

Research Report
Educational Task Order T1242, Task 4
Framework for Research, Development, and Implementation of New Pavement Technology

A FRAMEWORK FOR WSDOT PAVEMENT RESEARCH

by

Joe P. Mahoney
Professor of Civil and Environmental
Engineering
University of Washington

Martin D. Pietz
Director of Research
Washington State Department of
Transportation

Keith W. Anderson
Research Project Manager
Washington State Department of
Transportation

Linda M. Pierce
Pavement and Soils Engineer
Washington State Department of
Transportation

Washington State Transportation Center (TRAC)
University of Washington, Box 354802
University District Building
1107 NE 45th Street, Suite 535
Seattle, Washington 98105-4631

Prepared for

Washington State Transportation Commission
Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

December 2000

1. REPORT NO. WA-RD 492.1	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE A FRAMEWORK FOR WSDOT PAVEMENT RESEARCH		5. REPORT DATE December 2000	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Joe P. Mahoney, Martin D. Pietz, Keith W. Anderson, and Linda M. Pierce		8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Transportation Center (TRAC) University of Washington, Box 354802 University District Building; 1107 NE 45th Street, Suite 535 Seattle, Washington 98105-4631		10. WORK UNIT NO.	11. CONTRACT OR GRANT NO. T1242-04
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building, MS 7370 Olympia, Washington 98504-7370 WSDOT Project Manager: Keith Anderson, 360-709-5405		13. TYPE OF REPORT AND PERIOD COVERED Final Report	
15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.		14. SPONSORING AGENCY CODE	
16. ABSTRACT This study documents the development of a pavement research framework for the Washington State Department of Transportation. The framework extends over a six-year period (three biennia) and includes provision for extensive collaboration with other agencies, the private sector, and national funding organizations.			
17. KEY WORDS Pavements, Research, Framework, Prioritization		18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616	
19. SECURITY CLASSIF. (of this report) None	20. SECURITY CLASSIF. (of this page) None	21. NO. OF PAGES	22. PRICE

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

CONTENTS

EXECUTIVE SUMMARY.....	ix
CHAPTER 1. INTRODUCTION.....	1
Pavement Research in Perspective.....	1
Study Goals and Objectives	5
CHAPTER 2. HISTORICAL BACKGROUND.....	7
Historical View of WSDOT Pavements.....	7
Historical View of WSDOT Pavement Research.....	12
CHAPTER 3. REVIEW OF LITERATURE AND RESEARCH ORGANIZATIONS	25
Literature	25
Research Organizations.....	38
CHAPTER 4. DEVELOPMENT OF THE FRAMEWORK	42
WSDOT Pavement Research Questionnaire.....	42
State Pavement Technology Consortium	46
Pavement Needs Seminar.....	49
WSDOT Prioritization of South African Pavement Technology.....	49
Superpave and LTPP.....	50
Proposed Framework.....	50
CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS.....	75
Conclusions	75
Recommendations	76
REFERENCES.....	78
APPENDIX A. SUMMARY OF RESPONSES OF INTERNAL WSDOT QUESTIONNAIRE ON PAVEMENT RESEARCH ORIENTED QUESTIONS ...	A-1
APPENDIX B. WSDOT RESPONSE TO THE STATE PAVEMENT TECHNOLOGY CONSORTIUM QUESTIONNAIRE ON TRAINING AND IMPLEMENTATION— 1999	B-1
APPENDIX C. SUMMARY OF WSDOT VIEW ON ASSESSMENT AND IMPLEMENTATION OF SOUTH AFRICAN PAVEMENT TECHNOLOGY.....	C-1

TABLES

<u>Number</u>		<u>Page</u>
1	Special Interest Research Organizations	41
2	Question 1—The WSDOT Pavement Research Program	58
3	Question 2—National Pavement-Oriented Research Programs...	59
4	Question 3—What Pavement Information Has Most Affected Your Work?	60
5	Question 4—What Are The Major Issues Facing WSDOT with Respect to Pavements (Other Than Funding)?	61
6	Pavement Research Needs.....	62
7	Structural Design and Analysis Program Area—Detailed Considerations/Needs	63
8	Pavement Materials Program Area—Detailed Considerations/Needs	64
9	Pavement Performance Program Area—Detailed Considerations/Needs	65
10	Pavement Rehabilitation Program Area—Detailed Considerations/Needs	66
11	Pavement Construction Program Area—Detailed Considerations/Needs	67
12	Information Systems and Training Program Area—Detailed Considerations/Needs	68
13	Framework Program and Subprogram Areas	69
14	Urgency Impact Assessment Points	70
15	Prioritized Framework Program	71
16	Prioritized Framework Program Funding and Implementation....	72
17	Number of Studies in Each Subprogram	73
18	Specific Studies in Each Subprogram with No. 1 Ranking.....	74

FIGURES

<u>Number</u>		<u>Page</u>
1	International Research and Development as a Percentage of GDP	27
2	U.S. R&D Performing Sectors—Percentage of Total.....	27
3	Illustration of Internet Technology Cost Reduction.....	37

EXECUTIVE SUMMARY

Numerous pavement-oriented research activities have been recently completed, under way, or are about to start in the state, nation, and internationally. The Washington State Department of Transportation has a wide range of pavement research opportunities and needs a structure in which to evaluate and prioritize its pavement research, as well as related development and technology transfer activities. This report proposes a framework for identifying and classifying opportunities and prioritizing them over a six-year period. The framework identifies the resources and processes needed to assess pavement technology developed by others, to prioritize development and implementation efforts, and, finally, to identify the types of studies that WSDOT, specifically, should do. Use of new technology also allows for major enhancements to implementation and training—two of the most important areas of the innovation process. The product of this report is a six-year research, development, and implementation framework.

On the basis of previous collaborative efforts (such as the State Pavement Technology Consortium (SPTC)), various surveys, a Pavement Needs Seminar (August 2000), and knowledge of pavement research needs, pavement technology program and subprogram areas are recommended (Table 16). There are six major program areas and 27 subprogram areas (on average, about five subprograms per program area). A subprogram will constitute one or more research studies. The large number of subprograms suggests that innovative strategies are required to move forward. The subprograms within each program are listed with the highest priority first and in descending order.

The overall timeframe in which to accomplish the framework is estimated to be six years (three biennia). That includes conduct of the research, development, and initial implementation. Naturally, the framework will evolve and so will the timeframe. Importantly, technical personnel within WSDOT must be given the opportunity to grow with the conduct of the programs within the framework. As shown in the discussion of the historical development of WSDOT pavements, important decisions were made during the 1940s and 1950s that served WSDOT well. These programs can be used to aid the development of the next group of WSDOT pavement decision makers. It is recommended that a structure similar to the SPTC be set up within WSDOT. The targeted WSDOT personnel will serve on technical advisory committees or study groups (similar to the SPTC structure) and be active participants in specific subprograms. Furthermore, a Technology Forum will be created for all active participants. Frequent communication via the Internet should be considered rather than infrequent face-to-face meetings. A Web site similar to (or incorporated in) the new SPTC Web site <<http://pavements.ce.washington.edu/sptc/>> will also aid communication.

A number of options are available to achieve the proposed pavement research framework. The following considerations are listed:

- Maximize the use and/or participation of WSDOT personnel in the conduct of specific research studies within each of the subprograms.
- Maximize collaboration with other highway agencies and the FHWA. Specific emphasis will continue to be placed on collaboration with the state departments of transportation (DOTs) in the SPTC.

- Use international technology to the extent possible. The potential for this was well illustrated by the South African/U.S. Pavement Technology Workshop.
- Seek support, as appropriate, from the National Science Foundation, industry (such as the National Asphalt Paving Association and American Concrete Paving Association), US Department of Transportation (USDOT) Centers such as TransNow, and the Washington State Technology Center (WTC).
- Funded studies via the WSDOT State Planning and Research (SPR) program (or other internal WSDOT funding) should, to the extent possible, assist in the training of better-informed employees—both for WSDOT and contractors.

An overall picture of the estimated funding levels, funding mechanisms, and implementation benefits and venues is shown (Table 16). Each subprogram is shown with respect to funding level (Low < \$100K, Medium = \$100K-250K), and High > \$350K). The total of all the subprograms is \$6.5 million. The funding mechanisms are possible ways the subprograms can be supported. Shown are SPR funding (only), a combination of SPR and WSDOT in-house effort, Pooled Fund (multi-state effort), and WSDOT in-house (only). The total WSDOT budget needed to accomplish the six-year program is estimated to be about \$3.3 million.

Subprogram implementation potential and venues are also shown (Table 16). All of the highest priority subprograms are considered to have a “high” potential for implementation. The implementation venues fall into five basic categories (or combinations of the five). These are

- Training
- Procedures

- Specifications
- Policies
- Contracts

These venues represent the ultimate location for implementation, though numerous steps are likely required to get there.

CHAPTER 1

INTRODUCTION

PAVEMENT RESEARCH IN PERSPECTIVE

The direct costs associated with building, rehabilitating, and maintaining the nation's pavements are huge—about \$110,000,000,000 for 1999 (although this is only 10 percent of the cost to the American public for auto ownership and operation). The added effects of rough pavements on user costs, traffic congestion due to construction activities, and highway-related environmental impacts result in truly impressive numbers. Naturally, there are significant benefits because these highway pavements are generally well maintained and available to users.

Pavement technology has undergone a continuous process of research, development, and implementation over a period that dates back to Telford and Macadam in the early 1800s. More recently, pavement-related research in the U.S. has accelerated with the advent of the Strategic Highway Research Program (SHRP), starting in 1987, and increased National Cooperative Highway Research Program (NCHRP) funding in 1992 via the Intermodal Surface Transportation Equity Act (ISTEA) federal legislation. During the last decade, a number of major research efforts and developments have occurred in the U.S., as follows:

- SHRP related activities
 - Long-term Pavement Performance
 - Superpave asphalt concrete mix design system
- Use of new wearing courses such as Stone Mastic Asphalt (SMA) based on European pavement technology
- Accelerated pavement testing (not an inclusive list)
 - Cal/APT (a key component is the Heavy Vehicle Simulator (HVS), which is a South African developed system)

- U.S. Corps of Engineers Waterways Experiment Station (airfield pavement-HVS, partially based on South African pavement technology)
 - U.S. Corps of Engineers Cold Regions Research and Engineering Laboratory (HVS)
 - Mn/Road
 - WesTrack
 - Federal Highway Administration (FHWA) Turner-Fairbank (the key component is the Accelerated Loading Facility (ALF), which is an Australian developed system)
- Acquisition and assessment of international pavement technology
 - New directed federal research funding for portland cement concrete pavements (PCCP) through the Innovative Pavement Research Foundation (IPRF).

In addition to these major state and national efforts, several studies have been completed or are under way in the State of Washington. Some of these include the following:

- A complete, documented Washington State Department of Transportation (WSDOT) process for new and rehabilitated pavement structural design (included in the WSDOT Pavement Guide).
- Development of the WSDOT Pavement Guide and, subsequently, the CD version that resulted in improved pavement technology sharing.
- A full suite of pavement analysis software ranging from elastic layer to finite element analyses that resulted in improved pavement analyses and utilization of nondestructive testing.
- Improvements to the WSDOT Pavement Management System (Kay et al, 1993).
- An examination of the best and worst performing pavements on the state route system that resulted in greater research emphasis on construction-related factors (Baker et al, 2000).
- A review of studded tire effects that aided the passage of legislation to reduce their impact on state highways (Angerinos et al, 1999).
- A review of various truck tire-axle configurations on the WSDOT route system that resulted in an improved understanding of regulatory priorities (Koehne et al, 1994).
- Increased research on how construction-related factors influence pavement performance, such as

- Effect of differential temperatures on the compaction of asphalt concrete hot-mix.
 - An examination of the WSDOT Quality Assurance/Quality Control specification for asphalt concrete (Mahoney and Backus, 2000).
 - Innovative traffic control techniques to enhance construction productivity and reduce traffic congestion.
- Completion of a WSDOT strategic plan for pavements (WSDOT, 1999).

The studies done within the state have been a combination of formal studies and staff investigations.

A review of the above illustrates that substantial work has been done or is under way, but fundamental issues remain for agencies such as WSDOT and include the following:

- Directed federal funding in TEA-21 will put substantially more emphasis on rigid pavement research via the IPRF. How will WSDOT deal with all the current and future information that will be generated from such studies?
- Development of the American Association of State Highway and Transportation Officials (AASHTO) 2002 Pavement Guide via National Cooperative Highway Research Program 1-37A is under way. What impacts will that have on state department of transportation (DOT) pavement practices and WSDOT, specifically?
- WSDOT is a partner in the State Pavement Technology Consortium (SPTC) along with the state DOTs of California, Minnesota, and Texas. How will WSDOT interact with this consortium to best enhance the knowledge gained and implement results. [A summary report on the first-year effort of the SPTC is contained in a report by Mahoney, Pietz, and Anderson, 2000.]

- What role will information from international organizations play in WSDOT practices, and how is it best developed and implemented (for example the World Road Association and the International Road Federation)?
- WSDOT is about to have at least one design-build project under way. How will this type of project affect pavement practices in the State of Washington?

The above discussion illustrates the need to thoroughly assess the opportunities presented, and to prioritize and focus WSDOT research and technology efforts on those areas of greatest need and potential benefit.

WSDOT is considered a national leader on pavement issues; however, with numerous research activities recently completed, under way, or about to start in the state, nation, and internationally, there exists a clear need to develop a pavement research framework. The framework will identify the needed resources/processes for assessing pavement technology developed by others, prioritize development and implementation efforts, and, finally, identify the types of studies that should specifically be sponsored or conducted by WSDOT. Additionally, use of new technology allows for major innovations in implementation and training—two of the most important areas of needed improvement. The product will be a six-year research, development, and implementation framework. Organizations such as the National Asphalt Pavement Association (NAPA) have recognized the need for a research framework for identifying and prioritizing studies funded by both government and industry so that specific focus areas are advanced (NAPA, 2000).

Use of new technology is recognized in the WSDOT strategic plan for pavements (WSDOT, 1999). In the plan it is noted that “WSDOT has and will continue to be

aggressive in selecting and using the best of national, international, and locally developed procedures and practices to design, build, and maintain economical pavements... .” The strategic plan includes three action items that relate directly to this study. These are as follows:

- Action Item 1: “Continue to implement appropriate SHRP related technology as it applies to pavements.”
- Action Item 2: “Utilize other pavement technologies as opportunities arise.”
- Action Item 3: “Produce and maintain the Pavement Guide and related information on CD-ROM format that is accessible and useable by all.”

STUDY GOALS AND OBJECTIVES

The overall goal was to develop a framework that will maximize the use of available and new pavement technology to enhance the performance of the WSDOT route system. The framework includes an examination of the processes for disseminating and implementing such information. The framework can be used to identify pavement-related issues and technologies that show the greatest potential. Included in the framework is a set of priorities, identification of needed resources, and timing for best addressing these issues and technologies. This framework will enable WSDOT to adopt the best, appropriate pavement technology.

The remainder of the report is organized in four additional chapters:

- Chapter 2. Historical Background
- Chapter 3. Review of Literature and Research Organizations
- Chapter 4. Development of the Framework
- Chapter 5. Conclusions and Recommendations.

CHAPTER 2 HISTORICAL BACKGROUND

This chapter will start with a short overview on the evolution of WSDOT pavements. This will include past to current design practices and relevant pavement research. The information will be useful in examining future pavement needs and specifically pavement research.

Today, the WSDOT route system has about 17,900 lane-miles of pavement (WSDOT, 1999). This includes asphalt concrete surfaced pavement (10,776 lane-miles (60 percent)), bituminous surface treatment (4,843 lane-miles (27 percent)), and portland cement concrete (2,262 lane-miles (13 percent)).

HISTORICAL VIEW OF WSDOT PAVEMENTS

Flexible Pavement Design

As of 1948, the Washington State Department of Highways used a flexible pavement design procedure that related the California Bearing Ratio (CBR) to "thickness" with two levels of traffic.

Because of problems with some clean sands and clayey gravels along the Washington coast, the agency switched from using CBR to R-value (LeClerc, 1956a). A revised design procedure was issued in March 1951. LeClerc noted that the new design procedure was based on the work of Hveem and Carmany (1948) of the then California Division of Highways (typically referred to as the "Hveem" method); however, a few modifications were incorporated that resulted in more conservative designs (resulting in a better match with actual pavement performance). The R-value test as it evolved in Washington State is conducted a bit differently than in California.

The LeClerc report of October 1956 (LeClerc, 1956b) laid out the rationale for converting mixed truck repetitions to 5,000-lb equivalent wheel loads (EWLs) to Traffic Index (TI). The TI was used by WSDOT for about 35 years (1956 to 1991). During the early 1990s, traffic characterization for pavement design was switched to equivalent single axle loads (ESALs) to accommodate the use of the AASHTO design process.

WSDOT used the “Hveem” derived flexible pavement design procedure until the adoption of the AASHTO Guide for Design of Pavement Structures (initially the 1986 version followed by the 1993 version). This change occurred during the early 1990s.

Rigid Pavement Design

The earliest reference to the WSDOT approach for the design of rigid pavements is contained in a report prepared at the WSDOT Materials Laboratory about 1953. It was noted at that time that PCC pavement would be considered only when the 10-year design traffic exceeded 3,000,000 EWLs (or a $TI \approx 6.5$ or $ESALs \approx 475,000$). Thus, PCC was considered for ESALs per year levels of about 50,000 (compare this to contemporary ESALs per year of greater than 2,000,000 on I-5 in the Tacoma area—a factor of 40 higher).

The 1953 information also noted that PCC slabs must be supported by at least 100 mm (4.0 in.) of "clean crushed material" to prevent pumping and to provide a "uniform, stable foundation under the full width of the slab."

A 1958 Materials Laboratory report prepared by LeClerc (1958) again noted that about 100 mm (4.0 in.) of clean granular material is required under PCC slabs to provide a "stable base and prevent pumping." To ensure that this in fact occurs, LeClerc noted that a 150-mm (6.0-in.) minimum base depth was considered the “practical minimum

requirement.” He further noted that the minimum rigid section was 345 mm (1.15 ft) in depth as follows:

- 195 mm (7.8 in.) PCC slab
- 150 mm (6.0 in.) clean granular base

For "large volume roadways" in wetter climate areas the minimum PCC section was to be

- 225 mm (9.0 in.) PCC slab
- 150 mm (6.0 in.) clean granular base

These slab thicknesses and associated base materials were, in effect, a standard design for WSDOT for almost 20 years. Importantly, many of these pavements so designed are still in service today. LeClerc further noted that base course depths of greater than 150 mm (6.0 in.) might be required on the basis of R-value of the subgrade/embankment (the assessment apparently based on previous pavement performance).

Since the 1986 (and eventually the 1993) AASHTO Guide for Design of Pavement Structures became available, WSDOT Materials Laboratory personnel have used this procedure for rigid pavement design.

WSDOT contraction joint practice has evolved over time. For example, SR11 south of Bellingham (for those portions not overlaid) has joints roughly every 9.0 m (30 ft.). This pavement was constructed in 1921 with a portion of the original slabs still in service. PCC placed on SR 2 near Spokane ("Sunset Highway") in 1919 had contraction joints that were generally less than 6 m (20 ft.) apart. In general, WSDOT joint design can be summarized as follows:

- 1940s-1950s: Straight (non-skewed) joints spaced 4.6 m (15 ft.) apart.

- 1966: Random spacing was adopted, which ranged from 4.3 to 5.6 m (14 to 18 ft.)
- 1967-1992: Random spacing was reduced to a range of 2.7 to 4.3 m (9 to 14 ft.) for an average of 3.5 m (11 ft.). The actual spacing pattern is 2.7, 3.0, 4.3, and 4.0 m (9, 10, 14, and 13 ft.).
- 1992: A mixture of undoweled joints with the spacing of the 1967-1992 time period and doweled joints generally spaced 4.6 m (15 ft.) apart.
- Current: Mostly doweled joints spaced at 4.6 m (15 ft.); however, WSDOT does allow undoweled PCCP for low ESAL applications.

Asphalt Concrete Mix Design

WSDOT currently uses both the Hveem and Superpave asphalt concrete mixture design procedures. The Hveem mix design system was largely adopted from the California Division of Highways during the 1950s. That mix system was used until the Superpave (SUPERior PERforming Asphalt PAVements) system was developed during the Strategic Highway Research Program. The Superpave system primarily addresses three pavement distress types: permanent deformation or rutting, low temperature cracking, and fatigue cracking. The system consists of two interrelated elements: asphalt binder selection and specification, and the volumetric mix design and analysis system. The Superpave binder specification is a performance-based specification. It classifies binders into performance grades (PG) on the basis of a range of climates and pavement temperatures. The first number indicates the high-temperature grade; the second number indicates the low-temperature grade. For example, a binder classified PG 58-22 would meet the required physical properties at pavement temperatures as high as 58°C and as low as -22°C. The mix designer selects a Superpave binder on the basis of the climate in which the pavement will serve and the traffic it will bear.

The Superpave system is not fully developed. National research currently under way should produce a fully functional system by 2005.

WSDOT primarily uses three grades of PG binders with some adjustments made for traffic. These three grades are

- Western Washington PG 58-22
- Northeastern Washington PG 58-34
- Southeastern Washington PG 64-28

The physical properties required for the binders are the same for all grades, but the temperature at which those properties are attained is determined by the specific climatic conditions at the paving location.

The Superpave mix design system is based on volumetric proportioning of the asphalt cement and aggregate materials. These materials are laboratory compacted with the Superpave gyratory compactor. The gyratory compactor kneads the mixture to fabricate test specimens. The level or amount of compaction is dependent on the environmental conditions and traffic levels expected at the job site.

Specimens fabricated with the gyratory compactor are used to determine the volumetric properties (air voids, voids in the mineral aggregate, and voids filled with asphalt) of Superpave mixes. These properties, measured in the laboratory, indicate how well the mixture will perform in the field. The gyratory compactor is also suited for quality control/quality assurance at the job site to verify that the delivered asphalt mix meets the volumetric specifications.

The Superpave mix design system also includes specifications and procedures for an aggregate quality test, aggregate angularity, as well as gradation requirements to ensure that the mixture has a high degree of internal friction and thus high shear strength.

The design goal is for a strong aggregate skeleton that will resist rutting yet include enough asphalt binder and voids to allow for adequate mix durability.

An eventual goal of the Superpave system is to allow prediction of mix field performance. The nationally funded research associated with development of the required tests and models to allow for such predictions is under way.

WSDOT purchased its initial Superpave test equipment in 1993.

HISTORICAL VIEW OF WSDOT PAVEMENT RESEARCH

Most of the pavement research performed by WSDOT up to the 1960s was performed in-house—largely at the Materials Laboratory. Use was often made of research done elsewhere (such as the California Division of Highways and the WASHTO and AASHO Road Tests). During 1960s, stabilized base testing was jointly conducted at both Washington State University (WSU) and the University of Washington (UW). A circular test track was used in the work at WSU (the G.A. Riedesel Pavement Test Facility). Eventually, the test track was used to conduct a number of experiments relating to studded tire effects during the 1970s into the early 1980s. A significant in-house report by Peters et al (1986) showed that hot mix recycling in Washington State was cost effective. This led to sensible decisions allowing recycled AC in paving projects on a regular basis.

Subsequently, numerous studies were performed in Washington State via combinations of State Planning and Research (SPR), the FHWA, U.S. Forest Service funds, or unfunded/informal efforts. Several topic areas have been identified and will be briefly overviewed. This overview provides a historical perspective on past WSDOT

pavement research, and, as such, is of value in the development of this framework. These topic areas include the following:

- Sulfur-Extend Asphalt
- Mechanistic-Empirical Design and Analysis
- Pavement-Related Frost Effects
- Granular Overlays
- Information Systems
- Vehicle/Pavement Interaction
- Pavement Rehabilitation
- Pavement Construction
- Superpave
- Long Term Pavement Performance

Sulfur-Extend Asphalt

During the early 1980s, research funded by WSDOT along with the Federal Highway Administration (FHWA) investigated the efficacy of sulfur-extended asphalt binders. WSU, UW, and WSDOT jointly did the work. The use of sulfur to extend asphalt cement largely came about because of rapidly increasing crude oil prices and substantial stockpiles of elemental sulfur that had been removed from sour natural gas production (mostly in Alberta). The final WSDOT study report (Mahoney et al, 1982) showed that the economics of using sulfur-extended asphalt in Washington State were poor, given the then-prevailing sulfur prices and sources. Furthermore, working with molten sulfur added safety issues for the paving process. However, the overall research program did show that sulfur-extended asphalt performed adequately in comparison to traditional, dense-graded hot mix (WSDOT Class B). The research program included the use of highway test sections (SR 270 near Pullman), the G.A. Riedesel Pavement Test Facility at WSU, and laboratory tests at UW and WSDOT.

Mechanistic-Empirical Design and Analysis

During the early 1980s, WSDOT started what became a research program on the development and use of mechanistic-empirical pavement design that focused on rehabilitation (specifically AC overlays). Then, as now, most of WSDOT's paving is resurfacing or rehabilitating pavements with AC overlays. Early work by Newcomb et al (1983) started the development process. Eventually, the overall effort, along with funding from the Long Term Monitoring (LTM) study, resulted in the following:

- The acquisition of the Falling Weight Deflectometer (FWD) in 1983 by WSDOT.
- Acquisition of laboratory triaxial equipment by WSDOT for testing asphalt concrete cores and unstabilized samples (bases, subbases, and subgrade soils).
- The development of the Everseries software
 - Evercalc: Backcalculation of layer elastic moduli by use of FWD deflection data.
 - Everstress: General purpose layer elastic analysis software.
 - Everpave: Elastic analysis software for designing the thickness of AC overlays.
- The development of seasonal factors to adjust layer moduli and transfer functions (failure criteria) required for thickness design (fatigue cracking and rutting).

Eventually, three doctoral dissertations were produced from that specific research effort, along with several Masters theses. Project reports documented the development process, concluding with the summary report by Mahoney et al, 1989. Both formal and informal training was provided to WSDOT Regional Material Engineers and their staff during the study and following its completion.

Starting in the mid-1990s, a new PCCP analysis tool was developed partially in response to the dowel bar retrofit program. The resulting computer code was user-friendly, 3-D finite element software called EverFE (Davids et al, 1998). This analysis tool allows for consideration of transverse joint aggregate interlock, dowel bars, various

base types, joint configurations, number of wheel loads, and temperature gradients. The study also examined the issue of dowel looseness and its affect on joint load transfer (low load transfer contributes to joint faulting). Dowel looseness is becoming a major national issue because of the early age effects associated with PCC paving, as was recently reported by Sargand (2000). This is directly relevant to SPTC discussions concerning rapid freeway reconstruction. Furthermore, WSDOT is currently supporting enhancements to EverFE and development of the EverFlex software.

Pavement-Related Frost Effects

Also starting in the early 1980s, WSDOT commenced a study on pavement related frost effects (Lary et al, 1984). The findings from the initial study concluded that a primary reason for spring load restrictions (mostly on lower volume WSDOT roads) was the weakened condition caused by excessive moisture in the granular base course. Until that study, the prevailing view both locally and nationally was that the weakening was primarily occurring in the subgrade soils. This study then led to another funded by the FHWA that developed guidelines on when and where to place load restrictions on thaw weakened highways (Mahoney et al, 1986). The concluding work in this topic area was funded by the U.S. Forest Service and provided the opportunity to reassess WSDOT seasonal moduli adjustments to pavement materials (Uhlmeier et al, 1994). That study built upon the lessons learned during the development of mechanistic-empirical rehabilitation design done 10 years earlier. The results confirmed that the seasonal moduli adjustments being used by WSDOT were appropriate. A manifestation of this type of work is the rock cap overlays being used on SR 20 and within the city of Colfax,

Wash.; however, the basic concept for rock cap overlays is credited to the Idaho Department of Transportation.

Granular Overlays

During the early 1990s, WSDOT granular overlays (“cushion courses”) received attention. This type of overlay had been in use by WSDOT for about 30 years, but no systematic examination of its performance had been made. The FHWA, through WSDOT, funded a study that examined granular overlays with the focus on WSDOT pavements in Eastern Washington. The final report was distributed nationally (O’Neil et al, 1992). The conclusions of the study were that the use of granular overlays was sound, modifications to material selection were recommended, and limitations on layer thicknesses were suggested. The most recent examination of granular overlays was conducted within WSDOT, with the results reported via a TRB paper submitted for presentation and publication at the 2001 Annual Meeting (Uhlmeier et al, 2000). The recent findings add new information about granular overlay performance, and recommendations are made for inputs to the mechanistic-empirical rehabilitation design process.

Information Systems

During the 1980s and early 1990s, at least four studies were performed within WSDOT and at UW that enhanced the management of WSDOT pavements. The specific focus was the Washington State Pavement Management System (WSPMS). The first major report was by Nelson et al (1982) that documented the basic structure of the in-house developed PMS. This was followed by reports from Mahoney et al (1988) and Kay

et al (1993) that examined pavement performance equations, improved the calculation of condition scores, and added a rehabilitation “scoping” tool. Additional WSPMS enhancements were reported by Mahoney and Seferian (1995). Funding for these WSPMS studies was a mix of WSDOT SPR and FHWA funds. The WSPMS is the most important WSDOT tool for managing the pavement preservation program. Therefore, WSDOT staff at the FOSSC Materials Laboratory continually improve the system both for effectiveness and ease of use by the Regions and the quality of roadway performance data. The referenced studies aided the Material Laboratory’s continuous improvement process.

During the early 1990s, the first version of the WSDOT Pavement Guide was released (WSDOT, 1993). The purpose of the Guide was to provide a clear statement on pavement design policy (adoption of the AASHTO design process for the design of new and reconstructed flexible and rigid pavements), detailed information that relates to design (such as typical inputs), and other relevant information. Given the size of the WSDOT Guide (hundreds of pages of text), it was transferred to a compact disc (CD) format during 1997. The CD version included updated text, photographs, and interactive equations for using the AASHTO Guide design equations. The most recent version of the WSDOT Guide (WSDOT, 2000a) was issued during 2000 and includes extensive improvements to Volume 3 (Pavement Analysis Computer Software and Case Studies). The Everseries software is now available on the WSDOT Electronic Pavement Guide and the WSDOT Web Site (<http://www.wsdot.wa.gov/fossc/mats/>).

Vehicle/Pavement Interaction

During the early to mid-1990s, pavement/vehicle interaction effects were studied. This resulted in a collaborative effort between WSDOT, PACCAR, UW, and the University of California at Berkeley. The primary study report (Mahoney et al, 1995) showed the following:

- Faster traveling trucks can significantly reduce the measured strains in the pavement structure. This verified the kinds of rutting often observed at intersections and truck climbing lanes. Implementation for WSDOT is to not slow trucks unnecessarily. That may seem obvious, but a common practice had been to add low speed limits to spring load-restricted highways.
- The effect of high tire pressures on AC surfaced pavements results in significantly higher strains in the AC. This finding was used, in part, by Weyerhaeuser to justify the use of Central Tire Inflation systems on their log hauling trucks. Furthermore, the concept of using substantially reduced tire pressures (and low speeds) gained use both in the U.S. and Canadian forestry industries (however, these practices gained substantial momentum via work by the U.S. Forest Service).
- The concept of spatial repeatability was confirmed (i.e., different truck configurations and suspension systems apply their peak dynamic loads at the same location following a roughness event).
- The steer axle on tractors resulted in the highest applied strains.
- Stiffer truck suspensions (such as walking beam suspensions) caused the highest pavement strains; however, the results did not support any type of regulatory changes on suspension systems.

- Rougher pavements caused truck axles to apply higher dynamic loads. This finding was expected; the recommendation to WSDOT is that smooth roads do matter—not only in minimizing dynamic truckloads but also in reducing accelerations in the trucks.
- Improvements in backcalculation of layer moduli were developed on the basis of the PACCAR field results (treatment of saturated layers). This finding has had a significant impact on AC overlay design (an earlier research focus area).

One of the earliest funded works in this topic area was an examination of state legislation on tire sizes, configurations, and load limits (Sharma et al, 1983). That work showed that axles with single tires (as compared to dual-tire configurations) will do more pavement damage. The then-current pound per inch of tire width regulations used by WSDOT were also assessed. This eventually led to a change in the regulation that, in effect, discourages widespread use of single tires in Washington State. This work also resulted in the introduction of WSDOT, UW, and PACCAR personnel. This led to the vehicle/pavement interaction study described above. Additional truck studies included an examination of lift axle regulations (Koehne et al, 1994) and examination of truck traffic (Hallenbeck et al, 1993) based on weigh-in-motion sites in Washington State.

Pavement Rehabilitation

Several studies fit into this category, including some previously noted in other topic areas. The work summarized on mechanistic-empirical design was largely devoted to pavement rehabilitation design. Urban PCCP rehabilitation was the thrust of work reported during the early 1990s (Mahoney et al, 1991). WSDOT, UW, and the University of Illinois jointly conducted the effort. In that study, various rehabilitation options were

examined for the urban freeways in both the Seattle and Spokane areas. Options came down to overlaying the PCCP with AC or reconstruction with AC or PCC. Dowel bar retrofits (DBR) were discussed. Performance of AC overlays in both Washington State and California (including cracking and seating of PCCP slabs) was summarized. Importantly, the report was used to formally introduce life cycle costing analysis (LCCA) to WSDOT and was eventually adopted as official policy. Additionally, given the performance of preexisting WSDOT PCCP, it was concluded that structural designs of 40 years could be attained (in lieu of the 20-year design lives used before). Eventually, this was also reflected in WSDOT pavement policy.

Pavement Construction

Starting in the early 1990s, studies that examined some of the construction aspects of pavements began. This started via unfunded work performed by Markey et al (1994) and Masters theses by Phillips (1995) and Cadicamo (1999). A related study by Mahoney (1994) was used to provide background information on statistical methods. The intent was to aid the understanding of the statistical basis for the Quality Assurance specification and statistical aspects related to the WSPMS. Markey et al (1994) concluded, on the basis of a limited number of early QA AC specification projects, that the overall quality was a bit better with the QA specification than with the previously used non-QA specification. However, caution was noted because the QA process was relatively new, with only limited information. Subsequently, various concerns arose about the QA specification. This resulted in an SPR study that is currently being conducted for WSDOT.

A significant effort has been under way since the 1998 paving season to examine the effect that differential temperatures play in the resulting density variation of compacted AC mats. The early study results were summarized in a TRB paper by Mahoney et al (1999). The study's final report will be released during January 2001.

Superpave

This activity in Washington State has been the focus of a significant in-house effort by WSDOT for about seven years. Much of the documentation is in terms of internal memos, manuals, and Microsoft Excel spreadsheets. A recently completed SPR funded report on Superpave prepared by Leahy (1999) examined AC mix performance for 60 projects. Only one-half of the projects (30) were full Superpave with most of these constructed during the 1998 and 1999 paving seasons. The earliest WSDOT Superpave projects date back to 1994. Most of those early projects incorporated PG binders but not necessarily full Superpave mix criteria. It is too early to assess the impact of the Superpave mix system. As the paved projects age, the performance of these mixes will become clear. Such information will be significantly aided by the in-house documentation of these projects.

The WSDOT Research Office and the Asphalt Paving Association of Washington (APAW) participated in the purchase of Superpave mix and binder equipment for Washington State University. At least one training course using that equipment was completed during early 2000.

There has been only one funded study on Superpave by WSDOT—though WSDOT has expended considerable effort in-house. The vast majority of the Superpave developments have been done nationally—and that continues today. Nationally, 550

million tons of hot mix were placed during 1999 (Acott et al, 2000)—so Superpave will affect one of the larger expenditures for pavements. As noted in the Acott article, “it is clear that the entire system [Superpave], and all of its accompanying mix, binder, and aggregate specifications, will need to be continuously evaluated, enhanced, and perhaps even discarded, as appropriate.” Acott also noted that

- Superpave has the potential to reduce local specifications, thus making bidding across state boundaries easier for contractors.
- It is anticipated that future Superpave developments will incorporate open graded friction courses and stone matrix asphalt (SMA) mixtures.
- The current major limitation of Superpave is a lack of a physical test that differentiates mix quality—commonly referred to as a “simple performance test.” Work is under way at Arizona State University to develop this type of test via NCHRP 9-19.

Long-Term Pavement Performance

WSDOT’s formal involvement with long-term pavement performance dates back to at least the early 1980s. The agency participated in the Long-Term Pavement Monitoring (LTM) that was part of the Highway Cost Allocation Study mandated by the Surface Transportation Act of 1978 (Lary, 1983). “The LTM Program was developed to assess the need for long term or continuous monitoring of roadway deterioration to determine the relative damage attributable to traffic and environmental factors.” Five states, one of which was Washington, were chosen to participate in the program.

The LTM activity evolved into the Long-Term Pavement Performance (LTPP) program. This program was recommended in a 1984 TRB report entitled “America’s Highways: Accelerating the Search for Innovation.” More specific plans for LTPP were subsequently published for the NCHRP in May 1986 (TRB, 1986). In that report it was noted that “[LTPP] seeks to gain knowledge of the specific effects on pavement

performance of various design features, traffic and environment, use of various materials, construction quality, and maintenance practices.” The LTPP program contains two primary experiments: General Pavement Studies (GPS) and Specific Pavement Studies (SPS). The May 1986 TRB report noted that accelerated pavement testing (APT) was a potential part of the overall experimental plan, but this was not implemented to any significant degree.

WSDOT has both types of LTPP test sections under study. Currently, there are 19 GPS sections and four SPS in Washington. In addition, 13 PCCP sections were built for SPS on U.S. 395 near Ritzville during September 1995. The primary WSDOT responsibilities for all LTPP sections in Washington State are coordination, traffic control, friction testing, and weigh-in-motion (WIM) measurements. The responsibility is shared between the coordinator located at the WSDOT Materials Laboratory and the Data Office (WIM data). To date, all LTPP data have been analyzed on a national basis. A recent document by the FHWA (2000) overviews the findings to date.

Historical Bottom Line

By examining the evolution of WSDOT pavement structures and related research, the following trends are noted:

- Most pavement related research was done in-house until the late 1970s/early 1980s.
- WSDOT has a long history (documented through the 1950s) of sensibly assessing its pavement practices. These assessments often made use of pavement research done elsewhere (such as California, various national road tests). WSDOT has a history of well-done design practices. This continues today.

- Much of the pavement related research performed during the last 20 years can be grouped into 10 broad topic areas. The duration of investigation within topic areas varies widely but generally spans about a four- to ten-year period. Once WSDOT personnel are knowledgeable about a specific topic, they generally continue with developments in that area—while there is a need for such improvements.
- Three of the more recent research topic areas for WSDOT are mix design (Superpave mostly), construction of pavements, and enhancement of pavement analysis tools.
- Research products include not only study documentation and implementable results but also knowledgeable individuals within WSDOT and its associated universities. These individuals have demonstrated the ability to carry topics forward for complete development, evolution, and use.

The next chapter will provide an examination of the literature and research organizations. This information will aid in the development of the WSDOT pavement research framework.

CHAPTER 3

REVIEW OF LITERATURE AND RESEARCH ORGANIZATIONS

LITERATURE

The review of the literature will focus on the following:

- Relevant definitions
- Overview of research and development funding in the U.S.
- Overview of highway industry research and technology funding
- Examination of future trends (including the pharmaceutical and manufacturing industries).

Definitions

First, two definitions. **Research and technology** (R&T) was defined by the Research and Technology Coordinating Committee (RTCC, 1994) as “activities [that include] basic research, applied research, development, demonstration, technology transfer, and education.” Abramson et al (1997) defined **technology transfer** as “the movement of technological and technology-related organizational know-how among partners in order to enhance at least one partner’s knowledge and expertise and strengthen each partner’s competitive position.” Importantly, Abramson et al went on to note the following:

- “Technology transfer occurs throughout all stages of the innovation process, from initial idea to final product.
- “Technology transfer can take place via informal interactions between individuals; formal consultancies, publications, workshops, personnel exchanges, and joint projects involving groups of experts from different organizations; and the more readily measured activities such as patenting, copyright licensing, and contract research.

- “Technology transfer may be confined to specific regions, or it may span regions or nations within one continent or across several continents.”

Abramson et al also described two forms of technology transfer as direct and indirect. Specifically, they noted

- “Direct technology transfer is linked to specific technologies or ideas and to more visible channels such as contract or cooperative research projects.
- “Indirect technology transfer concerns the exchange of knowledge through such channels as informal meetings, publications, or workshops. In the early stages of the technology life cycle, indirect technology transfer predominates, so that it is often difficult to trace the origins of specific technologies or ideas.”

Research and Development Funding

Figure 1 shows that the R&D funding in several industrialized countries ranges between 1.5 to 2.5 percent of gross domestic product (GDP). To further illustrate how this translates to people and institutions, specific, related statistics for U.S. R&D are as follows (Abramson et al, 1997):

- Employs 963,000 scientists and engineers
- Performed by
 - 41,000 companies
 - 720 federal laboratories
 - 875 colleges and universities
 - 2,300 nonprofit R&D performing organizations.

U.S. R&D development, applied, and basic research can be further broken out among performing sectors. The four groups (federal, industry, universities, and nonprofits) and their relative percentages as of 1995 are shown in Figure 2.

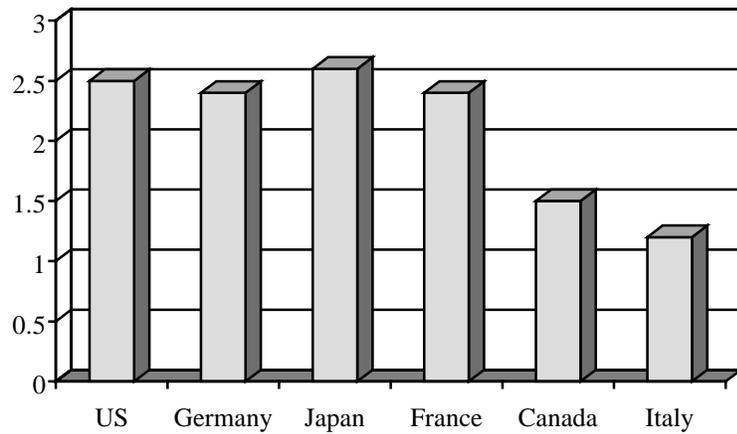


Figure 1. International Research and Development as a Percentage of GDP (after Abramson et al, 1997)

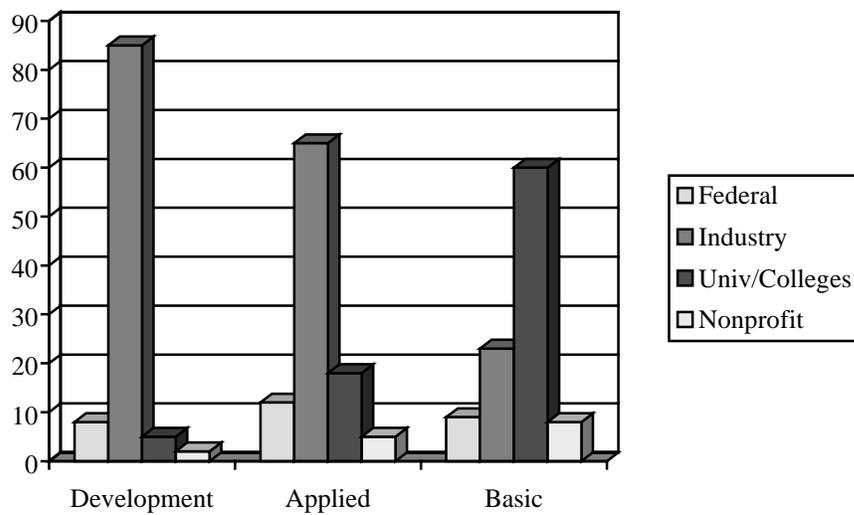


Figure 2. U.S. R&D Performing Sectors—Percentage of Total (after Abramson et al, 1997)

Thus, in the U.S., industry does most of the development and applied research, while the universities do the majority of the basic research. The federal laboratories and

nonprofits have substantially smaller roles. What is the picture for the U.S. highway industry?

Highway-Oriented R&T Programs

Who are the players with respect to transportation research and technology funding (which includes the highway sector)? There are at least four categories:

- State Planning and Research (funding based on 2 percent of the federally collected highway construction funds and passed back to each state DOT)
- Federal Highway Administration
- National Cooperative Highway Research Program
- Private sector research.

Each of these will be briefly discussed.

State Planning and Research (SPR) funding will amount to \$120 million in FY 2000 and is the minimum state DOTs must spend on research, development, and technology transfer. SPR funding is based on 2 percent of total federal apportionment, with the requirement that at least 25 percent be used for research, development, and technology transfer (RTCC, 1999). More locally, WSDOT will spend \$2.2 million this year (or about 0.13 percent of the annual WSDOT budget (1999-2000 biennium)). With SPR funds, each state must decide what kinds of research studies will be done. Typically, study budgets are about \$100,000.

For historical perspective, the total WSDOT research budget in 1958 was \$341,322 (from HRB, 1960). Adjusted for inflation, this amounts to about \$2.1 million in FY 2000—approximately the same amount WSDOT actually spent. However, highway research funding in 1958 amounted to 0.26 percent of total state highway expenditures—approximately twice today's rate.

The Federal Highway Administration (FHWA) had a budget of \$329 million for research and technology programs for FY 1999. The categories for these funds include

- Surface Transportation Research
- Technology Deployment
- Training and Education
- Intelligent Transportation Systems
- ITS Deployment
- University Transportation Research

For pavement research, the FHWA has a total budget of \$20.4 million, and of that, \$8.8 million (or 43 percent of the total) will be spent on LTPP.

The National Cooperative Highway Research Program (NCHRP) is funded by an allocation of 5.5 percent of state SPR funds to perform national highway-oriented studies. Participation by the states is voluntary, and those funds amount to \$21.5 million for FY 2000. The studies are selected for funding by the AASHTO Standing Committee on Research (SCOR). Typically, studies are funded at levels ranging from \$100,000 to \$500,000. More recently NCHRP funds are being used to support LTPP and the development of the AASHTO 2002 pavement guide—both of which have large budgets. For FY 2000, about 77 percent of the total NCHRP budget is allocated to pavement-oriented studies; however, this high allocation for pavements via NCHRP is a recent and likely temporary phenomenon. Since 1965, the NCHRP program has spent \$175 million for research on a wide range of topics (RTCC, 1999). During 33 years (1965-1998), approximately 29 percent of the funds were allocated for pavements and the related topics of materials and construction.

It is estimated that the private sector annually spends about \$100 million on highway-oriented research. The following breakout is an estimate of how that funding is spent:

- Aggregate-related: 0.7%
- Asphalt-related: 2.0%
- Steel-related: 3.0%
- Highway and traffic safety: 9.2%
- Concrete-related: 10.0%
- Construction equipment: 75.0%

Addition of current R&T funding via the SPR, FHWA, NCHRP, and Industry programs totals about \$570 million, or approximately 0.5 percent of annual total highway sector spending. This can be contrasted to Microsoft, which spent \$3.8 billion on R&D during 2000 (16.4 percent of total revenue).

Current highway research spending can be compared to that of about 40 years ago (i.e., 1958). Total state and federal highway research funding in 1958 was estimated to be \$17.8 million (HRB, 1960). This amounted to about 0.2 percent of all the nation's highway expenditures. If private sector research is removed from the current funding, the total state and federal research funding (\$470 million) amounts to about 0.4 percent of total highway expenditures—about twice the rate for 1958.

The total, current research and technology expenditures (as a percentage of total expenditures) for highways amounts to about 0.5 percent, as noted above. This can be compared to other sectors in the U.S. such as (after Abramson et al, 1997):

- Fabricated metal products: 2.0%
- Other manufacturing 7.5%
- Pharmaceuticals: 8.0%
- Industrial chemicals 8.0%
- Motor vehicles: 10.0%
- Aerospace 14.0%

The total percentage of gross domestic product spent by the U.S. on research and development was estimated to be 2.5 percent in 1994, with about 40 percent contributed by the public sector and 60 percent by the private sector.

The RTCC (1994) noted the following:

- The highway industry is large.

[The highway system in the U.S. has 6.3 million centerline kilometers (3.9 million miles).]

- The economic impact of the industry is great.

[Total highway expenditures, including motor vehicle ownership and operation, highway freight, highway construction and maintenance, etc., amount to 12 percent of the U.S. gross domestic product.]

- Administration of the highway system is decentralized.

[Approximately 39,000 public agencies own and maintain portions of the highway system.]

- Dispersed private companies provide essential products and services.

[Thousands of private sector companies provide products and services to highway agencies, which illustrates the low level of vertical and horizontal integration within the construction industry. Based on 1991 data, only 12 percent of highway construction contractors performed work outside their home states.]

- The highway industry provides few incentives for innovation.

[“Highway agencies operate as virtual monopolies and face no regular market pressures to improve service and reduce cost. The cost pressures that they face in times of budgetary crisis favor immediate cost reduction over strategies that will lower the long-term, life cycle costs of highways. Private highway contractors and suppliers have little incentive to innovate because their products and services are procured through a low-bid competitive process that is based on prescriptive

specifications that sometimes have little to do with real performance or life cycle cost and frequently preclude new products and methods.”]

- The highway industry has a low-tech image.

[“The fact that highway construction employs common materials, some of which have been used for centuries, fosters the impression that the performance of these materials is well understood and that there is little room for further innovation. In truth, the composition of many basic construction materials is complex and critical gaps in knowledge about them hamper the ability to construct highways that are more durable and more cost effective.”]

- Highway spending is substantial.

[“Total federal, state, and local disbursements for highways were more than \$85 billion in 1992” (more recently about \$110 billion).]

- The highway industry is now redefining its mission.

[“For 35 years, construction of the Interstate system was the centerpiece of the U.S. highway program, but now that the system is virtually complete, the highway industry no longer has such a clear, unambiguous goal.”]

In summary, the highway industry in the U.S. is large. It is the biggest single asset in the highway network, which amounts to 6.3 million kilometers. The economic impact is large, amounting to 12 percent of GDP. The administration of the highway system is very decentralized with about 39,000 road-owning agencies in the U.S. The total spending in the highway sector will amount to about \$110 billion during FY 1999. These expenditures exceed the combined incomes of the airline and railroad industries and are about the same as the total for aircraft manufacturing.

The bottom line we can draw from the above information is that, broadly speaking, the industrial sector performs 70 percent of U.S. research and development and employs 90 percent of all scientists and engineers. Thus, funding programs such as SPR in the highway sector are unusual. Further, the major conclusions drawn by the RTCC (1994) are that

- The highway industry provides few incentives for innovation.
- The highway industry has a “low-tech” image.

As to how R&D funds are allocated within the highway community, it is advisable to know typical costs. For large highway projects, the breakout is about 21 percent for wages, 43 percent for materials and supplies, and 36 percent for equipment, overhead, and profit. It is not a surprise that a modest portion of highway research funds is allocated to materials and, more specifically, pavements (this will be examined in more detail for the SPTC states in the last section of this chapter).

Typical R&D expenditures for the highway sector range from between 0.1 to 0.5 percent of total expenditures. These values can be contrasted to other industries and sectors that have R&D values ranging from 2.0 to 15.0 percent—or 4 to 150 times higher.

An examination of “typical” lives is in order. This will be done by contrasting human lives with pavements (an odd comparison, admittedly). For human lives, the following statistics apply (from Blank (1997) and Shermer (1997)):

- Life span (average lifetime if no premature deaths from accidents or disease): 85 to 95 years.
- Life expectancy (average lifetime accounting for accidents and disease):
 - Worldwide: 62 years
 - U.S.
 - 1900: 47 years
 - 1950: 68 years
 - 1998: 75 years

- Maximum for human life: 115-120 years

When we examine pavement lives, we first must understand what constitutes life spans and expectancies. An analogy might be the difference between reconstruction (i.e., bury the dead) and rehabilitation (heal the patient). Thus, the lives of pavements are not as finite in definition as for humans. Further, it is important to sort out “accidents” (such as construction-related problems) and “disease” (such as stripping of asphalt concrete, etc.). The bottom line for pavement-oriented research is to move toward the “maximum” pavement life possible. To achieve this, “construction accidents” must be avoided and “pavement disease” better understood and reduced. These broad goals fit into a pavement research framework.

Future Trends

To develop possible trends, an examination of other areas is appropriate. The two that will be briefly reviewed are the health, pharmaceutical, and manufacturing industries.

The federal contribution to the nation’s healthcare is about \$152 billion for FY 2000 (or 8.4 percent of the total federal budget). Of this, \$13.6 billion is allocated for health related research and training. This amounts to 8.9 percent of the total federal healthcare budget. Hatfield (2000) estimates that about 5 percent of all healthcare spending goes into medical research. For additional perspective, 1958 estimated medical research in the U.S. (\$485 million) amounted to 2.2 percent of the nation’s total healthcare expenditures (HRB, 1960). Thus, the medical research rate has at least doubled over the last 40 years.

The kinds of resources used in the pharmaceutical industry (a \$700 billion international industry) to develop new drugs are staggering. The time from “molecule to

market” is about 15 years and requires about \$200 million per drug (Fried, 1998). A recent conference in Baltimore pegged the typical development cost at more like \$635 million. (Pharmaceutical manufacturers annually spend \$9 billion on R&D and \$10 billion on marketing.) As noted earlier, Abramson et al (1997) estimated that pharmaceutical companies annually spend about 8.07 percent of total expenditures on research and technology.

The future of manufacturing has been examined in a recent NRC (1998) study. A major issue presented in that report dealt with concurrency. This includes future trends such as the following:

- Consumer products, which currently take 6 to 9 months to market, will do so within weeks of conceptualization.
- Composite and synthetic materials will be available immediately upon identification of properties.
- Large products that are combinations of mechanical structures and electronics that now take years to develop will be put into service with months.
- Reduction in time-to-market
 - Market opportunities will arise and disappear quickly
 - Lot sizes (or batch sizes) will be small, as customers demand products and services tailored to meet their individual needs.
 - Rapid changes in available technologies will cause rapid changes in products and reductions in production costs.
 - Competitors from all parts of the world will enter and exit markets rapidly as opportunities emerge and fade.

Given the “trends” illustrated by the pharmaceutical and manufacturing industries, what is the message for the pavement community—if any? These could include the following:

- Get in, get out, and stay out—long lasting and rapidly built pavement.
- Need for high-speed pavement condition data collection and analysis thereof.

- Improved quality assessment of the constructed pavement including major improvements in monitoring pavement construction.
- Smaller quantities of materials targeted for very specific applications such as high friction wearing courses and rapidly constructed and durable repairs. This can include rapid reconstruction of urban intersections.

The list could be longer, but those suffice.

Based in part on the preceding information, what might we expect to see in the future with respect to pavement technology? The list, which follows, is somewhat self-evident.

- Improved analytical techniques
- The combining of measurement and analytical techniques
- New NDT equipment
- Improved practices with a major focus on construction-related factors
- More services and options from the private sector
- Increased use of the Internet
- Consortia
- Improved training

Three of these will be briefly illustrated.

For improved analytical techniques we can expect a continued evolution of pavement-oriented software. However, there are issues to consider, such as

- What do pavement engineers need to know about specific software and when do they need to know it? This relates to training issues as well.
- Software support? Generally not much available.
- Distribution of software. Do not expect Microsoft quality for free. The pavement software market is small and not oriented toward marketing/commercial software opportunities. There is little funding (or income) available for software improvements.

The Internet relates more to how we take effective advantage of that technology. Will this be education and training (definitely), marketing (likely), and/or data services (possibly)? There is ample evidence of the exciting possibilities via the Internet. Statistics

from Gates (1999) on the reduction in banking costs per transaction are shown in Figure 3. Gates illustrated numerous, mostly corporate, examples of Internet-based technologies. Additionally, in further support of growth of Internet applications, the U.S. has approximately 50 percent of the installed computer capacity worldwide (NRC, 1998). Thus, much of the necessary hardware is in place. The NRC report also states that “computer-based training will become the norm.”

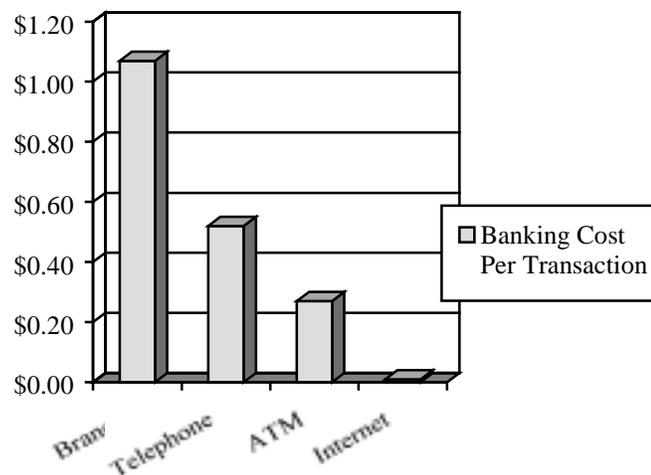


Figure 3. Illustration of Internet Technology Cost Reduction
(after Gates, 1999)

Finally, we turn to consortia. Consortia are simply two or more organizations that fund or perform collaborative R&D. Typically, these can include (after Abramson et al, 1997)

- Shared facilities and costs
- Pooled talent
- Facilitate standards setting
- Market products
- Exchange research results

Major joint ventures in the U.S. have increased over 100 percent during the last ten years.

Why mention consortia? Currently, much of the R&D in this topic area must be classified as a “cottage industry” (small scale, loosely organized). The creation and operation of consortia such as the SPTC with the intent to further pavement technology will likely increase.

Finally, a note on the worldwide information “explosion.” Four hundred years ago, two scientific journals existed; currently, 100,000 journals publish 6,000,000 articles annually (Shermer, 1997). The issue is straightforward: how can we improve synthesization of important technical information?

RESEARCH ORGANIZATIONS

Of the five research organizations with substantial pavement-oriented research programs, the funding allocated to pavement research varies substantially—both by the amount of funding and the percentage that pavement research is of the total agency research budget. This is illustrated in Table 1. Comparing the four state DOTs of California (Caltrans), Minnesota (MnDOT), Texas (TxDOT), and Washington, the following is noted:

- Caltrans currently allocates 24 times more funding (annual basis) for pavement research than WSDOT.
- Caltrans spends approximately twice as much on pavement-oriented research as MnDOT and TxDOT.
- Of these four state DOTs, the percentage of total agency research funding allocated to pavement-oriented research ranges from a low of 11 percent (TxDOT) to a high of 40 percent (Caltrans). WSDOT spends about 14 percent of its total research budget on

pavement-oriented studies. MnDOT allocates 24 percent of its research budget to pavements.

Caltrans believes that its 40 percent allocation to pavement research is reasonable because it estimates that the same percentage (40 percent) is what Caltrans spends on pavements from its total agency budget. The portion of total budget spent on pavements can be explored for WSDOT by examining recent budget data (WSDOT, 2000b). The total WSDOT budget for the current biennium (1999-2001) is about \$3.5 billion. Specific subcategories with high levels of pavement expenditures include Improvements/Preservation (estimated at 50 percent), Highway Maintenance and Operations (50 percent), Highways and Local Programs (75 percent), and Support Services (30 percent). This results in about 36 percent of the total WSDOT budget being spent on pavements. This percentage is in approximate agreement with the Caltrans estimate.

The number of in-house research staff for the five agencies (including the U.S. Corps of Engineers WES Airfields and Pavements Division, which is an ex-officio member of the SPTC) varies widely. WSDOT in-house staff largely manages pavement studies performed by contractors (universities primarily but also consultants). On the other hand, MnDOT has a significant number of in-house staff devoted to pavement research.

The summary of major pavement research focus areas by these five agencies has substantial overlap. There is substantial, mutual interest by the SPTC states in

- Long life pavements
- Improved AC mixes

- Pavement construction issues
 - AC related
 - Reduction of construction time
 - Smoothness
 - PCC related
- Nondestructive testing of pavement structures
- Mechanistic-empirical pavement design.

Table 1. Special Interest Research Organizations

Organization	Annual Research Pavement-Oriented Expenditures	Number of In-House Research Staff	Pavement Focus Areas	Web Addresses
California DOT	\$7,200,000 (\$18,000,000 Total Caltrans research budget) Pavements = 40% of total	60 total	Cal/APT is primary focus -Rehab of Interstate PCC -Improved AC Mixes -Longer Life Pavements -QA/QC	http://www.dot.ca.gov/hq/newtech/ http://www.dot.ca.gov/functionalorgchart/
Minnesota DOT	\$3,000,000 (\$12,700,000 Total Minnesota research budget) Pavements =24 % of total	35 total	Mn/Road Test primary focus -Mech/Empirical Design -Whitetopping -NDT -Spring Load Restrictions -Micro-Surfacing	http://mnroad.dot.state.mn.us/
Texas DOT	\$2,000,000 (\$18,000,000 total TxDOT research budget) Pavements = 11% of total	16 total	-Pavement Smoothness -Cyclic Segregation -Longitudinal AC Joints -Reduction of Construction Time -Longer Life Pavements -NDT	http://manuals.dot.state.tx.us/dynaweb/
Washington State DOT	\$300,000 (\$2,200,000 total WSDOT research budget) Pavements = 14% of total	6 total	-Hot Mix Laydown (Temperature Differentials included) -QC/QA -NDT -Superpave -Pavement Tools (training)	http://wsdot.wa.gov/ppsc/research/rpage.htm
US Army Corps of Engineers Waterways Experiment Station Airfields and Pavements Division		38 FTE + 3 Contractor = 41	Refer to summary on SPTC Web Site and WES Web Site	http://pavements.ce.washington.edu/sptc/wes.html http://pavement.wes.army.mil/

CHAPTER 4 DEVELOPMENT OF THE FRAMEWORK

This chapter will provide the basis for the pavement research framework. First, a summary of a recent pavement research questionnaire posed to three groups within WSDOT will be presented. This will be followed by a short overview of the State Pavement Technology Consortium (SPTC) and an associated questionnaire on state DOT training and implementation issues. The SPTC developed a list of research topic areas during its first year of operation, which is reflected in its current work activities. Additionally, a summary of the WSDOT sponsored Pavement Needs Seminar will be described, followed by a brief discussion of the WSDOT prioritization of South African pavement technology (SPTC representatives from California, Minnesota, Texas, and Washington State attended the South African/U.S. Pavement Technology Workshop during March 2000, and that technology was discussed and prioritized soon afterward).

The information is used to develop and rank a set of pavement research topic areas.

WSDOT PAVEMENT RESEARCH QUESTIONNAIRE

A questionnaire was sent to 18 individuals within WSDOT that have a direct interest in or need for pavement related research. The questionnaire was sent to all Regional Materials Engineers and Regional Construction Trainers. The third group was selected individuals within the FOSSC Materials Laboratory. Additional background about the questionnaire, including the questions and a summary of all responses, is contained in Appendix A.

The responses were summarized into six topic areas for each of the four major questions. These summaries are shown in Table 1 (Question 1), Table 2 (Question 2), Table 3 (Question 3), and Table 4 (Question 4). The six topic areas are

- Structural Design and Analyses
- Pavement Materials Including Hot Mix Design
- Pavement Performance
- Pavement Rehabilitation
- Pavement Construction
- Information Systems and Training.

The number of studies noted by the respondents in the six topic areas are not intended to establish prioritization of current or future studies for WSDOT. The questionnaire represents a somewhat biased sample but is from informed populations of WSDOT personnel; their opinions need to be considered in a research framework.

In Table 2 the three questions had to do with the WSDOT pavement research program. For the first question, “WSDOT pavement studies most aware of,” the most frequent study referred to was in the **Construction** topic area (each of the six topic areas will be noted in **bold**) and, specifically, the hot mix laydown temperature differential work. This is not unexpected since this work is ongoing, with numerous presentations in various venues starting in 1996. Additionally, over 50 paving projects have been visited for data collection during the 1998-2000 paving seasons. The second most noted study area had to do with the Everseries software and was in the **Structural Design and Analyses** topic area. The third most noted studies were the WSDOT Pavement Guide in **Information Systems and Training**, and QA specifications and PCCP intersections in **Construction**. Numerous other studies were noted in all topic areas. Interestingly, the least noted topic area of the six was **Pavement Performance**.

The second question addressed in Table 2 asked which pavement studies have or will positively impact WSDOT. This question calls for an opinion on the part of the respondent. The most frequently selected study was again temperature differentials in the **Construction** topic area. Superpave followed in **Pavement Materials Including Hot Mix Design** topic area but was selected about the same number of times as several other studies.

The third question summarized in Table 2 asked for identification of studies that should be funded by WSDOT. The top six (because of ties) included the following:

- Tack Coats in the **Pavement Materials Including Hot Mix Design** topic area
- Hot Mix Laydown Procedures in **Construction**
- Inverted Pavements (South African pavement designs) in **Structural Design and Analyses**
- Full Development of Pavement Tools for Training in **Information Systems and Training**
- Top Down Cracking in **Performance**
- Micro-surfacing in **Pavement Rehabilitation**

Note that a specific study was identified in each of the six topic areas.

The three questions summarized in Table 3 dealt with national pavement-oriented research programs. The first question asked which national studies the respondent was most aware of. The top selections were

- Superpave in **Pavement Materials Including Hot Mix Design**
- Long Term Pavement Performance in **Pavement Performance**
- Temperature Differentials and Density of Longitudinal Joints (tied) in **Construction**
- The AASHTO 2002 Pavement Guide (officially NCHRP 1-37A) in **Structural Design and Analyses**

The second question addressed in Table 3 asked which national pavement studies have or will positively impact WSDOT. The responses were less frequent to this question but the top selections were

- Superpave in **Pavement Materials Including Hot Mix Design**
- Temperature Differentials in **Construction**
- WesTrack in **Pavement Performance**

Note is made that no study responses fell in the **Pavement Rehabilitation** topic area.

The third question shown in Table 3 asked for opinions on the type of national studies that should be funded. No responses fell in the **Pavement Rehabilitation** or **Information Systems and Training** topic areas. The most frequently noted was WSDOT Access to Accelerated Pavement Testing (two “votes”) in the **Pavement Performance** topic area. All others received one “vote.”

Table 4 provides a summary of Question 3, which asked, “What pavement information has most affected your work?” Only two responses were selected more than once. These are temperature differentials (**Construction**) and mechanistic-empirical design procedures (**Structural Design and Analyses**).

Table 5 summarizes the respondents’ views on the major issues facing WSDOT with respect to pavements (other than funding). Opinions were requested in five categories: pavement design, pavement construction, pavement maintenance, pavement management, and an “other” category. A summary of the responses follow

- Pavement Design
 - Training for the Regions
 - Several study areas all of which fell into the **Structural Design and Analyses** and **Pavement Materials Including Hot Mix Design** topic areas.

- Pavement Construction
 - Contractor QC
 - Uniformity of Hot Mix
 - Hot Mix Laydown
 - Personnel Experience
- Pavement Maintenance
 - Development of a Pavement Maintenance Management System
 - Several study areas including thin overlays and others
- Pavement Management
 - WSPMS issues including performance modeling and timeliness of performance data
- Other
 - Several topics including thin surface treatments, end result material specifications, warranties, need for training, etc.

STATE PAVEMENT TECHNOLOGY CONSORTIUM

The SPTC is an organization that evolved as a pooled fund study among four states—California, Minnesota, Texas, and Washington (Mahoney et al. 2000). The intent of the SPTC is to share information among researchers and practitioners in these states. Four technical meetings were held between July 1999 and January 2000, one in each of the participating states. The four states quickly identified topics of mutual interest. The SPTC collaboration to date has resulted in significant sharing of pavement technical information and development of specific, funded activities, including the following:

- Development and offering of the South African/U.S. Pavement Technology Workshop, held during March 20-23, 2000.
- Software enhancement to aid decisions concerning construction, duration, and logistics of urban pavement rehabilitation and reconstruction.

- Support for a synthesis type of report on improved pavement field characterization, building on the recently published NCHRP Synthesis No. 278 (Measuring In Situ Mechanical Properties of Pavement Subgrade Soils).
- Analysis of longitudinal joint compaction in hot-mix asphalt pavement.

Decisions were made to fund or otherwise support a number of other actions, including

- A retrofitted dowel bar study to be conducted in California that includes the use of the Heavy Vehicle Simulator (HVS), complemented by the experience, field data, and research findings of the Minnesota and Washington DOTs;
- Development of a four-state Superpave database to examine the mix system and monitor field performance of Superpave mixes (currently under development);
- Monitoring of selected paving projects in the four states during the year 2000 paving season, using infrared cameras and in situ density measurements to examine hot mix segregation and possible mitigation techniques (data and images from the WSDOT and MnDOT studies were obtained and are currently stored in an online database).
- Investigation of Internet-based training technology for possible application among the four states and associated universities, and for sharing experiences in the use of this technology with similar efforts under way by WSDOT, the National Asphalt Pavement Association (NAPA), and TransNow (a USDOT funded center).

Informal collaboration among the participants has achieved benefits in a number of areas. For example, WSDOT is using Minnesota's research on alkali-silica reactivity (ASR) to assess the potential impacts of changing from Type 2 to Type 1 portland cement. The WSDOT Research Office explored the Texas research implementation

program and procedures, and adopted a modified version for use in its implementation efforts. The University of California at Berkeley received modified software developed at the University of Minnesota for use in determining asphalt concrete cooling times. Texas has shared the results of a paving remixing equipment rodeo (held in El Paso) with the other participants, as well as detailed specifications for calibration and use of lightweight profilers. Minnesota and Washington State have made available their pavement analysis and design software. All four states discussed and are collaborating on hot-mix temperature differentials, the implication on in situ mix quality, and the required data for development of logical mitigation measures.

The framework must recognize the work and collaboration of the SPTC—not only in the identification of topic areas and specific studies but also in how to best accomplish the required studies.

One of the initial efforts sponsored by the SPTC was a survey of the four state DOTs relating to their training and implementation needs. A summary of the WSDOT response is contained in Appendix B. A few comments on training followed by research implementation are relevant.

The WSDOT respondents rated the effectiveness of new and experienced technicians working for contractors as average to below average. This suggests that additional training is needed in this area.

With respect to research implementation, WSDOT does not have a formal, documented process. However, because of a highly selective study identification process, completed research studies are generally straightforward to implement. One reason this

works is the interaction between the WSDOT Project Manager (from the Research Office), the Technical Contact (WSDOT expert), and the research team.

PAVEMENT NEEDS SEMINAR

The WSDOT Research Office held a Pavement Needs Seminar on August 30, 2000. Representatives from WSDOT (Materials Laboratory, Construction, and Research Offices), a private sector consulting firm, a major paving contractor, the Asphalt Paving Association of Washington, the American Concrete Paving Association, and both Washington State University and the University of Washington attended the meeting. Six program areas were used to list pavement research needs suggested by the attendees. These areas were structural design and analyses, pavement materials, pavement performance, pavement rehabilitation, pavement construction, and information systems and training. That meeting aided the submittal of biennial research problem statements and assisted WSDOT in prioritizing those statements.

A summary of the research needs from the Pavement Needs Seminar sorted by program area is shown in Table 6. Tables 7 through 12 summarize specific comments about the identified needs by program area. The priorities shown in tables 7 through 12 range from a low of 3 to a high of 9. These numbers were obtained via balloting of WSDOT personnel who attended the Pavement Needs Seminar. Those research needs that received priorities of 6 or higher were factored into the final priority listing.

WSDOT PRIORITIZATION OF SOUTH AFRICAN PAVEMENT TECHNOLOGY

A meeting was held at the FOSSC Materials Laboratory on April 17, 2000, to discuss the South African pavement technology that was presented at the March 20-23, 2000, RSA/U.S. Pavement Workshop. The WSDOT attendees organized their views into

three categories that reflect the potential order and timing. These are shown below along with the associated subtopics

- Act on Now
 - Embankment/base design and construction
 - Assessment of BST performance
 - Construction of a G1 pavement system (“inverted” pavement with thin bituminous surfacing)
 - Alternative stabilized base types (such as emulsion treated bases)
- Needs Refinement
 - Integration of DCP data and analysis with FWD/backcalculation process
- Longer Term
 - Implementation of BST design and construction improvements
 - Assist local agencies with South African pavement technology
 - Monitor the performance of a constructed G1 pavement system
 - Use South African tire pressure data to illustrate the effects of changing wheel loads and pressures on WSDOT pavements.

SUPERPAVE AND LTPP

As discussed in Chapter 2, Superpave and LTPP are two major national programs. WSDOT has been an active participant in both—particularly Superpave. The primary roles for WSDOT appear to be to monitor the national studies and locally obtained information, evaluate that information, and tailor the results for WSDOT use. Since most of these two efforts have a national focus and funding, limited WSDOT funding is required other than support of the current in-house efforts.

PROPOSED FRAMEWORK

Research Programs

On the basis of the preceding collaborative efforts (such as the SPTC), various surveys, the Pavement Needs Seminar, and knowledge of pavement research needs, the recommended but unprioritized pavement research program and subprogram areas are presented in Table 13. Shown in the table are the six topic areas discussed earlier. They

serve well as program areas. Also shown are 27 subprogram areas (on average about five subprograms per program area). A subprogram will constitute one or more research studies. The large number of subprograms suggests that innovative strategies are required to move them forward. The research program areas approximately match the action item areas noted in the WSDOT Strategic Pavement Plan (WSDOT, 1999) as follows:

<u>Proposed Research Program Areas</u>	<u>Action Item Areas in WSDOT Strategic Plan</u>
Structural Design and Analyses	Pavement Design and Type Selection
Pavement Materials	Pavement Design and Type Selection
Pavement Performance	Pavement Design and Type Selection and Pavement Management
Pavement Rehabilitation	Pavement Rehabilitation
Pavement Construction	Construction Quality and Customer Relations
Information Systems and Training	Pavement Management and New Technologies

All 27 subprograms were ranked, and a description of that process follows. The collective evidence from surveys, the Pavement Needs Seminar and the SPTC were used to the extent possible.

To develop a ranking for the 27 subprogram areas, two separate criteria were used. These criteria are an urgency impact assessment and a listing of the five prioritization elements shown below. The urgency impact assessment is based on a point scheme shown in Table 14. Points are summed as a function of average daily traffic (ADT) and estimated benefits due to the proposed research, with higher points associated with higher ADT and potential benefits. The point range is a maximum of 20 to a minimum of 5. The prioritization elements, the second criterion, are simply a listing of the elements applicable to a specific subprogram. These are as follows:

1. The type and extent of pavements currently used by WSDOT.
2. Possible collaboration with the state DOTs and specifically the SPTC (implies the use of leveraged funding and/or knowledge), which includes maximizing pavement technology developed by others (both nationally and internationally)
3. Stated pavement research needs via surveys and workshops.
4. Previous WSDOT decisions to adapt nationally developed pavement technology (such as Superpave).
5. Probability of success including implementation and training.

Table 15 combines the two criteria. The final rankings are based on a multiplication of a ratio of the prioritization elements by the urgency assessment. This process results in numerous ranking “ties,” but this is not a surprise given the process that led to identification of the 27 subprograms.

The ranking process has subjective features but brings an objective process to their development. The ranking of any specific subprogram is best judged within its program area.

Roadmap for Accomplishment

Given the limitations on WSDOT research funding, innovative approaches are required to execute a more ambitious pavement research program. The key elements to do this include the following:

- Leveraged funding with other agencies and private industry (pooled fund studies for example)
- Collaboration via the SPTC and other State DOTs on both funded and unfunded efforts
- Collaboration with organizations such as the Washington Technology Center

- Use of WSDOT personnel to monitor subprograms and contribute effort to specific studies.

Furthermore, WSDOT should encourage contract researchers to leverage SPR funding to the extent possible. Leverage can be defined as non-WSDOT funding, indirect support, or collaboration. Evidence of leveraging should be contained in study proposals submitted to WSDOT.

The overall timeframe for accomplishing most, if not all, of the framework is estimated to be six years (three biennia). That includes conduct of the research, development, and initial implementation. Naturally, the framework will evolve and so will the timeframe.

A number of options are available to achieve the proposed pavement research framework. The following considerations are listed:

- Maximize the use and/or participation of WSDOT personnel in the conduct of specific research studies within each of the subprograms.
- Maximize collaboration with other highway agencies and the FHWA. Specific emphasis will be placed (as now) on collaboration with the state DOTs in the SPTC.
- Use international technology to the extent possible. The potential for this was well illustrated by the South African/U.S. Pavement Technology Workshop.
- Seek support, as appropriate, from the NSF, industry (such as NAPA and the ACPA), USDOT Centers such as TransNow, and the Washington State Technology Center (WTC).
- Funded studies via WSDOT SPR or other internal WSDOT funding should, to the extent possible, assist in the training of better-informed WSDOT staff, university students, and faculty.

The overall picture of the needed funding levels, funding mechanisms, and implementation venues is shown in Table 16. Each subprogram is shown with respect to funding level (Low < \$100K, Medium = \$100K-250K), and High > \$250K). The total of all the subprograms is \$6.5 million (assumption that Low = \$100K, Medium = \$200K, and High = \$400K). The funding mechanisms are possible ways the subprograms can be supported. Shown are SPR funding (only), a combination of SPR and WSDOT in-house effort, Pooled Fund (multi-state effort), and WSDOT in-house (only). It is estimated that the total WSDOT budget needed to accomplish the six-year program is about \$3.4 million. The assumptions made to develop that figure are the following:

- SPR only = 100 percent WSDOT SPR funds plus state match
- SPR/In-House = 100 percent WSDOT SPR funds plus state match
- In-House only = 0 percent WSDOT SPR funds
- SPR/Pooled Fund or Pooled Fund = 33 percent WSDOT SPR funds (funding is equally split between at least three state DOTs).
-

All of the subprograms are considered to have strong potential for implementation. The implementation venues fall into five basic categories (or combinations of the five). These are

- Training
- Procedures
- Specifications
- Policies
- Contracts

These venues represent the ultimate location for implementation, though numerous steps will likely be required to get there.

Schedule, Budget, and Specific Studies

All subprograms ranked No.1 (including ties), presumably, would be scheduled earlier than those with lower rankings. Given costs estimated from Table 16, this will require the initial execution of 11 subprograms with an estimated total cost of \$1.5 million. If these subprograms are conducted over a three-year period, approximately \$500,000 per year will be needed (i.e., the first 1.5 biennia of the three biennia planning horizon). If the remaining 16 subprograms ranked No. 2 and No. 3 are conducted during the last three years of the six-year period, this will require a budget allocation of about \$1.9 million, or about \$600,000 per year. This sequence is logical, since the proposed schedule and budget represents at least a doubling of current WSDOT supported pavement research efforts. A “slower” initial start will allow WSDOT in-house research teams and research contractors to ramp up.

Table 17 shows the total number of studies needed for each subprogram. Table 18 provides a brief description of each study and the approximate WSDOT SPR funding. The WSDOT SPR funding commitment for Pooled Fund studies represents only 33 percent of the total anticipated study cost.

Note that the proposed framework schedule and budget will place increased demands on the WSDOT Research Office and pavement personnel.

WSDOT Personnel Involvement

Personnel within WSDOT should have the opportunity to benefit directly from the conduct of the programs within the proposed framework. As noted in the discussion of the historical development of WSDOT pavements, important decisions were made during the 1940s and 1950s that served WSDOT well. The pavement research program

can be used to aid the development of the next group of WSDOT pavement decision makers. This happens today but not in a structured manner. It is suggested that a structure similar to the SPTC be set up within WSDOT. Specifically, a selection of WSDOT personnel could serve in two separate forums—the Pavement Technology Management Council and the Pavement Technology Users Group.

The Pavement Technology Management Council (PTMC) would serve the purpose of providing continuing guidance to the WSDOT pavement research program. Additionally, the PTMC would review and assess relevant, emerging pavement issues on state, national, and international levels. Members would include representatives from

- Planning and Programming Service Center (PPSC) Research Office
- Field Operations Support Service Center (FOSSC) Materials Laboratory
- FOSSC Construction Office
- FOSSC Maintenance Office
- Assistant Secretary for FOSSC
- Regions (at least two regions, one Westside and one Eastside)
- Highways and Local Programs Service Center
- Ex Officio members: University of Washington and Washington State University.

The total number of members would be about 10 to 15 persons meeting twice a year.

A Pavement Technology Users Group (PTUG) would serve the purpose of sharing relevant pavement technology with a broader group of WSDOT personnel. This group would meet at least once per year for a “pavement technology day.” The meeting would constitute a series of presentations and discussions that illustrate ongoing pavement research and appropriate pavement technology. It is likely that electronic delivery systems would allow such information to be shared throughout the year. The following WSDOT offices should be represented:

- Regional Materials Engineers
- Regional Construction Engineers
- Regional Construction Trainers

- FOSSC Materials Laboratory
- FOSSC Construction Office
- FOSSC Maintenance Office
- Washington State Technology Transfer Center
- PPSC Research Office

The total attendance would be about 30+ persons.

As an aid to the creation of these two groups, a web site similar to (or incorporated in) the new SPTC web site (<http://pavements.ce.washington.edu/sptc/>) will aid communication.

Table 2. Question 1—The WSDOT Pavement Research Program

Question	Structural Design and Analyses	Pavement Materials Including Hot Mix Design	Pavement Performance	Pavement Rehab	Construction	Information Systems and Training
1(a) WSDOT pavement studies most aware of?	Everseries Software and EverFE: 4	WSDOT Superpave Projects: 1 SMAs: 1 Emulsifiers: 1 Aggregate Requirements:1	Geotextile Separators: 1 Class D: 1	Micro-Surfacing: 1 BSTs: 1 Hot In-Place Recycling: 1 Dowel Bar Retrofit: 1	Temp Differentials: 9 PCCP Intersections: 2 QA Specifications: 2 Public Perception of Smoothness: 1	WSDOT Pavement Guide: 2 Pavement Tools: 1
1(b) Pavement studies that have or will positively impact WSDOT?	Mech-Empirical Design Process: 1 Everseries and EverFE: 1	Superpave: 2 SMA: 1	Class D: 1 Top-Down Cracking: 1		Temp Differentials: 8 Public Perception of Smoothness: 1 PCCP Intersections: 1 QA Specifications: 1	WSDOT Pavement Guide: 1 Pavement Tools: 1
1(c) Pavement studies for WSDOT funding?	Improved Evercalc: 1 Inverted Pavements (SA Designs): 3	Tack Coats: 4 BSTs: 1 Durability of PCC: 1 Impact of high %'s of P200: 1	Top-Down Cracking: 2 Crack Sealing Performance: 1 SMA Performance: 1 Improved Performance Modeling for WSPMS:1 Impact of Superpave on Performance: 1	Micro-Surfacing: 2 Urban Freeway Reconst: 1	Hot Mix Laydown Procedures: 3 General Paving Operations: 1 Impact of Superpave on Construction and QA/QC: 1	Full Development of Pavement Tools for Training: 2 Implementable Results: 1

Note: Numbers indicate the number of respondents that identified a specific study area.

Table 3. Question 2—National Pavement-Oriented Research Programs

Question	Structural Design and Analyses	Pavement Materials Including Hot Mix Design	Pavement Performance	Pavement Rehab	Construction	Information Systems and Training
2(a) National pavement studies most aware of?	Life Cycle Costs: 1 NCHRP 1-37A (AASHTO 2002): 3	Superpave: 5 SMAs: 1	LTPP: 5 AASHTO Road Test: 1 WesTrack: 1 Caltrans APT: 1 Use of gyratory compactor to predict rutting: 1		Done via SPTC: -Temp Differentials: 3 -Long. Joints: 3 -Fast Pave Rehab: 1 -APT: 1	
2(b) National pavement studies that have or will positively impact WSDOT?	AASHTO 2002: 1	Superpave: 3	LTPP: 1 WesTrack: 2 Caltrans APT: 1		Done via SPTC: -Temp Differentials: 2 -Long. Joints: 1 -Fast Pave Rehab: 1 -APT: 1	Training Aids by Organizations such as NAPA: 1
2(c) National pavement studies that should be funded?	Inverted Pavements: 1 Improved Backcalculation including Layer Thickness Determination: 1	SMAs: 1 Large Aggr Mixes: 1 Performance Related Specs: -SMA: 1 -Superpave: 1 Rubber Modified Binders for Superpave: 1	Top-Down Cracking: 1 WSDOT Access to APT: 2 Multi-State Agreement on Pavement Smoothness: 1		Warranties: 1 Improving PCCP Construction: 1 Construction Techniques to Eliminate Temp. Differentials: 1	

Notes: Numbers indicate the number of respondents that identified a specific study area.
 PTC = State Pavement Technology Consortium (State DOTs of California, Minnesota, Texas, and Washington State).
 APT = Accelerated Pavement Testing.

Table 4. Question 3—What Pavement Information Has Most Affected Your Work?

Structural Design and Analyses	Pavement Materials Including Hot Mix Design	Pavement Performance	Pavement Rehab	Construction	Information Systems and Training
Mechanistic Design Procedures: 3 Life Cycle Costs: 1 Urban PCCP Rehab Study: 1	Superpave (and AC studies in general): 1	Accelerated Pavement Testing Results: 1 Top-Down Cracking: 1		Temp Differentials: 4 Fast PCCP Rehab: 1 Smoothness: 1	WSDOT Pavement Guide: 1 WSPMS: 1 Automated (Video) Condition Survey for WSPMS: 1 Information Sharing Via SPTC: 1 Short, Informative Publications: 1

Note: Numbers indicate the number of respondents that identified a specific study area.
 SPTC = State Pavement Technology Consortium.

Table 5. Question 4—What Are The Major Issues Facing WSDOT With Respect to Pavements (Other Than Funding)?

Question Categories	Structural Design and Analyses	Pavement Materials Including Hot Mix Design	Pavement Performance	Pave Rehab	Construction	Information Systems and Training
Pavement Design	Whitetopping ACP: 1 FEM Modeling: 1 Improvement of Backcalculation: 1	Large Aggr Mixes: 1 PG Asphalts: 1 Technologies to Improve LCC: 1				Training for Regions: 2
Pavement Construction					Contractor QC: 2 Uniformity of Hot Mix: 2 Personnel Experience: 2 Hot Mix Laydown: 2 Work Zone Traffic Volumes: 1	
Pavement Maintenance		Thin Overlays and Recycling: 1	Studded Tire Damage: 1 Potholes: 1		Improve Consistency: 1	Development of Pavement Maint. Management System: 2
Pavement Management	Life Cycle Costs: 1		Pavement Perf. Modeling WSPMS: 2 Assessment of PSC: 1 Perf. of Dowel Retrofits: 1			Timeliness of Performance Data in WSPMS: 1 WSPMS: 2
Other		Thin Surface Treatments: 1	Ability to Predict Performance of AC and PCC Based on Simple Lab Testing: 1		End Product Specs: 1 Warranties: 1	Pavement Post Mortem Evaluation: 1 Loss of Technical Expertise: 1

Note: Numbers indicate the number of respondents that identified a specific study area.

Table 6. Pavement Research Needs (from August 2000 Pavements Needs Seminar)

Structural Design and Analyses	Pavement Materials	Pavement Performance	Pavement Rehabilitation	Pavement Construction	Information Systems and Training
Perpetual Pavements-AC Long Life Pavements-PCC 2002 Guide	Effects of Producer Mixes on PCC Quality Superpave High Performing AC Surfaces Bonding of AC Layers Consideration of RAP in the AC Mix Design Process Asphalt Absorption Stripping of AC and Lime Treatment Abrasion Resistance of PCC	Top-Down Cracking Verification of WSDOT Shear Tester BST Performance Initial Smoothness versus Long Term Performance IRI Trends Dowel Bars South African Pavement Sections SPS 2 Monitoring Performance Related Specifications	Rapid Construction Techniques Micro-Surfacing and Thin Overlays Rehabilitation Selection Based on Life Cycle Costing	Treatment/Disposal of Slurry from PCC Grinding Longitudinal AC Joints Density Differentials Compactability of AC Mixes Innovative Contracting Practices Development of Volumetric AC Mix Specification Environmental Barriers Variability versus Appropriate Specifications Premature Pavement Failures as Related to Construction	WSPMS Training Multi-State Databases

Note: Needs shown are not ranked by priority. Refer to Tables 8 through 13 for WSDOT developed priorities.

**Table 7. Structural Design and Analysis Program Area—Detailed Considerations/Needs
(from August 2000 Pavements Needs Seminar)**

Perpetual Pavements-AC (Priority 5)	Long Life Pavements-PCC (Priority 4)	2 002 AASHTO Guide (Priorities—see below)
<p>Illinois initiative</p> <p>California initiative (I-710)</p> <p>The Perpetual Pavement national initiative will be featured at the February 2001 NAPA annual meeting</p> <p>At least a 40-year structural design life and 20 year wearing course</p> <p>Roles for WSDOT, APAW, and WCAT require definition</p>	<p>IPRF initiative</p> <p>California and Illinois initiatives</p> <p>Cement type consideration</p> <p>Dowel bar performance (namely corrosion and consideration of alternative materials)</p>	<p>Need to characterize traffic data (9)</p> <p>Need to characterize HMAC complex modulus (8)</p>

Note: Priority ranking developed by WSDOT. Highest priority = 9; lowest priority = 3.

Table 8. Pavement Materials Program Area—Detailed Considerations/Needs
(from August 2000 Pavements Needs Seminar)

PCC Producer Mixes (Priority 5)	Superpave (Priorities—see below)	High Performing AC Wearing Course (Priority 7)	Bonding of AC Layers (Priority 7)	Use of RAP in AC Mix Design (Priority 6)	Asphalt Absorption (Priority 4)	Stripping and Lime Treatment (Priority 3)	Abrasion Resistance of PCC (Priority 4)
<p>Effect of producer mixes on PCC quality.</p> <p>Analyze aggregates</p> <p>Cements: They are changing and the chemistry generates more heat.</p>	<p>Track Superpave performance (9)</p> <p>Amount of allowable fines passing a No. 200 sieve (3)</p>	<p>Evaluate mixes such as SMA.</p>	<p>An additional consideration to this issue is stripping of the underlying layers.</p>	<p>Contractor RAP is not currently incorporated into the AC mix design process. It was noted that some State DOTs do this now.</p>	<p>Field versus lab values.</p> <p>Examine specific aggregates.</p>	<p>Lime treatment of AC aggregate is widely used in other states. This should be examined for Washington State.</p> <p>The cost of lime treatment must be considered.</p>	<p>Examine aggregates and mix design</p> <p>Consider banning of studded tires.</p>

Note: Priority ranking developed by WSDOT. Highest priority = 9; lowest priority = 3.

Table 9. Pavement Performance Program Area—Detailed Considerations/Needs
(from August 2000 Pavements Needs Seminar)

Top-Down Cracking (Priority 8)	WSDOT Shear Tester (Priority 3)	BST Performance (Priority 7)	Pavement Smoothness (Priority 8)	IRI Trends (Priority 6)	Dowel Bars (Priority 5)	South African Pavement Sections (Priority 8)	SPS 2 Monitoring (Priority 4)	Performance Related Specifications (Priority 3)
<p>Understand the phenomenon</p> <p>Can different AC mixes mitigate the problem.</p> <p>Attention should be paid to Japanese and Florida studies.</p> <p>Layer bonding, tire and climate effects?</p>	<p>The WSDOT Shear Tester needs to be assessed via WSDOT Superpave projects.</p>	<p>Design of BST systems.</p> <p>Improved construction techniques.</p>	<p>Initial smoothness vs long-term pavement performance.</p>	<p>IRI trends with time are needed.</p>	<p>Verify best type of dowels to use.</p> <p>Work with California on accelerated pavement testing of retrofitted dowel project.</p> <p>Performance of grout materials.</p> <p>Temperature effects on grout set time.</p>	<p>Design, build and monitor test sections.</p> <p>Most likely to occur on U.S. 395 in the South Central Region</p>	<p>LTPP data vs WSPMS data?</p>	<p>A need exists to monitor developments.</p>

Note: Priority ranking developed by WSDOT. Highest priority = 9; lowest priority = 3.

Table 10. Pavement Rehabilitation Program Area—Detailed Considerations/Needs
 (from August 2000 Pavements Needs Seminar)

Rapid Construction Techniques (Priority 7)	Micro-Surfacing and Thin Overlays (Priority 4)	Rehabilitation Selection (Priority 4)
Pavement performance issues associated with materials used in rapid construction. California: Monitor work. Monitor related work in other states (such as Illinois).	Supplying quality aggregate for these types of mixes currently an issue (propriety mixes). The basic question is what aggregate quality is really needed.	Rehabilitation based on life cycle costing.

Note: Priority ranking developed by WSDOT. Highest priority = 9; lowest priority = 3.

Table 11. Pavement Construction Program Area—Detailed Considerations/Needs
(from August 2000 Pavements Needs Seminar)

Slurry from PCC Grinding (Priority 6)	AC Density Differentials and Longitudinal Joints (Priorities—see below)	Lab Compaction of AC Mixes (Priority 3)	Innovative Contracting Practices (Priority 3)	Volumetric AC Specification (Priority 6)	Environmental Barriers (Priority ?)	Variability vs Appropriate Specifications (Priority 5)	Premature Pavement Failures (Priority 6)
Deposit/treatment of slurry an issue.	Density differentials: This will be a continuing issue. Much work has been done (7) Longitudinal Joints: Contractor noted success with “step joints” that improve long. joint quality (5)	Extension of use of gyratory compactor. Issue has to do with maximizing the mix charact. via lab testing.	Warranties Deign, build, and maintain. Effects of specifications on contractors and impact on their business. Difference between performance related and performance based specifications.	This is currently not done by WSDOT. Task Force should be involved in the process.	Consideration of environmental barriers to construction. It was noted that the amount of RAP in AC is restricted by air quality criteria.	Need a risk analysis of specifications.	A new initiative is underway within the Materials Lab-forensic analyses.

Note: Priority ranking developed by WSDOT. Highest priority = 9; lowest priority = 3.

Table 12. Information Systems and Training Program Area—Detailed Considerations/Needs
(from August 2000 Pavements Needs Seminar)

WSPMS (Priorities—see below)	Training (Priorities—see below)	Multi-State Databases (Priority 9)
<p>Maintenance: Establish data collection for maintenance. Capture impact of maintenance on pavement performance. Appropriate triggers for preventive maintenance. Need easy data entry (8)</p> <p>Deduct equation evaluation—move from ranges to actual values (8)</p> <p>PMS benchmarking—possibly based on IRI (6)</p>	<p>2002 AASHTO Pavement Guide (3)</p> <p>PMS training: For all agencies in Washington State (3)</p> <p>Industry joint training (?)</p> <p>Implementation protocols—those that work best (3)</p> <p>Just-in-time training and training venues (Internet, CDs, DVDs, etc.) (7)</p>	<p>There is a need for databases on</p> <ul style="list-style-type: none"> --Superpave --Thermal imaging --PMS

Note: Priority ranking developed by WSDOT. Highest priority = 9; lowest priority = 3.

Table 13. Framework Program and Subprogram Areas (Unprioritized)

Structural Design and Analyses (A)	Pavement Materials (B)	Pavement Performance (C)	Pavement Rehabilitation (D)	Pavement Construction (E)	Information Systems and Training (F)
<p>A.1 Support Continued Use and Development of Mech-Empirical Design (can include steps necessary to adopt AASHTO 2002)</p> <p>A.2 Complete Development and Maintain Everseries Software</p> <p>A.3 Support the Trial Use of South African Pavement Designs and Analysis Tools</p> <p>A.4 Investigate Embankment Design for Support of Pavement Structures</p>	<p>B.1 Monitor Performance of Superpave System</p> <p>B.2 Evaluate AC Layer Interface Bonding with Emphasis on Tack Coats</p> <p>B.3 Support Development and Use of High Performance AC Wearing Courses (such as SMAs and Resin Modified Pavement (RMP))</p> <p>B.4 Evaluate Durability of PCC Mixes</p> <p>B.5 Evaluate Granular Material for Use As G1Base</p>	<p>C.1 Assess Top-Down Cracking of AC Wearing Courses</p> <p>C.2 Collaborate with Caltrans on Dowel Bar Retrofit HVS Tests</p> <p>C.3 Provide WSDOT Access to Accelerated Pavement Testing</p> <p>C.4 Assess WSDOT BST Performance</p>	<p>D.1 Collaborate on Construction and Logistics Associated with Urban Freeway Rehabilitation and Reconstruction Projects</p> <p>D.2 Investigate Use of Thin Overlays and Micro-Surfacing Techniques</p> <p>D.3 Integrate the Use of DCP Tests into NDT for Pavement Rehabilitation Projects</p>	<p>E.1 Improve Hot Mix Laydown Placement</p> <p>E.2 Improve Construction of AC Longitudinal Joints</p> <p>E.3 Support Evolution of Quality Control and Quality Assurance Material Specifications</p> <p>E.4 Support Improvement and Knowledge of Pavement Smoothness</p> <p>E.5 Support Examination of Warranties and Alternative/Innovative Contracting Procedures</p>	<p>F.1 Develop Tools to Aid Training for Agency and Contractor Personnel (major emphasis on construction)</p> <p>F.2 Collaborate on Development of Training Delivery Systems</p> <p>F.3 Support the Development of Multi-State Databases</p> <p>F.4 Support Improvement of the WSPMS including Development of a Maintenance Management System</p> <p>F.5 Support Development of WSDOT Technical Personnel</p> <p>F.6 Assist Local Agencies with South African Pavement Technology</p>

Table 14. Urgency Impact Assessment Points

Highway Classification	Average Daily Traffic (points)	Potential Benefits Associated with Research (points)
Interstate And Principal Arterial	High (10)	<ul style="list-style-type: none"> • Significant (10) • Refinement (5) • Minor Gain (0)
Other	Medium to Low (5)	<ul style="list-style-type: none"> • Significant (10) • Refinement (5) • Minor Gain (0)

Table 15. Prioritized Framework Program

Programs and Subprograms	Urgency Points (from Table 13)	Applicable Priority Elements (5 max)¹	Ranking Calculation	Ranking
Structural Design and Analyses				
A.1 Embankment Design	20	1, 2, 3, 5	$(4/5)(20) = 16$	1
A.2 M-E Development	15	1, 2, 3, 5	$(4/5)(15) = 12$	2
A.3 Maintain Everseries	15	1, 3, 5	$(3/5)(15) = 9$	3 (tie)
A.4 South African Pavement Designs	15	2, 3, 5	$(3/5)(15) = 9$	3 (tie)
Pavement Materials				
B.1 High Performing AC Wearing Courses	20	1, 2, 3, 5	$(4/5)(20) = 16$	1 (tie)
B.2 Durability of PCC	20	1, 2, 3, 5	$(4/5)(20) = 16$	1 (tie)
B.3 Monitor Superpave Performance	15	1, 2, 3, 4, 5	$(5/5)(15) = 15$	2
B.4 Layer Interfaces/Tack Coats	15	1, 3, 5	$(3/5)(15) = 9$	3 (tie)
B.5 G1 Base	15	2, 3, 5	$(3/5)(15) = 9$	3 (tie)
Pavement Performance				
C.1 Caltrans Dowel Bar Retrofit	20	1, 2, 3, 5	$(4/5)(20) = 16$	1 (tie)
C.2 WSDOT Access to APT	20	1, 2, 3, 5	$(4/5)(20) = 16$	1 (tie)
C.3 Top-Down Cracking	15	1, 2, 3, 5	$(4/5)(15) = 12$	2
C.4 BST Performance	10	1, 2, 3, 5	$(4/5)(10) = 8$	3
Pavement Rehabilitation				
D.1 Urban Freeway Rehab/Reconstruction	20	1, 2, 3, 5	$(4/5)(20) = 16$	1
D.2 Thin Overlays/Micro-Surfacing	15	1, 2, 3, 5	$(4/5)(15) = 12$	2 (tie)
D.3 Integrate DCP with FWD	15	1, 2, 3, 5	$(4/5)(15) = 12$	2 (tie)
Pavement Construction				
E.1 Pavement Smoothness	20	1, 2, 3, 4, 5	$(5/5)(20) = 20$	1 (tie)
E.2 AC Warranties and Innovative Contracting	20	1, 2, 3, 4, 5	$(5/5)(20) = 20$	1 (tie)
E.3 Hot Mix Laydown Improvements	20	1, 2, 3, 5	$(4/5)(20) = 16$	2 (tie)
E.4 Longitudinal Joints	20	1, 2, 3, 5	$(4/5)(20) = 16$	2 (tie)
E.5 QC/QA Materials Specifications	20	1, 2, 3, 5	$(4/5)(20) = 16$	2 (tie)
Information Systems and Training				
F.1 Tools for Training	20	1, 2, 3, 5	$(4/5)(20) = 16$	1 (tie)
F.2 Multi-State Databases	20	1, 2, 3, 5	$(4/5)(20) = 16$	1 (tie)
F.3 Improvement of WSPMS and Develop MMS	20	1, 2, 3, 5	$(4/5)(20) = 16$	1 (tie)
F.4 Training Delivery Systems	15	1, 2, 3, 5	$(4/5)(15) = 12$	2 (tie)
F.5 Development of WSDOT Tech. Personnel	15	1, 2, 3, 5	$(4/5)(15) = 12$	2 (tie)
F.6 Local Agency SA Designs	15	2, 3, 5	$(3/5)(15) = 9$	3

Note 1: Priority elements are: (1) WSDOT pavement type and extent, (2) potential for collaboration and use of existing technology, (3) research needs from surveys and workshops, (4) commitment to nationally developed pavement technology, and (5) probability of success.

Table 16. Prioritized Framework Program Funding and Implementation

Programs and Subprograms	Funding Level¹	Funding or Development Mechanism	Implementation Venue(s)
Structural Design and Analyses			
A.1 Embankment Design	Medium	SPR	Procedure
A.2 M-E Development	Medium	SPR	Procedures and Training
A.3 Maintain Everseries	Low	SPR/In-House	Procedures
A.4 South African Pavement Designs	High	Pooled Fund	Procedures and Training
Pavement Materials			
B.1 High Performing AC Wearing Courses	High	Pooled Fund	Specifications and Training
B.2 Durability of PCC	Medium	SPR	Specification
B.3 Monitor Superpave Performance	Low	In-House	Procedures and Specifications
B.4 Layer Interfaces/Tack Coats	Low	In-House	Specifications and Training
B.5 G1 Base	Medium	SPR/In-House	Specification
Pavement Performance			
C.1 Caltrans Dowel Bar Retrofit	High	Pooled Fund	Procedures
C.2 WSDOT Access to APT	High	Pooled Fund	Procedures and Specifications
C.3 Top-Down Cracking	Medium	SPR	Procedures and Specifications
C.4 BST Performance	Low	SPR/In-House	Specification
Pavement Rehabilitation			
D.1 Urban Freeway Rehab/Reconstruction	Medium	Pooled Fund	Policies and Procedures
D.2 Thin Overlays/Micro-Surfacing	Medium	SPR	Policies and Specifications
D.3 Integrate DCP with FWD	Medium	Pooled Fund	Procedure
Pavement Construction			
E.1 Pavement Smoothness	Medium	SPR	Specifications and Procedures
E.2 Warranties and Innovative Contracting	High	Pooled Fund	Policies, Contracts, and Specifications
E.3 Hot Mix Laydown Improvements	High	SPR/Pooled Fund	Specifications and Training
E.4 AC Longitudinal Joints	Low	Pooled Fund	Specifications and Training
E.5 QC/QA Materials Specifications	Medium	SPR	Specifications and Training
Information Systems and Training			
F.1 Tools for Training	High	SPR/Pooled Fund	Training
F.2 Multi-State Databases	Low	Pooled Fund	Specifications, Procedures, and Training
F.3 Improvement of WSPMS and Develop MMS	Medium	SPR/In-House	Procedure
F.4 Training Delivery Systems	High	SPR/Pooled Fund	Training
F.5 Development of WSDOT Tech. Personnel	Medium	In-House	Training
F.6 Local Agency SA Designs	Medium	SPR	Procedures and Training

Note: (1) Funding levels are: Low (< \$100K), Medium (\$100K-250K), and High (>\$250K.)

Table 17. Number of Studies in each Subprogram

Programs and Subprograms	Number of Studies within a Subprogram	Ranking (from Table 14)
Structural Design and Analyses		
A.1 Embankment Design	2	1
A.2 M-E Development	1	2
A.3 Maintain Everseries	1	3
A.4 South African Pavement Designs	2	3
Pavement Materials		
B.1 High Performing AC Wearing Courses	2	1
B.2 Durability of PCC	1	1
B.3 Monitor Superpave Performance	1	2
B.4 Layer Interfaces/Tack Coats	1	3
B.5 G1 Base	2	3
Pavement Performance		
C.1 Caltrans Dowel Bar Retrofit	2	1
C.2 WSDOT Access to APT	1	1
C.3 Top-Down Cracking	1	2
C.4 BST Performance	1	3
Pavement Rehabilitation		
D.1 Urban Freeway Rehab/Reconstruction	2	1
D.2 Thin Overlays/Micro-Surfacing	1	2
D.3 Integrate DCP with FWD	1	2
Pavement Construction		
E.1 Pavement Smoothness	2	1
E.2 Warranties and Innovative Contracting	2	1
E.3 Hot Mix Laydown Improvements	2	2
E.4 AC Longitudinal Joints	1	2
E.5 QC/QA Materials Specifications	1	2
Information Systems and Training		
F.1 Tools for Training	2	1
F.2 Multi-State Databases	1	1
F.3 Improvement of WSPMS and Develop MMS	1	1
F.4 Training Delivery Systems	2	2
F.5 Development of WSDOT Tech. Personnel	1	2
F.6 Local Agency SA Designs	1	3

Table 18. Specific Studies in each Subprograms with No. 1 Ranking

Programs and Subprograms	Study Description	Approximate WSDOT SPR Funding
Structural Design and Analyses		
A.1 Embankment Design	Conduct literature review, survey state and international practices, and identify related research needed to enhance pavement base course and embankment design and construction.	\$50K
	Conduct specific tests and complete process for enhanced base course and embankment design and construction.	\$150K
Pavement Materials		
B.1 High Performing AC Wearing Courses	Enhanced mix design for SMA wearing courses including studded tire wear assessment.	\$80K (PF)
	Enhanced field control for SMA and Superpave wearing courses.	\$50K (PF)
B.2 Durability of PCC	Relationship between mix ingredients (including aggregate quality) and long term PCCP performance.	\$200K
Pavement Performance		
C.1 Caltrans Dowel Bar Retrofit	Provide technical assistance to Caltrans and UCB on dowel bar retrofit study at Ukiah, California.	\$20K (PF)
	Support additional HVS tests on dowel bar retrofitted Caltrans PCC pavements.	\$110K (PF)
C.2 WSDOT Access to APT	Support HVS tests on Variable Density AC mats.	\$130K (PF)
Pavement Rehabilitation		
D.1 Urban Freeway Rehab/Reconstruction	Support development of UCB/Caltrans software on urban freeway logistics and traffic control.	\$30K (PF)
	Apply new software to WSDOT case studies.	\$40K (PF)
Pavement Construction		
E.1 Pavement Smoothness	Evaluate new WSDOT specification on pavement smoothness.	\$100K
	Develop relationship between pavement smoothness levels and construction related variability.	\$100K
E.2 Warranties and Innovative Contracting	Collaborate with the SPTC on the development and use of pavement warranties.	\$40K (PF)
	Collaborate with the SPTC on the privatization of pavement rehabilitation and maintenance. Overview existing national and international practices and experience.	\$30K (PF)
Information Systems and Training		
F.1 Tools for Training	Enhance Internet delivery of pavement training.	\$75K (PF)
	Enhance SPTC communication via the Internet.	\$60K (PF)
F.2 Multi-State Databases	Develop and support multi-state databases for the SPTC.	\$30K (PF)
F.3 Improvement of WSPMS and Develop MMS	Incorporate a Maintenance Management System into the existing WSPMS structure.	\$200K

Note: PF = Pooled Fund

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following conclusions are made:

- Most WSDOT pavement related research was done in-house until the late 1970s/early 1980s.
- WSDOT has a long history (documented through the 1950s) of sensibly assessing its pavement practices. These assessments often made use of pavement research done elsewhere (such as in California, various national road tests). WSDOT has a history of well-done design practices. This continues today.
- Highway research expenditures as a percentage of total highway expenditures are low in comparison to a selection of other U.S. sectors, and this has been the case for several decades. Typical highway R&D expenditures range from 0.1 to 0.5 percent of total expenditures. When these values are contrasted to other industries and sectors, the highway percentages range from 4 to 150 times lower. Furthermore, in comparison to a 40-year span for medical research, highway R&D percentages were 10 times lower in 1958 and about the same in 2000. For WSDOT, the percentage of total expenditures on R&D has decreased by a factor of 2 during the same 40-year period.
- Most WSDOT pavement related research performed during the last 20 years can be grouped into 10 broad topic areas. The duration of investigation within topic areas varies widely but generally spans about a four- to ten-year period. Once WSDOT

personnel are knowledgeable about a specific topic, they generally continue with developments in that area—given that there is a need for such improvements.

- Three of the more recent research topic areas for WSDOT are mix design (Superpave mostly), construction of pavements, and enhancement of pavement analysis tools.
- Research products include not only study documentation and, usually, implementable results but also knowledgeable individuals within WSDOT and its associated universities. These individuals have demonstrated the ability to carry topics forward for complete development and evolution.
- A framework for WSDOT pavement research includes six major program areas with a total of 27 subprograms. Over a six-year period (three biennia) the total cost to WSDOT is estimated to be \$3.4 million. This is about one-half of the total expense. It is assumed that a combination of pooled fund and other collaborative efforts will cover the remaining costs. This view is supported by the success of the SPTC collaboration started during 1999 between the state DOTs of California, Minnesota, Texas, and Washington.

RECOMMENDATIONS

The following recommendations follow from the conclusions:

- Comparison with highway and other R&D sectors suggests that WSDOT should increase support for R&D. Specifically, it is recommended that WSDOT's support for pavement research be doubled over current levels for the next three biennia.
- Maximize the use of WSDOT SPR funds by developing collaborative efforts (this has begun with the SPTC during the 1999 and 2000).

- Use the framework structure to develop a six-year view of WSDOT pavement research needs.
- Periodically update the framework.
- Establish a Pavement Technology Management Council (PTMC) and a Pavement Technology Users Group to guide research, implement new technology, and monitor progress.

REFERENCES

- Abramson, H. N. et al (1997), "Technology Transfer Systems in the United States and Germany," National Academy of Engineering, National Academy Press, Washington, D.C.
- Acott, M., Decker, D., Epps, J., Witzak, M. (2000), "Hot Mix Asphalt Visions—2000 and Beyond," *HMAT Magazine*, Volume 5, Number 4, National Asphalt Pavement Association, Lanham, Maryland, July/August 2000.
- Angerinos, M.J., Mahoney, J.P., Moore, R.L., and O'Brien, A.J. (1999), "A Synthesis on Studded Tires," Research Report WA-RD 471.1, Washington State Department of Transportation, Olympia, Washington, August 1999.
- Baker, M.J. and Mahoney, J.P. (2000), "Identification and Assessment of Washington State Pavements with Superior and Inferior Performance," Research Report WA-RD 437.1, Washington State Department of Transportation, Olympia, Washington, August 2000.
- Blank, Robert H. (1997), "The Price of Life—The Future of American Health Care," Columbia University Press, New York.
- Cadicamo, M.P. (1999), "A Partial Analysis of the Washington State Department of Transportation Quality Assurance Specification," Thesis, Master of Science in Civil Engineering, Department of Civil and Environmental Engineering, Seattle, Washington.
- Davids, W.G., Turkiyyah, G.M., and Mahoney, J.P. (1998), "Modeling of Rigid Pavements: Joint Shear Transfer Mechanisms and Finite Element Solution Strategies," Research Report WA-RD 455.1, Washington State Department of Transportation, Olympia, Washington, July 1998.
- Federal Highway Administration (2000), "Key Findings from LTPP Analysis: 1990-1999," Research Report FHWA-RD-00-085, Federal Highway Administration.
- Fried, S. (1998), "Bitter Pills—Inside the Hazardous World of Legal Drugs," Bantam Books, New York.
- Gates, B. and Hemingway, C. (1999), "Business @ The Speed of Thought," Penguin Books, London.
- Hallenbeck, M. and Kim, S.G. (1993), "Summary of Truck Loading Patterns in Washington State," Research Report WA-RD 314.1, Washington State Department of Transportation, Olympia, Washington, September 1993.

- Hatfield, M. (2000), "If You Think Research Is Expensive, Try Disease," Northwest Science and Technology, published by the University of Washington Office of Research and the Department of Technical Communication, Seattle, Autumn 2000.
- Hiebeler, R., Kelly, T., and Ketteman, C. (1998), "Best Practices—Building Your Business with Customer-Focused Solutions," Simon and Schuster, New York.
- HRB (1960), "Highway Research in the United States—Needs, Expenditures and Applications," Special Report 55, Appendix A, Highway Research Board, Washington, D.C.
- Hveem, F.N. and Carmany, R.M. (1948), "The Factors Underlying the Rational Design of Pavements," Proceedings, Highway Research Board, Washington, D.C., December 7-10, 1948.
- IPRF (1998), "Creating a New Generation of Pavements—An Action Plan to Execute the Blueprint for Portland Cement Concrete Pavement Research," Innovative Pavement Research Foundation, Skokie, Illinois, May 1998.
- Kay, R.K., Mahoney, J.P., and Jackson, N.C. (1993), "The WSDOT Pavement Management System—A 1993 Update," Research Report WA-RD 274.1, Washington State Department of Transportation, Olympia, Washington, June 1993.
- Koehne, J.L. and Mahoney, J.P. (1994), "An Evaluation of the Lift Axle Regulation (WAC 468.38.280) in Washington," Research Report WA-RD 342.1, Washington State Department of Transportation, Olympia, Washington, March 1994.
- Lary, J.A. (1983), "LTM Site Models and A Comparison of Field and Laboratory Resilient Moduli," Field Order F-772559, Work Order L-7327, Report Prepared by the University of Washington for the Washington State Department of Transportation, December 1983.
- Lary, J.A., Mahoney, J.P., and Sharma, J. (1984), Evaluation of Frost Related Effects on Pavements," Research Report WA-RD 67.1, Washington State Department of Transportation, Olympia, Washington, May 1984.
- Leahy, R.B. (1999), "Superpave—Washington DOT Assessment and Status," Research Report WA-RD 486.1, Washington State Department of Transportation, Olympia, Washington, December 1999.
- LeClerc, R.V. (1956a), "Flexible Pavement Design in Washington," Highway Research Record, Highway Research Board, Washington, D.C.
- LeClerc, R.V. (1956b), "Proposed Modifications of Present Methods of Flexible Pavement Design," Internal Report, Materials Laboratory, Washington State

- Highway Commission, Department of Highways, Olympia, Washington, October 1956.
- LeClerc, R.V. (1958), "Proposed Revisions in Methods of Evaluating Traffic by Equivalent Wheel Loads and in Standard Surfacing Design Chart for Flexible Pavements," Materials Laboratory, Washington State Highway Commission, Department of Highways, Olympia, Washington.
- Mahoney, J.P., Loose, M.K., and Lary, J.A. (1982), "Sulfur Extended Asphalt—Availability of Sulfur," Research Report WA-RD 53.1, Washington State Department of Transportation, Olympia, Washington, April 1982.
- Mahoney, J.P., Rutherford, M.S., and Hicks, R.G. (1986), "Research Summary Report—Guidelines for Spring Highway Use Restrictions," Research Report WA-RD 80.2, Washington State Department of Transportation, Olympia, Washington, June 1986.
- Mahoney, J.P., Kay, R.K., and Jackson, N.C. (1988), "Pavement Performance Equations," Research Report WA-RD 143.1, Washington State Department of Transportation, Olympia, Washington, March 1988.
- Mahoney, J.P., Lee, S.W., Jackson, N.C., Newcomb, D.E. (1989), "Mechanistic-Based Overlay Design Procedure for Washington State Flexible Pavements," Research Report WA-RD 170.1, Washington State Department of Transportation, Olympia, Washington, January 1989.
- Mahoney, J.P., Lary, J.A., Pierce, L.M., Jackson, N.C., and Barenberg, E.I. (1991), "Urban Interstate Portland Cement Concrete Pavement Rehabilitation Alternatives for Washington State," Research Report WA-RD 202.1, Washington State Department of Transportation, Olympia, Washington, April 1991.
- Mahoney, J.P. (1994), "Statistical Methods for WSDOT Pavement and Material Applications," Research Report 315.1, Washington State Department of Transportation, Olympia, Washington, February 1994.
- Mahoney, J.P., and Seferian, M. (1995), "The WSDOT Pavement Management System - Operational Enhancements," Research Report WA-RD 315.1, Washington State Department of Transportation, Olympia, Washington, December 1995.
- Mahoney, J.P., Winters, B.C., Chatti, K., and Moran, T.J. (1995), "Vehicle/Pavement Interaction at the PACCAR Test Site," Research Report WA-RD 384.1, Washington State Department of Transportation, Olympia, Washington, June 1995.

- Mahoney, J.P. and Backus, A.W. (2000), "QA Specification Practices," WA-RD 490.1, Washington State Department of Transportation, Olympia, Washington, August 2000.
- Mahoney, J.P., Pietz, M.D., and Anderson, K.W. (2000), "Summary Report of the State Pavement Technology Consortium," Research Report WA-RD 487.1, Washington State Department of Transportation, Olympia, Washington, May 2000.
- Mahoney, J.P., Muench, S.T., Pierce, L.M., Read, S.A., Uhlmeyer, J.S., Jakob, H., and Moore, R. (1999), "Identification and Assessment of Construction-Related Asphalt Concrete Pavement Temperature Differentials," Paper accepted for publication, Journal of Transportation Research, Transportation Research Board, Washington, D.C.
- Markey, S.J., Mahoney, J.P., and Gietz, R.H. (1994), "An Initial Evaluation of the WSDOT Quality Assurance Specification for Asphalt Concrete," Research Report WA-RD 326.1, Washington State Department of Transportation, Olympia, Washington, April 1994.
- Nelson, T.L., and LeClerc, R.V. (1982), "Development and Implementation of Washington State's Pavement Management System," Research Report WA-RD 50.1, Washington State Department of Transportation, Olympia, Washington, September 1982.
- Newcomb, D.E., Bubushait, A.A., Mahoney, J.P., and Sharma, J. (1983), "State-of-the-Art on Pavement Overlay Procedures," Research Report WA-RD 65.1 and 65.2, Washington State Department of Transportation, Olympia, Washington, December 1983.
- National Asphalt Pavement Association (2000), "NAPA News," Volume 26, Number 17, National Asphalt Pavement Association, Lanham, MD, August 21, 2000.
- National Research Council (1998), "Visionary Manufacturing Challenges for 2020," Committee on Visionary Manufacturing Challenges, Board on Manufacturing and Engineering Design, and the Commission on Engineering and Technical Systems, National Academy Press, Washington, D.C.
- O'Neil, D.J., Mahoney, J.P., Jackson, N.C. (1992), "An Evaluation of Granular Overlays in Washington State," Research Report WA-RD 226.1 (FHWA-SA-92-042), Washington State Department of Transportation, Olympia, Washington, June 1992.
- Peters, A.J., Gietz, R.H., and Walter, J.P. (1986), "Hot Mix Recycling Evaluation in Washington," Research Report WA-RD 98.1, Washington State Department of Transportation, Olympia, Washington, December 1986.

- Phillips, H.C. (1995), "A Risk and Pay Factor Analysis of Washington State's Department of Transportation 1994 Standard Specification, Thesis, Master of Science in Civil Engineering, Department of Civil Engineering, Seattle, Washington, July 1995.
- RTCC (1994), "Highway Research—Current Programs and Future Directions," Special Report 244, Research and Technology Coordinating Committee, Transportation Research Board, National Academy Press, Washington, D.C.
- RTCC (1999), "Managing Technology Transfer—A Strategy for the Federal Highway Administration," Special Report 256, Research and Technology Coordinating Committee, Transportation Research Board, National Academy Press, Washington, D.C.
- Rust, F. C. (1999), "A Proposed Model for Managing Technology Development in the Road Building Industry in South Africa," Volumes 1 and 2, Draft Doctoral Dissertation, Pretoria, South Africa, May 1999.
- Sargand, S. (2000), "Performance of Dowel Bars," Draft Report Prepared by Ohio University, Federal Highway Administration, July 2000.
- Sharma, J., Hallin, J., and Mahoney, J.P. (1983), "Evaluation of Present Legislation and Regulations on Tire Sizes, Configurations, and Load Limits," Research Report WA-RD 59.1, Washington State Department of Transportation, Olympia, Washington, July 1983.
- Shermer, M. (1997), "Why People Believe Weird Things," W. H. Freeman and Company, New York.
- TRB (1986), "Strategic Highway Research Program—Research Plans," NCHRP Project 20-20, Transportation Research Board, Washington, D.C., May 1986.
- Uhlmeyer, J.S., Mahoney, J.P., Hanek, G., Wang, G., Copstead, R.L., and Janssen, D.J. (1994), "Estimation of Seasonal Effects for Pavement Design and Performance," U.S. Forest Service, Technology and Development Center, San Dimas, California, May 1994.
- Uhlmeyer, J.S., Lovejoy, J., and Mahoney, J.P. (2000), "Structural and Performance Characteristics of Granular Overlays in Washington State," Paper submitted for publication, Journal of Transportation Research, Transportation Research Board, Washington, D.C.
- WSDOT (1993), "WSDOT Pavement Guide," Volumes 1, 2, and 3, Washington State Department of Transportation, Olympia, Washington.

WSDOT (1999), “Washington State Highway Pavements—Trends, Condition, and Strategic Plan”, Washington State Department of Transportation, Olympia, WA, May 1999.

WSDOT (2000a), “Electronic Pavement Guide,” Compact Disc, Washington State Department of Transportation, Olympia, Washington.

WSDOT (2000b), “Key Facts—A Summary of Transportation Information,” Washington State Department of Transportation, Olympia, Washington, January 2000.

APPENDIX A

SUMMARY OF RESPONSES OF INTERNAL WSDOT QUESTIONNAIRE ON PAVEMENT RESEARCH ORIENTED QUESTIONS

INTRODUCTION

The questionnaire was submitted to WSDOT Regional and central office personnel during May through July 2000. Specifically, a short set of questions were posed to all Regional Materials Engineers, Regional Construction Trainers, and a selection of central Materials Laboratory staff. A total of 18 questionnaires were sent; 14 responses were received. The response rate was 50 percent for Regional Materials Engineers, 100 percent for Regional Construction Trainers, and 100 percent for central FOSSC Materials Laboratory staff.

The questions were grouped into five categories: the WSDOT research program, national research programs, pavement information that has most affected the respondents' work, the major issues facing WSDOT with respect to pavements (other than funding), and concluding comments.

1. WSDOT Research Program

- (a) What past or current WSDOT supported (in-house or contract) pavement studies are you most aware (please limit the response to no more than three)?
- Respondent 1: SMA, Micro-surfacing, Temperature Segregation
 - Respondent 2: PCCP Intersections, ACP Temperature Differentials, Performance of Geotextile Separators.
 - Respondent 3: Temperature differential study.
 - Respondent 4: Class D ACP, emulsifier changes, and aggregate requirements.
 - Respondent 5: Shoulder Storm water Runoff Control, 1995.
 - Respondent 6: Development of Evercalc/Everpave software.
 - Respondent 7: No Comment.
 - Respondent 8: Asphalt Seal Coats, Nov. 1987 (I have used this report and sent numerous copies to PE's!), Hot in Place Recycling, and the WSDOT Pavement Guide.

- Respondent 9: **SR 395 and SR 82 Superpave projects variations in Rice and it's effect on the volumetric properties and also the specific gravity of the aggregate and how it effects the properties.**
- Respondent 10: **Temperature differential, modifications to EverFE, concrete intersections.**
- Respondent 11: **Everseries (includes EverFlex and Ever FE development project; WSDOT Pavement Design Guide development: Temperature differential study.**
- Respondent 12: **Evaluation of statistical acceptance based specifications; thermal segregation of HMAc; and perception of pavement smoothness.**
- Respondent 13: **Thermal segregation; Pavement Tools; and Ever FE enhancements.**
- Respondent 14: **Thermal differentials; Dowel bar retrofit.**
- Respondent 15: **Cyclic density problems with AC; Review of statistical acceptance tests for AC.**

(b) What pavement study, in your view, has or will positively impact WSDOT pavements?

- Respondent 1: **SMA, Infrared Temperature Studies, Superpave**
- Respondent 2: **The ACP temperature differential study is tops on my list. I believe most of our pavement segregation problems are temperature related and anything that can be done to reduce this effect will have dramatic results upon our pavement life. I would like to see this become part of our acceptance program. Temperature segregation will usually show up two years after placement. It is a cancer that is eating away at our infrastructure.**
- Respondent 3: **No Comment.**
- Respondent 4: **Stop using Class D; mix gradations.**
- Respondent 5: **No Comment.**
- Respondent 6: **Don't know**
- Respondent 7: **No Comment.**
- Respondent 8: **WSDOT Pavement Guide, with all the research and time involved, I consider this a pavement study.**
- Respondent 9: **Volumetrics, Infrared Imaging.**
- Respondent 10: **Temperature differentials, concrete intersections, mechanistic-empirical design process.**
- Respondent 11: **Everseries and EverFE development project.**
- Respondent 12: **Evaluation of statistical acceptance based specifications; thermal segregation of HMAc; and perception of pavement smoothness.**
- Respondent 13: **Thermal segregation (aid pavement performance); Pavement Tools (benefit WSDOT inspectors); and Top-down cracking (will aid improved pavement design—structural and mix).**
- Respondent 14: **Thermal differential/density profile.**
- Respondent 15: **AC cyclic density.**

(c) What kinds of studies would you like to see done via WSDOT funded pavement research?

- Respondent 1: **New technology in thin overlays such as Nova Chip and Micro-surfacing.**
- Respondent 2: **If we cannot eliminate studs, is there something we can do to reduce the effects? Could Nova Chip or micro-surfacing applied to a newly paved roadway extend the life of the underlying pavement? Assuming we have sufficient pavement structure, would this be a cost effective treatment?**

- Respondent 3: Improvement of hot mix laydown procedures.
- Respondent 4: Comments fall into three categories:
 - Tack Coats for ACP: What effect does spilt diesel, paraffin oils and/or hydraulic fluids have on the tack coat? How does CSS-1 compare to STE for tack coats? What chemicals affect CSS-1 and STE when shipped in a contaminated tanker? What effect does cooling and reheating of tack coat have? Is there a better way to determine the amount of tack needed for a specific job?
 - Paving Operations: Does the vibrator on a screed make any difference? Does “winging” out without augers make any difference? What effect does water have on cooling the ACP, after compaction, to allow traffic on the surface early?
 - Environmental: Do grindings (ACP and PCCP) pose a threat to the environment at any time?
- Respondent 5: No Comment.
- Respondent 6: More work to investigate causes/mechanics of top down AC cracking.
- Respondent 7:
 - Tack Coat Application:
A complete overview of the tack coat process including type, rate of application, and definition break or curing. We are experiencing top down cracking in our thicker asphalt sections and pavement failures that do not penetrate through the asphalt section. Is this a result of poorly placed or inadequate application rates?
 - Crack Sealing:
Does crack sealing provide additional pavement life when done during the placement of an ACP overlay? Is crack sealing more of a maintenance procedure than a construction procedure? Does crack sealing provide sufficient during construction to justify the cost?
- Respondent 8: Update the Asphalt Seal Coats that is written for designers, maintenance personnel, and street inspectors with simple and easy to follow diagrams and sketches like the first edition.
- Respondent 9: I would like to see some test section areas established with infrared images that are known to be low in temperature to determine the potential for premature pavement failures.
- Respondent 10: Evaluation of Superpave and its impact on construction. QA/QC, and pavement performance; Full development of Pavement Tools for training; Modification of Evercalc to potentially improve estimates of layer moduli.
- Respondent 11: Pavement performance modeling as it relates to WSPMS; Inverted pavements and their feasibility in the Washington environment.
- Respondent 12: Implementation strategy for customer focused design and construction of pavements; performance of tack coats—leading to field application tests and performance based tests; SMA performance; and trial implementation using South African pavement design (inverted pavement) in Eastern Washington.
- Respondent 13: Construction training tools—tools that train but also show the consequences of poor construction practices; Urban freeway reconstruction; Application of South African techniques in WSDOT pavements; and Implementable results.
- Respondent 14: Correct tack coat applications; Controlled experiment with respect to thick, tight tarps and aggressive rolling to offset thermal differentials and/or low temperatures.
- Respondent 15: Define durability of PCC; Assess impacts of high percentages of No. 200 sieve material in AC.

2. National Research Programs (includes any FHWA, NCHRP, Pooled Fund, and SHRP funded studies)

(a) What past or current nationally supported pavement studies are you most aware (please limit the response to no more than three)?

- Respondent 1: **Superpave**
- Respondent 2: **SHRP SPS-2 (PCCP study on SR 395); Superpave (PG binders and volumetric mix design).**
- Respondent 3: **SMA mixes, SHRP-related studies including Superpave.**
- Respondent 4: **Superpave.**
- Respondent 5: **Methodology to Improve Pavement-Investment Decisions.**
- Respondent 6: **AASHTO Road Test, SHRP LTPP, Westrack, Caltrans APT**
- Respondent 7: **No Comment.**
- Respondent 8: **NAPA Designing and Constructing SMA Mixtures: State-of-the-Practice, January 1999; SHRP Studies, and Life Cycle Cost Analysis (FHWA-SA-98-079).**
- Respondent 9: **SHRP, WesTrack.**
- Respondent 10: **NCHRP 1-37A, Superpave, LTPP**
- Respondent 11: **LTPP, LCCA of pavement design in urban areas, AASHTO 2002 Guide.**
- Respondent 12: **Four States Pooled Fund Study (thermal segregation; longitudinal joints; and fast pavement rehabilitation).**
- Respondent 13: **NCHRP 1-37A; SPTC work on thermal segregation and longitudinal joint study; and LTPP.**
- Respondent 14: **SPTC work on thermal differentials, longitudinal joints, and APT.**
- Respondent 15: **Use of gyratory compactor to predict rutting in AC mixes.**

(b) What nationally performed pavement study, in your view, has or will positively impact WSDOT pavements?

- Respondent 1: **Superpave**
- Respondent 2: **I am optimistic that the Superpave technology will translate into increased pavement performance. We are seeing higher asphalt contents from mix designs on our secondary highways because of volumetric design. The increased film thickness on the aggregates will reduce the effects of raveling from stud wear and associated water damage.**
- Respondent 3: **No Comment.**
- Respondent 4: **Do not know.**
- Respondent 5: **Same as above.**
- Respondent 6: **SHRP LTPP, Westrack, Caltrans APT**
- Respondent 7: **No Comment.**
- Respondent 8: **SHRP Studies**
- Respondent 9: **SHRP, WesTrack.**
- Respondent 10: **Superpave.**
- Respondent 11: **AASHTO 2002 Guide**
- Respondent 12: **Four States Pooled Fund Study (thermal segregation; longitudinal joints; and fast pavement rehabilitation).**
- Respondent 13: **Training tools such as the effort by NAPA on SMA.**

- Respondent 14: **Thermal differentials; APT with respect to dowel bar retrofit and pavements in general.**
- Respondent 15: **No Comment.**

(c) What kinds of studies would you like to see done via national funded pavement research?

- Respondent 1: **Pavement warranties, costs vs benefits**
- Respondent 2: **None**
- Respondent 3: **No Comment.**
- Respondent 4: **Same as local studies.**
- Respondent 5: **No Comment.**
- Respondent 6: **Desired projects:**
 - **Nationwide investigation of top-down cracking of thick AC pavements - perhaps a re-look at SHRP crack data.**
 - **Pooled fund project to make APT research accessible to more of the states. The states build the test sections, someone comes along with a mobile APT device with instrumentation, destroys the sections, and moves along to the next state**
 - **Investigation of the relationship of ride quality trends vs. variations in structural properties within a given length of pavement**
- Respondent 7: **No Comment.**
- Respondent 8: **More research on SMAs would be great.**
- Respondent 9: **The use of larger aggregate hot mix (Superpave).**
- Respondent 10: **Improving concrete construction and long-term performance including pavement smoothness—what is smooth, standard procedure for all states to adopt (and be compared with), etc.**
- Respondent 11: **Inverted pavements; FWD backcalculation programs that can determine pavement layer thicknesses in addition to in-situ moduli.**
- Respondent 12: **Superpave Performance Based Specifications—including statistical acceptance; Performance Based Specifications for SMAs; Superpave techniques as applied to rubber modified binders; and construction techniques to eliminate thermal segregation.**
- Respondent 13: **APT testing.**
- Respondent 14: **No Comment.**
- Respondent 15: **No Comment.**

3. What pavement information has most affected your work?

- Respondent 1: **Mechanistic pavement design procedures**
- Respondent 2: **None.**
- Respondent 3: **Temperature differential related hot mix study.**
- Respondent 4: **All information affects my work.**
- Respondent 5: **No Comment.**
- Respondent 6: **Continued development of mechanistic pavement modeling, various APT test results**
- Respondent 7: **No Comment.**
- Respondent 8: **WSDOT Pavement Guide**
- Respondent 9: **WSPMS.**
- Respondent 10: **Mechanistic-empirical design procedures; temperature differential study; life cycle costs and urban reconstruction.**

- Respondent 11: Automated pavement condition survey (video survey).
- Respondent 12: Smoothness; thermal segregation; and fast PCC rehabilitation.
- Respondent 13: Short, snappy information like the SMA publication produced by NAPA; Information sharing by other DOTs—this is why the SPTC works so well.
- Respondent 14: Top-down cracking; and Thermal differentials.
- Respondent 15: ACP related studies and specifically Superpave.

4. What are the major issues facing WSDOT with respect to pavements (other than funding)? For convenience, the following categories are provided:

(a) Pavement Design

- Respondent 1: New technologies that will improve life-cycle costs
- Respondent 2: Composite design for whitetopping ACP.
- Respondent 3: No Comment.
- Respondent 4: PG grade asphalts.
- Respondent 5: No Comment.
- Respondent 6: No Comment.
- Respondent 7: No Comment.
- Respondent 8: Priority 3 out of 4.
- Respondent 9: Larger aggregate
- Respondent 10: Finite element modeling and improving backcalculation techniques.
- Respondent 11: No Comment.
- Respondent 12: Priority 4 out of 4.
- Respondent 13: Training—both initial and follow-up.
- Respondent 14: More training for Regional personnel—how to use software and what the results mean.
- Respondent 15: No Comment.

(b) Pavement Construction

- Respondent 1: Contractor QC
- Respondent 2: Uniformity! Asphalt content, gradation, density, and surface texture/segregation.
- Respondent 3: Need knowledgeable people doing the paving.
- Respondent 4: Rolling, temperatures, segregation, cleaning, and grinding.
- Respondent 5: Not having enough right of way already in place to accommodate expansion. We have to build with many restrictions and constraints in our projects. Heavy traffic volumes are continuing to increase and this creates dangers within work zones.
- Respondent 6: No Comment.
- Respondent 7: No Comment.
- Respondent 8: Priority 1 out of 4.
- Respondent 9: Traffic volumes.
- Respondent 10: QA/QC—actually getting the contractor to construct according to plan and if not, requiring contractor to remove and replace until a quality product is obtained.
- Respondent 11: No Comment.

- Respondent 12: **Priority 1 out of 4.**
- Respondent 13: **Contractor QC; Training for WSDOT inspectors.**
- Respondent 14: **Expanded use of infrared imaging—information to contractors and Regional personnel about what works and what does not.**
- Respondent 15: **No Comment.**

(c) Pavement Maintenance

- Respondent 1: **Thin overlays and recycling**
- Respondent 2: **Raveling, stripping, and rutting of pavements due to studded tires is a continuing problem.**
- Respondent 3: **No Comment.**
- Respondent 4: **Reoccurring potholes.**
- Respondent 5: **No Comment.**
- Respondent 6: **No Comment.**
- Respondent 7: **No Comment.**
- Respondent 8: **Priority 4 out of 4.**
- Respondent 9: **No Comment.**
- Respondent 10: **Development of a pavement maintenance management system that is tied to the WSPMS.**
- Respondent 11: **No Comment.**
- Respondent 12: **Priority 2 out of 4.**
- Respondent 13: **Improve consistency of pavement maintenance statewide.**
- Respondent 14: **Doing the correct maintenance at the right time.**
- Respondent 15: **No Comment.**

(d) Pavement Management

- Respondent 1: **Life-cycle costs**
- Respondent 2: **The time schedule for analyzing pavements versus when they are constructed. We currently are asked for information two years prior to construction. This has led to pavements being rehabilitated with outdated information. In the case of a deteriorating pavement, two full seasons can significantly affect the method chosen for rehabilitation.**
- Respondent 3: **No Comment.**
- Respondent 4: **Funding.**
- Respondent 5: **No Comment.**
- Respondent 6: **No Comment.**
- Respondent 7: **No Comment.**
- Respondent 8: **Priority 1 out of 4.**
- Respondent 9: **WSPMS**
- Respondent 10: **Continual updating to provide the most accurate assessment of pavement performance, predicting due dates, and providing a performance measure of pavement performance versus P1 spending.**
- Respondent 11: **Pavement performance modeling; re-evaluation of Pavement Structural Condition deduct equations for the video survey; performance of dowel bar retrofitted PCCP pavements.**
- Respondent 12: **Priority 3 out of 4.**

- Respondent 13: WSPMS performance curves—however these should improve with the recent changes in distress acquisition.
- Respondent 14: No Comment.
- Respondent 15: No Comment.

(e) Other (please define)

- Respondent 1: End product specifications
- Respondent 2: None
- Respondent 3: No Comment.
- Respondent 4: No Comment.
- Respondent 5: No Comment.
- Respondent 6: I suppose the trend towards privatization (design, build, operate, and provide warranties ala Koch Materials in New Mexico) should be given some consideration. This is an exciting area. If it ever got to the point where private companies are required to provide and maintain pavements, I think that things may be done a bit differently. How? Heavier initial designs, use of tried and true materials, more operating restrictions on trucks, to name a few...the R&D area would probably change dramatically due to financial pressures. Research projects would be less political, shorter in duration, with more emphasis on implementable results.
- Respondent 7: In the Olympic Region we have a lot of asphalt pavements that are 8 inches or thicker. Placing minimum 0.12' Class A ACP structural overlays is becoming less of an option. We are beginning to recommend more mill and fill type projects. Thin surface treatments such as chip seals are difficult to construct in much our area and are not looked upon favorably. Exposure to and the availability of other thin layer surface treatments that can be applied in our somewhat wet climate could have a great impact on our ability to provide a pleasant looking roadway after pavement repair has been completed.
- Respondent 8: No Comment.
- Respondent 9: No Comment.
- Respondent 10: No Comment.
- Respondent 11: No Comment.
- Respondent 12: Pavement troubleshooting; pavement post mortem evaluation.
- Respondent 13: Loss of technical expertise.
- Respondent 14: No Comment.
- Respondent 15: The ability to predict the performance of ACP or PCC based on reasonably simple laboratory testing.

5. Concluding comments?

- Respondent 1: None.
- Respondent 2: None.
- Respondent 3: Interested in working with the PaveCool software; expressed a need for certified inspectors that have received well-done instruction and testing.
- Respondent 4: How do you get the inspectors to follow specifications when management only cares about “partnering”? Also, doing more with less does not allow the time or resources necessary to ensure a quality job. Certification of products rather than testing allows for substandard products.
- Respondent 5: None.

- Respondent 6: **Frank Botelho (FHWA) is pushing the States to adopt and implement the AASHTO distress protocols. This may affect the way distresses are measured, recorded, and used in the WSDOT PMS. Someone should probably be looking at this.**
- Respondent 7: **None.**
- Respondent 8: **Keep up the excellent work!**
- Respondent 9: **None.**
- Respondent 10: **None.**
- Respondent 11: **None.**
- Respondent 12: **None.**
- Respondent 13: **Pay special attention to needs of WSDOT inspectors. Many of their difficulties focus on administrative issues but research problems will be identified.**
- Respondent 14: **None.**
- Respondent 15: **No Comment.**

**APPENDIX B
WSDOT RESPONSE TO THE STATE PAVEMENT TECHNOLOGY
CONSORTIUM QUESTIONNAIRE ON TRAINING AND
IMPLEMENTATION—1999**

PURPOSE

This questionnaire was developed by John Harvey at the University of California, Berkeley, and submitted to the state DOTs of California, Minnesota, Texas, and Washington during August 1999. The purpose of the questionnaire was to assist in understanding the demographics and training needs of technical staff at State DOTs to improve recruitment, training, and research implementation. Bottom line: improve the ability of state DOTs to deliver quality pavements.

This questionnaire was completed before the public's vote on Initiative 695. The WSDOT responses are shown in bold font.

WSDOT RESPONSE

STATE DOT DESCRIPTION

- Indicate the number of districts in your state: **six**
- Indicate if your DOT is centralized or decentralized as a decision-making agency.
Centralized 1 2 3 4 **5** Decentralized

We are decentralized however; pavement designs and rehabilitation are submitted for approval (concurrence) by the "Headquarters" Pavements Section.

PERSONNEL AND RECRUITMENT

- How many employees are in your DOT?

6,500 and includes 1,700 employees in the WSDOT Ferry System.

- What is the hiring frequency? (e.g. employees / year)

This is difficult to quantify at this time. With the large amount of retirements that are occurring (as in all DOT's), it is difficult to find enough technicians / engineers to maintain current level of employees.

- Do you anticipate a growing or shrinking trend in the pavement division?

Maintain current status.

- What is the effectiveness of new technicians working for the contracting industry?

Poor 1 2 3 4 5 Excellent

This response is related to construction more than pavement design. Unaware as to whether any of the contractors have new or experienced technicians with pavement design or rehabilitation experience.

- What is the effectiveness of experienced technicians working for the contracting industry?

Poor 1 2 3 4 5 Excellent

TRAINING

- What is the DOT training program for Engineers and Technicians?

For construction – the DOT has developed a number of training courses for all aspects of construction inspection.

For pavements – We've developed a Pavement Guide that covers a wide variety of topics from design, rehabilitation, life cycle costs, construction, etc. This Guide is one of the first training tools that we provide employees new to pavements. We conduct numerous one on one training sessions as needed, discuss issues with the Region Materials Engineers at annual meetings, and on an as needed basis, conduct training sessions on new developments (mechanistic-empirical design, backcalculation, for example).

- Where do you hire Engineers and Technicians?

Universities, Community Colleges, and Technical Centers

- What kind of pavement training do they (Engineers and Technicians) have before you hire them? (e.g. Engineers from Universities with or without intensive pavement programs)

For the Pavements Section we have typically hired Engineers from Universities that have conducted their thesis work in the pavements area. The majority of these engineers have had an undergraduate and graduate course in pavements. These courses primarily discuss AASHTO design, resilient modulus, ESALs, backcalculation, layer elastic theory, etc. For the Regions the majority of the employees have some experience in either roadway design (geometrics, etc.) or construction. In general, they have minimal pavement training that may have included an undergraduate course.

- What training activities are needed?

At least for the two Universities in Washington State, the curriculum is appropriate. Our difficulty is finding engineers who want to work for WSDOT.

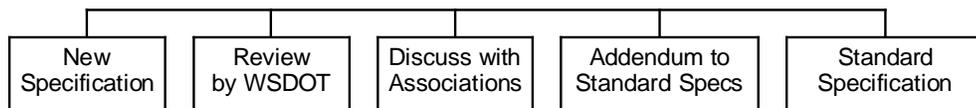
IMPLEMENTATION

- Is there a formal or documented implementation process for research or new ideas in your agency?

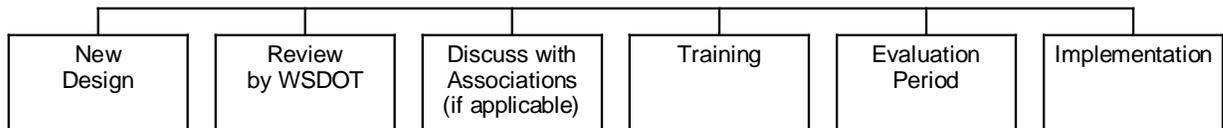
We do not have a documented implementation process. However, we are extremely selective in what research projects are conducted such that the research has been identified as a definite need with high potential payoff. A WSDOT project manager (from the WSDOT Research Office) and technical contact (WSDOT expert) are assigned to each research project. The responsibility of these two individuals is not only the monitoring of research progress, but to ensure the project direction is in line with WSDOT objectives and will result in implementable research.

- Indicate in a flow chart the steps in the typical implementation process of:

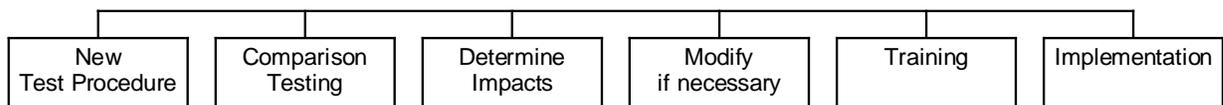
- **A new specification**



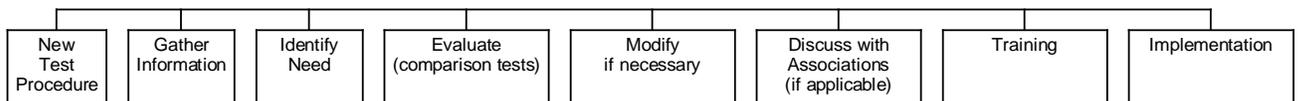
- **A new design procedure**



- **A new test procedure using an existing equipment**



- **A new test procedure using a new equipment**



- At what organizational level is the implementation authorized and at which success is reviewed?

The level of authorization is totally dependent on the product. Any type of policy change will require the support of the Assistant Secretary and possibly the Secretary of

Transportation. If the product is construction related, the authorization could either be at the Assistant Secretary, State Construction Engineer or Materials Engineer level (see attached organization chart). If the product is materials or pavement design related, then authorization is within the Materials Laboratory (Materials Engineer or Assistants).

In general if the product is functional (equipment/test procedure/design methodology) the authorization and measure of success is established at the level of development. For example, Superpave was evaluated at the Materials Laboratory, discussed with Region Construction Engineers and Materials Engineers, Contractors, Suppliers, Asphalt Paving Association of Washington, and then the Materials Laboratory began the implementation process. This process included the selection of projects, materials analysis (binder testing and mix design), assisting field inspectors and testers during construction, and final evaluation. If and when the state decides to move to Superpave it will be based on the decision of the Materials Laboratory.

- Indicate at least four essential items for a successful implementation based on past implementations.
 - **Product is implementable – cost effective, easy to use, easy to understand**
 - **Obtain “buy off” from end user. This is accomplished by including them during the evaluation, asking for their input, informing them on project status, and demonstrating (training) product usefulness.**
 - **Product improves current practice.**
 - **Required inputs are readily available.**

- Indicate common factors for an unsuccessful implementation.
 - **Too expensive to purchase equipment**
 - **To difficult to operate**
 - **Does not improve current process**
 - **Input information is difficult to obtain**

APPENDIX C
SUMMARY OF WSDOT VIEWS ON ASSESSMENT AND
IMPLEMENTATION OF SOUTH AFRICAN PAVEMENT
TECHNOLOGY

A meeting was held at the WSDOT Field Operation Support Service Center (FOSSC) Materials Laboratory on April 17, 2000, to discuss the South African pavement technology that was presented at the March 20-23, 2000 RSA/U.S. Pavement Workshop. In attendance were Tom Baker, Jim Spaid, Marty Pietz, Keith Anderson, Linda Pierce, Siva, Jeff Uhlmeyer, Kim Willoughby, and Joe Mahoney.

By a consensus process, the action items resulting from the meeting are summarized in the table below. The action items were sorted into the three categories shown as the table headings.

Act on Now	Needs Refinement	Longer Term
Embankment/base design and construction as a system. Include compaction levels of unstabilized materials. Evaluate COMPACT software. Do cost-benefit analysis. System must include selection of embankment materials. The RSA presented information illustrated the need of this item.	Integration of DCP data analysis with FWD/backcalculation for pavement rehabilitation.	Implementation of BST design and construction improvements. Develop a protocol/guide for seals.
Assessment of BST performance.		Support local agencies on RSA pavement technology. Make use of UCB produced videotapes and related materials.
Contact Local Programs on: <ul style="list-style-type: none"> • Otta Seal • DCP • RCCD 		Performance and application of the G1 system.
Check to see if South Central Region still plans to construct a G1 system on U.S. 395.		Use RSA tire pressure data and related analyses to illustrate effects of changing wheel loads and pressures on WSDOT pavements (develop a "White Paper" on the topic).
Assemble information for Regions on base systems for possible use in projects (ETB, foamed asphalt, etc.)		