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KTC-08-08/TA23-05-1F

KENTUCKY TRANSPORTATION CENTER

EVALUATION OF NOISE IMPACT MITIGATION PROTOCOLS TO SUPPORT CSS

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Research Report KTC-08-08/TA23-05-1F

EVALUATION OF NOISE IMPACT MITIGATION PROTOCOLS TO SUPPORT CSS

(Final Report)

by

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16. Abstract:

This research project developed and evaluated practical ways of involving the public in context sensitive sound mitigation strategies. The integrated use of photo montage, powerpoint presentation, linked traffic sound files, and audience response systems demonstrated that significant visual and aural differences could be clearly portrayed and clear preferences could be expressed by citizens and professionals alike, even where the choice menu was quite complex.

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1 Executive Summary

This project assesses some likely methods for involving the public in making decisions about alternative context sensitive noise mitigation strategies. There are a wide range of potential individual tools available to the professional, depending upon the context of the problem. In this project, the problem of the urban arterial was focused on and a menu of ‘mix and match’ tools was modeled visually and aurally for public presentation. These tools were presented to various public agencies who customarily deal with these design problems, and they acted as subjects, providing feedback through the audience response systems, and as critical reviewers, commenting on the suitability of various tools and potential strategies as they relate to particular problem sets.

We have learned that, using only modest technical resources, transportation professionals can garner very useful feedback about a complex menu of potential sound mitigation strategies. With a laptop running PowerPoint or similar tool, a modest set of speakers, and a modest amount of digital photography modifications, they can prepare a presentation that will quickly and effectively educate the public and gather useful feedback about the most acceptable mitigation tradeoffs. This is in contrast to other design problems that require sophisticated planning and resource-intensive tools and time to gather accurate information about transportation infrastructure questions. While it may be desirable to have more sophisticated representation tools in cases where the project is large and affects hundreds or thousands of people, most mitigation projects concern only the residents fronting the arterial and can be easily addressed with comparatively modest, straightforward tools. We encourage professionals to consider this approach as a regular component of sound mitigation studies.

2 Introduction

For many years urban streets in the U.S. were improved to increase traffic speeds and volumes; this approach is known as traffic flow oriented efforts. However, some of these streets are now being modified to reduce traffic speeds or volumes and create more pedestrian oriented streets (i.e., safer and quieter streets). Over the past 25 years there has been a movement toward an interdisciplinary approach to providing roadway infrastructure, while protecting the quality of the environment. For example, traffic calming techniques, such as, speed humps, speed tables, raised intersections, and roundabouts, involve Context Sensitive Design (CSD) practices. Roadway engineers or planners have flexible standards that can accommodate community values and street environments, which can make streets safer and quieter, as well as increase local economic activity (Department for Transport, 2005c).

This led to the primary concept of Context Sensitive Design (CSD). “Context Sensitive Design (CSD) asks questions first about the need and purpose of the transportation project, and then equally addresses safety, mobility, and the preservation of scenic, aesthetic, historic, environmental, and other community values. CSD involves a collaborative, interdisciplinary approach in which citizens are part of the design team” (Neuman et al, 2002).

The early legal basis for integration of context sensitivity in transportation dates back to the Highway Beautification Act of 1965 and National Environmental Policy Act (NEPA) of 1969. CSD is similar to Sustainable Development, which is practiced in the European countries and their international counterparts.

As one of the environmental impacts of transportation projects, highway noise problems need to be analyzed and addressed in several ways. The most effective method to reduce highway noise is noise barriers. However, other alternatives such as quiet pavements, traffic management, and traffic calming devices need to be evaluated. This literature review provides an overview of the state-of-practice of context sensitive noise design.

3 Problem Statement

One of the overall goals of Context Sensitive Design, or Context Sensitive Solutions (CSS), is to minimize the adverse impacts of new and existing public infrastructure. One significant property of highway traffic is the noise generated by acceleration, braking, and tire/pavement interaction. The composition and relative intensity of these sounds vary by vehicle type, propulsion and braking systems, speed variation, and absolute speed. The perception of noise impacts is also affected by background (ambient) noise. Thus streets at all levels may generate public perceptions of excess traffic noise, which may not be necessarily related to absolute levels. Because current research is aimed at absolute tolerances, little systematic attention has been paid to overall noise mitigation protocols at all scales of transportation planning.

Traditional noise barriers are most useful in high volume, high speed traffic situations. Less is known about how to reduce the overall impact of noise generated by local and regional traffic. Based on information gathered from a query of state DOT's, there is little or no systematic approach to noise impact mitigation, or the design and delivery of noise impact mitigation protocols across all scales of transportation planning and design.

4 Traffic Noise Mitigation Strategies

4.1 Design of a Noise Barrier

“Most residents near a barrier seem to feel that highway noise barriers effectively reduce traffic noise and that the benefits of barriers far outweigh the disadvantages of barriers. While noise barriers do not eliminate all highway traffic noise, they do reduce it substantially and improve the quality of life for people who live adjacent to the busy highway” (U.S. DOT, 2001).

The most important function of a noise barrier is to protect sensitive receivers from extreme noise generated by adjacent highway traffic. For the context sensitive noise barrier design, both acoustic and non-acoustic aspects should be considered.

Acoustical design considers the barrier material, barrier locations, dimensions and shapes so as to meet minimum Insertion Loss criteria. Non-acoustical design is equally important. It considers such issues as maintainability, structural integrity, aesthetics, safety, and other non-acoustical factors in order to reduce potential negative effects of noise barriers (Hong Kong, 2003).

4.1.1 Acoustical Design Considerations

Two sound wave transmission paths are created with the construction of a noise barrier. One is the path through the barrier. In this case, the amount of noise transmitted is dependent mainly on barrier material properties. Regardless of the material selected for the noise barrier, the transmitted noise can be ignored if the material is dense enough to get at least a 10 dB transmission loss (Kurze and Anderson, 1971). However, transmission loss will be reduced if sound leaks exist, due to holes, slits, or gaps through or beneath the noise barriers.

The other path is the diffracted path. The noise contribution from this path is dependent on the location, shape, and dimension of the barriers. Reflected noise should also be considered with parallel noise barriers to avoid a tunnel effect (Hong Kong, 2003 and Fleming et al, 2000).

A noise barrier should be long enough to prevent sound from traveling around either end. A commonly used rule-of-thumb is to require that a barrier extend a distance beyond the last receiver equal to 4 times the perpendicular distance from that receiver to the barrier.

A barrier should be high enough to break the line of sight (LOS) between the vehicles on the highway and the receiver or home. In this case, a 5 dBA noise level reduction (IL) can normally be expected. A rule-of-thumb is that for each 2 feet increase in height, approximately 1 dBA additional noise reduction can be obtained (Fleming et al, 2000 and Cohn, 1981).

In complex urban areas, noise barriers occasionally need to be overlapped to allow for ramp entry or maintenance access points. A commonly used rule-of-thumb for this case is to ensure that the minimum overlap gap distance is 4 times the gap width (Cohn, 2005).

4.1.2 Non-Acoustical Design Considerations

Not only acoustic attenuation but also safety, emergency access, maintenance, and aesthetics issues need to be carefully considered when implementing a noise barrier along a highway. These important matters should be considered in the barrier design process (Fleming et al, 2000).

In the case of elevated structures, which include bridges and elevated roadways, wood barriers and steel barriers are more appropriate than concrete and concrete masonry because of weight consideration (Simpson, 1976). Different design loads must be considered, especially when the barrier is designed on a bridge structure. These loads include dead load, wind load, snow load, and impact load.

Drainage is also an issue that must be considered. The two most common methods applied are: (1) moving the water through openings in the barrier with a variety of sizes and shapes. (2) using a drainage ditch to carry the water to a catch basin and then under the barrier (Cohn, 2005).

4.1.3 Aesthetic Aspect

The design process of a noise barrier should consider the visual impact on the surrounding area. Particularly, a tall noise barrier close to a residential area may generate adverse shadows and air circulation problems. In addition, some residents have been documented to feel a restriction of view and a sense of confinement. In order to avoid these issues, the distance of the noise barrier from a residential structure should be at least four times the height of the barrier (Simpson, 1976).

In addition to shielding the community from excessive noise, noise barriers can also affect the aesthetic perception of road users. A well designed barrier can improve the visual quality of the area. In addition, it can reflect community characteristics as well as historic values. By using different types of landscaping, noise barriers can harmoniously blend into the environment. Aesthetics are subjective in nature and closely related to the appearance of the noise barrier. To the extent possible, noise barriers should blend into the roadway environment (Cohn, 1981).

Normally, vertical alignment changes in the top elevation of a barrier follow the terrain by “stepping” the panels. For the barrier end treatment, the abrupt ending of a “tall” wall should be avoided. This can be accomplished by stepping the barrier height down and adding landscaping treatment.

To reduce the linear nature of the barrier and enrich the visual quality, treatments such as segmentation, curving and articulation of the surface texture and color can be applied. Architectural elements including rhythm, proportion, order, harmony and contrast can be used to enhance the overall appearance of the barriers (Hong Kong, 2003).

4.1.4 Public Acceptance

Public acceptance is a critical evaluation criterion for noise barrier design. A well designed barrier will be accepted by a majority of the community. There are two subjective components of barrier design that tend to dominate community acceptance: the perception of noise mitigation, and the perception of visual compatibility. Public perception of visual compatibility is more important than the acoustic performance for perceived effectiveness (Cohn, 1981). For example, many people perceive that landscaping would reduce noise levels, even though the noise reduction by landscaping is negligible.

Characteristics of the barriers have been identified that influence the community's acceptance of noise barriers (Cohn and Bowlby, 1984). These characteristics include size and mass, material selection and color, landscaping, and public involvement in the project.

Public involvement is an interdisciplinary process that includes all stakeholders. As noted by 23 CFR 772, a public meeting is held when a noise barrier is determined to be warranted. Therefore the public involvement process should start during the early planning stages.

4.1.5 Perceptions of Noise Reduction

Despite the widespread belief that any type of visual screening would reduce the perception of traffic noise, some studies have demonstrated otherwise. In fact, several studies have found that the perception of noise levels actually increases in the presence of sound barriers (Watts, Chinn, Godfrey, 1998), (Aylor and Marks, 1976), (Mulligan, et al., 1987).

A determining factor in the perception of noise is the transparency of the sound barrier. Perceptions of noise levels are generally higher when the source of the noise is hidden by the sound barrier. For example, at a site where the roadway is hidden behind a thick hedge, perceptions of traffic noise levels would be relatively high as compared to a site where the barrier is comprised of tall trees between which the traffic is visible. This effect is present with other types of sound barriers as well. Perceptions of traffic noise from listeners behind a brick wall would be higher than perceptions of traffic noise from listeners behind a glass barrier.

A possible explanation for the effect is that of false expectations. When a sound source is visually screened, a listener expects its loudness to be significantly reduced, perhaps in the same manner that light from a source is diminished when the observer moves into the shadow cast by a fixed source. Many sound barriers, such as vegetation screens, are aesthetically pleasing and effective at visually obscuring the source of the noise. However, such screens are minimally effective at actually reducing the loudness of the traffic noise. This could result in the listener overestimating the loudness of the visually screened sound source.

4.2 Quiet Pavement

Research in Europe and in the United States has indicated that it is possible to build pavement surfaces that will reduce highway noise (Hanson and James, 2004). In this section, a review of noise reduction pavements will be presented.

Three main sources are responsible for the generation of noise from vehicles traveling on a highway: aerodynamic noise, power train noise, and tire/pavement noise. It has been estimated that the tire/pavement noise accounts for 75-90 percent of the overall noise energy for light vehicles. If pavement noise level can be reduced, the overall highway noise levels will also be largely decreased.

Tire/pavement noise comes from three different mechanisms (Bendtsen and Anderson, 2004).

- Aerodynamic noise generated by air pumping:

  Air pumping is generated when air is sucked in and forced out between the rubber blocks of the tire when the tire rolls on the road surface. The higher frequency bands range between 1000 and 3000 Hz dominate this part of noise. To reduce aerodynamic noise generated by air pumping, the road surface needs to be porous with a high percentage of air voids so the air can be pumped down into the pavement structure.

- Vibration noise:

  When the rubber blocks of the rolling tire hit the pavement texture formed by the aggregate at the top layer of the pavement, vibrations are generated in the tire structure, with a dominate lower frequency bands range between 100 and 1000 Hz. If the pavement surface is smoother, the vibration generated noise can be reduced.

- The horn effect noise:

  In the driving direction, an acoustical horn is formed by the pavement surface and the curved structure of the tire, and this horn effect will amplify the noise generated by tire/pavement interaction. Use of noise absorbing material on the pavement side will reduce horn effect noise.

These mechanisms for noise generation are the background for the acoustical design of quiet pavements and quiet tires.

4.2.1 Rubberized Asphalt Overlay

Rubberized asphalt is a bituminous mix composed of blended aggregates, recycled rubber and binding agents. The recycled rubber often comes from used tires. Previous studies have shown that rubberized asphalt can reduce highway noise pollution.

The use of recycled tire rubber as a pavement material has been employed in the United States for more than 50 years. In the 1940's, the U.S. Rubber Reclaiming Company added recycled tire rubber to asphalt paving material, as a dry particle additive. In the mid-1960's, crumb rubber was used to develop a modified asphalt binder.

The FHWA will not approve use of rubberized asphalt as a noise mitigation measure. However ISTEA, Section 1038, mandates the use of recycled tires in asphalt paving. A percentage of the total tons of asphalt laid in a state with Title 23 funds must contain rubber. The percentage grew from 5% in 1995 to 20% in 1997.

Through 1995, Congress provided moratoriums on implementation of this requirement, but the section remains as federal law (ISTEA, 1995). This dilemma resulted in projects being dropped in favor of more traditional practices.

Rubberized asphalt can also be used as part of tire waste management mitigation programs if cost effectiveness criteria are met. However, it is not allowed as a noise mitigation measure in National Environmental Policy Act (NEPA) documents.

The use of rubberized asphalt has increased significantly over the last 10 years, due to increased noise pollution and excess used tires. To date, rubberized asphalt has been primarily used to resurface existing pavements. The Arizona Department of Transportation (ADOT) is considered a pioneer in this effort (ADOT Quiet Roads, 2005). The first use of asphalt rubber by ADOT was in 1964. In 1973, ADOT developed an asphalt rubber overlay system for PCC with a two-layer system. The first use of the ARFC (Asphalt Rubber Friction Course) strategy occurred on I-19 near Tucson. ADOT has used rubberized asphalt in paving projects with more than 4.2 million tons since 1988 (Scofield et al.). The ADOT experience has demonstrated the superior performance of rubberized asphalt, including increased pavement durability and service life, and superior resistance to reflective cracking. Accompanying research has demonstrated that rubberized asphalt is also an effective method to mitigate noise problems related to highway transportation. Studies have shown a reduction in noise energy on rubberized asphalt of approximately 65 to 85 percent.

Table 4-1: Countries Using Rubberized Asphalt and Resulting Noise Reduction

Country	Year	Reported Noise level Reduction
Germany	1980	3 dB(A)
Belgium	1981	8-10 dB(A)
France	1984	3 to 5 dB(A) with no trucks 2 to 3 dB(A) with 5 percent trucks
Vienna		4.1-5.5 dB(A)
Austria	1988	3+ dB(A)
Netherlands	1988	2.5 dB(A)
Europe	1989	3-10 dB(A)
Canada	1991	Shown noise reduction
Japan (called PERS, porous elastic road surface)	1995	13-19 dB(A), 8-9 dB(A), 6-10 dB(A) reduction for cars, light trucks, and heavy trucks. (Meiarashi, 2004)
Ireland	1998	5 dB(A) reduction (Brennan et al, 2001)
England	1998	Project not completed
Japan	2003	6-10 dB(A) (EXPO 2005 in Japan, 2005)

4.2.2 Evaluation of ARFC Noise Reduction over Time

The life span for a rubberized asphalt overlay is shorter than a concrete overlay. However, it is expected to be longer than conventional asphalt (ADOT Quiet Roads, 2005). The non-acceptance of ARFC as a noise mitigation measure is based on the belief by FHWA that “quiet pavements” lose their noise attenuation characteristics after 3 to 5 years and thus are not a permanent solution (Scofield et al). Some studies have evaluated the ARFC noise characteristics over time, as shown in Table 4-2.

Table 4-2: States using rubberized asphalt and resulting noise reduction

State	County or City	Year	Noise level reduction
Arizona	Tucson	1989	6.7 dB(A)
	Phoenix	1990	10 dB(A)
	Phoenix	1995	4.7 dB(A)
	Scottsdale	2002	3-5 dB(A) (Higgins & Associates, 2002)
	Phoenix	2004	7-10 dB(A), 4.9 dB(A), and 7-9 dB(A) for site I, II, and III
	Tucson	1989	6.7 dB(A)
	Pima county		2-3 dB(A)
California	Los Angeles County	1991	3-7 dB(A)
	Orange County	1992	3-5 dB(A)
	Sacramento County	1993	5.1-7.7 dB(A)
	San Diego County	1998	Project in process
Texas	San Antonio	1992	Data not provided
Oregon	Corvallis	1994	Data not provided
	Kansas	1992	noise reduction on sites 1 and 3

During the summer of 2002 ADOT conducted a network level survey of ARFC ranging in age between 3 years and 12 years. The results indicated that ARFC produced CPX noise levels between 94 and 99 dB(A) throughout their 10 year period. The data further suggested that there was approximately a 5 dB(A) reduction in noise attenuation characteristics with time. Several issues regarding this conclusion should be further considered. First, the ARFC surfaces were overlays on flexible pavements, not PCC. Second, the ARFC thickness was just 1/2 inch, not the one inch used on PCC. Last, the design life of the flexible pavements tested was 10 years, so the noise reduction data on pavements was obtained near the end of their design life (Scofield et al). In addition, a 1995 study indicated that no relationships were found regarding the different noise levels produced by ARFC segments of different ages.

4.2.3 U.S. Experiences with Rubberized Asphalt

Table 4-3: Rubberized noise test results (CEI, 2001)

Roadway	Pavement Type	Duration of Time Elapsed after paving	Change in Noise Levels, dB(A) Leq
Alta Arden Expressway	Rubberized Asphalt	1 month	-6 dB(A)
		16 months	-5 dB(A)
		6 years	-5 dB(A)
Antelope Road	Rubberized Asphalt	6 months	-4 dB(A)
		5 years	-3 dB(A)

4.2.3.1 Sacramento County, CA Study

Since 1992, rubberized asphalt has been used in Sacramento County. A recent noise study on rubberized asphalt pavement lasted for 6 years. The conclusions of this study indicate that the use of rubberized asphalt on Alta Expressway resulted in an average 4 dB(A) reduction in traffic noise levels as compared to the conventional asphalt overlay used on Bond Road. This noise reduction continued six years after the paving with rubberized asphalt (Sacramento County and Bollard & Brenan, 1999).

4.2.3.2 Orange County, CA Study

Orange County studied the effectiveness of rubberized asphalt as a noise mitigation measure in 1992. Sound levels on four different pavement types were measured: dense grade asphalt, rubber asphalt (gap graded), rubber asphalt (open graded), and open grade (with latex). The conclusion of this study was that rubber asphalt-open graded was 3.9 dB(A) quieter than new dense grade asphalt.

4.2.3.3 Phoenix, AZ Study

The city of Phoenix conducted a study to compare the noise levels on two different pavement types: standard chip seal asphalt laid in 1984 and rubberized asphalt laid in 1989. The study concluded that the rubberized asphalt reduced noise levels by 10 dB(A) more than the chip seal asphalt.

4.2.4 Other Noise Reduction Pavements

4.2.4.1 United States Experience

A summary of the results of studies in the U.S. evaluating different pavement surface types are presented in Table 4-4:

4.2.4.2 International Studies

European countries have conducted numerous studies to determine the noise reduction on different pavement surfaces since the 1980s (Kandhal, 2004). The European experience proved that porous mixes are effective in reducing noise, and recommends that porous mixes be placed on highways where speeds are above 45 mph because highly porous mixes tend to clog under slow speed (Carlson, 2005). A reduction of aggregate size in the wearing surface is recommended and should yield a noise reduction of 1-3 dB.

Japan also engaged in research on Drainage Asphalt Pavement (DAP) and Porous Elastic Road Surface (PERS) in the 1990s. In South Africa, an OGAC pavement called the “Whisper Course” has an excellent noise reduction performance; it has demonstrated a noise reduction of 9 dB over a single-seal surface and a reduction of 11.7 dB over a grooved surface.

A summary of the results of International studies evaluating different pavement surface types are presented in Table 4-5.

4.2.5 Surface Texture Related to Noise Reduction

In 1996, FHWA published a comprehensive technical report related to highway noise and pavement texture (Kuemmel, 2000). The report covered information on the pavement research status in foreign countries and the states of CA, CO, IA, MI, MN, ND, VA, and WI.

Table 4-4: Noise from different pavement surface types: U.S. studies

State/Agency	Surface Types	General Conclusions
FHWA (1975)	HMA, OGFC, PCC	OGFC was 2 dB(A) quieter than HMA, and HMA was 1 dB(A) quieter than PCC based on studied in AZ, CA, and Nevada.
Minnesota (1979,1987,1995)	HMA, OGFC, PCC	OGFC was quieter than HMA in 1979 study; HMA was quieter than PCC in all three studies.
Maryland (1990)	OGFC, PCC	OGFC was 2.3 to 3.6 dB(A) quieter than PCC.
Wisconsin (1993)	HMA, SMA	SMA was 1 dB(A) lower than HMA
Maryland (1994)	HMA, SMA	SMA was 1 dB(A) lower than HMA
New Jersey (1994)	HMA, SMA, PCC	One PCC pavement and one HMA pavement were overlaid by SMA. Before overlaid, HMA was 2 dB(A) quieter than PCC. After overlaid, SMA was 4.1 dB(A) quieter than PCC, and 2.1 dB(A) quieter than HMA.
Oregon (1994)	OGFC, PCC	OGFC was 5.7 to 7.8 dB(A) quieter than PCC.
U.S.DOT (1995)	HMA, OFGC, PCC	Volpe National Transportation Center conducted studies for TNM. PCC was 3 dB(A) louder than HMA, OGFC was 1.5 dB(A) quieter than HMA.
Wisconsin (1997)	HMA, PCC	HMA was 2 to 5 dB(A) less than PCC.
Texas (2000)	OGFC, PCC, Coarse Matrix High Binder	OGFC is 6.5 dB(A) quieter than PCC, CMHB is 5.3 dB(A) quieter than PCC. (McNerney, 2000)
Michigan (2000,2001)	HMA, SMA, PCC	HMA was 4-5 dB(A) quieter than PCC. SMA was 4 dB(A) quieter than HMA.
Michigan (2002)	HMA, SMA, PCC	CPX method at 60 mph: noise levels in dB(A): SMA=98.3, HMA=98.8, and PCC=98.9 to 100.8.
California (2002)	HMA, OGFC	OGFC is quieter than the HMA by 4 to 6 dB(A). (I-80,2002)
Texas (2003)	OGFC, PCC	Continuously reinforced concrete pavement (CRCP) was overlaid with OGFC, noise was reduced from 85 to 71 dB(A). (TX DOT, 2003)
Kentucky (Kim, 2004)	DGAC, PCC, OGAC	DGAC is 2-4 dB(A) quieter than PCC,
New Jersey (NJDOT, 2004)	PCC, HMA, OGFC	HMA is 4.1 dB(A) quieter than PCC.
		OGFC is with the lowest noise levels.
Colorado (Hanson and James, 2004)	OGFC(fine gradation), OGFC(coarse gradation) HMA, SMA	CPX method:
		OGFC (fine graduation) mixes: 93 dB(A)
		HMA: 95 dB(A)
		SMA: 96 dB(A)
		OGFC (coarse gradation mixes: 97 dB(A)
National Center for Asphalt Tech. (Bennet, Hanson, and Maher, 2004)	OGFC, HMA, SMA	CPX method: OGFC(coarse gradation) 97 dB(A), OGFC(fine graduation) 93 dB(A), HMA 95 dB(A), and SMA 96 dB(A).

HMA = Dense-Graded Hot Mix Asphalt; OGFC = Open-Graded Asphalt Friction Course; PCC = Portland Cement Concrete; SMA = Stone Matrix Asphalt

Table 4-5: Noise from different pavement surface types: international studies

Country/Agency (year reported)	Surface Types Evaluated	General Conclusion
Italy (1990)	HMA, OGFC	OGFC was 3 dB(A) quieter than HMA
Germany (1990)	HMA, OGFC	OGFC was 4 to 5 dB(A) quieter than HMA
Sweden (1990)	HMA, OGFC	OGFC was 3.5 to 4.5 dB(A) quieter than HMA.
France (1990)	HMA, OGFC	OGFC was 3 to 5 dB(A) quieter than HMA
Netherlands (1990)	HMA, OGFC	OGFC was 3 dB(A) quieter than HMA
Denmark (Nordic Road & Transport Research No.1, 1997)	Drainage asphalt, HMA	3 dB(A) reductions on national roads, 3 dB(A) dropped to 0 dB(A) after 2-3 years, probably due to clogging of the upper layer of pores in the surface.
Germany (1991 and 1998)	HMA, SMA	SMA was 2.5 and 2.0 dB(A) quieter than HMA.
Danish Road Institute (1992)	HMA, OGFC	OGFC was 4 dB(A) quieter than HMA
United Kingdom (1993)	OGFC, PCC, Rolled Asphalt	OGFC, PCC by 4 dB(A). OGFC was 6-7 dB(A) quieter than PCC.
World Road Association (1993)	HMA, OGFC, PCC, Chip Seal	OGFC 69-77 dB(A); HMA 72-79.5 dB(A); and PCC 76-85 dB(A). This indicate HMA is at least 4 dB(A) quieter than PCC.
Belgium (1994)	HMA, OGFC, PCC	HMA was 3.4 dB(A) quieter than PCC. OGFC was 7.5 dB(A) quieter than PCC. OGFC was 10.5 dB(A) quieter than transverse grooved PCC.
England (1996)	Concrete surface and bituminous surface	Some concrete roads are genuinely subjectively noisier than bituminous roads. (Watts, 1996)
Africa (1996)	OGA whisper course, 13 mm seal, JCP, DGA, OGA	CPX method: Whisper course OGA produced the lowest dB(A) and the second-lowest values on the normal dB scale.(McNerney, 2000)
Italy (1998)	HMA, SMA	SMA was 7.0 dB(A) quieter than HMA at the speed of 110 km/h
British Columbia, Canada (1999)	HMA, OGFC	OGFC is 3.5 to 4.0 dB(A) quieter than HMA.
Japan (Fujiwara, 2005)	DAP(drainage asphalt pavement), HMA	DAP is 4-7 dB(A) and 2-5 dB(A) quieter than HMA for cars and medium trucks.
Denmark (Bendtsen and Anderson, 2005)	Single-layer porous, two-layer porous, thin open pavement	First one has 3-4 dB(A) quieter than HMA, second one has 4 dB(A) noise reduction, third has 2-3 dB(A) noise reduction

The FHWA report noted that the German study showed exterior noise levels on longitudinally tined and exposed aggregate surfaces were within 1 dB(A) of each other. However, the transversely tined surfaces were about 3 dB(A) different.

Studies in Japan indicated that noise increases with the increase of texture depths for almost all tires. Australian researchers further concluded that up to 3.5 dB(A) higher noise levels can be expected on tined concrete surfaces compared to asphaltic concretes.

A study on I-70 east in Colorado found that the longitudinal astro-turf dragged surface and longitudinally tined section produced the lowest noise level, while variable transverse tinning sections yielded the highest noise level.

A study on I-94 in North Dakota concluded that skewed tinning and variable spaced tinning produced the lowest noise level. Furthermore, this study concluded that no significant differences existed between the transversely tined, longitudinally tined, or skewed-tined textures in terms of interior noise levels.

In March 1998 Wayson (Wayson, 1998) prepared a National Cooperative Highway Research Program Synthesis report regarding pavement surface texture and highway traffic noise. Several of the main findings are as follows:

Transverse tinning causes the greatest roadside noise levels and may lead to irritating pure tone noise, this tonality noise can be reduced by randomized spacing surfaces.

Texture depth of transverse tinning seems important to roadside noise levels from PCC pavement.

In Europe, the tonal noise was thoroughly studied in the late 1970's. As a result, Europe abandoned the use of grooved or tined concrete pavements in the 1980's.

The Wisconsin DOT and FHWA conducted research regarding the texture and noise characteristics of Portland Cement Concrete (PCC) pavements in 2000. Noise measurement and pavement texture on 57 sites in Colorado, Iowa, Michigan, Minnesota, North Dakota and Wisconsin were investigated. The report made the following conclusions:

The longitudinal tined PCC and the Asphaltic Concrete (AC) pavements exhibited the lowest exterior noise levels, and AC pavements and the longitudinally tined, random skewed PCC surfaces and the European texture exhibit the lowest interior noise levels.

Transverse tined surfaces with the deepest and widest textures were often the noisiest. Longitudinal and random skewed tinning (1:6 skew) can eliminate discrete frequencies while substantially reducing noise levels.

When comparing different surface textures to the uniform transverse tined PCC pavements, a well randomized transverse will yield a 1-3 dB(A) reduction in exterior noise levels, a random skew 4 dB(A), and a longitudinal tined 4-7 dB(A).

In 2002, ADOT conducted a project to evaluate the PCC pavement surface noise by altering the tinning procedures (Scofield et al). The results indicated that a uniform longitudinal texture produced approximately a 5 dB(A) reduction over ADOT's standard uniform transverse texture, and approximately an 8-9 dB(A) reduction over the Wisconsin random transverse texturing. The comparisons of pavement surface texture are shown in Table 4-6.

Table 4-6: Comparisons of pavement surface texture

Surface Texture Type	CPX Noise Level Measured at Tire (dB(A))
Random Transverse (WI Spec)	104.9
ADOT Uniform Transverse Tined (3/4”)	102.5
ADOT Uniform Longitudinal Tined (3/4”)	99.1
Whisper Grinding (Diamond Grinding)	95.5 (As-Constructed)

4.3 Traffic Management

“The term “traffic management” can be described as an application of different strategies and measures to change the flow of traffic on roads either to reduce the speed of vehicles passing by and/or to reduce the traffic volume itself” (Bendtsen et al, 2004).

Controlling traffic on a road will sometimes reduce traffic noise problems. This measure includes reducing traffic volume, acceptable alternative truck routes, reduction of trucks, and changing the traffic distribution. In addition, the flow of traffic can be improved at intersections in order to diminish frequent stops. Reduction in traffic speed can also reduce noise on the roadway. According to a FHWA report, a 20 mph reduction in traffic speed results in a noticeable decrease in noise levels (Bendtsen et al, 2004 and US DOT, 1995).

4.3.1 Speed Control

Table 4-7 demonstrates expected noise reduction from implementing traffic management strategies that reduce vehicle speeds. The noise reduction was predicted by utilizing the Nordic Prediction Method in 1996. As shown in Table 4-7, reducing speed from 60 to 50 km/h yields a noise reduction of 2.1 dB(A). On the other hand, no noise reduction was yielded by reducing speed from 40 to 30 km/h (Bendtsen et al, 2004).

Table 4-7: Expected noise reduction caused by reducing speed (10% heavy traffic) (Bendtsen et al, 2004)

Change in speed	Noise reduction
From 110 to 100 km/h	0.7 dB(A)
From 100 to 90 km/h	0.7 dB(A)
From 90 to 80 km/h	1.3 dB(A)
From 80 to 70 km/h	1.7 dB(A)
From 70 to 60 km/h	1.8 dB(A)
From 60 to 50 km/h	2.1 dB(A)
From 50 to 40 km/h	1.4 dB(A)
From 40 to 30 km/h	0.0 dB(A)

4.3.2 Volume Control

Table 4-8 shows the expected noise reduction caused by reducing the traffic volume, without changing either speeds or the percentage of trucks (Bendtsen et al, 2004). Normally, a reduction of 3 dB(A) (barely perceptible by public) will be achieved with a halving of the traffic volume.

Table 4-8: Expected noise reductions caused by reducing traffic volume (Bendtsen et al, 2004)

Reduction in traffic volume	**Reduction in noise**
10%	0.5 dB(A)
20%	1.0 dB(A)
30%	1.6 dB(A)
40%	2.2 dB(A)
50%	3.0 dB(A)
75%	6.0 dB(A)

Diverting some traffic volume to less-sensitive remote roadways can result in a lowering of noise levels. The noise reduction can be noticeable while insignificant additional noise is generated on the remote roadways with existing heavy volumes (Garcia, 2001).

4.3.3 Truck Access Control

Typically, truck noise from roadways seriously affects receivers late at night and early in the morning. The city of Peoria, AZ has attempted to pass an ordinance (i.e., Restricted Truck Hour Operation) to prohibit truck operations from 9:00 pm to 5:00 am (City of Peoria, AZ, 2006 Internet).

In addition, noise levels can be reduced by lowering the percentage of heavy vehicles in the traffic stream. The number of heavy trucks can be restricted by prohibiting such vehicles from entering a prescribed roadway, or by restricting entrance at certain times, usually at night.

Table 4-9 shows noise reductions that can be expected by reducing the percentage of heavy trucks. This measure significantly reduces the overall noise level by reducing heavy trucks about 15 percent.

Table 4-9: Noise reductions caused by reductions in the percentage of heavy traffic (Bendtsen et al, 2004)

Reduction in percentage of heavy trucks	**50 km/h**	**80 km/h**
From 5 to 0%	0.7 dB(A)	1.0 dB(A)
From 10 to 0 %	1.4 dB(A)	1.9 dB(A)
From 15 to 0 %	2.0 dB(A)	2.6 dB(A)

4.3.4 Vehicle Acceleration and Deceleration

A vehicle's acceleration and deceleration can result in a substantial increase of noise levels. To reduce the noise levels, traffic flow needs to be controlled smoothly and to minimize the need for a vehicle to accelerate.

Table 4-10 illustrates the predicted noise influence of acceleration/deceleration at junctions, ramps, or intersections. The Harmonoise Model, which makes it possible to estimate noise levels of acceleration/deceleration, was used in this study (Bendtsen et al, 2004). As can be seen, the noise influence caused by acceleration and deceleration of automobiles is not as large as that of heavy trucks. Also, acceleration has a larger noise contribution than deceleration.

Table 4-10: The influence on noise emission from vehicles of uneven driving pattern (Bendtsen et al, 2004)

Acceleration/ deceleration	**Vehicle type**	**Noise influence**	**Note**
1 m/s^2	Light	1.7 dB(A)	Moderate acceleration
2 m/s^2	Light	4.5 dB(A)	High acceleration
0.5 m/s^2	Heavies	+2.1 dB(A)	Moderate acceleration
1 m/s^2	Heavies	+4.5 dB(A)	High acceleration
-1 m/s^2	Light	-0.8 dB(A)	Slow deceleration
-2 m/s^2	Light	-1.2 dB(A)	High deceleration
-1.5 m/s^2	Heavies, 2 axles	-4.5 dB(A)	Moderate deceleration
-1.5 m/s^2	Heavies, 3 axles	+4, 5 dB(A)	Moderate deceleration

4.3.5 International Research Work

European countries have much relevant experience with traffic management. Some highlights are presented in this section. A summary is contained in Table 4-11.

In urban traffic situations, the vehicle occupancy per private car averages 1.1 persons (Brambilla, 1993). Further, 50% of all trips are 3 km or less. If the occupants of the private vehicles can take other modes of transportation, such as public, bicycle or pedestrian transport, noise levels generated by private vehicles can be minimized.

In order to reduce environmental noise, the following traffic management actions are recommended (Brambilla, 1993).

- Improvement of public transportation and incentives for its use
- Discouragement and limitations of private and commercial transportation
- Measures to avoid traffic congestion, such as car pool, van pool, HOV lanes, traffic signal optimization, and flexible working hours.
- Road pricing strategies, e-tolling system (Muromachi et al)

- Convenient pedestrian areas and bicycle routes.

Table 4-11: Summary of European traffic management and noise effects (Bendtsen et al, 2004)

Country	**Measures used**	**Effect on noise reduction (L_{Aeq})**	**Remarks**
Austria	Automatic speed limits when noise is to high combined with signs about noise annoyance to neighbors	Up to 6 dB(A)	On-line noise measurements near houses determines speed limits and warning signs
Austria	30 km/h zones in residential areas	Up to 1.9 dB(A)	Speed reductions were implemented by setting up signs at the beginning of the 30km/h zones
Austria	Night time restrictions on heavy vehicles	Up to 7 dB(A) at night time	Ban on heavy vehicles from 22 to 05. Might increase noise in the morning period from 5 to 9.
Germany	Speed limit on motorway combined with signs about noise reduction	1-4 dB(A)	Depends very much on the police enforcement of the reduced speed limit
France	Green waves	No measurements,	There is a potential for speed reductions and even driving pattern

4.4 Traffic Calming

As defined by the Institute of Transportation Engineers, “Traffic Calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street user” (Ewing, 1999). Traffic calming has proven to be effective in reducing traffic speeds and shifting traffic volumes. As a result, traffic noise is also reduced. Since traffic calming devices are small in scale (US DOT, 2006), the effect of noise reduction can be easily evaluated. In this section, a review of traffic calming devices and their influence on traffic noise will be presented.

4.4.1 Neighborhood (or Modern) Roundabouts

The United Kingdom first implemented the modern roundabout in 1966 after solving problems with previous traffic circles that had operational and safety faults. Since then, not only the United Kingdom but also many other countries have adopted the modern roundabout in order to improve traffic safety and reduce traffic speed in neighborhoods. Roundabouts are rapidly gaining popularity in the United States. They have the potential to eliminate the need for traffic signals or stop signs, as traffic flow is improved and a more constant speed can be maintained (Kentucky Community Transportation Academy, 2005).

Normally, a neighborhood roundabout is designed so that approaching traffic must yield to traffic within the circle in order to improve traffic safety inside the circle and reduce traffic speed. The main control facility is a “YIELD” sign, which has an important role in roundabout operation. Therefore, the approaching traffic movement will slow down before entering, and then move counterclockwise around the circle. This operation has been shown to minimize traffic conflicts. However, small roundabouts sometimes make it difficult for fire or heavy trucks to traverse the circle. This consideration should be included when designing a small roundabout (Pennsylvania’s calming, 2006).

Implementation of a neighborhood roundabout is the most effective tool to reduce vehicle speeds near residential areas according to Pennsylvania’s Neighborhood Traffic Calming Resource (Pennsylvania’s calming, 2006). Table 4-12 presents the effectiveness of implementing roundabouts either in the United States or countries in Europe.

As shown in Table 4-12, roundabouts can reduce noise levels up to 4 dBA within a distance of 100m, depending on the design of the roundabout. However, subjective annoyance may increase due to the driving behaviors like braking and accelerating of the vehicles at the entrances or the exits of roundabouts. In addition, one study showed that no noise reduction was measured at a distance of around 100m from the roundabouts if speed reduction measures are not set up on the streets approaching the roundabout (Bendtsen et al, 2004).

Table 4-12: Noise reduction by roundabouts (Bendtsen et al, 2004)

Country	Measures used	Effect on noise reduction (L_{Aeq})
Norway	Roundabout instead of intersection without traffic lights. Speed limit before and after 50 km/h	2 dB(A) close to the roundabout.
		0 dB(A) 100 m from roundabout
Sweden	Roundabout on urban roads in combination with other speed reducing measures	2 dB(A)
Great Britain	Mini roundabout on rural road. Speed limit before and after 48 km/h	3-5 dB(A) Community complains about noise from body-rattle and braking and accelerating around the mini roundabout.
Switzerland	Roundabout instead of an intersection with traffic lights. Speed on nearby road 50 km/h	2 dB(A) daytime
		3 dB(A) night time.
Switzerland	Roundabout instead of an intersection with traffic lights or stops (Victor Desarnaulds et al, 2006 Internet)	1-2 dB(A)
France	Roundabout instead of intersection with traffic lights.	2-4 dB(A) daytime
		2-3 dB(A) night time
France	Roundabout instead of intersection with full stop signs.	1-3 dB(A) daytime
		1-3 dB(A) night time
U.S.	Roundabout compared to signal-controlled junctions (Desarnaulds et al and Robinson et al, 2000)	Decrease noise levels

4.4.2 Speed Humps and Speed Cushions

Speed humps are designed to reduce travel speed in residential areas. Usually, the design speed depends on the dimensions of the speed hump. Even if this measure is a very efficient tool in reducing traffic speed, traffic noise levels might possibly increase (Pennsylvania's calming, 2006). For example, speed humps and cushions (i.e., a form of speed hump) reduce traffic speed, which therefore reduce noise levels for the light vehicles. However, heavy vehicles are more sensitive to the profiles of the speed humps or speed cushions due to body noise (Bendtsen et al, 2004).

Table 4-13 demonstrates the noise effect with different speed hump or speed cushion profiles. As seen in Table 4-13, it was found that round-top/circle type speed humps normally produce a noise reduction of 1-4 dB(A). Conversely, flat top humps increase noise levels by up to 8 dB(A). The speed cushions were found definitely reduce noise levels for automobiles. However, any aggressive deceleration and acceleration maneuver near the humps could lead to an increase in noise levels (Lawson, 2003).

Table 4-13: Noise reductions by Speed humps and speed cushions (Bendtsen et al, 2004)

Country	**Measures used**	**Effect on noise reduction (L_{Aeq})**
Denmark	Circle-top humps	1-4 dB(A)
		Annoyance was increased near the humps
Great Britain	Round-top/circle-top humps	1-3 dB(A)
Great Britain	Flat-top humps	6-8 dB(A) increase for heavy vehicles
Great Britain	Narrow speed cushions	0-2 dB(A) increase
Great Britain	Speed humps (Department for Transport, 2005b)	Day time: 3 dB(A) reductions,
		Night time: 2 dB(A) increase
Great Britain	Speed cushions (Department for Transport, 2005c)	Day time: 4 dB(A) reductions
		Night time: 2 dB(A) reductions
Great Britain	Speed cushions (Department for Transport, 2005b)	3.8 dB(A) at the cushions and 4.1 dB(A) at the level surface for light vehicle
		2.7 dB(A) at the cushions and 1.6 dB(A) at the level surface for heavy vehicle
Germany	Speed cushions (Department for Transport, 2005a)	Substantial noise reductions, possible nuisance could be caused
U.S (Seattle)	Seminole humps, Watts humps (Marek and Walgren, 2006)	47% felt that noise levels decreased with Watts humps, only 10% to the Seminole humps
U.S. (California)	Speed humps (Davis III and Lum, 2006)	43% of a survey said that noise had increased due to deceleration and acceleration.

Further examination of Table 4-13 illustrates that vertical speed control facilities such as speed humps and cushions can reduce noise levels as a result of speed reductions for a light vehicle. Therefore, if it is possible to combine a speed hump with a truck restriction, traffic annoyance can be reduced in residential areas during night time hours.

Table 4-14 shows a list of other more special measures that have an effect on noise levels. According to measurements in Denmark, a rumble area can decrease noise levels from 2 to 4 dB(A), as illustrated in Table 4-14. In Norway, the reduced speed from narrowing driving lanes does not lead to decreased noise levels. Areas with paving stones show an increase in noise levels up to 3 dB(A).

Table 4-14: Noise reduction by other special measures (Bendtsen et al, 2004)

Country	**Measured used**	**Effect on noise level (L_{Aeq})**
Denmark	Environmentally adapted through roads	1-3 dB(A)
	Rumble areas with thermoplastic strips or cut down stripes	2-4 dB(A) increase
		Suggestion of plus 5 dB(A) for impulse noise
	Rumble areas with paving stones	2 dB(A) increase
		Suggestion of plus 5 dB(A) for impulse noise
Norway	Raised levels with paving stones	3 dB(A) increase
	Environmentally adapted street by narrowing driving lanes	0 dB(A)
		1-3 dB(A) (L_{Amax})
Austria	30 km/h zones implemented by speed limit signs	0-2 dB(A)
Switzerland	Road narrowing (central blocks, traffic islands, parking bays, etc.) (Desarnaulds et al, 2006)	Up to 2 dB(A)
	Adaptive signal control (Desarnaulds et al, 2006)	2 dB(A)

4.4.3 Shift from Private Vehicles to Buses

A study by Roof, et al, examined the noise reduction due to the replacement of a certain percentage of automobiles with shuttle buses in both Zion and Acadia national parks. The FHWA's Traffic Noise Model (TNM) was used in this analysis (Roof et al, 2002). Receivers were placed at a distance of 50 feet away from the source before and after the implementation of the shuttle buses. Tables 4-15 and 4-16 compare sound levels before and after the implementation of the shuttle buses. The TNM modeling was assumed for both interrupted flow vehicles (before) and uninterrupted flow vehicles (after), respectively. A further examination of Tables 4-15 and 4-16 illustrate that a consistent and effective noise reductions from 5.8 dB(A) to 9.6 dB(A) resulted from the implementation of bus services in both Zion and Acadia National Parks (Roof et al, 2002).

Table 4-15: Noise Level Reduction after Shuttle Buses in Zion National Park (Roof et al, 2002)

Speed (mph)		**Sound Level Benefit (dBA)**
Before-bus Implementation	**After-bus Implementation**	
6	16.7	9.2
8	16.7	9.5
10	16.7	9.6
12	16.7	9.5
14	16.7	9.3
16.7	16.7	8.6

Table 4-16: Noise Level Reduction after Shuttle Buses in Acadia National Park (Roof et al, 2002)

Speed (mph)		**Sound Level Benefit (dBA)**
Before-bus Implementation	**After-bus Implementation**	
6	25	7.6
8	25	7.9
10	25	8.0
12	25	7.9
14	25	7.7
17	25	7.0
20	25	6.3
25	25	5.8

As defined by the FHWA Highway Noise Barrier Design Handbook, “typically, a 5 dBA insertion loss can be expected for receivers whose line-of-sight to the roadway is just blocked by the barrier” (Fleming et al, 2000). Therefore, the noise reduction obtained in Zion and Acadia area is similar to the effects of a common noise barrier.

4.4.4 Shift from Conventional to Fuel Cell Buses

Studies by Matheny et al. and Karlstrom emphasize the environmental benefits, such as air and noise emission reductions, of using fuel cell-powered buses (Matheny et al, 2002 and Karlstrom, 2005). Fuel cell vehicles are definitely quieter and produce fewer emissions than traditional diesel-powered vehicles and gasoline-powered vehicles (Matheny et al, 2002).

The sound levels were measured by Karlstrom at a distance of 30 feet away from the source. The Karlstrom study provides noise measurements from three different fuels used; 77.5 dB(A) for the diesel-powered bus, 76.5 dB(A) for the natural gas-powered bus, 70.5 dB(A) for the fuel cell-powered bus (Karlstrom, 2005).

The study by Matheny et al. also shows a difference in noise levels between the fuel cell-powered and similarly sized diesel-powered buses (Matheny et al., 2002). At a distance of 9 feet the maximum SPL for a fuel cell bus was 73 dB(A); however, the diesel-powered bus (Gillig 50' bus, 1995), produced a maximum SPL of 84 dB(A) (Matheny et al., 2002). According to these studies the diesel-powered buses were much louder.

4.4.5 Public Involvement

The most important issue in implementing traffic calming devices is gaining acceptance by the local community. Public involvement should begin at an early stage of the planning process (Farzana et al, 2005). This will allow designers to better understand the perceptions of the community, and for the community to understand the nature and scope of potential mitigations. It is even possible to begin to use visualization tools to help communities understand how different mixes of mitigation tools will result in different roadway environments, visually and audibly. The follow pair of images demonstrates such a before-and-after exploration.

Some noise mitigation tools such as barriers are very specifically aimed at particular impacted subsets of the community, namely those within 350 feet of the roadway. While they provide significant benefits for that group, they may do little to alleviate the noise impacts for anyone else. Conversely, tools that lower the emitted noise from the roadway, such as quiet pavement or traffic calming measures that slow traffic clearly benefit everyone in the nearby areas, and provide secondary benefits by improving the overall safety of the roadway environment for pedestrians. Such considerations are not figured into standard noise wall determinations. The efficacy and thus utility of sound barriers is determined solely by reference to their attenuation properties and the calculated total impact on the defined portion of the community. With effective community involvement, the opportunity to significantly improve the roadway environment is better realized when designers understand which of their tools is most valued by the community.

5 Structured Public Involvement Protocol

5.1 SPI Overview

Structured Public Involvement (SPI) is a method or protocol for organizing the integration of professional and non-professional input into complex infrastructure design problems. It has been developed over time through related research projects and problems that involve the public in transportation planning and design (Grossardt and Bailey 2007, 2006, 2003). As applied to the transportation problem, it is most often manifested as a set of linked processes and tools that allow the professional to access a useful set of public planning and/or design preferences to guide her in creating solutions with a high level of technical, financial, and political performance. It is not a single process that is applied to all design problem types; rather SPI is the set of guidelines and assumptions that structure the specific combination of dialogic processes, decision modeling tools, and visualization tools most appropriate for a given problem situation.

5.2 SPI Description

The Structured Public Involvement protocol typically involves the following phases:

1. Definition of the scope of the design or planning problem. The ultimate goal to be reached, problem to be solved, or conditions of successful resolution must be clearly established. In the case of CSS sound mitigation, it will often derive from anticipated impacts from new upgrades to corridors, wherein various mitigation options would impact the potential design.

2. Definition of the parameters of the design or planning problem. To the best of the professionals' knowledge, what specifically are those design parameter questions likely to be? For sound mitigation, those broad parameters are the combined visual impact and audible impact of various mitigation strategies.

3. Definition of the decision terrain. What portion of the problem is legitimately to be under public consultation? Certain minimum performance standards are the responsibility of the professional, whether it is noise levels or highway congestion. Potential solutions that are not technically feasible should not be included in the design envelope presented to the public.

4. Creation of the public solicitation and decision modeling process. Once the designer has determined what kind of public input she wants, then the building of a process to gather that information can be pursued. It necessitates careful engagement with the design professional to define the terms with which she will solicit input from the public. In the case of noise mitigation, that takes the form of a set of design options presented visually and aurally. The designer can use these to show and discuss design options to the public, and then gather preference information from them after that discussion.

5. Generation and documentation of the public input for use by the design team. It is critical to the SPI process that the public input be transparently rendered and the design team is able to clearly show how their designs articulate with the publicly documented

inputs. This does not mean that the public inputs necessarily define the solution. In most cases, the guidelines provided by public input help to focus the solution set and help the design team recognize and avoid unpopular solutions. In fact, as the problem becomes more complex, the designer should be relieved to have some guidance in narrowing the range of options and avoiding embarrassing public meetings where honestly developed options are roundly condemned for unanticipated reasons. For sound mitigation, presentations that integrate sound and aesthetics can give designers useful insight into the most acceptable ways to deal with traffic noise impacts.

6. Review, revise, redesign. Once the initial designs are available, they can then be the starting point for design revisions and the focus of the conversation between the professional and the public. Rather than the professional defending her designs, she can discuss with the public how well each of them meets different needs documented for the public and introduce her skill as a designer in helping to creatively meet those needs.

5.3 Basic Tools of SPI

5.3.1 Dialogic Processes

Dialogic group processes may be aimed at defining problems, generating solutions, evaluating or comparing solutions, expressing preferences, or establishing evaluation criteria and goals. The actual output may be a listing of items, a categorization of items, prioritization, scoring, or multi-criteria evaluation of solutions, or complex multi-variable feedback models. The group process(es) are designed to encourage efficient, democratic, informed input from the participants. This input is in a form that is useful to the design professional, without requiring the public to learn specialized skills or tasks in order to contribute. The questions are thus customized to the problem. A common mode of gathering feedback is through Audience Response Systems (ARS), sometimes referred to as electronic keypads.

5.3.2 Visualization Tools

The visualization mode is linked to the nature of the problem at hand. If the question is aesthetic, the mode will frequently be photographic, video, or virtual reality. In some cases GIS or GIS+VR may be appropriate. Sound simulation has also been used in conjunction with visual samples. The level of sophistication and detail of the representation tool will reflect the level of importance of the questions and focus the public's attention on the questions being posed.

5.3.3 Public Feedback Tools and Translation

Participant input may be designed to be used directly by the client if the questions are straightforward. More often, the goal is to gather information about complex questions of judgment, preference, and priority that must be post-processed to create a data-based resource that can be used to inform subsequent steps of the planning or design process. Common data analysis tools include the Analytic Hierarchy Process (AHP) and Fuzzy Set Theory (FST).

5.3.4 Summary

This set of process steps and tools were combined to create an evaluation protocol for CSS Noise

Mitigation. This protocol is described in the next chapter.

6 Content and Process of Protocols

6.1 Noise Mitigation Strategies Tested

Using the process steps and tools described above, the researchers derived a protocol for testing an appropriate range of CSS Sound Mitigation strategies. The scope of the problem was defined as corridor-scale strategies that could be used comprehensively or locally, depending on the nature of the problem. As mentioned before, the basic parameters of the problem are those of visual (aesthetic) and aural impact, taken together. This means, for example, that the protocol is not designed to test various designs for their ability to promote pedestrian or bike modes, although those may be 'side benefits' of a particular configuration. The decision terrain included quiet pavements, sound barriers, and traffic calming tools. The researchers did not attempt to simulate system-wide traffic management tools that would, for example, alter the number or composition of vehicles on a corridor.

The researchers then devised a menu of possible combinations of surface treatments, barrier types and heights, and traffic calming tools as applied to a typical urban arterial. This arterial was defined as a 20,00 ADT, five 12-foot lane plus a 6 foot shoulder, concrete paved street with a free-flow speed of 45 mph. The researchers used standard noise estimation tools to generate an expected noise level of 70dB for a receptor standing on the front porch of a house 40 feet from the shoulder.

The various tool combinations thus simulate situations where the typical receptor's received noise level would be raised or lowered due to the type of pavement, the presence and/or height of any intervening noise barrier, the changes in overall speed of the traffic, and changes in distance between the receptor and the traffic lanes. This creates a set of up to 25 possible distinct noise envelopes, as follows:

Table 5-1: Modeled Decibels Associated With Various CSS Strategies

	60 mph	50 mph	40 mph	30 mph	20 mph
5 12-Ft. Lanes 20K ADT 40' Distance					
Conventional Concrete	74	72	70	68	63
Conventional Asphalt	70	68	66	64	62
Quiet Pavement	66	64	62	60	58
Conventional Asphalt + 6 ft barrier	65	63	61	59	57
Quiet Pavement + 6 ft barrier	59	57	55	53	51

6.1.1 Method of Representation

6.1.1.1 Sound

Researchers developed a set of traffic noise files at two-decibel intervals across the applicable range of levels above. All the files were of the same recording, but at the different levels. When played over a speaker system with sub-woofer, the noise sensation is quite close to a typical traffic noise condition. Before beginning a session, researchers would adjust the amplification of the files so as to match the decibel levels described in the presentation.

6.1.1.2 Aesthetic/Visual

The visual representation was composed of a set of altered photographs from various locations on a typical corridor: a residential area, an intersection, a business building. The 'original' photographs were modified in Photoshop to represent different paving surfaces through color changes, and to show changes such as brick or terra-cotta sound barriers, re-striped lanes, raised medians, etc. It was not deemed cost-effective to use virtual reality or live video feeds to simulate variable traffic speeds. While this might have more clearly represented the differences in overall traffic impact due to changes in speed, our goal was to understand the differences in sound and structure impacts.

The 'base' view for one set of scenarios appears as follows. The concrete roadway is represented by a medium grey color, with an appropriate number of autos in the space, and the orientation of the receptor indicated by the front porches of the houses facing the street.

A modification of this scene to include, for example, traffic calming, quiet pavement, and a 6 foot barrier would appear as below, with attendant lower noise levels of 54 db. versus 70 in the original case.

Another portion of the corridor was represented this way, under the same traffic conditions.

A modified view shows the various traffic calming strategies below.

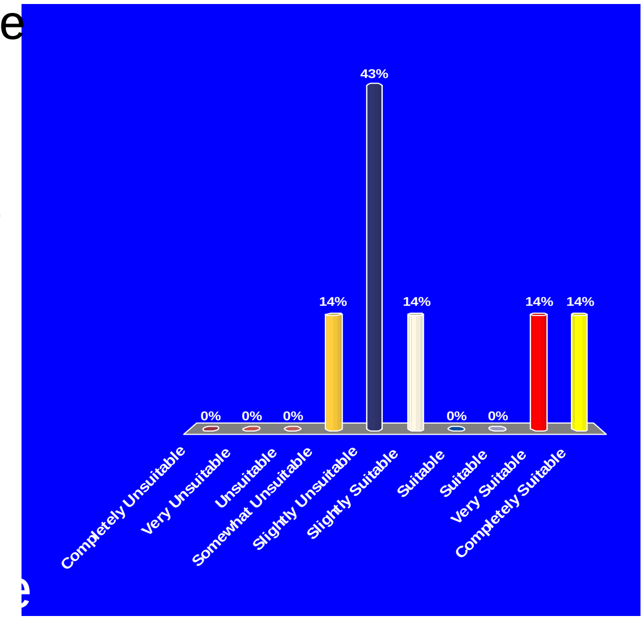
6.2 Feedback Method

The combination of these two modes of representation then required a simultaneous presentation and feedback method. Researchers used ordinary presentation tools (e.g. PowerPoint) to link photographs to sound files, so that they could be organized and presented to an audience in an expeditious manner. The nature of the problem was explained to participants, and the logic behind the presentation tools. They were asked to make a global evaluation about the combined aesthetic of the visual and aural impact of a range of suitable solutions.

The researchers provided participants with an ARS to use for this purpose, so that each person's response was anonymous and simultaneous (thus independent). Respondents were not asked to speculate specifically about the relative or absolute sound levels, rather they were asked to translate the entire effect into a suitability judgment, using a rating scale where 1 = completely unsuitable and 10 = completely suitable for the location. Their responses were shown to them in real time. A typical feedback screen would look like this:

Suitability of Scenario 2

- Completely Unsuitable
- Very Unsuitable
- Unsuitable
- Somewhat Unsuitable
- Slightly Unsuitable
- Slightly Suitable
- Suitable
- Suitable
- Very Suitable



7 Results of Protocol Testing

7.1 Testing Venues

The protocol was tested with both highway districts and state DOT staff in Kentucky and Arizona. The researchers were unable to obtain a design venue where the protocol could be deployed directly in a public meeting format. Transportation professionals worked with the researchers to explore the functionality of the process and the ability of the protocol to elicit appropriate feedback. They were readily able to understand, interpret and respond to the visual and aural representations and to make simultaneous judgments about the overall suitability of various scenarios for a particular context.

7.2 Summary of Test Feedback

The transportation professionals generally gave the protocol good marks for doing an efficient job of representing the wide range of possible sound mitigation options and their comparative outcomes. In each presentation, professionals were themselves surprised by the large perceptible differences in noise levels as various combinations of tools were presented. This suggests that professionals themselves use only numeric scores to make judgments about suitable sound mitigation levels, and that they do not have a good internal sense of what those decibel levels mean in terms of impact. Thus, ironically, such a tool might be quite valuable for professionals to use when doing internal evaluations of options, rather than relying on ‘objective’ scales of noise impact. Individuals typically cannot easily detect a sound level difference of two decibels or less, yet the visual impact of that change could be quite adverse.

8 Conclusions

8.1 Appropriate Venues for Use

Because this was a test protocol, a fairly wide range of options were modeled and considered, more than would have been considered in any one particular context. For example, reducing traffic speeds from 60 mph to 20 mph on the same roadway, as a sound mitigation strategy, is obviously not practical. Professionals pointed out that the specific menu of options to be shown would have to be limited to those options realistic for the context. The researchers concur: this is a premise of all SPI protocols.

This protocol was designed for urban arterial contexts generally, and so contains some mitigation strategies and visual content not suited to limited access, high speed type problems. This is by design, as many of the tools available for urban arterials are not appropriate for high speed facilities. Traffic calming, traffic mix, and intersection management are not tools for interstate highways.

8.2 Potential Process and Content Changes

The professionals also opined that the general public does not understand noise issues and noise mitigation, and that any presentation of this sort to the public should be prefaced by a "Noise 101" discussion that lays out the basic relationships between noise levels, decibel measurements, how mitigation strategies work, and how regulations regarding noise mitigation are applied in transportation planning.

Professionals also inquired about an evaluation protocol that represents the entire corridor at once, or represents the effect of a set of tools across an entire corridor. While the researchers agree that might bring CSS sound mitigation into greater harmony with other traffic planning goals, it would require another level of research commitment, possible including a greatly expanded visualization component that simulates traffic flow both in a plan view and from a street-level perspective. The research team made a judgment early in the project that such high-resource approaches would not be explored until all more practical visualization techniques were exhausted.

9 Summary

This project has shown that with modest resources, transportation professionals can garner very useful feedback about a complex menu of potential sound mitigation strategies. With a laptop running standard presentation tools, a modest set of speakers, and a modest amount of digital photography modifications, they can prepare a presentation that will quickly and effectively educate the public and gather useful feedback about the most acceptable mitigation tradeoffs. This is in contrast to other design problems that require sophisticated planning and resource-intensive visualization tools and time to gather accurate information about transportation infrastructure questions. While it may be desirable to have more sophisticated representation tools in cases where the project is large and affects hundreds or thousands of people, many mitigation projects concern only the residents fronting the arterial and can be easily addressed with comparatively modest, straightforward tools.

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