# Long-Term Pavement Performance Warm-Mix Asphalt Study Final Report, Volume II: SPS-10 Experimental Matrix and Research Plan

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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 the 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 research 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 Study-10 (SPS-10) experiment called "Warm Mix Asphalt Overlay of Asphalt Pavement Study."

The purpose of this volume of the report series is to document the research plan and experimental design 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

The purpose of this report is to document the research plan and experimental design for the Specific Pavement Studies-10 (SPS-10) experiment for the Long-Term Pavement Performance (LTPP) program. Projects nominated for the SPS-10 experiment would be constructed specifically to satisfy experiment design cells within the experimental matrix and would adhere to the guidelines set forth in this research plan. Because these projects would be nominated prior to construction, all material properties, sampling, and construction activities could be documented to ensure a complete data set. This document defines the goals/objectives of the SPS-10 experiment, the independent variables to be studied, and the methods used to control other factors that affect pavement performance.

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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<br>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 second 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 all the volumes of this report 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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| | |
|---|---|
| AC | asphalt concrete |
| ESAL | equivalent single axle load |
| ETG | expert task group |
| FHWA | Federal Highway Administration |
| GPS | General Pavement Studies |
| HMA | hot-mix asphalt |
| LTPP | Long-Term Pavement Performance |
| NCHRP | National Cooperative Highway Research Program |
| PPDB | pavement performance database |
| RAP | recycled asphalt pavement |
| RAS | recycled asphalt shingle |
| SPS | Specific Pavement Studies |
| WMA | warm-mix asphalt |

# CHAPTER 1. INTRODUCTION

The purpose of this report is to document the research plan and experimental design for the Specific Pavement Studies-10 (SPS-10) experiment for the Long-Term Pavement Performance (LTPP) program. This experiment is designed to capture information on the short- and long-term performance of warm-mix asphalt (WMA) relative to hot-mix asphalt (HMA). This experiment has been structured to ensure consistency and compatibility with the existing LTPP objectives and database while addressing information gaps regarding WMA performance. The experiment will capture field performance and laboratory test data that will allow both user-agencies and researchers a better understanding of the potential benefits of WMA. Collectively, this information could be used for performance prediction.

For the purposes of this experiment, WMA is defined as asphalt mixtures produced at least 17 °C (30 °F) below normal HMA production temperatures, or asphalt produced at or below 135 °C (275 °F).

The SPS-10 experiment described in this document is intended for test sections not previously in the LTPP database. Projects nominated for the SPS-10 experiment would be constructed specifically to satisfy cells within the experimental matrix and would adhere to the guidelines outlined in this research plan. Because these sections would be nominated prior to construction, all material properties, sampling, and construction activities could be documented to ensure a complete data set. SPS experiments in the LTPP program are focused on very specific topics with limited independent variables. This document defines the goals/objectives of the SPS-10, the independent variables to be studied, and the methods used to control other factors that affect pavement performance.

Existing LTPP test sections that are rehabilitated with WMA technology are included in the General Pavement Studies-6 (GPS-6) and GPS-7 experiments. Details regarding the expanded GPS-6 and GPS-7 experiments can be found in the LTPP maintenance and rehabilitation data collection guide, which has been revised and expanded to account for WMA overlays of existing LTPP test sections (Simpson et al. 2021).

# CHAPTER 2. 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 of the tour were promising, but several challenges using WMA still needed to be addressed, including long-term performance. As a compaction aid with a number of benefits (i.e., extending the paving season, increasing haul distance, and reducing fuel consumption and emissions), WMA has become increasingly popular in the United States. The first WMA 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. Interest in WMA has continued to gain momentum, and in 2011, 30 States had specifications for WMA construction (Prowell, Hurley, and Frank 2012). In addition, the amount of WMA increased by 175 percent from 2009 to 2010, accounting for 13 percent of total asphalt production in the United States (Prowell, Hurley, and Frank 2012).

At the time of the writing of this report, currently over 35 WMA technologies are offered in the United States that alter the properties of the asphalt binder to improve aggregate coating and compactability at lower production and compaction temperatures than conventional HMA (Corrigan 2011). The 35 technologies available can be grouped into the following four categories (some technologies are a combination of these categories):

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

The LTPP SPS-10 experiment focuses on the chemical additive and foaming process categories. Given the growth and popularity of WMA, a number of States have conducted studies on WMA. Additionally, at the time of this research, the National Cooperative Highway Research Program (NCHRP) had sponsored eight studies on WMA. The majority of studies have investigated mixture design practices, engineering properties, and constructability. While NCHRP 9-49A was structured to address the long-term performance of WMA, the project's 5-yr duration can only capture a fraction of the pavement's intended design life (Martin et al. 2014). As such, a research plan is needed that successfully captures long-term performance and behavior over the typical 20-yr design life while also obtaining materials testing results, construction details, pavement structure information, traffic levels, and climate data. Additionally, the SPS-10 experiment considers the use of recycled asphalt pavement (RAP). Initial research on the use of RAP with WMA has demonstrated improved mixture properties in terms of the blending of old and virgin (new) binders; however, studies have not evaluated the long-term performance aspects of the use of RAP with WMA, such as the effect of different production temperatures and asphalt production plant type on the blending process and final mixture and the optimal binder replacement determination procedures.

Table 1 below summarizes the NCHRP-funded WMA studies considered.

**Table 1. NCHRP projects including WMA (as of 2014).**

| Project Number | 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 1 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 |

The LTPP WMA research team carefully considered how these NCHRP projects may 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 expert task group (ETG) meeting.

Integrating existing WMA sections into the LTPP program would provide a jump start in evaluating the long-term performance of in-service sections. The LTPP program has rigorous guidelines for data collection, review, and storage. These guidelines apply to the test section construction, materials sampling and testing, and performance monitoring data.

While the NCHRP (and other) test sections often had onsite personnel during construction and occasionally utilized LTPP practices for elements of the data collection, overall, these sections were not compatible with the existing LTPP pavement performance database (PPDB). The following summarizes the reasons that prevented the inclusion of these test sections in the SPS-10 experiment:

- Use of short test sections: Standard LTPP test sections are 152.4 m (500 ft) in length, but most of the NCHRP projects were significantly shorter.

- Use of improper sampling and testing: The LTPP program prohibits destructive sampling within the test section, but the NCHRP projects performed coring within the test sections. Also, materials sampling and testing processes were not conducted utilizing LTPP protocols.

- Use of nonaccredited raters: The LTPP program requires distress surveys to be performed by accredited raters using specific forms and definitions. Although these definitions were largely incorporated, the surveys were performed by nonaccredited raters.

- Collection of limited data: Deflection and roughness data were collected on very few of the existing WMA projects, and the equipment used to collect the limited data were not calibrated per LTPP specification.

- Nonuse of LTPP forms: None of the data sets utilized LTPP forms. As a result, even if the information could be found, substantial effort would be needed to get it documented and entered into the LTPP PPDB.

While the test sections themselves were not recommended for inclusion into the LTPP PPDB, the lessons learned in the conduct of the above projects contributed to optimizing decisions made in association with the LTPP WMA projects.

# CHAPTER 3. KEY CONSIDERATIONS

The SPS-10 experiment has been designed to address information gaps that currently exist with WMA pavements. This chapter describes some of the key considerations used to develop the SPS-10 experimental design.

The data needs for WMA center on how binder and mixture properties affect performance relative to HMA. The first factor in the experimental design allows a direct comparison of WMA to HMA in a comprehensive range of in situ climatic conditions and traffic loading. In addition, questions exist about the use of WMA technology in RAP-included mixtures. As a result, RAP was included in the experimental matrix. While various categories of WMA technologies are currently in use, pavement performance data on the applicability of each category under different in situ conditions have not been collected.

Because WMA is relatively new, long-term field performance data are not available. Concerns with moisture sensitivity due to lower production temperatures and the presence of aggregate moisture have been documented but have not yet been thoroughly evaluated on in-service pavements. The SPS-10 is designed to address this concern as well as the effect of WMA over time on low-temperature cracking, fatigue cracking, rutting, and stiffness.

Many factors were considered in developing the preliminary experiment design. However, given practical constraints—financial resources and size of the experimental matrix required to adequately represent all factors—the resulting experiment design reflects the prioritization of factors within a statistically sound full factorial, as described in the following section. This experiment will only consider mixture produced and placed at warm-mix temperatures. Mixtures produced at normal hot-mix temperatures but placed at warm-mix temperatures, where the warm-mix technology is only used as a compaction aid, will not be considered as part of the core experiment. But such mixtures could be implemented as supplemental sections.

# CHAPTER 4. SPS-10 EXPERIMENTAL DESIGN

SPS experiments typically consist of projects located across North America. Each project is selected and constructed to populate a specific set of site conditions/experimental factors. These factors are combined to develop an experimental matrix, which provides an overview of the projects required to achieve a statistically sound and robust experiment. The representation of WMA technology in the primary-tier factorial of the SPS-10 experiment is shown in table 2, which identifies the primary experimental factors and their relationships. The site factors are identified across the top of the matrix in table 2, while pavement mixture factors are listed on the left side. The factors included within the experimental design were selected based on input from the ETG assembled specifically for this study. While many characteristics (or independent variables) were considered, only the major factors discussed below were selected with assistance from the ETG and approval from the Federal Highway Administration (FHWA). Attempting to account for all of the independent variables would not be practical, especially those that have shown little or poor correlation with overall performance.

**Table 2. Final experimental matrix for SPS-10.**

| 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 HMA control section and two different WMA categories (foaming process and chemical).

Each row in table 2 represents the recommended quantity of projects to be nominated and constructed for the SPS-10 experiment. Each project location contains a minimum of three test sections (each of them 152.4 m [500 ft ] in length) constructed contiguously along a section of highway. The SPS-10 experiment is designed such that all factors (i.e., traffic, climate, subgrade, existing pavement structure, and asphalt production plant) are constant across all test sections at one project location. The WMA technology used varies in the core test sections in order to directly compare the specific WMA technology to HMA under the same in situ conditions, eliminating confounding effects typically introduced when comparing pavement features at different locations.

The core experiment avoids constructing an SPS-10 experiment where both WMA test sections are using technology from the same category. If an agency wants to evaluate different WMA technologies within the same category, additional test sections may be built so that the project has more than three test sections. However, each project must consist of test sections representing at least one WMA test section using a chemical additive, one WMA test section using foaming process, and at least one HMA control section. The three sections defined here will be considered the "core" experiment and will be used to populate the national experimental design. Any additional test sections constructed within the project will be considered supplemental sections. While data will be collected and stored in the LTPP database for these supplemental sections, they will not be used to populate the national experimental matrix. Supplemental sections are valuable components of the SPS-10 project as they allow U.S. State and Canadian Provincial highway agencies to study specific mixtures of local interest.

## REPLICATION CONSIDERATIONS

The experimental matrix in table 2 includes replication of the primary-tier factorials. A minimum of two projects must be recruited for each combination of primary-tier factorials of climate and traffic. If more than two projects are nominated and constructed for some cells within the matrix, they will be included in the LTPP database. The intent of the matrix is to achieve a balanced experiment with all factors represented but does not prevent or limit additional replicates from being included in the program.

Including an adequate number of replications helps to estimate unbiased estimation of experimental errors in designed experiments. Estimation of experimental error is very important in inferential statistics to compare both main and interaction effects and to estimate the standard errors and confidence intervals for treatment means. In addition, to have an adequate number of replications, true replications are required to estimate unbiased experimental error. True replication is only achieved when treatment combinations within a factorial design are randomly assigned to replicated experimental units. Failure to randomly assign treatments to replications results in pseudoreplication. Experimental error computation obtained from pseudoreplication is not an independent estimate and underestimates the true error increasing the probability of errors occurring and the chances of detecting false-positive treatment differences.

Having repeat test sections at one SPS-10 (i.e., multiple test sections using the same WMA technology) is not true replication. In the case of the SPS-10, true replication only occurs when multiple projects are constructed for each primary-tier factorial. As such, the experimental design in table 2 provides for at least two independent projects to be constructed under the same primary factorials.

## SPS-10 WMA DEFINITION

For purposes of this LTPP experiment, WMA is defined by the following criteria:

- A mixture produced at or below 135 °C (275 °F).
- A mixture produced at least 17 °C (30 °F) below the production temperature of the HMA control.

The ETG developed this definition of WMA with consideration given to accommodate the water-foaming technologies.

## CLIMATE

Four climatic zones have been previously defined by the LTPP program: wet-freeze, dry-freeze, wet-no freeze, and dry-no freeze. The criteria established to distinguish wet and dry climates is based on annual precipitation. Climates with annual precipitation of fewer than 508 mm/yr (20 inches/yr) are considered dry by LTPP definitions. Conversely, wet climates are those receiving more than 508 mm/yr (20 inches/yr) of precipitation. The LTTP program uses the freezing index to define the freeze and no-freeze climates. A site located where the annual freezing index is greater than 83 °C d (150 °F d) is, according to LTPP definitions, in the freeze climatic zone by LTPP definitions.

Climate is a site condition that is addressed in the project location experimental matrix. The SPS-10 experiment requires equal representation in all four climatic zones.

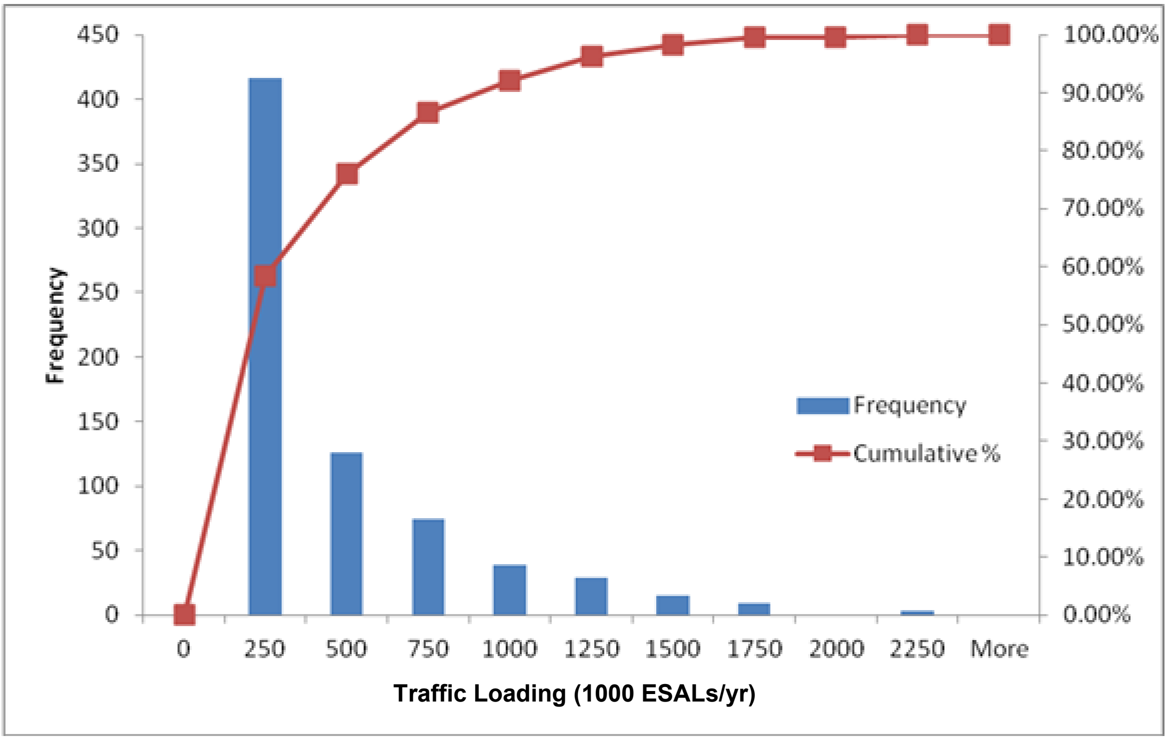
The SPS-10 experiment does not require the installation of an automated weather station onsite; however, having a fully functional weather station (maintained and operated as part of the National Oceanic and Atmospheric Administration or National Weather Service) in the nearby vicinity is preferable.

## TRAFFIC LEVELS

Traffic loading has a direct and significant impact on the long-term performance of pavements. Annual traffic loading typically grows with time, and the rate of growth is dependent on many factors. This phenomenon can result in significant differences in annual loading between the beginning and end of the pavement service life. To ensure that the WMA experiment captures a range of loading conditions, two categories were established by evaluating measured loading at the existing LTPP sites. The distribution of average annual equivalent single axle loads (ESAL)/yr is provided in figure 1, while summary statistics are provided in table 3. These data were assembled from all LTPP locations where monitored traffic data are available and represent the annual average of all years collected for each location. The ESAL values reported are for one lane in one direction of travel (i.e., design ESALs). As can be seen in table 3, the mean for the data set is 338,000 ESALs/yr; however, the distribution is skewed, with approximately 60 percent of the sites receiving less than 250,000 ESALs/yr. In addition, traffic loads continue to grow, thereby increasing ESAL levels. Some of the data included in figure 1 were captured in the early to mid1990's and have not been adjusted for growth. Based on this distribution and considering the difficulties in obtaining lane closure in high-traffic areas, the low-traffic category is defined as sites receiving less than 500,000 ESALs/yr. A site with traffic greater than or equal to 500,000 ESALs/yr will fall into the high traffic category for purposes of this experiment.

Traffic information will be quantified and stored as part of the monitoring data from each site. While test sections with only traffic data from either portable or permanent equipment will be considered for inclusion in the experiment, sections with a continuously operating permanent device are preferred for classification and weight data. This level of data collection is preferred for two reasons: to provide the accurate traffic loading measurements required to develop mechanistic and mechanistic/empirical design models and to provide the base data necessary to understand the intricacies of the interactions among pavement, traffic load, and environment. During the nomination process, selected project locations should have a full-time, fully operational weigh in motion on the same route and within close proximity to the SPS-10 experiment project that captures traffic patterns equivalent to those seen at the test section location.

While data collection is preferred on the site continuously for the year, the minimum recommended data collection effort for each site is 2 wk of continuous classification data, four times/yr (a total of 8 wk of classification data/yr). The U.S. State or Canadian Provincial highway agency is responsible for ensuring that data collected are representative of local conditions, accounting for seasonal variation, weekday/weekend differences, and inconsistent truck loading patterns throughout the year.




Source: FHWA.

**Figure 1. Graph. Distribution of annual traffic loading at LTPP sites.**

**Table 3. Summary statistics of annual traffic loading at LTPP sites.**

| Statistic | Average Annual Traffic Loading (1,000 ESALs/yr) |
|---|---|
| Mean | 338 |
| Median | 195 |
| Standard deviation | 377 |
| Minimum | 2 |
| Maximum | 2,172 |

## WMA TYPES

While there are over 35 different WMA products available, the products can be grouped into four broad categories based on the mechanisms used to modify the binder properties during mixing and compaction. The SPS-10 experimental matrix will focus on the chemical additive and foaming process categories for core test sections. The lists provided under each category are not intended to be a comprehensive set, and other products meeting the definitions described below can be used in the SPS-10 experiment.

Chemical additives are defined as water-free (nonaqueous) chemistry packages that modify the binder properties to enhance coating, adhesion, and workability at reduced temperatures, including surfactants, fatty acid chemical additives, cationic surface-active agents, and rheology modifiers. Examples of products that fall into this category include the following:

- CECABASE®.
- Evotherm®.
- HyperTherm/QualiTherm™.
- Rediset™.

Organic additives are plant-based, wax-based, or sulfur-extended materials designed to provide viscosity reduction, aid in asphaltenes dispersion, and act as a lubricant at mixing temperatures below that of conventional HMA. Organic additives are not included in the core experiment but are strongly encouraged for use in supplemental sections. Examples of organic additives include the following:

- BituTech PER™.
- LEADCAP™.
- Sasobit®.
- SonneWarmix™.
- Thiopave®.

Foaming additives are defined as water-containing materials added to the mixture to foam the asphalt. The most common foaming additive is synthetic zeolite. Zeolite contains 20–30 percent water that is released at temperatures above the boiling point of water. The water from the zeolite foams the asphalt binder. Examples of foaming additives include the following:

- Advera®.
- Aspha-min®.

The foaming process category includes all WMA types that utilize assemblies/modifications to the asphalt production plant to foam binder without additives (other than water), including foaming nozzles, expansion chambers, vortex mixers, and shearing devices. While the other categories may be added to the mixture using some type of nozzle or other addition, the key distinction between the foaming process category and others is the absence of additives. WMA technologies that fall into the foaming process category only utilize water. Examples of this category include the following:

- Accu-Shear™.
- AQUABlack™.
- AquaFoam®.
- Astec Green System™.
- Eco-Foam™.
- Gencor ultrafoam™®.
- Low emission asphalt.

**RAP**

Results from the NCHRP 9-43 project indicate that binder from aged RAP will blend with virgin binder at WMA temperatures if the production temperatures exceed the high-temperature PG grade of the RAP binder (Prowell, Hurley, and Frank 2012). Field trials have been constructed in the United States using WMA technologies in mixes with RAP contents ranging from 20-50 percent (Bonaquist 2011). Segments of the pavement community are interested in evaluating the long-term performance of RAP-included WMA.

The LTPP SPS-5 experiment required all recycled test sections to have a RAP content of 30 percent. The project description for the report *NCHRP 9-46: Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content* defines high-RAP content mixtures as those containing more than 25 percent RAP (West, Willis, and Marasteanu 2013). The current practice of U.S. State and Canadian Provincial highway agencies must also be considered. Establishing a threshold incompatible with State practices could result in difficulties nominating and populating the experimental design with test sections.

A multiple-factorial approach for RAP was not utilized in the SPS-10 experiment design. However, a requirement for all of the core test sections to have RAP contents between 10 percent and 25 percent based on binder replacement (expressed as the amount of binder contribution from RAP as a percentage of total binder in the mixture) has been included. The U.S. State or Canadian Provincial highway agency is expected to follow standard practice for the RAP binder replacement. The three core test sections on each project must have the same RAP percentages and should achieve the same binder replacement levels. If an agency wishes to vary the RAP binder replacement levels or include recycled asphalt shingles (RAS), supplemental sections can be included. However, varying binder replacement levels were not incorporated into the national experimental design of core test sections.

Contractors typically introduce additives to RAS stockpiles to ensure workability. In some cases, WMA additives are used for this purpose. If a WMA technology is added to the RAS stockpile, the material can still be used on supplement sections of an SPS-10 project as long as the control section is constructed at HMA temperatures (without additional WMA technology used during the mixing process). The stockpile additive will be documented and recorded in the LTPP database.

## PAVEMENT STRUCTURE

The SPS-10 experiment will only include new asphalt concrete (AC) overlays over existing HMA pavements. New construction, complete reconstruction, overlays of existing portland cement concrete, or composite pavements will not be allowed in the SPS-10 experiment.

The U.S. State or Canadian Provincial highway agency's standard practice will determine the thickness of the overlay. A strong correlation between the overlay thickness and the annual traffic loading is expected. As such, the overlay thickness will be treated as a covariate in the study and will not be a multilevel category in the experimental design. The agency-determined thickness will be documented along with the design process and all inputs used in determining the design. The minimum overlay thickness required for the SPS-10 experiment is 51 mm (2 inches). This minimum thickness was selected to alleviate complications that arise when performing materials testing, ride quality, and structural testing on thin layers. The maximum overlay thickness required for the SPS-10 experiment is 102 mm (4 inches).

Pavement structural factors (subgrade, subbase, base, binder, and surface course thicknesses) are not controlled as multilevel design factors in the SPS-10 experiments. The subgrade may be either fine or coarse-grained material. The base may be either a granular or stabilized type.

The pavement thickness (and depth of milling, or other surface preparation, if applicable) should remain constant across all test sections at any project location to allow for direct comparison between WMA and HMA. Similarly, the existing pavement structure thicknesses, surface distress types and extents, and subgrade conditions should be consistent throughout the project.

For the SPS-10 experiment, tack coats must be required prior to the placement of all WMA and HMA lifts.

## MIXTURE DESIGN

The SPS-10 experiment focuses on dense-graded asphalt mixtures for the core test sections. The mixture design will be developed by the U.S. State or Canadian Provincial highway agency in accordance with their standard practice. The mixture design for the WMA test sections should be identical to the HMA control. Some agencies allow minor adjustments to the mixture design between the HMA and WMA, while others forbid it. The agency standard practice will be allowed for the SPS-10 experiment. In addition, antistrip agents may be required in the HMA mixture, while some of the WMA additives interact with antistrip agents in a way that makes the mixture more susceptible to moisture damage. In such a case, slight changes to the mixture design between HMA and WMA are warranted and are acceptable in the SPS-10 experiment. The complete mixture design and volumetric mixture properties of the HMA and WMA mixtures will be documented and stored in the LTPP PPDB.

If the agency wishes to study other mixture types (i.e., stone-matrix asphalt or open-graded friction course), test sections may be included in the SPS-10 experiment as supplemental sections.

The binder used in the mixture will be 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 will be documented and stored in the LTPP database. Binder type and modifier type are not included in the SPS-10 experimental matrix and will be a covariate of the project.

The binder source, binder grade, and binder modification must be consistent across the three core test sections of each project. Should the agency wish to vary binder properties, supplemental sections can be included and will be monitored as part of the LTPP program. Direct comparisons between different binder types or different sources of the same binder type are not a part of the national experimental design for the SPS-10.

In addition, aggregate type, source, and gradation must be consistent across the three core test sections of each project. Variations in aggregate properties will be allowed in supplemental sections.

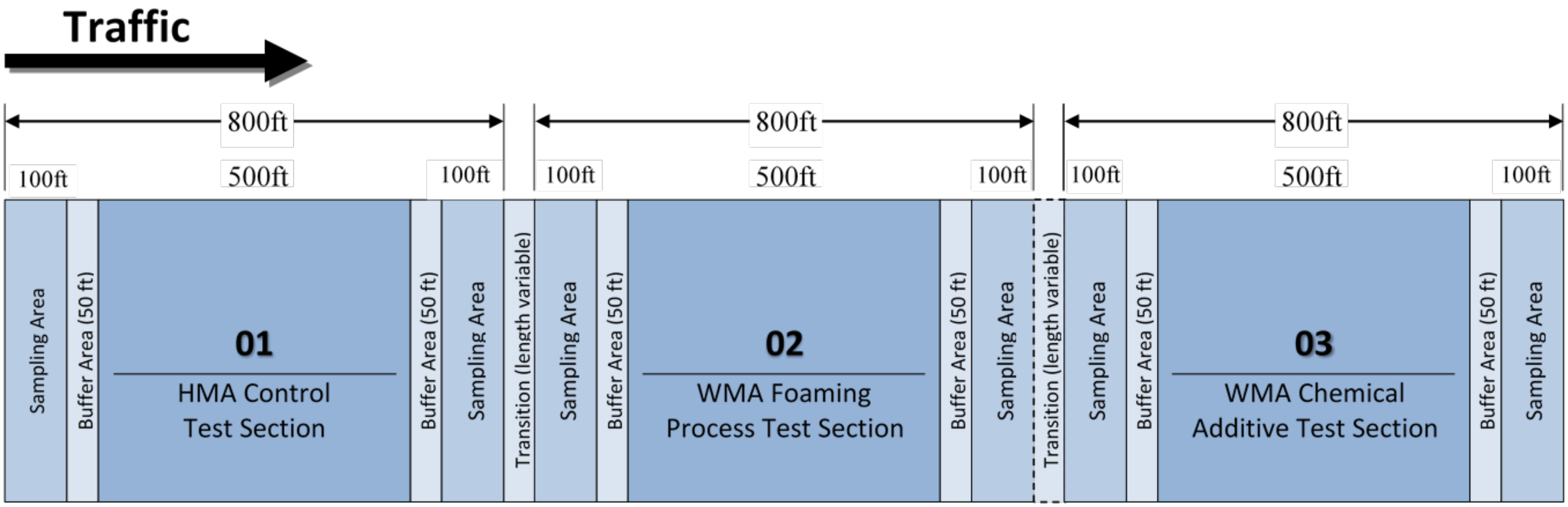
# CHAPTER 5. TEST SECTION CONFIGURATION AND CONSTRUCTION CONSIDERATIONS

The SPS-10 test pavements will be built as part of an overlay of existing asphalt pavement. In all cases, the cross section must be uniform. Lane-widening projects are not suitable for this experiment because of the difficulty of discerning the relationship of distresses developed in the existing lanes and in the widened test section.

Figure 2 illustrates the conceptual test site layout for the SPS-10 experiment. The experimental design requires a minimum length of 243.8 m (800 ft), with a core monitoring section of 152.4 m (500 ft ) that will be 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 consists of 30.5 m (100 ft) on each side built at the same time with the same specifications to allow material sampling without disturbing the 152.4-m (500-ft) monitored area, including the outside (i.e., truck) lane only. Sufficient asphalt plant production should be provided to ensure acceptable uniformity and consistency in the AC mixture delivered and placed. Transition zones are required between test sections and must be a minimum length of 243.8 m (800 ft). The project requires at least three different mixtures (one HMA and two WMA) to be produced at the same asphalt production plant, and each mixture may only be placed on the test section after the plant has reached steady-state operation. The transitions will also be used to ensure the paving train has reached uniform operation and is achieving consistent densities prior to paving within the test section. This requirement for steady-state operation may require longer transitions between the sections or some other use/disposal of mixture produced before the asphalt production plant achieves steady-state operation. The length of these transitions depends on onsite conditions, production plant configurations, and construction practices that influence the amount of material required to reach steady-state operations. The minimum project length is 1,219 m (4,000 ft). But the project length may be longer if more than the minimum number of sections are built and/or if the transition zones are longer than the minimum length.

Each SPS-10 project must have a minimum of three test sections. One test section must consist of HMA as a control. The other two test sections must be WMA (as defined above): one using the foaming process and the other using a WMA chemical additive. Additional test sections may be constructed above this minimum. The additional sections will be agency-constructed supplemental sections and will be monitored using LTPP data collection guidelines.

The job-mix formula for the HMA control and WMA sections must be identical (except for the warm-mix technology). Obtaining consistent densities (and air voids) across all test sections is important to the SPS-10 experimental objectives. Care should be taken to ensure that rolling procedures and patterns as well as required compactive effort are established for each mixture so that uniform densities are achieved both within each 243.8-m (800-ft) monitoring/sampling length and within the entire experiment to facilitate appropriate comparisons of performance. In addition, the same compaction equipment must be used on all three test sections.




Source: FHWA.
1 ft = 0.3048 m

**Figure 2. Diagram. Typical SPS-10 site layout.**

# CHAPTER 6. BENEFITS TO PARTICIPATING HIGHWAY AGENCIES

Though coordinated through the FHWA LTPP Program, the SPS-10 experiment is conducted for and by U.S. State and Canadian Provincial highway agencies. Therefore, the details of the experiment aim to address the needs of the highway community. However, the experimental rigor necessary to achieve the desired results from this research requires that participating agencies agree to the same experimental factors and required test sections. The statistical aspects of this experiment make the full cooperation of participating highway agencies crucial to its success. While all highway agencies will benefit from the information, knowledge, and products that result from this research, participating agencies will accrue additional direct benefits. Since a portion of this research will be conducted in their jurisdiction on test sections exposed to local climate and traffic loadings and constructed using their materials, mixture designs, specifications, and techniques, participating agencies will be able to make direct use of the results. The study will also allow highway agencies the opportunity to quantify the performance differences between their standard HMA and WMA technologies employed in their jurisdiction.

In addition to these direct benefits, participating agencies will also receive ancillary benefits from their involvement in the experimental process, including valuable insights from and intellectual exchanges with the FHWA research team as well as other highway agency personnel.

# CHAPTER 7. SUPPLEMENTAL SECTIONS

Sponsoring highway agencies can expand the experiment to address some of their own interests and concerns as well as incorporate innovative technology through the construction of supplemental sections. Additional WMA technologies can be constructed above the required minimum, and their performance can be directly compared to that of the core experimental test sections. Supplemental sections provide participating agencies the opportunity to conduct relatively economical, intensive pavement field research by taking advantage of the LTPP program-provided research infrastructure and monitoring.

The construction of supplemental sections is strongly encouraged. FHWA is prepared to assist interested U.S. State or Canadian Provincial highway agencies in the experimental design, data collection, and performance monitoring of such supplemental experiments. Further, if a group of participating agencies want to collaborate in such activities (i.e., as a pooled-fund study), FHWA is also prepared to work with these agencies to coordinate a multiState/Provincial supplemental experiment. The following section provides a list of recommended supplemental sections for consideration.

## RECOMMENDED SUPPLEMENTAL SECTIONS

Potential supplemental sections are provided in the following list, along with additional recommendations based on discussion with the ETG:

- Organic WMA additives.
- Foaming additives.
- RAP of varying levels or the inclusion of RAP percentages outside the acceptable range for core test sections.
- RAS.
- Overlay layer of varying levels of thickness.
- Varied binder grade.
- Varied production temperatures or constructing sections with WMA technology produced at temperatures above the acceptable range for core test sections.
- Varied WMA technologies.
- Stone-matrix asphalt, gap-graded, or open-graded mixtures.
- Varied aggregate sources.
- Varied density levels.

# CHAPTER 8. PARTICIPATING AGENCY RESPONSIBILITIES

Participating highway agencies play a key role in the development, construction, and conduct of the SPS, including the following activities:

- Participating in experiment and implementation plans.
- Nominating test sites.
- Validating in situ conditions at the site.
- Providing inventory data of existing pavements.
- Preparing plans and specifications.
- Selecting construction contractors.
- Developing mixture designs.
- Sampling materials.
- Constructing test sections.
- Controlling, inspecting, and managing construction.
- Collecting and submitting traffic data.
- Providing traffic control for all test site data collection.
- Collecting and reporting as-built construction data.
- Conducting and reporting maintenance and rehabilitation activities.

The primary role of FHWA is to provide coordination and technical assistance to participating highway agencies to help ensure uniformity and consistency in construction and data collection to achieve the desired study results. Some of the activities the FHWA LTPP program team will be responsible for include:

- Development of experimental design.
- Coordination among participating agencies.
- Acceptance of nominated test sites.
- Development of uniform data collection guidelines and forms.
- Coordination of materials sampling and testing.
- Observation of pavement performance.
- Development and operation of comprehensive database and data entry platform.
- Control of data quality.
- Analysis and reporting of data.

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