/proj. 10%-20% share Minor	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
Path control: Noise barrier by Locality	Project mitigation Tech. Assist.	Local gov't WSDOT	Local gov't Taxpayer Affected resident WSDOT	Install & maintain Taxes Assessment Annual	$12-30/sq.ft. Variable Up to $1000s/res Moderate if active	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
Path control: Noise barrier by Developer	Project mitigation Review & approval Tech. Assist.	Developer WSDOT	Developer Affected resident WSDOT	Install & maintain Purchase price Annual	$12-30/sq.ft. Up to $1000s/res. Moderate if active	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
Path control: Road lids by WSDOT	Project mitigation. Pass resolution of support	WSDOT Local gov't	WSDOT Taxpayer Federal gov't U.S. taxpayer	Install & maintain State budget Federal-aid Gas tax	$1000s/linear ft Millions/proj. 10%-20% share Moderate	Residents near streets, Residents near highways	5-20 dB	1. Traffic volume and truck mix 2. Background noise

Table 3. 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 4. 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 Tech. Assist.	Local gov't WSDOT	Local gov't WSDOT	Purchase price Review & approval Tech. Assist.	Variable Minor Moderate if active	Residents near roads Local Gov't WSDOT	5-20 dB No need for other mitigation	1. Distance to road 2. Traffic volume 3. Background noise
Receiver Control: Proponent Noise Mitigated Development	Develop & impl. program Tech. Assist. Install & maintain	Local gov't Developer WSDOT	Developer Affected resident Local gov't WSDOT	Install & maintain Purchase price Review & approval Tech. Assist.	$12-30/sq.ft. Variable Minor Moderate if active	Residents near roads Local Gov't WSDOT	5-12 dB No need for other mitigation	1. Distance to road 2. Traffic volume 3. Background noise
Receiver Control: Building sound insulation	Develop & implement program Tech. Assist. Install	Local gov't WSDOT Developer	Developer Affected resident Local gov't WSDOT	Install & maintain Purchase price Review & approval Tech. Assist.	$5-20K/res $5-20K/res Minor Minor	Residents near roads	10-20 dB interior	1. No outdoors protection 2. Distance to road 3. Traffic volume
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

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 2 lists strategies described in item 1.b 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 3 and Table 4 present the framework for assessing path and receiver control strategies respectively. As with Table 2, 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 2, 3, and 4 are designed to be used together. For example, the strategy Reduction of New Vehicle Engine/Driveline Noise in Table 2 could be compared with the strategy Path control: Noise Barrier by WSDOT in Table 3 and Receiver Control: Proponent Mitigation Noise Barrier in Table 4. 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 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 2, 3, and 4 are not designed to produce a decision but to aid decision makers by organizing important factors to be considered when selecting traffic noise 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.

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 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 studied in this report are listed in Table 4 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.

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. 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
b. Building orientation and site layout
c. Building design
d. Landscaped berms
e. Berm/wall combination
f. Wall
g. Depressed roadways
h. Money to compensate homeowners
i. Acoustical treatments to buildings

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.

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. 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 steps.

1. <u>Produce Noise and Land Use Compatibility Planning Guidelines</u>. 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.

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.

2. <u>State Office of Technical Assistance</u>. 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.

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.

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 the technical report of this study 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. This workshop should also contain a component to address educational needs for workshop attendees in the area of 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. 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.

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.

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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