# Long-Term Pavement Performance Warm-Mix Asphalt Study, Volume I: Final Report

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U.S. Department of Transportation
**Federal Highway Administration**

Research, Development, and Technology
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LTPP™

# FOREWORD

Warm-mix asphalt (WMA), an innovative material that is part of the Federal Highway Administration Every Day Counts program, has been implemented by State highway agencies throughout the United States. WMA covers a variety of categories, each designed to allow for production and compaction of asphalt concrete at temperatures lower than conventional hot-mix asphalt (HMA).

Recognizing that a knowledge gap exists in the comparison of WMA and HMA over the performance life of each type of pavement, the Long-Term Pavement Performance (LTPP) program initiated this project to design a national experiment to study the performance of WMA relative to HMA. New test sections were recruited into the LTPP program under the designation of the Specific Pavement Studies (SPS)-10 experiment called "Warm Mix Asphalt Overlay of Asphalt Pavement."

The purpose of this volume of the report series is to document the overall conduct of the project with a focus on the guidelines for recruitment, selection, implementation, construction, sampling, testing, and monitoring for the SPS-10 experiment for the LTPP program. This experiment is designed to capture information on the short- and long-term performance of WMA relative to HMA. This experiment has been structured to ensure consistency and compatibility with the existing LTPP program objectives and database while addressing information gaps regarding WMA performance. The intent of the SPS-10 experiment is to capture not only field performance but also laboratory test data that will provide both user-agencies and researchers a better understanding of the potential benefits of WMA. Collectively, this information could be used for performance prediction.

Mark Swanlund
Acting Director, Office of Infrastructure
Research and Development

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16. Abstract

This report documents all activities performed as part of the Long-Term Pavement Performance (LTPP) program's Warm-Mix Asphalt (WMA) Study. The report describes the overall conduct of the project with a focus on the guidelines for recruitment, selection, implementation, construction, sampling, testing, and monitoring of the LTPP Specific Pavement Studies (SPS)-10 "WMA Overlay of Asphalt Pavement" experiment. This experiment was designed to compare the performance of WMA to current hot-mix asphalt pavements and is the first new SPS experiment within the LTPP program since the mid-1990s. Also included in the report are the recommended changes to existing LTPP experiments and practices to more fully incorporate WMA test sections.

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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 1,000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2,000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C |
| | | **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 (2,000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/m2 | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 2.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

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

**LONG-TERM PAVEMENT PERFORMANCE WARM-MIX ASPHALT STUDY PROJECT REPORT SERIES**

This volume is the first of six volumes in this research report series. Volume I is the final report, and volume II through volume VI contain detailed information about the design and operations of the experiment. The following list contains the volumes of this series:

| Volume | Title | Report Number |
|---|---|---|
| I | Long-Term Pavement Performance Warm-Mix Asphalt Study, Volume I: Final Report | FHWA-HRT-22-018 |
| II | Long-Term Pavement Performance Warm-Mix Asphalt Study Final Report, Volume II: SPS-10 Experimental Matrix and Research Plan | FHWA-HRT-22-019 |
| III | Long-Term Pavement Performance Warm-Mix Asphalt Study Final Report, Volume III: SPS-10 Nomination Guidelines | FHWA-HRT-22-020 |
| IV | Long-Term Pavement Performance Warm-Mix Asphalt Study Final Report, Volume IV: SPS-10 Materials Sampling and Testing Requirements | FHWA-HRT-22-021 |
| V | Long-Term Pavement Performance Warm-Mix Asphalt Study Final Report, Volume V: SPS-10 Performance Monitoring Guide | FHWA-HRT-22-022 |
| VI | Long-Term Pavement Performance Warm-Mix Asphalt Study Final Report, Volume VI: SPS-10 Construction Documentation Guide | FHWA-HRT-22-023 |

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| | |
|---|---|
| AASHTO | American Association of Highway and Transportation Officials |
| AC | asphalt concrete |
| AMPT | asphalt mixture performance tester |
| AVC | automated vehicle classification |
| AWS | automated weather station |
| BBR | bending beam rheometer |
| DC(T) | disk-shaped compact tension |
| DSR | dynamic shear rheometer |
| DT | direct tension |
| ETG | expert task group |
| FHWA | Federal Highway Administration |
| FWD | falling weight deflectometer |
| GPS | General Pavement Study |
| HMA | hot-mix asphalt |
| HWTD | Hamburg Wheel-Tracking Device |
| IDT | indirect tensile |
| IMS | Information Management System |
| LDEP | LTPP Data Entry Portal |
| LTPP | Long-Term Pavement Performance |
| MAP | materials action plan |
| MEPDG | Mechanistic-Empirical Pavement Design Guide |
| MRL | Materials Reference Library |
| MSCR | multiple stress creep recovery |
| MTS | Materials Tracking System |
| NCHRP | National Cooperative Highway Research Program |
| NCSU | North Carolina State University |
| PAV | pressure aging vessel |
| PCC | portland cement concrete |
| PPDB | pavement performance database |
| QA | quality assurance |
| QC | quality control |
| RAP | recycled asphalt pavement |
| RAS | recycled asphalt shingle |
| RSC | regional support contractor |
| RTFO | rolling thin film oven |
| SCB | semi-circular beam |
| SHA | State highway agency |
| SHRP | Strategic Highway Research Program |
| SPS | Specific Pavement Studies |
| S-VECD | simplified viscoelastic continuum damage |
| TFHRC | Turner-Fairbank Highway Research Center |
| TSS | triaxial stress-sweep |
| TSSC | technical support services contractor |

| | |
|---|---|
| VWS | virtual weather station |
| WIM | weigh-in-motion |
| WMA | warm-mix asphalt |

# EXECUTIVE SUMMARY

Warm-mix asphalt (WMA) is an innovative material that is part of the Federal Highway Administration (FHWA) Every Day Counts program, which State highway agencies have implemented throughout the United States. WMA covers a variety of categories, each designed to allow for the production and compaction of asphalt concrete (AC) at temperatures lower than those used for conventional hot-mix asphalt (HMA).

Recognizing that a knowledge gap exists in the comparison of WMA and HMA over the performance life of each type of pavement, the Long-Term Pavement Performance (LTPP) program initiated this research to design a national experiment to evaluate the performance of WMA relative to HMA. New test sections were recruited into the LTPP program under the designation of Specific Pavement Studies (SPS)-10 experiment, "Warm Mix Asphalt Overlay of Asphalt Pavement."

The work completed under this project falls within the following tasks:

- Establishing an expert task group (ETG).
- Experiment design.
- Materials sampling and testing.
- Performance monitoring.
- Construction documentation.
- Other data collection.
- Marketing and technical support.

The research team, working with FHWA, recruited ETG members from a representative cross-section of agency, industry, and academia. A group of eight members was established, with one of the members choosing not to have voting rights because of his affiliation with FHWA. This group reviewed materials describing the proposed project activities and provided valuable feedback both electronically and in three ETG meetings—one face-to-face meeting and two webinars. ETG input was used to develop and finalize the documentation provided in this report.

In designing the SPS-10 experiment, the research team, with concurrence from FHWA and the ETC, selected a set of primary factors. These factors included the type of WMA technology used, the climatic elements of temperature and moisture, and the traffic loading. Table 1 provides the final number of projects versus experimental factors of the SPS-10 experiment.

Additionally, other aspects were controlled in the experiment by establishing criteria for the projects. For example, only AC overlays of existing pavements are candidates for the SPS-10 experiment. Every SPS-10 project will include an HMA control section and two different WMA categories (foaming process and chemical additive). Should an agency wish to consider additional features, they would be handled as supplemental test sections that LTPP has committed to document and monitor. Complete documentation on the experimental design, research plan, site requirements, and project nomination process is provided in this report and its associated volumes.

**Table 1. SPS-10 number of test sections versus experimental factors.**

| Moisture | Temperature | Traffic | Number of Projects |
|---|---|---|---|
| Wet | Freeze | High | 2 |
| Wet | Freeze | Low | 2 |
| Wet | No freeze | High | 2 |
| Wet | No freeze | Low | 2 |
| Dry | Freeze | High | 2 |
| Dry | Freeze | Low | 2 |
| Dry | No freeze | High | 2 |
| Dry | No freeze | Low | 2 |

Note: Projects consist of an HMA control section and two different WMA categories (foaming process and chemical additive).

Designing the materials sampling and testing plan involved both understanding existing LTPP sampling and testing procedures and collecting information on new and emerging test procedures. Many laboratory tests involve reheating mixture samples, which has the potential to change WMA mix properties; therefore, every attempt was made to identify tests that could be performed on field cores. Testing on field cores also permits examination of changes over time in the WMA and HMA mixes.

Laboratory test procedures for pavement materials have evolved dramatically since the inception of the LTPP program. Therefore, the research team evaluated many new materials testing protocols and worked with the ETG to develop priority-based ranking recommendations on various materials testing protocols. The FHWA LTPP used these recommendations in selecting which new testing protocols should be included in the SPS-10 project. The team developed the materials sampling and testing guidelines, materials tracking system, and the new LTPP testing protocols based on the tests selected by FHWA.

In addition, the research team worked with the ETG and the FHWA team to develop performance monitoring guidelines for the SPS-10 experiment, including nondestructive testing to be performed over the life of the pavements. The research team also established construction documentation requirements, which involved developing formats for construction reports as well as a complete set of construction forms that capture all the relevant information related to the SPS-10 projects. Other data collection needs were also evaluated and captured in this project. Lastly, the team provided marketing and technical support during the project.

# CHAPTER 1. INTRODUCTION

The Long-Term Pavement Performance (LTPP) warm-mix asphalt (WMA) experiment was initiated to develop a platform for long-term monitoring of WMA field sections. The experiment's objective is to evaluate the long-term performance of WMA. This experiment is designed to capture information on the performance of WMA, in both the short and the long term, and to provide the ability to directly compare its performance to that of hot-mix asphalt (HMA), thereby evaluating any differences in relative performance between WMA and HMA. For consistency purposes, the experiment design developed under this research accounts for the existing contents and structure of the LTPP database while specifically addressing the current information gaps regarding WMA performance. The experiment will allow field performance to be captured over the long term while providing data from laboratory testing of WMA materials for use by researchers looking to evaluate various features of WMA. Collectively, this information could be used to make performance predictions by linking material properties to field performance.

The overall purpose of this experiment is to capture the long-term performance of WMA in a way that allows direct comparison to the performance of HMA. More specifically, the objectives of this research are as follows:

- Establish a comprehensive experimental design matrix to account for key factors relevant to WMA performance and capture the range of conditions present across the United States and Canada.
- Assemble recommendations on the materials sampling and testing required to adequately characterize material properties within the test section layer structure.
- Develop guidelines for documenting activities during construction.
- Create performance monitoring requirements for surface distress, falling weight deflectometer (FWD) measurements, and transverse and longitudinal profile data.
- Identify additional data collection requirements that would be beneficial to the pavement community.

The research consists of developing documentation that describes and governs the processes necessary to solicit, construct, test, and monitor field sections for the LTPP WMA experiment. Documentation development is split into a series of tasks, as follows:

1. Expert task group (ETG).
2. Experiment design.
3. Materials testing plan.
4. Performance monitoring.
5. Construction requirements.
6. Other data collection needs.
7. Marketing and technical support.

The first three tasks were performed as part of phase I, whereas the remaining tasks were done in phase II. This document describes the approaches and outcomes of these tasks. This report also provides the guidelines and manuals that were developed as a result of this project. These guidelines and manuals were developed as stand-alone documents and were distributed internally to the Federal Highway Administration (FHWA) team during the research so that recruitment and nomination of the Specific Pavement Studies (SPS)-10 could begin before completion of this research. The stand-alone guidelines have been included in associated volumes of this report and are described at the end of this chapter.

## LTPP BACKGROUND

In 1985, the Strategic Highway Research Program (SHRP) Pavement Performance Advisory Committee established the following six objectives as a basis for developing the LTPP program:

1. Evaluate existing design methods.
2. Develop improved design methods and strategies for pavement rehabilitation.
3. Develop improved design equations for new and reconstructed pavements.
4. Determine the effects of loading, environment, material properties and variability, construction quality, and maintenance levels on pavement distress and performance.
5. Determine the effects of specific design features on pavement performance.
6. Establish a national long-term pavement database to support SHRP objectives and future needs.

Several LTPP experiments were established to meet these objectives.

The following General Pavement Studies (GPS) experiments were established:

- GPS-1: Asphalt Concrete (AC) on Granular Base.
- GPS-2: AC on Bound Base.
- GPS-3: Jointed Plain Concrete Pavement.
- GPS-4: Jointed Reinforced Concrete Pavement.
- GPS-5: Continuously Reinforced Concrete Pavement.
- GPS-6: AC Overlay of AC Pavement.
- GPS-7: AC Overlay of Portland Cement Concrete (PCC).
- GPS-9: Unbonded PCC Overlays on PCC Pavements.

The following Specific Pavement Studies (SPS) experiments were established:

- SPS-1: Strategic Study of Structural Factors for Flexible Pavements.
- SPS-2: Strategic Study of Structural Factors for Rigid Pavements.
- SPS-3: Preventive Maintenance Effectiveness of Flexible Pavements.
- SPS-4: Preventive Maintenance Effectiveness of Rigid Pavements.

- SPS 5: Rehabilitation of AC Pavements.
- SPS-6: Rehabilitation of Jointed PCC Pavements.
- SPS-7: Bonded PCC Overlays on Concrete Pavements.
- SPS-8: Study of Environmental Effects in the Absence of Heavy Loads.
- SPS-9: Validation of SHRP Asphalt Specification and Mix Design (Superpave).

Note that GPS-6 and -7 were originally developed to study existing overlays where there was no information on the condition of the pavement before the overlay was placed. When pavements already in the GPS-1, -2, -3, -4, and -5 and SPS-1, -2, -5, -6, -7, -8, and -9 experiments were overlaid, they were eligible to be shifted to GPS-6 and -7 experiments where the condition of the existing pavement was known. These sections were denoted as GPS-6* or 7* (where the * could be many different letters depending on the type of mix and rehabilitation approach taken at each section).

Limitations to the GPS experiments should also be noted. The primary limitation is that the data collection is usually less rigorous than that in the SPS experiments, and changes in mix types or process are not usually addressed. In addition, the GPS experiments tend to have more variability. The SPS experiments were established to perform controlled comparative studies on different pavement features within one project location and so have a better structure for the controlled comparison of different warm mix technologies, which was identified as one of SHRP's six objectives.

The existing SPS experiments are not sufficiently adaptable for use in studying warm mix technology. SPS-9 comes close, but it was not structured to study different mix technologies, just to compare Superpave mix designs and specifications to a State or provincial highway agency's current practice. A new SPS experiment was warranted to study a number of warm mix technologies in some detail.

## WMA BACKGROUND

WMA pavements were first constructed in Europe in 1997. The European experience has been documented in *Warm-Mix Asphalt: European Practice* (D'Angelo et al. 2008). The results captured in that report were promising, but several challenges still needed to be addressed, including the long-term performance. Because of the potential benefits of WMA (e.g., as a compaction aid, to extend the paving season, to increase haul distance, and to reduce fuel consumption and emissions), construction of WMA in the United States has increased exponentially. The first field trials in the United States were constructed in North Carolina and Florida in 2004 (Prowell and Hurley 2008). By 2008, 32 States had conducted WMA field trials (Prowell, Hurley, and Frank 2012). Interest in WMA has continued to gain momentum, and in 2011, 30 States had specifications for WMA construction. In addition, the amount of WMA used in 2010 increased by 175 percent over that used in 2009 and accounted for 13 percent of total asphalt production.

Currently, more than 35 WMA technologies are offered in the U.S. market, each of which is designed to alter the properties of the asphalt binder to allow for improved aggregate coating and compaction efficiencies at lower production and compaction temperatures than conventional

HMA (Corrigan 2011). The technologies currently available can be grouped into the following four categories (some technologies are a combination of the following categories):

- Foaming additive.
- Chemical additive.
- Organic additive.
- Foaming process.

Given the growth and popularity of WMA, a number of States have conducted studies on WMA. Additionally, the National Cooperative Highway Research Program (NCHRP) has sponsored seven studies on WMA. The majority of these studies have investigated mix-design practices, engineering properties, and constructability. Although NCHRP 9-49A was initiated specifically to look at the long-term performance of WMA, the project's 5-yr duration captured only a fraction of the pavement's intended design life. As such, there is a need to establish a research plan that successfully captures long-term performance (over the entire lifecycle) of in-service WMA pavements while also obtaining materials testing results, construction details, pavement structure information, traffic levels, and climatic data. The SPS-10 experiment is designed to capture this information coupled with data on the use of recycled asphalt pavement (RAP) in WMA mixtures. Initial research on the use of RAP with WMA has demonstrated that RAP can be combined with virgin materials; however, the long-term performance needs to be studied.

Between 2005 and 2015, the NCHRP initiated a number of projects that included WMA as part of the research. Only two of the projects had been completed and published during the time this research was conducted, but the NCHRP generously provided the research team with access to interim reports, and several of the project managers on ongoing projects provided expertise to inform the decisions made during phase I. Table 2 summarizes the NCHRP work considered.

**Table 2. NCHRP projects including WMA.**

| Project No. | Project Name | Start Date | End Date |
|---|---|---|---|
| 09-33 | A Mix Design Manual for Hot Mix Asphalt (Advanced Asphalt Technologies, LLC 2011) | 7/1/2005 | 6/30/2010 |
| 09-47 | Engineering Properties, Emissions, and Field Performance of Warm Mix Asphalt Technologies (Anderson et al. 2008) | 3/31/2008 | 1/8/2009 |
| 09-47A | Properties and Performance of Warm Mix Asphalt Technologies (West et al. 2014) | 7/31/2009 | 1/12/2013 |
| 09-49 | Performance of WMA Technologies: Stage I Moisture Susceptibility (Martin et al. 2014) | 7/26/2010 | 9/30/2013 |
| 09-49A | Performance of WMA Technologies: Stage II Long-Term Field Performance (Washington State University, Pennsylvania State University-Altoona, and Louisiana Transportation Research Center 2017) | 4/29/2011 | 7/28/2016 |
| 09-52 | Short-Term Laboratory Conditioning of Asphalt Mixtures (Newcomb et al. 2015a) | 6/1/2012 | 11/30/2014 |
| 09-53 | Properties of Foamed Asphalt for Warm Mix Asphalt Applications (Newcomb et al. 2015b) | 6/1/2012 | 8/31/2014 |
| 09-55 | Recycled Asphalt Shingles in Asphalt Mixtures with Warm Mix Asphalt Technologies (West et al. 2018) | 6/10/2013 | 9/10/2016 |

## RESEARCH APPROACH

The research was initiated by assembling an ETG to guide the project and provide input on current practices, ongoing research, and long-term data needs. The research team held one face-to-face meeting and two webinars with the ETG as a group. In addition, the research team conversed extensively with individual ETG members during the project. Details on the ETG are discussed in chapter 2 of this report.

To accomplish the overall research objectives and develop a comprehensive platform to study WMA, the research team developed one new experiment for the LTPP program: SPS-10, "Warm Mix Asphalt Overlay of Asphalt Pavement." Test sections for this experiment were constructed specifically for the LTPP program to address key factors deemed critical to WMA performance.

To accommodate existing LTPP test sections that may receive overlays with WMA technologies, the team expanded the following two existing experiments within the LTPP program:

- GPS-6: AC Overlay of Existing AC Pavements
- GPS-7: AC Overlay of Existing PCC Pavements

This expansion required revising the existing documentation and testing requirements of the experiments. However, no changes to the experimental matrices were required because new test sections will not be recruited to the GPS-6 and GPS-7 experiments. Rather, populating the expanded experiments were retroactive and based on State or provincial highway agencies deciding to overlay an existing test section with WMA, allowing existing test sections to remain in the study and receive continued monitoring. Details on the required revisions are discussed in chapter 3 of this report.

In addition to the experimental design and research plan, this report discusses materials sampling and testing recommendations for the LTPP WMA experiment. The research team evaluated the existing LTPP testing requirements as well as new tests that were not available during the original planning of the LTPP program. Based on this investigation, the research team identified a list of materials tests along with recommended priorities for each. Details are discussed in chapter 4 of this report.

The research team also developed performance monitoring guidelines, construction documentation requirements, and other data collection needs in consultation with the ETG, FHWA, and other LTPP stakeholders.

Lastly, the research team provided marketing and technical support services throughout the research.

## REPORT VOLUMES

In addition to this report, which is volume I in the series, there are five other related volumes, each published separately. These volumes contain detailed information about the design and operations of the SPS-10 experiment and include the following:

- Volume II: SPS-10 Experimental Matrix and Research Plan, Report Number FHWA-HRT-22-019.
- Volume III: SPS-10 Nomination Guidelines, Report Number FHWA-HRT-22-020.
- Volume IV: SPS-10 Materials Sampling and Testing Requirements, Report Number FHWA-HRT-22-021.
- Volume V: SPS-10 Performance Monitoring Guide, Report Number FHWA-HRT-22-022.
- Volume VI: SPS-10 Construction Documentation Guide, Report Number FHWA-HRT-22-023.

These volumes should be consulted for details concerning the SPS-10 experiment.

# CHAPTER 2. EXPERT TASK GROUP

This task started with the research team developing a list of potential candidates for the ETG. The list was developed to include people involved with WMA either through national projects or at State highway agency (SHA)-level implementations. Candidates included people with expertise in mixture design and testing, construction, performance modeling, pavement research, and laboratory testing. The ETG consisted of three members who work at SHAs, which was critical because the LTPP program was developed to serve as a product for the SHAs to use. In addition, two members were from the research and academic sector. They were intimately familiar with the LTPP program and provided a perspective from the research community. Industry was also represented on the ETG by one member from the National Asphalt Paving Association and one contractor. These members provided expertise in the production, construction, and compaction aspects of WMA.

In aggregate, the ETG was well balanced and provided a range of expertise relevant to the research. In addition, the ETG members represented a diverse geographic background, allowing WMA experiences from different climatic settings to be incorporated into the experiment.

The first ETG meeting was held on November 8, 2012, in Reno, NV. The meeting was convened to discuss the general approach to the research. Prereading materials and discussion topics focused on the critical factors to be included in the experimental matrix as well as on establishing priorities for the materials testing requirements to adequately capture properties of the pavement structure. The input from this first meeting was used to develop draft versions of the experimental design, research plan, nomination process, site selection procedure, and materials sampling and testing plan.

A webinar was held on March 11, 2013, to review the draft documentation and receive feedback from the ETG on materials sampling and testing recommendations.

A second webinar was held on August 14, 2013. The objective of this webinar was to discuss phase II of the research, in particular the performance monitoring, construction documentation, and other data collection tasks. In addition, the team discussed FHWA's recommended revisions to the experimental design and materials sampling and testing documentation submitted in phase I.

Details on the outcomes from all ETG interactions are incorporated throughout the remainder of this report.

# CHAPTER 3. EXPERIMENTAL DESIGN

This chapter focuses on the SPS-10 experimental design development process—how projects were nominated and accepted into the SPS-10 experiment. The team also provided recommendations on expanding the GPS-6 and GPS-7 experiments to include WMA overlays of existing LTPP test sections. Also included in this chapter is a summary about why existing projects constructed outside of the LTPP program (i.e., sections included in ongoing NCHRP investigations) were not viable candidates to be added to the LTPP pavement performance database (PPDB).

The SPS-10 experiment is designed to capture information on the performance of WMA, in both the short and the long term, and to provide the ability to directly compare performance of WMA to HMA, thereby evaluating the difference in relative performance between WMA and HMA. The experiment will capture field performance over the long term while providing data from laboratory testing of WMA materials for use by researchers looking to evaluate various features of WMA. Collectively, this information could be used to make performance predictions.

The SPS-10 experiment as described herein is intended for test sections not previously in the LTPP program. Projects nominated into the SPS-10 experiment were constructed specifically to satisfy cells within the experimental matrix and will adhere to the guidelines developed by the research team and approved by FHWA. Because these sections were nominated into the program before construction, all construction activities, materials properties, and sampling will be documented to ensure a complete dataset. Each SPS experiment in the LTPP program is designed to have a set of limited goals, specified construction requirements, data requirements, and experimental approaches. The SPS experiments are generally aimed at intensive studies of a few independent variables. This chapter defines the goals and objectives of the SPS-10 experiment, the independent variables to be studied (including how they were established), and the methods used to control other factors that contribute to pavement performance.

## EXPERIMENTAL MATRIX

The primary objective of the SPS-10 experiment was to quantify the performance of WMA relative to an HMA control section. As such, each SPS-10 project location will consist of the following, at a minimum:

- One HMA control section.
- Two WMA test sections (each using a different category of WMA technology).

The final experimental matrix approved by FHWA for this project evolved throughout the project based on feedback from the ETG and various stakeholders, including FHWA. This section provides details on the development process and final experiment design.

### Initial Experimental Matrix

The initial experimental matrix was developed using a tiered factorial approach. Key factors of moisture, temperature, traffic, and RAP and recycled asphalt shingle (RAS) content were selected for the primary tier factorial. The experiment was designed to ensure that each WMA category was represented in every possible combination, as illustrated in table 3. For example, the foaming process WMA category is represented in all moisture (2), temperature (2), traffic (2), and RAP and RAS (2) categories for a total of 16 permutations. The same holds true for the foaming additive, chemical additive, and organic additive WMA categories.

**Table 3. Combinations of WMA technology in primary tier factorial.**

| Combination Number | WMA Category | RAP/RAS Content | Moisture | Temperature | Traffic |
|---|---|---|---|---|---|
| 1 | Foaming process | High | Wet | Freeze | High |
| 2 | Foaming process | High | Wet | Freeze | Low |
| 3 | Foaming process | High | Wet | No freeze | High |
| 4 | Foaming process | High | Wet | No freeze | Low |
| 5 | Foaming process | High | Dry | Freeze | High |
| 6 | Foaming process | High | Dry | Freeze | Low |
| 7 | Foaming process | High | Dry | No freeze | High |
| 8 | Foaming process | High | Dry | No freeze | Low |
| 9 | Foaming process | Low | Wet | Freeze | High |
| 10 | Foaming process | Low | Wet | Freeze | Low |
| 11 | Foaming process | Low | Wet | No freeze | High |
| 12 | Foaming process | Low | Wet | No freeze | Low |
| 13 | Foaming process | Low | Dry | Freeze | High |
| 14 | Foaming process | Low | Dry | Freeze | Low |
| 15 | Foaming process | Low | Dry | No freeze | High |
| 16 | Foaming process | Low | Dry | No freeze | Low |
| 17 | Foaming additive | High | Wet | Freeze | High |
| 18 | Foaming additive | High | Wet | Freeze | Low |
| 19 | Foaming additive | High | Wet | No freeze | High |
| 20 | Foaming additive | High | Wet | No freeze | Low |
| 21 | Foaming additive | High | Dry | Freeze | High |
| 22 | Foaming additive | High | Dry | Freeze | Low |
| 23 | Foaming additive | High | Dry | No freeze | High |
| 24 | Foaming additive | High | Dry | No freeze | Low |
| 25 | Foaming additive | Low | Wet | Freeze | High |
| 26 | Foaming additive | Low | Wet | Freeze | Low |
| 27 | Foaming additive | Low | Wet | No freeze | High |
| 28 | Foaming additive | Low | Wet | No freeze | Low |
| 29 | Foaming additive | Low | Dry | Freeze | High |
| 30 | Foaming additive | Low | Dry | Freeze | Low |
| 31 | Foaming additive | Low | Dry | No freeze | High |
| 32 | Foaming additive | Low | Dry | No freeze | Low |
| 33 | Chemical additive | High | Wet | Freeze | High |
| 34 | Chemical additive | High | Wet | Freeze | Low |
| 35 | Chemical additive | High | Wet | No freeze | High |
| 36 | Chemical additive | High | Wet | No freeze | Low |
| 37 | Chemical additive | High | Dry | Freeze | High |

| Combination Number | WMA Category | RAP/RAS Content | Moisture | Temperature | Traffic |
|---|---|---|---|---|---|
| 38 | Chemical additive | High | Dry | Freeze | Low |
| 39 | Chemical additive | High | Dry | No freeze | High |
| 40 | Chemical additive | High | Dry | No freeze | Low |
| 41 | Chemical additive | Low | Wet | Freeze | High |
| 42 | Chemical additive | Low | Wet | Freeze | Low |
| 43 | Chemical additive | Low | Wet | No freeze | High |
| 44 | Chemical additive | Low | Wet | No freeze | Low |
| 45 | Chemical additive | Low | Dry | Freeze | High |
| 46 | Chemical additive | Low | Dry | Freeze | Low |
| 47 | Chemical additive | Low | Dry | No freeze | High |
| 48 | Chemical additive | Low | Dry | No freeze | Low |
| 49 | Organic additive | High | Wet | Freeze | High |
| 50 | Organic additive | High | Wet | Freeze | Low |
| 51 | Organic additive | High | Wet | No freeze | High |
| 52 | Organic additive | High | Wet | No freeze | Low |
| 53 | Organic additive | High | Dry | Freeze | High |
| 54 | Organic additive | High | Dry | Freeze | Low |
| 55 | Organic additive | High | Dry | No freeze | High |
| 56 | Organic additive | High | Dry | No freeze | Low |
| 57 | Organic additive | Low | Wet | Freeze | High |
| 58 | Organic additive | Low | Wet | Freeze | Low |
| 59 | Organic additive | Low | Wet | No freeze | High |
| 60 | Organic additive | Low | Wet | No freeze | Low |
| 61 | Organic additive | Low | Dry | Freeze | High |
| 62 | Organic additive | Low | Dry | Freeze | Low |
| 63 | Organic additive | Low | Dry | No freeze | High |
| 64 | Organic additive | Low | Dry | No freeze | Low |

The initial experimental design also included a secondary tier factorial that encompassed the combination of WMA categories colocated at one project. This secondary tier was included to prevent the possibility of a gap developing from the same two WMA categories (foaming process and chemical additive) being constructed together frequently and other combinations being unrepresented in the experiment. The ETG stressed the importance of covering the various combinations as part of the SPS-10 experiment.

Given that the primary objective of the SPS-10 experiment is to study the performance of WMA relative to HMA, it was deemed unnecessary and impractical to include every combination of WMA category in every primary tier factorial. Doing so would have required 96 SPS-10 projects to populate the experiment completely. Therefore, a tiered factorial approach was used. The primary site factors were fully populated with each WMA technology paired with an HMA control in each combination of primary tier factorials. Table 4 presents the initial SPS-10 combination of primary tier factorials.

**Table 4. Initial SPS-10 experimental matrix.**

| WMA Category 1 | WMA Category 2 | RAP/RAS Content | Moisture | Temperature | Traffic |
|---|---|---|---|---|---|
| Foaming process | Foaming additive | High | Wet | Freeze | High |
| Foaming process | Foaming additive | High | Dry | Freeze | High |
| Foaming process | Foaming additive | Low | Wet | Freeze | Low |
| Foaming process | Foaming additive | Low | Wet | No freeze | High |
| Foaming process | Foaming additive | Low | Dry | Freeze | Low |
| Foaming process | Foaming additive | Low | Dry | No freeze | High |
| Foaming process | Chemical additive | High | Wet | Freeze | Low |
| Foaming process | Chemical additive | High | Wet | No freeze | High |
| Foaming process | Chemical additive | High | Dry | No freeze | High |
| Foaming process | Chemical additive | Low | Wet | No freeze | Low |
| Foaming process | Chemical additive | Low | Dry | Freeze | Low |
| Foaming process | Chemical additive | Low | Dry | No freeze | Low |
| Foaming process | Organic additive | High | Wet | No freeze | Low |
| Foaming process | Organic additive | High | Dry | No freeze | Low |
| Foaming process | Organic additive | Low | Wet | Freeze | High |
| Foaming process | Organic additive | Low | Dry | Freeze | High |
| Foaming additive | Chemical additive | High | Wet | No freeze | Low |
| Foaming additive | Chemical additive | High | Dry | No freeze | Low |
| Foaming additive | Chemical additive | Low | Wet | Freeze | High |
| Foaming additive | Chemical additive | Low | Dry | Freeze | High |
| Foaming additive | Organic additive | High | Wet | Freeze | Low |
| Foaming additive | Organic additive | High | Wet | No freeze | High |
| Foaming additive | Organic additive | High | Dry | No freeze | High |
| Foaming additive | Organic additive | High | Dry | No freeze | Low |
| Foaming additive | Organic additive | Low | Wet | No freeze | Low |
| Foaming additive | Organic additive | Low | Dry | Freeze | Low |
| Chemical additive | Organic additive | High | Wet | Freeze | High |
| Chemical additive | Organic additive | High | Dry | Freeze | High |
| Chemical additive | Organic additive | Low | Wet | Freeze | Low |
| Chemical additive | Organic additive | Low | Wet | No freeze | High |
| Chemical additive | Organic additive | Low | Dry | Freeze | Low |
| Chemical additive | Organic additive | Low | Dry | No freeze | High |

**Final Experimental Matrix**

Based on review comments received from FHWA, the research team revised the experimental matrix to constrain some of the variables. The intent was to focus on those factors that are most important to the WMA community. The primary site factors remained unchanged in the final matrix, but the secondary factors were condensed to include only one RAP level (10–25 percent based on binder replacement) and two WMA technologies (foaming process and chemical additive) because, collectively, these two technologies account for more than 95 percent of the WMA currently being produced in the United States. Additional constraints were added to the site requirements to include only overlays of existing AC pavements. Including only overlays reduced variability within the experiment while focusing on overlay projects, which are currently the most common type of roadway construction. The final core projects required for the experiment are provided in table 5, with two projects recommended per cell to achieve replication in these primary experiment factors.

**Table 5. Final experimental matrix.**

| Moisture | Temperature | Traffic | Projects Per Experiment Cell |
|---|---|---|---|
| Wet | Freeze | High | 2 |
| Wet | Freeze | Low | 2 |
| Wet | No freeze | High | 2 |
| Wet | No freeze | Low | 2 |
| Dry | Freeze | High | 2 |
| Dry | Freeze | Low | 2 |
| Dry | No freeze | High | 2 |
| Dry | No freeze | Low | 2 |

Note: Projects consist of an HMA control section and two different WMA categories (foaming process and chemical additive).

## OTHER FACTORS CONSIDERED BUT NOT INCLUDED

Practical and resource constraints precluded other factors from being implemented into the SPS-10 experiment design. Both the LTPP WMA ETG and FHWA provided feedback to identify those factors not critical to achieving the experiment objectives, which included the following:

- Including all four WMA categories on each project in addition to the HMA control section.
- Including multiple products within the same WMA category on each project.
- Varying binder replacement levels within a project.
- Varying the overlay thickness within the same WMA category on a project.
- Varying the pavement structure in any other way between sections on a project (e.g., varying subsurface layer composition, thicknesses, or condition).
- Varying the RAP and RAS content on a project.
- Varying existing pavement conditions between projects.

Should State or provincial highway agencies wish to investigate any factors not included in the SPS-10 experimental design, they may do so by constructing additional supplemental sections within their project(s). The team worked with the FHWA Asphalt Mixtures ETG to develop a white paper on recommended supplemental sections. FHWA distributed this white paper to each highway agency during the SPS-10 recruitment process. Those recommendations have been incorporated into the SPS-10 documentation.

## SUMMARY OF EXPERIMENT SPECIFICS

Each project shall have test sections representing at least two of the WMA categories (foaming process and chemical additive) along with at least one HMA control section. The three sections defined here are considered the "core" experiment and were used to populate the national experimental design. Any additional test sections constructed within a project are considered supplemental sections. Although data will be collected and stored in the LTPP PPDB for these supplemental sections, they are not used to populate the national experimental matrix.

Supplemental sections are valuable components of an SPS-10 project because they allow agencies to study specific mixtures of interest.

An overview of key experimental requirements is included in the next sections of this chapter. The research team, working with FHWA and the ETG, carefully considered the balance between appropriate control of the experimental factors and allowing flexibility between State or provincial highway agency practices in developing the SPS-10 experiment.

The SPS-10 experiment comprises new AC overlays over existing AC pavements. The thickness of the AC overlay was determined by the agency's standard practice; however, the overlay must be between 2 and 4 inches thick to be considered for the SPS-10 experiment. The minimum thickness was selected to alleviate complications that arise when performing materials testing on thinner layers.

Pavement thickness (and depth of milling, if applicable) must remain constant between all core test sections at any one project location to allow for direct comparison between WMA and HMA under homogeneous conditions. Similarly, the existing pavement structure thicknesses, surface distress types and extents, and subgrade conditions should be consistent throughout the project. Tack coats shall be required before the placement of all WMA and HMA lifts constructed as part of the SPS-10 experiment.

The AC binder used in the mixture was selected using the agency's normal practice. Modified binders (both polymer and rubber) are allowed in the SPS-10 experiment. Information on the binder modifier type and quantity is documented and stored in the LTPP PPDB. The binder grade and binder modification must be consistent among the three core test sections of each project. Should the agency wish to vary binder properties, supplemental sections can be included and are monitored as part of the LTPP program.

## SITE LAYOUT AND SITE REQUIREMENTS

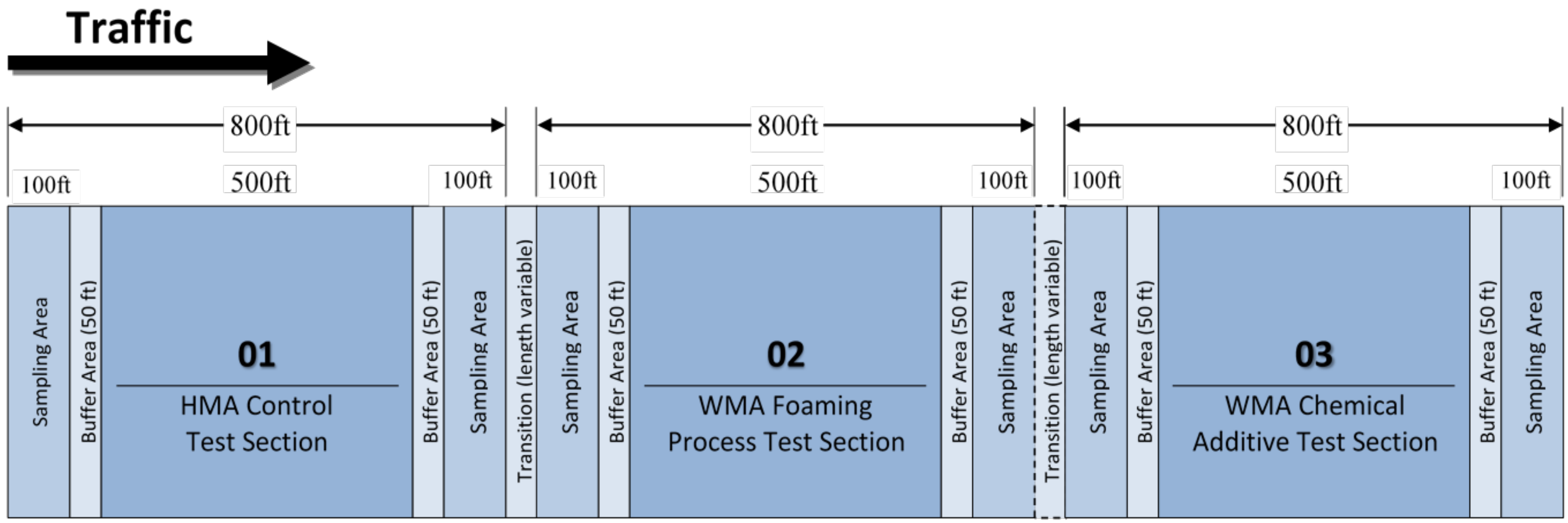
The matrix of conditions (moisture, temperature, and traffic) in table 5 represents the recommended minimum number of projects to be constructed to achieve a statistically robust dataset. Each project location will contain a minimum of three test sections (each 152.4 m

[500 ft] in length) constructed contiguously along a section of highway, interstate, or state route. The SPS-10 test pavements must be built as part of an overlay of the existing pavement.

Figure 1 illustrates a conceptual test site layout for the SPS-10 experiment. The experimental design requires a minimum of 243.8 m (800 ft) in length for each test section plus transition zones (each project is likely to be around 1,219 m [4,000 ft]), with a core monitoring section of 152.4 m (500 ft) that is used for future nondestructive performance monitoring. A 15.2-m (50-ft) buffer on each side of the monitoring area is included to separate the destructive sampling area from the monitoring area. The destructive sampling area will consist of 30.5 m (100 ft) on each side of the monitoring area. The sampling area will be built at the same time and to the same specifications as the monitoring area to allow material sampling without disturbing the 152.4-m (500-ft) monitored area and will consist of the outside lane (i.e., truck lane) only.

Sufficient plant production should be provided to ensure acceptable uniformity and consistency in the asphalt concrete mixture delivered and placed. The project will require at least three different mixes (one HMA and two WMA) to be produced at the same plant. All mixes must be produced from the same stockpiled aggregate with the same aggregate gradation. The aggregate must come from the same aggregate source. Each mix may be placed on the test section only after the plant has reached steady-state operation, which may require either longer transition zones between the sections than is typical in the LTPP program, using the mix for other purposes, or disposing of the produced mix before the plant achieves steady-state operation. The length of the transition zones depends on site conditions, plant configurations, and construction practices that influence the amount of material required to reach steady-state operations. The minimum project length, including the three test sections, buffer areas, sampling area, and transition zones, is 1,219 m (4,000 ft) but may be longer if more than the minimum number of sections are built or if long transition zones are used.

Obtaining consistent densities (and air voids) across all test sections is important to the SPS-10 experimental objectives. Care should be taken to ensure rolling patterns and compactive efforts are established for each mixture so that uniform densities are achieved within each 243.8-m (800-ft) monitoring and sampling length. The transition zones are used to ensure that steady-state operations are achieved at the plant and that proper rolling patterns and compactive efforts are established before construction of the monitoring and sampling areas.




Source: FHWA.
1 ft = 0.3048 m.

**Figure 1. Diagram. Typical SPS-10 site layout.**

## NOMINATION AND ACCEPTANCE PROCESS

A comprehensive set of guidelines and accompanying forms were developed to support the SPS-10 project nomination process. This information is included in volume III of this report (Puccinelli et al. 2022a). The nomination process is coordinated between FHWA, the State and provincial highway agencies, the regional support contractors (RSCs), and the technical support services contractor (TSSC). Discussions between the RSCs and the agencies begin the process, and then the agencies review the participation requirements and project selection criteria to determine candidate projects, during which time the RSCs, FHWA, and the TSSC are available to answer any questions that arise.

Once candidate projects are identified, the agencies complete the nomination forms and return them to the RSC with which they have been coordinating. The nomination forms are then provided to FHWA for consideration. In many cases, the projects are accepted as submitted, although there may be an instance wherein questions regarding the nominated project are returned to the agencies.

Formal acceptance of the projects as nominated is provided by FHWA and transmitted through the RSCs. At this point, the agencies and RSCs coordinate on the construction schedule and ensure all appropriate project information is captured and entered into the LTPP PPDB.

## JUSTIFICATION FOR NOT INCLUDING NCHRP WMA PROJECTS

The research team carefully considered how the NCHRP projects involving WMA test sections could be brought into the LTPP program as test sections. Other sections, such as those constructed as part of ongoing work under the Asphalt Research Consortium, were also evaluated. This evaluation was part of the original scope of work and was also encouraged during the initial WMA ETG meeting.

Incorporating existing WMA sections into the LTPP program would jump start evaluating the long-term performance of in-service sections. The LTPP program has established rigorous guidelines regarding the processes by which data is collected, reviewed, and stored. These guidelines apply to the construction, materials sampling and testing, and performance monitoring data.

Although the NCHRP (and other) test sections often had research personnel onsite during construction (and in some instances used LTPP practices for elements of the data collection), these sections are too different from those in the LTPP program to fit within the existing LTPP PPDB. The following is a sampling of the reasons this conclusion was reached:

- Standard LTPP test sections are 152.4 m (500 ft) in length, but most NCHRP projects involve significantly shorter sections.

- The LTPP program prohibits destructive sampling within test sections, whereas the NCHRP projects performed coring within the test sections.

- The LTPP program requires distress surveys to be performed by accredited raters using specific forms and definitions; although these definitions were largely incorporated in the NCHRP projects, the surveys were performed by nonaccredited raters.
- Deflection and roughness data were collected on very few of the existing NCHRP WMA projects, and the equipment used to collect the limited data was not calibrated per LTPP specifications.
- LTPP protocols were not used for materials sampling and testing processes.
- None of the NCHRP datasets used LTPP forms, meaning that even if the information could be found, a substantial effort would be required to get it documented and entered into the LTPP PPDB.

Although the test sections themselves are not recommended for inclusion in the LTPP PPDB, the lessons learned in the conduct of the NCHRP WMA projects contributed to optimizing decisions made in association with the LTPP WMA experiment for phase I.

There was a similar consideration when SHRP set up the original LTPP test sites. Sites that had previous or existing monitoring were evaluated and included only when they met the LTPP criteria used to nominate test sections.

# CHAPTER 4. MATERIALS SAMPLING AND TESTING

The activities necessary to collect the materials testing data relevant to the SPS-10 experiment are described in the Materials Sampling and Testing Plan (the Plan) provided in volume IV of this report (Puccinelli et al. 2022b). The key goal of the Plan is to provide laboratory materials testing data that, when combined with observed field performance, can be used to enhance the understanding of WMA, including related improvements to mix- and pavement-design procedures. Specifically, the Plan's goals are as follows:

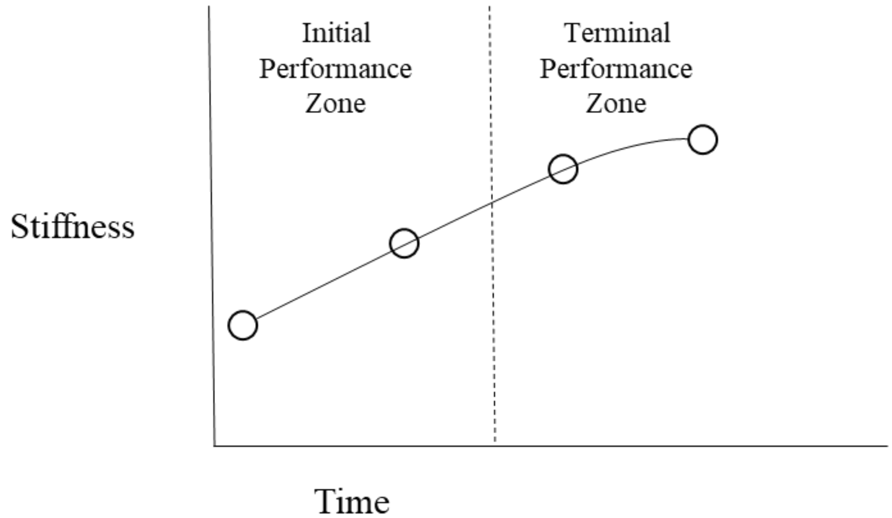
- Enhance mix-design procedures for WMA materials by providing field performance data that can be linked back to the parameters typically determined at the time of mix design.
- Enable evaluation and calibration of existing pavement-design procedures for WMA materials.
- Provide a dataset that can be useful in the development of the next generation of pavement-design tools.

Based on discussions with the ETG and industry experts, a key gap in the current understanding of WMA materials is the change in properties due to initial aging. This change is expected to be significantly greater than that for conventional HMA, which makes performance predictions based on experience with HMA problematic. Furthermore, because this initial aging process is expected to be strongly dependent on site-specific climatic conditions and no laboratory aging processes adequately simulate site-specific conditions for asphalt materials in general (or for WMA in particular), determination of the change in properties due to initial aging must be performed on field-sampled materials.

This focus on the initial aging of field materials leads to a fourfold concept for materials sampling:

- Determination of the initial aging curve.
- Determination of properties related to failure during the initial performance zone.
- Determination of properties related to failure during the terminal performance zone.
- Determination of properties necessary for Mechanistic-Empirical Pavement Design Guide (MEPDG) modeling.

This concept is shown in figure 2 using a hypothetical initial aging curve. The terms "initial performance zone" and "terminal performance zone" are included only to frame the discussion; they do not have precise definitions. However, as used here, the initial performance zone includes failures well before the expected life of the pavement, which are typically ascribed to mix-design problems and may be exacerbated by the initial workability of WMA. The terminal performance zone includes failures later in the pavement's life that are addressed in the pavement-design process and are typical of conventional asphalt materials.




Source: FHWA.

**Figure 2. Graph. Initial aging curve and performance zones.**

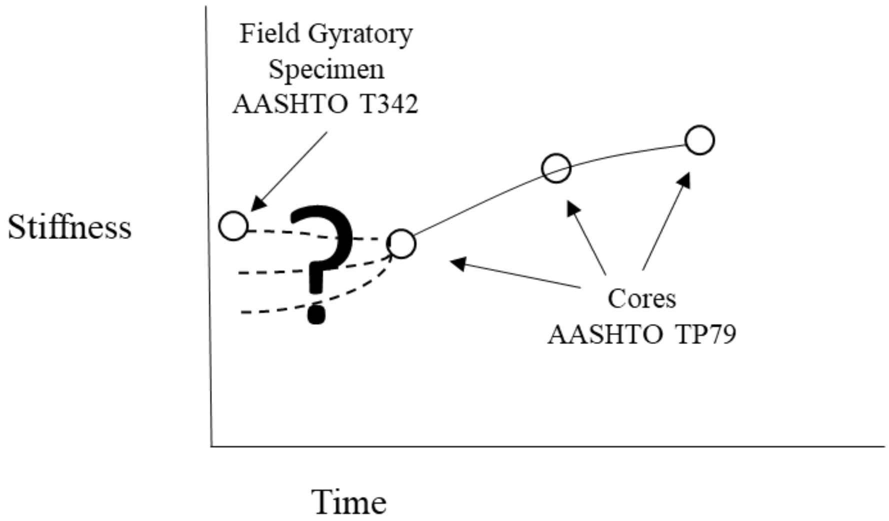
Material parameters relevant to the initial aging curve, initial performance zone, and terminal performance zone are shown in table 6.

**Table 6. Material parameters relevant to aging curve and performance zones.**

| Aging Component | Relevant Material Properties |
|---|---|
| Aging curve | Binder rheology |
| | Mix stiffness |
| Initial performance zone | Rut resistance |
| Terminal performance zone | Fatigue resistance |
| | Rut resistance |
| | Fracture energy/thermal cracking resistance |
| | Moisture susceptibility/stripping |
| | Bond strength/delamination |

The properties listed in table 6 are not enough to permit MEPDG modeling. For the WMA layer, aggregate properties, including gradation, absorption, and specific gravity, are required to perform this modeling. Stiffness and component properties of the remaining layers in the pavement system are also required.

This focus on time-dependent properties necessitates test procedures that can be performed on field core samples. A hybrid approach, using tests performed on laboratory-mixed or compacted samples for the initial period and cores for the remaining periods, was considered but rejected. Although this approach would permit tests with specimen geometries unobtainable with field cores for the initial data point, there are many disadvantages. Laboratory mixing was deemed not to be sufficiently representative, especially in the case of injection-foamed materials. Laboratory compaction of plant-mixed materials requires reheating, which is expected to be particularly problematic in the case of WMA. Field gyratory compaction of plant mix was also considered but was too costly and would present construction schedule–related logistical problems. In addition, because of likely bias between different specimen types and test procedures, the determination of the shape of the initial aging curve could be problematic, as shown in figure 3.




Source: FHWA.
AASHTO = American Association of State Highway and Transportation Officials.

**Figure 3. Graph. Potential effect of bias on the initial aging curve.**

## MATERIAL PROPERTIES AND TEST SELECTION

The material properties listed in table 6 were discussed with the ETG, and a list of potential tests was developed. A summary of these discussions is presented in the following sections. The ETG did not reach a consensus on some items, so a ballot was prepared, and the ETG members were asked to assign priorities to each potential test. The defined priorities were as follows:

- Essential to the experiment.
- Recommended if funding permits.
- Not recommended.

The testing plan was largely determined based on five responses to the ballot. A justification is provided in areas where the plan diverges from these responses.

### Binder Rheology

Most previous LTPP materials sampling and testing plans included only kinematic and absolute viscosity (LTPP test designation AE05) as measures of binder rheology. The exception is the SPS-9 experiment, which also included dynamic shear rheometer (DSR), bending beam rheometer (BBR), and direct tension (DT) tests to be performed by (or at the direction of) the participating State or provincial highway agency. The choice of kinematic and absolute viscosity for the initial testing plans was based on the state of the practice at the time. Although the SPS materials action plan (MAP) was developed after the introduction of the Superpave binder tests, kinematic and absolute viscosity were retained for consistency with previous results. However, viscosity testing was not considered appropriate for the SPS-10 experiment because it is rarely used in current mix-design processes and has questionable relevance to highly modified binders.

Based on discussions with the ETG, the DSR, BBR, and multiple stress creep recovery (MSCR) tests were included in the MAP as measures of binder rheology. DT was not included because of its decreased usage in mix design and its higher cost. All DSR and BBR testing is to be performed at multiple temperatures in accordance with ASTM 7643 to establish the continuous binder grade (ASTM 2016). MSCR is included because of its increased sensitivity to binder modifications as well as its use in predicting rutting susceptibility.

Binder testing is to be performed on various binder samples at various aging conditions:

- Virgin (tank) binder—unaged, rolling thin film oven (RTFO), and pressure aging vessel (PAV) conditions.
- RAP/RAS stockpile material—extracted binder at RTFO condition.
- Pavement cores, immediately after construction—extracted binder at unaged and PAV conditions.
- Pavement cores, time series—extracted binder at field-aged condition (i.e., no laboratory aging).

This binder testing plan will permit the following analyses:

- Change in binder properties due to warm-mix additives and processes.
- Change in WMA and HMA binder properties due to field aging.
- Applicability of laboratory RTFO and PAV aging processes to WMA materials.

BBR at the RTFO aging condition and MSCR at the PAV aging condition were rated as important by some of the ETG members but are not included in the Plan. Although these tests at these aging conditions may have some research value, they are not necessary for binder grading, and their inclusion would increase the already large quantity of binder tests as well as the proportion of testing costs expended on binder properties investigation.

This binder testing plan does not include “tank” WMA binder (i.e., virgin binder after the addition of WMA additives or processes). Depending on the plant design, this material may be impossible to sample or meaningless (especially for injection-foaming processes and/or mixes including RAP and RAS). Mixing of virgin binder and additives in the laboratory was considered but rejected because of its complexity and questions about how well this would represent the material placed in the field. Samples of virgin binder and warm-mix additives will be obtained and stored in the Materials Reference Library (MRL) in case other researchers wish to perform the mixing process themselves.

**Mix Stiffness**

In previous LTPP testing plans, indirect tension resilient modulus testing (LTPP designation AC07) was performed as the measure of mix stiffness (Simpson, Schmalzer, and Rada 2007).

This test procedure was adopted because, at the time, there was no dynamic modulus test that could be performed on cores. Since that time, dynamic modulus has increased in importance because of its usage in the MEPDG, and two dynamic modulus test procedures that are applicable to cores have been developed. Both tests are relatively new and untried, and limited information is available regarding their ruggedness and cost.

North Carolina State University (NCSU) has developed an indirect tensile (IDT) dynamic modulus test. This test is similar to AC07 in configuration, and the procedure is documented in American Association of Highway and Transportation (AASHTO) protocol T 342 (AASHTO 2011). This test has similar drawbacks as AC07, including a complex stress state induced by the indirect tension configuration and the need to measure both horizontal and vertical deformation on both faces of the core. In addition, the test procedure is not in widespread use, and no off-the-shelf equipment is available.

Both Turner-Fairbank Highway Research Center (TFHRC) and NCSU have performed asphalt mixture performance tester (AMPT) dynamic modulus testing on small-scale specimens obtained by horizontal recoring of 150-mm (6-inch) diameter cores (AASHTO TP 79 2012). The specimen obtained in this manner is 37 mm (1.5 inch) in diameter by 110 mm (4.3 inch) in height, which is sufficient to permit axial testing without excessive end effects. A key advantage of this test over the IDT is that the stress state is much simpler, and it does not require measurement of both vertical and horizontal deformation on both faces of the core and a complex data analysis procedure. Another advantage is that the AMPT equipment is available off the shelf, and the AASHTO TP 79 procedure can be used with minor modifications. An additional advantage is that the specimen geometry allows for testing layers with a thickness of 50 mm (2 inches) or greater. A disadvantage is that the ratio of the specimen diameter to nominal maximum aggregate size is small, which would be expected to increase specimen-to-specimen variability.

Based on discussions with the ETG and others in the community, the small-specimen AMPT dynamic modulus procedure was selected as the best choice for this experiment, given the information available currently. The Plan includes this test both as a time-series test for the experiment layer and as an initial test for the existing AC layer(s).

**Rut Resistance**

Rut resistance has not been specifically addressed in previous LTPP materials testing plans. Rutting has been measured as a field condition, and these results have been linked to mix component properties through various models, including those used in the MEPDG. These models are focused on rutting as a terminal service condition, not as an early failure mode.

Rut resistance is a specific area of concern for WMA in the initial aging period because the additives and processes used to improve compatibility may also decrease rut resistance. Based on this concern, rut resistance testing was considered from a mix-design perspective, not from a pavement-design perspective.

Two rut resistance tests were considered—the Hamburg Wheel-Tracking Device (HWTD) and the triaxial stress-sweep (TSS) test (AASHTO 2019). The HWTD is widely used but is considered to be a "torture test" that does not yield fundamental properties of use in pavement modeling (Bhasin, Button, and Chowdhury 2004). The TSS is currently a research-only test that does not have a published protocol, but it does use the AMPT test equipment. It can be performed only on laboratory-compacted specimens.

Based on the mix-design perspective on rut resistance, the HWTD is the more appropriate test. It is also much more widespread and should therefore be more affordable. It can be performed wet, so it also yields a measure of moisture susceptibility. HWTD is included in the MAP as an initial test only. Time-series testing was considered to be a lower priority and is discussed later in this chapter. To a degree, the lack of time-series mixture rut resistance testing is made up for by mixture component testing, especially MSCR and aggregate gradation.

### Fatigue

Fatigue has not been previously included in LTPP materials testing plans. As with rutting, fatigue cracking has been measured as a field condition, and various studies have linked these data back to mix component properties. The project team considered simplified viscoelastic continuum damage (S-VECD) model fatigue testing. This procedure is described in draft AASHTO protocol TP 107, *Standard Method of Test for Determining the Damage Characteristic Curve and Failure Criterion Using the Asphalt Mixture Performance Tester (AMPT) Cyclic Fatigue Test* (AASHTO 2018). The procedure can be performed in the AMPT using small-scale specimens, as described for dynamic modulus testing. Industry experience with this test is limited, and it seems likely to be expensive. In addition, because most of the SPS-10 projects are expected to consist of thin overlays of existing pavements, fatigue cracking is unlikely to be very sensitive to the fatigue resistance properties of the experiment layer.

### Fracture Energy

The LTPP program has performed fracture energy testing for most AC materials on SPS projects as part of the AC07 resilient modulus test. The test procedure for AC07 includes measurement of fracture energy (IDT configuration) at 25°C (77°F).

Because the SPS-10 MAP envisions replacing AC07 with a modified version of the TP 79 AMPT dynamic modulus test, fracture energy data will no longer be collected without adding a specific test to measure it.

Fracture energy at low temperatures (typically −10°C [50°F]) is generally considered the best measure of a mixture's susceptibility to low-temperature cracking. Fracture energy at moderate temperatures (typically 25°C [77°F]) is of interest as a fatigue-related parameter. Three potential fracture energy tests were considered: disk-shaped compact tension (DC(T)), semicircular beam (SCB), and the Fénix test. All three can be performed on cores. DC(T) is described in ASTM protocol D7313 (ASTM 2013). SCB is described in AASHTO protocol TP 124 (AASHTO 2020). There is no published protocol for Fenix, draft or otherwise.[1]

[1]Although no official set of standards exists for the Fénix test, Pérez-Jiménez et al. (2010) discuss the test in detail.

The DC(T) test was recommended by Pooled Fund Study TPF-5(132) on low-temperature cracking in asphalt concrete (Marasteanu et al. 2012). A drawback of the DC(T) test is that it cannot be performed at moderate temperatures. The Fénix test was designed as a simple fracture energy test that can be performed over a range of temperatures to determine a fracture energy envelope. How this envelope shifts as a function of warm-mix technology is potentially of greater interest than change in fracture energy at a single test temperature.

There was no consensus from the ETG regarding whether DC(T) or the Fénix test is more appropriate for the SPS-10 experiment. Based on information from the testing community, the Fénix test should be more affordable because it involves simpler specimen preparation, so the team developed an LTPP testing protocol (discussed later in this chapter).

FHWA decided to include Fénix fracture energy in the Plan. The test is to be performed at three temperatures (−10 [14], 5 [41], and 20°C [68°F]) on initial postconstruction cores only.

### Moisture Susceptibility

The LTPP program has some moisture susceptibility data collected using the P05 tensile strength ratio test (LTPP designation AC05), also described in AASHTO protocol T 283 (AASHTO 2014). The data are of limited quantity and questionable quality. AC05 was not included in the MAP because of a lack of perceived value.

Moisture susceptibility is an item of specific concern with WMA mixes because of their typically higher moisture contents in the aggregate and/or binder. P05/T283, HWTD, and S-VECD with moisture conditioning were considered for moisture susceptibility testing. Based on input from the ETG, T283 is still widely used by SHAs, but there is interest in replacing it with HWTD. Because the MAP already includes HWTD as a rut resistance test, it is simple to perform it submerged and include it as a moisture susceptibility test.

The MAP does not include any method of measuring the progression of moisture damage and stripping in the field other than as visually identified in cores taken for other purposes. Although a measuring method was considered, no practical, reliable, and objective measuring method was found. If moisture damage occurs during the initial aging period, it may be detected in the routine core examination. It may also be evaluated at the end of the pavement's life should a forensic examination be performed. The lack of field monitoring data to compare to moisture susceptibility testing limits the value of this testing as a basis for model development/calibration.

### Bond Strength

None of the ETG members considered the investigation of bond strength and delamination to be an important study objective, so no further consideration was given to relevant testing. The ETG did recommend that proper tack coats be required, which should help ensure that delamination is not a failure mode.

### Ballot Responses

The ETG ballot responses are summarized in table 7 through table 17. The column titled "Assigned" includes the value assigned by the project team. Only tests with an assigned priority of 1 are included in the MAP. The priority 1 tests were established by the ETG recommendations as well as feedback from FHWA on the phase I report recommendations. Although some of the tests were rated as lower priority by the ETG, FHWA decided to include them to ensure a complete suite of materials properties is captured for the SPS-10 experiment. The column titled "Designation" is the LTPP test designation for existing tests. For tests new to the LTPP program with an assigned value of 1, new test designations were developed, which are used in these tables and in the MAP.

**Table 7. Subgrade tests.**

| Test Name | Designation | Priority 1 | Priority 2 | Priority 3 | Priority 4 | Priority 5 | Priority Assigned | Notes |
|---|---|---|---|---|---|---|---|---|
| Sieve analysis | SS01 | 1 | — | — | 1 | 1 | 1 | — |
| Atterberg limits | SS03 | 1 | — | — | 1 | 1 | 1 | — |
| Classification | SS04 | 1 | — | — | 1 | 1 | 1 | — |
| Natural moisture content | SS09 | 1 | — | — | 1 | 1 | 1 | — |
| Specific gravity | SS13 | 1 | — | — | 2 | 3 | 2 | — |
| Standard proctor | SS05 | 1 | — | — | 2 | 3 | 1 | — |
| Resilient modulus | SS07 | 2 | — | — | 2 | 1 | 1 | — |
| Dynamic cone penetrometer | SS14 | 2 | — | — | 2 | 2 | 1 | Field test, LTPP owns equipment already, minor extra cost |

—No data.

**Table 8. Base and subbase tests.**

| Test Name | Designation | Priority 1 | Priority 2 | Priority 3 | Priority 4 | Priority 5 | Priority Assigned | Notes |
|---|---|---|---|---|---|---|---|---|
| Sieve analysis | UG01 | 1 | — | — | 1 | 1 | 1 | — |
| Atterberg limits | UG04 | 1 | — | — | 1 | 2 | 1 | — |
| Classification | UG08 | 1 | — | — | 1 | 2 | 1 | — |
| Specific gravity | UG13 | 1 | — | — | 2 | 3 | 2 | — |
| Standard proctor | UG05 | 1 | — | — | 2 | 3 | 1 | — |
| Resilient modulus | UG07 | 2 | — | — | 2 | 1 | 1 | — |
| Dynamic cone penetrometer | UG14 | 2 | — | — | 2 | 2 | 1 | Field test, LTPP owns equipment already, minor extra cost |
| Specific gravity, absorption of fine aggregate | AG02 | 2 | — | — | 2 | 3 | 2 | — |

—No data.

**Table 9. Existing AC materials tests.**

| Test Name | Designation | Priority | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | Assigned | |
| Core exam/thickness | AC01 | 1 | — | — | 1 | 1 | 1 | — |
| Bulk specific gravity | AC02 | 1 | — | — | 1 | 1 | 1 | — |
| Maximum specific gravity | AC03 | 1 | — | — | 1 | 1 | 1 | — |
| Extraction/asphalt content | AC04 | 1 | — | — | 1 | 1 | 1 | — |
| Dynamic modulus: AMPT | AC08 | 3 | — | — | 1 | 2 | 1 | Necessary for MEPDG modeling |
| Binder specific gravity | AE03 | 3 | — | — | 2 | 3 | 2 | — |
| DSR | AE07 | 3 | — | — | 2 | — | 1 | Necessary to determine binder grade |
| BBR | AE08 | 3 | — | — | 2 | — | 1 | Necessary to determine binder grade |
| MSCR | AE10 | 3 | — | — | 2 | — | 1 | — |
| Specific gravity, absorption of coarse aggregate | AG01 | 2 | — | — | 2 | 3 | 2 | — |
| Specific gravity, absorption of fine aggregate | AG02 | 2 | — | — | 2 | 3 | 2 | — |

—No data.

**Table 10. Tank binder, unaged tests.**

| Test Name | Designation | Priority | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | Assigned | |
| Binder specific gravity | AE03 | 1 | — | 1 | 1 | 3 | 1 | — |
| DSR | AE07 | 1 | — | 1 | 1 | 1 | 1 | — |
| BBR | AE08 | 1 | — | 1 | 1 | 3 | 2 | Test not performed on unaged binder for grading |
| MSCR | AE10 | 1 | — | 1 | 1 | 2 | 2 | Test not performed on unaged binder for grading |
| Recycled engine oil bottoms | AE11 | 1 | — | 1 | 2 | 2 | 1 | To be performed by TFHRC |

—No data.

**Table 11. Tank binder, RTFO tests.**

| Test Name | Designation | Priority | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | Assigned | |
| DSR | AE07 | 1 | — | 1 | 1 | 1 | 1 | — |
| BBR | AE08 | 1 | — | 1 | 1 | 3 | 2 | Test not performed on RTFO binder for grading |
| MSCR | AE10 | 1 | — | 1 | 1 | 1 | 1 | — |

—No data.

**Table 12. Tank binder, PAV tests.**

| Test Name | Designation | Priority | | | | | | Notes |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | Assigned | |
| DSR | AE07 | 1 | — | 1 | 1 | 1 | 1 | — |
| BBR | AE08 | 1 | — | 1 | 1 | 1 | 1 | — |
| MSCR | AE10 | 1 | — | 1 | 1 | 3 | 2 | Test not performed on PAV binder for grading |

—No data.

**Table 13. RAP and RAS stockpile material, RTFO tests.**

| Test Name | Designation | Priority | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | Assigned |
| Binder Specific Gravity | AE03 | 1 | 1 | 1 | 1 | 3 | 1 |
| DSR | AE07 | 1 | 1 | 1 | 1 | 1 | 1 |
| BBR | AE08 | 1 | 1 | 1 | 1 | 3 | 1 |
| MSCR | AE10 | 1 | 1 | 3 | 1 | 2 | 1 |

**Table 14. Experiment layer, AC mix tests.**

| Test Name | Designation | Priority | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | Assigned |
| Core exam/thickness | AC01 | 1 | — | 1 | 1 | 1 | 1 |
| Bulk specific gravity | AC02 | 1 | — | 1 | 1 | 1 | 1 |
| Maximum specific gravity | AC03 | 1 | — | 1 | 1 | 1 | 1 |
| Dynamic modulus: small-scale AMPT | AC08 | 3 | 1 | 1 | 1 | 1 | 1 |
| HWTD | AC09 | 1 | 1 | 1 | 2 | 1 | 1 |
| AASHTO T283 | AC05 | 1 | 2 | 2 | 1 | 2 | 2 |
| Fénix fracture energy | AC10 | 1 | 2 | 1 | 2 | 2 | 1 |
| DC(T) | — | 3 | 1 | 3 | 1 | 1 | 2 |
| Extraction/asphalt content | AC04 | — | — | 1 | 1 | — | 1 |
| S-VECD fatigue | — | 3 | 1 | 3 | 1 | 2 | 2 |
| Conditioned versus unconditioned fatigue (moisture susceptibility) | — | 3 | 2 | 3 | 2 | 3 | 2 |

—No data.

**Table 15. Experiment layer, extracted binder, unaged tests.**

| Test Name | Designation | Priority 1 | Priority 2 | Priority 3 | Priority 4 | Priority 5 | Priority Assigned | Notes |
|---|---|---|---|---|---|---|---|---|
| Binder specific gravity | AE03 | 3 | — | 1 | 1 | 3 | 1 | — |
| DSR | AE07 | 1 | — | 1 | 1 | 1 | 1 | — |
| BBR | AE08 | 1 | — | 1 | 1 | 3 | 2 | Test not performed on unaged binder for grading |
| MSCR | AE10 | 1 | — | 1 | 1 | 2 | 1 | — |

—No data.

**Table 16. Experiment layer, extracted binder, PAV tests.**

| Test Name | Designation | Priority 1 | Priority 2 | Priority 3 | Priority 4 | Priority 5 | Priority Assigned | Notes |
|---|---|---|---|---|---|---|---|---|
| DSR | AE07 | 1 | — | 1 | 1 | 1 | 1 | — |
| BBR | AE08 | 1 | — | 1 | 1 | 1 | 1 | — |
| MSCR | AE10 | 1 | — | 1 | 1 | 3 | 2 | Test not performed on PAV binder for grading |

—No data.

**Table 17. Experiment layer, extracted aggregate tests.**

| Test Name | Designation | Priority 1 | Priority 2 | Priority 3 | Priority 4 | Priority 5 | Priority Assigned |
|---|---|---|---|---|---|---|---|
| Specific gravity, absorption of coarse aggregate | AG01 | 2 | — | 1 | 2 | 3 | 2 |
| Specific gravity, absorption of fine aggregate | AG02 | 2 | — | 1 | 2 | 3 | 2 |
| Aggregate gradation | AG04 | 1 | — | 1 | 1 | 1 | 1 |

—No data.

### Time-Series Testing

The tests in table 7 through table 17 apply to samples obtained immediately after construction only. The MAP also includes time-series testing at 3–6, 12, and 18 mo after construction. Although no good evidence exists about the time required for WMA properties to stabilize, conversations with the ETG and industry experts indicate that this process should be complete within 12 mo after construction or after one entire summer. The tests at 18 mo after construction are included as checks to ensure that properties have indeed stabilized. Time-series tests are shown in table 18.

**Table 18. Time-series tests.**

| Test Name | Designation | Priority |
|---|---|---|
| Bulk specific gravity | AC02 | 1 |
| Dynamic modulus | AC08 | 1 |
| DSR | AE07 | 1 |
| BBR | AE08 | 1 |
| MSCR | AE10 | 1 |
| HWTD | AC09 | 2 |
| Fénix/DC(T) | AC10 | 2 |
| S-VECD | — | 2 |

—No data.

The MAP currently includes only bulk-specific gravity, mixture dynamic modulus, and binder rheology time-series tests. The HWTD test has been included in the MAP primarily to evaluate early rutting potential, and in that context, it makes little sense as a time-series test. However, time-series results from the HWTD may provide data that will enable it to be calibrated for use as a terminal service life predictor. A change in the stripping inflection point may also be useful in evaluating the progression of moisture damage.

**Test Quantities**

The test quantities in the MAP were based on two basic premises:

- For the experiment layer, one test is required per *section*.
- For existing layers, two replicate tests are required per *project* layer.

Because a requirement of the experiment is that all sections at a project have an identical existing structure, ideally, the two test results for the existing project layers would represent the materials for all sections on the project. The MAP includes a discussion of adapting the site-specific sampling and testing plan in cases where the existing layer structure is not identical among sections.

For dynamic modulus testing, the testing requirement is doubled (two tests per new section layer, four tests per existing project layer) because of potential variability arising from the small ratio of specimen diameter to nominal maximum aggregate size. It is also required that all cores be examined and measured, and all cores for subsequent mix testing be tested for bulk specific gravity. Core examinations (AC01) are performed on all layers in the core—for simplicity, the core examination test is counted for the experiment layer only for the purpose of computing test quantities, although it will yield results for all bound layers. In addition, to obtain the extracted binder necessary for time-series testing, asphalt content test results well in excess of the minimum value are obtained for the experiment layers.

The total test quantities for a project will vary according to the existing layer structure. For an example project consisting of the three core sections only with an existing structure consisting of a subgrade, granular base, and two AC layers, total test quantities are shown in table 19 through table 26. This example is a relatively simple structure for an LTPP project, and the numbers represent probable minimum values.

**Table 19. Subgrade test quantities.**

| Test Name | Designation | Quantity |
|---|---|---|
| Sieve analysis | SS01 | 2 |
| Atterberg limits | SS03 | 2 |
| Classification | SS04 | 2 |
| Natural moisture content | SS09 | 2 |
| Resilient modulus | SS07 | 2 |
| Dynamic cone penetrometer | SS14 | 3 |

**Table 20. Granular base test quantities.**

| Test Name | Designation | Quantity |
|---|---|---|
| Sieve analysis | UG01 | 2 |
| Atterberg limits | UG04 | 2 |
| Classification | UG08 | 2 |
| Resilient modulus | UG07 | 2 |
| Dynamic cone penetrometer | UG14 | 3 |

**Table 21. Existing AC layer test quantities.**

| Test Name | Designation | Quantity |
|---|---|---|
| Bulk specific gravity | AC02 | 6 |
| Maximum specific gravity | AC03 | 3 |
| Extraction/asphalt content | AC04 | 3 |
| Dynamic modulus: AMPT | AC08 | 4 |
| DSR | AE07 | 3 |
| BBR | AE08 | 3 |
| MSCR | AE10 | 3 |
| Aggregate gradation | AG04 | 3 |

**Table 22. Tank binder test quantities.**

| Test Name | Designation | Quantity |
|---|---|---|
| Binder specific gravity | AE03 | 1 |
| DSR | AE07 | 3 |
| RTFO | AE12 | 1 |
| PAV | AE13 | 1 |
| BBR | AE08 | 1 |
| MSCR | AE10 | 1 |
| Recycled engine oil bottoms | AE11 | 1 |

**Table 23. RAP and RAS stockpile material test quantities.**

| Test Name | Designation | Quantity |
|---|---|---|
| RTFO | AE12 | 1 |
| DSR | AE07 | 1 |
| BBR | AE08 | 1 |
| MSCR | AE10 | 1 |

**Table 24. Experiment layers, initial testing quantities.**

| Test Name | Designation | Quantity |
|---|---|---|
| Core exam/thickness | AC01 | 18 |
| Bulk specific gravity | AC02 | 18 |
| Maximum specific gravity | AC03 | 3 |
| Dynamic modulus: small-scale AMPT | AC08 | 6* |
| HWTD | AC09 | 3 |
| Fénix fracture energy | AC10 | 3** |
| Extraction/asphalt content | AC04 | 3 |
| Binder specific gravity | AE03 | 3 |
| RTFO | AE12 | 3 |
| PAV | AE13 | 3 |
| DSR | AE07 | 6 |
| BBR | AE08 | 3 |
| MSCR | AE10 | 3 |
| Aggregate gradation | AG04 | 3 |

*Performed at three different test temperatures and four different frequencies.
**Performed at three different test temperatures.

**Table 25. Experiment layers, time-series testing quantities (6, 12, and 18 mo).**

| Test Name | Designation | Quantity |
|---|---|---|
| Core exam/thickness | AC01 | 27 |
| Bulk specific gravity | AC02 | 27 |
| Dynamic modulus: small-scale AMPT | AC08 | 18* |
| Extraction/asphalt content | AC04 | 9 |
| DSR | AE07 | 9 |
| BBR | AE08 | 9 |
| MSCR | AE10 | 9 |

*Performed at three different test temperatures and four different frequencies.

**Table 26. Total AC test quantities.**

| Test Name | Designation | Quantity |
|---|---|---|
| Core exam/thickness | AC01 | 45 |
| Bulk specific gravity | AC02 | 51 |
| Maximum specific gravity | AC03 | 6 |
| Dynamic modulus: small-scale AMPT | AC08 | 28* |
| HWTD | AC09 | 3 |
| Fénix fracture energy | AC10 | 3** |
| Extraction/asphalt content | AC04 | 14 |
| Binder specific gravity | AE03 | 4 |
| DSR | AE07 | 17 |
| RTFO | AE12 | 5 |
| PAV | AE13 | 4 |
| BBR | AE08 | 16 |
| MSCR | AE10 | 16 |
| Recycled engine oil bottoms | AE11 | 1 |
| Aggregate gradation | AG04 | 5 |

*Performed at three different test temperatures and four different frequencies.

**Performed at three different test temperatures.

## TEST PROTOCOL AND DATA STRUCTURE DEVELOPMENT

To implement the MAP, several new LTPP test protocols were developed, in addition to PPDB tables, data entry forms, and quality control (QC) programs and procedures. In addition, some existing protocols were modified. New test protocols are contained in volume IV of this report series (Puccinelli et al. 2022b). Draft specifications for new PPDB tables, including QC, were provided to the TSSC and FHWA for review.

## New Protocols

### *P74/AC08 Dynamic Modulus*

The dynamic modulus protocol is designated P74, with an LTPP test designation of AC08. This test protocol is based on AASHTO TP79-12 (AASHTO 2012). Modifications include the following:

- Deletion of the flow number procedure.
- Modification of the specimen preparation procedure for small-scale specimens.
- Use of Teflon™ end-friction reducers.

Test temperatures will be 5 (41), 20 (68), and 45°C (113°F), with test frequencies of 0.1, 1, 10, and 25 Hz. No confinement will be used.

Data will be stored in a master (TST_AC08_MASTER) and data table (TST_AC08_DATA). The data table will contain test results for individual temperature/frequency combinations. The master table will contain specimen information.

AASHTO TP 79 includes several raw data quality measures that are included in and reported by the AMPT software (AASHTO 2012). These include deformation drift, peak-to-peak strain, load standard error, deformation standard error, deformation uniformity, and phase uniformity. These checks are intended to eliminate the need for a specialized QC program like P07 Check or P46 Check. The results of these quality measures are included in the data table. Level D QC checks based on the recommended ranges in AASHTO TP 79 were developed. Level E QC checks on data trends with temperature and frequency were also developed.

### *P75/AC09 Hamburg Wheel Track*

The Hamburg wheel track protocol is designated P75, with an LTPP test designation of AC09. This test protocol is based on AASHTO T324-11 (AASHTO 2019), with a modification requiring the cylindrical specimen mounting system described in section 5.6 of the standard to be used. The test will be performed submerged in water at 50°C (122°F).

Test results include the number of passes at maximum impression, maximum impression, creep slope, strip slope, and stripping inflection point. Because the test requires a large number of passes (on the order of magnitude of 10,000), storage of the raw rut depth versus the number of passes in the Information Management System (IMS) is impractical; however, the raw data are stored in the Ancillary Information Management System. Level D and E QC checks were developed to check data quality.

### *P79/AC10 Fénix Fracture Energy*

The Fénix fracture energy protocol is designated P79, with an LTPP test designation of AC10. This test protocol is based on information in Transportation Research Record 2181, *Fénix Test: Development of a New Test Procedure for Evaluating Cracking Resistance in Bituminous Mixtures* (Pérez-Jiménez et al. 2010), and information available from the testing community. The test is to be performed at −10 (14), 5 (41), and 20°C (68°F).

A data table (TST_AC10) and associated QC were also developed.

### *P73/AE10 Multiple Stress Creep Recovery*

The MSCR protocol is designated P73, with an LTPP test designation of AE10. This test procedure is based on AASHTO TP70-12 (AASHTO 2013a). The test temperature is based on the default high-temperature grade for the project location, determined using LTPPBind.

Data will be stored in a master (TST_AE10_MASTER) and data table (TST_AE10_DATA). The master table will include specimen information, average percent recovery and nonrecoverable creep compliance at each stress level, and the percent difference in percent recovery between the two stress levels. The data table will contain the raw data for each of the 10 cycles at the two different stress levels, including initial strain, adjusted strain, strain at the end of the recovery period, adjusted strain at the end of the recovery period, and percent recovery. Level D and E QC checks were developed to check data quality.

### *P76/AE11 PPA and Motor Oil Test*

The PPA and motor oil test protocol is designated P76, with an LTPP test designation of AE11. This test has been developed by FHWA and performed at TFHRC. A full description of the protocol and resulting data and data storage structures has not been included in this report because the protocol is under development by FHWA.

### *P77/AE12 Rolling Thin Film Oven*

The RTFO protocol is designated P77, with an LTPP test designation of AE12. This test procedure is based on AASHTO T240-09 (AASHTO 2013b). The result of this test is the percent mass change of the specimen as a result of the aging process. This result is of marginal utility to the experimental plan. However, the test is necessary to prepare specimens for additional testing. A table was designed for this test to maintain the relational integrity of the PPDB. This table also contains the percent mass change of the specimen.

### *P78/AE13 Pressure Aging Vessel*

The PAV test is designated P78, with an LTPP test designation of AE13. This test procedure is based on AASHTO R 28-12 (AASHTO 2012). AASHTO considers this to be a standard practice, not a test, because it produces no results. However, treating it as a test in the context of LTPP will help maintain the relational integrity of the PPDB and ease the process of communicating with the laboratory because the specimens produced by this procedure are required for additional testing.

## Existing Protocols

### *P27 Dynamic Shear Rheometer*

A limited amount of DSR testing was performed for the SPS-9 experiment, and there is an existing LTPP protocol and data structures. This protocol was updated to include testing at multiple temperatures, in accordance with ASTM D7643 (ASTM 2016). The existing table structures were also updated to account for time-series and binder component testing.

#### *P28 Bending Beam Rheometer*

As with DSR, a limited quantity of BBR testing was performed for the SPS-9 experiment, and there is an existing LTPP protocol and data structures. These were updated to account for continuous binder grading, time-series testing, and binder component testing.

### MRL SAMPLES

The MAP includes sampling to obtain specimens for storage in the MRL. These specimens will be made available to researchers for future investigations that supplement the goals of the SPS-10 experiment. Specimens include bulk samples of uncompacted mix from each section, bulk samples of virgin binder, bulk samples of warm-mix additive, cores of the bound pavement layers from each sampling interval, and bulk samples of unbound materials. These samples are summarized in table 27, which includes two levels of MRL sampling recommendations: minimum quantity and NCHRP 9-57–recommended quantity (Zhou et al. 2016). The following containers are recommended for long-term storage at the MRL:

- Bulk asphalt and RAP materials: 5-gal UN-rated steel pails with pigmented phenolic coating with lug cover.
- Asphalt cement materials: 1-gal UN-rated steel pails with pigmented phenolic coating with lug cover.
- WMA additive: 1-gal containers, per recommendations of the WMA additive manufacturer.
- Bulk unbound materials: 6 mil (or thicker) gusseted poly bags inside of 18 by 24 inches (457 by 610 mm) (or larger) woven polypropylene bags.

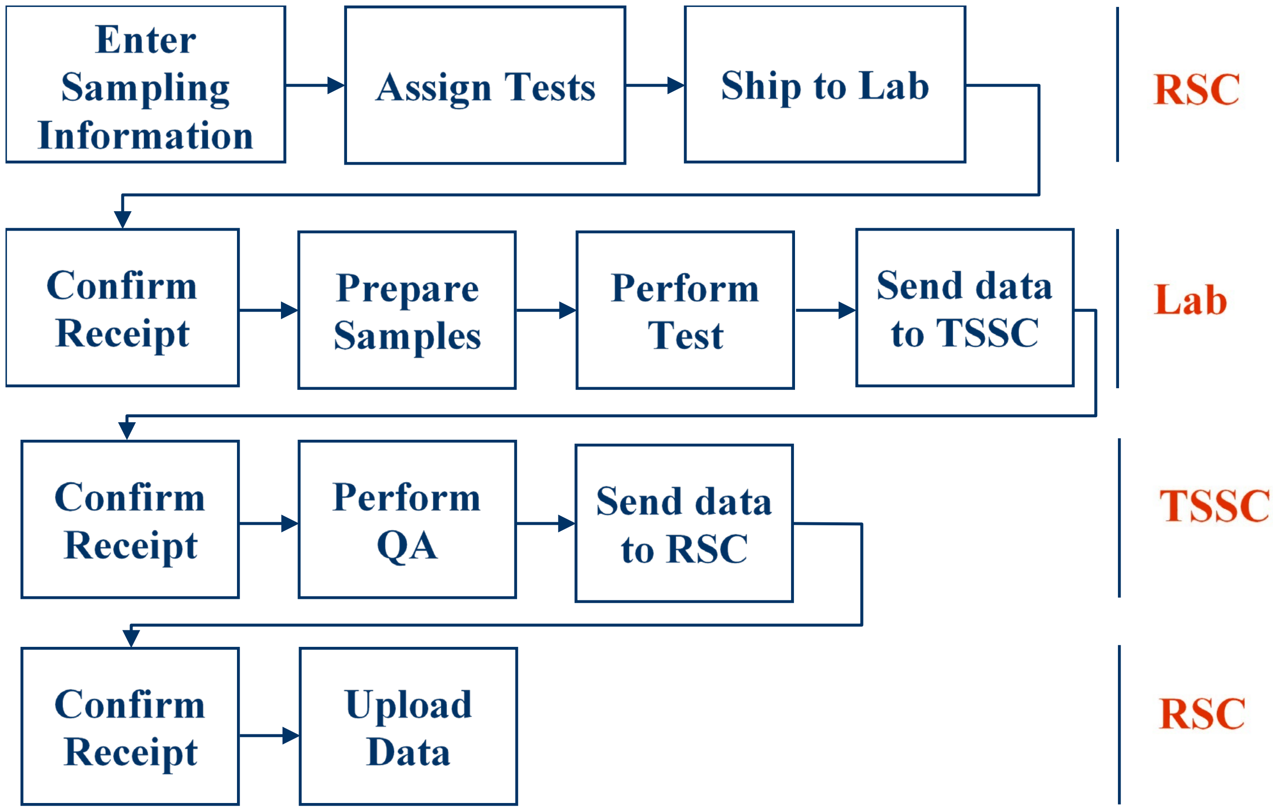
**Table 27. MRL Specimens.**

| Specimen Type | Minimum Quantity | NCHRP Quantity |
|---|---|---|
| Asphalt cement collected from the plant in 3.8 L (1-gal) cans | 5 for each type of binder | 10 for each type of binder |
| Bulk asphalt mix collected onsite in 18.9-L (5-gal) buckets | 8 for each section | 15 for each section |
| Bulk combined aggregate collected from the plant in 18.9-L (5-gal) buckets | 5 for each mix | 20 for each mix |
| Bulk RAP material collected from the plant in 18.9-L (5-gal) buckets | 5 for each mix | 10 for each mix |
| WMA additive collected from the plant in 3.8-L (1-gal) cans | 1 for each type of additive | 3 for each type of additive |
| 152-mm (6-inch) cores at time interval t0 | 4 per test section | 4 per test section |
| 152-mm (6-inch) cores at time intervals t1 to t3 | 3 per test section at each time interval | 3 per test section at each time interval |
| Bulk unbound material in bags | 3 per test section at each time interval | 3 per test section at each time interval |

## MATERIALS TRACKING SYSTEM

LTPP materials sampling and testing activities typically involve multiple organizations. These organizations may include FHWA, the State or provincial highway agency, the RSC, the TSSC, and the laboratory contractor. Because of the number of hands that material samples and data pass through, a robust online Materials Tracking System (MTS) is vital. The purpose of the MTS is to ensure that specimens and data do not "fall through the cracks" as they transfer from one organization to the other.

The MTS includes basic sampling information, a means to track the current location of the sample, a means to assign laboratory tests to the sample, a means to track the status of the laboratory testing, and a means to track test results. LTPP has previously developed such an MTS, as part of the MAP, and it was hosted within LTPP. The activities performed by the previous MTS are shown in figure 4.



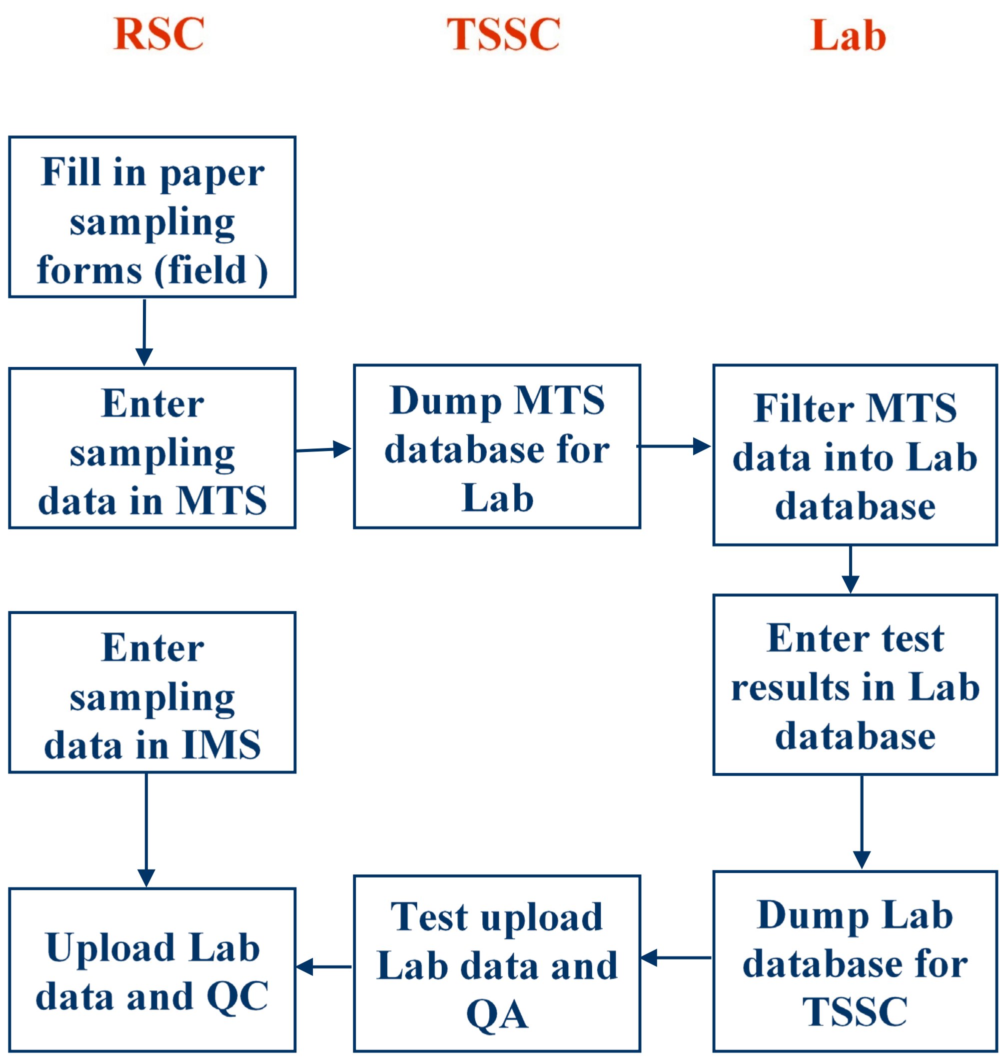

Source: FHWA.
QA = quality assurance.

**Figure 4. Flowchart. MTS tracking activities.**

A drawback to the previous MTS is that it involved three separate databases. These databases were as follows:

- The LTPP PPDB, the ultimate repository of sampling and testing data.
- The MTS database, an online database that serves as an intermediary for the various entities.
- The laboratory's database.

In the previous MTS, the RSC was required to enter sampling information into both the MTS and the PPDB. The TSSC would then periodically send snapshots of the MTS to the laboratory, and these snapshots were used to populate the key fields in the laboratory's database. The laboratory entered the test results associated with those key fields in their database and sent a snapshot of their database to the TSSC. The TSSC then performed a test upload of the laboratory database into the PPDB and performed quality assurance (QA) checks. Once these checks were complete, the TSSC forwarded the files to the RSC for upload. This data flow is shown in figure 5.




Source: FHWA.

**Figure 5. Flowchart. Existing MTS data flow.**

The complexity of data flow in the previous MTS was necessary because the PPDB was not online at the time, which required the MTS to act as an intermediary between the PPDB and the laboratory database. This approach had several drawbacks:

- The RSC must enter sampling data into both the MTS and the laboratory database.
- There are many instances where data were sent from one entity to another. Although these transmittals are tracked in the MTS, the tracking required effort.
- The laboratory contractor must create their own database containing all information necessary to populate the PPDB tables. This increased costs for the contractor and put laboratories without extensive LTPP experience at a disadvantage in the bidding process.

Since the development of the previous MTS, LTPP has updated the IMS, using a single database to store data for all regions. Data entry is performed using the LTPP Data Entry Portal (LDEP) web portal (Elkins and Ostrom 2019). The new online nature of the PPDB enabled changes to the MTS concept that can overcome the drawbacks mentioned previously. By implementing the MTS on the same server as the PPDB, data can be easily transferred between the two databases, eliminating the need to duplicate data entry or upload files and greatly easing the process of tracking data. In addition, the laboratory contractor is spared the expense and complexity of maintaining a separate database as well as the need to understand and keep track of the many key fields used for materials data in the PPDB.

Development of the new MTS was performed on an Oracle Apex instance on the LTPP production server (APEX version 4.2.5.00.08) (Oracle 2014). This MTS provides the same functionality as the previous MTS with the following enhancements:

- Autogeneration of specimen identification numbers.
- Tracking of laboratory modification and combination processes.
- Assignment of test order when multiple tests are performed on the same specimens.
- Allowance for more than one laboratory testing contractor.
- Inclusion of additional sampling information, which can allow for automatic population of PPDB sampling tables, such as TST_HOLE_LOG, TST_SAMPLE_LOG, TST_ASPHALT_CEMENT, and TST_UNCOMP_BITUMINOUS.

# CHAPTER 5. PERFORMANCE MONITORING

Working with FHWA and the ETG, the research team established the performance monitoring guidelines for SPS-10 experiments. These guidelines have three distinct phases: pre-overlay, short term, and long term. The timeframes and intervals for testing in these phases are described in this chapter. Volume V of this report series provides the complete SPS-10 Performance Monitoring Plan (Puccinelli et al. 2022c).

## PRE-OVERLAY MONITORING

Current LTPP practice captures the condition within 6 mo before and 6 mo after completion of an overlay. This practice will also be used for the SPS-10 experiment. Pre-overlay testing will consist of manual distress surveys, FWD testing, transverse profile, longitudinal profile, and texture measurements.

## SHORT-TERM PERFORMANCE MONITORING

To consider early aging effects and take advantage of the fact that field personnel will be onsite to conduct materials sampling, the SPS-10 experiment has a modified monitoring frequency to collect early-life performance over each project's first 18 mo. The increased frequency monitoring includes distress, FWD, texture, transverse profile, and longitudinal profile. Table 28 summarizes the desired short-term monitoring intervals for the SPS-10 experiment.

**Table 28. Summary of short-term LTPP performance monitoring intervals.**

| Time After Construction (mo) | Longitudinal Profile/Texture | Distress/Transverse Profile | FWD |
|---|---|---|---|
| 0 | ✓ | ✓ | ✓ |
| 3–6 | ✓ | ✓ | ✓ |
| 12 | ✓ | ✓ | ✓ |
| 18 | ✓ | ✓ | ✓ |

## LONG-TERM PERFORMANCE MONITORING

After the first 18 mo of short-term monitoring, the monitoring frequency of the WMA experiments is the same as that of the other SPS experiments, listed in table 29. This frequency is consistent with the current LTPP directive on performance monitoring (currently Directive GO-68) (Nehme 2019). These intervals may change in the future in response to any directive modifying or replacing Directive GO-68.

**Table 29. Summary of LTPP SPS-10 performance monitoring intervals.**

| Performance Measure | Desired Level | Maximum Allowable Interval Period |
|---|---|---|
| Longitudinal profile/texture | Annual | Every 2 yr |
| Distress/transverse profile | Annual | Every 2 yr |
| FWD | Every 3 yr | Every 5 yr |

## MONITORING PROCEDURES

Current LTPP guidelines and documentation were used to describe how the data collection is performed. Manual distress surveys are performed using the LTPP *Distress Identification Manual* (Miller and Bellinger 2014). Likewise, the *LTPP Manual for Collecting and Processing Longitudinal Profile, Macrotexture, and Transverse Profile Data* is used without modification (Perera and Elkins [forthcoming]). The FWD testing plans (i.e., lane designations, drop sequences, stationing) for the SPS-1 in the LTPP *Manual for Falling Weight Deflectometer Measurements*, Version 4.1, are used for SPS-10 WMA projects (Schmalzer 2006).

# CHAPTER 6. CONSTRUCTION DOCUMENTATION REQUIREMENTS

Completely capturing all-important construction activities and information is critical to future analysis activities involving SPS-10 projects. These activities and information include a range of data elements identified as contributing to test section performance as well as detailed construction reports documenting all work performed on each project. Volume VI of this report series provides all the construction documentation requirements for SPS-10 projects (Puccinelli et al. 2022d).

## SPS-10 CONSTRUCTION DATA SHEETS

Working with FHWA and the ETG, the project team developed a series of 38 Construction Data Sheets. These sheets are completed on each project—some are at the project level, and others are at the test section level—and the information is then entered into the LTPP PPDB. Table 30 shows the SPS-10 Construction Data Sheets (more detailed information on each sheet can be found in volume VI of this report series) (Puccinelli et al. 2022d). The team worked with the TSSC to streamline the construction data collection for the SPS-10. In previous experiments involving the rehabilitation of existing pavements, data were captured in the Inventory, Rehabilitation, and SPS modules of the LTPP database. For the SPS-10, all this information was folded into one module for ease of storage and use by the data users. It is the responsibility of the RSCs to work with the State and provincial highway agencies to collect this information.

**Table 30. List of LTPP data sheets and titles.**

| LTPP SPS-10 Construction Data Sheet Number | LTPP SPS-10 Construction Data Sheet Title |
|---|---|
| LTPP SPS-10 Data Sheet 1 | SPS ID |
| LTPP SPS-10 Data Sheet 2 | Project Stations |
| LTPP SPS-10 Data Sheet 3 | General Information |
| LTPP SPS-10 Data Sheet 4 | Layer |
| LTPP SPS-10 Data Sheet 5 | Age and Major Improvements |
| LTPP SPS-10 Data Sheet 6 | Snow Removal/Deicing |
| LTPP SPS-10 Data Sheet 7–9 | Highway Performance Monitoring System (HPMS) Data Items (Project Level) |
| LTPP SPS-10 Data Sheet 10 | HPMS Data Items (Section Level) |
| LTPP SPS-10 Data Sheets 11–13 | PMA Aggregate Properties |
| LTPP SPS-10 Data Sheet 14 | PMA Binder |
| LTPP SPS-10 Data Sheets 15–16 | PMA Binder Aged |
| LTPP SPS-10 Data Sheet 17 | RAP |
| LTPP SPS-10 Data Sheets 18–20 | PMA Lab Mix Design |
| LTPP SPS-10 Data Sheets 21–22 | PMA Mix Prop |
| LTPP SPS-10 Data Sheets 23–24 | PMA Construction |
| LTPP SPS-10 Data Sheets 25–26 | Unbound |
| LTPP SPS-10 Data Sheets 27–28 | Subgrade |
| LTPP SPS-10 Data Sheet 29 | QC Measurements |
| LTPP SPS-10 Data Sheet 30 | Field Thickness |
| LTPP SPS-10 Data Sheet 31 | Notes and Comments |
| LTPP SPS-10 Data Sheet 32 | Milled Sections |
| LTPP SPS-10 Data Sheet 33 | Improvement Listing |
| LTPP SPS-10 Data Sheet 34 | Pre-Overlay Surface Preparation Sketch |
| LTPP SPS-10 Data Sheet 35 | PMA Pre Overlay (Patch) |
| LTPP SPS-10 Data Sheet 36 | PMA Pre Overlay (Sealing) |
| LTPP SPS-10 Data Sheets 37–38 | PMA Pre-Overlay Seal Coat |

In addition to the sheets themselves, detailed instructions on completing every field on each sheet were developed, and recommended QC checks to be incorporated into the PPDB were provided to FHWA and the TSSC. Several of the sheets required the development of new data entry codes or modification of existing codes to include information relevant to WMA pavements.

## SPS-10 CONSTRUCTION REPORTS

A lesson learned from the construction of the SPS-1 through SPS-9 projects was the importance of having project-specific construction reports. Furthermore, having standardized report elements helps the State and provincial highway agencies and the pavement community compare projects to one another and the original experimental design. Therefore, the project team developed a template for what should be included in each SPS-10 Construction Report. These reports are to comprise the following:

- Cover Page.
- Table of Contents (including List of Tables and List of Figures).
- Chapter 1: Introduction.
- Chapter 2: Project Description.
- Chapter 3: Construction.
- Chapter 4: Summary.
- Chapter 5: Key Observations.
- Appendix A: Construction Photographs.
- Appendix B: Mix Designs.
- Appendix C: Materials Sampling and Testing Layouts.
- Appendix D: Other Construction Documents.
- Appendix E: Complete set of SPS-10 Data Sheets.
- Appendix F: SPS-10 Deviation Report.

Instructions regarding what to include in every chapter and appendix are also part of the guidelines. In some instances, specific text (i.e., a general overview of the SPS-10 experiment to be included in the Introduction) was developed to be included in each SPS-10 Construction Report.

# CHAPTER 7. OTHER DATA COLLECTION NEEDS

Beyond the routine pavement performance data collection activities described in chapters 4 and 5 and the construction data described in chapter 6, several other data collection needs were established and described for this project. These involved both GPS and SPS experiments.

## GPS PROJECTS

The following two existing experiments within the LTPP program were expanded to accommodate existing LTPP test sections that receive overlays with WMA technologies:

- GPS-6: AC Overlays of Existing AC Pavements.
- GPS-7: AC Overlays of Existing PCC Pavements.

This expansion required revision to the existing documentation of the two experiments. However, no changes were required to the experimental matrix because new test sections will not be recruited to the GPS-6 and GPS-7 experiments. Populating the expanded experiments is retroactive and based on the State or provincial highway agency's decision to overlay an existing test section with WMA, allowing existing test sections to remain in the study and receive continued monitoring.

The two expanded experiments are called GPS-6W and GPS-7W. Revisions to the LTPP Inventory, Maintenance, and Rehabilitation documentation were made to accommodate the expanded experiments. A revised version of the LTPP Maintenance and Rehabilitation Data Collection Guide was created and published outside the SPS-10 report volumes. These changes were included as part of the phase I interim report and were reviewed by the LTPP team. The major changes are summarized as follows:

- Added descriptions for WMA and definitions for SPS-10, GPS-6W, and GPS-7W experiments.
- Added Rehabilitation Sheets 68–78 to document WMA overlays.
- Added Rehabilitation Sheets 79–95 to document WMA overlays with RAP and RAS.
- Added Inventory Sheets 24–26 to document Superpave mixture properties.
- Updated relevant codes tables.

In addition, several additional tables will need to be created within the LTPP PPDB, including tables in the LTPP Inventory and Rehabilitation modules. Detailed information on the database schema and table designs recommended for the changes made to these modules was provided to the TSSC.

## SPS-10 PROJECTS

Compared to the GPS-6W and GPS-7W experiments, the other data collection needs for the SPS-10 experiment were considerably greater. Some of the types of data have been described in chapters 4, 5, and 6 of this report, and the following sections describe the additional items.

### Traffic Data

LTPP has long been the leader in the collection of quality traffic data. These data are critical in assessing the vehicle loading on pavements. To quantify traffic loading, LTPP collects both automated vehicle classification (AVC) and weigh-in-motion (WIM) records. Because traffic data collection is the responsibility of the State and provincial highway agencies participating in the program, the team included the traffic data collection requirements as an attachment to the SPS-10 Nomination Guidelines.

Developed working with FHWA and the WMA ETG, the Guidelines describe the preferred and minimum requirements for SPS-10 traffic data. Strongly preferred is a continuous WIM site calibrated per LTPP protocols. As part of the nomination process, the agency would indicate whether a WIM system was in place already that would be sufficiently close to the proposed project to use or whether the agency was willing to install a WIM system. Failing that, the minimum requirement to be an acceptable SPS-10 project would be to provide 2 w of continuous classification data four times per year to account for seasonal, weekday and weekend, and truck loading pattern variations. All monitored traffic data are required to be submitted regularly and formatted in accordance with the FHWA *Traffic Monitoring Guide* (FHWA 2016). Sites with only AVC data also require an LTPP Traffic Sheet 10 every year to provide Equivalent Single Axle Load estimates for the SPS-10 project.

### Weather Data

Climatic data at the location of the test sections are a critical component in studying long-term performance. SPS-1, -2, and -8 projects captured onsite weather information via an automated weather station (AWS) constructed specifically for the LTPP experiment. The AWS sites were decommissioned in 2004. However, SPS-3, -4, -5, -6, and -9 projects, as well as all GPS sections, use a virtual weather station (VWS) where up to five nearby operational weather stations (typically National Oceanic and Atmospheric Administration) are triangulated to provide an estimate of weather conditions at the test sections. Although onsite measurement is the most accurate, FHWA decided to use the VWS system for all WMA experiments incorporated into the LTPP PPDB. The costs and resources associated with installing onsite AWS at the WMA were not believed to be worth the incremental accuracy improvement.

The procedure used in establishing VWS data for existing LTPP test sections is used for the SPS-10 projects. Modifications to the procedure are not required.

### Ancillary Data

The team also recommended having the RSCs record a walking video survey of each test section nominated into the LTPP program. These videos provide a permanent record of the baseline condition of the test section, provide landmark and geometric information that can be useful in locating the site and determining whether traffic control is feasible at the location, and can identify geological and drainage features at the site. The team's experience has been that similar videos taken during the nomination of existing GPS test sections have been extremely valuable over time in answering questions about the site. The videos can be stored in Ancillary Data Entry Portal under current protocols.

# CHAPTER 8. MARKETING AND TECHNICAL SUPPORT

Throughout the research, the team provided marketing and technical support services regarding the LTPP WMA experiment. Because this research involves a number of entities, significant coordination took place between the WMA team and FHWA, the RSCs, the TSSC, and State and provincial highway agencies. This chapter summarizes the activities performed related to marketing and technical support of the WMA experiment.

Coordination with FHWA involved several activities. In addition to regular updates on the research status, the team also developed presentations on the status of the research for FHWA LTPP team members to use when presenting internally within FHWA as well as to AASHTO and committees. The team also participated in the Team LTPP meetings held by FHWA. The WMA team presented the project's status and answered questions about the project at those meetings.

As mentioned, the team worked closely with the TSSC and the RSCs throughout this research. Because new data tables and elements were created for the LTPP WMA experiment, the team worked with the TSSC on database schema and QC/QA protocols. Additional coordination took place when implementing the MTS because the system was integrated into the LDEP platform, which the TSSC manages.

As each component of the SPS-10 experiment was developed, the team answered questions from the RSCs and addressed questions and comments associated with draft versions. Presentations on the SPS-10 tailored to State and provincial highway agencies were developed for the RSCs to use in their visits with agencies. The team also responded to questions from the RSCs specific to the nomination process. Before implementing the new MTS, a webinar with the RSCs and the TSSC was developed and delivered as a training tool for its use.

A number of marketing/outreach presentations were produced and targeted agencies and the pavement community. Two webinars on the SPS-10 experiment were developed and delivered as part of this research. In addition, the team developed and delivered presentations at the annual Transportation Research Board meeting. Other coordination took place with the FHWA Asphalt Mixtures ETG in developing a white paper on recommended supplemental test sections and ancillary materials tests for agencies to consider when building SPS-10 projects. In addition to these presentations, the team developed a TechBrief to announce the recruiting process of the SPS-10 projects.

The overall purpose of the marketing and outreach activities described was to ensure that the WMA experiment developed could be easily incorporated into the existing LTPP framework while also ensuring highway agencies were informed of the new experiment. Using the variety of outreach methods described allowed for smooth implementation both internally and externally.

# CHAPTER 9. CONCLUSIONS

The LTPP program, established by the original SHRP and continued through FHWA, has been the main source of national in-service pavement performance data since its inception in the late 1980s. Over that time, the program has developed a number of experiments to study specific areas of interest to the pavement community. The last test sections to be incorporated into the program were constructed in 2000. Since that time, SHAs have seen a number of changes in paving materials and practices, including a rapid increase in the use of WMA. Recognizing the need to answer long-term performance questions related to WMA, FHWA embarked on this research. The overall objective of the study was to develop a means for the LTPP program to study WMA. The result was the development of the SPS-10 experiment, "WMA Overlays of Existing AC Pavements." This report discussed the tasks involved in completing this research as well as the documentation developed to support the nomination, recruitment, construction, testing, and monitoring of WMA overlays.

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