Framing Report for Track 1 of the CP Road Map
Mix Design and Analysis

Background

The FHWA, in cooperation with Iowa State University (ISU) and the American Concrete Pavement Association (ACPA), developed the Concrete Pavement Road Map, which outlines a collaborative approach to strategic concrete pavement research and technology transfer for the future. The CP Road Map development process relied heavily on input from the stakeholder community. The CP Road Map Operations Group, a team assembled by Iowa State University's National Concrete Pavement Technology Center (CP Tech Center) under contract to the FHWA, is working with industry and government partners to get the CP Road Map off the ground.

Mix Design and Analysis (MDA), the first of 12 research tracks defined under the CP Road Map, has been identified as one of four initial priority tracks by the CP Road Map Executive Committee. Several initial priority projects have been identified, and a scope of work developed, to meet the early objectives of the MDA Track. Specifically, these initial projects will quickly move the state of the art of mix design into the state of the practice.

This framing document briefly describes the purpose and history of the MDA Track and the impact of recent events and accomplishments on the research and priorities outlined in the track. This will be a living document, revised regularly by the Operations Group as research gaps are filled, priorities readjusted, and new needs identified.

The MDA Track is critical for several reasons. Concrete is a complex material. A decision by the design engineer may require changes to the materials specification. Selection of a particular material may change the maintenance needs of the pavement. All parties in the mix design process need to understand how their actions will affect the whole system, and by how much.

Another issue is that development of materials and mixture specifications is currently based on failure. Something goes wrong with a project, so the engineer tweaks the spec to prevent a repeat of the problem. This approach often attacks the symptom, not the cause of the problem, and can actually initiate or exacerbate other problems.

Another reason that this topic requires attention is that sustainability can no longer be ignored. The need to develop sustainable pavement systems is forcing us to change our approaches to some decisions. When considering project optimization, we have to include not only financial cost but environmental load. We can no longer insist on the best possible materials; we are running out of them. Instead we have to decide the limits of acceptability for locally available and recycled materials.

The complexity of the problem is compounded by the fact that many ingredients in concrete are changing as cost or environmental constraints are imposed on the manufacturers. As a result, some commonly used rules of thumbs may no longer be valid.

MDA Track Mission Statement

The aim of the Mix Design and Analysis Track of the CP Road Map is to develop and deliver integrated tools and techniques that will make it possible to specify, proportion, and construct concrete mixtures that meet the combined needs of owners and contractors for constructible, long lasting, sustainable, cost efficient, and verifiable concrete mixtures for pavements.

Current Gaps in Mix Design and Analysis

In October 2006, more than fifty representatives of agency, industry, and university members of the concrete pavement construction industry met for a day and a half at Turner-Fairbank Highway Research Center (TFHRC). Anticipating the startup of the CP Road Map MDA Track, participants discussed the needs of the industry with respect to mix design and proportioning. They validated the research needs, or gaps, outlined in the MDA Track. The wide variety of opinions expressed at that meeting can be summarized in four categories:

- **Tests**. There is an over-arching need for cost effective, fast, reliable tests that measure the properties we are really interested in, both for incoming materials and for the mix itself. Some are for QC (contractor internal work) and some are for QA (client acceptance) as discussed below. We therefore have to establish the parameters that define acceptable performance, and develop tests to measure them.
  - The first family of tests needed includes those that assess the acceptability of a given material. Many of these are currently used based on existing ASTM and AASHTO methods. However, some parameters are still not resolved such as methods to assess alkali reactivity of aggregates, in which the most reliable test takes up to 2 years to run, while the rapid 2 week test is reportedly unreliable about half of the time.
  - Tests are needed to monitor the variability of materials coming into a mixture, so that adjustments can be made on the fly to ensure that the delivered mixture is uniform and appropriate for the conditions in which it is being used.
  - The other tests required are those that assess the quality and / or performance of the mixture as it is placed. Tied to this is the need for appropriate limits that allow unambiguous decisions to be made regarding the acceptability of a given material or mixture. Without these tests, it is impossible to develop good performance based specifications, because it is impossible to measure the concrete performance.

  Other points to note include that:
  - Critical, high priority parameters needing attention include verification of materials or mixtures, workability, durability and shrinkage.
  - Such parameters and tests should be appropriate for adoption in incentive payment systems.
  - Measurements must be able to be conducted in real time so that contractors can make adjustments on the fly.
  - Specifications must allow some flexibility to ensure that that the needed adjustments are not forbidden.
  - Approaches are needed to measure and allow for variability in the mix ingredients. Definitions are needed that define when a variation is significant enough to require re-approval.
  - A better understanding is needed about limitations and applications of recycled materials including concrete as aggregate and recycled water.

- Approaches that should be considered include:
  - Embedded sensors that can track system chemistry
  - Embedded sensors that can assess the quality of the air-void system
  - An instrumented vibrator that reports the rheological properties of a mix

- **Models**. Tied to the needs for tests is a need to correlate test results with long term performance of a concrete system. At present we lack the tools to be able to predict the potential life of a pavement based on accelerated or early age performance data.
  - Other models needed include development of more robust predications of fresh concrete properties based on the properties, proportions and interactions of the ingredients. This is especially evidenced in the current approaches taken to addressing interactions between ingredients. It is known that class F fly ash may improve alkali silica reaction expansion, but this can only be quantified using slow or imprecise tests. At the same time the use of the ash will likely retard setting and early strength gain, thereby increasing the risk of plastic cracking. The decision then of "how much fly ash" is based on empirical estimates.
  - Specifiers and plant operators need effective guidelines on the effects and side effects that may be expected if they change the source, type or dosage of a given material.

- **Specifications**. Current contracts are built around lowest cost, therefore innovations impose high risk to the specifier and to the contractor. It is more conservative to continue with business as usual.
  - Prescriptive practices also allow little flexibility to accommodate variation in materials or environment, potentially leading to distress or unacceptable variation in the finished pavement.
  - The aim of a good specification is to ensure that the owner is given the highest probability of getting what they pay for, while affording suppliers and contractors a reasonable opportunity to optimize their decisions.
  - As specifications become more performance based, there is a need for a guidelines addressing who should make what decisions – for instance, should designers specify slump when they do not know what equipment the contractor will use, and what slumps will be optimum for that equipment?

- **Communication.** When changing the rules, we have to prove that they work and teach the people involved what the new rules are and how to use them.
  - The need for education is growing because cement based systems are becoming increasingly complex with multiple admixtures and supplementary cementitious materials in most concrete mixtures made today. This is coupled with increasingly stringent demands being placed on the mixtures as budgets and time constraints become tighter.
  - The potential for problems is exacerbated as staffing levels are being reduced, leaving relatively inexperienced personnel being required to make decisions beyond their experience or training.

This meeting helped identify initial priority activities for the MDA Track, while clarifying the need for the MDA Track to be updated and "reframed" in light of newly completed and current research. See figure 1. It also led to the development of a track administrative structure.

Recently Completed Work

Several significant research projects have been completed since the TFHRC meeting. These include the following:

- Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements (MCO). This Iowa DOT led Pooled Fund project has developed a Testing Guide that recommends a graduated series of tests based on the type of road being constructed. The tests are intended to be used by contractors to monitor materials and reduce variability in the concrete mixture.

- Identifying Incompatible Combinations of Concrete Materials. The project funded by FHWA developed a protocol on tools to identify whether materials within a given mixture were likely to interact causing unacceptable performance of the mixture.

- Concrete Mixture Performance Analysis System (COMPASS) is a Windows-based application aimed at optimized paving mixtures based on materials characteristics selected to achieve desired mixture performance.

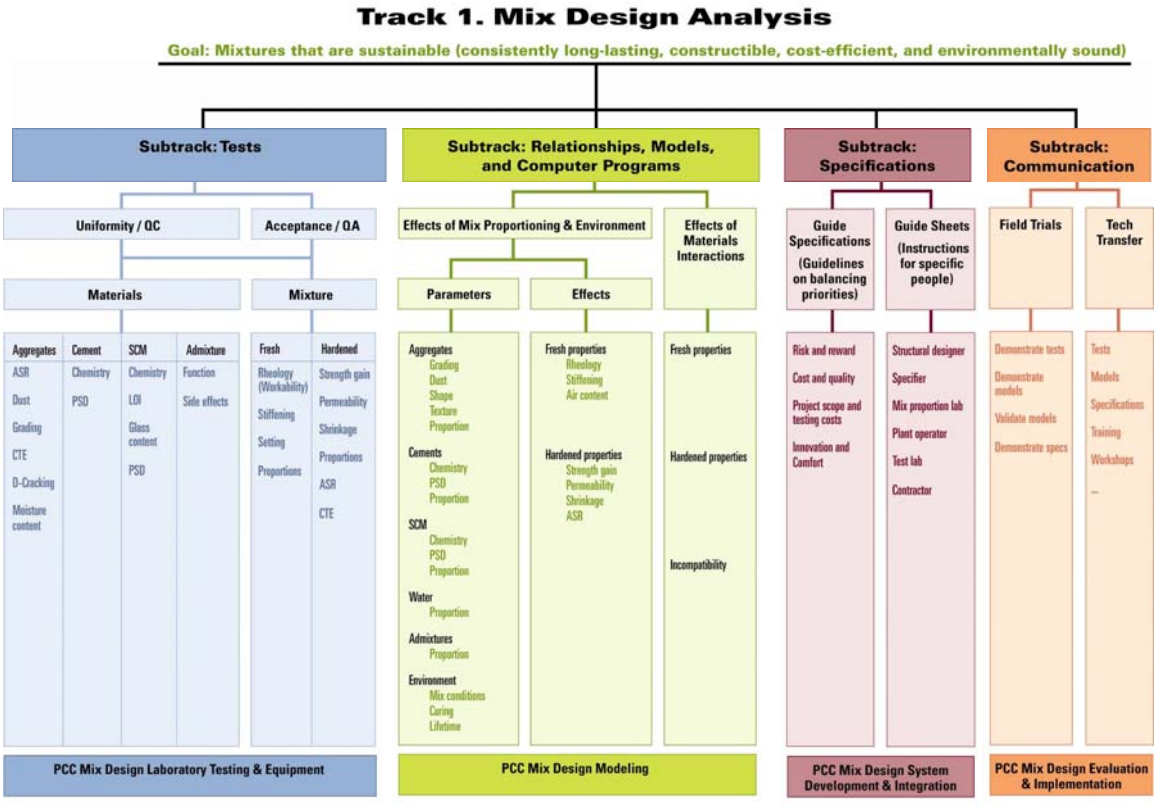

Figure 1. Updated Framework of MDA Track Research Needs

- The Integrated Materials and Construction Practices for Concrete Pavement (IMCP) Manual provides broad information on the effects of materials properties and proportions on concrete performance.

- A Guide Specification for airfield pavements has been prepared in a project funded by IPRF.

Ongoing Work

Several projects are currently underway that address some of the needs described above:

- FHWA is currently funding a significant, multi-year project with the aim of implementing best practices with respect to preventing and mitigating alkali silica reaction.

- FHWA has also recently released a request for proposals for innovative methods to analyze and test for alkali reactivity of concrete mixtures and to develop mitigation methods.

- Indiana DOT is leading a new Pooled Fund that is aimed at finding a reliable method of assessing the permeability of pavement concrete.

- NCHRP is funding a project aimed at better understanding the effects of currently available fly ash on concrete mixtures, including improved tools to characterize and specify the material.

- IPRF is funding work on investigating the effects of deicing salts on concrete pavements for airfields.

- South Dakota is the lead state in a Pooled Fund project investigating the effects of magnesium chloride on concrete This project is nearing completion.

- A project is underway aimed at developing guidelines for using ternary mixtures in concrete. Phase 1 work based on tests on pastes and mortars is complete, and was funded by a Pooled Fund led by Iowa. Phase 2 is starting under the sponsorship of FHWA.

- A project funded by an Iowa led Pooled Fund is investigating field temperature monitoring devices for assessing setting times and potential incompatibility / variability is nearing completion.

Planned Work

From the updated framework of research needs (figure 1), a number of specifically defined, high-priority tasks have been identified for immediate action. Some of the work will be conducted under a pooled fund currently being established. Other work is being conducted by agencies using their own funding sources. As additional organizations collaborate with the Track Leadership Team, their projects and the gaps they fill can be identified. The priority projects include the following:

Pooled Fund

An FHWA pooled fund led by Iowa is being set up to address specific needs within each of the four categories described above that summarize ideas from several Technology Transfer Concrete Consortium (TTCC) meetings:

- **Tests.** The following tests may be considered to be in three different states of development: 1) Nearing implementation, 2) Under development, and 3) Conceptual. The actions needed for each test will vary and are described as appropriate for each test.
  - Rheology test. The slump test is currently the standard approach to determining workability of a mixture. However it is not always valid for use in mixtures needed for slipform paving, and it does not describe the parameters needed to be known by paver operators. There is a need to develop a simple field test for measuring how much a paving mixture will move when vibrated (viscosity) and whether it will be prone to edge slump (yield stress). Some work has been conducted in this field in the past with limited success. A pilot investigation into alternative approaches to this issue is needed. It is planned that the results of the test will allow for a more definitive description of the workability of a mixture.
  - AVA. The air void analyzer is a device intended to provide on-site evaluation of the air void system in fresh concrete. Work is being conducted by a number of researchers to evaluate the device and to develop guidelines on its use. The findings of these researchers need to be gathered and interpreted, and a formal method statement needs to be developed for submission to AASHTO and ASTM.
  - If performance based specifications are to become more acceptable, there is a need to be able to verify that a mixture delivered to a given site contains the correct materials in the given proportions used in the verification testing during design stage. At present there is no good way to do this, but the topic is worth investigating.
  - If the AVA does not prove to be useful, consideration should be given to investigating alternative methods of assessing the air void system in fresh concrete.
  - Foam index test. Several versions of this test are used by fly ash producers and purchasers as a quality control tool. There is a need for this test to be standardized and submitted to AASHTO and ASTM.

Other tests that need to be further investigated include:

- Coefficient of Thermal Expansion (CTE), is a measure of the change in dimension of a concrete sample due to changes in temperature. The parameter has a direct impact on the risk of temperature related cracking in newly placed concrete pavements. A test has been developed at FHWA and needs to be field tested and validated, and a formal method statement needs to be developed for submission to AASHTO and ASTM.
- Field Temperature Monitoring. Monitoring the rise in temperature due to hydration of a fresh mixture provides a tool to assess the uniformity between material and concrete batches, as well as indicating setting times useful for saw-cutting operations. A project is nearing completion investigating the various devices available including some field tests. A formal method statement needs to be developed for submission to AASHTO and ASTM.
- Permeability. European specifications are using a permeability test developed by Torrent. There is a need to investigate the applicability of this test to US pavement construction.

Recommendations have also been made to use the ASTM C 642 boiled water test as a simple measure of potential durability. This test has been the subject of a brief investigation in Minnesota. The test warrants further investigation. Work under this task will be coordinated with the Indiana Pooled Fund Permeability work.

- **Models.** The models discussed below include tools or methods to correlate different parameters, and to help users select appropriate materials and proportions.
  - Seminal work conducted by Klieger in the 50's on which we base our current limits on air content and air void system parameters was conducted using no supplementary cementitious systems and a single type of air entraining admixture. Some of the recommendations of this work need to be verified as still appropriate for current cements, SCM's and air entraining admixtures, all of which have changed significantly over time.
  - There is a need to correlate paste content with mixture shrinkage and cracking risk, for all types of binders
  - There is a need to set out standard information to be recorded and stored at the time of construction so that in later years, the performance of pavements can be compared with the construction data, thus allowing development of durability models based on field performance rather than extrapolation of laboratory data.

Other models that need to be further investigated include:
  - Interaction Hyperdoc – it is planned to develop an interactive electronic document based on the IMCP that will enable users to observe the effects that their decisions on materials type and dosage will have on properties of the concrete.
  - Current specifications impose limits on minimum working temperatures for concrete pavements. The validity of these limits needs to be verified.
  - Current tools used to asses the combined aggregate grading are empirical in nature, and are difficult to impose specified requirements around. It is accepted that while a good combined grading increases the probability of an acceptable mixture, it is still possible to make good concrete pavement with a poor grading and bad pavement with good grading. This topic needs further investigation.

- **Specifications.** Changes and innovations to the way we do things can only be achieved within the context of specifications. It is therefore critical that appropriate specifications be developed and implemented.
  - A guide specification and commentary will be prepared that lays out current state of the art thinking with respect to materials and mixture selection, proportioning and acceptance. This document will take into account the different environments, practices and materials in use across the US, and will allow optional inputs for local application. The specification will be developed based on existing documents including the recent IPRF Draft P501.
  - As a supplement to the IMCP Manual, it is planned to develop check-sheets for different parties involved in the development of a mix design. They will help inexperienced practitioners make appropriate selections for the tasks they are conducting (e.g. preparing a specification or selecting aggregates). It is also intended that decisions are made at the correct location (e.g. slump is selected by the contractor rather than the specifier).

- **Communication.** An integral part of any significant change to the methods or process of mix design is education. Users from all parties have to be made familiar with what has changed, why it was necessary, and how it affects they way they do things.
  - Field trials to demonstrate and validate new tests
  - Field trials to demonstrate and validate new models
  - Field trials to demonstrate and validate new specifications
  - Training materials as needed

Other Planned Projects

Two other projects are currently planned as early activities under the MDA Track:

One is the development of a publication entitled *Design and Control of Concrete Pavement Mixtures*" This will be prepared by PCA and ACPA staff using their own funding. It will be based on current state of the practice technology and will be similar in style and content to the PCA's "Design and Control of Concrete Mixtures". It will be reviewed by a panel of representatives from owners, engineers, materials suppliers, and contractors.

A project is one being conducted by FHWA to coordinate the various software packages that they already have had developed. These include COMPASS, HIPERPAV, and COST.

Stakeholders and Partners

At present, the following organizations have expressed interest in committing to the activities of this track:

- Several states have indicated that they will contribute to the Iowa-led pooled fund described above. A work statement is in the last stages of preparation for this fund.
- Cement industry through PCA
- ACPA
- FHWA

MDA Track Administration

- A Track Leadership Team has been established comprising the following:
  - Richard Meininger – FHWA
  - John Staton – MI DOT
  - Leif Wathne – ACPA
- A Technical Advisory Committee for the MDA Track was selected. The committee is comprised of 15 people representing federal, state, and industry interests as noted below:

Contractors:	Hamad, Farid	FKHamad@laneconstruct.com
	Capon, Pete	PCapon@Rieth-Riley.com
	Brown, Mark	brownm@zachry.com
Suppliers:	Descheneaux, Barry	barry.descheneaux@holcim.com
	Taubert, Don	dtaubert@capitolcement.com
	Lobo, Colin	clobo@nrmca.org

Academia/Consulting:	VanDam, Tom	tvandam@mtu.edu
	Shilstone, Jay	jay2003.shilstone@shilstone.com
DOT:	Lukefahr, Lisa	elukefa@dot.state.tx.us
	Staton, John	statonj@michigan.gov
	Hanson, Todd	todd.hanson@dot.iowa.gov
FHWA:	Tyson, Sam	sam.tyson@fhwa.dot.gov
	Meininger, Rick	Richard.Meininger@fhwa.dot.gov
	Correa, Angel	angel.correa@fhwa.dot.gov
Team:	Kosmatka, Steve	skosmatka@cement.org
	Voigt, Jerry	GVoigt@pavement.com
	Wilson, Michelle	mwilson@cement.org
	Wathne, Leif	lwathne@pavement.com
	Taylor, Peter	ptaylor@iastate.edu
	Hover, Ken	kch7@cornell.edu

- The Iowa-led Pooled Fund will also appoint its own TAC representing those states that contribute to the fund.

The goal of the Track Leadership Team is to provide an environment that fosters

- Collaboration between
  - Funding agencies to ensure that research money is leveraged to deliver as much useful information as possible at minimum cost
  - Researchers to unite their resources and abilities to the same end
- Coordination, so that
  - Work is not repeated unnecessarily
  - Efforts are focused appropriately
- Implementation so that
  - The results of the work can be made public
  - Opportunities are provided to test developments in the field
  - Acceptance in regulatory bodies is facilitated
  - Effective use of new, proven, tools is encouraged into the future.