REPORT NO. FHWA-HIF-09-005

ADVANCED CONCRETE PAVEMENT TECHNOLOGY (ACPT) PROGRAM

A STATUS REPORT ON AVAILABLE PRODUCTS

MARCH 2009

U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-HIF-09-005		

4. Title and Subtitle **Advanced Concrete Pavement Technology (ACPT) Program: A Status Report on Available Products**	5. Report Date March 2009 6. Performing Organization Code
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9. Performing Organization Name and Address Fugro Consultants, Inc. 10025 Governor Warfield Parkway, Suite 212 Columbia, MD 21044	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-08-D-00016
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Pavement Technology 1200 New Jersey Avenue, SE Washington, DC 20590	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

The Advanced Concrete Pavement Technology (ACPT) Program is an integrated, national effort to improve the long-term performance and cost-effectiveness of the Nation's concrete highways. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, the goals of the ACPT Program are to reduce congestion, improve safety, lower costs, improve performance, and foster innovation. The ACPT Program was developed to identify, refine, and deliver for implementation the available technologies from all sources that can enhance the design, construction, repair, and rehabilitation of the Nation's concrete highways.

This report documents the availability of advanced concrete pavement technology products that show a high potential for improving the performance of concrete pavements through improved design, material selection, construction practices, testing procedures, and repair and rehabilitation techniques. These technologies also include concrete overlays for rehabilitation of existing concrete and asphalt pavements. The ACPT products for technology transfer, as documented in this report, are the result of research and development projects with various sponsors, both domestic and international.

17. Key Words	18. Distribution Statement
Concrete, concrete overlays, concrete pavements, construction traffic management, pavement materials, pavement rehabilitation, pavement repair, pavement testing	Distribution unlimited. Authorized for public release.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	48	

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PREFACE

The Advanced Concrete Pavement Technology (ACPT) Program is an integrated, national effort to improve the long-term performance and cost-effectiveness of the Nation's concrete highways. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, the goals of the ACPT Program are to reduce congestion, improve safety, lower costs, improve performance, and foster innovation. The ACPT Program was developed to identify, refine, and deliver for implementation the available technologies from all sources that can enhance the design, construction, repair, and rehabilitation of the Nation's concrete highways.

ADVANCED CONCRETE PAVEMENT TECHNOLOGY (ACPT) PROGRAM
A STATUS REPORT ON AVAILABLE PRODUCTS

CHAPTER 1—INTRODUCTION

Introduction

Pavements are the critical elements of an efficient highway transportation system for moving people and goods. Without well-performing pavements, the transportation infrastructure cannot effectively function, road users suffer (in terms of increased costs, travel/commute time, and unsafe roads) and the overall economy suffers (in terms of higher costs for goods and commodities). Modern societies cannot function without mobility, and mobility requires well-performing pavements: it is as simple as that. Therefore, long-lasting pavements that are safer, smoother, and environmentally sensitive and can be cost-effectively constructed and maintained are an important part of the U.S. transportation system. In the United States, billions of dollars are spent every year to construct, maintain, preserve, and rehabilitate the Nation's highway pavement infrastructure. The accumulated investment in our roadway pavements is in the trillions of dollars. This investment needs to be protected and managed efficiently so that generations of our citizens can continue to enjoy the benefits of one of the best highway systems in the world.

The Federal Highway Administration (FHWA), as part of its congressionally mandated role to improve mobility on our Nation's highways through national leadership, innovation, and program delivery, has been actively involved in improving the technologies related to all types of pavements that are used on the federally funded National Highway System. FHWA currently conducts its Pavement Technology Program as authorized under the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). Within that program, FHWA's Innovative Pavement Research and Deployment (IPRD) Program accounts for a significant portion of SAFETEA-LU funds; and, the deployment, delivery, and implementation of advanced concrete pavement technology (ACPT) products are key elements of FHWA's IPRD program efforts to improve the long-term performance of portland cement concrete (PCC) pavements.

Since the late 1950s and early 1960s, when construction of the Interstate Highway System began, there have been significant developments in various aspects of concrete pavement technology. During the Interstate highway construction era, concrete pavements were designed to provide a low-maintenance service life of about 20 years, whereas now the current practice, as followed by most U.S. highway agencies, is to consider design life requirements of 40 to 50 years. While much progress has been made in the last few decades to improve the performance of concrete pavements and to reduce overall life cycle costs, many challenges remain, and new challenges surface that necessitate a strong commitment to a vigorous research and development program and a strong technology transfer program to improve concrete pavement technology. Some of the challenges are listed below:

1. Constrained agency budgets.
2. Optimizing various design features that address local needs related to material availability, environment, site conditions, and future traffic.
3. Urban area traffic volumes and restrictions on construction zones.
4. Pavement noise considerations.

5. User demands for a safer and smoother ride.
6. Sound understanding of factors that affect concrete pavement behavior.
7. Developing durable concrete mixtures.
8. Environmental effects on short-term and long-term performance.
9. Sustainability considerations.

FHWA has traditionally been committed to maintaining and funding a strong research and development program to improve concrete pavement performance. During the late 1990s, with funding support from the TEA-21 bill, FHWA began consolidating its overall concrete pavement research and development (R&D) program under the Concrete Pavement Technology Program (CPTP) umbrella in partnership with the State departments of transportation (DOTs), industry, American Association of State Highway and Transportation Officials (AASHTO), Transportation Research Board (TRB), and academia. More than 30 R&D and technology transfer implementation projects were funded under the CPTP covering a broad range of topics, from evaluations of pavement design and design features to assessment of materials, construction, and repair and rehabilitation activities. FHWA has also supported several other topic-specific programs related to alkali-silica reactivity (ASR), concrete overlays, continuously reinforced concrete pavements (CRCP), precast concrete pavements, and pavement surface characteristics (ride, safety, and noise). In addition, advanced research and technology transfer activities are also supported by State DOTs, academia, and industry. Recently, under the CPTP, the Concrete Pavement (CP) Road Map was developed and many of the research activities are now being coordinated under the umbrella of the CP Road Map, in partnership between FHWA, State DOTs, industry, and academia (Ferragut et al. 2005).

FHWA has initiated the ACPT Program to capture the best advanced technologies available or soon to be available for concrete pavements and deliver these technologies to highway agencies and the construction industry. The ACPT program has tremendous potential to build upon the successes of past concrete pavement technology programs to deliver implementable products that pavement engineers and managers can apply to design and construct more cost-effective, longer lasting, and environmentally sensitive concrete pavements, and to be able to rehabilitate concrete pavements more effectively by adhering to the philosophy of "*Get in as soon as possible; do it right; get out as quickly as possible; and stay out as long as possible.*" This report documents the availability of advanced concrete pavement technology products that show a high potential for improving the performance of concrete pavements, through improved design, material selection, construction practices, testing procedures, and repair/rehabilitation techniques. These technologies also include concrete overlays for rehabilitation of existing PCC and asphalt pavements.

The ACPT products for technology transfer, as documented in this report, are the result of research and development projects with one or more sponsors, either domestic or international. The primary sources of ACPT products include projects sponsored by FHWA, State highway agencies, industry, and academia. However, the results of concrete pavement research activities conducted in other countries, principally European countries, have been considered, as they can make a significant contribution to the full range of ACPT products available for deployment, delivery, and implementation in the United States.

Current State of Pavement Technology

Since the late 1950s, when the U.S. interstate highway construction program was initiated, significant progress has been made in advancing the state of practice and the state of knowledge related to both asphalt and concrete pavements. Pavements, in both urban and rural areas, are being designed for long life. For concrete pavements, the initial planned design life is typically 30 to 40 years. The advances in optimizing concrete pavement design features (use of stabilized bases, widened lanes, concrete shoulder, drainage, and doweled joints), availability of improved concrete-making materials, more efficient construction equipment, and better understood processes for achieving quality construction, are helping pave the way for constructing *smoother, safer, sustainable, environmentally friendly, and longer lasting concrete pavements*. While much progress has been made in concrete pavement technology, gaps do remain in achieving consistently what we know to be attainable.

A significant amount of effort and monies expended by U.S. highway agencies is directed at preservation, repair, and rehabilitation (PRR) of existing asphalt, concrete, and composite pavements. Pavements do deteriorate with time and traffic loadings and because of concrete material failures. Sound corrective measures performed in a timely manner can greatly extend the service life of existing pavements. The goal of the corrective measures is to extend the useful life of these pavements (structural capacity and functional characteristics) with the least life cycle costs and in a sustainable manner. Over the last two decades, there has been much progress in developing effective PRR techniques. However, many gaps remain, and many practices are not implemented consistently from one region to another. An important technical limitation is associated with our ability to rationally determine what treatments need to be performed at what stage in the pavement's life and what are the consequences of delaying needed treatments. In today's environment, where highway agency budgets cannot fully meet the needs for managing pavement assets, and with no lessening in traffic growth and public expectations, it is important that the limited funds available to maintain our highway systems be expended in an optimum manner. Furthermore, there is a greater demand to minimize the impacts of pavement rehabilitation activities on facility users.

Summary

There are many needs that are driving the push for advancing the technologies that provide *smoother, safer, sustainable, environmentally friendly, and longer lasting concrete pavements:*

1. Highway agency budget constraints.
2. Highway safety.
3. Highway congestion.
4. Pavement ride.
5. Pavement sustainability issues.

The ACPT program is expected to help bridge the gap between current practices and user expectations of the level of service that pavements need to provide. As discussed in subsequent parts of this report, advances continue to be made in concrete pavement technologies. The promising technologies to be implemented under the ACPT Program will support the goals of FHWA and highway agencies for effective and responsible management of the Nation's highway pavement infrastructure.

CHAPTER 2—ACPT TECHNOLOGY ACTIVITIES

Introduction

This section presents a summary of the broad range of efforts underway by many agencies and industry organizations to improve concrete pavement technology.

FHWA Initiatives

Concrete Pavement Technology Program

CPTP, initiated in 2001 and completed in 2009, was a national program of research, development, and technology transfer that operated within the Office of Pavement Technology of FHWA. The focus of the program was on implementing improved methods of designing, constructing, evaluating, and rehabilitating PCC pavements to promote cost-effective designs and long-term performance for Federal-aid highways. Four goals were established for the CPTP early in its development, reflecting critical needs within the area of concrete pavements:

- Reduce user delays.
- Reduce costs.
- Improve performance.
- Foster innovation.

These goals addressed the needs of the State DOTs, the concrete pavement industry, and the highway user, while supporting FHWA's strategic goals to improve the mobility, productivity, and safety of the Nation's highway system by developing longer lasting, better performing pavements with safer, smoother rides and reduced congestion caused by construction work zones.

The CPTP initiative encompassed a broad range of projects, ranging from materials research to field testing of new technologies, from the development of computer programs to the implementation of technology transfer activities. For purposes of categorization, the CPTP initiative was divided into six focus areas relating to various aspects of concrete pavements (Tayabji and Smith 2004):

1. Advanced Designs.
2. Improved Materials.
3. Improved Construction Processes.
4. Rapid Repair and Rehabilitation.
5. Enhanced User Satisfaction.
6. Trained Work Force.

More than 30 projects, referred to as tasks, were included in these focus areas, and each was closely tied to the overall goals and objectives of the program. A summary of the key products developed under CPTP is given below:

Focus Area 1: Advanced Designs: Projects in this area studied ways to improve or advance pavement structural designs. Key products include the following:

- Improved procedures for design of whitetopping overlays.

- Status of high-performance concrete pavements.
- Alternative dowel bars for load transfer in jointed concrete pavements.
- Guidelines for determining need for transverse joint sealing.
- AASHTO provisional specification on determination of concrete coefficient of thermal expansion (CTE).

Focus Area 2: Improved Construction Materials: Projects in this area studied ways to improve or advance concrete material selection processes and concrete mix design procedures to result in durable concrete paving mixes that can be placed and finished effectively for slipform operations. Key products include the following:

- Guidelines for identifying incompatible combinations of concrete materials.
- Improved guidelines for optimizing project specific concrete mixtures.
- Improved procedures for evaluating concrete durability.

Focus Area 3: Improved Construction Processes: In this focus area, CPTP projects studied the use of new or innovative equipment and technologies for improving all aspects of concrete pavement construction. Key products include the following:

- Guidelines for construction traffic management.
- Enhanced software programs for managing concrete paving (HIPERPAV II).
- Field evaluations of performance-related specifications (PRS).
- Field demonstrations of new testing equipment and technologies (e.g., MIT Scan devices).
- Guidelines for concrete curing.

Focus Area 4: Rapid Repair and Rehabilitation: Projects in this area studied ways to improve or advance concrete pavement rehabilitation technologies that would allow for faster and more durable repair and rehabilitation/reconstruction of concrete pavements. Key products include the following:

- Guidelines for repair of ultrathin whitetopping.
- Guidelines for rapid urban concrete pavement reconstruction.
- Precast pavement for full-depth repair of concrete pavements.
- Precast pavement for asphalt concrete and concrete pavement rehabilitation and reconstruction.
- Improved guidelines and strategies for concrete pavement rehabilitation.
- Improved guidelines for concrete pavement restoration techniques.

Focus Area 5: Enhanced User Satisfaction: In this focus area, the CPTP projects were aimed at increasing user satisfaction by reducing congestion and improving functional performance. Key products include the following:

- Guidelines on pavement surface texturing.
- Pavement Profile Viewer and Analyzer (ProVAL 2.0) software.
- Determination of the effect of materials properties on pavement smoothness.
- Guidelines for specifying and constructing pavements that are smooth and have good long-term performance.

Focus Area 6: Trained Work Force: CPTP Focus Area 6 was directed at ensuring that appropriate training was made available in a timely manner. The principal products of Focus Area 6 were the development, integration, and presentation of training for various aspects of the CPTP.

Concrete Pavement Road Map

The CP Road Map is a 10-year, innovative, strategic plan that outlines the use of approximately $250 million in needed concrete pavement research. Published in late 2005, the Road Map's official title is “Long-Term Plan for Concrete Pavement Research and Technology.” The CP Road Map was developed under FHWA’s CPTP Task 15 and is currently administered by the National Concrete Pavement Technology Center (NCPTC), based at Iowa State University in Ames. The CP Road Map combines more than 250 problem statements into 13 integrated research tracks. Each track has specific goals and a path for reaching the goals. The tasks are listed below:

1. Performance-Based Concrete Pavement Mix Design System.
2. Performance-Based Design Guide for New and Rehabilitated Concrete Pavements.
3. High-Speed Nondestructive Testing and Intelligent Construction Systems.
4. Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements.
5. Concrete Pavement Equipment Automation and Advancements.
6. Innovative Concrete Pavement Joint Design, Materials, and Construction.
7. High-Speed Concrete Pavement Rehabilitation and Construction.
8. Long-Life Concrete Pavements.
9. Concrete Pavement Accelerated and Long-Term Data Collection.
10. Concrete Pavement Performance.
11. Concrete Pavement Business Systems and Economics.
12. Advanced Concrete Pavement Materials.
13. Concrete Pavement Sustainability.

The concept for funding projects under the CP Road Map is that stakeholders will voluntarily align opportunities to pool funds and intellectual resources in ad hoc research collaborations. As an example, State agencies are providing support for the Road Map by joining FHWA pool-funded studies to support several high-priority projects. Currently (as of March 2009) the following activities are in progress (NCPTC 2009):

Active Tracks

1. Performance-Based Concrete Pavement Mix Design System.

Launching Tracks

2. Performance-Based Design Guide for New and Rehabilitated Concrete Pavements.
4. Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements.
11. Concrete Pavement Business Systems and Economics.
13. Concrete Pavement Sustainability.

The Alkali-Silica Reactivity Program

SAFETEA-LU Section 5203 (e) established funding for furthering the development and deployment of techniques to prevent and mitigate ASR. Funding was provided for $10 million over 4 years. The ASR Development and Deployment Program (ASRDDP) activities were initiated during 2005 (FHWA 2009a). The ASRDDP includes research activities as well as field demonstration projects. As part of the field program, FWHA will make funding available to

States for the implementation of technologies and techniques to prevent and mitigate ASR. Currently, it is anticipated that field trials can be implemented by the end of 2009.

One of the tasks under ASRDDP is the development of three ASR protocols, targeted to assist State highway agencies with their ASR problems. The three protocols are as follows:

- Protocol A: Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in Concrete.

- Protocol B: Diagnosis and Prognosis of Alkali-Aggregate Reaction in Transportation Structures.

- Protocol C: Selection of Mitigation Measures for Alkali-Aggregate Reactive-Affected Structures.

The research projects initiated during 2008 include the following:

- Objective 1: Advancing the fundamental understanding of the ASR mechanism and developing a concrete mixture design process that is resistant to the ASR phenomenon.

- Objective 2: Developing a reliable, improved, rapid laboratory test method to evaluate concrete mixture design to predict field performance.

- Objective 3: Nondestructive field test methods for evaluation of concrete structures for the presence of ASR to determine concrete deterioration rates and predict future expansion.

- Objective 4: Develop cost-effective methods to control ASR and extend the service life of existing highway structures.

Cooperative Agreements

In the past few years, FHWA has entered into three cooperative agreements with outside agencies to advance concrete pavement design and construction technologies in support of the CPTP:

1. *Technology Transfer of Best Practices for Concrete and Concrete Pavements*—American Concrete Institute (ACI). This agreement will provide education and training activities for FHWA's customers and partners, including the following deliverables:

    - Training materials for seminars, workshops, and conferences, including a training syllabus and related materials needed by State DOTs to prepare their inspectors for the ACI Transportation Inspector Certification test; and updates of materials used in FHWA-sponsored seminars.

    - Seminars and related training activities for State DOTs, FHWA field offices, and members of the concrete industry.

    - Conferences for the highway community, including the coordination of a process for FHWA's participation in and funding of up to three conferences per year.

2. *Advancement of Continuously Reinforced Concrete Pavement Through Technology Transfer and Delivery of Industry Guidance for Design and Engineering*—Concrete Reinforcing

Steel Institute. Products of the ongoing agreement include technical guides addressing the design, construction, and repair and rehabilitation of CRCP that are available for review and implementation by highway agencies. Deliverables include the following:

- A strategy for technology transfer of CRCP guidance, including a national communications plan to develop a shared sense of purpose among all of FHWA's partners and customers in the States, the concrete pavement industry, and related supplier groups.

- Conferences, seminars, and workshops for those stakeholders.

- A strategy for assisting State DOTs in accepting and implementing industry guidance for design and engineering of CRCP.

3. *Advancement of the Precast Prestressed Concrete Pavement System Through Technology Transfer and Development of Industry Guidance for Design and Engineering*—Precast-Prestressed Concrete Institute. This agreement will encourage timely acceptance and technically sound implementation of precast prestressed concrete pavement (PPCP) as a proven alternative pavement system. It includes the following deliverables:

   - A strategy for technology transfer on the PPCP system in the agency/owner and industry communities, including preparation and distribution of informational flyers, videos, and technical reports.

   - A strategy for industry guidance of design and engineering of the PPCP system, including organization of program activities among the agency/owner and industry communities through technical committee meetings and related activities.

FHWA Pavement Surface Characteristics Program

The FHWA Pavement Surface Characteristics (PSC) Program considers smoothness, friction, tire–pavement noise, and splash/spray in an integrated manner. The PSC Program is aimed at improving the ride on the National Highway System and to provide pavement surface texture that meets the dual needs of highway safety and lower pavement noise. FHWA also anticipates starting work on an improved functional performance indicator.

FHWA has established ride targets for all National Highway System roads (FHWA 2009b). As of January 2009, these targets are an International Roughness Index (IRI) of 95 in/mi (or less) as the primary performance target, with the secondary performance target of 170 in/mi (or less).

With respect to improving ride quality, FHWA-sponsored activities include development and delivery of customized pavement smoothness workshops, improved pavement smoothness specifications using inertial profilers, advanced pavement profile analysis software (ProVAL), and use of advanced profile measurement technology (ultra-light inertial profiler).

With respect to pavement surface texture, current work sponsored by FHWA is focused on addressing noise-related issues. These activities include improved pavement/tire noise-measurement techniques, comprehensive program of data collection and analysis on new and existing pavements, splash and spray reduction, and development of innovative texturing techniques that have the potential to significantly reduce noise.

Office of Pavement Technology Projects

In addition to FHWA's program initiatives, a number of activities are being conducted by the FHWA Office of Pavement Technology, including the following:

1. *Pavement Design and Analysis Support*—Provide assistance to State highway agencies for implementation of the Mechanistic-Empirical Pavement Design Guide (MEPDG). The assistance will include various products for implementation of this new design procedure including deployment of innovative equipment, materials, tools, and techniques as well as working with partners to improve pavement design, performance, and rehabilitation.

2. *Materials and Construction Technology Support*—Evaluate and refine innovative materials and construction techniques that will provide a durable long-life pavement and develop strategies for deploying these technologies to state highway agencies on active field projects. Several of the research products from FHWA's Turner-Fairbank Highway Research Center, such as HIPERPAV, CTE, and SmartCure, will be refined through on-site demonstrations to State highway agencies. Other technologies to be evaluated include air void analyzer testing, MIT SCAN evaluation of dowel bar alignment, and pavement thickness as well as other emerging technologies as a result of Track 2 of the CP Road Map.

3. *Quality Assurance Program Effectiveness*—Provide State DOTs with guidelines for the implementation of both quality control (QC) procedures and quality assurance (QA) in an effort to advance the state of the practice for those tests that affect the long-term performance of pavements during the mixture design, mixture verification, and construction phases of a project. This project will build upon the results of the 17-State pooled-fund study, "Material and Construction Optimization for Prevention of Premature Distress in PCC Pavements," which resulted in a testing guide for QC procedures. This activity will collect data on actual field projects, demonstrate appropriate quality control techniques for ensuring a quality product, and stress other factors that affect the long-term durability of concrete pavements beyond measuring compressive strength.

4. *Coefficient of Thermal Expansion of Concrete*—Conduct a study of as many current users of manual and Gilson CTE devices as possible to determine the differences in CTE measurements as well as the variability in the different CTE devices. FHWA is soliciting State DOT laboratories and university research centers with the CTE equipment capability to conduct CTE testing of three specimens for this study. It is anticipated that at least 15 laboratories will participate. This exercise would yield enough information to determine within-lab and between-lab variability for the CTE devices. The study is not aimed at determining precision and bias for the AASHTO TP 60 test method. It is intended to obtain some understanding of the variability in CTE test results with various measuring devices.

Turner-Fairbank Highway Research Center Activities

The TFHRC, in McLean, Virginia, oversees federally funded research and conducts research in several areas of highway technology, including concrete pavement design and performance. Among the studies on concrete pavements currently being overseen by TFHRC are the following:

- Long-Term Pavement Performance (LTPP) program. An ongoing program that involves evaluation of pavement performance at hundreds of pavement test sections that include concrete pavements. Data collected from these test sections are being used to improve pavement design, construction, and rehabilitation practices.

- Refining PPCP technology for slab replacement under bridges. This study is aimed at addressing a research need identified in FHWA's National Concrete Pavement Road Map (FHWA Report No. HT-05-053). Design details for precast, post-tensioned slabs will be refined and tested in the laboratory.

- Evaluating the NCHRP 1-37A rigid pavement performance models. This study involves examining the predictions obtained from the MEPDG software developed under NCHRP 1-37A for cracking, faulting, spalling, punchouts, and IRI for concrete pavements.

- Evaluating lithium-based methods for mitigating ASR in concrete and documenting the benefits of the most promising methods.

- Developing a system for monitoring pavement properties using embedded sensors. This study will develop a sensor system for continuously monitoring both the early-age and long-term physical properties of concrete or asphalt pavements.

- Enhancing the current computer-based guidelines for concrete pavements (HIPERPAV III). This study will add new features to the HIPERPAV software, including improved sensitivity analysis capabilities, enhanced curing and moisture-transport prediction capabilities.

- Incorporating the MEPDG prediction models for jointed plain concrete pavement (JPCP) into the PaveSpec PRS software. This effort will produce a new version of the PaveSpec software and user manual and provide guidance to State DOTs on developing both job-specific and statewide PRS for JPCP.

- Integrating software to optimize design, construction, evaluation, and performance of concrete pavements. Software products to be considered for integration under this contract include PaveSpec, SpecRisk, Prob.O.Prof (Probabilistic Optimization for Profit), COMPASS, HIPERPAV, and SAPER, which have undergone various degrees of implementation.

- Determining the application of second-generation fiber-reinforced polymer (FRP) technology to pavements. This study is investigating and developing two FRP applications in concrete pavements—FRP dowels for JPCP and FRP rebars for CRCP.

- Expanding, improving, and upgrading Prob.O.Prof. Prob.O.Prof is a software tool that can be used by contractors to help decide what quality levels to target under QA specifications and by highway agencies to help validate their specifications. The new version (Prob.O.Prof 2.0) is improved and has been expanded to cover other PCC paving acceptance quality characteristics, several State specifications, and asphalt paving.

State Department of Transportation Initiatives

Several State DOTs maintain an active program of research related to concrete pavements to meet specific local needs. The research may be conducted in-house, awarded to local universities, or contracted to outside organizations. Examples of concrete pavement–related research programs at State DOTs include the following:

Caltrans

- Evaluation of dowel-bar retrofit strategy

- Development and implementation of a mechanistic-empirical pavement design procedure for rigid and flexible pavements in California
- Quieter Pavement Research Program—Concrete Pavements
- Continued refinement of simulation software for constructability analysis—*CA4PRS* (Construction Analysis for Pavement Rehabilitation Strategies)
- Long-life concrete pavement design (JCP and CRCP)
- Sustainable concrete pavements
- PCC durability
- Dowel bar performance at JPCP Joints
- Quiet and smooth PCCP
- Abrasion-resistant PCCP
- Nondestructive testing for pavement thickness determination
- Precast concrete pavement use for rapid repair and rehabilitation

Colorado DOT
- Thin concrete overlays over existing concrete pavements
- Implementation of the AASHTO MEPDG

Delaware DOT
- Performance of precast prestressed roadway slabs
- Performance of PCC inlay

Iowa DOT
- TR-505 Improving Portland Cement Concrete Mix Consistency and Production Rate Through Two-Stage Mixing
- TR-520 Evaluation of Dowel Bar Retrofits for Local Road Pavements
- TR-587 Impact of Low Shrinkage Mixes on Late-age Random Cracking in Pavements With Use of Early Entry Sawing
- TR-600 Improving Concrete Overlay Construction
- Development of Performance Properties of Ternary Mixes, Phase I
- Self-Consolidating Concrete—Applications for Slip Form Paving, Phase 2

Illinois DOT
- Development of an improved specification for maximum plastic concrete temperatures (study at the University of Illinois)

Kansas DOT
- Improve the Life Expectancy of PCCP Using Low Permeability Concrete Mixtures

Minnesota DOT
- MnRoad test sections (Phase II studies)
- Unbonded concrete overlays
- Pervious concrete pavement and overlay
- PCCP surface characteristics—construction- and rehabilitation-related
- High-performance concrete pavement
- SHRP 2 composite pavement study
- Thin whitetopping design procedure (pooled-fund study)
- Quiet concrete pavements using an innovative diamond-grinding process
- Application of intelligent compaction

Missouri DOT
- Thin unbonded concrete overlay with geo-fabric interlayer

Texas DOT

- Using cement paste rheology to predict concrete mix design problems
- Use of manufactured sands for concrete paving (at University of Texas)

Virginia DOT

- Precast pavement applications for rapid rehabilitation of concrete pavements

Washington DOT

- Implementation of MEPDG
- Improved mix designs to reduce studded tire wear

West Virginia

- FRP bars for CRCP

Many State DOTs also participate in the FHWA-coordinated Transportation Pooled Fund (TPF) Program that allows Federal, State, and local agencies and other organizations to combine resources to support transportation research studies. The current TPF studies related to concrete pavements are listed in Table 1.

Table 1. Transportation Pooled-Fund Program Studies Related to Concrete Pavements

Project No.	Title
Cleared by FHWA	
TPF-5(188)	Evaluation of Fiber-Reinforced Composite Dowel Bars and Stainless Steel Dowel Bars
TPF-5(183)	Improving the Foundation Layers for Concrete Pavements
TPF-5(165)	Development of Design Guide for Thin and Ultrathin Concrete Overlays of Existing Asphalt Pavements
TPF-5(150)	Extending the Season for Concrete Construction & Repair, Phase III
TPF-5(141)	Pavement Surface Properties Consortium: A Research Program
TPF-5(139)	PCC Surface Characteristics: Tire–Pavement Noise Program Part 3—Innovative Solutions/Current Practices
TPF-5(135)	Tire/Pavement Noise Research Consortium
TPF-5(134)	PCC Surface Characteristics—Rehabilitation (MnROAD Study)
TPF-5(117)	Development of Performance Properties of Ternary Mixes
Contract Signed	
TPF-5(079)	Implementation of the 2002 AASHTO Design Guide for Pavement Structures
TPF-5(179)	Evaluation of Test Methods for Permeability (Transport) and Development of Performance Guidelines for Durability

National Cooperative Highway Research Program

Administered by TRB and sponsored by the member departments of AASHTO (i.e., individual State DOTs) in cooperation with FHWA, the National Cooperative Highway Research Program (NCHRP) conducts research in acute problem areas that affect highway planning, design, construction, operation, and maintenance nationwide. NCHRP-sponsored projects have resulted in many improvements in concrete materials and concrete pavement technology over the last 40-plus years. Projects recently completed, ongoing, and planned for 2009 that are of interest to the ACPT program include the following:

1. *NCHRP 1-40B—User Manual and Local Calibration Guide for the Mechanistic-Empirical Pavement Design Guide and Software*. The objective of this project is to prepare (1) a user manual for the MEPDG and software and (2) a detailed, practical guide for highway agencies for local or regional calibration of the distress models in the MEPDG and its accompanying design guide software. The manual and guide will be presented in the form of draft AASHTO recommended practices; the guide will contain two or more examples or case studies illustrating the step-by-step procedures.

2. *NCHRP 1-40D (02)—Technical Assistance to NCHRP and NCHRP Project 1-40A: Versions 0.9 and 1.0 of the M-E Pavement Design Software*. The objectives of this project are to (1) work in coordination with the contractor for Project 1-40D(02) to produce improved, corrected versions 0.9 and 1.0 of the M-E Pavement Design Guide software and (2) provide ongoing troubleshooting support for NCHRP and FHWA.

3. *NCHRP 1-44—Measuring Tire-Pavement Noise at the Source*. The objectives of this research are to (1) develop rational procedures for measuring tire-pavement noise and (2) demonstrate applicability of the procedures through testing of in-service pavements.

4. *NCHRP 1-46—Handbook for Pavement Design, Construction, and Management*. The objective of this research is to develop a handbook that addresses design, construction, and management aspects of pavements. The *Handbook* shall be prepared in an interactive-electronic, easily editable format with a printer-friendly option, suitable for consideration and adoption by AASHTO.

5. *NCHRP 1-47—Sensitivity Evaluation of MEPDG Performance Prediction*. The objective of this research is to determine the sensitivity of the performance predicted by the MEPDG to variability of input parameter values. The research will deal with all types of flexible and rigid pavements included in the MEPDG. The research shall be conducted using the MEPDG software version available as of October 1, 2008.

6. *NCHRP 18-13—Specifications and Protocols for Acceptance Tests of Fly Ash Used in Highway Concrete.* The objective of this research is to recommend potential improvements to specifications and test protocols to determine the acceptability of fly ash for use in highway concrete.

7. *NCHRP 21-09—Intelligent Soil Compaction Systems*. The objectives of this research are to determine the reliability of intelligent compaction systems and to develop recommended construction specifications for the application of intelligent compaction systems in soils and aggregate base materials. Intelligent compaction involves the use of rollers that are equipped with a control system that can automatically adjust compactive effort in response to a materials modulus during the compaction process.

8. *NCHRP 04-36—Characterization of Cementitiously Stabilized Layers for Use in Pavement Design and Analysis.* The objective of this research is to recommend performance-related procedures for characterizing cementitiously stabilized pavement layers for use in pavement design and analysis and incorporation in the MEPDG. The research will deal with material properties and related test methods that can be used to predict pave-

ment performance. This research is concerned with subgrade, subbase, and base materials stabilized with hydraulic cement, fly ash, lime, or combinations and used in flexible and rigid pavements.

Strategic Highway Research Program 2

Congress established the second Strategic Highway Research Program (SHRP 2) in 2006 to investigate the underlying causes of highway crashes and congestion in a short-term program of focused research. To carry out that investigation, SHRP 2 has targeted goals in four interrelated focus areas:

1. Safety: Significantly improve highway safety by understanding driving behavior in a study of unprecedented scale

2. Renewal: Develop design and construction methods that cause minimal disruption and produce long-lived facilities to renew the aging highway infrastructure

3. Reliability: Reduce congestion and improve travel time reliability through incident management, response, and mitigation

4. Capacity: Integrate mobility, economic, environmental, and community needs into the planning and design of new transportation capacity

The renewal focus area has several studies that are looking at ways to extend the service life of existing concrete pavements as well as to accomplish rapid repair and rehabilitation of concrete pavements. The specific projects dealing with concrete pavements include the following:

1. *R05: Modular Pavement Technology*. The objective of this project is to develop tools for public agencies to use for the design, construction, installation, maintenance, and evaluation of modular pavement systems. It is anticipated that these tools should include, at a minimum: a) guidance on the potential uses of modular pavement systems for specific rapid renewal applications; b) generic design criteria; c) project selection criteria; d) guidelines and draft or model specifications for construction, installation, acceptance, and maintenance; and e) a long-term evaluation plan to assess the performance of modular systems and lead to refinements in designs and materials.

2. *R06: A Plan for Developing High Speed, Nondestructive Testing Procedures for Both Design Evaluation and Construction Inspection*. The overall objective of this work is to develop a process to identify existing or, if necessary, to develop new and quickly implementable technologies for rapid, nondestructive testing of *in situ* conditions for purposes of design, construction inspection, and performance monitoring. These technologies would limit or reduce traffic disruption on existing facilities during preliminary engineering investigations and provide more rapid and reliable information on as-built conditions. Similarly, rapid inspection of new construction would facilitate timely reopening of roadways and structures during reconstruction.

3. *R06B: Evaluating Applications of Field Spectroscopy Devices to Fingerprint Commonly Used Construction Materials.* The purpose of this project is to identify and evaluate practical hand-held equipment for quantitative analyses of applications such as the following (as applicable to concrete pavements):

- Quality and uniformity of curing compounds.
- Quality and uniformity of epoxy materials used for concrete spall repair.
- Quality and uniformity of cement and/or concrete.

An additional objective is to develop relatively simple and easy-to-use nondestructive procedures and protocols that inspectors and front-line personnel could use in the field to ensure quality construction.

4. *R06E: Real-Time Smoothness Measurements on Portland Cement Concrete Pavements During Construction*. The purpose of this project is to enable real-time control of concrete pavement smoothness during construction by providing a) proven technologies for measuring smoothness in real time; and b) model specifications and guidelines for use by transportation agencies.

5. *R06F: Development of Continuous Deflection Device*. The objective of this project is to critically assess the potential of existing continuous deflection devices as a practical and cost-effective tool for use in the development of optimum pavement rehabilitation strategies on rapid renewal projects.

6. *R07: Performance Specifications for Rapid Renewal*. The objectives of this project are the following:

   - Reduce the completion time of renewal projects while maintaining or improving quality.
   - Encourage further innovation by reducing mandatory method requirements and defining the end products.
   - Develop different specifications that can be used effectively in various contracting scenarios (design-bid-build, design-build, warranties, etc.).
   - Develop recommendations on the transition to the use of these specifications (i.e., an implementation plan).
   - Quantify relative shared risk between project owners (State DOTs) and contractors and between contractors and subcontractors through the use of warranties and guarantees and identify strategies to equitably manage and minimize the short- and long-term risk to all parties.

7. *R21: Composite Pavement Systems*. This project will investigate the design and construction of new composite pavement systems, and not those resulting from the rehabilitation of existing pavements. The research will focus on two promising applications of composite pavement systems: a) an asphalt layer(s) over a PCC layer and b) a PCC surface over a PCC layer. Specifically this effort shall:

   - Determine the behavior and identify critical material and performance parameters.
   - Develop and validate mechanistic-empirical performance models and design procedures consistent with the MEPDG.
   - Recommend specifications, construction techniques, and quality management procedures.

8. *R23: Using Existing Pavement in Place and Achieving Long Life*. The objective of this project is to provide guidance to public agencies for achieving long-lived pavements, reducing construction time, and minimizing the impact to the public by utilizing existing pavement in place in a rapid renewal environment. Specifically this project will:

    - Identify approaches for using existing pavements in-place for rapid renewal projects.
    - Determine the advantages and disadvantages for each approach under different project conditions.
    - Develop detailed criteria on when an existing pavement can be used in place, with or without significant modification.
    - Identify practices and techniques to construct these types of pavements in a rapid renewal environment.
    - Determine the optimal way to integrate the renewed pavement with adjacent pavements and structures.

9. *R26: Preservation Approaches for High Traffic Volume Roadways*. The objective of this project is to develop guidelines on pavement preservation strategies for high traffic volume roadways that can be used and implemented by public agencies. A secondary objective is to identify promising preservation strategies for application on high traffic volume roadways that may not commonly be used and make recommendations for further research opportunities.

Industry-Sponsored Developments

The industry continues to maintain an active program to support research in high-priority areas of interest to specific industry organizations. Industry research in concrete pavement technology is being carried out as follows:

1. By the American Concrete Pavement Association (ACPA).
2. By the Innovative Pavement Research Foundation (IPRF).
3. By individual vendors of products (material and equipment).

ACPA research projects that have recently been completed include the following:

1. *Longitudinal Joint Requirements for Concrete Pavements (Phase II)*—This project is reevaluating the longitudinal joint tie bar system design process and developing an improved design procedure that accounts for the critical factors involved. During the development of the NCHRP 1-32 Design Catalog, several State, FHWA, and industry concrete pavement experts assembled to provide input into many details of concrete pavement design concluded that the “subgrade drag theory” was inadequate and should not be used for design purposes. Thus, there is no valid design procedure available, and an urgent need exists for improved design of tie bars that considers this past performance but provides a more rational way of designing the tie system between traffic lanes and lanes and shoulders. This will allow for a more reliable and optimal design for the many variations of site conditions (number of lanes, shoulders, base types, truck traffic levels, PCC mixes, pavement designs, and climates).

2. *Development of Robust and Practical Dowel Bar Guidelines for the Concrete Paving Industry*—Alternative dowel bar designs can prove cost effective while at the same time increasing the performance of roads significantly. With the proliferation of widening and urban applications of jointed concrete pavements and overlays, guidance is needed to optimize dowel designs that can fit to “real world” constraints that may preclude the use of today’s typical sections. DowelCAD 2.0 aims to aid designers in analyzing the effects of various dowel bar configurations and types, and to provide guidance on means to make such alternate designs feasible. The models in DowelCAD are based on fundamental mechanistic equations of beam behavior and the dowel-concrete interaction including work by Timoshenko, Westergaard, Skarlatos, Friberg, Colley, and Humphrey and by Ioannides. The finite element method developed by Huang is also used to characterize more global slab behavior.

The IPRF-sponsored projects, directed at airfield applications but having application to the ACPT Program, include the following:

1. Project 06-1—Concrete Mixes Using Flyash

2. Project 04-8—ASR Mitigation Studies

3. Project 04-6—Lithium Admixtures and Early-Age Properties of Production Concrete

4. Project 03-8—Field Trial and Evaluation of Innovative Concrete Pavement Technologies or Practices for Airport Pavements

5. Project 03-10—Selected Methods for Mitigating ASR in Affected Airfield Pavements

6. Project 05-5—Concrete Mixes Using Ground Granulated Blast Furnace Slag

7. Project 06-4—Demonstration Project: Study the Combined Aggregate Concepts of the ASTM C-1260 Test

8. Project 05-02—Joint Load Transfer Efficiency—Concrete Airfield Pavements

9. Project 05-03—Highway Materials for Airfield Pavement (Concrete)

The industry-sponsored research applicable to concrete pavement is typically of a proprietary nature. The research involves development of advanced construction materials, improved construction techniques, new testing equipment, and improved or new construction equipment.

International Research and Development Programs

The research activities in Canada, Europe, and Japan that are related to the ACPT Program are summarized below:

Canada

1. Evaluation of pervious concrete pavement (Ontario).
2. FHWA-Ministry of Transport Ontario quiet texturing project.
3. Evaluation of dowel bar alignment using the MIT Scan (Ontario).
4. Evaluation of precast concrete slabs for concrete pavement repairs (Ontario, Quebec).

5. Use of galvanized steel as reinforcement for CRCP (Quebec).
6. Various studies on ASR being conducted at several Canadian universities.

Europe

1. Modie Slab precast concrete pavement (The Netherlands).
2. Advanced design and construction procedures for CRCP (Belgium).
3. Hexagonal shaped precast pavement for urban application (France).
4. Improved catalog design procedures for new concrete pavements (Germany).
5. Low-noise concrete pavement surface using exposed aggregate surface (Austria, Belgium, the Netherlands).
6. Higher strength concrete for pavement applications.
7. Optimizing concrete pavement design features (Austria, Germany).
8. Studies on ASR (Germany).

It should be noted that the Europeans have a different philosophy with respect to pavement design. The key differences with U.S. practices are the following:

- Use of field-proven catalog designs.
- Use of higher strength concretes.
- Use of thinner concrete slab.
- Use of a well-designed support system under the concrete slab.
- Routine use of widened outside lane and concrete shoulder in urban areas.

Japan

1. Composite pavement performance—study of asphalt surface course with a continuously reinforced concrete base course.

2. Application of precast reinforced concrete slab pavements at airports.

3. Evaluation of the performance of porous concrete pavements in Japan.

4. Structural design method of precast reinforced concrete pavement with consideration of concrete and steel fatigue.

South Africa

1. Ultrathin CRCP.

Summary

As noted in this section, a wide range of activities have recently been completed, are in progress, or will be initiated soon to continue to advance concrete pavement technologies. The promising products from these technologies will include software, draft standards, guide documents, and other technology transfer materials. A discussion of the promising technologies, for possible implementation under the ACPT Program, is presented in the next section.

CHAPTER 3—ACPT PRODUCT AVAILABILITY

Introduction

To provide an understandable framework for ACPT products, the promising products are categorized by focus areas. The focus areas allow for a rational categorization of the many diverse ACPT products that show promise for deployment. A list of the most promising ACPT products already developed or to be developed within the next 3 to 5 years is provided next. The list is categorized in accordance with the following ACPT focus areas:

- *Focus Area 1: Advanced Designs*—ACPT projects in this area are investigating ways to improve or advance pavement structural designs and optimizing use of cost-effective design features.

- *Focus Area 2: Improved Construction Materials*—ACPT projects in this area are investigating ways to improve or advance concrete material selection processes and concrete mix design procedures to result in durable concrete paving mixes that can be placed and finished effectively for slipform operations.

- *Focus Area 3: Improved Construction Processes*—In this focus area, ACPT projects are investigating the use of new or innovative equipment and technologies for improving all aspects of concrete pavement construction.

- *Focus Area 4: Rapid Repair and Rehabilitation*—ACPT projects in this area are investigating ways to improve or advance concrete pavement rehabilitation technologies that will allow for faster and more durable repair and rehabilitation/reconstruction of concrete pavements.

- *Focus Area 5: Sustainable Concrete Pavements*—Sustainability is a term used to describe the broad notion that we, as a society, should be able to meet our present-day needs without compromising the ability of future generations to meet their needs. In pavement engineering, the goal is to make pavement systems, materials, products, and processes more sustainable. ACPT projects in this area are exploring ways to extend the service life of existing concrete pavements, extend the service life of new concrete pavements, reuse and recycle construction materials, and adopt processes that reduce the carbon footprint.

- *Focus Area 6: Enhanced User Satisfaction*—In this focus area, ACPT projects are aimed at increasing user satisfaction, which includes reducing congestion and improving functional performance (ride, safety, noise).

List of Recommended ACPT Products for Deployment

The following is a summary of the ACPT products identified for possible deployment over the next 5 years. The information is based on information on advanced concrete pavement technology activities presented in Chapter 2. The selection of these promising products was based on the following factors:

1. Need for improved technology and identification of critical gaps.
2. Potential cost savings—new construction and rehabilitation.

3. Potential construction time savings.
4. Potential resource conservation.
5. New innovation or concept.
6. Impact on user ride and safety.
7. Environmental benefits.
8. Sustainability benefits.
9. Workforce training benefits.

ACPT Program Focus Area 1: Advanced Designs

1. Mechanistic-Empirical Concrete Pavement Design
   a. NCHRP-developed and AASHTO-approved MEPDG (AASHTO 2008)

2. Concrete Overlays Design
   a. NCPTC-funded project
   b. Pooled-fund project

3. Concrete Pavement Design Catalogs
   a. Based on the European approach, using the MEPDG
   b. State DOT approaches

4. Advanced Concepts for Joint Design
   a. Industry initiatives/DOT best practices—Optimizing round dowel bar design (diameter, length, spacing)
   b. Industry products—Corrosion-protection for load-transfer devices (clad dowels)
   c. ACPA study/European guidelines—Optimized tie-bar design

5. Optimizing Design Features and Life Cycle Costs
   a. CPTP findings—Best practices for joint sawing and sealing
   b. NCHRP findings and FHWA guidelines—Best practices for pavement drainage
   c. Edge strengthening—Widened lane and tied concrete shoulder
   d. European approach—Improved foundation versus slab thickness
   e. European approach—High-strength concrete versus slab thickness
   f. European approach—Concrete slab/stabilized base interface—asphalt concrete interlayer and thick geotextile
   g. Best practices catalog of design sections

6. Innovative Design Procedures for Concrete Pavements (CRCP, Prestressed, Precast, roller-compacted concrete pavement [RCCP])
   a. FHWA/Concrete Reinforcing Steel Institute cooperative agreement project—Improved CRCP design guidelines
   b. FHWA/Precast-Prestressed Concrete Institute cooperative agreement project—Improved precast concrete pavement guidelines
   c. Portland Cement Association—Best practices for RCC shoulder
   d. Texas DOT—Cast-in-place prestressed concrete pavement design

ACPT Program Focus Area 2: Improved Construction Materials

1. Optimizing Use of Recycled Materials

2. Advanced High-Performance Materials

   a. Lower cost materials
   b. Longer lasting materials (greater durability)
   c. Replacement materials
   d. Additive materials that extend or improve performance of conventional materials
   e. New/innovative materials

3. Concrete Mixture Optimization
   a. Optimizing workability, strength, and durability using the FHWA COMPASS software and other industry-developed procedures

4. Concrete Durability
   a. ASR test protocols
   b. ASR prevention guidelines
   c. ASR mitigation guidelines

5. Concrete Testing
   a. Improved air void analyzer
   b. Improved impact-echo testing
   c. Improved permeability testing
   d. Remaining service life assessment
   e. Workability testing
   f. Improved coefficient of thermal expansion testing
   g. Testing for concrete material compatibility
   h. Accelerated strength testing

ACPT Program Focus Area 3: Improved Construction Processes

1. Improved Processes for Construction Process Control and Acceptance Testing
   a. Dowel alignment testing
   b. In-situ concrete density testing
   c. Surface texture testing
   d. Concrete slab thickness testing
   e. Smoothness testing

2. Performance-Related and End-Product Specifications
   a. PRS

3. Improving Concrete Pavement Performance and Sustainability Through Two-Lift Construction

ACPT Program Focus Area 4: Rapid Repair and Rehabilitation

1. Rapid Pavement Condition Evaluation
   a. Improved guidelines for falling-weight deflectometer load-transfer efficiency testing
   b. Remaining service life assessment

2. Rapid Rehabilitation and Reconstruction of High-Volume Facilities
   a. Nighttime construction
   b. Weekend construction
   c. Full-closure construction

3. Precast Panels for Repair (Tayabji et al. 2009)

   a. FHWA/generic systems
   b. U.S. proprietary systems

4. Precast Panels for Reconstruction and Rehabilitation (Merritt and Tayabji 2009)
   a. FHWA PPCP system
   b. U.S. proprietary system
   c. Non-U.S. systems

5. Innovative Repair and Rehabilitation Processes
   a. Industry-developed repair materials

6. Construction Traffic Management
   a. Software—Minimize lane closures (FHWA 2009c)

ACPT Program Focus Area 5: Sustainable Concrete Pavements

1. Sustainable Pavement Designs
   a. Two-lift concrete slabs

2. Sustainable Use of Construction Materials
   a. Recycled concrete aggregate use

3. Sustainable Construction Practices
   a. Improved construction traffic management

4. Sustainable Repair and Rehabilitation Processes

5. Catalog of Sustainable Concrete Pavement Practices

6. Environmental Life Cycle Analysis Tools

ACPT Program Focus Area 6: Enhanced User Satisfaction

1. Processes to Reduce Construction-Related Traffic Congestion
2. Innovative Pavement Surface Texturing for Safety and Noise Reduction
3. Techniques to Improve Pavement Ride

ACPT Product Matrix

The ACPT product matrix is summarized in Table 2.

Table 2. The Advanced Concrete Pavement Technology Program Product Matrix

No. A	CPT Product	FA 1 Design	FA 2 Materials	FA 3 Construction	FA 4 Rapid Repair /Rehab	FA 5 Sustainability	FA 6 User Satisfaction
1. Advanced Designs							
FA1-1	Mechanistic-Empirical Concrete Pavement Design	P				S	
FA1-2	Concrete Overlays Design	P				S	
FA1-3	Concrete Pavement Design Catalogs	P				S	
FA1-4	Advanced Concepts for Joint Design	P				S	
FA1-5	Optimizing Design Features and Life Cycle Costs	P				S	
FA1-6	Innovative Design Procedures for Concrete Pavements	P				S	
2. Improved Construction Materials							
FA2-1	Optimizing Use of Recycled Materials		P			S	
FA2-2	Advanced High-Performance Materials		P			S	
FA2-3	Concrete Mixture Optimization		P			S	
FA2-4	Concrete Durability		P			S	
FA2-5	Concrete Testing		P	S			
3. Improved Construction Processes							
FA3-1	Improved Processes for Construction Process Control and Acceptance Testing			P			
FA3-2	Performance-Related and End-Product Specifications			P			
FA3-3	Improving Concrete Pavement Performance and Sustainability Through Two-Lift Construction			P			

continued next page

Table 2. The Advanced Concrete Pavement Technology Program Product Matrix (continued)

No. A	CPT Product	FA 1 Design	FA 2 Materials	FA 3 Construction	FA 4 Rapid Repair /Rehab	FA 5 Sustainability	FA 6 User Satisfaction
4. Rapid Repair and Rehabilitation							
FA4-1	Rapid Pavement Condition Evaluation				P		
FA4-2	Rapid Rehabilitation and Reconstruction of High-Volume Facilities				P		
FA4-3	Precast Panels for Repair				P		
FA4-4	Precast Panels for Reconstruction and Rehabilitation				P		
FA4-5	Innovative Repair and Rehabilitation Processes				P		
FA4-6	Construction Traffic Management			S	P		S
5. Sustainable Concrete Pavements							
FA5-1	Sustainable Pavement Designs	S				P	
FA5-2	Sustainable Use of Construction Materials		S			P	
FA5-3	Sustainable Construction Practices			S		P	
FA5-4	Sustainable Repair and Rehabilitation Processes				S	P	
FA5-5	Catalog of Sustainable Concrete Pavement Practices					P	
FA5-6	Environmental Life Cycle Analysis Tools					P	S
6. Enhanced User Satisfaction							
FA6-1	Innovative Pavement Surface Texturing for Safety and Noise Reduction						P
FA6-2	Techniques to Improve Pavement Ride						P

P = primary; S = secondary

Deployment Timeline for ACPT Products

The timeline for delivery of the above promising ACPT products can be categorized as follows:

1. Immediate availability for delivery.

2. Within 24 months—product available, but requires further refinement or better packaging for delivery.

3. Under development—product available within 24 months.
   a. Product ready for delivery.
   b. Product may require further refinement or better packaging for delivery.

4. Under development—product available after 24 months.
   a. Product ready for delivery.
   b. Products may require further refinement or better packaging for delivery.

The specific timelines for the identified promising products will be included in the marketing plan to be developed under Task C of this contract.

Summary

A broad range of products are available or will soon be available to further advance concrete pavement technologies. These products have been categorized under six focus areas. Additional details on each product are provided in the next section.

CHAPTER 4—PROMISING ACPT PRODUCTS IN DETAIL

Introduction

This section presents details on each promising ACPT product identified in Chapter 3.

ACPT Program Focus Area 1: Advanced Designs

FA1-1: Mechanistic-Empirical Concrete Pavement Design (MEPDG)

Development of the MEPDG was sponsored by NCHRP under Project 1-37A. Initiated in 1996, the project developed a comprehensive approach to the design of pavement structures, with formal documentation produced in 2004 and ongoing refinements to the accompanying software program culminating in the release of version 1.0 in 2007.

Primary benefits of the new design guide are the improved reliability of the resultant designs and the ability to handle any and all combinations of materials, traffic, and climatic conditions. The current released version of the software is being implemented by many U.S. highway agencies. The implementation activities include characterizing locally available/used construction materials and developing local calibrations for the performance models used in the software.

There is a continuing need to support highways agencies with the implementation activities related to the MEPDG. The support can include workshops on the MEPDG, topical presentations, as well as development of best practices techbriefs.

Timeline for product delivery: Immediately
Product availability: AASHTO, State DOTs

FA1-2: Concrete Overlays Design

The need for optimizing preservation and rehabilitation strategies used to maintain the Nation's highway pavements has never been greater. Concrete overlays have a long history of use to preserve and rehabilitate concrete and asphalt pavements, and many of the practices are well established. However, of recent origin are techniques that use thinner concrete overlays with shorter joint spacing. Field experience over more than 15 years with the thinner concrete overlays under a range of traffic and site conditions has demonstrated their viability as a cost-effective solution to extend the service life of deteriorated asphalt and concrete pavements.

A current gap in concrete overlays technology is the absence of nationally validated rational design procedures for thin-bonded and unbonded concrete overlays of existing asphalt concrete and composite pavements. The availability of a rational design procedure will encourage many highway agencies to consider use of thin concrete overlays as alternates for rehabilitation of asphalt and composite pavements. Work is currently underway at the University of Illinois and University of Pittsburgh to develop improved design procedures for bonded concrete overlays.

Timeline for product delivery: Within 24 months
Product availability: NCPTC/University of Illinois, FHWA Pooled Fund Study

FA1-3: Concrete Pavement Design Catalogs

There has been continued interest in the development of concrete pavement catalog-based design procedures. These procedures typically use simple tabular format for establishing pavement designs and consider the key design parameters, such as traffic level and base/subbase/subgrade support condition. Design details, such as joint spacing, dowel bar use, use of a widened outside lane or a tied concrete shoulder are fixed. The Europeans use the design catalogs extensively for low-level as well as high-level roadways. The catalogs are based on field experience, theoretical analysis, and field and laboratory testing and are reviewed and modified, as necessary, on a 5-to-10-year cycle.

The MEPDG, when fully implemented, will involve a level of complexity that many highway agencies may not be able to respond to on a routine basis. As such, there will be a need to implement a simplified version of the MEPDG for routine pavement design determination. As part of the implementation of the new MEPDG, several highway agencies are expected to develop catalog-based design procedures. The industry, including ACPA, is also pursuing the development of design catalogs for concrete pavement design.

Timeline for product delivery: Within 24 months
Product availability: AASHTO MEPDG, State DOTs, European Catalogs,

FA1-4: Advanced Concepts for Joint Design

Considerable work has been performed recently to improve the performance of joints in concrete pavements. This work can be classified as follows:

1. Dowel bar material—corrosion resistant
    a. Corrosion-resistant steel (e.g., MMX)
    b. Clad steel bars
    c. Nonmetallic bars
    d. Advanced dowel bar coatings

2. Dowel bar design—shape (cross section), cross-sectional area (diameter), length, spacing

3. Impact of dowel misalignment on joint performance

4. Joint-sawing requirements
    a. Width of sawing
    b. Depth of sawing
    c. Timing of sawing

5. Need for a second sawcut (sealant reservoir)

6. Joint-sealing requirements

7. Tie-bar design for longitudinal joints

There is a need to develop best practices guidance based on findings from recently completed studies and based on newly implemented practices at several U.S. highway agencies.

Timeline for product delivery: Immediately

Product availability: State DOT specifications, NCHRP, FHWA

FA1-5: Optimizing Design Features and Life Cycle Costs

Recently, a CPTP project (CPTP Task 6) resulted in a process to evaluate the tradeoffs between performance benefits of design enhancements in concrete pavements and the costs of these added features. The process and the associated software are good educational tools for users who want to better understand concrete pavement design and its impact on construction costs and performance. There is a need to provide further refinement to the process by incorporating the analytical features and findings from detailed parametric studies using the MEPDG and using FHWA's RealCost software.

Timeline for product delivery: Within 24 months
Product availability: AASHTO MEPDG, State DOTs, FHWA RealCost software

FA1-6: Innovative Design Procedures for Concrete Pavements (CRCP, Prestressed, Precast, RCCP)

The MEPDG addresses primarily the needs for jointed concrete pavements. However, there is a need to provide better guidance to stakeholders for the design of CRCP, precast pavements, and RCCPs. Source material is available for the design of these pavement types.

In addition, there is work underway in South Africa related to design and performance of very thin CRCP and in Chile for design and performance of thin jointed concrete pavements. These innovative practices need to be evaluated and, if applicable, refined for application to U.S. conditions.

The available information and assessment need to be integrated in a single best practices compendium of design procedures for these different pavement types that have not been directly incorporated in the MEPDG. The compendium will identify the key steps and parameters to consider when designing these pavements.

Timeline for product delivery: Within 24 months
Product availability: FHWA, Industry, Non-U.S. research organizations

ACPT Program Focus Area 2: Improved Construction Materials

FA2-1: Optimizing Use of Recycled Materials

Recycled aggregates (RA) are produced from the processing of previously used construction materials, such as concrete. Recycled aggregate is routinely used for highway pavement construction in the United States. The principal application of RA has been as a base material. However, the use of RA as aggregate in new concrete is not as widely accepted. This is primarily due to concerns related to the durability of concrete that includes RA. As raw aggregate materials become scarce or more expensive, it is important that the use of RA be optimized, especially for use in concrete. When used in concrete, RA is typically blended in with raw aggregates.

The use of recycled concrete continues to grow as an increasing number of agencies are showing renewed interest in this technology. However, the full benefit of this technology, particularly as it relates to various sustainability factors, has yet to be realized, and the state of the technology needs to be synthesized and presented in a practice-ready implementation package, including guidelines and test protocols for evaluating the project-specific RA.

Timeline for product delivery: Immediately
Product availability: FHWA, industry, State DOTs

FA2-2: Advanced High-Performance Materials

As good construction material sources become scarce or more expensive, there will be a need to develop and use advanced high-performance materials (HPMs) in the construction of new and rehabilitated pavements. The HPMs can be classified as follows:

1. New materials to replace current materials that are in short supply (irrespective of cost).
2. New materials that perform similarly to conventional materials but are less expensive.
3. New materials that result in longer service life (irrespective of cost).
4. New materials that meet our needs for sustainable solutions (smaller carbon footprint, conservation of resources, carbon sequestering, etc.).
5. New materials that improve the properties of marginal materials.
6. Waste and recycled materials that are optimized for use in highway pavement construction.

There is an urgent need to develop a white paper on HPMs in highway construction. The knowledge base on HPMs must be developed as a matter of national urgency as the availability of HPMs is expected to be critical in the future for designing and constructing longer lasting pavements that meet user expectations related to ride and safety.

Timeline for product delivery: Immediately
Product availability: Industry

FA2-3: Concrete Mixture Optimization

Concrete mixture design requires the consideration of a wide array of aggregate sources, cement sources and types, chemical admixtures, supplementary cementitious materials, and recycled materials. The designer must also consider the interaction of ingredients within the mixture and how a given environment may affect the construction and the long-term performance of the pavement. With the emphasis on accelerated construction and long-lasting pavements coupled with a wider variety of materials options, concrete mixture optimization has become more challenging than ever. Recently, as part of the CPTP, a mixture optimization software, COMPASS, and guidelines were developed that simplify the concrete mixture design and proportioning process based on job-specific conditions. In addition, significant effort is underway to develop advanced concrete mixture optimization procedures under the CP Road Map's Mixture Design track. These new concrete mixture design procedures are expected to result in better performing concrete that optimizes use of locally available materials, including RA.

Timeline for product delivery: Immediately, with refinements to be made as additional products come on line.
Product availability: FHWA, NCPTC, industry

FA2-4: Concrete Durability

It is well accepted that concrete pavement failure should be a result of structural failure due to traffic and environmental loadings. Concrete pavement failure should not be a result of premature failure of the concrete itself. The best means of maximizing the probability that concrete will be durable is to produce concrete that will provide the desired service for the environment in which it will be placed and used. Exposure to freezing and thawing, sulfates, and deicing chemicals should be considered when selecting materials and proportions. In addition, available materials must be selected to prevent excessive expansion due to ASR and alkali-carbonate rock reaction. The fundamental factor in creating durable concrete is optimizing the use of supplementary cementitious materials (pozzolan and ground granulated blast-furnace slag) and chemical admixtures in combination with cement and the proper use of combined aggregate gradation. In the last 10 years, significant progress has been made in improving our understanding of concrete material–related distresses, and test protocols have been developed to identify marginal materials. More work is underway as part of the CP Road Map initiatives and through State DOT and industry sponsorship. There is a need to develop a best practices implementation package that provides guidance and includes test protocols that will ensure that nondurable concrete will be a thing of the past.

Timeline for product delivery: Within 24 months
Product availability: FHWA ASR Program, NCPTC, State DOTs, industry

FA2-5: Concrete Testing

Concrete testing is an important part of the QC and QA testing at concrete pavement construction projects. Currently, the following gaps exist in routine testing of concrete:

1. Lack of a concrete workability test. The slump test is used as a surrogate test to estimate workability, but the slump test only provides information related to concrete consistency from batch to batch. A good workability test can help ensure that concrete that is deposited in front of a slipform paver can be placed, consolidated, and finished without much additional hand manipulation of the concrete.

2. Lack of tests for freshly placed and consolidated concrete behind the paver. There is a need to determine the air content (and air void characteristics) and concrete consolidation in freshly placed concrete.

Work is underway to develop rapid test procedures for determining workability of concrete on the basis of concrete rheology and for rapid evaluation of the air system and consolidation of freshly placed concrete. The findings from these studies need to be disseminated to the concrete pavement stakeholder as soon as possible.

Timeline for product delivery: Within 24 months
Product availability: Industry

ACPT Program Focus Area 3: Improved Construction Processes

FA3-1: Improved Processes for Construction Process Control and Acceptance Testing

For the most part, concrete pavement process control and product acceptance testing (QC and QA) is performed using processes developed more than 50 years ago. Most of the testing on fresh concrete is performed before concrete is placed, and little testing of fresh concrete is performed behind the slipform paver. In addition, testing of hardened concrete typically requires a destructive test, requiring cores from the hardened concrete.

The contractor is required to perform a series of tests to ensure that he is not delivering marginal concrete to the project site and that the construction process will not produce a pavement that is deficient. The owner also performs a series of test to ensure that the end product delivered (the concrete pavement) will result in long-term service as per design expectations. The owner's tests typically include concrete strength, concrete thickness, concrete "quality," and pavement ride. Dowel alignment and pavement surface texture are important specification requirements, but acceptance testing for these items is typically not performed as the means to perform these tests have not been readily available.

Recently, progress has been made with regard to evaluating dowel bar alignment in freshly placed concrete using a device based on magnetic tomography. A device developed in Germany, MIT Scan, has been introduced in the United States under CPTP. Many agencies are investigating the applicability of the MIT Scan device either as part of the contractor's process control or as part of the owner's acceptance testing. In addition, another similar device, MIT Scan T2, has also been introduced in the United States under CPTP. This device accurately measures slab thickness nondestructively, eliminating the need for cores to determine slab thickness. Work is in progress to develop an improved version of the air void analyzer system to measure the air system of freshly placed concrete. Also, work is continuing to improve nondestructive testing procedures, such as the Impact Echo procedure, to reliably estimate in-place concrete strength. In addition, FHWA-developed software systems such as HIPERPAV and PROVAL are expected to play an important role in improving contractor process control operations.

The most up-to-date information on improved test methods (equipment, software, and protocols) for concrete pavement construction needs to be made available to agencies and industry in a timely manner.

Timeline for product delivery: Immediately
Product availability: FHWA, industry

FA3-2: Performance-Related and End-Product Specifications

PRS are an outgrowth of current end-result, QA specifications. In highway construction, PRS are defined as specifications for key materials and construction quality characteristics that have been demonstrated to correlate significantly with long-term pavement performance. PRS include sampling and testing procedures for acceptance quality characteristics along with acceptance or rejection criteria. A major feature of PRS is the development of rational pay adjustments based on the projected performance of the pavement.

FHWA has been promoting the development and implementation of PRS since the 1980s. A model PRS was developed in the mid-1990s and has been employed on several trial projects in several States. As more agencies and contractors become familiar with the PRS methodology, the approach is expected to lead to higher quality construction that is more cost effective and that incorporates innovative construction methods. The end result will be longer-lasting pavements.

The evolvement of PRS is expected to continue, with future work looking at, among other things, the development of improved performance models based on the MEPDG and the use of nondestructive acceptance testing procedures for as-placed concrete and concrete pavement. A recently initiated FHWA study is expected to result in a significantly improved PRS model that can be easily implemented by highway agencies.

Timeline for product delivery: Within 24 months
Product availability: FHWA, State DOTs

FA3-3: Improving Concrete Pavement Performance and Sustainability Through Two-Lift Construction

Two-lift concrete pavement construction offers a number of innovative opportunities to improve concrete pavement performance and sustainability. The lower lift can be optimized to make the best use of locally available or recycled materials, whereas the top lift can be optimized for long life and functionality (improved safety and lower tire-pavement noise levels) under high traffic loading. It is reasonably simple and cost effective to use two very different concrete mixture designs to achieve increased economic and environmental benefit while also achieving maximum social value. Two-lift construction is a common practice in many European countries. In the United States, a two-lift pavement test section was constructed in 1992, and efforts are underway to re-introduce this concept. A two-lift test section was constructed in Kansas in 2008. The use of two-lift concrete pavements is being investigated by several agencies, especially when there are direct economic advantages in adopting this technology. The full benefit of this technology has yet to be realized, and the state of the technology, as improved, needs to be synthesized and presented in a practice-ready implementation package. A more aggressive technology transfer effort is needed to showcase this very promising technology in the United States.

Timeline for product delivery: Immediately
Product availability: State DOTs, European highway agencies, industry

ACPT Program Focus Area 4: Rapid Repair and Rehabilitation (of all pavement types)

FA4-1: Rapid Pavement Condition Evaluation

Hundreds of miles of concrete pavement need to be rehabilitated every year due to rapidly declining pavement condition. A critical decision that needs to be made as part of the rehabilitation strategy relates to timing of the rehabilitation, and this decision depends on objective evaluation of the condition of the concrete pavement. Concrete pavement condition evaluation includes structural evaluation as well as evaluation of the concrete material–related distress (MRD). Good techniques are available for performing project-level structural evaluation based on deflection testing and condition surveys. However, good protocols do not yet exist to assess the durability of the concrete. For example, for pavements affected by ASR or D-Cracking, there are no definitive protocols to determine the right time to perform rehabilitation. Many concrete pavements continue to provide good service for many years after initiation of the MRD; on the other hand, many pavements rapidly deteriorate after initiation of the MRD.

There is a need to provide tools to rapidly perform structural evaluation as well as MRD evaluation of concrete pavements. Much work has already been performed, and many studies are underway. The FHWA ASR Program is expected to provide better test protocols to evaluate the state of ASR-related damage in concrete and to help estimate the remaining service life of affected pavements.

Timeline for product delivery: Within 24 months
Product availability: FHWA, industry

FA4-2: Rapid Rehabilitation and Reconstruction of High-Volume Facilities

Pavement rehabilitation and reconstruction, major activities for all U.S. highway agencies, have significant impact on agency resources and traffic disruptions because of extensive and extended lane closures. The traffic volumes on the primary highway system, especially in urban areas, have increased tremendously over the last 20 years. This has resulted, in many instances, in an earlier-than-expected need to rehabilitate and reconstruct highway pavements. Highway agencies continue to wrestle with the age-old problem: longer delays now and longer service life versus shorter delays now and shorter service life. In recent years, agencies have been investigating alternative strategies for pavement rehabilitation and reconstruction that allow for faster yet durable rehabilitation and reconstruction of pavements.

Accelerated construction, which minimizes construction impact on the driving public, is being implemented by many highway agencies that allow the use of concrete for rehabilitation and reconstruction of deteriorated pavements, both concrete and asphalt. Accelerated construction optimizes use of pavement design, available concrete materials, construction practices, and traffic management strategies to construct long-life concrete pavements. A key feature of accelerated construction is the recognition that pavement rehabilitation and reconstruction under traffic does not provide for longer lasting pavements and actually requires more extended lane closures with consequences on travel times and user and construction worker safety. Contractors typically prefer better management of the construction zones that include full road closure. Full closures are being achieved using three strategies: nighttime, weekend, and extended closures. At the CPTP conference on accelerated construction held in Atlanta, Georgia, in 2007, several highway agencies discussed their practices and future directions. The discussion at the conference indicated that there is a real need to develop guidance on accelerated construction and rehabilitation of concrete pavements. There is a need to synthesize the best procedures currently being used by agencies and to develop improved guidance for undertaking accelerated rehabilitation and reconstruction.

Timeline for product delivery: Within 24 months
Product availability: State DOTs, FHWA, industry

FA4-3: Precast Panels for Repair

Precast concrete pavement technology is an innovative process that can be used to meet the need for rapid repair and rehabilitation of asphalt and jointed concrete pavements. Precast pavement technology is ready for implementation. Precast pavement systems are fabricated or assembled offsite, transported to the project site, and installed on a prepared foundation (existing or regraded). The system components require little or no field curing time to achieve strength before opening to traffic. These systems are primarily used for rapid repair and rehabilitation of asphalt and PCC pavements in roadways with high-volume traffic. The precast technology can be used for intermittent repairs or full-scale, continuous rehabilitation. In intermittent repair of PCC pavement, isolated full-depth repairs at joints and cracks or full-panel replacements are conducted using precast concrete slab panels. The repairs are typically full-lane width.

Performance of the installed panels, though short in terms of time, indicates that precast pavement systems have the potential for providing rapid repairs that will be durable. The installation of precast pavements has a higher first cost. However, the rapid application that minimizes lane closures and the long-term durability may easily offset the higher initial costs. In the last 5 years, many highway agencies have begun using precast panels for intermittent repairs of jointed concrete pavements. However, there is still some reservation on the part of many highway agencies with regard to implementing this new technology because of higher costs and the lack of performance data. A study currently underway in the SHRP 2 Rapid Renewal Area is expected to develop improved guidance for design, fabrication, and installation of precast panels for intermittent repairs. In addition, many agencies have developed specifications for use of precast panels for repair applications. Recently, a techbrief on this subject was developed under FHWA's CPTP.

The available information needs to be disseminated to highway agencies, precasters, and general contractors. The increase in use of this technology is expected to result in lower costs and improved processes.

Timeline for product delivery: Immediately, with refinements incorporated based on findings from the SHRP 2 study.
Product availability: FHWA, industry

FA4-4: Precast Panels for Reconstruction and Rehabilitation

Precast concrete pavement technology comprises new and innovative construction methods that can be used to meet the need for rapid pavement repair and construction. Precast pavement technology is ready for implementation. Precast pavement components are fabricated or assembled offsite, transported to the project site, and installed on a prepared foundation (existing pavement or regraded foundation). The system components require minimal field curing time to achieve strength before opening to traffic. These systems are primarily used for rapid repair, rehabilitation, and reconstruction of both asphalt and PCC pavements in high-volume-traffic roadways. The precast technology can be used for intermittent repairs or full-scale, continuous rehabilitation. In *continuous applications*, full-scale, project-level rehabilitation or reconstruction of both asphalt and PCC pavements is performed using precast concrete panels. One technology developed for continuous applications is PPCP. It is based on the experience gained from several cast-in-place prestressed concrete pavement projects constructed during the 1980s in the United States.

Use of precast concrete pavements for reconstruction and rehabilitation is a viable alternative to conventional cast-in-place concrete pavement construction, especially in situations where high traffic volumes and consideration of the delay costs to users due to lane closures favor reconstruction and rehabilitation solutions that allow expedited opening to traffic. Precast concrete also offers the advantage of being "factory made" in a more controlled environment than cast-in-place construction and thus is potentially more durable and less susceptible to construction and material variability.

In the last 5 years, many highway agencies have begun implementing or investigating the use of precast panels for continuous applications. However, there is still some reservation on the part of many highway agencies with regard to implementation of this new technology because of higher costs and the lack of performance data. A study currently underway in the SHRP 2 Rapid Renewal Area is expected to develop improved guidance for design, fabrication, and installation of precast panels for continuous application. In addition, many agencies have developed specifications for use of precast pavement for pavement reconstruction application. Recently, a techbrief on this subject was developed under FHWA's CPTP.

The available information needs to be disseminated to highway agencies, precasters, and general contractors. The increase in use of this technology is expected to result in lower costs and improved processes.

Timeline for product delivery: Within 24 months
Product availability: FHWA, industry

FA4-5: Innovative Repair and Rehabilitation Processes

Most concrete pavements exhibit distress after many years in service, and these pavements need to be repaired to extend the service life of these pavements while providing safe and smooth ride for the users. Conventional practices for repair are well established, and these procedures involve repair materials, equipment for installing repairs, and proper techniques to ensure long-lasting repairs. Since most repairs are performed under difficult traffic conditions and restricted site access, many repairs do not perform well. There is a need to use materials, equipment, and techniques that provide a higher reliability with respect to repair performance. The processes should be '"failure-proof." The industry continues to make advances in developing improved processes for repairing concrete pavements. However, there is no effective process to compile information on what works and what does not as new repair processes are developed. There is a need to develop a library of case studies based on State DOT experience with new repair processes.

Timeline for product delivery: Immediately
Product availability: Industry, State DOTs

FA4-6: Construction Traffic Management

The need for well-planned construction traffic management is very important, particularly on high-volume freeways in urban areas, because of the need to minimize traffic disruptions and travel delays associated with lane closures during pavement rehabilitation or reconstruction. Pavement construction and rehabilitation in urban areas almost always requires the use of accelerated construction techniques that minimize the impact of construction on the travelling public. Accelerated construction work done under traffic places a burden on both the highway agency and contractor to produce a high-quality pavement while minimizing traffic delay and maximizing traffic safety. In some cases, the option of a long-life pavement is ruled out for such projects because of concerns related to user delays and safety. Over the last 10 years, much effort has been focused on developing tools that allow highway agencies to evaluate and optimize construction traffic management strategies.

A popular software for this application is CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies), developed at the University of California at Berkeley. FHWA has encouraged use of CA4PRS for pavement rehabilitation projects. AASHTO has also endorsed wider use of the software. Other new tools are being developed that will allow contractors and highway agencies to analyze different construction traffic management strategies prior to construction, allowing them to select the optimal traffic management strategy. The best practices and the best analytical tools for analysis of construction traffic management strategies need to be made available to agencies and contractors.

Timeline for product delivery: Within 24 months
Product availability: Academia, AASHTO, industry

ACPT Program Focus Area 5: Sustainable Concrete Pavements

A number of concrete pavement products are emerging in the materials and sustainability area that are deployable and implementable. Some of these products have emerged after years of research and are finally at a stage where they can be employed with confidence. Others are techniques that have been used elsewhere in the world for over a decade, most notably in Europe, and are now ready for acceptance in the United States. Consistent with the Concrete Pavement Sustainability Track in the CP Road Map, the products are described here.

FA5-1: Sustainable Pavement Designs

There is a need to extend initial concrete pavement service life beyond 40 years with little maintenance or repairs. This can be accomplished through the incorporation of certain design features as well as the use of durable materials. The contribution to sustainability of extended life has been presented in an ad-hoc basis through publication of few articles but needs to be better documented and disseminated.

Timeline for product delivery: Immediately
Product availability: FHWA, NCPTC, State DOTs, industry

FA5-2: Sustainable Use of Construction Materials

It is well documented that, for conventional concrete mixtures, the production of portland cement is overwhelmingly the largest contributor of energy consumption and emissions generated associated with concrete production, accounting for roughly 80 percent of the total energy consumed and 90 percent of the CO_2 emissions. Thus, a reduction in portland cement content, by replacing the cement with supplementary cementitious materials (SCMs) or reducing the total cementitious content through optimized aggregate grading, will have very positive effects on the sustainability of concrete pavement.

Multiple studies are underway or have been recently completed by various agencies to increase the usage of SCMs and reduce the total cementitious content in concrete by using an optimized aggregate gradation. The CP Road Map Track 13: Sustainable Concrete Pavements is focusing considerable attention on developing guidance on how to reduce the portland cement content in transportation concrete. Work being conducted on CP Road Map Track 13 will result in a briefing document during 2009 that will detail the state of the practice and identify future projects. A manual of practice will be completed within during 2010.

Timeline for product delivery: Within 24 months
Product availability: FHWA, NCPTC, State DOTs, industry

FA5-3: Sustainable Construction Practices

Increasingly, the environmental and social impacts of pavement construction are being recognized, as increased truck traffic, emissions and particulates, noise, and congestion all negatively impact the surrounding communities. Further, the construction process itself consumes vast amounts of resources, generates considerable waste, and uses significant quantities of water. As a result, a number of studies are underway to improve the sustainability of concrete pavement construction through better management of construction traffic, reduction of construction wastes, and better management of water. All elements of the construction process need to be considered.

Concerns regarding the sustainability of the concrete pavement construction process continue to grow as a number of local and State agencies are showing increasing interest in this technology. The full benefit of considering this technology has yet to be realized, as the information needs to be synthesized and presented in a practice-ready implementation package.

Timeline for product delivery: Immediately
Product availability: FHWA, NCPTC, State DOTs, industry

FA5-4: Sustainable Repair and Rehabilitation Processes

Timely and appropriate repair and rehabilitation will ensure that a concrete pavement will achieve the extended service life that is expected. Designing and constructing concrete pavements to anticipate restoration in 30 to 50 years—for example, by adding nominal additional thickness to accommodate diamond grinding—enhances pavement life and functionality at little additional initial cost. The sustainability of such practices will be enhanced by recognizing the importance of the life cycle, where consideration of repair and rehabilitation will reduce economic and environmental costs over the extended service life.

Although many projects have been completed on concrete pavement repair and rehabilitation, the information needs to be synthesized to capture new technology, particularly as it pertains to sustainability. Deployment and implementation efforts will focus on the accurate anticipation and timely execution of the appropriate treatment, as this is paramount to reducing cost and extending pavement life.

Timeline for product delivery: Immediately
Product availability: FHWA, NCPTC, State DOTs, industry

FA5-5: Catalog of Sustainable Concrete Pavement Practices

Sustainability is becoming an important consideration in all pavement management decisions, yet it is unclear exactly what is meant by the term and how sustainability of concrete pavements can be improved. The concrete paving industry has suggested sustainable features to be incorporated in concrete pavement design and construction, but little specific guidance is provided. The CP Road Map Track 13 on Sustainable Concrete Pavements is working on establishing a framework document to guide research and implementation into the future.

There is an urgent need to catalog the current state of the practice to improve concrete pavement sustainability and to disseminate this information to the industry, so as to achieve an immediate increase in understanding and improvement of concrete pavement sustainability.

Timeline for product delivery: Immediately
Product availability: FHWA, NCPTC, State DOTs, industry

FA5-6: Environmental Life Cycle Analysis Tools

One of the most critical challenges facing us is to understand how to quantify and compare the environmental benefits and impacts of various engineering solutions as is done in Europe. There is a need to adopt a quantification process that is robust and unbiased, allowing the identification of desirable solutions while creating the synergy needed to promote these solutions. Such a process must also be flexible enough to allow for the consideration of a broad category of alternatives, including those that contain innovative features. The quantification process does not assume that one strategy is better than another, but allows comparison of one type of solution to another over a broad range of environmental considerations. The effort conducted under this category is at the heart of advancing sustainability of concrete pavements through adoption of a life cycle analysis (LCA) approach.

An LCA requires the assembling of available data to create and maintain a concrete pavement specific life cycle inventory (LCI) with local/regional North American data. The data would include values assigned to materials and processes for impact categories such as embodied energy (both primary and feedstock), global warming potential, water (use, reuse, and treatment), noise, airborne particulate, emissions, human toxicity, etc. The LCI would also assign ranking of the significance of the impact categories for all the materials and processes used in the design, initial construction, maintenance, restoration, rehabilitation, and recycling of the pavement. In accordance with European practice, the LCA protocol must adhere to international standards such as those described in the International Organization for Standardization's 14000 standards, and must be accessible to the concrete pavement community as a tool or toolkit in an easily usable format to help improve the sustainability of concrete pavements. The technology to advance this important tool currently exists, and it is simply a matter of deployment and implementation.

Timeline for product delivery: Immediately
Product availability: FHWA, NCPTC, State DOTs, industry

ACPT Program Focus Area 6: Enhanced User Satisfaction

FA6-1: Innovative Pavement Surface Texturing for Safety and Noise Reduction

Pavement surface characteristics (functional properties) except smoothness are not typically addressed on current projects except by method specifications. The recently published AASHTO *Guide for Pavement Friction*, the NCHRP 1-43 Final Research Report, the 2005 FHWA Technical Advisory on Surface Texture, the proposed FHWA Technical Advisory update on the Skid Accident Reduction Program, and the proposed 2009 publication of the Highway Safety Manual should all generate need for enhanced evaluation procedures for pavement surface texture and project-specific guidance.

There is a critical need to reduce the annual number of fatalities and serious injuries on our Nation's highways. Safety of the traveling public and pedestrians should be a very high priority goal. Guidance on friction and texture for new and rehabilitated PCC pavements will help accomplish this goal. Since pavement surface texture affects both pavement-tire noise and surface friction (safety), surface texture issues need to be considered by assessing impact on both noise and safety.

Improved guidelines are needed in the following areas:

1. PCC surface texture design and construction techniques—selection guidelines.
2. Methods and equipment to evaluate PCC friction, noise, and texture—laboratory and field techniques.
3. PCC friction and noise performance prediction models and monitoring procedures.
4. Guide Specifications for PCC Pavement Macro-texture.

Timeline for product delivery: Immediately
Product availability: FHWA, NCPTC

FA6-2: Techniques to Improve Pavement Ride

Research by FHWA, other highway agencies, and industry is ongoing to improve concrete pavement ride quality and support FHWA's national goal to significantly improve pavement smoothness on the National Highway System. The research is aimed at resolving the following specific issues unique to concrete pavements:

- Construction factors that affect the smoothness of concrete pavements.
- Proper procedures to measure the smoothness of pavements for construction acceptance using inertial profilers including profiler equipment factors that influence measurements.
- Objectionable profile characteristics that are created during paving and how such features can be identified from profile data.
- How texture and joints affect measurements made by inertial profilers.
- The lower limit of IRI beyond which road users will not be able to able to detect an improvement in smoothness.
- The relationship between the ride quality deterioration rate and the initial smoothness of a pavement.
- A procedure to detect and correct localized roughness features from profile data.
- The effect of a localized roughness feature on the dynamic loads that are applied on the pavement.

The findings from recently completed CPTP studies and ongoing studies will help improve our understanding of the concrete pavement profile characteristics that impact user satisfaction with ride quality and will help to develop rational procedures to measure the profile characteristics of interest.

Timeline for product delivery: Within 24 months
Product availability: FHWA, NCPTC

CHAPTER 5—SUMMARY

Priority ACPT Products

Based on the critical need for specific products and the status of product availability and product development, the following ACPT products and product areas are considered high-priority products for immediate delivery to stakeholders:

FA1-1	Mechanistic-Empirical Concrete Pavement Design
FA1-2	Concrete Overlays Design
FA1-4	Advanced Concepts for Joint Design
FA2-1	Optimizing Use of Recycled Materials
FA2-2	Advanced High-Performance Materials
FA2-4	Concrete Durability
FA3-1	Improved Processes for Construction Process Control and Acceptance Testing
FA3-3	Improving Concrete Pavement Performance and Sustainability Through Two-Lift Construction
FA4-2	Rapid Rehabilitation and Reconstruction of High-Volume Facilities
FA4-3	Precast Panels for Repair
FA4-4	Precast Panels for Reconstruction and Rehabilitation
FA4-6	Construction Traffic Management
FA5-1	Sustainable Pavement Designs
FA5-2	Sustainable Use of Construction Materials
FA5-3	Sustainable Construction Practices
FA5-4	Sustainable Repair and Rehabilitation Processes
FA5-5	Catalog of Sustainable Concrete Pavement Practices
FA5-6	Environmental Life Cycle Analysis Tools
FA6-1	Innovative Pavement Surface Texturing for Safety and Noise Reduction
FA6-2	Techniques to Improve Pavement Ride

Marketing Plan

As stated earlier, FHWA has initiated the ACPT Program to capture the best advanced technologies available or soon to be available for concrete pavements and deliver these technologies to highway agencies and the construction industry. This report has documented the availability of advanced concrete pavement technology products that show a high potential for improving the performance of concrete pavements, through improved design, material selection, construction practices, testing procedures, and repair and rehabilitation techniques.

The next phase in the ACPT Program initiative is to develop a marketing plan to deliver the promising ACPT products to the stakeholder. The marketing plan will need to consider the unique features and application of each product or series of products as well as stakeholder needs. The product delivery mechanism can include the following:

1. Field demonstration projects and open houses.
2. Test equipment loan program.
3. Best practices workshops.
4. Best practices topical presentations.
5. Best practices topic-specific regional workshops and national conferences.
6. Guides and training materials.
7. Refined test protocols.
8. Techbriefs and technical summaries.
9. Communication (CD-based information delivery, Web site, ACPT product updates, product alerts.)
10. Webinars and other distance learning processes for adult education.

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