Long-Term Plan for Concrete Pavement Research and Technology—The Concrete Pavement Road Map (Second Generation): Volume I, Background and Summary

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FOREWORD

The concrete paving industry has experienced many changes in the last 15 years. To achieve concrete pavement's full potential in the 21st century, the industry has identified trends that call for dramatic, even revolutionary, improvements. Aiming for a holistic approach, the improvements can best be implemented through a carefully developed and aggressively implemented strategic plan for research and technology transfer known as the Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map).

This report is volume I of II. It provides the background and summary information on the effort that led to the CP Road Map. Sufficient copies of this report are being distributed to provide eight copies to each Federal Highway Administration (FHWA) Resource Center, five copies to each FHWA division, and a minimum of eight copies to each State highway agency. Direct distribution is being made to the division offices for forwarding to the State highway agencies. Additional copies for the public are available from the National Technical Information Service.

Jorge E. Pagán-Ortiz
Director, Office of Infrastructure
Research and Development

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16. Abstract

The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a holistic strategic plan for concrete pavement research and technology transfer. The CP Road Map is a living plan that includes 12 distinct but integrated research tracks leading to specific products and processes. The resulting improvements will help the concrete pavement industry meet the challenges of, and achieve the industry's full potential in, the 21st century. The plan was developed in close partnership with stakeholders representing all aspects of the concrete pavement community, public and private, and the research will be conducted through partnerships of stakeholders. Over the last several years, the plan has been managed through an operational support mechanism provided by a transportation pooled fund project. The CP Road Map is presented in two volumes. Volume I describes why the research plan is needed, how it was developed, and, generally, what the plan includes. Volume I also describes the research management plan that will guide the conduct and implementation of research. Volume II describes in detail the 12 tracks of research. Each track description includes a general overview, a track goal, track action items, a list of subtracks, and detailed problem statements within each subtrack.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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EXECUTIVE SUMMARY

THE CP ROAD MAP

The Concrete Pavement (CP) Road Map is a comprehensive and strategic plan for concrete pavement research that guides the investment of research dollars. It is a living plan with broad stakeholder involvement. For the last 5 years, it has tracked and facilitated technologies that have been helping the concrete pavement community meet the paving needs of today as well as the paving challenges of the future. The CP Road Map is guiding the industry work toward a new generation of concrete pavements for the 21st century.

WHAT IS UNIQUE ABOUT THE CP ROAD MAP?

Strategic: It combines more than 270 research problem statements into 12 integrated and cohesive tracks of research, leading to specific products that will dramatically affect the way concrete pavements are designed and constructed.

Innovative: From the way it was developed, to its unique track structure and cross-track integration, to the plan for conducting the research, the CP Road Map introduces a new, inclusive, and far-reaching approach to pavement research.

Stakeholder involvement: The CP Road Map plan is for the Federal, State, and private concrete pavement community. Peers helped create it, so it reflects all needs. It has guided stakeholders in both research selection and prioritization.

No cost or time limitations: The research contained in the CP Road Map is at an estimated overall cost of $275 to $500 million.

Independent of any one agency or pot of money: Stakeholders with funds and expertise will pool their resources, jointly conduct and coordinate the research, and apply the results. The plan incorporates innovative, effective research implementation to move useful new products and systems to the field quickly.

A VISIONARY CHARGE

The Federal Highway Administration (FHWA) and the concrete pavement industry have commissioned a national research plan for the 21st century. Why is such a plan needed?

For most of the 20th century, the same materials—portland cement, high-quality aggregate, and water—were used in pavement concrete with only minor refinements. It was a fairly forgiving formula that allowed some variations in subgrade quality, construction practices, and other variables without sacrificing pavement performance. For generations, the industry had the luxury of keeping traffic off of new concrete pavements for several days (even weeks) while the concrete developed its intended design strength.

In the past 20 years, the industry has experienced more changes than those that occurred in the previous 80 years, and the following changes are turning the process of building concrete pavements on end:

- Today's concrete mix designs must integrate a multitude of new—sometimes marginal—materials, resulting in serious compatibility problems and reduced tolerance for variations.
- Motorists are more demanding. They will tolerate only minimal road closures and delays due to roadwork, increasing the need for new paving methods that allow road crews to get in, get out, and stay out. Motorists want smoother, quieter pavements, pushing the industry to control pavement surface characteristics.
- Highway agency focus has shifted from building new pavements to rehabilitating and maintaining existing ones, which requires different designs, systems, materials, and equipment.
- Environmental pressures, including traffic congestion, drainage, and runoff issues, are affecting mix designs and pavement construction practices.
- Highway budgets are being squeezed at every level. The pavement community must do more with less.

In this environment, the old system for constructing concrete pavements is not meeting today's demands. Pavement failures have occurred that were unheard of 30 years ago. The concrete pavement community cannot continue business as usual if it is going to meet the growing demands on highway construction and rehabilitation. The CP Road Map gives the community an opportunity to proactively reinvent itself through research.

DRAWING A NEW MAP FOR CONCRETE PAVEMENTS

The project to develop the CP Road Map began in 2001 through an agreement between the Innovative Pavement Research Foundation (IPRF) and a team led by Iowa State University's Center for Portland Cement Concrete (PCC) Pavement Technology (PCC Center, now the National Concrete Pavement Technology Center (National CP Tech Center)).

In May 2003, FHWA initiated a new agreement with the National CP Tech Center to complete the work. The Transportation Research Board (TRB) Committee for Research on Improved Concrete Pavements acted as the project advisory panel. Twenty percent of total funding for the project was provided by Iowa State University. The concrete pavement industry and State transportation departments provided valuable input to the CP Road Map and supported its implementation.

An Iowa State University-led team facilitated the development of the CP Road Map. They developed a database of existing research and gathered input, face-to-face, from the highway community. The team identified gaps in research that became the basis for problem statements, which are organized into a cohesive strategic research plan.

A "Living" Research Database

The research database is a thorough catalog of recently completed and in-progress research projects and their products. Over the years, this database has been regularly updated and has served as a valuable resource as part of the research management.

Stakeholder Input

The success of the CP Road Map has been a result of a cooperative process involving high levels of stakeholder teamwork.

This cooperative process began during the CP Road Map development when five major brainstorming and feedback sessions were conducted at the following events: the October 2003 meeting of the Midwest Concrete Consortium (currently the National Concrete Consortium) in Ames, IA; a special November 2003 regional workshop for eastern and southern stakeholders in Syracuse, NY; the May 2004 meeting of the American Concrete Pavement Association (ACPA) in Kansas City, MO; a special January 2004 regional teleconference for western stakeholders; and an October 2004 final meeting of national stakeholders hosted by FHWA at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA.

Through these events, plus special presentations at more than 20 professional conferences and workshops across the country, more than 400 engineers and managers provided direct input into the CP Road Map.

Participants represented the following entities:

- State and local transportation departments.
- FHWA.
- ACPA, including several State chapters.
- Portland Cement Association (PCA).
- American Association of State Highway and Transportation Officials (AASHTO).
- National Ready Mixed Concrete Association (NRMCA).
- TRB/National Cooperative Highway Research Program (NCHRP) committees.
- American Public Works Association (APWA).
- National Association of County Engineers (NACE).
- Contractors.
- Materials suppliers.

- Research universities, especially departments conducting applied research.
- Private concrete testing laboratories.

Input was provided in the following four broad categories:

- Mixtures and materials.
- Design.
- Construction.
- Pavement management/business systems.

Again and again, stakeholders who participated in these brainstorming events said they needed more and better analysis tools for measuring the "hows" and "whys" of pavement failures and successes—that is, to measure pavement performance. Better quality assurance (QA) and quality control (QC) methods/tools are needed for every stage of the pavement system, particularly mix design, design, and construction. Because variables in each stage affect the others, the methods/tools must be integrated across stages.

From these concepts of pavement performance and systems integration, the following overall vision for the CP Road Map was developed:

> *By 2020, the highway community will have a comprehensive, integrated, and fully functional system of concrete pavement technologies that provides innovative solutions for customer-driven performance requirements.*

Based on this goal and other stakeholder input, the following specific research objectives were identified:

- Maximize public convenience.
- Improve the driving experience.
- Integrate design, mixtures and materials, and construction with pavement performance predictions.
- Improve pavement reliability.
- Identify new and innovative business relationships to focus on performance requirements.
- Constrain costs while improving pavement performance.
- Protect and improve the environment.
- Expand opportunities to use concrete pavement.

The objectives were "filtered" through the project team's database of existing research to determine gaps in the research. These gaps became the basis for problem statements.

Approximately 250 problem statements were written, reviewed, and fine-tuned. Final versions of the problem statements were added to the research database as work to be accomplished via the CP Road Map.

Research problem statements, projects, budgets, timelines, and research results in the database must be regularly updated. The CP Road Map will succeed only if the database is managed and maintained.

From Stakeholder Input to Plan

Most of the 270+ problem statements did not fit neatly into just one of the brainstorming categories (mixtures and materials, design, construction, and pavement management/business systems). To capture the cross categories and the integrated nature of the problem statements, the problem statements were organized into 12 product-focused tracks of research within the database. This structure encourages various stakeholder groups to step forward as champions for a specific track. While there have been refinements, additions, and subtractions to the CP Road Map over the last 10 years of implementation, 12 tracks remain.

Problem Statements

Each problem statement is a topical summary only. Most problem statements are further broken down into specific research project statements that provide detailed descriptions of the research to be accomplished, budgets, and timelines. The research management plan (described later in this report) makes research track team leaders responsible for data entry of detailed project statements into the database.

Track Integration

As noted in the 12 brief track descriptions below, research in one track often affects or is affected by research in another track. In the CP Road Map, this interdependence and other critical relationships are outlined in the track and problem statement descriptions. It is the responsibility of research track team leaders, as described later in this document, to ensure that research is appropriately coordinated and integrated.

Moreover, the research database can be sorted to isolate problem statements on a variety of subjects. For example, several important problem statements related to foundations and drainage systems, maintenance and rehabilitation, and environment advancements are included in various tracks. In the CP Road Map, problem statements related to these particular topics have been listed in separate cross reference tables.

CP ROAD MAP RESEARCH TRACKS

Each of the CP Road Map tracks is a full research program in itself, with its own budget, 2 to 7 subtracks, and as many as 45 problem statements. Subtracks include statements describing the development of innovative technology transfer, training tools, and methods to ensure that innovative research products are quickly and efficiently moved into practice.

The following list provides a brief description of each research track:

1. **Materials and Mixes for Concrete Pavements.** The final product of this track will be a practical, yet innovative, concrete mix design procedure with new equipment, consensus target values, common laboratory procedures, and full integration with both structural design and field QC—a lab of the future. This track also lays the groundwork for the concrete paving industry to assume more responsibility for mix designs as State highway agencies move from method specifications to more advanced acceptance tools. For such a move to be successful, it is important that the concrete paving industry and owner-agencies refer to a single document for state-of-the-art mix design.

2. **Performance-Based Design Guide for New and Rehabilitated Concrete Pavements.** Under this track, the concrete pavement research community will expand the mechanistic approach to pavement restoration and preservation strategies. This track builds on the comprehensive work done under NCHRP 1-37A, which led to the development of the *Mechanistic-Empirical Pavement Design Guide* (MEPDG) subsequently released by AASHTOWare® as the design software DARWin-ME™.(1) This track intends to continue to develop the models from that important work. The work in this track needs to be closely integrated with track 1.

3. **Intelligent Construction Systems and Quality Assurance for Concrete Pavements.** This track will develop intelligent construction systems (ICSs) consisting of high-speed nondestructive QA methods to evaluate pavement properties continuously during construction. As a result, immediate adjustments can be made to ensure the highest quality finished product that meets given performance specifications. Many problem statements in this track relate to tracks 1 and 2.

4. **Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements.** This track will improve the understanding of concrete pavement surface characteristics. It will provide tools for engineers to help meet or exceed predetermined requirements for friction/safety, tire-pavement noise, smoothness, splash and spray, hydroplaning, light reflection (albedo), rolling resistance, and durability (longevity). Each of the functional elements of a pavement listed above is critical. The challenge is to improve one characteristic without compromising another characteristic, especially when it comes to public safety.

5. **Concrete Pavement Equipment Automation and Advancements.** This track will result in process improvements and equipment developments for high-speed, high-quality concrete paving equipment to meet the concrete paving industry's projected needs and the traveling public's expectations for highway performance in the future. Examples include the next generation of concrete batching and placement equipment; behind-the-paver equipment to

improve curing, surface treatment, and jointing; mechanized ways to place and control subdrains and other foundation elements; equipment to remove/replace the slab in one-pass construction; improved repair processes that decrease the time of operations and provide the workforce and traveling public with less exposure; and methods for evaluating new equipment on actual construction projects.

6. **Innovative Concrete Pavement Joint Design, Materials, and Construction.** Potential products for this track include guidelines that address premature joint deterioration, a new joint design, high-speed computer analysis techniques for joint performance, a more accurate installation scheme, and faster rehabilitation strategies. The problem statements in this track address the basics—joint design, materials, construction, and maintenance activities. The track also specifies research that will help develop breakthrough technologies and extremely high-speed joint repair techniques. This is a crosscutting track to ensure that all topics related to innovative joints are addressed. Much of the proposed research will develop important incremental improvements.

7. **Concrete Pavement Maintenance and Preservation.** This track focuses on maintenance and preservation of concrete pavements in order to preserve existing highway infrastructure assets. Problem statements in this track seek to establish reliable procedures and develop new and innovative methods for concrete pavement maintenance and preservation. Many enhancements to existing maintenance and preservation treatments are also envisioned through this research, including automation of distress and maintenance need identification, automation application of maintenance and preservation treatments to reduce the cost and expedite the application of treatments, and enhancement of safety for maintenance workers.

8. **Concrete Pavement Construction, Reconstruction, and Overlays.** Concrete pavements across the country will continue to need rehabilitation under high-speed traffic conditions. Tremendous gains have been made in the past decade with respect to fast-track concrete paving, and this track will seek to expand research related to construction and reconstruction of concrete pavements in these types of environments. Furthermore, while asphalt pavement had traditionally been viewed as the only solution for overlays of existing pavement, over the past decade, tremendous advances have been made in understanding and usage of concrete for overlays. This track will facilitate continued momentum with respect to concrete overlays, particularly as a solution for fast-track applications.

9. **Evaluation, Monitoring, and Strategies for Long-Life Concrete Pavement.** Long-life pavements are needed to handle the congestion and traffic loading that pavements will experience in their lifetime. To meet a 30-year calendar design life, a pavement built today may need to withstand 70 to 100 percent more axle loads per mile than a similar pavement built 10 years ago. This track will focus on strategies, materials, and construction processes for long-life concrete pavements. It will address tools to help ensure long-life concrete pavements through data collection and usage of accelerated loading test facilities.

10. **Concrete Pavement Foundations and Drainage.** It has long been established that principal components of a long-life concrete pavement include a uniform foundation and proper measures taken for drainage. Given the sheer variety of potential conditions that can be present on any given job (e.g., soil type), there is no "one size fits all" solution. This track

explores research and technology related to these important topics, with a particular emphasis on tasks that can be readily applied in a site-specific manner.

11. **Concrete Pavement Economics and Business Management.** Roles and responsibilities are changing in the highway industry, affecting the way paving projects are designed, bid, built, and maintained. Contractors are being asked to assume more control of the operation and QC inspections. By including warranty provisions and innovative contracting clauses in project contracts, owner-agencies are asking for additional assurance that pavements will be built and will perform as expected. Internationally, many countries have made dramatic changes in project funding methods and in the roles of contractors and suppliers. This track captures some important research that should be considered as this process of transformation continues in the United States. Problem statements cover topics such as contracting options, new technology transfer systems, public-private partnerships, and economic models.

12. **Concrete Pavement Sustainability.** The key to successfully increasing sustainability of concrete pavements is to consider the three "pillars" of sustainability: economic, environmental, and social considerations. In the context of this track, sustainability refers to the use of materials and practices in concrete pavement design, construction, operation, preservation, rehabilitation, and recycling (things we do now) that reduce life-cycle costs, improve the environmental footprint, and increase the benefits to society (things we need to learn to do). This track will focus on research into sustainable practices for both new construction and the concrete pavement network, which already exists. Research will identify and quantify characteristics of concrete pavement systems that contribute to enhanced sustainability of roadways in terms of economic, environmental, and social considerations, provide the tools and data needed to quantify each, and understand the relationship to one another.

REACHING THE DESTINATION

To date, implementation of the CP Road Map has followed the spirit of the research management plan as originally proposed—a framework that outlined a progressive, cooperative approach to managing and conducting the research. Under this plan, organizations identify common interests, partner with each other in executing specific contracts, and, in the end, produce and share a product that is greater than the sum of the parts.

The research management plan emphasizes scope control, phasing of research, reporting, systems integration, voluntary peer review, maintenance of the research database, program-wide technology transfer, and assistance to organizations that want to leverage their funds and human resources.

Philosophy for Managing Research

The research management plan is based on the following assumptions:

- The CP Road Map is a national research plan. It is not a plan solely for FHWA, but for State agencies and the industry as well.

- Even in a decentralized arena like research, it is possible (and critical) for stakeholder groups to come together voluntarily. Federal, State, and industry research staff and engineers around the country are looking for more opportunities to pool their funds and other resources in win-win situations. The National Concrete Consortium is an example of a successful cooperative approach to research.

- The all-too-common disconnection between research results and implementation of those results must be fixed. Communication, technology transfer, and outreach activities must be elevated to the same level of importance as research itself.

- The CP Road Map is too comprehensive and important for a part-time implementation effort. Managing the overall research program effectively and judiciously will require full-time, dedicated personnel with adequate resources.

Governing Structure

In line with this general philosophy, the research management plan outlines a four-tier system of participation and responsibility: an executive advisory committee (EAC), an administrative support group, research track team leaders, and sustaining organizations.

A tri-party EAC, representing FHWA, State transportation departments, and industry, will provide broad oversight of the CP Road Map. It will be a decisionmaking and policy-making facilitation group with many responsibilities, including the following:

- Assembling research track team leaders.

- Promoting partnering arrangements.

- Ensuring adequate integration of research across tracks.

- Developing and implementing a strategy to ensure that software products developed through various research tracks will be compatible with each other.

- Identifying new research program areas.

- Overseeing updates and maintenance of the research database.

- Developing a comprehensive technology transfer and training program for products of the CP Road Map.

- Developing a communications effort to keep the CP Road Map and its products in front of stakeholders and the public.

- Conducting self-evaluation studies.

- Keeping the momentum focused on outcomes, not just output.

An administrative support group will provide professional management services for the EAC and, to a lesser degree, the research track team leaders. It will be the "doing" body for coordination and support activities, like maintaining the research database.

Research track team leaders will coordinate and oversee all activities within a specific research track as follows:

- Validating and updating the track.
- Developing broad problem statements into specific, separate research projects, with scopes of work, timelines, and budgets.
- Identifying organizations to conduct or partner in the research.
- Establishing and overseeing subordinate technical expert working groups to guide complex work.
- Ensuring proper integration of work within the track and across track lines.
- Developing status reports.

Sustaining organizations, including agencies, consultants, universities, professional associations, and other organizations, with specialized interests and skills that are interested in pooling dedicated funds will assume responsibility for conducting research through cooperation, partnerships, and funding agreements. Some people and organizations will assume multiple roles.

In addition, sustaining organizations conducting research under the CP Road Map may retain full fiscal and technical control of the work under their jurisdictions. The key to successful conduct of the research, however, is cooperation, and the research management plan facilitates and supports cooperative efforts.

The implementation of the CP Road Map has largely followed this plan, with the National CP Tech Center providing administrative support under contract through a transportation pooled fund project, TPF-5(185).(2)

THE CP ROAD MAP TRACKS AND SUBTRACKS

The CP Road Map is a plan for concrete pavement research consisting of 12 tracks and subtracks. Since its development, the management of these tracks has been conducted via track management teams consisting of leaders in the respective areas.

The general range of costs associated with each track represents the time dedicated to the CP Road Map by multiple stakeholders who contributed to its development. The support needed for this effort comes from in-kind services and funding provided by a number of participants including industry organizations, State transportation departments, and Federal agencies. The estimates are subject to change as the CP Road Map evolves. All numbers provided are rounded. The total cost for all tracks is $277 to $492 million.

1. **Materials and Mixes for Concrete Pavements ($38–$81 million)**

    - 1-1. Performance-Based Mix Design and Specifications.
    - 1-2. Materials Selection and Testing.
    - 1-3. Innovative Materials.
    - 1-4. Materials Proportioning.
    - 1-5. Mixture Evaluation.
    - 1-6. Post-Construction Pavement Materials Evaluation.

2. **Performance-Based Design Guide for New and Rehabilitated Concrete Pavements ($41–$60 million)**

    - 2-1. Design Guide Structural Models.
    - 2-2. Design Guide Inputs, Performance Models, and Reliability.
    - 2-3. Special Design and Rehabilitation Issues.
    - 2-4. Improved Mechanistic Design Procedures.
    - 2-5. Design Guide Implementation.

3. **Intelligent Construction Systems and Quality Assurance for Concrete Pavements ($20–$41million)**

    - 3-1. Quality Assurance.
    - 3-2. Intelligent Construction System Technologies and Methods.
    - 3-3. Intelligent Construction System Evaluation and Implementation.

4. **Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements ($25–$54 million)**

    - 4-1. Concrete Pavement Texture and Friction.
    - 4-2. Concrete Pavement Smoothness.
    - 4-3. Tire-Pavement Noise.
    - 4-4. Other Concrete Pavement Surface Characteristics.
    - 4-5. Integration of Concrete Pavement Surface Characteristics.

- 4-6. Evaluation of Products for Concrete Pavement Surface Characteristics.
- 4-7. Concrete Pavement Surface Characteristics Implementation.

5. **Concrete Pavement Equipment Automation and Advancements ($26–$56 million)**
   - 5-1. Concrete Batching and Mixing Equipment.
   - 5-2. Concrete Placement Equipment.
   - 5-3. Concrete Pavement Curing, Texturing, and Jointing Equipment.
   - 5-4. Concrete Pavement Foundation Equipment.
   - 5-5. Concrete Pavement Reconstruction Equipment.
   - 5-6. Concrete Pavement Restoration Equipment.
   - 5-7. Advanced Equipment Evaluation and Implementation.
6. **Innovative Concrete Pavement Joint Design, Materials, and Construction (10–$15 million)**
   - 6-1. Joint Design Innovations.
   - 6-2. Joint Materials, Construction, Evaluation, and Rehabilitation Innovations.
   - 6-3. Innovative Joints Implementation.
7. **Concrete Pavement Maintenance and Preservation ($8–$13 million)**
   - 7-1. Optimization and Automation of Pavement Maintenance.
   - 7-2. Optimized Concrete Pavement Preservation.
   - 7-3. Distress Identification and Preservation Treatment.
   - 7-4. Feedback Loop for Concrete Pavement Preservation Effectiveness.
8. **Concrete Pavement Construction, Reconstruction, and Overlays ($31–$53 million)**
   - 8-1. Construction, Reconstruction, and Overlay Planning and Simulation.
   - 8-2. Precast and Modular Concrete Pavements.
   - 8-3. Concrete Overlays.
   - 8-4. Fast-Track Concrete Pavements.

- 8-5. Construction, Reconstruction, and Overlay Evaluation and Implementation.

9. **Evaluation, Monitoring, and Strategies for Long-Life Concrete Pavement ($21–$34 million)**

- 9-1. Technologies for Measuring Concrete Pavement Performance.
- 9-2. Strategies for Long-Life Concrete Pavements.
- 9-3. Construction Techniques and Materials Selection for Long-Life Concrete Pavements and Overlays.
- 9-4. Planning and Design of Accelerated Loading and Long-Term Data Collection.
- 9-5. Preparation of Data Collection/Testing Procedures and Construction of Test Road.
- 9-6. Long-Life Concrete Pavement Performance Implementation.

10. **Concrete Pavement Foundations and Drainage ($6–$12 million)**

- 10-1. Concrete Pavement Foundations.
- 10-2. Concrete Pavement Drainage.

11. **Concrete Pavement Economics and Business Management ($21–$31 million)**

- 11-1. Concrete Pavement Research and Technology Management and Implementation.
- 11-2. Concrete Pavement Economics and Life-Cycle Costs.
- 11-3. Innovative Contracting and Incentives for Concrete Pavement Work.
- 11-4. Technology Transfer and Publications for Concrete Pavement Best Practices.

12. **Concrete Pavement Sustainability ($30–$40 million)**

- 12-1. Materials and Mixture Proportioning Procedures for Sustainable Concrete Pavements.
- 12-2. Design Procedures for Sustainable Concrete Pavements.
- 12-3. Construction Practices for Sustainable Concrete Pavements.
- 12-4. Preservation, Rehabilitation, and Recycling Strategies for Sustainable Concrete Pavements.
- 12-5. Improved Economic Life-Cycle Cost Analysis for Sustainable Concrete Pavements.

- 12-6. Adoption and Implementation of Environmental Life-Cycle Assessment for Sustainable Concrete Pavements.
- 12-7. Design Procedures for Sustainable Concrete Pavements.
- 12-8. Concrete Pavement Decisions with Environmental Impact.

ORGANIZATION OF VOLUMES I AND II

The CP Road Map is published in two volumes. Volume I contains the executive summary plus the following eight chapters:

- Chapter 1 describes the background and need for the CP Road Map.
- Chapter 2 tells how the CP Road Map was developed.
- Chapter 3 provides an overview of the 12 tracks of planned research.
- Chapters 4 through 7 describe the critical issues and objectives that the CP Road Map addresses in the areas of design, mixtures and materials, construction, and pavement management/business systems.
- Chapter 8 describes the innovative research management plan that was developed to guide the conduct of research and how this management has been conducted to date.

Volume II contains the executive summary and describes in detail the 12 tracks of planned and ongoing research as follows:

- Each track begins with introductory material that summarizes the goal and objectives for the track and the gaps and challenges for its research program.
- A table of estimated costs provides the projected cost range for each problem statement, depending on the research priorities and scope determined in implementation.
- The problem statements within each track are grouped into subtracks. Each subtrack is introduced by a brief summary of the subtrack's focus and a table listing the titles, estimated costs, products, and benefits of each problem statement in the subtrack.
- The problem statements then follow.

Each problem statement clearly defines tasks that need to be performed to produce a desired product or achieve a desired objective. Each problem statement will need to be developed into appropriate research project statements with detailed descriptions of the research to be accomplished, specific budgets, and definite timelines.

HOW CAN YOU PARTICIPATE?

Managing a long-term research program is a long, slow process. The CP Road Map provides a framework for moving forward.

Stakeholders in the concrete pavement community are invited to participate.

To receive a copy of the full two-volume CP Road Map with complete problem statements, contact Ahmad Ardani, FHWA, (202)-493-3422, ahmad.ardani@dot.gov.

For additional information, go to http://www.cproadmap.org.

CHAPTER 1. WHY A LONG-TERM RESEARCH PLAN FOR CONCRETE PAVEMENTS?

For generations, concrete has been the workhorse for long-life, dependable pavements. By generally performing well for many years beyond their original design life, concrete pavements have provided a substantial return on taxpayers' investments.

For most of the 20th century, the same materials—aggregate, portland cement, and water—were used in concrete for pavements, with only minor refinements. It was a fairly forgiving, high-tolerance formula. Mixes made with portland cement and high-quality aggregates allowed some variations in subgrade quality, construction practices, and other variables without sacrificing pavement performance. For generations, the emphasis was on constructing new pavement miles, and the industry had the luxury of keeping traffic off new concrete pavements for several days, even weeks, while the concrete developed its internal maturity and design strength.

Over the past 20 years, however, the concrete pavement industry has experienced more changes than in the preceding 80 years, and these changes are turning the process of building concrete pavements on end. Some of the ongoing environmental, social, and economic trends affecting the industry include the following:

- Today's concrete mix designs integrate a plethora of new, sometimes marginal, materials, reducing tolerance for materials variations and sometimes resulting in serious compatibility problems.
- Motorists have become more demanding. They want smoother, quieter pavements than ever before, and they do not want to be delayed by road closures or work zones for road construction or repair. They want paving crews to "get in, get out, and stay out."
- Most of the highway system has been constructed, so the emphasis has shifted from building new miles of pavement to rehabilitating existing ones, requiring a wider variety of concrete pavement solutions.
- A serious squeeze on capital for pavements is reducing dollars available for upfront project costs.
- Growing environmental pressures are affecting mix designs and construction practices.
- Pavements are carrying significantly more and heavier traffic than ever before, and the trend will continue. According to industry projections, a lane-mile of pavement built in 2015 will have to carry 70 percent more trucks than a lane-mile built in 1995.

In this environment, the old system for constructing concrete pavements no longer works. In recent years, pavement failures unheard of 30 years ago have occurred. The industry has tried to stay ahead of the trends, but improvements in concrete pavement construction have been incremental, inconsistently implemented, and sometimes only marginally successful. In the coming decades, changes such as those described above will only increase, as will the consequent challenges for the concrete pavement community.

To achieve concrete pavement's full potential in the 21st century, the industry should respond to these trends soon with dramatic, even revolutionary, improvements. The improvements cannot be piecemeal. They should be the result of a carefully developed and aggressively implemented strategic plan for research and technology transfer. The CP Road Map is that plan.

NEW TRENDS AND NEW NEEDS

The following sections describe in more detail the trends listed previously in this report. Changes occurring in the concrete industry are interrelated, exacerbating the resulting challenges.

Materials and Mixes

Perhaps the most significant change in recent years is in concrete pavement mixtures. Mixtures are becoming more complex and are no longer so forgiving.

Many factors have led to the use of new materials in concrete. For example, to make fast-track or other special-use mixes, chemical additives are commonly included in mix designs. Fly ash and slag are also added to mixtures to replace some of the portland cement and enhance certain concrete mix characteristics, such as reduced alkali-aggregate reaction and increased resistance to attack by sulfates in soil and water.

Ironically, new materials or additives that solve one problem can cause other unforeseen problems often related to materials incompatibility. The host of aggregate, cement, and mineral and chemical admixture sources from which to choose makes it difficult to develop mix designs that perform consistently. Concrete can fail with only moderate variations in materials from supplier to supplier. There is no longer any room for error. In addition, complex mixtures that perform satisfactorily under lab conditions can be less predictable under actual field conditions.

The industry needs improved, reliable QC systems to ensure predictable and reproducible performance of today's complex mixes, pavement after pavement after pavement.

Motorists' Expectations

Pavement users (including funding providers) require a certain level of pavement functionality and performance. Motorists are demanding quieter and smoother pavements that improve the driving experience and do not adversely affect the communities they abut. Pavement surfaces should be perfected to eliminate joint noise and tire whine, while continuing to provide a safe level of friction and reduced tire hydroplaning and spray when wet.

Transportation agencies, concrete pavement engineers, materials providers, and contractors need new tools and strategies for better understanding and controlling pavement surface characteristics such as smoothness, friction, spray, drainage, rolling resistance, and visibility. Traffic noise is also a growing problem in urban areas. The industry must understand concrete pavement's role in this phenomenon and provide balanced solutions.

In addition, motorists have no patience for long road closures or work zone delays. The speed of completing construction, repair, and rehabilitation work has become a critical issue, with mottos like "fast-track construction" and "get in, get out, and stay out" becoming common industry themes. Needed solutions include better use of available material on the roadway and quicker and timelier inspections.

Shift from Traditional Concrete Pavement Construction

In the past 15 years or so, with most of the highway system built and in service, the industry's emphasis has changed from constructing new pavements to repairing and rehabilitating existing ones. According to a study by the Road Information Program, pavements on 25 percent of the Nation's major metropolitan roads—interstates, freeways, and other principal arterial routes—are in poor condition.(3) In the next few years, more than 25,000 mi of the Nation's highways will require serious attention. Up to 75 percent of pavements already identified as needing improvement are light-service pavements.

To remain competitive, the concrete pavement industry should be able to deliver affordable alternatives for a variety of road repair, maintenance, and rehabilitation needs. What truly is needed is the next generation of a mix of fixes: a menu of viable, cost-effective concrete pavement solutions that provide concrete's durability and strength for the short or very long term.

The industry is already experimenting with different types of concrete overlays, bonded and unbonded, which are further distinguished by the type of existing pavement they cover. Because of cost, time required for construction, and misconceptions about overlays, however, these alternatives have had only a minimal impact nationally. The industry needs new overlay design approaches, lower cost strategies, and faster construction methods.

The mix of fixes could also include two-lift construction, in which a thin overlay of superior concrete mixture is placed on a thick layer of lower quality concrete; stop-gap rehabilitation projects; and staged improvements, in which short-term pavements are later used as subbase when their design life is over. Some solutions could focus on improving pavement foundations so that thinner pavements can provide the same level of service as traditional, thicker pavements.

Different mix designs for different solutions exacerbate QC challenges related to materials compatibility and fast-track construction environments.

Capital Squeeze

The level of funding available for pavement repair and rehabilitation is not keeping pace with needs. In 2004, State and local funding for road and bridge improvements was down 18 percent from 2002 levels, and restraints on domestic budgets are not likely to end anytime soon. This directly relates to the need for a full array of concrete pavement products to provide an affordable mix of fixes that allows agencies to properly distribute limited funds.

Static or reduced public agency funding is spurring the transfer of roles and responsibilities from State and local transportation agencies to the construction industry. This transfer includes a shift from method specifications to end-result, or performance, specifications. Mix designs, QC, end-result testing, warranties, design-build, etc., require more expertise from the contractor than ever before. Contractors and agencies alike need better tools for monitoring, controlling, and ensuring desired pavement performance.

These tools include software for integrating mix designs with structural designs and construction inspections. They include software for conducting high-speed analyses and predicting mix performance during the critical 72-h period when concrete operations have a significant impact on overall pavement performance. They include new equipment and testing methodologies that will help control the product during construction, reducing variability.

It is difficult to reduce costs while maintaining predictable service. The industry needs better methods and tools to identify and address cost issues, test different designs, conduct life-cycle cost analyses, and use marginal materials.

Going Green

Pavements should also meet ever-more demanding environmental challenges. For example, rainwater runoff issues are driving the need to develop pervious pavements for specific applications, like parking lots, curbs, and gutters. In cold climates where snow is an issue, the salt brine placed on pavements to improve safety may actually cause premature damage to the concrete.

Quality building materials are harder to come by, and new sources are not being brought online, increasing the use of marginal materials. The cement industry, under pressure to reduce harmful byproducts of portland cement manufacture, is increasing its use of supplementary cementitious materials (SCMs), including recycled materials like fly ash (captured from exhaust gases of coal-burning electricity generating plants) and slag (tapped from the waste that floats to the top of iron blast furnaces).

As described previously in this report, using these new or marginal materials requires advancements in mix design, new construction methods that incorporate marginal mix designs, and QC systems to ensure that satisfactory performance can be reproduced reliably.

Congestion and Loads

Pavements are the backbone of the Nation's transportation system and are essential to its economic well-being. Virtually all of the goods produced and sold in this country are transported on U.S. highways. From 1970 to 1998, the average daily highway traffic volume increased 130 percent, while average daily loading increased 580 percent.

By 2020, the U.S. population is predicted to grow by 50 million people. Vehicle travel is expected to increase by about 42 percent and heavy truck travel by 49 percent, putting even greater stress on the Nation's roadways. Without additional lane capacity and with projected increases in truck traffic, a lane-mile of pavement built in 2015 will have to carry 70 percent more trucks than a lane-mile built in 1995.

Clearly, concrete pavements can carry heavy-duty truck traffic, but even this area has room for advancement. For example, the industry needs improved foundation designs that allow for better assignment of loads through the slab and better drainage mechanisms.

As congestion increases, access to facilities for constructing, maintaining, and rehabilitating pavements will become more difficult. Automobiles, trucks, the pavement, and neighborhoods abutting the pavement will all have to coexist. This will have a dramatic impact on pavement programs, including initial pavement selection, speed of construction, rehabilitation and maintenance strategies, and budgets. Developing concrete pavement systems to address these needs is a critical challenge.

NEW NEEDS: A NEW GENERATION OF SOLUTIONS

The bottom line is that one size no longer fits all. The concrete pavement industry must reinvent itself and develop a generation of pavement solutions for the 21st century.

What exactly would this new generation of solutions look like? How would they be developed? With AASHTO, ACPA, FHWA, PCA, State agencies, universities, and other organizations working relatively independently on specific challenges, how can stakeholders agree on the answers, establish common priorities, reduce duplication of effort, and make the solutions a reality?

To answer these questions, FHWA needs a unique long-term research plan with the following characteristics:

- **Strategic**. The CP Road Map should deliver performance-based concrete pavement systems that dramatically affect the way concrete pavements are designed and constructed. Performance-based concrete pavement systems use sophisticated and objective QC systems at every step of a pavement project to ensure that the desired performance is achieved.

- **Innovative.** The road map should result in revolutionary new technologies and processes for quickly constructing safe, quiet, and durable pavements for a variety of traffic, loading, and other service needs (a mix of fixes) at minimum cost and with materials that require higher compatibility standards and controls..

- **Embraced.** The CP Road Map should be embraced by the entire stakeholder community and developed by and reflect the needs of all stakeholder groups.

- **Independent.** The CP Road Map is not bound by cost or time limitations or tied to any one agency or pot of money. It should lead the concrete pavement community to overcome hurdles, pool their resources, and jointly conduct, coordinate, and implement the research over a period of 7–10 years.

- **Implementable.** The CP Road Map should include strategies to quickly move useful new products and systems to the field.

- **Accompanied by a research management plan.** The management plan should effectively guide the conduct and coordination of research outlined in the CP Road Map.

The following chapters describe how such a plan was developed, provide an overview of the resulting CP Road Map, and outline an innovative research management plan for conducting the research.

Accelerated Implementation and Technology Deployment

The demand for rapid, cost-effective, and innovative solutions to address these deficiencies has never been greater. It is not enough to just complete important research; a process needs to be developed to accelerate the implementation of the research and associated technology innovations. Historically, the implementation of research has taken approximately 10 years. As an industry, dramatic steps need to be taken to reduce the time needed to implement proven concrete pavement research and deploy innovations aimed at shortening project delivery, reducing costs, and providing a sustainable product.

One way to implement proven research and deploy innovations to users is through the following three-step process that has been proven effective:

1. All research that is ready for deployment should be detailed in a user-friendly guide or manual that clearly and concisely describes not only the method of implementation but why it is important and how it can meet the goals of shortening project delivery, protecting the environment, ensuring pavement durability, and engaging in cost-effective construction.

2. The guides or manuals should be used to create a program to educate agencies and industry throughout the country. Teams of subject experts need to be organized and deployed to educate agencies by using the guides or manuals and to assist agencies through the process of evaluation, design, and construction implementation for each new innovation. Reports of each step of the process need to be completed by the team to document the process and to record the lessons learned from each of the projects.

3. Once projects are constructed, the team should utilize the lessons learned to update the guides or manuals, which can then be deployed to other projects.

Other States, AASHTO, and FHWA have employed methods to accelerate the deployment of new technology that can reduce the time it takes to implement innovative research by half. For example, FHWA, in conjunction with AASHTO, has selected market-ready technology and innovations that warrant special focus and deployment within the transportation sector.

FHWA's Technology Deployment Initiative and Partnership Program encourages innovations and technology transfer in highway design and construction. This program provides technology deployment to Federal agencies, States, and local transportation agencies. To qualify for the program, an initiative must meet the criteria of a technology feature defined by FHWA as a material, process, method, equipment item, or other feature as follows:

- Has not been sufficiently tested under actual surface conditions to merit acceptance without reservation in normal highway construction.

- Has been accepted but needs to be compared with alternate acceptance features for determining relative merits and cost effectiveness.

This type of program strongly encourages the concrete pavement industry to address challenges through innovation and technology transfer.

CHAPTER 2. CP ROAD MAP DEVELOPMENT PROCESS

The team in charge of developing the CP Road Map conducted the following activities:

- Completed a literature search and developed a research database.
- Solicited input from the broad concrete pavement community.
- Identified and organized research needs and objectives into a cohesive strategic research plan.

LITERATURE SEARCH/RESEARCH DATABASE

The literature search consisted of two parts. First, information about all recently completed and ongoing research projects was entered into a research database. This database later was used as a filter to ensure that the new research plan does not duplicate existing research.

Second, several research and technology plans developed by other organizations were reviewed to identify concepts that should be included in the CP Road Map. These plans included the following:

- FHWA: *Building for the Future—A Technology Program for Portland Cement Concrete Pavements*.(4)
- IPRF: "Creating a New Generation of Pavements."(5)
- U.S. Department of Energy: *Vision 2030: A Vision for the U.S. Concrete Industry*.(6)
- National Materials Advisory Board: *Nonconventional Concrete Technologies, Renewal of the Highway Infrastructure*.(7)
- National Highway Research and Technology Partnership Forum: *Infrastructure Renewal Research Agenda*.(8)
- National CP Tech Center Research committee research plans.
- TRB committee A2FO1 research plans.
- ACPA research plans.

Although each of these plans was uniquely valuable, none contained a fully integrated sequential and cohesive series of research statements that would dramatically change the way concrete pavements are designed and built. Many of the plans, however, did include individual research statements that, on their own merit, were incorporated into the CP Road Map planning process and research database. The CP Road Map development process is illustrated in figure 1.

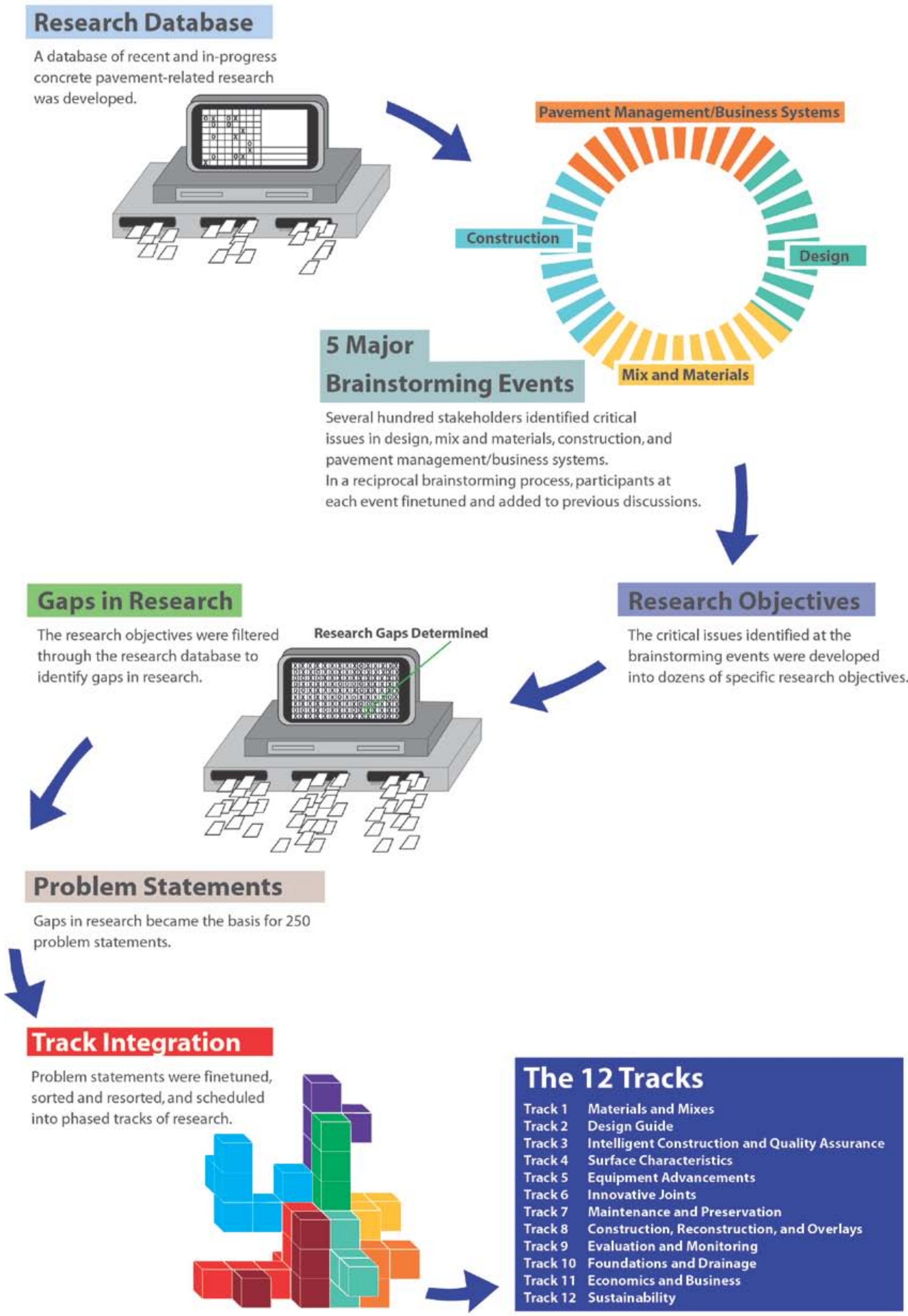


Figure 1. Illustration. CP Road Map development process.

BRAINSTORMING EVENTS

Five major brainstorming and feedback sessions were conducted at the following events: the October 2003 meeting of the National Concrete Consortium in Ames, IA; a special November 2003 regional workshop for Eastern and Southern stakeholders in Syracuse, NY; the May 2004 meeting of the ACPA in Kansas City, MO; a special January 2004 regional teleconference for Western stakeholders; and a final meeting of national stakeholders in October 2004 hosted by FHWA at TFHRC.

Stakeholders

Through these events, in addition to more than 20 presentations at workshops around the country (see appendix A for a detailed list of events), more than 400 engineers and managers representing every stakeholder group provided direct input into the CP Road Map.

Participating stakeholders include the following:

- State and local transportation departments.
- FHWA.
- ACPA, including several State chapters.
- PCA.
- AASHTO.
- NRMCA.
- TRB/NCHRP committees.
- APWA.
- NACE.
- Contractors.
- Materials suppliers.
- Research universities, especially departments conducting applied research.
- Private concrete testing laboratories.

Brainstorming Strategies

It is easy to talk about soliciting input from stakeholders. However, in a project of this size and complexity, it was critical to have a system to help focus stakeholders' brainstorming processes.

In addition, stakeholders came to the brainstorming events with specific goals or projects already in mind. It was important to help participants look beyond their own pet projects.

Two brainstorming strategies were used. First, participants responded to draft big-picture vision statements identifying research needed to provide the concrete pavement characteristics that will meet the needs of end users and owners well into the future. Through guided activities, participants evaluated, revised, added to, subtracted from, and prioritized the vision statements. This process helped participants dream big.

Then, in small groups, participants identified specific critical issues in each of the following areas that must be resolved through research to achieve desired pavement characteristics:

- Materials and mixtures.
- Design.
- Construction.
- Pavement management/business systems.

Participants discussed new tools they need and existing ones that need to be improved. They discussed systems that must be in place, including financing and bidding systems. They identified obstacles that must be overcome.

Again and again, stakeholders who participated in the brainstorming events said they needed more and better analysis tools for measuring the "hows" and "whys" of pavement failures and successes—that is, for measuring pavement performance. Better QA and QC methods and tools are needed for every stage of the pavement system, from design to maintenance to rehabilitation. Because variables in each stage affect the other stages, the methods and tools must be integrated across stages.

From these central concepts of pavement performance and systems integration, the following overall vision for the CP Road Map was developed:

> *By 2015, the highway community will have a comprehensive, integrated, and fully functional system of concrete pavement technologies that provides innovative solutions for customer-driven performance requirements.*

Based on this goal and stakeholder input at the brainstorming sessions, dozens of specific research objectives were identified, which were subsequently categorized. Some of these objectives included the following:

- Maximize public convenience.
- Improve the driving experience.
- Integrate design, mixtures and materials, and construction with pavement performance predictions.

- Improve pavement reliability.
- Identify new and innovative business relationships to focus on performance requirements.
- Constrain costs while improving pavement performance.
- Protect and improve the environment.
- Expand opportunities to use concrete pavement.

The objectives were filtered through the database of existing research to determine gaps in research. These gaps became the basis for problem statements. Approximately 250 problem statements were written, reviewed, and fine-tuned. Final versions of the problem statements were added to the research database as work to be accomplished via the CP Road Map.

Identifying critical research issues and objectives was an ongoing reciprocal process. Participants at successive brainstorming events responded to, refined, and prioritized critical issues and objectives identified at previous events. For the duration of this project, participants at the brainstorming events and stakeholders unable to attend were invited to submit additional feedback and ideas through the project Web site.

PUTTING IT ALL TOGETHER IN THE CP ROAD MAP

FHWA requested a strategic research plan outlining up to a decade of integrated activities, including research, technology development and implementation, and technology transfer, with ample details to guide technical panels that will implement the plan. Therefore, the CP Road Map is a synopsis of research needs outlined in problem statements and organized in tracks of research.

Between brainstorming events, the problem statements were constantly revised and improved. Some were culled completely, others were fine-tuned, and some closely related concepts were combined, all with feedback from stakeholders. The problem statements were sorted and resorted in a variety of ways to integrate and organize the statements into the most appropriate tracks for facilitating ownership by various stakeholder groups. This ownership will be critical for successful conduct of the research.

The integration process resulted in identifying and developing 12 research tracks. This manageable number of tracks is in line with recommendations from the FHWA panel and encourages the community to focus on research with the highest potential payback. Some tracks closely mimic the trends identified in chapter 1 of this report as driving the need for the CP Road Map.

Each research track was organized into subtracks of research problem statements that, as research is conducted, will lead to the achievement of a major objective or development of a major product. This organizational strategy lends itself to scheduling and strategically integrating related research.

Specific goals, expected outcomes, and estimated budgets were defined for each research track and subtrack. Several research problem statements were coordinated, or linked, with research in other tracks to ensure an integrated approach to QC for desired pavement performance. For example, pavement design models are linked to mix design and construction control; the linkages were built into the research database.

At a terminal event in October 2004, stakeholders provided final feedback on the CP Road Map. This event ensured that the CP Road Map's objectives are clear and its goals attainable. The research is a blend of the practical, incremental, and innovative; work priorities are clear; and the implementation strategy is innovative and doable.

CHAPTER 3. WHAT DOES THE STRATEGIC ROAD MAP LOOK LIKE?

A research plan of this size and complexity cannot be absorbed in one quick skim-through.[1] This chapter is for readers who do not need all of the details but simply want an overview of the CP Road Map. Following is a summary of the CP Road Map, highlights of the research tracks and subtracks, and the general budget and timeline.

SUMMARY

The CP Road Map consists of more than 270 problem statements. These were originally organized into the following 12 topical research tracks:

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.

Over the course of the last 5 years of implementation, the CP Road Map has evolved. The current organization includes the following tracks:

1. Materials and Mixes for Concrete Pavements.
2. Performance-Based Design Guide for New and Rehabilitated Concrete Pavements.
3. Intelligent Construction Systems and Quality Assurance for Concrete Pavements.

[1]See volume II of this report (Report No. FHWA-HRT-11-070) for a detailed description of the CP Road Map and its tracks, subtracks, problem statements, timelines, and budgets.

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. Concrete Pavement Maintenance and Preservation.
8. Concrete Pavement Construction, Rehabilitation, and Overlays.
9. Evaluation, Monitoring, and Strategies for Long-Life Concrete Pavements.
10. Concrete Pavement Foundations and Drainage.
11. Concrete Pavement Economics and Business Management.
12. Concrete Pavement Sustainability.

The problem statements in each track have been organized into subtracks of specific areas of research. As described in the research management plan (see chapter 8 of this report), each track is managed by a track team leader or team leaders with a technical working group. Each track includes its own budget, begins with a framing study in which the work is planned in more detail, and includes specific implementation activities.

The various tracks are integrated in strategic areas. For example, reducing mix performance variability (track 1) will require equipment advances (track 5). Validating and calibrating mix design models (track 1) will require enhanced data (track 9). Constructing long-lasting overlays (track 8) will require new mix and structural design techniques (tracks 1 and 2).

PROBLEM STATEMENTS

Each problem statement clearly defines the tasks that must be performed to produce a desired product or achieve a desired objective. Because this CP Road Map was not developed for a single budget or funding source or with a particular client in mind, it was not possible to put this into a format ready for bid.

Developing detailed research statements may take six to eight experts 18 h to develop, resulting in more than 100 h of time and experience per statement.

It should be noted that many of the problem statements identify products that are self-standing and usable. It is not necessary to complete the entire track to obtain useful and important outputs.

ESTIMATED BUDGET

Table 1 provides an estimated budget per track in millions of U.S. dollars for each of the 12 tracks.

Table 1. Estimated budget.

Track	Estimated Cost* (Millions)
1. Materials and Mixes for Concrete Pavements	$38–$81
2. Performance-Based Design Guide for New and Rehabilitated Concrete Pavements	$41–$60
3. Intelligent Construction Systems and Quality Assurance for Concrete Pavements	$20–$41
4. Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements	$25–$54
5. Concrete Pavement Equipment Automation and Advancements	$26–$56
6. Innovative Concrete Pavement Joint Design, Materials, and Construction	$10–$15
7. Concrete Pavement Maintenance and Preservation	$8–$13
8. Concrete Pavement Construction, Reconstruction, and Overlays	$31–$53
9. Evaluation, Monitoring, and Strategies for Long-Life Concrete Pavements	$21–$34
10. Concrete Pavement Foundations and Drainage	$6–$12
11. Concrete Pavement Economics and Business Management	$21–$31
12. Concrete Pavement Sustainability	$30–$40
Total	$277–$492

*All numbers are rounded.

TRACK HIGHLIGHTS

Track 1. Materials and Mixes for Concrete Pavements

Track 1 Subtracks

Track 1 subtracks are as follows:

- 1-1. Performance-Based Mix Design and Specifications.
- 1-2. Materials Selection and Testing.
- 1-3. Innovative Materials.
- 1-4. Materials Proportioning.
- 1-5. Mixture Evaluation.
- 1-6. Post-Construction Pavement Materials Evaluation.

This track will develop a practical, yet innovative, concrete mix design procedure with new equipment, consensus target values, common laboratory procedures, and full integration into both structural design and field QC. As opposed to mix proportioning, mix design engineers will create a concrete mixture to meet a variety of property or performance targets. The process begins by defining the end product. Next, the various materials are selected, proportioned, simulated, and optimized to meet the end product goals. This track will develop mix design rather than mix proportioning. Figure 2 shows a lab for developing advanced mixture designs.

Figure 2. Illustration. Lab for advanced mixture designs.

This track also addresses concrete pavement materials selection, including the use of recycled materials, SCMs, and new and innovative materials that will help mixture designers to better achieve performance requirements. Materials selection maintains a certain emphasis on sustainable materials, complimenting research conducted under track 12.

This ambitious track also lays the groundwork for the concrete paving industry to assume more mix design responsibility as State highway agencies move from method specification to a more advanced acceptance tool. To do this, however, the concrete paving industry and the owner-agencies must be able to refer to a single document for state-of-the-art mix design.

The track provides a plan for research in the following areas:

- Integration of volumetric-based, property-based, performance-based, and functionally based mix designs and recycled materials into the mix design system.
- Materials selection for achieving performance requirements and utilizing innovative and sustainable materials.
- Identification of new and upgraded equipment and test procedures.
- Development of an expert system that connects test results to each other.
- Improved models to predict slab performance.

- Field evaluation and implementation procedures that provide a mechanism for user feedback.

- Technology transfer activities.

Track 1 Goal

Innovative concrete mix material selections and mix design procedures will produce economical, compatible, and optimized concrete mixes integrated into both structural concrete pavement design and construction control.

Track 1 Action Items

The track 1 action items are as follows:

1. Develop a concrete lab that will give users a sequence of mix design tests and procedures that integrate structural design and QC with material selection and proportioning.

2. Develop the tools necessary to predict the compatibility and effectiveness of concrete mixes under specific field conditions before paving begins.

3. Detect potential construction problems early and correct them automatically using innovative QC tools.

4. Detect potential long-term durability problems more effectively during both the mix design process and the construction QC program.

5. Improve the ability to predict concrete mix properties and their relationship to slab behavior and performance (e.g., shrinkage, joint opening, and curing) using the next generation of advanced modeling techniques.

6. Identify and use innovative, nontraditional materials that accelerate concrete pavement construction, maintenance, and rehabilitation and/or extend product life at a fair cost.

Track 2. Performance-Based Design Guide for New and Rehabilitated Concrete Pavements

Track 2 Subtracks

Track 2 subtracks are as follows:

- 2-1. Design Guide Structural Models.

- 2-2. Design Guide Inputs, Performance Models, and Reliability.

- 2-3. Special Design and Rehabilitation Issues.

- 2-4. Improved Mechanistic Design Procedures.

- 2-5. Design Guide Implementation.

Under this track, the concrete pavement research community will develop a mechanistic approach to pavement restoration and preservation strategies. This track builds on the comprehensive work done under NCHRP 1-37A (development of the MEPDG), which subsequently led to the AASHTOWare® design software DARWin-ME™.[1] The problem statements serve to continuously improve the models, designs, rehabilitation efforts, and all aspects of the work done under NCHRP 1-37A. This track relies on a detailed understanding of the MEPDG, committing researchers to the power of modeling and predictions. However, the CP Road Map also identifies the need for simplified mix design procedures for cities and counties, as well as a design catalog approach. Because many materials properties are important to design success, it is critical that the research conducted under this track be closely coordinated with that done in track 1. Figure 3 demonstrates advanced models for performance-based design.

Figure 3. Illustration. Advanced models for performance-based design.

Empirical approaches to concrete pavement design are effective when the conditions remain the same, the focus is on structural design, and the attention is not on understanding and managing distress or failure modes. The pavement design practice of today is primarily empirical, although the state of the practice is moving toward mechanistic approaches. The primary source of much of today's pavement design is still the American Association of State Highway Officials' (AASHO) road test of the 1950s. This one subgrade, one base, one climate, limited traffic design guide was constructed using better-than-normal construction practices. Data analysis techniques were also basic, and the incorporation of reliability was insufficiently understood. Moreover, the AASHO road test did not incorporate many of the concepts and products used in concrete pavement practice today, including concrete overlays, permeable bases, different cements, dowel bar retrofits (DBRs), and other necessary repairs.

The state of the practice today is moving rapidly toward mechanistic-empirical (M-E) approaches, particularly with the AASHTOWare® release of the design software DARWin-ME™ and the expressed interest of many States.[1] These M-E approaches will allow the designer to account for new design features and characteristics, many materials properties, changing traffic characteristics, and differing construction procedures (such as curing and day/night construction). The designer now can consider additional design features and focus more on pavement performance, including limiting key distress types.

In continuing this work, this track not only looks to the next generation of modeling improvements, but it seriously considers integrating design with materials, construction, presentation, and surface characteristics. This track also explores the development of new high-speed computer analysis tools for optimizing pavement design that can address changes to multiple inputs and thus offer better data on potential life-cycle costs and reliability.

Track 2 Goal

Mechanistic-based concrete pavement designs will be reliable, economical, constructible, and maintainable throughout their design life and meet or exceed the multiple needs of the traveling public, taxpayers, and the owning highway agencies. The advanced technology developed under this track will increase concrete pavement reliability and durability (with fewer early failures and lane closures) and help develop cost-effective pavement design and rehabilitation.

Track 2 Action Items

The track 2 action items are as follows:

1. Develop viable (e.g., reliable, economical, constructible, and maintainable) concrete pavement options for all classes of streets, low-volume roads, highways, and special applications.

2. Improve concrete pavement design reliability, enhance design features, reduce life-cycle costs, and reduce lane closures over the design life by maximizing the use of fundamental engineering principles through mechanistic relationships.

3. Integrate pavement designs with materials, construction, traffic loading, climate, preservation treatments, rehabilitation, and performance requirements to produce reliable, economical, and functional (noise, spray, aesthetics, friction, texture, illumination, etc.) designs.

4. Integrate traditional structural pavement design with materials, construction, traffic loading, climate, preservation treatments, rehabilitation, and performance inputs that will produce reliable, economical, and functional (noise, spray, aesthetics, friction, texture, illumination, etc.) designs.

5. Design preservation and rehabilitation treatments and strategies using mechanistic-based procedures that use in-place materials from the pavement structure to minimize life-cycle costs and construction and maintenance lane closures.

6. Develop and evaluate new and innovative concrete pavement designs for specific needs (e.g., high traffic, residential traffic, parkways, etc.).

Track 3. Intelligent Construction Systems and Quality Assurance for Concrete Pavements

Track 3 Subtracks

Track 3 subtracks are as follows:

- 3-1. Quality Assurance.
- 3-2. Intelligent Construction System Technologies and Methods.
- 3-3. Intelligent Construction System Evaluation and Implementation.

The research community has studied various ICSs and nondestructive testing (NDT) technologies for nearly 30 years. While this technology is beginning to impact pavement management equipment and some hand-held test equipment in construction technology, ICS and NDT technology have not been applied extensively to concrete paving. The advancing technology could benefit both the construction and inspection teams in several key ways. Figure 4 shows several examples of advancing technologies.

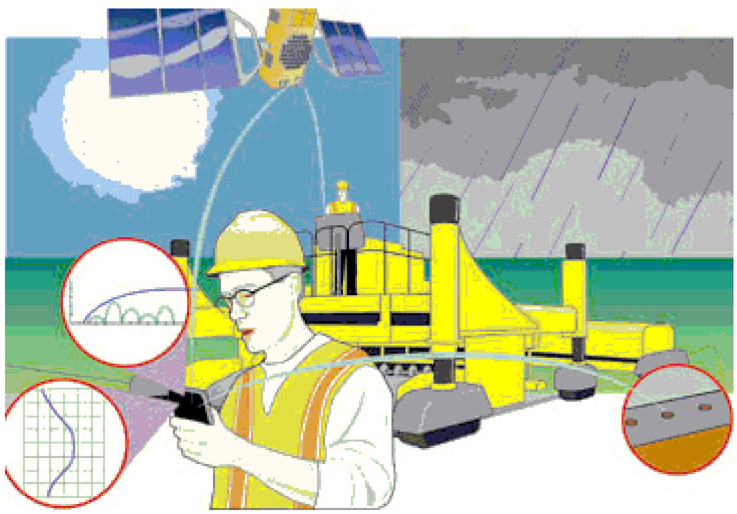


Figure 4. Illustration. Technologies for monitoring pavement data and making real-time adjustments during construction.

The equipment industry faces both a technical challenge and the challenge of investing in a methodology without being certain of a market. Establishing a working group that properly frames the issues, agrees on the technologies, and prioritizes the work efforts is critical for overcoming this investment challenge.

Both industry and government will benefit from ICS and NDT by reducing reliance on slow and sometimes poorly managed small-sample testing programs. ICS can adjust the paving process automatically while informing contractors and inspectors of changes and/or deficiencies in construction. Continuous and real-time sampling will be configured to detect changes to the approved mix design and the preprogrammed line and grade values. ICS and NDT technology will also allow industry and government to use the data collected for long-term pavement management and evaluation.

The ICS methods developed in this track can measure the following properties that impact concrete pavement durability and performance:

- Pavement depth.
- Horizontal and vertical slab alignment.
- Subgrade support and variability.
- Steel location (i.e., dowels and tie bars).
- Concrete strength through the slab.
- Concrete temperature through the slab.
- Moisture loss.
- Smoothness.
- Tire/pavement noise potential.
- Air.

Many problem statements in this track relate to tracks 1 and 2. Software standards will also ensure that the public can link to any software that the private sector produces.

Finally, human factors are critical for both researching and implementing this track. Pavement engineers, materials testers, and contractors need to understand ICS fundamentals to avoid the black box syndrome—that is, trying to get a technology to do something that they do not understand in principle.

Track 3 Goal

High-speed nondestructive ICS can continuously monitor pavement properties during construction to provide rapid feedback. As a result, automatic adjustments can ensure a high-quality finished product that meets QA and performance specifications.

Track 3 Action Items

Track 3 action items are as follows:

1. Perform QA tests and procedures that use continuous and real-time sampling to monitor performance-related concrete mix properties and reduce the number of human inspectors.

2. Improve construction operations by providing continuous and rapid feedback to make changes automatically.

3. Integrate data collection with materials management and pavement management systems (PMSs) to solve future problems and evaluate performance.

Track 4. Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements

Track 4 Subtracks

Track 4 subtracks are as follows:

- 4-1. Concrete Pavement Texture and Friction.
- 4-2. Concrete Pavement Smoothness.
- 4-3. Tire-Pavement Noise.
- 4-4. Other Concrete Pavement Surface Characteristics.
- 4-5. Integration of Concrete Pavement Surface Characteristics.
- 4-.6. Evaluation of Products for Concrete Pavement Surface Characteristics.
- 4-7. Concrete Pavement Surface Characteristics Implementation.

FHWA and State highway agencies have learned from opinion polling that American drivers value the quality of their ride experience. Over the past three decades, concrete pavement engineers have focused on improving pavement smoothness without jeopardizing surface friction or surface drainage characteristics. This difficult but important balancing act has led to advancements in smoothness indices, longitudinal tining, and measurement equipment, among other areas. However, the relationship between surface texture and surface characteristics, as well as concrete pavement performance, has yet to develop fully. While smoother concrete pavements are being constructed, the relationships between texture, noise, splash and spray, and friction require further study before widely accepted solutions become available. Figure 5 illustrates an optimized pavement surface.

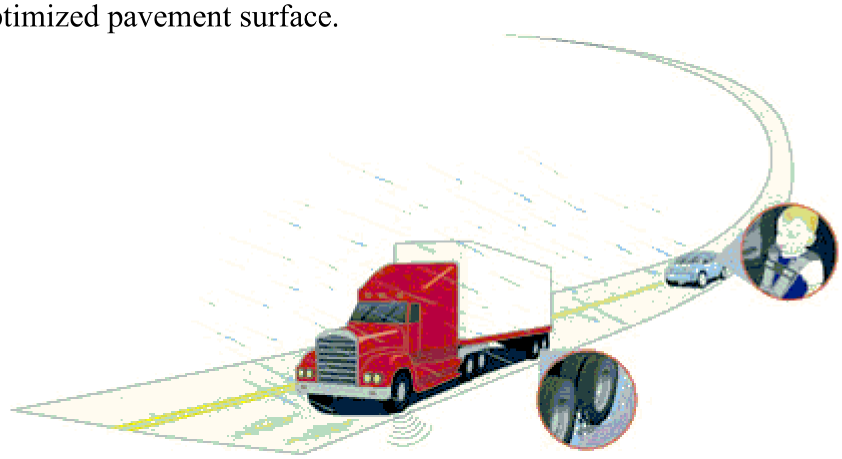


Figure 5. Illustration. Optimized pavement surfaces for a safe, quiet, and smooth ride.

In some areas of the United States, drivers and residents have demanded quieter rides and living experiences. These demands often eliminate concrete pavement as a construction option and, in some cases, has even led to the overlay of recently constructed concrete pavements. In the Phoenix, AZ, metropolitan area, for example, concrete pavements that have a harsh transverse texture used to make up nearly all of the freeway system. Because of noise complaints, these pavements have now been largely overlaid with an asphalt rubber friction course. While this may seem radical to some, the approach is not new. Noise has been a major problem in some of the most densely populated areas of Europe for more than two decades. As a result, concrete pavement construction has been impeded there.

Most European nations now place thin, asphalt-based wearing courses over their concrete pavements immediately after construction. However, some concrete surfacing solutions have been used successfully. These include thin, open-graded (porous) concrete wearing surfaces and exposed aggregate surfaces. Textures, such as fine longitudinal burlap drag and diamond grinding, are also used to reduce noise.

To address noise impacts to highway abutters, FHWA regulations currently dictate the noise mitigation efforts required, if any, for new or expanded highway facilities on the Federal aid system. To date, these regulations have resulted in questions about whether noise barriers are necessary and, if so, what their design should be. At the same time, automobile and tire makers have developed designs that meet more stringent friction (braking) demands, while at the same time reducing interior noise. In the near future, pavement will be observed to help with noise reduction. This will require concrete pavement engineers to take responsibility to find innovative materials and optimize pavement textures.

To meet this responsibility, concrete pavement engineers must balance smoothness, friction, surface drainage, splash and spray, and noise to develop economical and long-lasting solutions for concrete pavement surfaces. Any long-term solution must include research and experimentation that examines the integration of these elements into an array of viable incremental solutions. One consideration is developing standardized noise measurement and analysis techniques. Pavement engineers must also understand fundamental engineering properties better to assess noise, friction, and smoothness, isolating improved texturing options and tailoring solutions to location, traffic, and renewal requirements. Pavement engineers must understand the functional and structural performance of various solutions over time, as the data from many studies are sufficient to examine the relationships between noise and the other surface characteristics, including pavement durability.

Research must aim to develop various standardized measurement techniques, understand the tire-pavement interaction with various texturing options, predict the life expectancy of any solution, and identify possible repair and rehabilitation strategies for these pavements. Moreover, if noise criteria are ever imposed as design-build criteria, integration with national noise mitigation standards must be considered, and rational and achievable construction specification language must be developed.

Track 4 Goal

A better understanding of concrete pavement surface characteristics will provide the traveling public with concrete pavement surfaces that meet or exceed predetermined requirements for friction/safety, tire-pavement noise, smoothness, splash and spray, light reflection, rolling resistance, and durability (longevity).

Track 4 Action Items

Track 4 action items are as follows:

1. Develop reliable, economical, constructible, and maintainable concrete pavement surface characteristics that meet or exceed highway user requirements for all classes of streets, low-volume roads, highways, and special applications.

2. Develop, field test, and validate concrete pavement designs and construction methods that produce consistent surface characteristics that meet or exceed highway user requirements for friction/safety, tire-pavement noise, smoothness, splash and spray, light reflection, rolling resistance, and durability (longevity).

3. Define the relationship between wet weather accident rates, pavement texture, and friction demand levels.

4. Determine the design materials and construction methods that produce different levels of short- and long-term surface microtexture, macrotexture, megatexture, and unevenness.

5. Determine the relationship between pavement texture levels (microtexture, macrotexture, megatexture, and unevenness) and surface characteristic performance levels (friction, noise, smoothness, splash and spray, rolling resistance, and light reflectivity).

6. Evaluate and develop high-speed, continuous measurement equipment and procedures for measuring texture, friction, noise, smoothness, splash and spray, rolling resistance, and other key surface characteristics.

7. Develop design and construction guidelines for concrete pavement surface characteristics, protocols, guide specifications, and associated technology transfer products.

Track 5. Concrete Pavement Equipment Automation and Advancements

Track 5 Subtracks

Track 5 subtracks are as follows:

- 5-1. Concrete Batching and Mixing Equipment.

- 5-2. Concrete Placement Equipment.

- 5-3. Concrete Pavement Curing, Texturing, and Jointing Equipment.

- 5-4. Concrete Pavement Foundation Equipment.
- 5-5. Concrete Pavement Reconstruction Equipment.
- 5-6. Concrete Pavement Restoration Equipment.
- 5-7. Advanced Equipment Evaluation and Implementation.

Figure 6 illustrates several equipment and technology advancements.

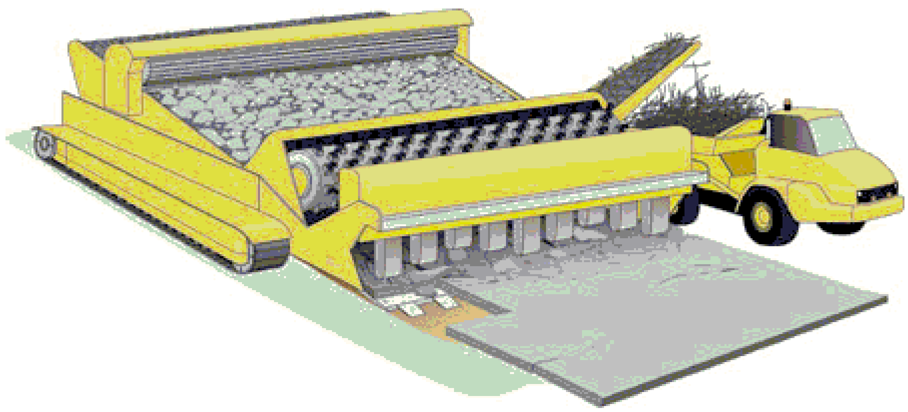


Figure 6. Illustration. Equipment and technology advancements.

The problem statements in this track propose process improvements and equipment developments for high-speed, high-quality concrete paving equipment. Research on the following technologies are needed to meet the concrete paving industry's projected needs and the traveling public's expectations for highway performance in the future:

- Next generation of concrete batching equipment.
- Next generation of concrete placement equipment that addressed new construction processes.
- Behind-the-paver equipment to improve quality, speed, and cost effectiveness.
- Mechanized ways to place and control subdrains and other foundation elements.
- Next generation of equipment that will integrate the removal/replacement of the slab in one-pass construction.
- Improved repair processes that decrease the time of operations and expose the workforce and traveling public to less construction.
- Methods for evaluating the new equipment on actual construction projects.

Efforts in the area of equipment automation and advancements will require collaborative partnerships between equipment manufacturers, contractors, and State highway agencies. After equipment concepts have been established, it is hoped that contractors and industry will be willing to invest in developing new equipment. Involving contractors and industry from the start is essential for ensuring the equipment is practical for actual implementation. This private funding will also help introduce the new equipment into everyday practice much faster than if development and implementation costs were solely carried by the government.

Stringless global positioning system control of slipform paving equipment is just one example of many pioneering technologies that, if further developed and tested, could increase efficiency, lower costs, and increase performance for the concrete paving industry.

Track 5 Goal

Concrete paving process improvements and equipment advancements will expedite and automate concrete pavement rehabilitation and construction, resulting in high-quality concrete pavements, reduced waste, and safer working environments.

Track 5 Action Items

Track 5 action items are as follows:

1. Develop batching equipment that will produce better quality concrete mixes by optimizing the materials used and allowing for rapid adjustment of mix proportions.

2. Improve paving techniques and equipment to produce higher quality concrete pavements while optimizing material usage and reducing construction time and processes.

3. Improve techniques for curing, texturing, and jointing concrete pavements while allowing pavements to be opened to traffic more quickly.

4. Improve equipment and techniques for expedited subbase stabilization and subdrain installation.

5. Develop equipment for rapid in-place reconstruction of concrete pavements using existing/recycled materials.

6. Improve and automate techniques and equipment for rapid concrete pavement restoration.

7. Introduce contractors and owner agencies to new advanced equipment and provide assistance for purchasing such equipment.

Track 6. Innovative Concrete Pavement Joint Design, Materials, and Construction

Track 6 Subtracks

Track 6 subtracks are as follows:

- 6-1. Joint Design Innovations.
- 6-2. Joint Materials, Construction, Evaluation, and Rehabilitation Innovations.
- 6-3. Innovative Joints Implementation.

Concrete has a propensity to crack. Because controlling cracks is essential for pavement performance, joints are an important feature of concrete paving. As the FHWA Technical Advisory on Concrete Pavement Joints (T 5040.30) explains, "The performance of concrete pavements depends to a large extent upon the satisfactory performance of the joints. Most jointed concrete pavement (JCP) failures can be attributed to failures at the joint, as opposed to inadequate structural capacity"(p. 1).[9]

Joints can also fail prematurely. Deterioration of concrete pavement joints has been reported nationwide, particularly in the northern States. Pavements affected include State highways, city and county streets, and parking lots. While it should be emphasized that only a small number of concrete pavements are affected, the distress is common enough to warrant research to identify preventative measures.

Ideal joints must be relatively easy to install and repair, consolidate around the steel, provide adequate load transfer, seal the joint or provide for water migration, resist corrosion, open and close freely in temperature changes, enhance smoothness and low noise, and be aesthetically pleasing. Figure 7 contains a graphic interpretation of the goal in developing these techniques. Joint failure can result in faulting, pumping, spalling, corner breaks, blowups, and transverse cracking (if lockup occurs).

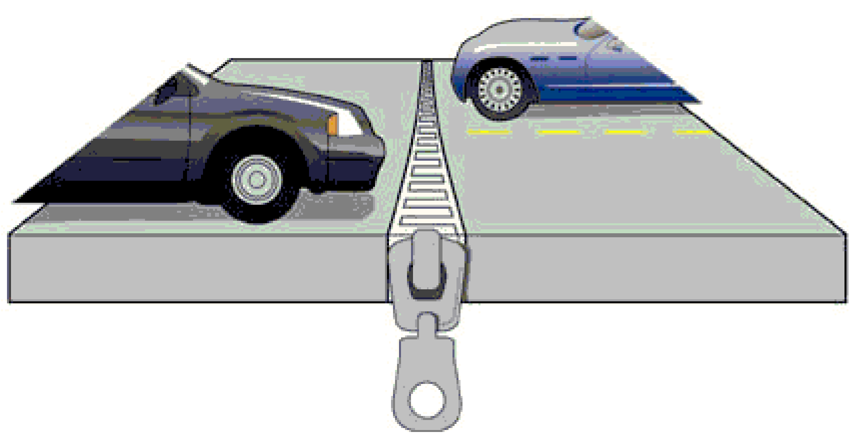


Figure 7. Illustration. Breakthrough techniques for designing and rehabilitating joints.

The problem statements in this track address new and innovative joint design, materials, construction, and maintenance activities. There is much room in this research for innovative concrete pavement joint design, such as in research to address the coefficient of thermal expansion and shrinkage issues. Additional incremental improvements to joint design, such as tie bar design for longitudinal joints, are addressed under track 2. Much of the proposed research in this track will develop important improvements, though the track also specifies research that will help develop breakthrough technologies. The problem statements also recognize that future joint repair will proceed quickly, and they propose research for accomplishing faster joint repair.

Some of the concepts that will be investigated include the following:

- Private and public sector knowledge and experience will be used to identify ways to enhance jointed pavements.
- Many JCPs that have lasted many years without dowels will require retrofitting with dowels to control faulting. Techniques will be explored.
- Doweled joints will be designed to last 60 years in relatively heavy traffic.
- Continuously reinforced concrete pavements will solve the problem of joint lifespan by eliminating the joints entirely.
- Joints for concrete overlays (20-year-and-less performance life) have not been studied sufficiently. The cost of a doweled joint in thin pavement can be exceptionally high for the life expectancy. Research in this track will develop a scaled-down but fully functional joint for this product, with owners specifying a less robust but fully functional joint for the shorter design period.

Track 6 Goal

This track will identify, develop, and test new and innovative joint concepts for concrete pavements that are more cost-effective, reliable, and durable than current alternatives.

Track 6 Action Items

Track 6 action items are as follows:

1. Identify the mechanisms leading to premature deterioration, along with remedies for both existing pavements and new construction.
2. Identify new and innovative alternatives to handling the forming, opening/closing, load transfer, and sealing for transverse and longitudinal concrete pavement joints.
3. Identify criteria for the design, materials, and construction of exceptionally long-lasting joints (e.g., more than 50 years) (see track 9).
4. Determine optimum joint design for concrete overlays.

5. Determine optimum joint design for low-volume, long-life pavements.

6. Develop an advanced high-speed computational model for joint condition analysis that can joint improve design, materials, and construction.

7. Develop fully and field test promising new and innovative joint designs to determine their cost effectiveness, reliability, and durability.

8. Develop and validate rapid methodology for evaluating existing joint conditions so that joints can be preserved and repaired.

Track 7. Concrete Pavement Maintenance and Preservation

Track 7 Subtracks

Track 7 subtracks are as follows:

- 7-1. Optimization and Automation of Pavement Maintenance.
- 7-2. Optimized Concrete Pavement Preservation.
- 7-3. Distress Identification and Preservation Treatment.
- 7-4. Feedback Loop for Concrete Pavement Preservation Effectiveness.

In the current economic climate, the need to maintain and preserve existing highway infrastructure assets has taken on a much greater importance. This is reflected by highway agency budgets shifting funding from new construction and/or reconstruction to maintenance and preservation. This shift in priorities emphasizes the importance of establishing reliable procedures and developing new and innovative methods for concrete pavement maintenance and preservation.

Proper maintenance and preservation treatments can significantly extend the life of concrete pavements, even well beyond their intended design life. There is a need to identify and implement proven maintenance and preservation practices and techniques and ensure proper application of those treatments.

Furthermore, many enhancements to existing maintenance and preservation treatments are envisioned. Automation of distress and maintenance need identification, and automated application of maintenance and preservation treatments can greatly reduce the cost and expedite the application of treatments, as well as enhance safety for maintenance workers.

Research in this track will include the following:

- Optimization of concrete pavement preservation.
- Optimization and automation of concrete pavement maintenance treatments.

- Distress identification and preservation treatments.
- Development of feedback loops for concrete pavement preservation effectiveness.

There is significant crossover with the problem statements presented in this track and other tracks; notably, problem statements from track 2 related to the effect of improvements in maintenance and preservation treatments on pavement design, problem statements from track 5 related to advancements in equipment automation for maintenance and preservation, and problem statements from track 9 related to the effect of maintenance and preservation on pavement life. Figure 8 illustrates one pavement preservation strategy.

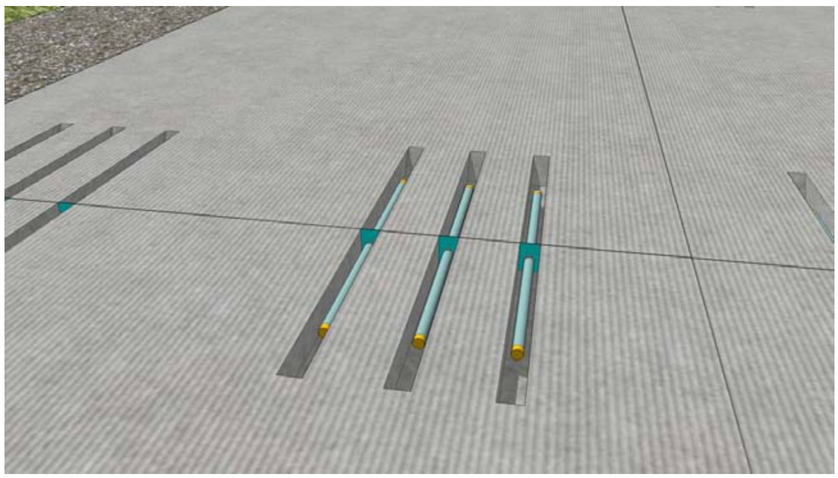


Figure 8. Illustration. Dowel bar retrofitting used for pavement preservation.

Track 7 Goal

Track 7 will focus on optimization and deployment of maintenance and preservation treatments for concrete pavements in order to preserve the asset and maximize its lifespan.

Track 7 Action Items

Track 7 action items are as follows:

1. Establish proven concrete pavement preservation methods and optimized preservation strategies for maximizing pavement life.
2. Establish essential concrete pavement maintenance needs and automated methods for identifying these needs.
3. Identify proven and new and innovative methods for automated pavement maintenance treatments and provide guidance for use of these methods.

4. Establish methods for automated distress identification and assessment of necessary preservation treatments.

5. Establish a system for continuous feedback on the effectiveness of pavement preservation methods such that adjustments can be made in a timely manner.

Track 8. Concrete Pavement Construction, Reconstruction, and Overlays

Track 8 Subtracks

Track 8 subtracks are as follows:

- 8-1. Construction, Reconstruction, and Overlay Planning and Simulation.
- 8-2. Precast and Modular Concrete Pavements.
- 8-3. Concrete Overlays.
- 8-4. Fast-Track Concrete Pavements.
- 8-5. Construction, Reconstruction, and Overlay Evaluation and Implementation.

For more than 20 years, the concrete pavement industry has confronted both facts and perceptions about concrete pavement construction under high-speed construction conditions. While the industry's record is generally positive, perceptions still determine concrete use in many situations. The traffic growth data presented in chapter 1 of this report show that, despite the gains made in the past decade, concrete pavements across the country will continually need rehabilitation under high-speed construction conditions.

Furthermore, while asphalt pavement has traditionally been viewed as the only solution for overlays of existing pavement, over the past decade, tremendous advances have been made in the understanding and usage of concrete pavements. Concrete overlays present a solution that facilitates high-speed rehabilitation by eliminating the need to remove the existing pavement prior to constructing a long-life concrete pavement. Figure 9 illustrates a bonded concrete overlay.

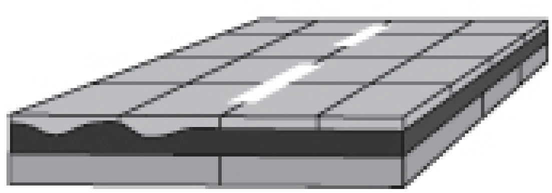


Figure 9. Illustration. Bonded concrete overlay over composite pavement.

The next generation of construction and rehabilitation tools combines the software and hardware required to simulate system design and predict problems that might surface during accelerated construction. High-speed computer simulation can troubleshoot a pavement's response to environmental changes, as well. Effective construction management, however, remains critical for meeting the goals and objectives of this track.

Future high-speed construction challenges the industry to move away from slipform paving and identify ways to make precast construction a more viable alternative. Precast modular construction not only might replace ultra high-speed construction but also improve product quality and extend the paving system.

Research in this track will include the following:

- Planning and simulation for high-speed construction and rehabilitation.
- Precast and modular options for concrete pavements.
- Fast-track concrete pavement construction and rehabilitation.
- Evaluation and technology transfer of high-speed construction and rehabilitation products and processes developed through research.

Some high-speed construction issues also are investigated in other research tracks, and those efforts will be coordinated closely with those in this track. For example, tracks 1 and 3 contain many elements required in a high-speed option.

Track 8 Goal

This track will explore new and existing products and technologies that facilitate high-speed rehabilitation and construction of concrete pavements.

Track 8 Action Items

Track 8 action items are as follows:

1. Develop planning and simulation tools that allow contractors, designers, and owner-agencies to identify potential problems before construction begins and identify the most efficient processes.
2. Explore and refine precast and modular pavement technology for new construction, rehabilitation, and maintenance.
3. Emphasize the benefits and provide guidance for usage of concrete overlays as a high-speed rehabilitation solution.
4. Refine fast-track construction technologies and techniques and synthesize them into best practice guidelines for contractors, designers, and owner-agencies.
5. Provide the means for all contractors, designers, and owner-agencies to learn about new high-speed construction and rehabilitation products and technologies.

Track 9. Evaluation, Monitoring, and Strategies for Long-Life Concrete Pavement

Track 9 Subtracks

Track 9 subtracks are as follows:

- 9-1. Technologies for Measuring Concrete Pavement Performance.
- 9-2. Strategies for Long-Life Concrete Pavements.
- 9-3. Construction Techniques and Materials Selection for Long-Life Concrete Pavements and Overlays.
- 9-4. Planning and Design of Accelerated Loading and Long-Term Data Collection.
- 9-5. Preparation of Data Collection/Testing Procedures and Construction of Test Road.
- 9-6. Long-Life Concrete Pavement Performance Implementation.

Long-life pavements are needed to handle the congestion and traffic loading that pavements experience in their lifetime. To meet a 30-year calendar design life, a pavement built today may need 70–100 percent more axle loads per mile than a similar pavement built 10 years ago.

One method for evaluating the performance of a particular pavement design is through accelerated loading at test tracks or accelerated loading facilities (ALFs). ALFs provide valuable performance data that allow engineers to improve current procedures and advance the state of the art. Throughout the 1980s and 1990s, many new accelerated testing programs with ALFs were installed. ALFs encourage innovation by eliminating the fear of failure associated with full-scale road testing, since ALFs can test innovations without the possibility of disastrous consequences that might occur on a real highway. ALFs also provide small-scale evaluation of full-scale designs to identify limitations and speed up the implementation of design improvements. At least 24 ALFs currently operate in the United States.

Data collection methods for monitoring both test roads and in-service pavements can be developed and expanded further. Continuously monitoring pavement performance will help improve concrete pavement design procedures, construction standards and specifications, and rehabilitation techniques. Developing a performance feedback loop to provide continuous condition reports will allow prompt improvements to existing pavements that fall short of user needs. Additional data are also needed for new materials, new test sections, model validation and calibration, innovative joint designs, and surface characteristics advancements. This data can contribute to many of the research tracks in the CP Road Map, which depend on quality data for validation or calibration and require experimental installations or access to long-term data from in-service pavements.

The research areas needed to design, build, evaluate, and monitor long-life pavements in this track are as follows:

- Identification of technologies for monitoring and predicting concrete pavement performance.
- Definition of long-life concrete pavements (including various warrants for longer life, noting that low-volume roadways must be included in this definition and analysis) and identification of long-life concrete pavement types, design features, foundations, and rehabilitation/maintenance strategies.
- A design catalog for long-life concrete pavements (thickness should not be a parameter included in this catalog, as thickness requires in-depth analyses, but all other details of concrete pavement design that affect long-life performance are important).
- Strategic application of preservation treatments to preserve long-life concrete pavements.
- Identification of material requirements and tests for long-life concrete pavements.
- Identification of accelerated and long-term data needs.
- Evaluation of experimental long-life concrete pavements.
- Evaluation of concrete overlays for long-life designs.
- Planning and designing of accelerated loading and long-term data collection.
- Accelerated and long-term data management and distribution.
- Development of a master plan for conducting accelerated product testing and full-scale road experiments.
- Development of experimental designs and a data collection and performance monitoring plan for accelerated loading and durability testing facilities and full-scale products testing.
- Preparation of data collection and testing procedures.
- Construction of accelerated loading sections and test road sections.

Figure 10 illustrates long-term pavement performance (LTPP).

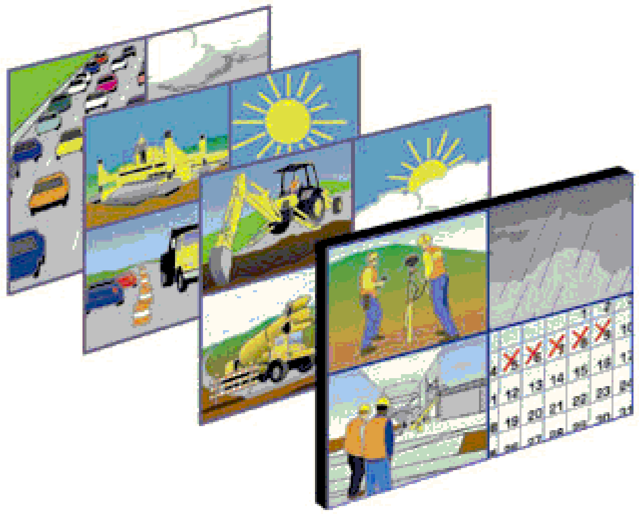


Figure 10. Illustration. Pavements that perform well for 60+ years.

Track 9 Goal

The problem statements in this track will identify both conventional and innovative pavement types, design features, foundations, materials, construction QC/QA, and preservation treatments that will provide the traveling public with a long-life concrete pavement requiring minimal lane closures for maintenance or rehabilitation over the design life.

Track 9 Action Items

Track 9 action items are as follows:

1. Develop ways to collect real-time data on concrete pavement conditions using a combination of embedded electronics, high-speed assessment equipment, traffic measurement devices, and performance prediction equations.
2. Develop clear and detailed definitions of long-life pavements, including information about warrants, required maintenance, a range of low- to high-traffic roadways, and other information.
3. Identify pavement strategies (design, foundation, restoration, and rehabilitation) for long life.
4. Identify design and foundation features that are likely to result in long-life concrete pavements.
5. Identify restoration treatments for preserving long-life concrete pavements.
6. Identify concrete and other material tests and requirements for long-life pavements.
7. Identify QC/QA procedures that will ensure quality long-life pavement construction.

8. Construct test highways of the most promising concrete pavement types that include design features, foundations, materials, construction QC/QA, and preservation treatments that will ensure long-life concrete pavements.

9. Develop an ALF and full-scale test road program for collecting materials, design, traffic, climate, and performance data from existing and future experimental pavements.

10. Establish reliable experimental testing programs along with testing protocols for ALFs and test road programs that include durability testing for materials and design.

11. Collect and analyze relevant test database programs that support the CP Road Map.

Track 10. Concrete Pavement Foundations and Drainage

Track 10 Subtracks

Track 10 subtracks are as follows:

- 10-1. Concrete Pavement Foundations.
- 10-2. Concrete Pavement Drainage.

This track addresses both foundations and drainage elements of concrete pavements. It has long been established that principal components of a long-life concrete pavement include a uniform foundation and proper measures taken for drainage. Given the sheer variety of potential conditions that can be present on any given job (e.g., soil type), there is no "one size fits all" solution. This track explores research and technology related to these important topics, with a particular emphasis on tasks that can be readily applied in a site-specific manner. Figure 11 illustrates research and technology related to concrete pavement foundations.

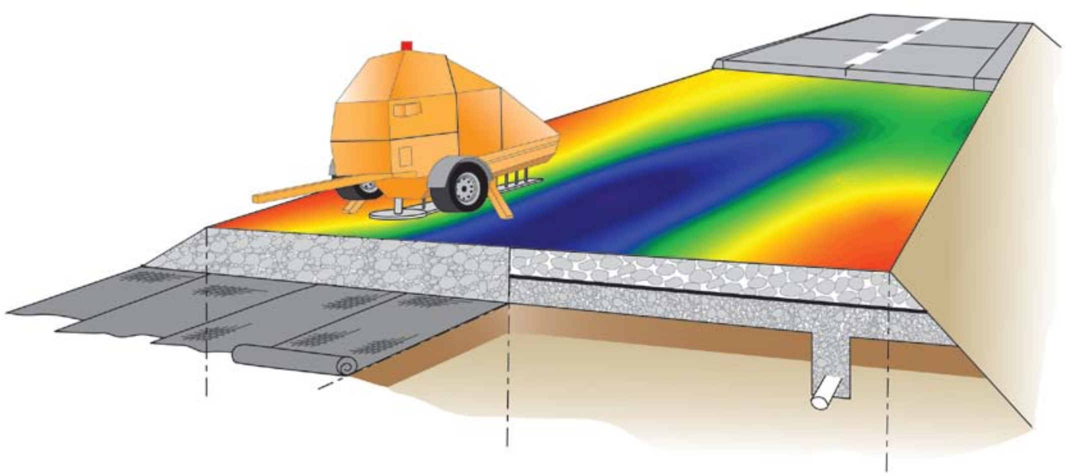


Figure 11. Illustration. Quality foundation and drainage system.

The research in this track will determine and address both foundations and drainage aspects of concrete pavements, particularly factors such as subgrade, subbase, base construction, subsurface, and surface drainage. It includes measurement design and construction methods, as well as measurement techniques.

Track 10 Goal

The research in this track will provide pavement engineers with the tools to better design, construct, and evaluate foundations and drainage systems for concrete pavements.

Track 10 Action Items

Track 10 action items are as follows:

1. Expedite and improve the quality of pavement foundations, particularly on projects with expedited construction.

2. Identify rapid measurement technologies that can gauge the quality of a concrete pavement foundation.

3. Improve the understanding of pavement subsurface drainage and its effect on design.

4. Identify advanced equipment capable of automated subdrain installation.

5. Identify rapid measurements for surface texture and the impact it can have on surface drainage.

Track 11. Concrete Pavement Economics and Business Management

Track 11 Subtracks

Track 11 subtracks are as follows:

- 11-1. Concrete Pavement Research and Technology Management and Implementation.

- 11-2. Concrete Pavement Economics and Life-Cycle Costs.

- 11-3. Innovative Contracting and Incentives for Concrete Pavement Work.

- 11-4. Technology Transfer and Publications for Concrete Pavement Best Practices.

The problem statements in this track address economics and business management issues in concrete paving. The research outlined here will quantify the value and benefits of concrete pavements and ensure that an adequate delivery mechanism is in place to supplement the low bid system. This track, when implemented, will help clarify the relationship between concrete pavements and economic issues, capital availability, risk and risk transfer, and alternative contracting. Figure 12 illustrates innovative business systems.

Figure 12. Illustration. Innovative business systems.

The research in this track will develop the following:

- An administrative support group to provide professional management services for the CP Road Map Research Management Plan.
- An innovative concrete pavement technology procurement program.
- Methods for achieving sustainability with concrete pavements.
- An improved understanding of the economic and systemic impacts of concrete pavement mix-of-fixes strategies for all levels of roadways, from low to very high traffic.
- Advanced methods for concrete pavement life-cycle cost analysis (LCCA) that include user costs.
- Optimized concrete pavement life-cycle decisions.
- Innovative contracting methods that consider performance-based maintenance and warranties.
- The next generation of incentive-based concrete pavement construction specifications.
- A concrete pavement best practices manual.
- Accelerated technology transfer and rapid education programs for the future concrete paving workforce.

Track 11 Goal

The research in this track will clarify the relationship between concrete pavements and economic issues, capital availability, risk and risk transfer, and alternative contracting.

Track 11 Action Items

Track 11 action items are as follows:

1. Understand more clearly the economics of concrete pavements, fix alternatives, and the cost implications of engineering improvements as they relate to pavement performance.

2. Determine the best combination of concrete pavement solutions (mix of fixes) that balances funds, traffic impact, and network efficiency.

3. Develop an array of alternate contracting techniques that enhance the procurement of concrete pavements with a clear determination of risk between the owner and the contractor.

4. Develop optimum technology transfer, training, and outreach for the entire concrete paving workforce that the new generation of efficient, targeted, high-quality, cross-disciplined, and available-on-demand pavements will require.

Track 12. Concrete Pavement Sustainability

Track 12 Subtracks

Track 12 subtracks are as follows:

- 12-1. Materials and Mixture Proportioning Procedures for Sustainable Concrete Pavements.

- 12-2. Design Procedures for Sustainable Concrete Pavements.

- 12-3. Construction Practices for Sustainable Concrete Pavements.

- 12-4. Preservation, Rehabilitation, and Recycling Strategies for Sustainable Concrete Pavements.

- 12-5. Improved Economic Life-Cycle Cost Analysis for Sustainable Concrete Pavements.

- 12-6. Adoption and Implementation of Environmental Life-Cycle Assessment for Sustainable Concrete Pavements.

- 12-7. Design Procedures for Sustainable Concrete Pavements.

- 12-8. Concrete Pavement Decisions with Environmental Impact.

At its core, sustainability is the capacity to maintain a process or state of being into perpetuity. In the context of human activity, it has been expressed as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Although not universally accepted, sustainability is often characterized as a three-legged stool supported by economic, environmental, and social considerations or pillars. Although there is often synergistic cooperation between the three pillars, it is also true in practice that a balance must be struck between competing interests. The system is in danger of toppling if only one or two of the pillars are considered because it will be unbalanced.

FHWA recently initiated a dedicated program to explore sustainability aspects of concrete pavements. Within this program, it is maintained that the key to successfully increasing the sustainability of concrete pavements is to consider all three pillars of sustainability by having the tools and data needed to quantify each and understand the relationships of one to the others. Sustainability, in the context of this track, is the use of materials and practices in concrete pavement design, construction, operation, preservation, rehabilitation, and recycling (which are performed now) that reduce life-cycle costs, improve the environmental footprint, and increase the benefits to society (which researchers need to learn to do).

Research into sustainable practices should not only consider new construction, but it should also include the concrete pavement network, which already exists. For example, a significant portion of the Nation's highway system is more than 40 years old, with some portions over 50 years old. The interstate and State primary road construction era of the 1950s, 1960s, and 1970s, much of which featured the use of concrete pavements, was followed by a period of rehabilitation featuring repeated asphalt resurfacings of these pavements. It must be recognized that through the appropriate application of sustainable preservation techniques, the service lives of concrete pavements can be extended for decades without the need for rehabilitation. It is also recognized that as traffic loadings increase, it might be necessary to add structural capacity to the existing pavement. This can be accomplished by selecting improvement techniques such as concrete overlays. The approach of extending the service life of the original pavement, and therefore maintaining equity, is fundamental to increasing the sustainability of an existing system. By choosing an appropriate preservation strategy, the low maintenance attribute of a concrete pavement can be preserved, as opposed to using strategies that can eventually lead to the complete reconstruction of the pavement. Figure 13 illustrates a life-cycle assessment (LCA) of concrete pavements.

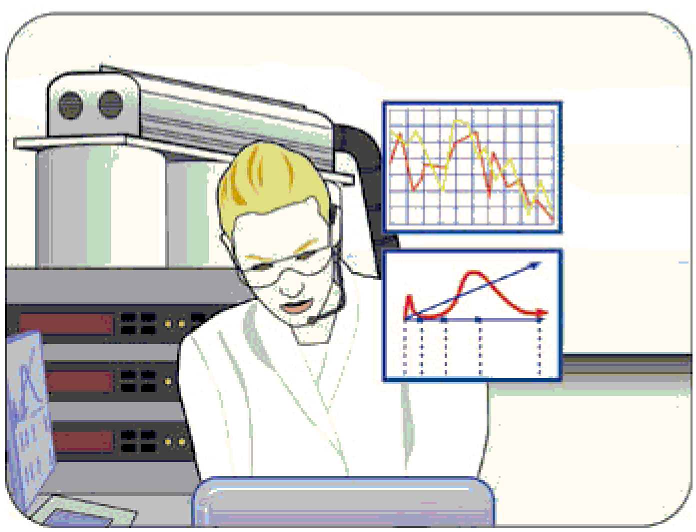


Figure 13. Illustration. LCA of sustainable concrete pavement alternatives.

Track 12 Goal

The goal of this track is to identify and quantify characteristics of concrete pavement systems that contribute to enhanced sustainability of roadways in terms of economic, environmental, and societal considerations.

Track 12 Action Items

Track 12 action items are as follows:

1. Develop advanced materials and processes that optimize reuse and conservation and measurably reduce waste, energy consumption, water usage, and pollutants generated during all phases of the pavement's life cycle.

2. Create innovative designs that make full use of the versatility of concrete as a paving material to improve pavement sustainability.

3. Adopt construction practices that directly enhance the overall sustainability of concrete pavements through increased efficiency, reduced emissions and waste, and decreased social disruption.

4. Apply preservation, rehabilitation, and recycling strategies that enhance the sustainability of the existing network of concrete pavements.

5. Refine LCCA to fully account for the economic attributes of sustainable concrete pavements.

6. Acquire, preserve, and distribute data as part of an environmental life-cycle inventory that accounts for all the individual environmental flows to and from a concrete pavement throughout its entire life cycle, as well as adopt an internationally recognized environmental LCA approach that examines environmental aspects of concrete pavements through their life cycles.

7. Further identify and quantify social considerations that are affected by concrete pavement for inclusion in the integrated design process.

8. Develop strategy selection criteria to assist in the decisionmaking process, allowing various alternatives to be compared based on economic, environmental, and social considerations.

9. Apply technology transfer for existing concrete pavement technologies that support the "triple bottom line."

10. Coordinate and collaborate with work being performed under other CP Road Map tracks.

CHAPTER 4. DESIGN CONSIDERATIONS

PERFORMANCE-BASED PAVEMENT SYSTEMS

Performance-based concrete pavement systems use sophisticated and objective QC/QA systems at every step of a pavement project to ensure the desired performance. Designing for performance is the first critical step. In subsequent phases of paving projects, performance is predicted during mix design to ensure, for example, materials compatibility, and then measured regularly during and after mixing and construction to determine to what extent optimums were missed and adjustments are needed.

Such systems require reliable, accurate performance-based prediction and measurement tools. They require tools for responding quickly to needed adjustments. They should be based on more and better history data. They should eliminate, to a significant degree, variabilities and inaccuracies due to human factors.

Chapters 4 through 7 discuss the performance-related considerations related to design, mixture materials and design, construction, and pavement management and business systems that are addressed in the various tracks of the CP Road Map.

Design is the plan and basis for pavement dimensions, joint and reinforcement details, materials selection, mix design, construction, maintenance, preservation, and rehabilitation.

WHY IS THIS TOPIC IMPORTANT?

If pavement design is deficient, the pavement owner will incur extra costs, and motorists will experience more lane closures over many years to come, no matter how good the subsequent maintenance and upkeep activities are.

Designers, owner agencies, and roadway users need better tools and innovative ideas for developing improved designs that are more reliable (i.e., have a better chance of serving their design lives without premature distress) and economical (i.e., provide good benefit-cost ratios for initial construction, preservation, and rehabilitation), as well as functional, constructible, and maintainable. That is, designs should be based on performance.

The CP Road Map will provide tools for performance-based design.

OVERALL DESIGN GOAL

Concrete pavement designs will be performance-based; that is, reliable, economical, constructible, and maintainable throughout their design life while meeting or exceeding the multiple needs of the traveling public, taxpayers, and owning highway agencies.

SPECIFIC DESIGN OBJECTIVES

The overall design goal will be met through the following specific objectives:

- Develop viable concrete pavement options for all classes of streets, low-volume roads, highways, and special applications.
- Maximize the use of fundamental engineering principles through mechanistic relationships.
- Integrate traditional structural pavement design with materials, construction, traffic loading, climate, geometrics, preservation treatments, rehabilitation, and performance inputs.
- Design preservation and rehabilitation treatments and strategies using mechanistically based procedures that use in-place materials from the pavement structure.
- Develop and evaluate new and innovative concrete pavement designs for specific needs (e.g., very high traffic, residential traffic, parkways, and tunnels).

RELATING DESIGN OBJECTIVES TO THE HIGHWAY USER

These design objectives can be accomplished only if adequate mathematical and computer models exist to make it possible to relate all aspects of design, such as site conditions, design features, and economic analyses, to the functional needs of highway users to successfully develop performance-based predictive designs. The CP Road Map provides resources to develop these prediction models.

CRITICAL DESIGN ISSUES

The following sections discuss several design issues addressed throughout the research tracks.

Models

These design objectives can be accomplished only by creating adequate models that relate all aspects of design to the needs of highway users. For example, mathematical models already exist that relate site conditions (e.g., natural subgrade, traffic, climate, and existing pavement) to functional requirements (e.g., ride, friction, noise, and fatigue cracking). Of course, other factors like foundation (e.g., base, subbase, and subdrainage) and design features (e.g., shoulders, slab dimensions, and coefficient of expansion of concrete) also affect functional requirements. Mathematical models, therefore, should be available for those relationships.

Understanding the Fundamentals of Concrete Pavement Response

Ever since the first structural response equations were published in 1926 by H.M. Westergaard, interest in engineering-based design of concrete pavements has been intense, demonstrated most recently in the MEPDG.[1] Although significant progress has been made over the past 75 years in improving mechanistic modeling of pavement structural behavior and deterioration, many fundamental problems still need to be resolved. These problems include, but are not limited to, the following:

- Accurate prediction of structural responses (deflections and stresses) of concrete pavements and overlays under repeated dynamic loading.
- The effect of bonding/slippage between the slab and base layers on structural responses (field measurements required) and how this develops over time.
- Formation, behavior, and deterioration of concrete joints and cracks (including reinforced cracks).
- Prediction of base/subgrade erosion and pumping using tests and models.
- Propagation and deterioration of reflection cracks in concrete pavements.
- Interaction between structural distresses (cracking, pumping, and faulting) and material-related distresses (i.e., spalling, D-cracking, and alkali-silica reaction).
- True effect of temperature gradients, moisture gradients, and creep on slab structural responses.
- Structural fatigue damage and cracking (of all types) of slabs subject to repeated heavy loadings.

Better understanding of concrete pavement structural responses under a wide range of common structural and climatic conditions will lead to improved designs that will provide more reliable and economical solutions with lower risks of premature failure.

Design Reliability

Of the many variables to be considered when designing pavements to provide a particular level of service, design life is pivotal. Most concrete pavements constructed in the last 50 years have significantly outlived their intended (designed) years of service and traffic loadings. Rarely does a concrete pavement fail prematurely when both design age and design traffic are considered. This indicates that concrete pavements have been designed to a very high level of reliability. Therefore, estimated first costs and future preservation and rehabilitation costs used in LCCAs have likely been higher than necessary because pavements are lasting longer.

In today's pavement type selection environment, it is not desirable to design concrete pavements to a higher-than-needed level of reliability. Rather, design reliability methods should be improved to be more accurate than the current approach, which uses a multiplier on equivalent single-axle loads. This is a great challenge because so many design, construction, material, traffic loading, and climatic factors affect reliability.

Feasible Designs for All Occasions

Existing procedures (e.g., AASHTO, PCA, etc.) have many limitations and deficiencies for designing concrete pavements economically at a desired level of design reliability. While this is true for nearly all situations, it is particularly true for the following conditions:

- Concrete overlays for low truck volume roads and collectors.
- Concrete overlays and pavements subjected to very heavy traffic in various geometric situations with multiple lanes.
- Concrete pavements and overlays for relatively short design lives.
- Concrete reconstruction of existing asphalt and concrete pavements without raising the pavement grade, using existing materials as much as possible for rapid construction.
- Unique widening structural solutions (both overlays and lane additions).
- Concrete pavements and overlays designed to minimize first costs while providing acceptable future performance, reliability, and costs.

Efficient Pavement Designs for Low-Volume Local Roads

Many concrete pavements have been designed on both rural and urban low-volume roadways. Often, these are placed directly on the natural subgrade after some type of preparation. Designing a concrete pavement for low-volume roads is in many ways more challenging than designing high-volume pavements because of the often greater desire for long-lasting pavements (e.g., pavements for an upscale residential area should last a long time). Currently, no performance data exist for these pavements to help verify or improve design. Such data are greatly needed in all major climatic areas because climate has an even greater effect on performance with the slab resting on the subgrade or on a thin granular or treated soil layer.

Lack of Integration of Design with Materials, Construction, and Rehabilitation

One of the major limitations of concrete pavement design is the ability to consider materials, construction, traffic loading, climate, preservation treatments, rehabilitation, and performance requirements simultaneously to produce reliable and economical designs and strategies. This limitation has led to many problems in concrete pavement performance. A design is judged successful only if it performs well after many years of traffic loadings. Increased design capabilities are linked to understanding and knowledge of the construction process and material properties. For example, greater joint spacing (e.g., more than 20 ft) may work well if construction processes and material selections are compatible with the design. It also may result in excessive slab cracking if large temperature gradients are built in during construction and/or aggregates with a high coefficient of thermal expansion are used in the mix. Only through a major research effort can such an integrated and systematic approach to design be achieved.

Design Procedures Deficiency

Current design procedures, including the widely used 1993 AASHTO *Guide for Design of Pavement Structures*, are almost completely empirical, so they carry many deficiencies and limitations.(10) There is a major national effort to implement an M-E-based design procedure, developed under NCHRP 1-37A, and released by AASHTOWare® as the design software DARWin-ME™.(1) This design methodology represents a paradigm shift forward in concrete pavement design. It is expected to significantly improve concrete pavement design because it is based on fundamental engineering principles, uses a finite-element model for structural responses, predicts key distress with mechanistic-based models and an incremental damage computation approach, and is calibrated using national performance data.

Nonetheless, successful implementation in many highway agencies will require significant effort and continual improvement or upgrading over the years. One key item might be called a high-speed computer analysis opportunity. This incremental damage approach (in which the increments are brought down to hourly analyses of damage) could address even more aspects of pavement design, such as early opening. These improvements will be identified as time goes on and agencies use the procedure and sponsor research to fund the improvements. Many improvements will be needed in the next 5 to 10 years to provide for and meet all of the design visions in this long-range research plan.

Preservation and Rehabilitation Design

Designing preservation and rehabilitation treatments has always been very difficult, as the design procedures are almost completely empirical. The MEPDG provides mechanistically-based procedures to more fully consider the existing pavement and subgrade structure, making it possible to use in-place materials from the pavement structure to minimize life cycle costs and lane closures.(1) Implementing this procedure will require a major effort, and many improvements will be needed to introduce it into highway agencies' daily use. In addition, many expansions will be needed to achieve this vision completely.

Base and Subbase Foundations and Subdrainage

There is a significant lack of technical knowledge and ability to design base and subbase courses that provide key benefits for a concrete pavement. These benefits include permanent uniform support, bonding or lack of bonding ability, no erosion over time, economical construction platform for the slab, and subdrainage. Additional material tests are needed for erosion and bonding characteristics. Criteria and tests are needed to determine the adequacy of layers in an existing pavement structure to be used as the base or subbase for a reconstructed concrete pavement. Determinations of required base and subbase layer thicknesses also are needed.

A method is needed to directly, reliably, and economically consider subdrainage of the pavement structure. Do we need costly permeable bases and edge drains? Can they be maintained for many years? Can we design more reliably and more economically without this level of positive subdrainage? How? What type of recycled materials can be used as bases, subbases, and other sublayers in concrete pavement?

New and Innovative Concrete Pavement Design

Ample opportunity exists to develop new and innovative design concepts for concrete pavements. For example, alternative types of pavements such as jointed ultrathin concrete overlays, thin jointed structurally reinforced concrete pavements, thin prestressed concrete pavements, and thin precast concrete pavements have all been constructed and have demonstrated some advantages. Innovations with the greatest potential should be identified and tested so that their benefits and costs are known to determine their viability for certain design situations (e.g., for very heavy traffic, special design needs are necessary to determine maximum thickness in reconstruction).

Designs for All Types of Underlying Strata

When unusual underlying strata exist that may shrink or expand, concrete pavements are often not used because of the fear of slab cracking. New and innovative ways are needed to design concrete pavements to handle these difficult underlying strata conditions economically and reliably. This would also include construction on bedrock, which often occurs in tunnels and major cuts. Such a stiff foundation may require special joint spacing or other design changes.

CHAPTER 5. MATERIALS AND MIXTURES CONSIDERATIONS

Materials and mixtures considerations include issues related to mix design parameters, materials specifications and selection, mixture proportioning, type and number of admixtures, and more.

WHY IS THIS TOPIC IMPORTANT?

As described in chapter 1, the challenges resulting from today's increasingly complex concrete mixtures are a major reason for developing the CP Road Map. The public demands fast construction and long-lasting pavements, which require specific mix additives and more durable materials. In addition, environmental, social, and economic pressures on the industry have introduced a host of new—sometimes marginal—aggregates, cements, and mineral and chemical admixtures. Singly or in combination, these materials can improve pavement performance in specific situations. They also can introduce new unforeseen problems.

It is expected that in the next decade, even more materials options will be available. The industry needs integrated solutions for optimizing complex concrete mixtures to ensure just the right mix for each specific job.

If developed within the right framework, integrated mix optimization solutions will benefit not only materials engineers and suppliers, who face day-to-day materials selection and mix proportioning decisions, but also everyone involved in the complex sequence of events in a pavement project, from design, to construction, to in-service maintenance and performance management. Integrating materials and mix proportioning with development of design specifications, for example, might provide a rational basis for a more objective specification, including items such as minimum cement content and pozzolanic replacement. In addition, a better understanding of the interaction among specific mixtures and construction practices and the environment should result in improved QC during construction. In-service pavement forensics and pavement inventories can be integrated in this overall process, providing valuable feedback to improve future materials selection and mix proportioning decisions.

The need for new, integrated materials solutions is intensified by changing roles and responsibilities in the highway community. Traditionally, many State transportation departments have relied on skilled, experienced staff not only to identify mix design parameters, but also to control mix proportions, type and number of admixtures, and much of the operations based on detailed specifications. The trend is to move these responsibilities to the contractor and specify only performance requirements. State agencies and contractors alike need well-developed national mix proportioning and materials selection guidelines to ensure successful implementation of performance-based specifications.

The CP Road Map clearly identifies the research and implementation steps needed to ensure that the proposed mix design system is technically sound, fully evaluated, and clearly understood by public and private sector engineers, technicians, and contractors through initial and continuing training and outreach programs. An important capability of the mix design system will be its ability to interact fully and provide key inputs to the structural design procedure.

OVERALL MATERIALS AND MIXTURES GOAL

The overall mix and materials goal of the CP Road Map is that innovative concrete mix material selection and mix design procedures will result in economical, compatible, and optimized concrete mixes integrated with both structural design and construction control.

SPECIFIC MATERIALS AND MIXTURES OBJECTIVES

This goal can be reached by achieving the following specific objectives, which are addressed in various tracks of the CP Road Map:

- Develop a sequence of mix design tests and procedures, integrating structural design and QC with selection and proportioning of materials that will be the cornerstone of concrete labs of the future.

- Develop the necessary tools to predict the compatibility and effectiveness of concrete mixes under specific field conditions before paving starts.

- Detect potential construction problems early and correct them immediately with innovative QC tools.

- Detect potential long-term durability problems more effectively during both the mix design process and construction QC.

- Improve the ability to predict concrete mix properties and how they relate to slab behavior and performance (e.g., shrinkage, joint opening, and curing) using the next generation of advanced modeling techniques.

- Identify and use innovative, nontraditional materials that could accelerate construction, maintenance, and rehabilitation and/or extend product life at a fair cost.

TOOLS FOR SUCCESS

End users' needs are ultimately the driving force for mix design and materials selection and proportioning because users dictate the functional requirements, or specifications, of the finished pavement. However, all projects begin with the individual material components of the concrete mix. The proportions and interaction of the materials will influence mix properties like strength and workability. Mix properties dictate production requirements, while production itself affects the as-produced pavement.

Numerous efforts have been made to address individual components of materials selection and proportioning. The CP Road Map is unique in that it includes tasks that link, or integrate, all of the elements of a paving project in a logical fashion. The next generation of materials selection and mix proportioning tools and procedures will therefore integrate a series of laboratory tests, analytical tools, and mechanistic models that will perform the following:

- Recommend cement, aggregate, and admixture proportions based on anticipated environmental and loading conditions.

- Predict any potential chemical compatibility, rheology, and handling issues that may affect the mix during construction.

- Predict the ability of the mix to shrink excessively because of normal variations in materials and climate during construction.

- Predict the ability of the mix to withstand the freeze-thaw cycle, alkali-silica reactivity, delayed ettringite formation, D-cracking, and other durability issues.

- Predict the ability of the mix (as a component of the pavement) to withstand spalling, cracking, fatigue, and other service-related problems.

- Predict the ability of the mix to provide functional service: ride, skid, surface drainage, noise, and aesthetics.

CRITICAL MATERIALS AND CONCRETE MIXTURES ISSUES

Following are brief discussions of some critical issues related to materials and mixtures for concrete pavement included in the CP Road Map.

Specifications

Standards drive how concrete pavements are built, including the selection of materials. Material specifications have evolved over time and typically have become more restrictive. As problems have appeared on various jobs, new specifications were commonly established to attempt to eliminate their recurrence. Unfortunately, the effect of the new specifications on other properties was not considered. This has led specifiers to intentionally seek out materials that meet one condition without knowing if the materials can meet additional conditions. For example, a finely ground cement may meet early-age strength requirements but lack the required long-term strength gain requirement.

Fortunately, because of these issues, this trend has been reversed somewhat. By recognizing that specifiers should focus on the end result rather than on process details, researchers have an opportunity to explore and develop a more performance-based approach to materials selection and concrete mixture proportioning.

Optimizing a mixture in terms of cost, performance, and durability requires mathematical and computer models to relate all variables to each other. For example, the material components and relationships should relate to mix properties so that a mixture with certain properties can be developed by computer before testing for verification in the laboratory. These variables should ultimately be related through models to the functional performance for the highway user. For example, the types of aggregates used in the mixture will in turn affect the friction, noise, and smoothness characteristics of the concrete pavement over the design period.

Mix Designs

For decades, it has been recognized that concrete mix design is really a misnomer. Current methods base proportioning only on highly empirical relationships of mix properties, which are not directly tied to performance or function. The industry needs to explore the selection and proportioning of mixes that ultimately are tied to user demands. Achieving this goal, however, requires a better understanding of the connectivity of the following issues:

- **Roles and responsibilities.** Who will execute the mix design? Who will be liable if problems are encountered?

- **Performance prediction.** Can the knowledge base link materials to indicators of pavement performance?

- **Increased demand for durability knowledge at the mix design stage.** Is there enough knowledge to link concrete mix design details to deteriorated concrete? Is it possible to identify which materials or combinations of materials cause this deterioration and separate them from operational issues for given climates?

- **New product evaluations.** Is there a way to assess the durability and performance aspects of new materials? If innovative materials are to be used more commonly, this evaluation will need to be expedited.

- **New test procedures.** Is equipment available to measure the properties identified as most relevant?

- **Economics.** Is it possible to develop a mix design procedure and sequence of tests that are time and cost effective? Is it possible to provide the proper training?

- **Marginal materials.** Is there a place for all grades of materials? Can what normally are considered marginal materials be used in noncritical mix designs and certain paving applications? With many countries moving toward a 100 percent reuse policy, is it possible to have such a policy in concrete paving?

- **Functional demands in the next generation of surface characteristics.** How will mix design procedures address the mix-related aspects of new demands for smoothness, noise, friction, illumination, rolling resistance, surface drainage, and aesthetics?

- **Constructability demands.** Can the materials selected and the ease of constructing be correlated with differing environmental and operational constraints?

Modeling

The complexity of concrete mixes makes the trial-and-error process of mix design in the laboratory even more time consuming and labor intensive than it already is. Means are needed to model the behaviors of concrete mixes without actually having to mix all of the possible combinations and cast specimens in the laboratory. Work has begun on developing computer simulations of concrete to optimize proportions and properties. This work needs to be continued so that most mix design details can be worked out through such simulations, with only small-scale laboratory follow-up testing needed to verify predictions. These models should be capable of designing concrete mixes incorporating recycled materials, as well as special mixes for maintenance or rehabilitation activities.

Materials Compatibility

The ever increasing complexity of concrete mixtures has made recipe specifications and empirical mix design rules less reliable for obtaining appropriate concretes for high-performance concrete pavements. The range of chemical and mineral admixtures used and the potential for compatibility problems have added to this complexity. Improved tests are needed that better characterize the materials involved in terms of their effect on the performance of the concrete produced. This is particularly true in the case of aggregates, whose potential influence on concrete performance has not been investigated or categorized sufficiently. A suite of tests should be developed to evaluate any waste, byproduct, or recycled material with the potential for use in paving concrete.

Material Changes During Construction

Material components of concrete pavement are tested and approved before pavement construction begins. Often, however, the materials used change during the course of the project. Substituting materials changes the concrete mix characteristics and can affect its durability. An important future consideration is developing accelerated methods for testing long-term concrete durability. Correlation should be made to current durability tests, as well as to concrete pavement field performance. These tests should be simple enough to use in the field, preferably on a construction site, and produce results in a matter of hours to help workers evaluate the effects of proposed materials changes. Current test methods, such as ASTM C666, measure freeze-thaw resistance of a concrete sample but are time consuming and should be performed in a laboratory.[11]

Durability Design Model

The ability to predict the performance of concrete pavements is critical to meeting service life requirements. A comprehensive durability (service life) design model for concrete pavements that fully addresses multiple chemical and physical environments could result in extended structural life, lower life-cycle cost, and increased energy efficiency. New families of embedded sensors and monitoring devices should be developed to provide the base data necessary to build and validate these predictive design models.

Future research should develop an integrated system that not only specifies a mix based on empirical relationships, but also takes into consideration all available materials, construction requirements for specific projects, and performance requirements for the finished product. Using a knowledge base, computerized guidelines, and innovative laboratory tests, designers will be able to determine the optimum mix design for each specific project quickly and efficiently.

CHAPTER 6. CONSTRUCTION CONSIDERATIONS

Construction considerations include issues related to equipment, construction operations, and QC.

WHY IS THIS TOPIC IMPORTANT?

Many key elements that can make or break a concrete paving project are related to construction operations. Although significant emphasis is placed on planning, designing, and selecting materials for a concrete pavement, several elements of construction operations can also impact the overall quality of the pavement.

OVERALL CONSTRUCTION GOAL

Concrete pavements will be built, rehabilitated, and maintained in way that minimizes negative impacts on the public, meets expected design requirements reliably, and provides immediate quality feedback during operations.

SPECIFIC CONSTRUCTION OBJECTIVES

This goal can be reached by accomplishing the following research objectives:

- Economically build and maintain concrete pavements within any traffic closing window, including high-speed modular construction for closures of 6 h or less.
- Develop a rehabilitation strategy that crushes and reprocesses existing pavement materials and uses them in new pavement, minimizing hauling requirements and environmental impacts.
- Develop context-sensitive concrete pavement construction operations that address materials flow (haul), lighting, noise, air, water, and other ecological issues, minimizing the impact on the public.
- Develop rapid (or instantaneous) and continuous feedback on paving variables, including materials and weather, that allow for immediate adjustments to paving operations.
- Develop performance specifications that allow contractors to exercise more innovation in construction material selection, processing, and construction operations, focusing on quality aspects that truly relate to performance.
- Develop graphic aids that allow designers and contractors to use three- and four-dimensional computer technologies (the fourth dimension being time) to “build” concrete paving projects and learn from them before initiating operations.

CRITICAL CONSTRUCTION ISSUES

As with pavement design and materials/mixes, the relationships among various elements and variables of pavement construction should be understood and demonstrated mathematically to optimize pavement performance. Ultimately, users drive construction requirements because they dictate the functional demands and essentially own the facility. Each project starts with basic variables, such as location, which dictates material availability, weather conditions, and construction windows, among other things. When combined, these basic variables dictate construction schedules and available mix alternatives, which, in turn, dictate the required construction techniques. Construction techniques influence the construction process and ultimately the as-constructed pavement. The as-constructed pavement has certain functional characteristics, which ultimately are accepted or rejected by users. While users do not actually make the decision to accept a finished product, they can apply the political pressure that will ensure their demands are met.

The following pavement construction issues are addressed in various tracks of the CP Road Map.

Accelerating Construction/Improving Workplace Safety

The pressure to “get in, get out, stay out” places a special emphasis on innovative techniques to accelerate highway construction. Concrete paving operations are no exception. If concrete pavements are to remain a competitive and viable alternative in future highway construction, new methods for high-speed construction should be identified, developed, and integrated into the state of the practice.

For example, fast-track paving is not new to the industry, but several methods are being used, most of which have inherent limitations. Nighttime construction is becoming more prevalent to minimize user delays, but adverse psychological impacts on workers and other safety issues related to nighttime construction have been identified. The mantra should be, “get in, stay safe, get out, stay out.”

Lane Closure and Traffic Management Issues

Highway users are less tolerant than ever of the temporary inconvenience that highway construction often brings. Innovative techniques are needed for both assessing the impact on the public and optimizing traffic mitigation during construction operations. Computerization is expected to assist in this goal, but additional work needs to be done before reliable optimization methods are adopted.

For contractors, the sequencing and timing of operations also need to be optimized. Contractors commonly face limited resources, including equipment and labor. Techniques should optimize the use of these resources to expedite construction operations at minimal cost. Closely related to this is the demand for more rapid concrete mixing and placement techniques. It has been demonstrated that even modest improvements in concrete placement production rates can significantly accelerate the construction process.

Finally, future research should include cutting-edge technologies, such as precast and prefabricated construction. These technologies have begun to show promise as a means to accelerate construction under certain circumstances.

ICSs and QA

Public agencies are becoming more sensitive to the quality of concrete pavements immediately and soon after construction. Several technical challenges, however, limit understanding and control of the numerous elements affecting initial quality. Existing products, such as FHWA's HIPERPAV® (HIgh PERformance Concrete PAVing) program, show promise as tools to accomplish this goal, but additional work is needed. Future research should address a number of these challenges, using a systems approach to recognize their connection with other elements.

Interaction of Variables

The factors that impact initial quality the most are related to temperature and moisture management. Concrete is a dynamic material, with several complex processes occurring simultaneously in a dynamic environment. The interaction of these variables can often lead to unexpected temperature and moisture conditions in the new concrete slab. These conditions, if severe enough, can compromise the initial quality of the pavement, which can ultimately impact long-term performance. A number of construction operations elements can also affect the temperature and moisture of the concrete, and additional work is needed to understand this complex process.

Other construction variables have also been identified as having an impact on initial pavement quality. For example, the consolidation of concrete as a function of vibration methods can affect dowel-concrete interaction, air void structure, and other factors. Saw cutting is also important. Selecting optimum depth and timing of saw cutting operations for a particular project are still insufficiently understood.

Variability

Variability is arguably the most important element that can impact overall initial pavement quality. Variability is inherent in every aspect of a pavement, including design, materials, environment, and construction. The impacts of construction variability especially need to be better understood. If too much emphasis is placed on controlling the variability of a particular construction aspect, additional cost is introduced into the system. If not enough emphasis is placed on controlling variability, however, the quality of the product can suffer.

Most experts agree that concrete pavement quality is impacted significantly by the quality of construction operations. With pressure to shorten the paving operation window and use less-than-desired materials, the room for error expands. One of the most critical aspects of concrete paving in the future will be rapid and continuous feedback on the numerous variables that drive quality. Variability in weather, support conditions, and concrete material quality ultimately will lead to variability in the end product.

A new concept, ICSs, could be the solution. First publicized in preparing the Future Strategic Highway Research Program (SHRP) Rapid Renewal Proposed Scope of Work, ICS is closely related to the way intelligent transportation systems help traffic engineers better manage traffic. ICS similarly will allow contractors to better control paving operations. ICS includes the rapid and continuous feedback of measurement data related to pavement quality and provides tools to make necessary corrections with predictable results. Before ICS can be fully advanced, however, a host of more fundamental research should be accomplished. ICS can improve contractor process control, improve and permanently record QC data, and integrate with asset management/PMSs.

NDT

NDT of concrete pavements is fundamental to the ultimate success of ICS and warrants extensive study and application. NDT has been used successfully, although not widely, to understand the in situ strength and durability of concrete pavements. A number of techniques are available to predict the properties of early-age concrete shortly after construction, but each technique has inherent benefits and limitations. Future research should further evaluate the use of NDT as a means to assess concrete quality rapidly and accurately.

Performance Specifications

Closely related to the initial quality of concrete pavement after construction is the means by which quality is controlled and ensured. In recent years, FHWA has emphasized developing performance specifications for concrete pavements. Performance specifications recognize the relationship between construction quality and long-term performance. By rationally controlling variables that impact long-term performance, the quality of the final product can be improved. Future research should identify the means of QC that require further study. In addition, the research should evaluate performance specifications, including warranties, for their benefits and limitations in the concrete pavement industry. Slow to gain acceptance, these alternative means for QC may prove beneficial to the industry in the long term.

Construction Operations and Equipment

The basic concrete pavement construction operations of today are not significantly different from those of 30 years ago. Concrete batching, transporting, placing, and curing are common elements of the construction process. Depending on the specifics of the project, other elements might include texturing and jointing. While the basic process has not changed, modest advancements have been made, including the use of technology to improve both efficiency and quality.

Future concrete pavement construction, however, should meet a growing set of user-driven demands. For construction, the most pertinent are the demands for quality and minimal delay. Sustainability is becoming a prevalent issue as well, leading to a need for its own unique set of solutions.

New equipment to permit operations such as one-pass paving will help meet these demands. One-pass paving is efficient while minimizing environmental impacts by incorporating 100 percent recycled materials into the process. Efficient NDT techniques also could be incorporated into one-pass paving operations to increase efficiency and ensure a high-quality product by automatically making necessary adjustments.

High-Speed/Low-Clearance Construction

Because of increasing pressures for temporal and spatial limitations on construction, the concrete pavement construction community will require new construction techniques. Precast modular construction, for example, can be used to place a high-quality surface rapidly. While cost certainly will be a consideration, the mounting costs of traffic delays will justify the higher placement cost. Rapid-set, high-durability patching also will be required, including placement techniques that reduce the overall time for construction. Construction projects that generate no waste can be achieved only if researchers find ways to use in situ materials without jeopardizing long-term durability and performance. In short, the idea of night paving and daytime trafficking should be considered.

Ensuring Long-Term Performance

Although long-term concrete pavement performance issues are considered in detail in the next section, some construction-related issues are closely related to performance. For example, there is a demand for a better understanding of the required surface preparation for bonded, unbonded, and whitetopping concrete overlays. It has been demonstrated that the methods and quality of preparation of the existing pavement can significantly affect long-term performance, but guidance is needed in selecting optimum techniques. Attention should be given to the impact of surface preparation as it relates to other factors affecting long-term performance.

Constructing and Controlling Surface Characteristics

Concrete pavement texturing is another issue that warrants attention. Many techniques for concrete pavement surface texturing are in use today. Their pros and cons are still being determined, with debate among and within agencies about the performance of various techniques.

Joint Sealing

Another construction issue closely related to long-term concrete pavement performance is joint sealing techniques. For a given method, a number of construction techniques can be used. The impact of joint sealing on LTPP is an area that needs future research.

Improving Competition

Research on improving the competitive nature of concrete paving in the highway industry is a construction-related issue that is sometimes overlooked. Two topics in particular are contractor training and alternative bidding procedures.

First, it has become increasingly difficult in recent years for contractors to hire and retain qualified labor. This applies to all levels of workers, from engineers to laborers. Additional research should be conducted to identify ways to rapidly and effectively train the concrete paving workforce. This training element is as important as any research and should be considered fundamental to research planning. The industry should remain competitive and viable.

A second topic worth considering is an investigation of alternative bidding procedures. Including elements other than cost into pavement bids could allow for contractor innovation. The resulting innovation could both improve the quality and lower the cost of the final product. As a result, concrete pavements would become more competitive in the highway industry.

CHAPTER 7. PAVEMENT MANAGEMENT AND BUSINESS SYSTEMS CONSIDERATIONS

This chapter considers research-related needs related to monitoring and improving long-term concrete pavement performance and maximizing economic value throughout a pavement's life cycle.

WHY IS THIS TOPIC IMPORTANT?

In the past, pavement performance requirements have focused on serviceability (i.e., ride quality) and friction. Now, performance indicators, such as tire-pavement noise, splash and spray, potential for hydroplaning, light reflection (albedo), fuel economy, and the availability of open traffic lanes (e.g., not closed for construction or maintenance) are of much greater interest to highway agencies and users. Future concrete pavement designs will be expected to provide all of these functional performance indicators to produce surfaces and structures that meet the needs and desires of highway agencies and users.

Monitoring concrete pavement performance indicators through PMSs is expected to be increasingly important to highway agencies in the future. It may become necessary to set up a performance feedback loop to provide continuous condition reports, making it possible to effect expeditious improvements to existing pavements not meeting users' needs, as well as to improve the concrete pavement design procedures (particularly functional considerations related to surface characteristics), construction standards and specifications, and rehabilitation techniques.

Research is required immediately on the functional aspects of concrete highway performance, particularly to address a combination of tire-pavement noise, friction, smoothness, and other related factors. Note that an entire research track is devoted to this extremely important topic. Research is also needed for providing more rapid feedback and ways to schedule improvements related to surface characteristics and conditions. A critical need also exists for setting up feedback loops in highway agencies' PMSs to monitor performance more effectively and rapidly and suggest improvements that minimize lane closures.

OVERALL PAVEMENT MANAGEMENT AND BUSINESS SYSTEMS GOAL

The traveling public will be provided with excellent pavement surface characteristics and a very high level of lane availability over the design life (i.e., minimal lane closures for maintenance or rehabilitation).

PAVEMENT MANAGEMENT AND BUSINESS SYSTEMS OBJECTIVES

Pavement management and business systems objectives include the following:

- Develop ways to collect real-time data on pavement condition, including surface characteristics (friction, noise, distress, smoothness, and others), climate parameters (temperature and moisture), traffic loading, and moisture sensors.

- Determine the condition of concrete pavements with a new generation of equipment and sensors that address structural support, smoothness, friction, noise, moisture beneath the slab, drainage, traffic, and other factors.

- Loop performance back to agency units, such as maintenance, planning, traffic, design, materials, and construction, through improved management systems so that required improvements to the concrete pavement surface and structure can be scheduled cost effectively and improvements to pavement technology can be carried out expeditiously over time.

- Use feedback condition and performance data to better plan and schedule preservation and maintenance activities for concrete pavements to minimize lane closures and congestion.

- Facilitate the number, type, and flow characteristics of traffic through long-lasting traffic monitoring sensors embedded in the pavement.

- Better understand the economics of concrete pavements and fix alternatives (for many reasons including innovative contracting needs), as well as the cost implications of engineering improvements as they relate to performance.

PAVEMENT MANAGEMENT AND BUSINESS SYSTEMS CONSIDERATIONS

Real-Time Data from Concrete Pavements

Real-time pavement condition data that can be collected from concrete pavements include surface characteristics (friction, noise, distress, smoothness, etc.), climate, traffic, and structural factors. Data collection methods could include a combination of embedded electronics, high-speed assessment equipment, traffic measurement devices, and performance prediction equations. This program will require a new generation of equipment and standard test methods that address structural support, smoothness, friction, noise, moisture, drainage, and other factors.

Consistently, achieving successful pavement performance requires a systematic and integrated approach that considers all key aspects. It is not enough to have good design, construction, and materials selection individually to produce a reliable and cost-effective pavement. Even if each activity is done well by itself, it by no means guarantees successful pavement performance under the critical conditions that exist today. Consistently successful performance requires an integrated approach using mathematical models that compute the impact of each factor on stresses and deflections, and predict the damage related to distress and various functional conditions (e.g., smoothness, noise, and friction).

Feedback Data for Continuous Improvement

PMSs do not provide feedback data adequate for improving concrete pavement performance. Many such systems cannot even relate performance-monitoring data to original construction project information and traffic data. This critical gap can be remedied by developing improved data measurement and storage systems that not only provide this information rapidly, but also help analyze it. The goal of these new systems would be to provide rapid feedback to both schedule improvements in response to user feedback and continuously improve design, construction, materials selection, rehabilitation, and other aspects affecting performance.

Performance Data on Innovations Through Accelerated Test Roads

Many aspects of design, construction, materials, and rehabilitation need further validation. Moreover, many innovative ideas are never tested because of the risks and costs of failure. Conducting full-scale testing or, in some cases, testing at existing ALFs, would provide a rapid and efficient means to meet both validation and testing needs. Some performance data, such as information on early opening of a roadway to traffic, can be gathered using ALFs (testing machines in buildings). Other data would need full-scale outdoor traffic testing using regular mixed traffic (similar to the Minnesota Road Research Project (Mn/ROAD)) or special trucks (similar to WesTrack vehicles). This plan would provide an excellent way to test new and innovative ideas for concrete pavement design, construction, and rehabilitation. A significant need exists to both supplement and build on the results from LTPP studies and sites such as Mn/ROAD.

Impact of Preservation Activities on Performance and Life

The impact of today's concrete pavement preservation alternatives (e.g., diamond grinding, dowel bar retrofit, and joint and crack resealing) on future life and performance is not fully understood and accepted. Establishing full-scale test sections under actual traffic loadings of innovative preservation activities would provide valuable information to establish the cost and benefits of such activities. These tests would build on information gained through the limited LTPP studies (Specific Pavement Studies (SPS)-4 and SPS-6). Since it is believed that well-timed preservation activities can be used to extend the service life of concrete pavements cost effectively, this is a significant gap that can be filled with appropriate research studies.

Economics and Innovative Contracting

In most markets, concrete pavements are generally considered a high-priced option compared to asphalt solutions when examining initial costs, but they are equal or lower in price when addressing life-cycle costs. This is the generally accepted norm given current design procedures. Few tools exist, however, to effectively determine the true initial costs and price of items such as joints, sealers, and tie bars in various designs in specific projects. Most estimating is based on previous bid estimates. In addition, long-term analyses in life-cycle costs lack knowledge on which to improve maintenance analyses and user impacts.

Over the past several years, interest has grown in looking at corridors or areas rather than projects. This requires a new analysis technique that studies pavements at different stages of life, but if examined in a way to mitigate traffic shutdowns, it might require multiple fixes on a single project.

In addition, alternative contracting techniques, such as design-build, best value, and warranties, have cost implications that have not been studied or consolidated. The need is especially strong to examine the relationship of risk to the concrete pavement designer/builder and how best to equalize or at least quantify the risk. If the use of warranties continues to grow with or without maintenance requirements, then new bonding, insurance, and guarantee mechanisms need to be explored. Roles between government and industry are changing, so tools need to be developed that equitably evaluate the risks.

Public-Private Partnerships

Interest is growing in public-private partnerships in which investors consider financing capital expenditures in return for either real or shadow tolls. Pavement costs could run 40–60 percent of a capital expenditure, with various options having a major impact when compared to traffic and tolling. Different concrete pavement solutions must be examined to balance initial cost, maintenance, traffic growth, and toll revenues.

Technology Transfer

Information is transferred too slowly to policymakers, engineers, and the concrete paving workforce. The concrete paving industry lacks innovation because of both the return on investment and the considerable time it takes to transfer innovation into practice across the United States.

CHAPTER 8. RESEARCH MANAGEMENT PLAN AND IMPLEMENTATION

Research plans can debut with great promise, only to fail to capture the imagination and support of the stakeholder community. With no less a mission than reinventing the concrete pavement industry, this research plan has not failed. The CP Road Map is accompanied by a unique and bold, yet realistic, research management plan that has kept stakeholders involved and committed to the CP Road Map's success.

The research management plan for the CP Road Map performs the following:

- Outlines a solid, long-term research management structure.
- Describes the administrative and estimated financial resources needed.
- Identifies potential barriers and critical issues for each research track.
- Suggests strategies, processes, and methods for moving forward with the CP Road Map.

Shortly after the CP Road Map was completed, a consortium of stakeholders initiated support for its implementation. To date, this administrative support has been sponsored in large part under transportation pooled fund TPF-5(185) and conducted by the National CP Tech Center.(2)

This chapter describes the plan as originally envisioned and provides a synopsis of the implementation activities to date.

ASSUMPTIONS

During its development, the research management was based on several assumptions. First, the CP Road Map is a national research plan, not a plan solely for FHWA or any one organization.

Second, the CP Road Map is not restricted to any single funding source. Publicly financed highway research is decentralized. Public and private organizations that enjoy dedicated funding are understandably hesitant to relinquish fiscal or technical control, but they are willing to partner if it is in their self interest.

Third, even in a decentralized arena like research, it is possible for stakeholder groups to come together voluntarily. The CP Road Map itself is an example of the dramatic success that can be accomplished through partnering and cooperation. Federal, State, and industry research staff and engineers around the country are looking for more opportunities to pool their funds and other resources in win-win situations, as has been done in the successful National Concrete Consortium. By working together to identify common interests and agreeing to cooperate for the long haul, stakeholders can pool resources to extend budgets and expand research results or programs.

Fourth, the all-too-common disconnect between research results and implementation of those results should be fixed. Communication, technology transfer, and outreach activities should be elevated to the same level of importance as research itself.

Finally, the CP Road Map is too comprehensive and too important for a part-time management effort. Managing the overall research program effectively and judiciously will require dedicated personnel with adequate resources.

OPERATING PRINCIPLES

Given these assumptions, the research management plan is based on the following four principles that govern conduct of the research:

- **Tri-party management**. Overall management of the CP Road Map is a cooperative effort undertaken by a tri-party group of Federal, State, and industry representatives who voluntarily choose to work together.

- **Project coordination**. Organizations with research funding can elect to fund and conduct research independently or join with others in pooled fund studies or similar pooling mechanisms. Research organizations, however, will make a good-faith effort to share both the scope of work and the research findings to help complete one or more research tracks outlined in the CP Road Map.

- **Long-term commitment**. Research organizations will make a good-faith commitment to work over the long term to effectively accomplish the goals.

- **Communication, outreach, and training**. Research organizations will inform, communicate, and train the workforce quickly and efficiently throughout the life of the program, accelerating final implementation of the products and promoting a continuing sense of accomplishment and value.

By following these principles, the research management plan will help organizations conduct more research with fewer staff, find new partners, and, most important, deliver new and improved products to their constituents.

CRITICAL ELEMENTS OF THE RESEARCH MANAGEMENT PLAN

The agreement between FHWA and the National CP Tech Center outlined the following specific issues that needed to be addressed in the research management plan:

- Research outputs.

- Consensus building—a consortium-type approach.

- Formal outreach and education programs.

- Continuous project management and updating the CP Road Map.

- Integration of cost and performance.

- Barriers to implementation.
- Effective use of the research database.

Each of these issues is thoroughly covered in the research management plan described in the rest of this chapter.

RESEARCH MANAGEMENT PLAN: A UNIQUE MODEL WITH ROOTS IN THE PAST

In developing this plan for managing research, the team evaluated the research and technology transfer phases of another major, long-term research effort—SHRP.

Each SHRP phase was managed by a specific organization (the research phase by the TRB SHRP Program Office and the technology transfer phase by FHWA's Office of Technology Application). Each phase had dedicated funding sources, although many technology transfer projects were undertaken using State funds, NCHRP awards, and pooled funds.

Although the broad, ambitious nature of the programs is similar, there are fundamental differences between the SHRP models and the CP Road Map research management plan. The CP Road Map is set up as follows:

- No funds have been dedicated to conduct the research outlined in the CP Road Map, nor is a single large pool of funding desired.
- No single Federal organization or office will manage the work. Instead, a volunteer oversight group representing Federal and State agencies and industry will provide broad management oversight, and the partnering organizations will fund a support services group to do the day-to-day, nuts-and-bolts work.
- The research tracks will be managed by volunteer organizations (universities, transportation departments, industry, etc.).
- Research will be conducted by organizations that want to share resources and leverage their own funds.

The FHWA Transportation Pooled Fund Program is similar to the CP Road Map research management plan. Under the program, States, universities, and private organizations voluntarily come together to share resources and achieve common goals. Many pooled fund activities have been and are very successful.

According to lessons learned on other shorter term projects and programs, the active participation of champions is needed for long-term success.

PLAN GOVERNANCE STRUCTURE

The research management plan has put these principles and critical elements into practice through the following four-tier governance system:

1. An EAC consisting of representatives from the Federal government, State agencies, and industry will be responsible for overseeing the CP Road Map.

2. Research track team leaders will assume responsibility for coordinating all activities in a specific research track and coordinating across track lines. Track leaders will be active, long-term champions (individuals or organizations) of what are, in essence, 12 individual but related research programs.

3. Core organizations, or sustaining organizations, will assume responsibility for conducting specific research within tracks.

4. An administrative support group will be responsible for providing professional management services for the CP Road Map, operating chiefly as the administrative arm of the EAC but also supporting the administrative functions of the research track team leaders and sustaining organizations.

These groups are described in more detail later in the research management plan. First, however, figure 14 provides a brief overview of the way these groups are organized and how they work together to implement the research.

Figure 14. Flow chart. Research management plan.

GETTING STARTED

It was noted in the original CP Road Map development that the research management should begin immediately. If not, the industry risks losing momentum and stakeholder enthusiasm for the CP Road Map. It also risks that the CP Road Map will become obsolete before it gets underway. Implementation has begun and is moving forward.

The following steps were deemed critical to begin the implementation process:

1. FHWA, industry, and several key State transportation departments will sponsor a meeting of leaders from organizations interested in participating in the CP Road Map (i.e., potential sustaining organizations and track team leaders). This meeting includes the following tasks:

    - Develop and finalize a tri-party agreement (industry, FHWA, and State agencies) that validates the CP Road Map, the research management plan, and the commitment to work cooperatively.

- Determine the EAC.

- Identify track team leaders for as many tracks as possible.

- Fund and identify the administrative support group.

- Develop a memorandum of understanding and cooperation among the sustaining organizations.

2. Convene the EAC, track team leaders, and administrative support group to develop an early action plan that identifies work underway, work planned, and critical unfunded work.

In reality, the entire process will start simultaneously and not in sequential steps. Many parties will express interest in specific research projects or tracks. As these organizations step forward, the principles may choose to assume a more managerial role on the EAC or as track team leaders. In addition, research will be funded continuously. Those who see merit in working together will identify ways to do so.

OPERATING DETAILS

The four governing groups described earlier have separate but coordinating responsibilities.

EAC

Membership

Members of the EAC should represent the three major interest groups: Federal and State agencies and industry. Each committee member should have appropriate experience, a progressive vision, a serious commitment to the CP Road Map, and a willingness to seek consensus among other organizations and special interests.

Beyond that, it is difficult to define committee membership in detail. The size of the committee depends, in part, on how many organizations believe it is in their best interest to participate. The committee should be balanced, with members representing different backgrounds, experiences, and viewpoints. Committee members should be committed champions in their own right.

Specific representatives may change from time to time, but the committee itself should be prepared to function for at least 2 to 4 years. As the work evolves, the committee should reinvent itself to stimulate continuous enthusiasm and interest.

Responsibilities

The EAC should be a decisionmaking, policy-making, and facilitating group with the following responsibilities:

- Determine research track team leadership.
- Promote partnering arrangements.
- Ensure adequate integration of research across tracks.
- Develop and implement a strategy to ensure that software products developed through various research tracks are compatible.
- Identify new research program areas.
- Oversee the update and maintenance of the CP Road Map database.
- Develop a communications effort to keep the CP Road Map and its products in front of stakeholders and the public.
- Conduct self-evaluation studies.
- Keep the momentum focused on outcomes, not just output.
- Encourage innovation throughout the process.
- Minimize bureaucracy.

To accomplish these responsibilities, the committee should have a strong, fully funded administrative support group.

The EAC has one final but closely related responsibility: act as track team leader for track 11. Track 11 consists of stand-alone problem statements covering key crosscutting efforts in the following areas: macroeconomics and life-cycle costs, alternative contracting and incentives, accelerated training programs, and development of major publications such as compendia and whitepaper series. Track 11 also contains an innovative subtrack on concrete roads of the future. These issues naturally fall within the purview of the EAC.

Research Track Team Leaders

Participation

The research track team leader strategy is a bold and creative way to oversee research. It depends on one or more sustaining organizations (described below) stepping forward to become team leader(s) for each research track. There are no real limits on who can assume track team leadership. Track leaders could be single organizations or a working structure consisting of either multiple sustaining organizations or individuals with stature in the concrete industry that wants to steer the track toward fulfilling the goals.

Responsibilities

In addition to cooperating with the EAC, research track team leaders should provide technical oversight of the actual conduct of research in their area. This oversight should include, but may not be limited to the following:

- Validating the overall research track and establish its credibility.
- Updating the track as required, including time, budget, and scope of work.
- Identifying organizations that want to conduct or partner in actual research.
- Establishing and overseeing subordinate technical expert working groups as appropriate to guide complex work.
- Ensuring proper integration of discreet research work within the track and across track lines.
- Developing status reports.
- Promoting track communications and outreach efforts.
- Identifying and conducting implementation (technology transfer) activities throughout the research phase.
- Identifying and facilitating the development and conduct of specific track-related training efforts.
- Continuing to solicit new and innovative ideas and concepts related to the track.

Research track team leaders should not develop and issue requests for proposals. Instead, working with the EAC, they should foster partnerships among organizations willing to pool and leverage dedicated funds to accomplish ambitious research projects within the tracks.

Sustaining Organizations

Participation

No single organization has the resources or experience to deliver all of the research suggested in the CP Road Map. However, several national organizations, plus numerous State and local/regional organizations, have research programs related to work outlined in the CP Road Map and, therefore, a vested interest in coordinating their efforts with the CP Road Map and supporting its overall goals. (Many of these groups were represented at one or more of the brainstorming events and provided input and feedback on the CP Road Map.) For purposes of the research management plan, these stakeholders are called “sustaining organizations.” Several potential sustaining organizations are described in appendix B of this report.

Responsibilities

Sustaining organizations should assume responsibility for conducting specific pieces of research, generally because they have the specialized interest, skills, or funding. Sustaining organizations will quickly see the benefit of supporting the overall CP Road Map, conducting specific research in support of the overall goals, and working together to leverage both funding and human resources.

Administrative Support Group

Participation

The voluntary nature of the governing structure outlined above should be linked to a fairly substantial funded support mechanism. The fourth tier of the governance system, the administrative support group, is that mechanism. This group should consist of an organization or an expert team with technical and administrative expertise in large program management. Its primary role is facilitation, not control.

Responsibilities

This group’s primary function is to be the administrative arm of the EAC, research track team leaders, and sustaining organizations. The administrative support group should be the “doing” body for all activities to coordinate the efforts of the groups on a continuing basis. The administrative support group’s second function is to provide the communication and outreach services recommended by the EAC.

Funding

It is proposed that funding be provided for the administrative support group through the tri-party agreement to hire full- and part-time staff.

MORE ABOUT THE EAC

Figure 14 identifies the following five general functions for which the EAC, supported by the administrative support group, should be responsible for:

1. Database management, CP Road Map update, and research track integration.
2. Partnering, fund management, and contracts.
3. Software integration.
4. Research management, communication, and training.
5. Concrete pavement innovation.

It is suggested that the EAC also act as research track team leader for track 11. The problem statements in track 11 support the committee's work.

As described below, each of these functions is critical to the success of the CP Road Map.

DATABASE MANAGEMENT: RECHARGING THE BRAIN OF THE CP ROAD MAP

In a real sense, the comprehensive database that accompanies this report is the CP Road Map, or at least its central nervous system. Successful implementation of the CP Road Map depends on a comprehensive approach to database management.

The administrative support group will maintain and update the database, but exact details on who, where, how, and how much should be decided by the EAC. There are many options, but database management should be based on the following principles:

- Research problem statements, projects, budgets, timelines, and research results in the CP Road Map database should be updated regularly.
- The database should include only those research problem statements, projects, budgets, timelines, and research results related to the CP Road Map as revised and updated during its implementation. (Other databases are better suited to the compilation of all concrete- and concrete pavement-related projects.)
- The database should include all research problem statements, projects, budgets, timelines, and research results related to the CP Road Map. The database should reflect the output as it relates to the accomplishment of each track.
- The projects should be plotted on spreadsheets, with full data in the narrative portion of the database.

The database administrator should provide regular status reports on the entire CP Road Map and specific research tracks. The database's principle audience is the EAC and research track team leaders. The second audience is sustaining organizations that want to see where proposed research fits into the overall road map. Brief monthly and annual reports on the status of the program should be prepared to keep everyone informed.

A potential third audience is the general researcher or information seeker. Only enough money and effort should be expended to serve the first two audiences. The database is intended to serve the infrastructure of the CP Road Map; it is not intended to serve the general pavement community, for whom other databases are available.

Database Management, Road Map Update, and Research Track Integration

The database includes two elements. The first is a Microsoft® Access database that includes all problem statements developed for the CP Road Map. The second is a series of Microsoft® Excel spreadsheets that contain the integrated research tracks with time phasing and coded linkage to the problem statements. The spreadsheets also contain budgets.

The database has a search engine that allows users to sort problem statements. This is an important feature for a program of this magnitude.

Keeping the database current is critical to the success of the CP Road Map. As research contracts with detailed scopes are identified, they should be added to the database. Likewise, completed contracts and their deliverables should be entered into the database.

A continuously updated database will perform the following:

- Provide status on the execution of all details of the program.
- Lead to recommendations to adjust CP Road Map goals as the program evolves.
- Determine completeness of research related to the goals of both the research tracks and the CP Road Map.
- Provide information to ensure that issues related to integrating research tracks are recognized and addressed.

Without immediate and continuous updating to include ongoing work around the country, the database will quickly become obsolete.

Software Integration

One of the CP Road Map's primary goals is to integrate design, mix, construction, and performance (e.g., to consider project-specific mix, materials, and construction issues when developing pavement design). The EAC should ensure that the capability exists to link these aspects of concrete pavement projects by exact formulae rather than by subjective personal experience and judgment. Therefore, several CP Road Map research tracks and problem statements focus on continued development of computer models that integrate variables across these lines. The power of integration depends on computer and software power. The goals of several tracks cannot be met without effective software management.

A software policy needs to be developed and implemented to support the integration process. Obviously, no single person, company, or agency should develop all of the software, so some complicated intellectual property right issues may need to be addressed. This should be an early order of business for the EAC.

Implementation, Coordination, and Training on Research Output

The entire U.S. highway community should be made fully aware of the CP Road Map, including research proposed and projects underway, key findings, and active participants. Strategic short- and long-range marketing strategies for research products should be developed, leading to implementation. Research products will fall into several categories and need to be marketed accordingly. As specific training media are developed, they should be added to the specific track.

More specifically, implementation, coordination, and training should include, but may not be limited to, the following activities:

- Identify products and techniques that are essentially complete and should move to implementation or deployment.

- Promote customer evaluation of products that require local materials and adaptation to regional, State, or specific industry practices.

- Advance promising products and processes through further research, development, testing, and evaluation.

- Provide training to use products and initiate activities to enhance long-range educational efforts.

- Promote activities by standard-setting organizations such as AASHTO, the American Concrete Institute, and ASTM International that enhance the acceptability and credibility of products. This would be especially beneficial in helping to reduce the number of State standards that inhibit regional and national consistency.

Each research track includes funds for outreach and training. The EAC, however, may recommend a fund strictly for outreach and training, pooling monies from each project. Historically, the cost of implementation and technology transfer activities is estimated at 10 percent of research funds, but in reality, implementation costs can vary from 1 to 500 percent of research, making a pool of funds for research results implementation and technology transfer very desirable. Such a pool should be part of the budget for the administrative support group's activities.

Partnering and Fund Management

Partnering efforts should help organizations that wish to participate in the CP Road Map research connect to others with similar interests. To be proactive in generating partners to conduct the research, a dedicated fund for seeding projects may entice sustaining organizations to fund projects. A key responsibility of the EAC, after the first wave of projects is funded, is to help establish a more detailed seed money management system and ensure its proper implementation.

Concrete Pavement Innovation

The challenge at the outset of this project was to think outside of the box and avoid searching only for incremental improvements. Given the total of research, technology, management, and funding issues addressed in the CP Road Map, this long-term research plan is innovative, challenging, and exciting. In addition, several specific problem statements in the CP Road Map, especially those involving development of new and innovative joints, call for innovation.

In addition, the research management plan includes establishing an innovative research initiative, similar to TRB's Innovations Deserving Exploratory Analysis programs, that focuses specifically on concrete pavement needs. The innovative research initiative should fund research on promising but unproven innovations with potential for helping to achieve overall goals of the

CP Road Map. Establishing such a program should require organizational development, funds, and a matching system.

RESEARCH MANAGEMENT CONSIDERATIONS FOR INDIVIDUAL TRACKS

The following brief discussion of research management issues within the CP Road Map tracks should help track team leaders get started quickly and efficiently.

Some of the tracks identified in the CP Road Map are, in essence, a complete research program in and of themselves. As such, they have management and research management issues that should be considered, especially early in the process. Some are even part of ongoing initiatives (e.g., a major pooled fund for tracks 1 and 4 and a large FHWA program addressing track 12). A framing study should be initiated for these tracks, calling for a full examination of the research track that includes formatting it into specific, manageable contract packages, depending on resources available from sustaining organizations.

The next step is to reevaluate the problem statements to ensure that the work is carefully sequenced and reflects a logical progress of research and funding availability. The final step is to expand each research problem statement into a detailed research plan with tasks, funding, and specific objectives.

Track 1. Materials and Mixes for Concrete Pavements

This track has several important research management issues to address. The framing study should call for developing a first cut of the future mix design procedure, using current consensus documentation. It should propose that State transportation departments and industry assemble the best mix of design and laboratory practices in an organized way, using today's technology and the following steps:

- Initiate consensus building among critical parties.
- Document and validate best practices.
- Validate new business models with the eventual transfer from transportation department-controlled method specifications to end-result and performance specifications.
- Eliminate variations among transportation departments in mix areas that are not border-sensitive.
- Provide a framework for follow-up and integrated research work—"plug-and-play." This framework should also provide a consistent mix design process for researchers to use in other projects. This will help reduce the wait for the completed product.
- Provide for integration with the proposed (track 2) performance-based design guide.
- Develop initial target values related to concrete pavement mix designs.

- Establish AASHTO (or industry) as the standard setting and control organization for future research, similar to Superpave®.

- Link this work to personnel training and begin the conversion process.

- Simplify the laboratory certification process by reducing the number of minor variations in the test procedures between borders.

Another critical point is to agree on a specification format for the new tests and procedures that should be developed. The AASHTO provisional standards process could be adopted as the model.

While not necessary, it would be extremely beneficial for the research track team leaders to have access to mix design laboratories and commit to evaluating new tests and procedures as soon as they come online. It is important that procedures and test equipment coming out of the research be validated by two or more additional laboratories. This should accelerate knowledge transfer and provide onsite expertise on many new procedures. It also would be advantageous to have two or three other laboratories, such as FHWA or NRMCA, involved in this track.

A critical element of this track is continuing FHWA's work on mix optimization and the National Concrete Consortium pooled fund study on mix designs. Both efforts need to be included; they should provide considerable insight into any additional research that might need to be added to the track.

Track 2. Performance-Based Design Guide for New and Rehabilitated Concrete Pavements

This track has several critical research management issues. First, as discussed earlier in the report, this track builds on the latest version of continuing the development of models, integrating design with mix design and construction specifications and improving reliability and the validation/calibration process. This is extremely complicated work and will require a close working relationship with current activities under MEPDG (DARWin-ME™), accelerated testing for validation and calibration, and specific software integration issues.

Second, the AASHTO Joint Technical Committee on Pavements historically has been the lead organization for developing the guide, while FHWA has financed many of the model development contracts. It is not clear which organization is best suited to manage this track. Most probably, it would be a combination of the two organizations, plus a major university with faculty deeply involved in concrete pavement modeling and design.

As new and updated models are developed, the software should be structured so these advanced models can be plugged in. Appropriate software protocols for the research products should be investigated.

The MEPDG focuses on the continued advancement of material properties and linkage with track 1, the mix design track. Both tracks show many model development activities. Ensuring compatibility and detecting gaps and overlaps is a role for the EAC through its systems integration function.

Elsewhere in the CP Road Map are projects to develop a mechanistic approach to concrete pavement restoration techniques, a design catalog, and improved low-volume road designs.

Track 3. Intelligent Construction Systems and Quality Assurance for Concrete Pavements

This track is probably the most challenging of the CP Road Map. It calls for identifying, researching, experimenting with, and adopting a full series of nondestructive tests for both handheld testing equipment and automation of the paving operation. These tests fall under the umbrella of ICSs. The framing study is truly critical, and much like the mix design track, should require significant coordination with both the equipment and sensor companies.

The objectives of intelligent construction equipment are as follows:

- Improve construction operation efficiency with early detection of potential problems.
- Provide continuous inspection that should reduce the dependency on small samples and onsite inspectors.
- Provide a long-term record for asset management systems.

If these goals are accomplished, concrete pavement construction technology should become more critical than any other highway construction operation.

The objective of the early framing studies should be to develop a detailed architecture for both hand-held and equipment-mounted test equipment. There should be a full investigation of both current NDT/ICS technology and sensor technologies in other industries. Sensor advancements in the manufacturing industries are accelerating at a rapid rate. Radio frequency identification technology, for example, should be understood and defined within the context of concrete pavement technology.

The work with equipment manufacturers should also be studied to develop a long-term, mutually beneficial research and development program, the scale of which may be unprecedented. This requires a clear understanding of the objectives, technology, application, and economics. The track team leadership could be facilitated by a State transportation department and an equipment manufacturer.

The following important questions should be addressed in all these framing studies:

- What is the real potential and effectiveness of the proposed technology?
- Do we have or can we get the human factor upgraded to understand, use, and maintain the new technology?
- Should the industry provide cooperative funding?

- What are the intellectual property issues and are they surmountable?
- How should we tackle software compatibility and integration with transportation department systems and between equipment systems?

It would be helpful in the framing study to develop a schematic and a three-dimensional, wall-mounted presentation of a fully automated and sensored concrete pavement operation, including aggregate crushing, storage, moisture, gradation, batching, transporting, placing, finishing, and opening to traffic. This would effectively outline the research details, help organize the concepts, and market the ideas to potential vendors.

Track 4. Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements

This track probably represents the newest addition to the concrete pavement industry's needs. The need for intensive research on noise generated by tire/pavement interaction was raised nearly two decades ago when FHWA and AASHTO conducted a study of European concrete pavement technology through the International Technology Scanning Program, but there has been no coordinated research effort in the United States until now. Noise research that addresses the highway abutters and elevates the driver's experience is needed. The track, however, promotes research in all surface characteristics areas—friction, smoothness, noise, lateral drainage, splash and spray, and rolling resistance—and suggests a balanced approach. Engineers will need to know more about megatexture, macrotexture, and microtexture and how each impacts specific surface characteristics. This track includes research on mix designs to meet predetermined values and innovative construction equipment to produce consistent field values.

Track team leaders must insist on long-term solutions for the noise element of the track and not be distracted by early pressures to develop a quick-fix solution. It also is important that measuring equipment be defined early in the process to ensure that data can be collected and analyzed properly. Eventually, the noise issue should be linked to noise mitigation strategies, which may link specific pavement solutions to the noise mitigation solution. This would require that a threshold value be established for pavement rehabilitation. Another critical factor is to determine whether pavement noise threshold values should apply to rural pavements, urban pavements, or all pavements, and if a solution for drivers can be found, as well.

The track also includes a full series of issues related to smoothness and friction. A critical issue with friction is tort liability and the setting of threshold values. This issue has been a deterrent to conducting more open research and technology sharing. In a truly performance-driven pavement design, setting various thresholds for factors like loadings, noise, friction, and spray over the service life of the pavement could expose drivers to unsafe conditions and agencies to the potential of increased legal risks should any of the thresholds be exceeded. This is especially true for setting friction thresholds.

Track 5. Concrete Pavement Equipment Automation and Advancements

Research management of this track is similar to the NDT/ICS track in that cooperation with the equipment manufacturers is critical. It is possible that the two tracks would be managed by the same group. This track, however, will focus on developing a clear description of each new or upgraded piece of equipment and determining if there is sufficient market to justify the product development costs. Equipment manufacturers constantly discuss the chicken-and-egg concept on equipment development. If they develop it, will there be a market? If there is market, they will develop it. The track will require a paradigm shift in market definition with more pressure on transportation departments to help define the future and make it a reality.

As a first step, a pool of transportation departments interested in this track could partner with contractors from their local concrete paving industry to review and provide input into the early planning process. This should help raise awareness, establish a potential market, and identify any barriers (such as specification impediments) that would impede the research. Another key step is to develop contract language to allow experimentation with the new equipment on active construction projects. With enough commitment from transportation departments to provide cooperative partnering and sufficient sites, equipment manufacturers should be better able to decide if the chicken-and-egg discussion is resolved.

Within the framing study, the track team leaders may want to examine in detail the French Charter of Innovation system of partnering with equipment manufacturers. This system is a joint-venture approach in which the government, equipment manufacturers, and contractors work collectively to advance equipment.

Track 6. Innovative Concrete Pavement Joint Design, Materials, and Construction

With the cost of joints running 12–20 percent of the cost of concrete pavements and joints being the primary driver of maintenance and rehabilitation, a blend of new performance data and incremental improvements in construction practices could have significant payoff. Many such projects are included in the track. Premature joint deterioration has emerged as a significant issue affecting all parts of the country, but particularly the northern States. This also warrants serious consideration. The track also addresses the need for breakthrough thinking on designing, constructing, and repairing joints. One idea to explore is bottom-up cracking (as opposed to joint sawing) through frames fastened to the subgrade. There are undoubtedly many more.

Track team leaders should strive for a balance in the overall program. The challenge on long-life pavements is to design and place a dowel configuration that will last 50–60 years with minimal maintenance. This is nearly double the current life on even moderately loaded pavements.

On shorter life pavements (e.g., thin overlays), the challenge is to find a solution somewhere above the load transfer provided by aggregate interlock and a full dowel assembly. Is there a dowel design with a lower initial cost that meets the performance requirements, something in the more moderate 20-year life? In addition, would the pavement design culture allow use of this shorter life assembly to save initial costs?

The track includes an innovative joint design competition. A strong competitive program could address both long- and short-term issues. The competition also will look for fresh ideas on joint design that break away from the one-size-fits-all dowel bar.

Track 7. Concrete Pavement Maintenance and Preservation

The current economic climate has severely limited funding for new pavement construction and shifted much of the focus of State transportation departments to maintaining and preserving existing pavement assets. As such, establishing proven and reliable maintenance and preservation methods for existing concrete pavements is essential.

Because maintenance and preservation issues are very important to the future of the concrete pavement community, the project team has recently identified track 7 as a separate track devoted to these topics. This track will help stakeholders see how and where maintenance and preservation research is headed and provide the mechanism for rapid implementation of both better practices and key innovations.

It is important to distinguish at the outset the differences between maintenance and preservation activities, such that research conducted under this track can be appropriately implemented. Maintenance should focus on the routine activities (e.g., resealing concrete pavement joints, cleaning out edge drains, etc.) that help a concrete pavement function as intended. Preservation should focus on specific treatments (e.g., diamond grinding to reduce curling and improve ride quality, DBRs to restore load transfer, etc.) that will help extend the functional and structural life of the pavement.

Track 8. Concrete Pavement Construction, Reconstruction, and Overlays

Two national initiatives, SHRP2 Renewal and the FHWA Highways for LIFE (Long-Lasting, Innovative, and Fast Construction of Efficient and Safe Highway Infrastructure) program, will influence this track. The specific problem statements included in the track could fit easily into either program, should they be funded and evolve as expected. There should be close coordination among the three programs.

The modular and overlay subtracks, for example, could easily be developed as independent tracks. The track team leaders should consider this in their planning; they may find that a small but important group of States would rally better around a smaller effort. In addition, the mix projects could be placed under the performance-based mix design track.

An important project within this track is the simulation and constructability effort. It is difficult to capture all of the important items learned on a project, so constructability reviews are helpful in applying experience from the field to the next project. This has great education merit, as well. Industry and transportation departments could gain insight into traffic management, plant and haul routes, waste disposal, and other issues that would help show how concrete paving operations could be conducted in different scenarios.

Track 9. Evaluation, Monitoring, and Strategies for Long-life Concrete Pavement

The concept of long-life pavements was difficult for many participants in the brainstorming sessions to grasp. Many factors come into play, including high initial costs for difficult-to-estimate traffic and land management changes for a 60-year period.

Before starting this research track, the track team leaders should use this input to clearly define a long-life pavement with the following factors:

- Long-term foundation and drainage at initial construction with service life of 50 to 60 years or beyond.
- Improvements to the functional requirements only (surface improvements).
- Predetermined staged construction for the slab.
- Some major rehabilitation, but only if it can be done at very high speed and be limited to the slab only.

Applications that seem appropriate are not just sections with heavy truck traffic. Sections with heavy motor vehicle traffic and relatively light truck traffic loadings that show extremely high user costs during repairs could be an application for a long-life pavement. The cost-effectiveness of long-life solutions is not clear for facilities already at peak volume with heavy truck loadings.

Regarding accelerated testing, current legislation limits the LTPP program to the experiment designed in the early 1980s. No new sections or parameters are accepted into the study. This is not expected to change in the next legislation. In addition, only a handful of the 24 accelerated pavement testing (APT) facilities in the United States are capable of testing concrete pavements. The framing study would analyze all of the APTs, identify those willing and able to evaluate concrete, and link them into a consortium of users. FHWA met with 13 APT owners in July 2004. All were interested in partnering, but specific topics and partnering details will be discussed in future meetings.

There also is a need to design and build experimental sections on active roadways with live traffic. Much has been learned from the LTPP program and SPS. The keys to building local sections are well known and include construction tolerances, sensor placement, loadings, and environmental data. Track team leaders should clearly address the experimental design and services to support that design before undertaking the experiment.

Finally, projects are included that address technical issues related to data collection and pavement management. The problem statements were restricted to issues dealing with concrete pavements and test road and network data collection and analysis systems. They are important projects in that they will close the feedback system to design.

Track 10. Concrete Pavement Foundations and Drainage

While the foundation effort is clearly a critical part of the performance-based design and NDT/ICS tracks, this new track underscores the importance of this area. Furthermore, the need for coordinated research to understand and improve the quality of drainage is included in this track as a companion subtrack. In this track, there should be close coordination with the geotechnical community to assist in identifying specialty foundation and drainage research needs that are applicable to concrete pavements. Technologies, such as intelligent compaction, and the use of existing NDT, such as ground-penetrating radar, should be part of early tasks.

Track 11. Concrete Pavement Economics and Business Management

Track 11 is unique in that it conducts dovetails with and supports the work of the EAC. Therefore, it is suggested that the executive advisory committee assume team leadership for track 11.

Track 12. Concrete Pavement Sustainability

Recently, the concrete pavement industry has been working toward a common definition of sustainability. Furthermore, FHWA recently initiated a major initiative in this area. Addressing this topic means addressing a gamut of concrete pavement-related environmental and energy issues, from cement and stone production to construction and recycling. This track includes several problem statements related to sustainability advancements in the concrete pavement industry, most of which are crosscutting with other tracks.

The key to improving the environmental record of concrete pavements is to find ways to reuse aggregates and fines in concrete pavements. This is definitely the higher use of raw materials and is within the industry's grasp. With the advent of the M-E approach to pavement design, it may be beneficial to look at materials characteristics based on modulus and stiffness type values. Many State transportation departments now require recycled materials to meet all of the conditions of virgin materials. However, work done in Germany and other places shows that recycled materials could perform exceptionally well under a stiffness or modulus criteria. This approach diminishes the importance of tests such as Los Angeles abrasion, fractured faces, and gradation, and relies more on plate load testing to determine structural adequacy.

The track leadership may want to work with existing programs that address environmental issues. The Environmental Council of Concrete Organizations, for example, could be more mainstreamed with the highway community. These and similar organizations should be examined thoroughly for scope of work, research funding, training, etc., that could be pulled into the CP Road Map.

THREE SPECIAL RESEARCH MANAGEMENT CHALLENGES

Three issues should be particularly important to the EAC: ensuring initial projects are begun quickly, supporting significant changes to business systems, and focusing on technology transfer. Many of these critical, initial issues are addressed in track 11, so the EAC should begin its work as team leader for that track as soon as possible.

Early Financing and Conduct of Research

Industry leaders should quickly validate the credibility of the CP Road Map and demonstrate their own commitment to work cooperatively to fund and implement it. Research track team leaders should begin at least one project in each track as quickly as possible. In addition, each track should be updated as soon as possible to show new starts and other ongoing work being accomplished by agencies across the country, including FHWA, the National CP Tech Center, and State transportation departments.

Business System Changes

The CP Road Map recognizes a significant transfer of roles and responsibilities from State Transportation departments to industry. To succeed, such a transfer requires a new business model—that is, a new way for transportation departments and industry to do business together. This model should include pavement economics, capital availability, risk and risk transfer, warranties, innovative contracting, incentives, and standards ownership.

The first objective is to determine the best combination of concrete pavement solutions (mix of fixes) that balances funds, traffic impact, and network efficiency. The second is to take advantage of an array of alternate contracting techniques that could enhance the procurement of concrete pavements with an improved determination of risk between the owner and the contractor.

Technology Transfer

During brainstorming events, the speed at which new technology is applied was discussed. Stakeholders were concerned about the slowness of communicating research results to agencies and industry, as well as the slowness of industry to accept new ideas and technologies. They were especially concerned about the lack of technology transfer and training materials for the workforce.

Effective technology transfer strategies will be critical for every research project that comes out of the CP Road Map, but particularly in the mix design and NDT/ICS tracks, where research results eventually will impact the job of every person on the construction site.

One stand-alone project under track 11 is to develop an expedited technology transfer plan. The EAC should encourage action in this area as soon as possible and monitor it continuously. Marketing and technology transfer resources available through projects such as FHWA's Advanced Concrete Pavement Technology (ACPT) program should be built into the technology transfer plan.

GETTING STARTED: NOT BUSINESS AS USUAL

Beginning a long-term research program is a slow process. During the final 3 years of the original CP Road Map development, the development team worked closely with stakeholders to enlist support. FHWA should now begin a strong research management effort.

The research tracks and management plan identify what needs to be done and how to succeed to achieve the following new goal of the CP Road Map:

> *By 2020, the highway community will have a comprehensive, integrated, and fully functional system of concrete pavement technology that provides innovative solutions for customer-driven performance requirements.*

Peer review, coordination, leveraging, and partnering are all valid strategies. For this plan to work, all participants must take on the role of champion (see figure 15), including the EAC, supported by the administrative support group and the research track team leaders..

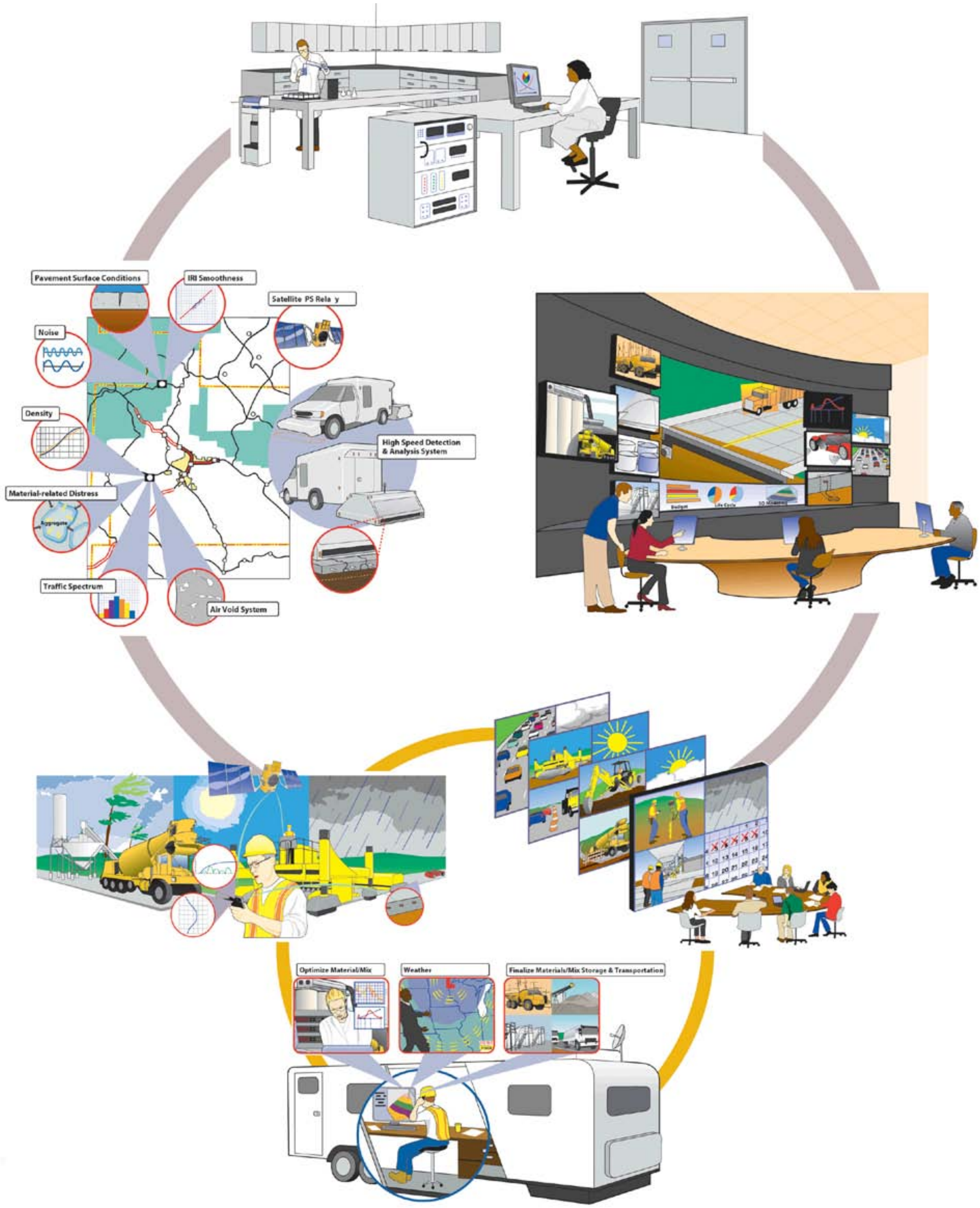


Figure 15. Illustration. CP Road Map goal.

SYNOPSIS OF CP ROAD MAP IMPLEMENTATION ACTIVITIES (2006–2011)

With recognition that the CP Road Map is a living research and technology document, the need for dedicated, structured administrative support has been identified. Shortly after the release of the CP Road Map, this support was provided via funding of an operations support group (OSG). Pooled Fund TPF-5(185), with sponsorship from FHWA, as well as New York, Virginia, Iowa, Michigan, Mississippi, and Pennsylvania, currently provides funding for the OSG, which is currently managed by the National CP Tech Center.(2)

The OSG helps agencies and industry partners meet their research goals efficiently and tracks national concrete pavement research which, in turn, helps Federal, State, industry, and academic partners work together to leverage resources and avoid costly duplication of research activities.

Work under TPF-5(185) has been conducted under individual task orders.(2) As of June 2011, five task orders have been issued. The following sections highlight the various implementation activities that have been executed under these task orders.

EAC

As part of the first task order, the OSG established an EAC. The role of the committee is to provide overall guidance and coordination of the National CP Road Map Program. The committee has met three to four times per year, and their responsibilities have included the following:

- Obtaining executive-level buy-in of stakeholders to the CP Road Map.
- Fostering collaborative sponsorships, conducting research and technology transfer activities.
- Fostering research integration within and between the CP Road Map's tracks.
- Suggesting/promoting innovative technology transfer activities and training activities.
- Globally reviewing research and identifying new or developing research areas.
- Prioritizing tracks, determining track leaders, and advising track leaders.
- Fostering research integration within and between the CP Road Map's tracks.
- Leading conduct of track 11 (economics and business management).
- Regularly evaluating progress of the CP Road Map.

Database

The original CP Road Map database was created as a tool to assist in the development of the CP Road Map plan, and it contains related research as of the end of 2000. As part of the operational support effort, the National CP Tech Center has augmented this database with research started, in progress, or completed since that time. The database has been designed to serve the following immediate specific purposes:

- Due to the way that the EAC and the track team meetings are organized, it is important to be able to share all the relevant work and inform the leaders of recent accomplishments and new directions.
- The administrative support team and track teams need to look at the detailed scope of work within these research efforts to see how they fit together and to determine whether they are accomplishing the overall goals of the tracks.
- The research managers and principal investigators identified in these lists will become an integral part of the track management.

The information included in the database includes work conducted under sponsorship of FHWA, NCHRP, pooled fund studies, the concrete paving industry, and some international work. Sources of information include traditional electronic clearinghouses (e.g., Transport Research International Documentation) and discussions with technical leaders from these organizations.

Track Team Meetings

The OSG has provided planning and facilitation services for various track teams. That said, the tracks cannot be moved forward without the agreement and support of organizations interested in sponsoring the research. One of the key steps has been to identify potential sponsors and bring them into the discussion. Sponsors have included FHWA, NCHRP, ACPA, PCA, NRMCA, and State transportation departments through pooled fund mechanisms. Table 2 includes the tracks that have met as part of the implementation work to date.

Table 2. Track coordinators.

Track	Coordination
1. Mix	Peter Taylor
2. Design	Dale Harrington
3. NDT/ICS	Rob Rasmussen
4. Surface Characteristics	Rob Rasmussen
8. Construction/Overlays	Dale Harrington
11. Business	Tom Cackler
13. Sustainability	Peter Taylor

The OSG has followed the guidance of FHWA and EAC in identifying which tracks to begin with as well as the strategies for initiating them. The CP Road Map includes 12 tracks. Originally, the first four were identified as priority tracks. Other tracks were identified as priority because of meetings of the EAC. These included coordination of overlay-related research under track 8, as well as the business management and sustainability tracks. The latter became known as the 13th track since it was added to the 12 tracks originally published. Because of the refresh task that led to the publication of this report, the tracks have once again been reduced to 12. For a comparison of the original tracks and the new, “refreshed” tracks, see appendix C.

Specific support for the research track teams has included the following:

- Identifying collaborative opportunities within the CP Road Map research program.
- Establishing track priorities.
- Developing project objective statements for each track's priority projects.
- Developing funding mechanisms for each priority project.
- Planning and scheduling meetings of individual research track teams.
- Identifying projects and elements to pursue under the sustainability track (since it is new).

Some of the track activities include the following:

Track 1. Materials and Mixes for Concrete Pavements

Management of this track has been conducted in recent years as part of a dedicated transportation pooled fund project, TPF-5(205), *Implementation of Concrete Pavement Mixture Design and Analysis (MDA) Track of Concrete Pavement Road Map*.[12] The Iowa Department of Transportation (Iowa DOT) leads this project, and partners include Iowa, Kansas, Missouri, Montana, New York, Oklahoma, Texas, and Wisconsin. The purpose of this project is to support activities that align with track 1 research needs statements. Currently, investigations are underway for the development of alternate methods for calculating mix proportions, evaluating on-site analysis tools, and assessing requirements for the air void systems. It is anticipated that a guide will be prepared. Recent work completed under this project investigated acoustical methods to determine set time.

Track 3. Intelligent Construction Systems and Quality Assurance for Concrete Pavements

As part of the CP Road Map, the following nine potentials technologies were proposed for development and integration into the paving operations:

1. Temperature/moisture/strength/stiffness changes and development.
2. Pavement thickness.
3. Dowel/tie bar/reinforcement alignment.
4. Curing effectiveness.
5. Slab support.
6. Workability.
7. Air void systems.

8. Mix density and volumetrics.

9. Smoothness/texture/skid resistance and splash/spray.

A track leadership team was formed to investigate this further, including individuals from the paving industry, equipment industry, transportation departments, FHWA, and academia. The team identified the most critical parameters to monitor during construction as fresh mix properties/variability, curing operations, and smoothness/texture. The team also identified the corresponding technology that could be used to assess the most critical factors. Since that time, several important projects have been monitored. Two notable national projects that fall under track 3 include the following:

- SHRP 2 R06(E): *Real-Time Smoothness Measurements on Portland Cement Concrete Pavements During Construction*.[13]

- FHWA SmartCure Practical Enhancements for Field Application.

Also of significance has been the ICS program that FHWA has recently been pursuing as part of the Every Day Counts initiative. The main objective of this effort is to identify existing and emerging technologies in the area of intelligent construction of pavements including but not limited to systems, components, processes, and software that can bring benefits, such as increased production, increased efficiency, cost savings, real-time measurements/feedback, and improved quality and uniformity.

Track 4. Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements

In track meetings conducted to date, a sound framework has been developed for this track. Various ongoing and foundational research efforts have been identified and are actively tracked. A summary of some of the more relevant national projects include the following:

- TPF-5(139): *PCC Surface Characteristics: Tire-Pavement Noise Program Part 3—Innovative Solutions/Current Practices*.[14]

- TPF-5(063): *Improving the Quality of Pavement Profiler Measurement*.[15]

- NCHRP 01-43: *Guide for Pavement Friction*.[16]

In addition, the following efforts have been identified:

- National CP Tech Center/FHWA: *Resources on Two-Life Concrete Paving*.[17]

- ACPA: *Development and Implementation of the Next Generation Concrete Surface*.[18]

- TPF-5(134): *PCC Pavement Surface Characteristics—Rehabilitation (Mn/ROAD Study)*.[19]

- NCHRP Project 10-67: *Texturing of Concrete Pavements*.[20]

- State Transportation Department Quiet Pavements Research Programs—California Department of Transportation, Washington State, Colorado, Texas, Florida, and Arizona.
- TPF-5(135): *Tire/Pavement Noise Research Consortium*.[21]
- FHWA/TPF-5(158): *FHWA Traffic Noise Model: Version 3.0 Software Development*.[22]
- FHWA/Volpe: *Traffic Noise Model (TNM)*.[23]
- NCHRP 1-44: *Measuring Tire-Pavement Noise at the Source*.[24]
- NCHRP 8-56: *Truck Noise-Source Mapping*.[25]
- NCHRP 10-76: *Methodologies for Evaluating Pavement Strategies and Barriers for Noise Mitigation*.[26]
- FHWA Technical Working Group/AASHTO: Standardization of On-Board Sound Intensity.
- FHWA: Modeling Splash and Spray Potential of Pavements.

Track 8. Concrete Pavement Construction, Reconstruction, and Overlays

For the last several years, the National CP Tech Center, with the sponsorship of FHWA, State transportation departments, and industry, has pursued a multifaceted effort to develop and implement better practices for the design, construction, and maintenance of concrete overlays. This effort has led to the development of the *Guide to Concrete Overlays*, a companion guide for the design of concrete overlays (expected to be released in fall 2011), and a field application program.[27] All of this work has been conducted with guidance provided by the CP Road Map.

CP Road Map Web site

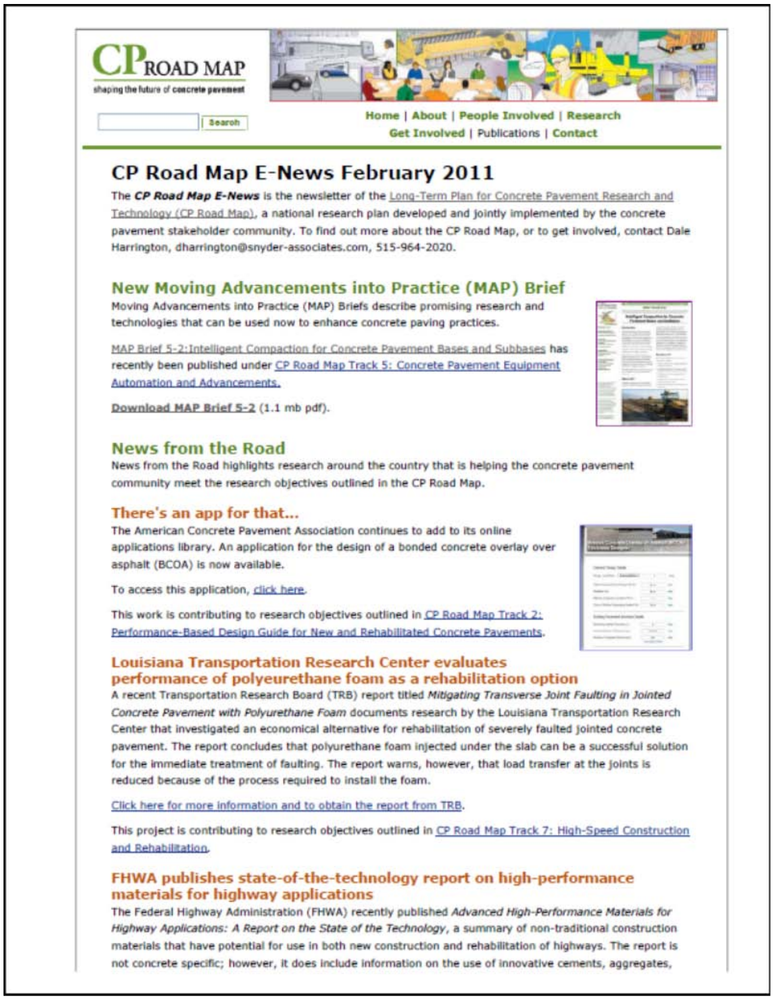
A Web site has been developed and maintained as part of the OSG effort. The Web site has been critical as a means to coordinate and communicate the CP Road Map. It provides the following:

- Program information and news.
- Contact information (CP Road Map directory) and organizational links.
- Status of current work.
- Links to aid implementation of completed work.
- Agendas and minutes of meetings.
- Ancillary documents.

E-News

One of the most effective means to project the mission of the CP Road Map has been the publication of a regular e-newsletter via e-mail. Illustrated in figure 16, the CP Road Map E-News issues highlight research from around the world that is helping the concrete pavement community meet the research objectives outlined in the CP Road Map. Every issue includes numerous links to publications of interest and highlights a research agency including work that they have sponsored or conducted. To date, highlights have been developed for the following:

- Indiana.
- Michigan.
- Wisconsin.
- Minnesota.
- Pennsylvania.
- Washington.
- Virginia.
- Mississippi.
- Iowa.
- Texas.
- New York.
- FHWA TFHRC.



CP ROAD MAP
shaping the future of concrete pavement

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CP Road Map E-News February 2011

The ***CP Road Map E-News*** is the newsletter of the Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map), a national research plan developed and jointly implemented by the concrete pavement stakeholder community. To find out more about the CP Road Map, or to get involved, contact Dale Harrington, dharrington@snyder-associates.com, 515-964-2020.

New Moving Advancements into Practice (MAP) Brief

Moving Advancements into Practice (MAP) Briefs describe promising research and technologies that can be used now to enhance concrete paving practices.

MAP Brief 5-2:Intelligent Compaction for Concrete Pavement Bases and Subbases has recently been published under CP Road Map Track 5: Concrete Pavement Equipment Automation and Advancements.

Download MAP Brief 5-2 (1.1 mb pdf).

News from the Road

News from the Road highlights research around the country that is helping the concrete pavement community meet the research objectives outlined in the CP Road Map.

There's an app for that...

The American Concrete Pavement Association continues to add to its online applications library. An application for the design of a bonded concrete overlay over asphalt (BCOA) is now available.

To access this application, click here.

This work is contributing to research objectives outlined in CP Road Map Track 2: Performance-Based Design Guide for New and Rehabilitated Concrete Pavements.

Louisiana Transportation Research Center evaluates performance of polyeurethane foam as a rehabilitation option

A recent Transportation Research Board (TRB) report titled *Mitigating Transverse Joint Faulting in Jointed Concrete Pavement with Polyurethane Foam* documents research by the Louisiana Transportation Research Center that investigated an economical alternative for rehabilitation of severely faulted jointed concrete pavement. The report concludes that polyurethane foam injected under the slab can be a successful solution for the immediate treatment of faulting. The report warns, however, that load transfer at the joints is reduced because of the process required to install the foam.

Click here for more information and to obtain the report from TRB.

This project is contributing to research objectives outlined in CP Road Map Track 7: High-Speed Construction and Rehabilitation.

FHWA publishes state-of-the-technology report on high-performance materials for highway applications

The Federal Highway Administration (FHWA) recently published *Advanced High-Performance Materials for Highway Applications: A Report on the State of the Technology*, a summary of non-traditional construction materials that have potential for use in both new construction and rehabilitation of highways. The report is not concrete specific; however, it does include information on the use of innovative cements, aggregates,

Figure 16. Screen shot. E-news example.

Moving Advancements into Practice (MAP) Briefs

To date, each release of an E-News has been accompanied by a specialized implementation brief called a MAP Brief. Illustrated in figure 17, the MAP Brief highlights a specific research effort and its products. More importantly, it discusses the potential for implementing the findings from that research.

CP ROAD MAP
shaping the future of concrete pavement
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FEBRUARY 2011

ROAD MAPTRACK 5
Concrete Pavement Equipment Automation and Advancements

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Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. MAP Brief 5-2 provides information relevant to Track 5 of the CP Road Map, Concrete Pavement Equipment Automation and Advancements.

The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by TPF-5(185).

MAP Brief 5-2 is available at: http://www.cproadmap.org/publications/ MAPbrief5-2.pdf

"Moving Advancements into Practice"
MAP Brief 5-2:
Describing promising technologies that can be used now to enhance concrete paving practices

Intelligent Compaction for Concrete Pavement Bases and Subbases

Introduction

Unfortunately, many concrete pavement failures in the United States are related to inadequate foundation layers—the soils and aggregates in the natural subgrade and in the subbase. One factor in foundation-related pavement failures is poor compaction practices. The use of conventional compaction machines, even when skillfully operated, cannot ensure uniform pavement foundation layer support conditions.

A relatively new "smart" technology—intelligent compaction (IC)—has the potential to significantly improve compaction processes with a near continuous record of compaction data that can aid in controlling uniformity of support conditions.

This MAP Brief provides a brief overview of IC technology, research, and implementation issues.

What is IC?

Intelligent compaction (IC) technologies consist of machine-integrated sensors and control systems that provide a record of machine-ground interaction on an on-board display unit in real-time using global positioning systems (GPS). With feedback control and automatic adjustment of vibration amplitude, frequency and/or speed during the compaction process, the technology is referred to as "intelligent" compaction. Without the vibration feedback control system the technology is commonly referred to as continuous compaction control (CCC).

Benefits of IC

The major potential benefits of IC can be categorized as follows:

- Improved uniformity through optimized compaction control
- Increased productivity (each pass is optimized; unnecessary passes are eliminated)
- Identification of non-compactable and unstable areas
- Continuous record of material-related stiffness parameter values
- Ultimately, reduced pavement failure and repair costs

Figure 1. Smooth-drum roller equipped with onboard display unit

Figure 17. Screen shot. MAP Brief example.

To date, MAP Briefs have been developed on the following topics:

- *Partial-Depth Repair for Concrete Pavements* (new track 8).[28]
- *Preventing Joint Deterioration in Concrete Pavements: A Summary of Current Knowledge* (track 6).[29]
- *Fly Ash as a Supplementary Cementitious Material in Concrete Mixtures* (track 1).[30]
- *Intelligent Compaction for Concrete Pavement Bases and Subbases* (track 5).[31]
- *Smart Cure: An Integral Part of an Intelligent Construction System* (track 3).[32]
- *Deleterious Chemical Effects of Deicing Solutions on Concrete Pavements* (track 1).[33]
- *Stringless Concrete Paving* (track 5).[34]
- *Roller-Compacted Concrete Pavements* (new track 9).[35]

- *Two-Lift Concrete Paving* (new track 12).[36]
- *Job-Specific Optimization of Paving Concrete with COMPASS (Concrete Mixture Performance Analysis System)* (track 1).[37]
- *Diamond Grinding to Reduce Tire-Pavement Noise in Concrete Pavements* (track 4).[38]
- *Use of Nonwoven Geotextiles as Interlayers in Concrete Pavement Systems* (new track 8).[39]

APPENDIX A

BRAINSTORMING EVENTS

Table 3 lists the brainstorming events and their respective dates.

Table 3. Brainstorming (outreach) events.

Date	Event
January 2002	TRB annual meeting (Session 345 and subcommittees A2E01, ASF01, and A2E06)
January 2002	Nebraska Concrete Pavement Association annual meeting
February 2002	Iowa Concrete Paving Association annual meeting
February 2002	Michigan Concrete Paving Association annual meeting
March 2002	Virginia Concrete Workshop
March 2002	TRB Committee for Improved Concrete Pavements
March 2002	Iowa Ready Mix Association annual meeting
April 2002	International Center for Aggregate Research
April 2002	Iowa State University National CP Tech Center advisory board meeting
April 2002	IPRF panel meeting
May 2002	FHWA TFHRC
June 2002	ACPA State chapter executive meeting
June 2002	TRB (Subcommittee A2F01)
March 2003	TRB Concrete Pavement Research Team presentation
August 2003	AASHTO Subcommittee on Materials
July 2003	FHWA TFHRC
July 2003	National Ready Mixed Concrete Pavement Association meeting
July 2003	ACPA summer meeting
October 2003	Midwest Brainstorming Session (in conjunction with National Concrete Consortium, ACPA, and Iowa Concrete Paving Association)
November 2003	Center for Advanced Cement Based Materials Research
November 2003	Eastern States Brainstorming Session (in partnership with ACPA chapters)
December 2003	ACPA annual convention
January 2004	TRB annual meeting
January 2004	Pennsylvania Concrete Conference
January 2004	Western States Teleconference
February 2004	Iowa Concrete Paving Association annual meeting
March 2004	Missouri-Kansas ACPA Chapter annual workshop
May 2004	ACPA State Chapter executive meeting
October 2004	FHWA TFHRC

APPENDIX B

OVERVIEW OF POTENTIAL SUSTAINING ORGANIZATIONS

FHWA: FHWA has internal committees that define, execute, and monitor its contract and in-house concrete pavement projects. FHWA manages some discretionary funding and has the freedom to establish and execute scopes of work in the national interest. It also manages and oversees earmarked funds, with each fund differing in its flexibility. The FHWA research program is organized and administered by the Office of Pavement Technology in cooperation with TFHRC and the Resource Center. Additional pavement work is done by the Office of Asset Management. FHWA has some flexibility in working with State transportation departments and industry in establishing scopes of work. Technical proposals generally are developed by FHWA staff. Once the contract is underway, technical working groups can be assembled to provide guidance to FHWA. Currently, FHWA is guided broadly by the ACPT program. FHWA also works with States to develop and implement studies under the Transportation Pooled Fund program. These studies can accept private sector money, as well.

AASHTO: Several AASHTO subcommittees and task forces are involved in concrete pavement technical issues, including the joint task force on pavements and the subcommittees on materials, construction, and maintenance. FHWA normally acts in either a secretarial or a liaison role for these groups. Industry may observe and comment on committee activities but has no formal role. From time to time, these committees develop long-range plans. For example, the Subcommittee on Construction prepares a research plan about every 10 years. The joint task force on pavements periodically holds strategic planning meetings.

NCHRP: NCHRP is administered by TRB and sponsored by individual State transportation departments. Support is voluntary and funds are drawn from the States' Federal Aid Highway program apportionment of State planning and research (SPR) funds. Furthermore, the funds can be spent only for administering problem statements approved on ballot by at least two-thirds of the States, as represented by the AASHTO Standing Committee on Research. Concrete pavement research statements are introduced by State(s), FHWA, an AASHTO committee, or a TRB committee. Industry solicits support from an individual State transportation department, which in turn submits the statement. NCHRP does not manage programs. Assuming it administers a series of concrete pavement-related projects, however, NCHRP will be an important sustaining member.

ACPA: ACPA has a research committee that identifies and fosters support for specific research items related to the industry's agenda and its own long-range plan. State transportation departments and FHWA are invited to observe and participate. Voting is restricted to members, although ACPA's work generally is by consensus. The association has been involved in many elements of the CP Road Map development. An association representative would be a welcomed participant on the CP Road Map's EAC.

NRMCA: NRMCA's research program is managed under the Ready Mixed Concrete Research Foundation. Established in 1991, this foundation identifies research, issues requests for proposals, issues grants or contracts, and develops training packages. To date, little research has been done specifically for concrete pavements, but several tracks or subtracks in the CP Road Map may be of particular interest to NRMCA, especially in mix design, innovative equipment, and NDT/ICS. It is also hoped that NRMCA will participate in new laboratory testing and evaluation programs.

PCA: PCA has a long history of conducting research, both with its wholly owned laboratory and through grants to other concrete-related associations or entities. This organization also may be interested in several subtracks in the CP Road Map, especially in the mix design track.

National Stone, Sand, and Gravel Association (NSSGA): NSSGA represents the crushed stone, sand, and gravel (aggregate) industries. Its membership accounts for 90 percent of the crushed stone and 70 percent of the sand and gravel produced annually in the United States. More than 3 billion tons of aggregate were produced in the United States in 2001 at a value of about $14.5 billion.(40) In 1992, NSSGA's funding arm (Aggregates Foundation for Technology, Research, and Education (AFTRE)) established the International Center for Aggregates Research (ICAR) at the University of Texas at Austin and Texas A&M University. ICAR is active on a wide range of aggregate research applications, including PCC, hot mix asphalt, and base courses. A cooperative research agreement between AFTRE and FHWA is now underway. This joint program, funded 75 percent by Federal money, sponsors aggregate research in multiple end-use applications.

National Concrete Consortium: The National Concrete Consortium is an organization that provides a very effective research coordination and technology transfer role. This group identifies specific research of interest to their members, solicits pooled funds, and sometimes conducts the research. Many of the pooled funds also include funds from FHWA, industry, and others. This is an excellent vehicle for using both public and private funds as one source of funding.

National CP Tech Center: In April 2000, the Iowa Board of Regents authorized formation of what is now the National CP Tech Center. It is a private, public, and university sector partnership that includes support from the ACPA, FHWA, Iowa Concrete Paving Association, Iowa DOT, Iowa State University, and Iowa State's Institute for Transportation. The center focuses research on critical needs of the concrete pavement industry and delivers the best findings, methods, and processes to people who will use them.

Working with its advisory board and standing committees, the center seeks sustainable support nationwide. The staff works with foundations and organizations to identify potential future partners and funding sources and to help develop an understanding of research, technology, and training priorities. Funding for specific projects comes from many sources, including Federal aid pooled funds from around the country. As an example, the center was the lead in the Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements project, an FHWA pooled fund project with 16 States and the private sector contributing funds.

State Transportation Departments: Each State transportation department is allotted Federal funds by formula for research (SPR funds). These funds traditionally have been used to conduct research for local needs. Many State transportation departments have relationships with one or more State universities. Transportation departments may use these funds to participate in pooled fund studies.

APPENDIX C

COMPARISON OF OLD TRACKS AND NEW TRACKS

Original Track/Subtrack Structure

Track 1. Performance-Based Concrete Pavement Mix Design System (MD)
Subtrack MD 1. PCC Mix Design System Development and Integration
Subtrack MD 2. PCC Mix Design Laboratory Testing and Equipment
Subtrack MD 3. PCC Mix Design Modeling
Subtrack MD 4. PCC Mix Design Evaluation and Implementation

Track 2. Performance-Based Design Guide for New and Rehabilitated Concrete Pavements (DG)
Subtrack DG 1. Design Guide Structural Models
Subtrack DG 2. Design Guide Inputs, Performance Models, and Reliability
Subtrack DG 3. Special Design and Rehabilitation Issues
Subtrack DG 4. Improved Mechanistic Design Procedures
Subtrack DG 5. Design Guide Implementation

Track 3. High-Speed Nondestructive Testing and Intelligent Construction Systems (ND)
Subtrack ND 1. Field Control
Subtrack ND 2. Nondestructive Testing Methods
Subtrack ND 3. Nondestructive Testing and Intelligent Control System Evaluation and Implementation

Track 4. Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements (SC)
Subtrack SC 1. Concrete Pavement Texture and Friction
Subtrack SC 2. Concrete Pavement Smoothness
Subtrack SC 3. Tire-Pavement Noise
Subtrack SC 4. Other Concrete Pavement Surface Characteristics
Subtrack SC 5. Integration of Concrete Pavement Surface Characteristics
Subtrack SC 6. Evaluation of Products for Concrete Pavement Surface Characteristics
Subtrack SC 7. Concrete Pavement Surface Characteristics Implementation

Track 5. Concrete Pavement Equipment Automation and Advancements (EA)
Subtrack EA 1. Concrete Batching and Mixing Equipment
Subtrack EA 2. Concrete Placement Equipment
Subtrack EA 3. Concrete Pavement Curing, Texturing, and Jointing Equipment
Subtrack EA 4. Concrete Pavement Foundation Equipment
Subtrack EA 5. Concrete Pavement Reconstruction Equipment
Subtrack EA 6. Concrete Pavement Restoration Equipment
Subtrack EA 7. Advanced Equipment Evaluation and Implementation

Track 6. Innovative Concrete Pavement Joint Design, Materials, and Construction (IJ)
Subtrack IJ 1. Joint Design Innovations
Subtrack IJ 2. Joint Materials, Construction, Evaluation, and Rehabilitation Innovations
Subtrack IJ 3. Innovative Joints Implementation

Track 7. High-Speed Concrete Pavement Rehabilitation and Construction (RC)
Subtrack RC 2. Precast and Modular Concrete Pavements
Subtrack RC 1. Rehabilitation and Construction Planning and Simulation
Subtrack RC 3. Fast-Track Concrete Pavements
Subtrack RC 4. Rehabilitation and Construction Evaluation and Implementation

Track 8. Long-Life Concrete Pavements (LL)
Subtrack LL 1. Pavement Strategy for Long-Life Concrete Pavements
Subtrack LL 2. Construction and Materials for Long-Life Concrete Pavements and Overlays
Subtrack LL 3. Long-Life Concrete Pavement Implementation

New Track/Subtrack Structure

Track 1. Materials and Mixes for Concrete Pavements
Subtrack 1-1. Performance-Based Mix Design and Specifications
Subtrack 1-2. Materials Selection and Testing
Subtrack 1-3. Innovative Materials
Subtrack 1-4. Materials Proportioning
Subtrack 1-5. Mixture Evaluation
Subtrack 1-6. Completed Pavement Materials Evaluation

Track 2. Performance-Based Design Guide for New and Rehabilitated Concrete Pavements
Subtrack 2-1. Design Guide Structural Models
Subtrack 2-2. Design Guide Inputs, Performance Models, and Reliability
Subtrack 2-3. Special Design and Rehabilitation Issues
Subtrack 2-4. Improved Mechanistic Design Procedures
Subtrack 2-5. Design Guide Implementation

Track 3. Intelligent Construction Systems and Quality Assurance for Concrete Pavements
Subtrack 3-1. Quality Assurance
Subtrack 3-2. Intelligent Construction Technologies and Methods
Subtrack 3-3. Intelligent Construction System Evaluation and Implementation

Track 4. Optimized Surface Characteristics for Safe, Quiet, and Smooth Concrete Pavements
Subtrack 4-1. Concrete Pavement Texture and Friction
Subtrack 4-2. Concrete Pavement Smoothness
Subtrack 4-3. Tire-Pavement Noise
Subtrack 4-4. Other Concrete Pavement Surface Characteristics
Subtrack 4-5. Integration of Concrete Pavement Surface Characteristics
Subtrack 4-6. Evaluation of Products for Concrete Pavement Surface Characteristics
Subtrack 4-7. Concrete Pavement Surface Characteristics Implementation

Track 5. Concrete Pavement Equipment Automation and Advancements
Subtrack 5-1. Concrete Batching and Mixing Equipment
Subtrack 5-2. Concrete Placement Equipment
Subtrack 5-3. Concrete Pavement Curing, Texturing, and Jointing Equipment
Subtrack 5-4. Concrete Pavement Foundation Equipment
Subtrack 5-5. Concrete Pavement Reconstruction Equipment
Subtrack 5-6. Concrete Pavement Restoration Equipment
Subtrack 5-7. Advanced Equipment Evaluation and Implementation

Track 6. Innovative Concrete Pavement Joint Design, Materials, and Construction
Subtrack 6-1. Joint Design Innovations
Subtrack 6-2. Joint Materials, Construction, Evaluation, and Rehabilitation Innovations
Subtrack 6-3. Innovative Joints Implementation

Track 7. Concrete Pavement Maintenance and Preservation
Subtrack 7-1. Optimization and Automation of Pavement Maintenance
Subtrack 7-2. Optimized Concrete Pavement Preservation
Subtrack 7-3. Distress Identification and Preservation Treatment
Subtrack 7-4. Feedback Loop for Concrete Pavement Preservation Effectiveness

Track 8. Concrete Pavement Construction, Reconstruction, and Overlays
Subtrack 8-1. Construction, Reconstruction, and Overlay Planning and Simulation
Subtrack 8-2. Precast and Modular Concrete Pavements
Subtrack 8-3. Concrete Overlays
Subtrack 8-4. Fast-Track Concrete Pavements
Subtrack 8-5. Construction, Reconstruction, and Overlay Evaluation and Implementation

Original Track/Subtrack Structure

Track 9. Concrete Pavement Accelerated and Long-Term Data Collection (DC)
Subtrack DC 1. Planning and Design of Accelerated Loading and Long-Term Data Collection
Subtrack DC 2. Preparation of Data Collection/Testing Procedures and Construction of Test Road
Subtrack DC 3. Accelerated Loading and Long-Term Data Collection Implementation

Track 10. Concrete Pavement Performance (PP)
Subtrack PP 1. Technologies for Determining Concrete Pavement Performance
Subtrack PP 2. Guidelines and Protocols for Concrete Pavement Performance

Track 11. Concrete Pavement Business Systems and Economics (BE)
Subtrack BE 1. Concrete Pavement Research and Technology Management and Implementation
Subtrack BE 2. Concrete Pavement Economics and Life Cycle Costs
Subtrack BE 3. Contracting and Incentives for Concrete Pavement Work
Subtrack BE 4. Technology Transfer and Publications for Concrete Pavement Best Practices
Subtrack BE 5. Concrete Pavement Decisions with Environmental Impact

Track 12. Advanced Concrete Pavement Materials (AM)
Subtrack AM 1. Performance-Enhancing Concrete Pavement Materials
Subtrack AM 2. Construction-Enhancing Concrete Pavement Materials
Subtrack AM 3. Environment-Enhancing Concrete Pavement Materials

Track 13. Concrete Pavement Sustainability

New Track/Subtrack Structure

Track 9. Long-Life Concrete Pavement Performance through Evaluation and Monitoring
Subtrack 9-1. Technologies for Determining Concrete Pavement Performance
Subtrack 9-2. Pavement Strategy for Long-Life Concrete Pavements
Subtrack 9-3. Construction and Materials for Long-Life Concrete Pavements and Overlays
Subtrack 9-4. Planning and Design of Accelerated Loading and Long-Term Data Collection
Subtrack 9-5. Preparation of Data Collection/Testing Procedures and Construction of Test Road
Subtrack 9-6. Long-Life Concrete Pavement Performance Implementation

Track 10. Concrete Pavement Foundations and Drainage
Subtrack 10-1. Concrete Pavement Foundations
Subtrack 10-2. Concrete Pavement Drainage

Track 11. Concrete Pavement Economics and Business Management
Subtrack 11-1. Concrete Pavement Research and Technology Management and Implementation
Subtrack 11-2. Concrete Pavement Economics and Life Cycle Costs
Subtrack 11-3. Contracting and Incentives for Concrete Pavement Work
Subtrack 11-4. Technology Transfer and Publications for Concrete Pavement Best Practices

Track 12. Concrete Pavement Sustainability
Subtrack 12-1. Materials and Mixture Design Procedures for Sustainable Concrete Pavement
Subtrack 12-2. Design Procedures for Sustainable Concrete Pavements
Subtrack 12-3. Construction Practices for Sustainable Concrete Pavements
Subtrack 12-4. Preservation, Rehabilitation and Recycling Strategies for Sustainable Concrete Pavements
Subtrack 12-5. Improved Economic Life Cycle Cost Analysis for Sustainable Concrete Pavements
Subtrack 12-6. Adoption and Implementation of Environmental Life Cycle Assessment for Sustainable Concrete Pavements
Subtrack 12-7. Identification and Quantification of Additional Environmental and Social Considerations for Sustainable Concrete Pavements
Subtrack 12-8. Concrete Pavement Decisions with Positive Environmental Impact
Subtrack 12-9. Sustainable Concrete Pavement Technology Transfer and Implementation

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