# The Roadmap to Quiet Highways

## Results of the FHWA Workshop
## September 14-16, 2004

Photo provided by Judith Rochat, U.S. DOT Volpe Center

THE INSTITUTE for SAFE, QUIET & DURABLE HIGHWAYS

U.S. Department of Transportation
Federal Highway Administration

ABSTRACT

The Workshop to develop a Roadmap to Quiet Highways was held September 14-16, 2004, on the campus of Purdue University. The program consisted of

- presentations to describe the state-of-practice for quiet highways,
- multiple breakout sessions and discussion forums to identify the key technological gaps in quiet pavement policy, construction, maintenance, analysis (measurement and prediction), research, and design practice,
- identification of the activities required to implement quieter highways, and
- identification of potential funding sources and leadership for the effort.

This document has been excerpted from the more complete FHWA-HEP-05-007, **Tire/Pavement Noise Strategic Planning Workshop: Proceedings and Roadmap**. The Roadmap to Quieter Highways lays out a plan to answer key research questions, describes a framework for initiating potential policy changes, and identifies the key issues for designing, building, and operating quieter highways. The destination of the Roadmap for Quieter Pavement is a reliable design specification for pavements that are safe, durable, and cost competitive and that are substantially quieter than existing pavement over their entire design life. When this design goal is achieved, policy changes may be initiated to permit the use of quiet pavement as an alternative for noise mitigation.

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## 1.0 Background

Community concern about highway traffic noise is becoming increasingly common. Well organized community efforts to either resist highway expansion or to demand mitigation have occurred in Michigan, California, Arizona, New York, New Jersey, and other states. Apparent success in constructing reduced noise pavement in some locales has also fueled interest in quieter pavement. Public resistance to environmental noise can be formidable, as evidenced by the challenges facing airports due to community concern about aviation noise. Thus, traffic noise is not only an issue of environmental impact, but of economic development and community relations.

Vehicle noise is due to several sources, including powertrain noise (which dominates for slow speed accelerating conditions), tire/pavement interaction noise, and aerodynamic noise (which dominates at high speeds beyond typical speed limits). Except for poorly maintained vehicles, some motorcycles, and trucks using engine compression brakes, at speeds between 30 mph and 90 mph, the dominant source of traffic noise is tire/pavement interaction noise. The typical distribution of noise with speed from automobiles is shown in Figure 1.1. Truck noise is similar, except that engine noise is important to approximately 40 mph. Thus, the highest priority for reducing traffic noise is reducing tire/pavement interaction noise.

European experience leads U.S. experience in addressing reductions of traffic noise and tire/pavement noise. Various European transportation agencies have dealt with communities about traffic noise since the 1970's. Most countries have a policy that requires mitigation of noise for cases where levels exceed a specified threshold. Countries have adopted strategies to mitigate the effects of noise using a combination of sound barriers, reduced noise pavement, home insulation, traffic controls, and in some cases, monetary compensation. The European Union has issued a directive that requires all countries to map transportation noise by 2007 and to develop a plan to address critical areas. Since highway traffic noise is more pervasive than other transportation noise sources and tire/pavement noise dominates highway traffic noise in free flow conditions at freeway speeds, many European countries have developed aggressive programs to identify and implement reduced noise pavement.

The Federal Highway Administration (FHWA) policy established in the mid 1990's for highway traffic noise prediction and the subsequent assessment of impact and mitigation measures may be found in "Highway Traffic Noise Analysis and Abatement: Guidance and Policy (June 1995)." The policy reads in part:

> *Pavement is sometimes mentioned as a factor in traffic noise. While it is true that noise levels do vary with changes in pavements and tires, it is not clear that these variations are substantial when compared to the noise from exhausts and engines, especially when there are a large number of trucks on the highway. Additional research is needed to determine to what extent different types of pavement and tires contribute to traffic noise.*
>
> *It is difficult to forecast pavement surface condition into the future. Unless definite knowledge is available on the pavement type and condition and its noise generating characteristics, <u>no adjustments should be made</u> for pavement type in the prediction of highway traffic levels. Studies have shown open-graded asphalt pavement can initially produce a benefit of 2-4 dB reduction in noise levels. However, within a short time period (approximately 6-12 months), any noise reduction benefit is lost when the voids fill up and the aggregate becomes polished. The use of specific pavement types or surface textures <u>must not be considered as a noise abatement measure</u>. …*

Policy regarding traffic noise prediction from "FHWA Traffic Noise Model (FHWA TNM) FHWA Policies: Pavement Types" reads in part:

*TNM defaults to "Average" for pavement type. The use of any other pavement type must be substantiated and approved by FHWA. … Additional studies are needed to determine to what extent different types of pavements and tires contribute to traffic noise. It is difficult to forecast pavement surface condition into the future. Therefore, unless definite knowledge is available on the pavement type and condition and its noise generating characteristics, no adjustments should be made for pavement type in the prediction of highway traffic noise levels.*

The purpose of the Roadmap to Quieter Highways Workshop was to bring together knowledgeable experts in all aspects of the problem, to examine the state-of-the art, to identify the major gaps in technology that would lead to quieter pavement, and to develop a plan to fill these gaps. It should also be stated explicitly in these introductory remarks that, during this Workshop, it was considered a requirement that safety not be compromised for noise. In addition, as a design feature, noise should be considered for its cost effectiveness and benefits, in the same terms as durability, smoothness and other functional performance features of pavement.

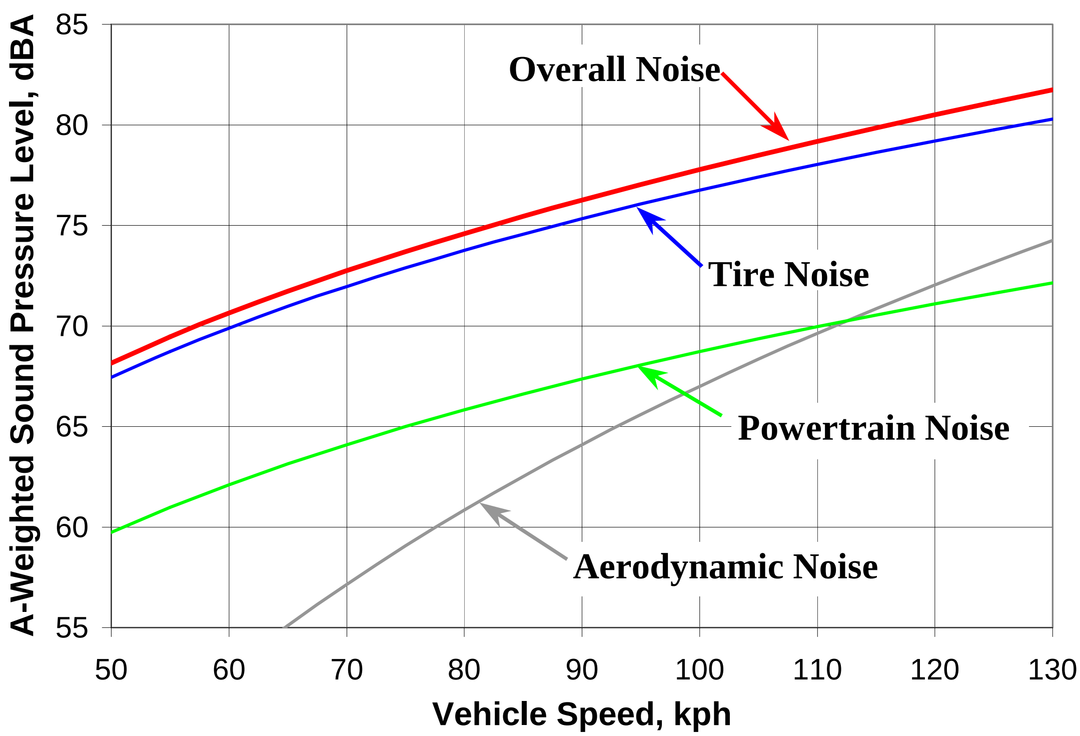


Figure 1.1 Estimate of light vehicle noise due to Tire/Pavement noise, Powertrain Noise, and Aerodynamic Noise. [Paul R. Donavan, "Vehicle Exterior Noise," Handbook of Noise and Vibration Control, Editor, Malcolm Crocker, John Wiley and Sons, to be published]

## 2.0 The Workshop

The Roadmap to Quieter Highways Workshop was sponsored by FHWA and hosted by the Institute for Safe, Quiet and Durable Highways at Purdue University. It was held from September 14 to September 16, 2004, on the campus of Purdue University. The agenda of the meeting is included in Appendix A of this report. The facilitator of the meeting was Bob Zahnke of the Center for Advancement of Transportation Safety at Purdue University.

A listing of the Workshop participants is included in Appendix B. The group was diverse in many dimensions and included 15 federal participants, 8 state DOT participants, 14 private sector participants, and 9 academic participants. The group included individuals with experience in acoustics, pavements and transportation vehicle design as well as individuals whose job functions include highway maintenance, technology transfer and continuing education, consulting, design, operations, and research. Attendees came from each region of the U.S.

The Workshop began with exercises to identify the gaps that exist that prevent the implementation of quieter highways. The group then considered these gaps and identified tasks that would maximize the use of available resources to develop new alternatives for the benefit of the public and to assist state and local transportation agencies as quickly as possible.

## 3.0 The Needs/Technology Gaps

To identify the technological gaps in the achievement of quieter highways, participants were asked to identify the gaps between our desired state-of-practice and our current state-of-practice. Participants attended three different breakout sessions of their choosing from the following six areas:

- Policy
- Construction
- Maintenance
- Analysis (measurement and prediction)
- Research
- Design

The gaps identified in each of the six areas from the three breakout sessions were then consolidated into a single list for each of the six areas during a fourth breakout session. This list was consolidated during a general session into a single list of gaps by eliminating duplication. The final consolidated list was prioritized to identify the gaps that should be addressed first. The final prioritized listing is contained in the table in Appendix C. The technological gaps with 18 or more votes are listed below in order of votes received and will be discussed in subsequent subsections.

| **Gap Voting** | | **Total** |
|---|---|---|
| R62: | How long do noise benefits last in relationship to other properties, clogging, aging, life cycle | 34 |
| A48: | Measurements: Relationship between source and wayside noise, correlation within source methods, correlation within wayside methods | 33 |
| R66: | Research measurement methodologies for U.S. applications: absorption measurements, source, wayside, mechanical impedance | 31 |
| M19: | Maintaining pavement quality: maintaining surface texture characteristics (durability, friction, noise, other safety parameters), replicating surface characteristics during repair, preventative routine maintenance, training of maintenance forces, communication of commitments | 29 |
| D36: | Texture/Friction: negative vs. positive texture, diamond grinding | 28 |
| P1: | Lack of federal policy for quiet pavement | 26 |
| R64: | Optimization of various pavement types: elasticity, noise, safety (friction), cost (life cycle), texture, mix designs/materials, durability, ride | 26 |
| D40: | Need standardized noise test procedure | 25 |
| R68: | Calibration/Certification of noise measurement equipment/ test methods/ operators, standardization | 24 |
| R70: | Quantification of benefits of quiet pavement vs. other noise mitigation methods | 24 |
| C25: | Need for construction acceptance methodologies for noise: performance specifications, measurement standards/targets, warranties, incentives/disincentives | 23 |
| R58: | Metric to incorporate perception: tonality, transients, spectrum, modulation | 23 |
| C24: | Concrete: understand texture as it relates to noise, relationship between grinding and noise, control variability, novel construction methods, joint slap | 22 |
| A50: | Relationship between light vehicles and heavy trucks: tires, sound generation, and sound propagation | 22 |
| D37: | Mix design: voids content, aggregate size/shape, binders, porosity, density, optimization of structural properties, lab vs. field mix, relationship of resilient modulus to impedance | |

properties, lack of noise/acoustical consideration 21

C30: Need for communication, public>politicians>technical people, stakeholders need to understand full scope of issue, educate people in the industry regarding tire/pavement noise 18

R63: Relationships of pavement characteristics to noise: variability and R64 18

In the following subsections, the various gaps will be grouped and described. The grouping for this discussion is according to shared common solution techniques.

### 3.1 Understanding the Durability of the Noise Reduction Effect

*R62: How long do noise benefits last in relationship to other properties, clogging, aging, life cycle*

The highest ranked gap identified by the Workshop participants was related to the longevity of the noise reduction effect of existing quieter pavement alternatives. There are a number of case studies reported in the literature which document loss of noise reduction effect with time for certain pavement types. If a pavement is constructed assuming certain noise benefits, and those benefits are lost with time, the public will not be protected.

There is disagreement about the cause of loss of the noise reduction effect. Conjecture about the loss of benefit range from clogging of porous pavements to changes in the pavement texture and material properties with age and wear. In fact, for different pavement types, the cause of the loss of noise reduction may be different. There is no definitive evidence to establish what causes loss of noise reduction benefit with time.

Since case studies exist where the loss of reduction effect has been measured and quieter pavement test sections are being constructed, it should be possible to closely examine texture and other properties of pavement samples to monitor changes with time that are correlated to changes in noise. The information gained in this study will also help to explain the fundamental behavior of quieter pavement and address the gaps described in Section 3.4. Better understanding of the loss of noise reduction benefit will also assist the development of novel quiet pavement alternatives.

### 3.2 Measurement Methods

*A48: Measurements: Relationship between source and wayside noise, correlation within source methods, correlation within wayside methods*

*R66: Research measurement methodologies for U.S. applications: absorption measurements, source, wayside, mechanical impedance*

*D40: Need standardized noise test procedure*

*R68: Calibration/Certification of noise measurement equipment/ test methods/ operators, standardization*

High quality and reliable measurement methods are important for acceptance, for monitoring, and for information gathering/exchange. Current tire/pavement noise measurements are done using an assortment of wayside (passby) and source (nearfield) methods. Wayside measurements are useful because these measurements are representative of the community exposure to traffic noise. Source measurements are typically easier to obtain and could be more easily applied to acceptance and monitoring applications. A limited subset of the measurement techniques has been standardized. Some of the methods are difficult to apply and others have not been fully developed to be reliable for the comparison of data taken by different operators. A common, reliable set of measurement methods is needed. Thus, a number of measurement standards must be developed and existing measurement standards must be refined and validated (D40).

When either source or wayside measurements are used to measure tire/pavement noise, they should provide the same relative ranking of pavement. Effort must be made to determine whether nearfield and wayside measurements are correlated (A48). If direct correlation is not possible due to the effect of the sound propagation between the source and the wayside measurement, other properties of the pavement should be used to build adjustment factors into the correlation. Depending on the properties required to compute the adjustment factors, additional properties of the pavement will be measured, such as pavement dynamic elasticity or pavement acoustical absorption coefficient. Measurement standards must be developed or adapted to make reliable measurements of these properties (R66)

Since a relatively small amount of data has been taken thus far, there has been limited comparison of data on the same pavement. The nature of the equipment, such as tires and surfaces used for noise measurements, and the skills of typical operators may result in variation that would make it difficult to compare data taken by different operators. It would be very helpful to establish a network of regional certification sites where operators could test and compare equipment and technicians to establish that their measurements are comparable to the measurements of other practitioners (R68).

### 3.3 Maintaining Quieter Pavements

*M19: Maintaining pavement quality: maintaining surface texture characteristics (durability, friction, noise, other safety parameters), replicating surface characteristics during repair, preventative routine maintenance, training of maintenance forces, communication of commitments*

As discussed in Section 3.1, it is imperative that the noise reduction effect of quieter pavements be durable. For certain pavement types it may be necessary to institute maintenance procedures to prolong the noise performance of the pavement. On the other hand, typical maintenance procedures may have an adverse effect on the noise performance of certain pavement. For example, winter maintenance using sand may cause porous pavements to clog. Mechanical snow removal may change the pavement texture of quieter pavement and reduce noise reduction performance. Patching may cause local texture changes that cause annoying transient noise.

Since the characteristics of pavement that control noise production are not well understood, as discussed in Sections 3.1 and 3.4, the preferred pavement condition is also not well understood. Thus, operations to maintain the pavement to desirable condition cannot be specified currently. When the technological gaps described in section 3.4 are filled, it will be necessary to examine maintenance procedures to ensure that the noise reduction effect is maintained for the life of the pavement.

### 3.4 Understanding Pavement Characteristics and Noise

*D36: Texture/Friction: negative vs. positive texture, diamond grinding*

*R64: Optimization of various pavement types: elasticity, noise, safety (friction), cost (life cycle), texture, mix designs/materials, durability, ride*

*C24: Concrete: understand texture as it relates to noise, relationship between grinding and noise, control variability, novel construction methods, joint slap*

*D37: Mix design: voids content, aggregate size/shape, binders, porosity, density, optimization of structural properties, lab vs. field mix, relationship of resilience modulus to impedance properties, lack of noise/acoustical consideration*

*R63: Relationships of pavement characteristics to noise: variability and R64*

While quieter pavements have been constructed and tested, most have been constructed initially for other purposes. For example, porous pavements and open graded pavements were constructed initially to enhance friction in wet pavement conditions. Asphalt rubber friction courses (ARFC) were developed to resist reflection cracking in Arizona. Most of the original quieter pavements were constructed by coincidence. Once identified, some effort has been made to optimize these pavements by trial and error but these efforts have been limited by available resources. Thus, the mechanisms that result in quieter pavement are not well understood and quieter pavements have not been optimized for noise reduction. (D36)

Furthermore, the over-riding requirement of pavement is that it be safe for the local conditions. Thus, safety, which is generally characterized by friction, texture and visibility under extreme conditions, can not be compromised for noise reduction. Furthermore given the economics of highway construction and the relative importance of environmental noise in a particular application, noise reduction must be balanced against life cycle costs, including initial costs, maintenance costs and durability. While compromises may have occurred in the construction of past test sections, it is a goal of research to develop pavement alternatives that meet all requirements of pavement design; safety, cost effectiveness, durability, smoothness and noise emissions. (R64)

Much of the pavement noise data collected in the U.S. and internationally have shown significant variability in the noise generation of pavement of nominally identical design. For most pavement types, the quietest samples of pavement measured thus far would be fairly desirable and quieter than the pavement source levels used for current traffic noise prediction. Some test sections of almost every pavement type could be considered a quieter pavement. It is clear that factors important to noise generation are not being controlled, and frankly, are not currently understood. (R63)

For Portland Cement Concrete (PCC) pavements, texture and joint properties appear to control noise. PCC is also especially prone to variability when transverse tining methods are used. Grinding methods have shown benefit as have some shallow texturing methods such as burlap drag. Longitudinal tining also appears to have a reliable positive benefit compared to transverse tining. Traditional and novel methods of constructing PCC pavement should be investigated to understand the relationship between texture and noise in PCC pavement and to optimize PCC pavement for noise, safety, and life cycle costs. (C24)

For asphalt surfaces, data suggests that porosity, density, aggregate size and shape, binders, and pavement elasticity may all play a role in noise generation. However, the relationship between these mix design parameters and noise is not understood and requires further investigation. Successful examination of these issues will require both laboratory and field tests. (D37)

### 3.5 Policy

*P1: Lack of federal policy for quiet pavement*

Current federal policy requires that average pavement noise characteristics be used for source data for traffic noise prediction unless source data for another *pavement type is substantiated and approved by FHWA*. As the policy quotes in Section 1.0 describe, these policies have been dictated due to the loss of noise reduction effect of some quieter pavement with aging and the unpredictable performance of some pavement types due to construction variability.

A formal Quiet Pavement Pilot Program (QPPP) has been developed and published by the FHWA Noise Office to allow states to build test sections of quieter pavement. States must provide evidence of (substantiate) the expected performance of the pavement used for these applications, monitor the noise performance of the sections, and agree to provide alternative mitigation if the pavement noise target performance is not achieved. The Arizona Department of Transportation is currently in the second year of a QPPP using ARFC pavement. The California Department of Transportation is in the final stages of negotiation with FHWA on a QPPP program.

Current federal policy does not restrict the use of quieter pavement alternatives for applications where noise mitigation is not required. Therefore, quiet pavement test sections can be built and tested for the relatively common situation where community noise complaints occur outside of highway sections where federally mandated noise mitigation is required.

In summary, there is current federal policy for quiet pavement but it is restrictive based on concerns about past performance of some quiet pavement alternatives. Results to fill the technological gaps identified in Sections 3.1, 3.3, and 3.4 and the results of the QPPP in various states will provide the basis for revised federal policy to encourage quieter pavement as a possible noise mitigation alternative in the future.

### 3.6 Cost/Benefits of Quieter Pavement

*R70: Quantification of benefits of quiet pavement vs. other noise mitigation methods*

Crude estimates of life cycle costs suggest that quieter pavements are a less expensive mitigation solution for highway traffic noise than sound barriers. Quieter pavement is also a more generally applicable solution for non-flat terrain and provides a larger region of mitigation in communities. Assuming that the technological issues of the durability of the noise reduction effect (R62, Section 3.1) and the variability due to pavement construction (R63, Section 3.4) can be resolved, quieter pavement alternatives would appear to be a desirable mitigation alternative and should be evaluated in pavement selection based on overall cost/benefit optimization. Better understanding of the cost/benefit of quieter pavement must be developed.

For example, economic studies in Denmark (*Larsen and Bendtsen, Inter-Noise 2001)* showed that life cycle costs, with extra construction and maintenance included for quieter pavement, were as small as 1/3$^{rd}$ the cost of sound barriers or home insulation programs to achieve similar performance. The study also included a Danish benefit metric that converted noise reduction to financial benefit. For cost/benefit studies using this benefit metric, quieter pavement showed greater advantage compared to the sound barriers and home insulation programs due to the larger number of people benefited.

Similar cost/benefit studies should be done in the U.S. to provide the basis for decision making and optimization of highway traffic noise mitigation. Studies should be done first to investigate and illustrate the benefits of quieter pavement relative to other noise mitigation strategies and then to provide a methodology for agencies to use for optimization and decision making.

### 3.7 Construction and Construction Acceptance

*C25: Need for construction acceptance methodologies for noise: performance specifications, measurement standards/targets, warranties, incentives/disincentives*

When technological questions have been answered about the design and maintenance of quieter pavement (Sections 3.1, 3.3., and 3.4), these pavements will be specified with an expected level of noise reduction performance. Construction specifications must be developed to ensure that this performance is achieved at construction. Given the current level of variability measured for nominally identical pavement, it is clear that the development of construction specifications is important. The effort to develop construction specifications will require integrated effort to incorporate improved understanding of the generation of tire/pavement noise (Section 3.4) and understanding of construction. This effort will require field trials and field testing.

Furthermore, for many applications construction acceptance specifications will be required. These will be used where performance specifications for noise have been included. Construction acceptance for noise performance must be done in accordance with other construction acceptance procedures. For example, acceptance should be done while pavement construction is ongoing. Suitable measurement methods must be developed (Section 3.2) to work for these conditions. A sufficient understanding of the change in behavior of quieter pavement from the *as constructed state* to the *aged state* (Section 3.1) must be included.

### 3.8 Improved Noise Metrics

*R58: Metric to incorporate perception: tonality, transients, spectrum, modulation*

Public perception of traffic noise is often different than the conventional understanding of response to sound level metrics would indicate. A common response to explanation of engineering measures of traffic noise reductions is "I know what I hear and this is not better". Conventional wisdom says that a 3 dB reduction in sound level is just perceptible, a 5 dB reduction is perceptible, and a 10 dB reduction is perceived as halving of sound. However, these rules of thumb apply only when the spectral and temporal character of the sound is unchanged. For many relative pavement comparisons, for example between a porous asphalt and a dense graded asphalt, the spectral and temporal content of the sound is significantly different. For such comparisons the change in perception is not well correlated with change expected based on sound pressure level. This lack of correlation results in various problems related to interaction between highway agencies and the public, but the most critical issue is that our design objective may be wrong.

Perceptions of sound have been widely studied in applications where customer quality and acceptance is a primary consideration, such as transportation vehicle passenger noise exposure. The science of the perception of sound to measure the effects of tonality, transients, modulation, and other aspects on perception can be utilized to develop traffic noise metrics that correlate better with the public's perception of sound. These studies will improve our understanding of which characteristics of traffic noise cause annoyance and help focus our efforts in the correct direction.

### 3.9 Traffic Mix Effects

*A50: Relationship between light vehicle and heavy truck: tires, sound generation, and sound propagation*

For current tire/pavement technology, when the heavy vehicle volume becomes greater than approximately 20% of the traffic volume at freeway speeds, the heavy vehicle noise component dominates the overall average sound pressure level of traffic noise. Except for cases where a heavy vehicle is poorly maintained or is using engine compression braking, source noise at these speeds is dominated by tire/pavement noise. Thus, for many urban highways where commercial traffic is at a high volume, reduction of heavy vehicle noise is the primary consideration.

Current applications of quieter pavements have been measured to perform differently for light vehicles than for heavy vehicles; a pavement that achieves 4 dB reduction for light vehicles may only achieve 2 dB noise reduction for heavy vehicles. This is hypothesized to be due to the different proportion of noise from tires versus the drivetrain and exhaust noise sources due to the difference in the height of the underbody of heavy vehicles. Thus, the sound created by heavy vehicles propagates differently than the sound generated by light vehicles.

Heavy vehicle tires are also fundamentally different than light vehicle tires. The compounds are different for durability considerations. The carcass construction is stiffer as well. Thus, the sound generation mechanisms of heavy vehicle tires will be different than the mechanisms for light vehicles.

The noise generation and reduction of heavy vehicle tires has not been studied in detail. To achieve quieter pavement for applications where the heavy vehicle proportion of traffic mix is high, effort should be made to understand noise generation from heavy vehicles and to identify quieter heavy vehicle tire alternatives.

In addition, consideration should be given to identifying quieter pavement technology specifically for heavy vehicles. Such strategies could be used for highways that carry high volumes of commercial traffic or to construct quieter heavy vehicle lanes.

### 3.10 Communication and Education

*C30: Need for communication, public>politicians>technical people, stakeholders need to understand full scope of issue, educate people in the industry re. tire/pavement noise*

In community noise control applications, such as highway traffic noise, progress is often limited unless there is a widespread, successful effort at education. Education must occur on many levels including;

- Designers
- Policy makers and government agencies
- Community groups

Except for curricula associated with traffic noise prediction, which discuss the effects of speed, traffic volume and traffic mix on traffic noise, there are currently no university level curricula or continuing education short courses that teach the principles of quieter pavement. For technical staffs that are involved with pavement design, instructional material and educational opportunities must be developed to teach the principles of quieter pavement.

Due to the decentralized legislative environment in the U.S., different agencies are responsible for various elements of federal, state and local policy. To ensure the technical feasibility and reasonableness of policy, information about quieter pavement and appropriate policy must be widely communicated to these agencies.

Community acceptance of environmental noise in all applications has been shown to be strongly affected by engagement with the public in the dialog about costs and benefits. Community groups are often highly industrious but sometimes misinformed. It is important to provide the public information about the potential benefits and costs of quieter pavement and other mitigation solutions for highway traffic noise.

## 4.0 The Roadmap

Pursuing the Roadmap to Quieter Highways will require effort across the complete pyramid of technological developments shown in Figure 4.1. The effort should be led by visionary individuals with resources and influence and should be assisted by a group with diverse expertise committed to solving the problem of tire/pavement noise.

While the elements of the pyramid were not comprehensively discussed at the Workshop, a few of the elements are captured here for later use.

- User – the communities neighboring the highway; drivers; local, state, and federal transportation agencies; elected officials, etc.
- Function – noise control, smoothness, safety, durability, …
- Technical Assembly – the "as constructed" pavement surface
  - Material (HMA, PCC, …)
  - Surface type/texture (ground, finished, porous)
- Interrelationships
  - Combined variables (equipment, aggregate, thickness, …)
  - Basic variables (material properties, …)

The leadership of this effort should be vested in the state DOTs, either through a FHWA Lead States program dedicated to quieter highways, or an AASHTO standing committee of the RAC, or in a 501C foundation. It was a consensus of the participants in the Workshop that the FHWA and state DOT's should seek to establish a Quiet Highways program as soon as possible.

After the leadership is identified, resources required to realize the Roadmap to Quieter Highways can be assembled from a variety of sources, including

- FHWA Research and Development funds,
- pooled- fund projects with the state DOT's,
- state DOT funded projects,
- the tire and vehicle manufacturers and pavement associations in the form of research funding and in-kind support and
- university in-kind contributions.

The effort required to follow the Roadmap to Quieter Highways has been divided into near term (effort that is either foundational to other effort or offers quick, easy benefits) and longer term (effort that either follows early results or will be more difficult to accomplish). The tasks along the roadmap are described in separate sections for short-term and long-term activities. The last section is a consolidation of the various comments of participants describing the ideal end result - the destination of the roadmap.

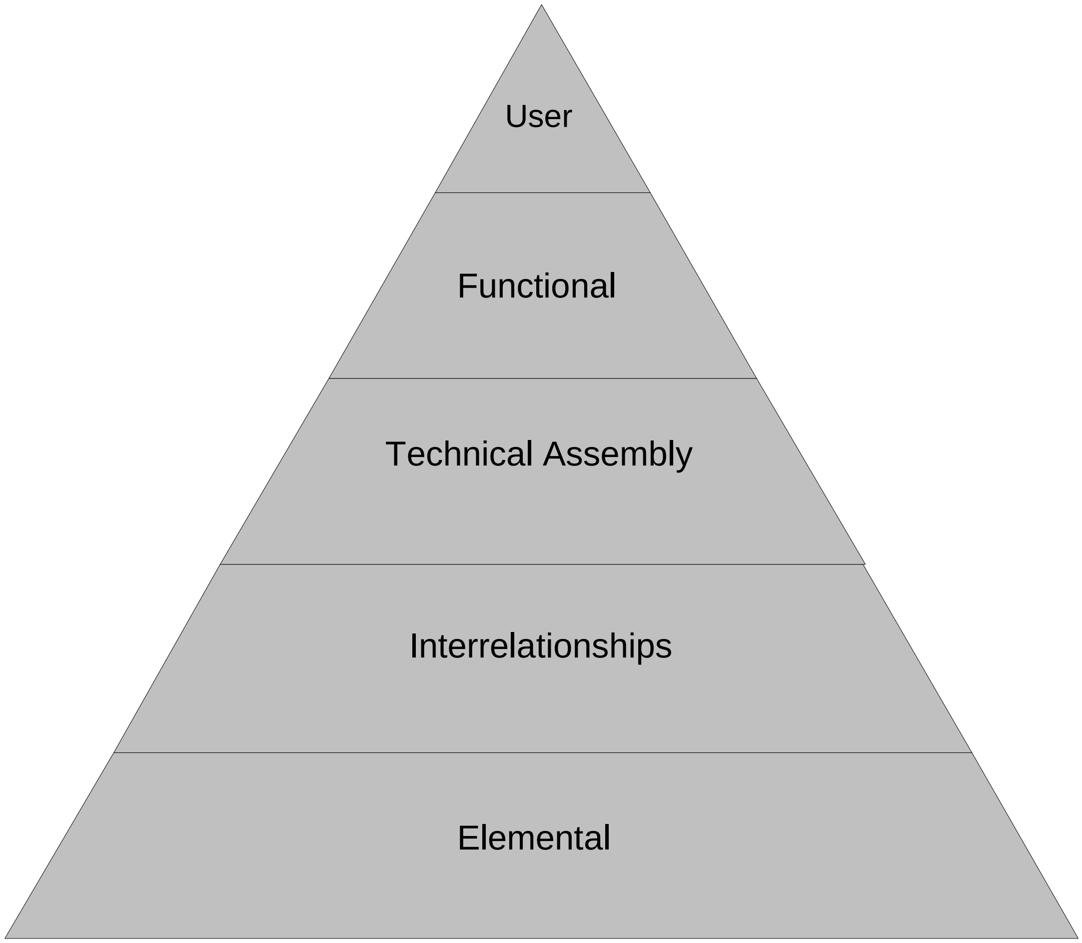


Figure 4.1 The pyramid of technology development [Robert O. Rasmussen, "Personal Communication," Transtec Group, Inc., 2004]

**4.1 The "Right" Turn Out of the Driveway – the Near Term**

A number of the activities of the roadmap were categorized as a high priority by the participants and should start immediately.

- **Clearinghouse**
  The FHWA will develop a web-based clearinghouse to do the following:
  - Clarify Federal policy
  - Provide references to standards and provisional standards for tire/pavement noise measurement
  - Collect and distribute data about tire/pavement noise measurements to help track the performance of different pavement within a specific type of pavement (variation and best practice), as well as noise performance over time

- **Measurements**
  Establish an Expert Task Group (ETG) on Tire/Pavement Noise Measurement (Expert Panel) by the January TRB meeting to do the following tasks:
  - Develop Provisional Standards for consideration by AASHTO for measurement of tire/pavement noise.
  - Coordinate with international groups and various practitioners in the U.S. to advance measurement methods.
  - Coordinate with international groups and various practitioners in the U.S. to establish the correlation between various types of measurements.
  - Contribute data to the FHWA clearinghouse.
  - Promote implementation of the Provisional Standards by practitioners..
  - Evaluate and refine the Provisional Standards to facilitate adoption as full Standards.

- **Quieter Current Pavement Technology**
  Mobilize state and federal resources, along with private sector contributions, to work to optimize several quieter pavement designs that are currently available:
  - diamond grinding for PCC pavements and
  - mix designs for asphaltic porous friction courses.

  Monitor case studies for noise, friction, and pavement condition to detect changes over time.

- **Education**
  Develop a training course or workshop with the objective of raising awareness of tire/pavement noise fundamentals to both the pavement community and the noise/environmental community.

### 4.2 The "Cross Country" Voyage – the Long Term

- **Measurements**
  Continue the work of the proposed Expert Task Group on Tire/Pavement Noise Measurement to ensure a final objective where all data collected on tire/pavement noise and traffic noise in the U.S. is directly comparable
  - Complete standardization of measurement methods for wayside and nearfield (sources) measurement and for pavement acoustical properties
  - Correlate wayside and source measurements and develop methods to relate tire/pavement source measurements, pavement acoustical characteristics and wayside measurements
  - Develop calibration and certification pavements (perhaps at test tracks or test sections in each region) to serve as references for practitioners

- **Research Noise/Safety/Durability/Cost**
  Examine the relationship of texture and pavement elasticity to noise, friction, and ride. This effort should be an integrated program of fundamental, laboratory-based work, and test-site-based work. Investigations should include but not be limited to the following:
  - Exposed aggregate concrete
  - Thin gap-graded asphalt overlays
  - Novel texturing methods such as dimpling
  - Porous concrete
  - Double layer porous asphalt

  As the relationships between pavement characteristics and functional performance are better understood, it is expected that other novel pavement concepts will evolve.

- **Research Cost/Benefit**
  Fund research work to examine the true costs and benefits of noise treatments, as well as safety, durability, and other performance aspects of pavement.

- **Guidelines**
  Based on research results and field studies, FHWA/AASHTO should develop Guidelines for ride, friction, and noise. Individual states would use these Guidelines to develop project specific performance targets.

- **Monitoring**
  Using measurement standards developed by the Expert Task Group on Tire/Pavement Noise Measurement, State DOT's should specify and monitor pavement noise (both as-constructed and in-service). For in-service monitoring, states should establish thresholds for (1) reactive maintenance and (2) replacement/reconstruction.

- **Accelerated Testing**
  A panel of pavement and noise experts should develop methods for accelerated testing for noise, based on existing methods for accelerated testing of pavements.

- **Education**
  Material should be developed and distributed for inclusion in an academic course of study to teach students the concepts of designing quiet pavement. Variations of this curriculum should be offered in continuing education format (e.g., short courses, DVD learning materials) to practicing design engineers.

### 4.3 The Destination

The destination of the Roadmap for Quieter Pavement is a reliable design specification for pavements that are safe, durable, and cost competitive and that are substantially quieter than existing pavement over their entire design life.

When this design goal is achieved, policy changes may permit the use of quiet pavement as an alternative for noise mitigation to protect the public. Policy changes may also include a methodology that utilizes pavement characteristics in noise predictions.

## 5.0 Keeping the Momentum

The diversity of expertise of the Workshop participants and their familiarity with the tire/pavement noise problem enabled the success of the Workshop. The participant group is energized for action. It will be a key step to identify committed and capable leadership within the next few months to guide the Roadmap to Quiet Highways effort.

Since many activities are being initiated simultaneously, it is expected that there will uneven progress in the short term. The participants recommended that regular communications among the participant group be developed and annual workshops be held to assess progress, reprioritize the roadmap, and reenergize the effort.

Appendix A

Agenda

## Agenda

**First Day – September 14**

| | |
|---|---|
| 11:00 a.m. to 12 noon | **REGISTRATION -** Room 214, Stewart Center |
| 12 noon - 12:45 p.m. | **Call to Order/Housekeeping Items**<br>*Don Johnson, Program Manager, SQDH* |

**- Welcome to Purdue University & Workshop**
*Robert J. Bernhard, Director, Institute for Safe, Quiet and Durable Highways*

**- Workshop Purpose, Goals and Outcome**
*Bob Zahnke – Facilitator, Director, Center for the Advancement of Transportation Safety at Purdue University*

| | |
|---|---|
| 12:45 p.m. to 1:45 p.m. | **Pavement Friction and Durability/Pavement Safety and Cost**<br>*Roger M. Larson, Applied Pavement Technology, Inc.* |
| 1:45 p.m. to 2:15 p.m. | **Highway Traffic Noise Measurement and Prediction**<br>*Judith L. Rochat, Volpe Center, Acoustic Facility, U.S.DOT* |
| 2:15 to 3:00 p.m. | **Basics of Tire/Pavement Noise**<br>*Bob Bernhard, Purdue University, SQDH* |
| 3:00 p.m. to 3:15 p.m. | **Break** |
| 3:15 p.m. to 3:45 p.m. | **Perspective from a Tire Manufacturer**<br>*Alan Hartke, Goodyear Tire and Rubber Company* |
| 3:45 p.m. to 4:05 p.m. | **Quiet Pavement Pilot Program**<br>*Robert E. Armstrong, FHWA* |
| 4:05 p.m. to 4:35 p.m. | **AASHTO/FHWA International Scanning Project – Quiet Pavement Systems**<br>*Chris Corbisier & Mark Swanlund, FHWA* |
| 4:40 p.m. | **Adjourn** |
| 4:40 p.m. | **Tour - SQDH Tire/Pavement Test Apparatus at the Ray W. Herrick Laboratories** |

**<u>Wednesday – September 15, 2004</u>**

7:00 a.m. to 8:00 a.m. **Continental Breakfast**

8:00 a.m. to 9:00 a.m. **State DOT Experiences**
*Arizona: Larry Scofield*
*California: Larry Orcutt*
*Florida: Mariano Berrios*
*Texas: Michael Shearer*

9:00 a.m. to 9:30 a.m. **SUMMARY OF PREVIOUS PRESENTATIONS**
*Bob Zahnke*

9:30 a.m. to 9:45 a.m. **Break**

9:45 a.m. to 10:45 a.m. **BREAKOUT SESSION #1**
(Design, Construction, Maintenance, Research, Analysis, Policy)

| | | |
|---|---|---|
| Room 214 Front | Design | **Objectives:** |
| Room 214 Rear | Construction | |
| Room 218a | Maintenance | 1. Identify Current State of Practice and Expertise |
| Room 218d | Research | 2. Identify Desired Future Levels of Practice and Expertise |
| Room 311 | Analysis | 3. Identify Gaps between Current and Desired Levels |
| Room 313 | Policy | |

10:45 a.m. to 11:45 a.m. **BREAKOUT SESSION #2**

Each attendee will be asked to attend a different session. Same objectives as Breakout #1.

11:45 a.m. to 12:45 p.m **Lunch**

12:45 p.m. to 1:45 p.m. **BREAKOUT SESSION #3**

Each attendee will be asked to attend a different session. Same goals as Breakout #1.

1:45 p.m. to 3:30 p.m. **FULL GROUP**

Each of the breakout sessions will present a summary of their important issues and gaps – six topics at each of the three sessions

3:30 p.m. to 3:45 p.m. **BREAK**

345 p.m. to 5:00 p.m. **BREAKOUT SUMMARY SESSIONS**

Each of the six areas will take their three reports and collapse them into one set of priority gaps for their areas. The purpose of this session is to clarify, expand, and eliminate duplicates. It is not intended to strike any items or to prioritize. Attendees will be asked to attend the one area that is of the most interest to them.

5:00 p.m. **Adjourn**

**Third Day – September 16, 2004**

7:00 a.m. to 8:00 a.m. **Continental Breakfast**

8:00 a.m. to 8:45 a.m. **FULL GROUP**

Spokespersons from each of the six groups will present a short summary of their now collapsed one list "Practice & Expertise' gap areas for each of the six areas. Clarify any overlaps. Attendees will prioritize the six lists into one set of gap areas through a voting process.

8:45 a.m. to 9:30 a.m. **VOTING/Break**

9:30 a.m. to 9:45 a.m. **PRESENT RESULTS**

Present the tallies of the voting process to the full group. Lead into the task of identifying the most likely resources/entities necessary to focus on the identified gap areas.

10:00 a.m. to 10:15 a.m. **Break**

10:15 a.m. to 11:15 a.m. **BREAKOUT SESSION**

Each breakout group will address one of the priority gap areas to discuss and present potential strategies/actions most logical resources (agencies/universities/ corporations/associations) to reduce/eliminate the gap.

Each breakout group will address a second issue – that is, what is the best way to continue to ensure that real progress is being made. This should include a discussion of "lead" groups/organizations, funding sources, maintaining a level of urgency, and a communications process.

11:30 a.m. to noon **FULL SESSION REPORT OUT**

12:00 noon to 1:00 p.m. **Lunch**

1:00 p.m. to 2:00 p.m. **TYING IT TOGETHER**

Addressing the second issue assigned to the breakout groups.

2:00 p.m. to 3:00 p.m. **WRAPUP**

Final Roadmap and Future Actions (Proceedings & Roadmap Publications)

3:00 p.m. **Adjourn**

*Bob Bernhard*

Appendix B

Tire/Pavement Noise Strategic Planning Workshop
ATTENDEES

**Tire/Pavement Noise Strategic Planning Workshop**
**ATTENDEES**


**Gary Aamold**
Penhall Company
Box 310
Rogers, MN 55374
Telephone: 763-428-2244
Fax: 763-428-2245
Email: gaamold@penhall.com

**Iyad Alattar**
FHWA-Nevada Division
705 North Plaza Street, Suite 220
Carson City, NV 89701
Telephone: 775-687-1206
Fax: 775-687-3803
Email: iyad.alattar@fhwa.dot.gov

**Robert E. Armstrong**
Federal Highway Administration
400 Seventh Street, SW
Washington, DC 20590
Telephone: 202-366-2073
Fax: 202-366-3409
Email: robert.e.armstrong@fhwa.dot.gov

**Bob Bernhard,** Director
Institute for Safe, Quiet and Durable Highways
Ray W. Herrick Laboratories
140 S. Intramural Drive
West Lafayette, IN 47907-2031
Telephone: 765-494-2141
Fax: 765-494-0787
Email: bernhard@ecn.purdue.edu

**Mariano Berrios**
Florida Department of Transportation
605 Suwannee Street, MS-37
Tallahassee, FL 32399-0450
Telephone: 850-410-5894
Fax: 850-410-5808
Email: mariano.berrios@dot.state.fl.us

**Anthony Brinkman**
Cooper Tire & Rubber Company
701 Lima Avenue
Findlay, OH 45840
Telephone: 419-429-4433
Fax: 419-424-4305
Email: aebrinkman@coopertire.com

**Doug Carlson**
Rubber Pavements Association
1801 S. Jentilly Lane, Suite A-2
Tempe, AZ 85281
Telephone: 480-517-9944
Fax: 480-517-9959
Email: dougc@rubberpavements.org

**Chris Corbisier**
Federal Highway Administration
400 Seventh Street, SW, HEPN-20
Washington, DC 20590
Telephone: 202-366-1473
Fax: 202-366-3409
Email: chris.corbisier@fhwa.dot.gov

**Brad Cruea**
Milestone Contractors, L.P.
5950 S. Belmont Avenue
Indianapolis, IN 46217
Telephone: 317-788-6890
Fax: 317-788-1098
Email: brad.cruea@milestonelp.com

**Ken Davies**
Federal Highway Administration
400 East Van Buren Street, Suite 410
Phoenix, AZ 85004-2285
Telephone: 602-379-3645, ext. 120
Fax: 602-379-3608
Email: ken.davis@fhwa.dot.gov

**Paul Donavan**
Illingworth & Rodkin, Inc.
505 Petaluma Boulevard South
Petaluma, CA 94952
Telephone: 707-766-7700
Fax: 707-766-7790
Email: pdonavan@illingworthrodkin.com

**Mark Ferroni**
Federal Highway Administration
400 Seventh Street, SW
Washington, DC 20590
Telephone: 202-366-3233
Fax: 202-366-3409
Email: mark.ferroni@fhwa.dot.gov

**Victor Gallivan**
Federal Highway Administration
575 N. Pennsylvania St., Rm 254
Indianapolis, IN 46204
Telephone: 317-226-7453
Fax: 317-226-7341
Email: victor.gallivan@fhwa.dot.gov

**Ron Glotzbach**
International Truck and Engine Corporation
2911 Meyer Road
Fort Wayne, IN 46803
Telephone: 260-461-1006
Fax: 260-428-3775
Email: ron.glotzbach@nav-international.com

**Kent Hansen**
National Asphalt Pavement Association
5100 Forbes Boulevard
Lanham, MD 20706
Telephone: 301-731-4748
Fax: 301-731-4621
Email: khansen@hotmix.org

**Doug Hanson**
National Center for Asphalt Technology
277 Technology Parkway
Auburn, AL 36830
Telephone: 334-844-6228
Fax: 334-844-6248
Email: hansodi@eng.auburn.edu

**Dale Harrington**
Iowa State University
2901 S. Loop Drive, Suite 3100
Ames, IA 50010
Telephone: 515-294-5542
Fax: 515-294-0467
Email: pcconc@iastate.edu

**Alan Hartke**
Goodyear Tire & Rubber Company
Technical Center, D/460G, Box 3531
Akron, OH 44309-3531
Telephone: 330-796-2927
Fax: 330-796-3292
Email: arhartke@goodyear.com

**Sunil Jha**
Bridgestone/Firestone NT
1200 Firestone Parkway
Akron, OH 44317
Telephone: 330-379-4626
Fax: 330-370-3961
Email: jhasunil@bfusa.com

**Don Johnson,** Program Manager
Institute for Safe, Quiet and Durable Highways
Ray W. Herrick Laboratories
140 S. Intrumural Dr.
West Lafayette, IN 47907-2031
Telephone: 765-494-9158
Fax: 765-494-0787
Email: donj@ecn.purdue.edu

**Ellis Johnson**
Michelin N.A.
One Parkway South
Greenville, SC 29602-9001
Telephone: 864-458-4291
Fax: 864-458-5425
Email: ellis.johnson@us.michelin.com

**Roger Larson**
Applied Pavement Technology, Inc.
7501 Candytuft Court
Springfield, VA 22153
Telephone: 703-455-7681
Fax: 703-455-7681
Email: rlarson@pavementsolutions.com

**William Lohr**
Federal Highway Administration
Galtier Plaza, 380 Jackson Street, Suite 500
St. Paul, MN 55113
Telephone: 651-291-6122
Fax: 651-291-6000
Email: william.lohr@fhwa.dot.gov

**William McColl**
New York State Department of Transportation
50 Wolf Road
Albany, NY 12232
Telephone: 518-457-2385
Fax: 518-457-6887
Email: wmccoll@dot.state.ny.us

**Rebecca McDaniel**
Purdue University-NCSC
Box 2382
1205 Montgomery Street
West Lafayette, IN 47906
Telephone: 765-463-2317 x226
Fax: 765-497-2402
Email: rsmcdani@purdue.edu

**Doug Moore**
General Motors
3300 General Motors Road
Milford, MI  48380
Telephone:  248-684-3779
Fax:
Email:  douglas.b.moore@gm.com

**Larry Orcutt**
California Department of Transportation
1120 N. Street, MS 49 Director's Office
Sacramento, CA  94814
Telephone:  916-654-6823
Fax:  916-654-6608
Email:  larry.orcutt@dot.ca.gov

**Mort Oskard**
FHWA/Advanced Research Team/TFHRC
6300 Georgetown Pike (HRDS-04)
McLean, VA  22101-2296
Telephone:  202-493-3339
Fax:  202-493-3417
Email:  mort.oskard@fhwa.dot.gov

**Rob Rasmussen**
The Transtec Group, Inc
1012 E. 38½ Street
Austin, TX  78751
Telephone:  512-451-6233
Fax:  512-451-6234
Email:  robotto@thetranstecgroup.com

**David R. Read**
USDOT/Volpe Center, Acoustics Facility
1043 West 12th Street, Unit A
San Pedro, CA  90731
Telephone:  310-833-1411
Fax:
Email:  read@volpe.dot.gov

**John Roberts**
International Grooving and Grinding Association, Inc.
P.O. Box 58
Coxsackie, NY  12051
Telephone:  518-731-7450
Fax:  518-731-7490
Email:  jroberts@pavement.com

**Michael Roberts**
FHWA Resource Center
61 Forsyth Street, Suite 17T26
Atlanta, GA  30303
Telephone:  404-562-3928
Fax:  404-562-3700
Email:  michael.roberts@fhwa.dot.gov

**Judy Rochat**
US DOT/Volpe Center
1043A West 12th Street
San Pedro, CA  90731
Telephone:  310-833-1711
Fax:
Email:  judy.rochat@volpe.dot.gov

**Mary Ann Rondinella**
Federal Highway Administration
12300 W. Dakota Avenue, Suite 340
Lakewood, CO  80228
Telephone:  720-963-3207
Fax:  720-963-3232
Email:  maryann.rondinella@fhwa.dot.gov

**Larry Scofield**
Arizona Department of Transportation
1221 North 21st Avenue
Phoenix, AZ  85009
Telephone:  602-712-3131
Fax:  602-712-3400
Email:  lscofield@dot.state.az.us

**J. Jeffrey Seiders**
Texas Department of Transportation
125 E. 11th St, Construction Division/M&P (CP-51)
Austin, TX  78701-2483
Telephone:  512-506-5808
Fax:  512-506-5812
Email:  jseider@dot.state.tx.us

**Mike Shearer**
Texas Department of Transportation
125 E. 11th Street
Austin, TX  78701-2409
Telephone:  512-416-2622
Fax:  512-416-2319
Email:  mshearer@dot.state.tx.us

**Stephanie Stoermer**
FHWA California Division
650 Capitol Mall, Suite 4-100
Sacramento, CA  95814
Telephone:  916-498-5057
Fax:  916-498-5008
Email:  stephanie.stoermer@fhwa.dot.gov

**Mark Swanlund**
Federal Highway Administration
400 Seventh Street, SW
Washington, DC  20590
Telephone:  202-366-1323
Fax:  202-493-2070
Email:  mark.swanlund@fhwa.dot.gov

**Will Thornton**
Ray W. Herrick Laboratories
120 S. Intramural Drive
West Lafayette, IN 47907-2031
Telephone: 765-496-6008
Fax: 765-494-0787
Email: wthornto@ecn.purdue.edu

**Manuel Trevino**
Center for Transportation Research
The University of Texas at Austin
3208 Red River, Suite 200
Austin, TX 78705-2650
Phone: (512) 232-3133
Fax: (512) 232-3151
manuel.trevino@mail.utexas.edu

**Curt Turgeon**
Minnesota Department of Transportation
1400 Gervais Avenue
Maplewood, MN 55109
Telephone: 651-779-5535
Fax: 651-779-5616
Email: curt.turgeon@dot.state.mn.us

**William Vachon**
Federal Highway Administration
400 E. VanBuren St, #410
Phoenix, AZ 85004
Telephone: 602-379-3546 ex 118
Fax: 602-379-3608
Email: william.vachon@fhwa.dot.gov

**Jay Waldschmidt**
Wisconsin DOT
Bureau of Equity and Environmental Services
4802 Sheboygan Avenue, Rm 451, Box 7965
Madison, WI 53707-7965
Telephone: 608-267-9806
Fax: 608-266-7818
Email: jay.waldschmidt@dot.state.wi.us

**Roger Wayson**
University of Central Florida
Civil & Environmental Engineering
Box 162450
Orlando, FL 32816-2450
Telephone: 407-823-2480
Fax: 407-823-3315
Email: roger.wayson@mail.ucf.edu

**Robert Zahnke**
Purdue University, BTC
1291 Cumberland Avenue, Suite F
West Lafayette, IN 47906
Telephone: 765-496-3716
Fax: 765-494-9797
Email: rzahnke@ecn.purdue.edu

# Appendix C

## The Gaps

## The Gaps

The following table lists the consolidated gaps identified in the four breakout sessions devoted to identifying the difference between our destination and the current state-of-the-art. These gaps are listed according to the breakout area where they were identified. The numbers are not consecutive because duplicates have been eliminated. Also, some of the gaps are described somewhat cryptically. The attendees had the benefit of discussion and context for their deliberations.

The table also includes the prioritization voting of the group to identify the highest ranking needs. 14 federal representatives, 7 state DOT representatives, 14 representatives of private industry, and 5 academic representatives that participated in the voting. These votes by sector are included to help identify differences in viewpoint and potential leadership for the different aspects of the problem.

| **Gap Voting** | **Federal** | **State** | **Private** | **Academic** | **Total** |
|---|---|---|---|---|---|
| **Policy** | | | | | |
| P1: Lack of federal policy for quiet pavement | 8 | 6 | 7 | 5 | 26 |
| P2: Lack of state policy to prioritize consideration of noise with other factors | 3 | 4 | 0 | 1 | 8 |
| P3: Lifecycle cost-effectiveness: pavement vs. other solutions | 0 | 1 | 1 | 0 | 2 |
| P6: Lack of holistic approach to include more than state DOTs ( academia, vehicle/tire manufacturers) | 1 | 0 | 1 | 0 | 2 |
| P7: Lack of national understanding of state quiet pavement pilot program | 3 | 1 | 1 | 2 | 7 |
| P8: Need for allowing flexibility to deliver project goals, to allow new ideas and technologies | 1 | 0 | 4 | 1 | 6 |
| P9: Need for action from this workshop- identifying funding sources | 4 | 3 | 1 | 2 | 10 |
| P10: Lack of knowledge regarding desire for quiet pavement. DOTs and AASHTO | 1 | 0 | 0 | 0 | 1 |
| P11: Need for engine compression brake policy | 1 | 0 | 0 | 1 | 2 |
| P12: Lack of policy for addressing public/local officials desires for abatement (walls AND quiet pavement) | 3 | 3 | 1 | 0 | 7 |
| P14: Lack of local noise-compatible land use planning policy | 1 | 0 | 0 | 0 | 1 |
| P15: Need for policy to allow construction of noise barriers that achieve less than 5 dBA reduction | 2 | 1 | 0 | 0 | 3 |

| | | | | | |
|---|---|---|---|---|---|
| P16: Need for procedure to disseminate information to the public | 1 | 1 | 0 | 0 | 2 |
| P17: Need for policy to incorporate systems management approach to noise | 2 | 0 | 3 | 1 | 6 |
| **Maintenance** | | | | | |
| M18: Cost of maintaining quiet pavements: unknown life-cycle costs, unknown resources ($, people) | 2 | 2 | 6 | 1 | 11 |
| M19: Maintaining pavement quality: maintaining surface texture characteristics (durability, friction, noise, other safety parameters), replicating surface characteristics during repair, preventative routine maintenance, training of maintenance forces, communication of commitments | 13 | 4 | 7 | 5 | 29 |
| M20: Environmental unknowns: pavement aging effects (durability, friction, noise), winter treatment effects (plowing, noise, salting, prewetting), other environmental effects (runoff, contamination) | 2 | 4 | 2 | 0 | 8 |
| M21: Noise barrier unknowns: long term effects- wall replacement $, resources needed to maintain quality/effectiveness, additional winter maintenance $ (plowing/snow removal), higher landscaping costs, aesthetic considerations | 4 | 2 | 2 | 0 | 8 |
| **Construction** | | | | | |
| C22: Need tools to control construction: predict durability and noise, warranty (for use in), what factors can be controlled/modified to meet noise targets, control variability, acceptable levels, standardize measurement methods, prepare contractors for measurements | 6 | 2 | 5 | 3 | 16 |
| C23: Hot-Mix asphalt: intelligent compaction, understand compaction as it relates to noise | 0 | 0 | 1 | 0 | 1 |
| C24: Concrete: understand texture as it relates to noise, relationship between grinding and noise, control variability, novel construction methods, joint slap | 7 | 3 | 9 | 3 | 22 |
| C25: Need for construction acceptance methodologies for noise: performance specs., measurements standards/targets, warranties, incentives/disincentives | 8 | 5 | 7 | 3 | 23 |
| C26: Need for specifications: best practices, what factors are more sensitive to noise | 0 | 0 | 2 | 0 | 2 |
| C28: Lack of equipment innovation, 2 lifts, twin lifts, exposed aggregate…, testing equipment in the lab, behind the paver testing, is aggregate processing equipment needed | 0 | 1 | 2 | 1 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| C30: Need for communication, public>politicians>technical people, stakeholders need to understand full scope of issue, educate people in the industry re. tire/pavement noise | 8 | 3 | 6 | 1 | 18 |
| **Design** | | | | | |
| D32: Bridge decks- texture | 0 | 2 | 0 | 0 | 2 |
| D34: Joint design: original design, resealing (choice of materials, shape of reservoir) | 0 | 0 | 3 | 0 | 3 |
| D36: Texture/Friction: negative vs. positive texture, diamond grinding | 7 | 4 | 14 | 3 | 28 |
| D37: Mix design: voids content, aggregate size/shape, binders, porosity, density, optimization of structural properties, lab vs. field mix, relationship of resilience modulus to impedance properties, lack of noise/acoustical consideration | 7 | 2 | 8 | 4 | 21 |
| D40: Need standardized noise test procedure | 7 | 5 | 8 | 5 | 25 |
| D41: Need prediction models: many choices many inputs to output pavement design criteria | 3 | 1 | 8 | 4 | 16 |
| D43: geometric design gaps: changes in pavement type/texture by lane, consideration of reflection path in geometric design (i.e.. Tilted, absorptive shoulders), absorptive jersey barriers, Jersey barrier shape change for noise, lane allocation by vehicle type, combination of all, lane additions restricted by barriers, integration of alternative/multiple noise mitigation solutions | 2 | 1 | 3 | 0 | 6 |
| D46: Lack of regulation for noise in tire designs ( vs. European requirements) | 1 | 1 | 0 | 0 | 2 |
| **Analysis** | | | | | |
| A48: Measurements: Relationship between source and wayside noise, correlation within source methods, correlation within wayside methods | 12 | 5 | 11 | 5 | 33 |
| A50: Relationship between light vehicle and heavy truck: tires,… | 8 | 3 | 8 | 3 | 22 |
| A52: Scheduling: pavement age, longevity of acoustical benefits, acceptance of surfaces,… | 2 | 0 | 0 | 0 | 2 |
| A53: Modeling- short term: adjustment factors (empirical, before/after) | 5 | 2 | 1 | 2 | 10 |
| A54: Modeling- long term: adjustment factors (source-tire/pavement, propagation over pavement) | 7 | 2 | 5 | 2 | 16 |

| Research | | | | | |
|---|---|---|---|---|---|
| R58: Metric to incorporate perception: tonality, transients, spectrum, modulation | 4 | 4 | 11 | 4 | 23 |
| R62: How long do noise benefits last: in relationship to other properties, clogging?, aging, life cycle | 12 | 7 | 10 | 5 | 34 |
| R63: Relationships of pavement characteristics to noise: variability and R64 | 8 | 2 | 5 | 3 | 18 |
| R64: Optimization of various pavement types: elasticity, noise, safety (friction), cost (life cycle), texture, mix designs/materials, durability, ride | 8 | 5 | 9 | 4 | 26 |
| R65: Lab based test to evaluate performance: accelerated aging, porosity | 0 | 0 | 5 | 3 | 8 |
| R66: Research measurement methodologies for U.S. applications: absorption measurements, source, wayside, mechanical impedance | 11 | 6 | 11 | 3 | 31 |
| R68: Calibration/Certification of noise measurement equipment/ test methods/ operators, standardization | 7 | 7 | 7 | 3 | 24 |
| R70: Quantification of benefits of quiet pavement vs. other noise mitigation methods | 7 | 6 | 7 | 4 | 24 |
| R71: Investigation of implementation of quiet pavements in TNM | 5 | 7 | 1 | 3 | 16 |
| R72: Methods for predicting/accounting for seasonal/diurnal/meteorological effects on traffic noise measurements, wet weather | 5 | 1 | 3 | 2 | 11 |
| R73: Research exchange: international, interstate, agency<>industry (tires, vehicles, pavement) | 4 | 3 | 5 | 0 | 12 |
| R74: Innovative pavement concepts: pre-cast, absorptive paths | 0 | 1 | 3 | 1 | 5 |