

UNDERSTANDING AND OPTIMIZING CONCRETE PAVEMENT SURFACE CHARACTERISTICS

Implementing the CP Road Map SC Track

Framework Document

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Background

What is a pavement surface characteristic (PSC)? Said simply, it is a way to describe a pavement surface that directly or indirectly connects to a human response or societal need. It includes things such as smoothness, friction, noise, splash & spray, surface drainage, and rolling resistance. Other characteristics include tire wear, vehicle wear, and reflectivity & illuminance. Affecting these surface characteristics are numerous pavement properties, with the most important being surface texture. These “bumps and dips” in the road range in size from long rolling undulations to asperities that cannot be seen with the naked eye. Other important pavement properties include the degree of permeability and porosity, cross-slope, and mechanical impedance (stiffness). Even the color of the surface will also affect some surface characteristics both directly and indirectly.

CP ROAD MAP
shaping the future of concrete pavement



it's your move!

In July 2006, the National Concrete Pavement Technology Center (CP Tech Center) published a *Strategic Plan for Improved Concrete Pavement Surface Characteristics*. The plan included an update to the Surface Characteristics (SC) Track of the *Long-Term Plan for Concrete Pavement Research and Technology – The Concrete Pavement Road Map* published in September 2005.

Meanwhile, a coordinated three-part effort has been underway since early 2005 termed the *Concrete Pavement Surface Characteristics Program*. Managed by the CP Tech Center, this effort has pooled funding and experience from within the FHWA, the concrete paving industry including ACPA, and numerous State DOTs. In early 2007, the third part of this program was launched under Pooled Fund TPF-5(135).

SC TRACK GOAL

To fulfill the needs and desires of society by designing, building, and maintaining concrete pavement surfaces that are safer, more comfortable, durable, and cost effective. To develop an integrated unified model that links concrete pavement surface characteristics to the human element, pavement properties, and the factors that affect these all.

The purpose of this document is to consolidate both ongoing and proposed activities related to concrete pavement surface characteristics. It is intended to be a technical framework document, developed as part of the CP Road Map SC Track implementation. The framework effort will, in turn, update and validate a prioritized, productive, coordinated, and non-duplicative research plan for addressing knowledge gaps and advancing improvements in concrete pavement surface characteristics.



Mission Statement for the SC Track

Under the SC Track, the concrete pavement industry will work together to develop specifications and guidelines to design, construct, and maintain concrete pavements that are safe, comfortable, durable, and cost effective. The goal is concrete pavements that invoke a pleasant human experience and address an array of societal needs. The SC Track will coordinate the research and technology that is necessary to achieve this goal. It will promote collaboration among partners, and ensure that duplication is minimized.

Identifying the Gaps using an Integrated Perspective

In developing the CP Road Map, and with the SC Track Goal in mind, a thorough review of the state of the practice was made. From this, numerous gaps were identified with respect to concrete pavement surface characteristics research and technology. The idea was that in order to fill these gaps, a workplan of activities would be developed.

Since that time, we have learned a lot, and while most of the gaps identified in the CP Road Map remain, they can now be presented more concisely. However, before presenting the gaps, we must first identify how PSC fit within the decision-making framework. With an integrated perspective, we can begin to understand how to more optimally direct the proposed research program.

Figure 1 illustrates this integrated perspective. As highway practitioners, our mission has always been to serve the public with a safe, comfortable, and cost effective highway system. What the pyramid shows are the logical connections between the human factors at the top and the technical factors at the bottom.

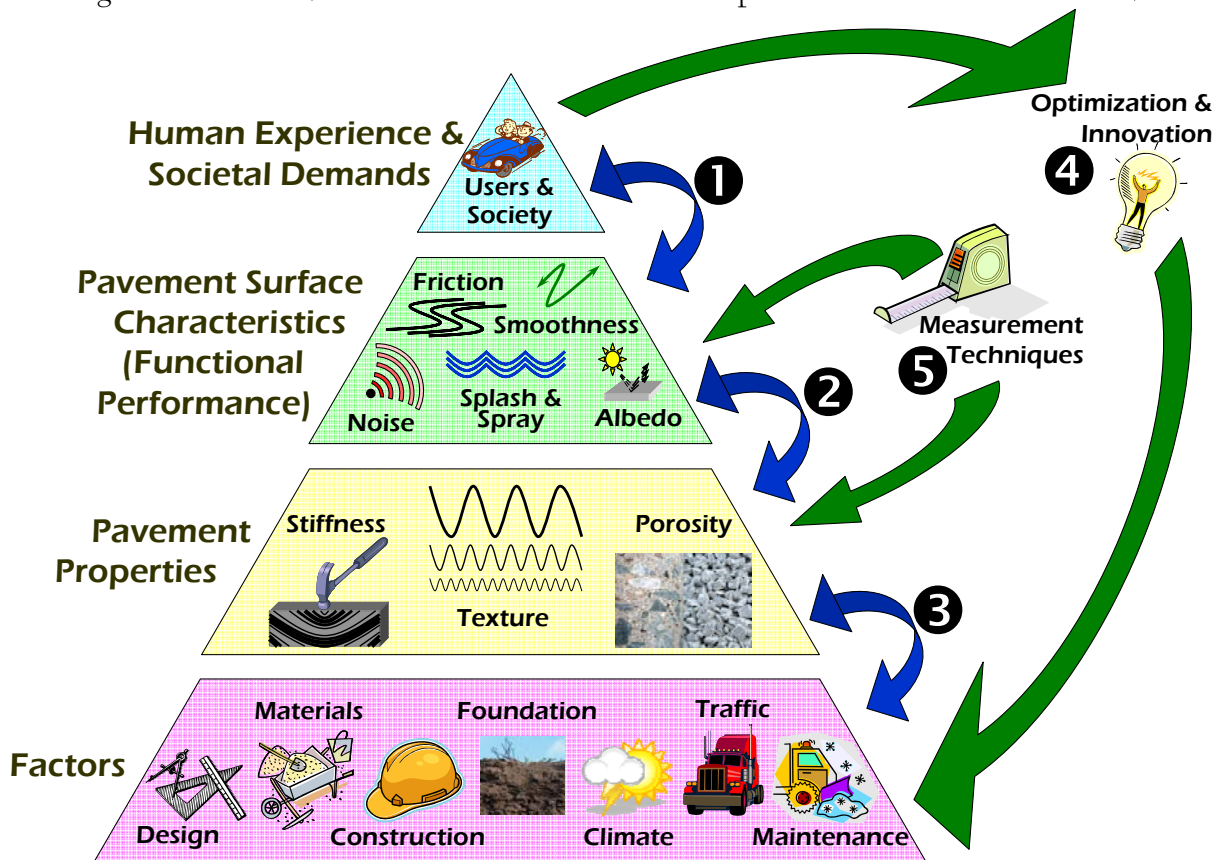


Figure 1. An Integrated Perspective of Pavement Surface Characteristics.



The levels of the pyramid represent components of this system. We could climb the pyramid by starting with the most basic factors at the bottom – some are under our control, others we need to recognize their influence and mitigate their effects if/as needed. Pavement properties are affected by these factors, including both as-constructed values and how they change over time. The properties, in turn, affect the PSC in various ways. Functional Performance is another way to describe PSC, as it is the ability to describe the nature of the pavement surface as it serves its intended function. This leads to the last connection where the PSC ultimately determine how the public is served.

Reversing this process also helps illustrate it. Climbing down the pyramid begins with the demands placed on the highway industry by the users and society. These could be legislative demands driven by public outcry. These demands would, in turn, translate into various thresholds or targets of PSC. To accomplish these levels of PSC, certain pavement properties and combinations thereof must be present. And in order to achieve these pavement properties, the various factors must be selected and controlled, ideally in a cost-effective manner.

The linkages (shown as the various arrows on the right) are key to the work proposed under the SC Track. The gaps in research and technology are largely borne from a need to understand these links. It is not enough to understand the link between just two of these levels; all of the levels must be connected if the SC Track is to achieve its ultimate goal.

With this integrated perspective, the gaps as they stand today can be presented in terms of five simple questions. Each question is cross-referenced back to the pyramid with the question number. The first three questions address the links between levels. The last two identify gaps that relate to the problem more globally.

❶ What are the links between PSC, human response, and societal benefit?

Affected by our highways are the drivers, those that live and work alongside these roads, and society as a whole. As highway engineers, we can measure PSC, but difficulty lies in relating these back to specific human perceptions and societal impacts. For example, how does friction (a measurable characteristic) relate to safety – or even more specifically, to wet-weather accident rates? With respect to smoothness, indicators such as the International Roughness Index (IRI) are mathematical transformations of physical measurements. But how does this relate to comfort or possibly the effect it might have on cargo? Finally, noise is measured in terms of level, but this should also be connected to annoyance.

The need exists to relate the physical measurements of PSC to the human responses that they trigger. A determination must also be made about how societal needs are being fulfilled. To understand this link will require tools such as life cycle analysis that not only account for tangible costs, but also indirect factors such as safety and comfort. Only then can rational threshold or target values for PSC be derived.

❷ What are the relationships between pavement properties and PSC?

Pavement surface characteristics describe a pavement in a number of unique ways. While some PSC are fundamental physical characteristics, others are the result of a response between the pavement and a vehicle and/or tire. As a result, the problem can be quite complex due to the sheer variety of vehicles that exist.

Pavement texture is arguably the most important pavement property affecting PSC. There are other important properties, however, including stiffness, cross-slope, color, and in some cases, porosity. Predicting PSC requires an understanding of the physical pavement properties as they interact with the vehicles, and compounded by other factors including weather. Identifying these relationships will fill a



gap, since only then can optimization of a pavement surface truly occur. To the greatest degree possible, models are needed that are mechanistic in nature so that current experience can be more confidently extrapolated to more innovative pavement materials and textures.

③ How do design, materials, construction, maintenance, climate, and traffic factors affect pavement properties, both initially and over time?

In the previous question, we identified the need to understand what pavement properties affect PSC. However, we must also determine what degree of control we have over the factors affecting those properties. For example, pavement texture can be specified during design in terms of nominal dimensions. The same is true of other relevant properties including cross-slope, stiffness, etc. However, how these properties are constructed and how they change over time will depend on the equipment used, properties of the concrete, and the weather conditions during placement and over time. Other contributing factors will also be at play including accumulated traffic and maintenance, especially snow plowing. How all of these factors affect both the pavement properties and the changes over time remain as critical gaps. Linked with this should be a keen understanding of the impacts to the material and structural performance of the pavement.

④ Can concrete pavement surfaces be optimized and/or innovation introduced to meet site-specific conditions?

Optimization of a pavement surface must consider the demand placed on that surface by the users and society. The demands will be, of course, site specific. From these demands, unique target and threshold values for PSC can be derived that, in turn, point to various combinations of pavement texture and materials. While it is believed that the vast majority of the highway system will continue to utilize “conventional” texturing techniques, each should be described in terms of what it can provide on a consistent and predictable basis. To complement this, innovative materials and techniques should also be explored, including exposed aggregate surfaces, porous concrete, and non-conventional textures, materials, and construction methods.

⑤ Are today’s measurement and analysis techniques satisfactory in characterizing pavement properties and PSC?

In order to collaborate effectively, standard techniques to measure and characterize the pavement surface must be established early in the SC Track. These techniques should attempt to measure pavement properties and PSC in as fundamental a way as possible. In contrast, many of the techniques in use today measure a system response, which in turn is a function of the test equipment. While separating the pavement effect from that of the equipment is difficult in some cases, it should be strived for. To fill this gap, measurement and analysis techniques are needed that are relevant, accurate, portable, and ideally performed both efficiently and with minimal training demands. Practical considerations must also be effectively addressed including things such as the effect of weather conditions during measurement.



The SC Track: a Plan to Fill the Gaps

Within the original CP Road Map, a structured outline for the SC Track was presented. The Track was divided into subtracks, and then again into tasks that describe individual “compartments” of research and technology. Collectively, the work program will meet the goal of the Track, but only if collaboration is realized.

Since 2005, work under the SC Track has been informally launched through the efforts of the FHWA, CP Tech Center, and others. However, the need now exists more than ever to more formally manage the SC Track to make it a success.

The SC Track currently identifies 40 problem statements representing an investment of between \$27 and \$56 million in research. The proposed research is organized into seven subtracks and presented in a recommended sequence:

- ✓ Subtrack SC.1: Innovative and Improved Concrete Pavement Surfaces
- ✓ Subtrack SC.2: Tire-Pavement Noise
- ✓ Subtrack SC.3: Concrete Pavement Texture and Friction
- ✓ Subtrack SC.4: Safety and Other Concrete Pavement Surface Characteristics
- ✓ Subtrack SC.5: Concrete Pavement Profile Smoothness
- ✓ Subtrack SC.6: Synthesis and Integration of Concrete Pavement Surface Characteristics
- ✓ Subtrack SC.7: Technology Transfer and Implementation of Concrete Pavement Surface Characteristics Research

Problem statements contained in the plan may correspond to one or more individual projects. Over the course of the SC Track, each problem statement will be developed into research project statements that will contain detailed descriptions of the research to be accomplished, specific budgets, and definite timelines. Detailed problem statements for the SC Track are not included here for brevity, but can be found in the National CP Tech Center Publication, *Strategic Plan for Improved Concrete Pavement Surface Characteristics*, published July 2006.

In order to effectively build off of the work to date, a number of early products are recommended under the SC Track. Most of these are proposed as syntheses given the fragmented reporting of the work to date. These early products should include:

1. A description of highway user (functional) requirements for all classes of roads (streets, low-volume, highways, special applications); identification of PSC levels that fulfill these requirements.
2. Relationships between pavement texture and other pavement properties as they affect all PSC.
3. Concrete pavement designs, materials, and construction methods that produce predictable levels of PSC.
4. Documentation of changes in PSC over time as a function of design, materials, and construction, along with traffic, climate, and maintenance.
5. Advancements in equipment and standardization for continuous and efficient measurement of PSC in an accurate and relevant manner.
6. Preliminary design, construction, and measurement guidelines including technology transfer products that serve to convey the lessons learned to date.

The research plan as organized under the SC Track should be used as a guide. Obviously, beyond these early products are numerous other tasks that seek to fulfill the ultimate goal of the Track.



Foundational, Recent, and Ongoing Work

The following is a summary of some of the more relevant work that is foundational in nature, recently completed, and/or ongoing. While categorized under the Subtrack headings, no attempt is made here to prioritize their relevance. Collaboration with the sponsors and researchers of these projects will be important to the success of the SC Track.

Subtrack SC.1: Innovative and Improved Concrete Pavement Surfaces

- ✓ Concrete Pavement Surface Characteristics Program, Part 3 – CP Tech Center / FHWA / Pooled Fund TPF-5(139)
- ✓ Two-Lift Concrete Paving Program – National CP Tech Center / Kansas DOT / FHWA
- ✓ Third-Generation Road Surfaces (Modieslab) – IPG Noise Innovation Program (Netherlands)
- ✓ Optimized Diamond Grinding and Innovative Texturing – ACPA
- ✓ PCC Surface Characteristics – Rehabilitation (Mn/ROAD Study) – Pooled Fund TPF-5(134)
- ✓ Innovative Methods for Creating Texture on Pavements, Conceptual Papers and Field Trials – FHWA
- ✓ Texturing of Concrete Pavements – NCHRP 10-67
- ✓ Concrete Mixtures with Inclusions to Improve the Sound Absorbing Capacity of PCC Pavements – Recycled Materials Resource Center / FHWA
- ✓ Use of Lightweight Aggregates for Tire-Pavement Noise Reduction – FHWA

Subtrack SC.2: Tire-Pavement Noise

- ✓ State DOT Quiet Pavements Research Programs – Caltrans, Washington State, Colorado, Texas, Florida, Arizona (QPPP)
- ✓ Tire-Pavement Noise Research Consortium – Pooled Fund TPF-5(135)
- ✓ Traffic Noise Model (TNM) 3.0 Software Development – FHWA / Pooled Fund TPF-5(158)
- ✓ Pavement Effects Study for TNM – FHWA
- ✓ Measuring Tire-Pavement Noise at the Source – NCHRP 1-44
- ✓ Truck Noise Source Mapping – NCHRP 8-56
- ✓ Methodologies for Evaluating Pavement Strategies and Barriers for Noise Mitigation – NCHRP 10-76
- ✓ Noise Intensity Testing in Europe (NITE) – Caltrans
- ✓ Sustainable Road Surfaces for Traffic Noise Control (SILVIA) – FEHRL (Europe)
- ✓ Standardization of On-Board Sound Intensity – AASHTO / ASTM / SAE

Subtrack SC.3: Texture and Friction

- ✓ Texture and Friction Measurement Equipment Loan Program – FHWA
- ✓ Guide for Pavement Friction – NCHRP 1-43
- ✓ Harmonization of Texture and Skid Resistance Measurements – Florida DOT
- ✓ Assessment of Alternate PCCP Texturing Methods in Colorado – Colorado DOT
- ✓ Harmonization of European Routine and Research Measuring Equipment for Skid Resistance (HERMES) – FEHRL (Europe)



Subtrack SC.4: Safety and Other PSC

- ✓ Relationship between SN with Ribbed and Smooth Tire and Wet Accident Location – Ohio DOT
- ✓ Wet Pavements Crash Study of Longitudinal and Transverse Tined PCC Pavements – Wisconsin DOT
- ✓ Review of UK Skid Resistance Policy – Highways Agency / TRL (UK)
- ✓ Relationship between Macrotexture and Crash Occurrence – ARRB (Australia)
- ✓ Characterizing the Splash and Spray Potential of Pavements – FHWA
- ✓ Cool Pavements Initiative – EPA / Arizona State Univ.
- ✓ Rolling Resistance of Tires on Road Surfaces – BAST (Germany)
- ✓ Effect of Pavement Surface Type on Fuel Consumption – NRC (Canada)
- ✓ State-of-the-Art Report: The Influence of Roadway Surface Discontinuities on Safety – TRB AFD90

Subtrack SC.5: Smoothness

- ✓ Development of a “Golden Tire Footprint” for Improvement of Profiler Reference – FHWA
- ✓ Improving the Quality of Pavement Profiler Measurement – FHWA / Pooled Fund TPF-5(063)
 - ◆ ProVAL Software
 - ◆ Reference Profilors
 - ◆ Benchmark Profiler
 - ◆ Single Accelerometer Study
- ✓ Smoothness Criteria for PCC Pavements – FHWA
- ✓ Ultra-Light Inertial Profiler Prototype – FHWA
- ✓ Smoothness Specification Implementation and Support – FHWA
- ✓ Measuring Pavement Profile at the Slipform Paver – Iowa HRB / FHWA

Subtrack SC.6: Synthesis and Integration of PSC

- ✓ Pavement Surface Properties Consortium – Pooled Fund TPF-5(141)
- ✓ Concrete Pavement Surface Characteristics Program, Part 1 – CP Tech Center / FHWA
- ✓ Concrete Pavement Surface Characteristics Program, Part 2 – CP Tech Center / FHWA / ACPA
- ✓ Synthesis of Performance-Based Surface Condition Measurements for Acceptance – FHWA

Subtrack SC.7: Tech Transfer and Implementation

- ✓ Little Book of Quieter Pavements and Listening Experiences – FHWA
- ✓ Tire-Pavement Noise IOI Workshops – FHWA
- ✓ Pavement Smoothness Workshops – FHWA



Proposed Short-Term Projects

With past and ongoing work summarized, gaps in research and technology identified, and a vision formed for the early products, a specific program of short-term work can now be laid out. The following is a list of five projects that would help fill the early gaps, and work within the timeline for the track:

Subtrack / Link to Integrated Perspective (see Figure 1)	Project Title	Project Scope	Cost Estimate
SC.6 ①	Development of an Integrated Functional Classification System for Concrete Pavement Surface Characteristics	<p>In this project, the links between societal/human factors and the various pavement surface characteristics will be identified. Using current measures/metrics for the various PSC, both target and threshold values will be identified that meet the demands for various types of roads.</p> <p>A classification system should be developed that is rational, simple to understand, and can be readily localized by State DOTs. The resulting system should be peer reviewed, and evaluated using network data from 3-5 States.</p>	\$500,000 to \$750,000
SC.2 SC.3 SC.4 SC.6 ②	Refinement of Models to relate Pavement Texture to Noise, Friction, Splash & Spray, and other Concrete Pavement Surface Characteristics	<p>To date, there has been some effort to link pavement texture to tire-pavement noise, friction, and other PSC. However, little has been done with respect to concrete pavement textures, and furthermore, little has been done to approach this problem with an ultimate goal of a unified model that links texture to all PSC.</p> <p>A number of individual projects will be undertaken with the goal of developing new or revising existing models with specific application to concrete pavement textures.</p> <p>Existing texture data can be used for model development, and validated with new data as necessary – both from in the field and under controlled conditions in the laboratory.</p>	3 to 5 projects of \$100,000 to \$250,000 each



Subtrack / Link to Integrated Perspective (see Figure 1)	Project Title	Project Scope	Cost Estimate
SC.3 SC.5 ③	Characterizing Design and Construction Artifacts in Concrete Pavement Surfaces	<p>Some effort has been undertaken to date to identify the potential effects that design, materials, construction, and climate can have on a concrete pavement surface. Specific properties include slab curvature, texture depth, and surface wear potential. This project will seek a more complete and coherent understanding of these relationships, along with the necessary links to material and structural performance.</p> <p>A robust analysis of available data should be conducted including that from LTPP SPS2 sites and sites previously evaluated under the CPSCP. Furthermore, new concrete pavement sections should be evaluated both during and subsequent to construction in order to identify those characteristics that can be attributed to specific construction activities and equipment.</p>	2 to 3 projects of \$500,000 each



Subtrack / Link to Integrated Perspective (see Figure 1)	Project Title	Project Scope	Cost Estimate
SC.7 ④	Training for Improved Surface Characteristics through Better Practices in Concrete Pavement Design, Construction, and Maintenance	<p>A lot of knowledge is amassing with respect to how concrete pavements can be designed, constructed, and maintained in order to make them safer and more comfortable without compromising durability or cost. Building off of the success of previous outreach efforts including the Tire-Pavement Noise 101 and Improved Pavement Smoothness Workshop series', the proposed training program will consist of up-to-date workshop series' that broaden the scope to include all PSC.</p> <p>While the training will include requisite sections on fundamentals, better practices will be the emphasis. The participants in the training should walk away with a skill set that can be immediately applied to daily practice. Follow-up support will also be provided, allowing participants of the training to have access to the experts that can assist them with specification development and related procedural changes.</p>	1 to 2 projects of \$250,000 to \$500,000 each



Subtrack / Link to Integrated Perspective (see Figure 1)	Project Title	Project Scope	Cost Estimate
<p>SC.3 5</p>	<p>Improved Concrete Pavement Texture Evaluation</p>	<p>Work under the SC Track will place a much higher demand for accurate texture data that is relevant to all PSC. Current measurement technologies fall short of these demands, and therefore a series of projects is proposed to address this. Ideally, three projects will be undertaken that 1) will specify the newer requirements for texture measurements; 2) develop equipment; and 3) evaluate the new equipment in terms of its ability to meet the more stringent demands.</p> <p>The first project would establish the criteria that can subsequently be used to evaluate the desirability of texture measurement systems. Possible criteria include measurement accuracy and representativity/relevance for texture of various sizes, cost, proprietary nature, and production (measurement) rate.</p> <p>Development of equipment can then proceed, which can be funded publicly (an open architecture prototype), privately (with response left to the free market), or a combination that might use seed (grant) money to spur development.</p> <p>The final step will include an evaluation of the equipment against the new criteria, and furthermore demonstrating the capabilities of the equipment on a variety of concrete pavement surfaces.</p>	<p>2 to 3 projects of \$250,000 to \$500,000 each – industry match and/or public/private partnerships</p>



Stakeholders and Partners

Successful collaboration under the SC Track will require participation from a number of diverse groups. The following includes a summary of stakeholders and partners divided into two tiers. The first includes organizations that have already demonstrated active roles in this area, primarily through sponsorship of work items previously described. Tier II includes groups that logically have a stake in the outcome of the research, but whose participation may need to be sought when the timing is deemed appropriate.

- ✓ Tier I – Active Stakeholders and Partners
 - ◆ FHWA
 - ◆ State DOTs / NCHRP
 - ◆ ACPA Chapters
 - ◆ ACPA National
 - ◆ IGGA
 - ◆ PCA
 - ◆ Concrete Paving Contractors
 - ◆ Diamond Grinding Contractors
 - ◆ Construction/Texturing Equipment Manufacturers
- ✓ Tier II – Reserve Stakeholders and Partners
 - ◆ AASHTO
 - ◆ City and County Governments
 - ◆ Public and Private Tollway Authorities/Concessionaires
 - ◆ ACI
 - ◆ Measurement Equipment and Sensor Vendors
 - ◆ Pavement Evaluation Firms
 - ◆ NRMCA
 - ◆ TRB
 - ◆ Concrete Paving Industry Consortiums (e.g., NCC, SCAN, ISCP)
 - ◆ RPUG
 - ◆ Vehicle and Tire Industries

Inaugural SC Track Meeting

Date/Location

- ✓ Date: 23-24 April 2008
- ✓ Location: Grapevine, TX

Objectives

- ✓ To achieve consensus on the ultimate objectives of the SC Track.
- ✓ To validate what knowledge gaps exist today.
- ✓ To identify how we as an industry can work to fill these gaps.
- ✓ To identify early projects and their funding mechanisms.
- ✓ To help advance the CP Road Map SC Track to a dynamically managed program.



Final Agenda

23 April 2008 (Wednesday) – 1:00 pm to 5:00 pm

- ✓ Introduction to CP Road Map (Wiegand)
 - ◆ History, CP Tech Center Role, Definition and Importance of Collaboration
- ✓ Presentation of Draft SC Track Framework (Rasmussen)
- ✓ Introduction to FHWA and ACPA Research Programs (Wiser and Scofield)
- ✓ Connection to TRB AFD90 (McGhee)
- ✓ Summary of SC Work (Rasmussen)
 - ◆ Foundational, Recently Completed, Ongoing
- ✓ Open Discussion of Track to Build Consensus (Wiegand and Rasmussen)
 - ◆ Overall Objective of Session
 - ◆ Individual Recommendations of Needs and Research/Implementation Tasks
 - ◆ Gaps
 - ◆ Short-Term Projects and Products
 - ◆ Long-term Project and Products

24 April 2008 (Thursday) – 8:00 am to 11:00 am

- ✓ SC Track Communications, Coordination, and Collaboration Plan (Wiegand)
- ✓ Identification of Funding Partners for Short-Term Projects (Wiegand)
- ✓ What Happens Next? (All)

Participant List

- ✓ FHWA/USDOT
 - ◆ Mark Swanlund, Office of Pavement Technology
 - ◆ Larry Wiser, TFHRC
 - ◆ Bob Orthmeyer, Pavement and Materials TST **
- ✓ State DOT
 - ◆ Bernard Izevbekhai, Minnesota DOT
 - ◆ Brian Schleppe, Ohio DOT
 - ◆ Jeff Seiders, Texas DOT
- ✓ Pavement Industry
 - ◆ Larry Scofield, ACPA
 - ◆ John Roberts, IGGA **
 - ◆ Ron Guntert, Guntert & Zimmerman
- ✓ Academia and Other Industry
 - ◆ Steven Karamihas, University of Michigan Trans. Res. Inst.
 - ◆ Kevin McGhee, VTRC
 - ◆ John Ferris, Virginia Tech University **
- ✓ National CP Tech Center
 - ◆ Paul Wiegand, National CP Tech Center
 - ◆ Ted Ferragut, TDC Partners, Ltd. **
 - ◆ Rob Rasmussen, The Transtec Group, Inc.
 - ◆ Tom Cackler, National CP Tech Center **
 - ◆ George Chang, The Transtec Group, Inc.
 - ◆ Gary Fick, Trinity Materials

** Note: could not attend meeting.