Long-Term Pavement Performance Program

Accomplishments and Benefits

1989–2009

U.S. Department
of Transportation
Federal Highway
Administration

LTPP 20

Long-Term Pavement Performance Program Highlights

Accomplishments and Benefits 1989–2009

Contents

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BACKGROUND

The need for information on how pavements perform over time came to the forefront in the early 1980s, as the deterioration of highways built two or three decades earlier became a concern for highway agencies. The mission to study performance data systematically all across the country and to promote extended pavement life was advanced by the National Academy of Sciences Transportation Research Board (TRB), American Association of State Highway and Transportation Officials (AASHTO), and Federal Highway Administration (FHWA).

Supported by Congress, the Long-Term Pavement Performance (LTPP) program started in 1987, as part of the Strategic Highway Research Program (SHRP), a 5-year applied research program funded by the 50 States and managed by TRB. The LTPP program mission was to

- Collect and store performance data from a large number of in-service highways in the United States and Canada over an extended period to support analysis and product development.
- Analyze these data to describe how pavements perform and explain why they perform as they do.
- Translate these insights into knowledge and usable engineering products related to pavement design, construction, rehabilitation, maintenance, preservation, and management.

Data collection began in 1989. Although SHRP ended as planned in 1992, the LTPP program continued under the leadership of FHWA, and continues today, with the participation of highway agencies in all 50 States and 10 Canadian Provinces.

Over a span of 20 years, the LTPP program has monitored the performance of nearly 2,500 in-service pavement test sections throughout the United States and Canada representing the wide range of climatic and soil conditions on the continent. Test sections are monitored until they reach the end of their design life or are otherwise recommended to be taken out of study by the participating agency. By following these pavements over time, researchers are gaining insight into how and why they perform as they do, which provides valuable lessons on how to build better, longer lasting, more cost-effective pavements.

Program Objectives

With the goal of extending the life of pavements through investigation of the long-term performance of various designs of pavements (as originally constructed or rehabilitated) under various conditions, the following objectives were established for LTPP:

- Evaluate existing design methods.
- Develop improved design methodologies and strategies for the rehabilitation of existing pavements.
- Develop improved design equations for new and reconstructed pavements.
- Determine the effects of loading, environment, material properties and variability, construction quality, and maintenance levels on pavement distress and performance.
- Determine the effects of specific design features on pavement performance.
- Establish a national long-term pavement database.

Test Sections

Test sections are the heart of the LTPP program. The test sections were nominated by State and Provincial highway agencies in accordance with statistically sound experimental matrices designed to achieve LTPP program

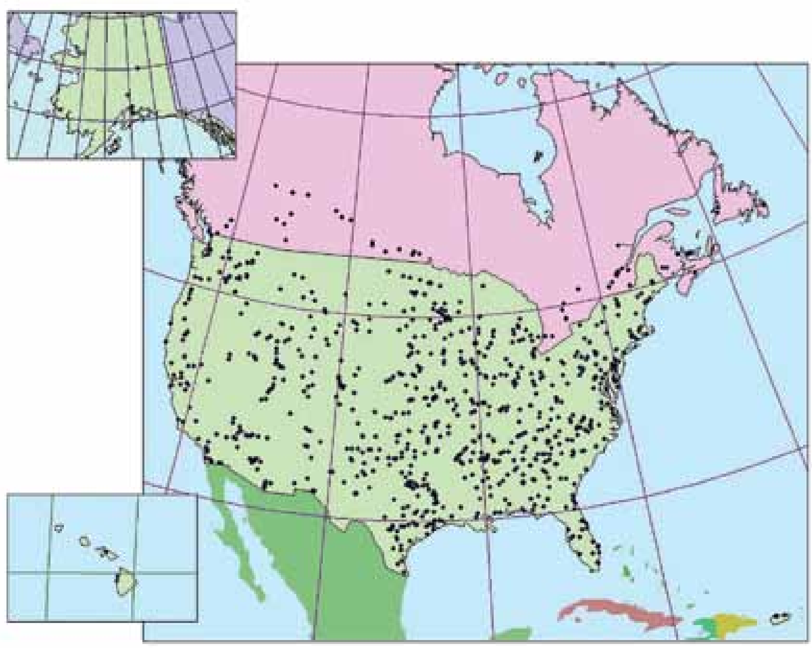
Above: Construction of an Arizona SPS-1 site in 1993.

Right: Materials sampling and testing for quality control during construction of the SPS-2 site in Washington State.

objectives. The nearly 2,500 test sections, both asphalt concrete (AC) and portland cement concrete (PCC), were designated throughout all 50 States, Puerto Rico, the District of Columbia, and Canada, as shown in figure 1.

Each test section is classified as being in either the General Pavement Study (GPS) or the Specific Pavement Study (SPS) category. GPS test sections were usually selected from in-service pavements designed and built according to good engineering practice by departments of transportation (DOTs), while SPS sections were designed and constructed to answer specific research questions. The broad study categories are listed in table 1. Nearly 800 LTPP test sections are in the GPS category, and more than 1,700 other test sections are in the SPS category. Full suites of data (such as distress, traffic, material sampling, and climatic data) have been collected for each of the test sections. Some data are collected centrally; others are collected by the States and Provinces.

FIGURE 1. Distribution of LTPP pavement test sections.



National and Highway Agency Investment

Establishing and operating a program of this magnitude requires significant resources, and the total Federal investment since 1987 exceeds $260 million.[1] These funds have supported the wide array of LTPP activities, including test section construction and data collection; database development and maintenance; rigorous quality control/quality assurance (QC/QA) programs; coordination through local, regional, and national meetings; and data analysis and product development.

State and Provincial highway agencies have supported the LTPP program by bearing most of the construction costs for the test sections, maintaining and allowing access to the sections, providing traffic control for field monitoring and materials testing, supplying monitored traffic loading and classification data, and serving on TRB's LTPP Committee and its supporting expert task groups. Many States have participated in pooled fund studies that have greatly extended the usefulness of the LTPP program.

Accomplishments and Benefits

The LTPP program has generated a wide range of benefits across the pavement engineering and performance spectrum. Hundreds of applications have been identified that make use of LTPP data, and the utility of LTPP data is increasing. A detailed listing of each report, procedure, and product utilizing LTPP information has been compiled on the FHWA LTPP Web site at http://www.fhwa.dot.gov/pavement/ltpp. A summary of available tools and resources for highway agency pavement engineers appears on the inside back cover of this report.

LTPP benefits and products fit broadly within three categories, which form the structure of this report:

- The LTPP database—largest and most comprehensive in the world.
- Advances in pavement performance measurement.
- Contributions to pavement design and management.

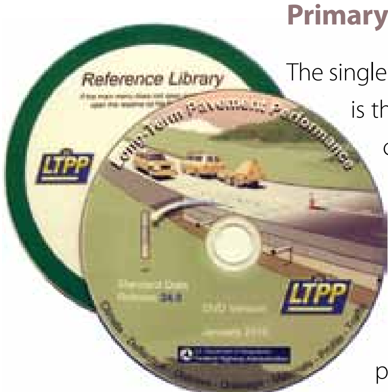
Examples in each category are highlighted in the following sections to show how LTPP-related findings continue to benefit the pavement community and the driving public.

Table 1. LTPP General and Specific Pavement Studies

General Pavement Studies (GPS)	Specific Pavement Studies (SPS)
GPS-1 Asphalt Concrete on Granular Base	SPS-1 Strategic Study of Structural Factors for Flexible Pavements
GPS-2 Asphalt Concrete on Bound Base	SPS-2 Strategic Study of Structural Factors for Rigid Pavements
GPS-3 Jointed Plain Concrete Pavement	SPS-3 Preventive Maintenance Effectiveness of Flexible Pavements
GPS-4 Jointed Reinforced Concrete Pavement	SPS-4 Preventive Maintenance Effectiveness of Rigid Pavements
GPS-5 Continuously Reinforced Concrete Pavement	SPS-5 Rehabilitation of Asphalt Concrete Pavements
GPS-6 Asphalt Concrete Overlay of Asphalt Concrete Pavement	SPS-6 Rehabilitation of Jointed Portland Cement Concrete Pavements
GPS-7 Asphalt Concrete Overlay of Portland Cement Concrete on Concrete Pavements	SPS-7 Bonded Portland Cement Concrete Overlays
GPS-8 (discontinued)	SPS-8 Study of Environmental Effects in the Absence of Heavy Loads
GPS-9 Unbonded Portland Cement Concrete Overlays on Portland Cement Concrete Pavements	SPS-9 Validation of Strategic Highway Research Program Asphalt Specification and Mix Design (Superpave)

BENEFITS of the LTPP DATABASE

Primary Data



An updated, comprehensive LTPP Standard Data Release is distributed each year. Also available on DVD is the comprehensive LTPP Reference Library. The primary LTPP database is maintained at the Turner-Fairbank Highway Research Center.

The single most significant product of the LTPP program is the pavement database—the largest and most comprehensive collection of research-quality performance data on in-service highway pavements ever assembled. The database has supported national, State/Provincial, and local research projects, as well as a variety of international analysis efforts. With appropriate maintenance and update activities in place, the LTPP database will continue to be the primary source of information for future generations of pavement researchers.

The LTPP database is composed of 21 modules containing data categories such as climate, materials testing, traffic volumes and loads, pavement layer types and thicknesses, material properties, and pavement condition (distress, longitudinal and transverse profile, and structural response). Each module contains a number of related tables. Within each table are data elements selected by their importance to pavement engineering applications. To help users navigate the millions of records stored in the database, the LTPP Table Navigator application was developed.

Ancillary Data

The LTPP Ancillary Information Management System (AIMS) data contains supplementary information that complements the LTPP database. Examples of AIMS data include the following:

- Time history files collected from falling-weight deflectometers (FWDs).
- Raw profile data.
- Scanned distress maps and photos.
- Traffic files from the central traffic database.
- Test section materials stored at the FHWA Materials Reference Library in Nevada.

Data Accessibility

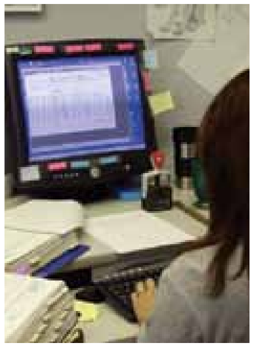
The LTPP Customer Support Service Center provides free access to the latest pavement performance data and related data quality information through the Customer Support Service Center's annual standard data release on DVD in Microsoft Access format and the LTPP Products Web site (www.ltpp-products.com). Users typically are from State and Provincial highway agencies, local highway agencies, academia, and pavement engineering firms. Information in the LTPP database is readily available to support user requests.

Users can submit data requests for pavement performance data as well as data from the AIMS system through

"We see the LTPP database serving into the indefinite future as a key component of the agency's pavement research activities, and those activities will benefit substantially from the many LTPP data collection and analysis activities in FY 2010–FY 2015 that are mentioned in the FHWA document."

Victor Mendez, Chairman
Twenty-third letter report of the Transportation Research Board Long-Term Pavement Performance Committee, December 27, 2007

LTPP's Customer Support Service Center, which has filled more than 5,000 data requests since 1997. The LTPP Products Web site has more than 3,000 registered users from 77 countries, and more than 45,000 requests have been processed online. The more than 50,000 total requests for LTPP information are a testament to the program's usefulness and its broad acceptance by the research community and State and Provincial partners.



LTPP DataPave and other LTPP products are available online at www.ltpp-products.com.

The LTPP database supports research and product development. By the end of 2009, more than 600 research documents that utilized LTPP data had been published. Based on the steady growth in the number of publications with time, it is anticipated this number will increase significantly in the years ahead. The benefits this information has yielded are far-reaching, and those benefits and accomplishments are discussed in the following sections.

A Foundation for Advancement

The LTPP database will continue to be the single largest benefit from the LTPP program, a legacy to future pavement researchers. Providing reliable pavement performance data to thousands of requestors throughout the academic community and the public and private sectors, the database has been the foundation for fundamental and applied research and the nucleus for advancements in pavement design and management processes. With continued support supplementing the quantity, quality, and accessibility of LTPP data, the LTPP database will be the catalyst for pavement advancements over the foreseeable future.

Future benefits will be achieved primarily through the exposure of engineers and researchers to the LTPP program and database. This effort is already underway, and many universities incorporate the LTPP database as part of undergraduate curriculums. Familiarity with the program will facilitate the implementation of LTPP products, and increased exposure to LTPP products will result in applications beyond those currently envisioned.

Data Analysis Program

Data analysis has been a critical component of LTPP from the program's inception. Members of expert task groups and other stakeholders have expended significant effort over the years in optimizing data analysis activities. For the past decade, the Strategic Plan for LTPP Data Analysis has guided the analysis efforts using LTPP program funds.[2] Testing the quality and completeness of the LTPP data has been a major activity under the program, which has funded many studies that provide a solid technical basis for understanding pavement performance. [3]

Seasonal Monitoring Program

Recognizing that weather and traffic loading are the two major causes of pavement deterioration, LTPP made the collection of research-quality environmental data a top priority. The Seasonal Monitoring Program (SMP) study was designed to measure the impact of daily and seasonal temperature and moisture changes on pavement structures and the response to loads. Sixty-four sites (see figure 2) were instrumented to collect climatic data and variations in parameters such as temperature and moisture content. Monitoring data were collected frequently, in many cases monthly, so that, for example, pavement deflection data could be correlated to seasonal variations of material properties.

Direct measurements at SMP projects and automated weather station locations have provided designers and researchers with an abundance of high-quality data. The further innovative step of developing virtual weather stations has already paid significant dividends, and all environmental data will support significant future savings.

Analysis using SMP data has been useful in evaluating seasonal load restrictions, defining moisture and frost penetration prediction models, and developing the LTPPBind software application that helps highway agencies select the most suitable and cost-effective SuperPave® asphalt binder performance grade for a particular site. The LTPP program has produced a set of three CD-ROMs that document the installation, monitoring, and decommissioning of SMP sites, as well as detailed information on the equipment and experimental design.

The climatic information available through the LTPP program has proved valuable in many areas. Of particular note is the LTPPBind software, which was developed to aid in the selection of performance-graded binders. This software was based on the original SHRPBind software

FIGURE 2. Distribution of instrumented sites in the LTPP Seasonal Monitoring Program.

An automated weather station at an SPS-8 site in Francis, Utah.

and incorporates LTPP's revised temperature models. In many instances, the original SHRPBind models were found to be overly conservative, and implementation of LTPPBind has resulted in significant cost savings—an estimated $50 million per year.

LTPP climatic information can be useful in other areas of research. One study used climatic data from the LTPP program to evaluate rigid pavement design procedures for airfields.[4] The research investigated the estimation of critical design edge stress, effect of finite slab width and length, effect of a second subbase layer and stress adjustment factor required due to effective temperature differential, thermal curling and moisture warping, fatigue versus thickness relationships, and alternative structural deterioration relationships.

Findings from the study were used to modify the fatigue curve used for airfield design. The new curve is more representative of actual critical edge stresses and can incorporate additional design features, such as various slab sizes, climatic effects, and multiple subbase layers, as well as innovative pavement configurations. The results from the study are currently being used to modify the stress analysis and thickness design program used for rigid pavement design in airfield applications.

"…Kansas DOT uses LTPPBind software as an integral part of their pavement design process."

Lon Ingram
Former Chief of Materials and Research, Kansas Department of Transportation

LTPP and the Next Generation of Pavement Professionals

Familiarizing users with the LTPP database is a major program accomplishment. LTPP data are used not only in pavement research at the State/Province and national levels, but also at local and county levels and internationally. Introducing LTPP data to analysts has long been a priority, particularly so at the university level. LTPP training has been given to interested professors, and several universities have introduced curriculums involving LTPP data. Using the LTPP database allows professors to create academic problems that relate to real conditions. Students learn to process the data, determine pavement condition, and recommend rehabilitation strategies. For graduate students in pavement engineering, using the pavement data is essential to investigating how pavement systems behave.

The American Society of Civil Engineers (ASCE) jointly with FHWA sponsors a competition to encourage use of LTPP data. The *ASCE-LTPP International Contest on LTPP Data Analysis* has been running since 1998 and has four entry categories: undergraduate students, graduate students, partnerships, and curriculum. (Contest information is available at www.fhwa.dot.gov/pavement/ltpp/contest.cfm.) Student participation is ensuring that the next generation of pavement designers and researchers will be LTPP savvy—and spurs the development of new products and practices.

"The best part of the database is that it allows students to 'get their hands dirty' with real data."

Susan Tighe, Ph.D.
Professor of Engineering, University of Waterloo

Through both design and necessity, the LTPP program has advanced pavement measurement and monitoring practices. In addition, bias and variability—which can have large consequences on pavement treatment selection—can be thoroughly evaluated using the data collected by the LTPP program. The data collection techniques developed for the program have been fully documented and have been implemented by highway agencies across North America, providing the highway community with better and more consistent data. Improved data collection practices have resulted in twofold savings—reducing both data collection costs and pavement rehabilitation or reconstruction life cycle costs.

Pavement condition data that are of consistently high quality are extremely important in pavement evaluation, design, and management to ensure that decision makers select the best possible alternatives and timing schedules for maintaining agency networks. Distress data are also used in research studies, construction QC/QA, and pavement failure investigations—all of which demand quality data.

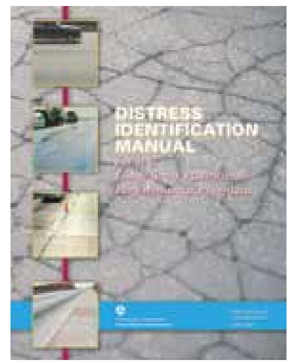
Based on its long history in managing LTPP activities, FHWA is uniquely qualified to assist agencies and industry with data collection issues.

Field Data Collection

The LTPP program has provided a wide variety of benefits related to field data collection equipment and procedures. Numerous LTPP data collection procedures have been adopted by AASHTO and industry, with the most widely implemented being the *Distress Identification Manual for the Long-Term Pavement Performance Program* (DIM). In discussions of LTPP implementation, 90 percent of State highway agencies have indicated that LTPP data collection equipment or test methods have been used by their organizations.

Distress Monitoring

The LTPP program has developed the robust and thorough DIM that highway agencies can use to improve or standardize their condition data collection. Illinois and Mississippi have used the DIM as the basis for quantifying distress on projects with pavement warranties. Additional benefit has been realized in other States, including Nevada and Oklahoma, as they update and standardize their condition data collection techniques for pavement management purposes. Many local agencies also use the DIM, which enables them to collect data on local roads without spending valuable resources to develop their own collection systems.



Distress Identification Manual, first issued in 1987, now in its 4th edition. Available at http://www.tfhrc.gov/pavement/ltpp/reports/03031.

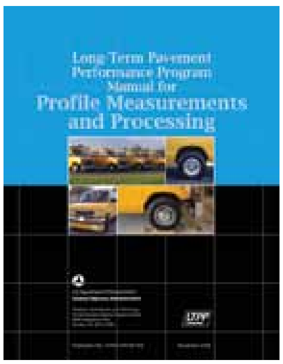
Distress Viewer and Analyzer (DiVA Online) is a software application that can overlay distress information for graphical analysis. Originally developed as a QA/QC review tool for LTPP distress data, DiVA is linked to the LTPP distress survey maps, photographs, and digital images. The distress data can be displayed to show a time series/time history of a pavement section under evaluation for trend analysis and variability bands for distress trends. DiVA can analyze several survey sections at the same time. It provides reports in both graphical and exportable tabular formats.

DiVA's ability to graphically display distress data can assist highway agencies in analyzing distress information in several ways, for example:

- Examining collected data prior to entry in a pavement management system.
- Comparing survey results against previous surveys and reviewing abnormalities.
- Evaluating trend discrepancies for possible explanations (e.g., differences in interpretation, maintenance or rehabilitation activities).

- Validating distress data for MEDPG calibration.
- Reviewing variability in distress data within pavement management systems, thus lessening the impact of variability.

Other recent publications include updated manuals for FWD measurements and for profile measurements and processing. These and other LTPP documents are available on the LTPP Web site or by contacting the LTPP Customer Support Service.



Operational procedures for measuring longitudinal pavement profiles. Available at http://www.fhwa.dot.gov/pavement/ltpp/pubs/08056.

Profile Monitoring

The LTPP program developed procedures for evaluating profiler equipment and comparing the performance of various models against actual elevation measurements. The program also developed tools to monitor the consistency of measurements between different devices and wrote model procurement specifications. LTPP also developed a set of routine premeasurement equipment checks, calibration procedures, and quality-control protocols. Ultimately, FHWA published the definitive work on the use of profiling technology: *Long-Term Pavement Performance Manual for Profile Measurements and Processing* (FHWA-HRT-08-056, 2008).

Traffic Monitoring

The LTPP program has made significant advances across the pavement engineering spectrum since its initiation in the late 1980s. It can be argued that the program's single greatest impact in pavement performance monitoring to date is in the area of collecting data on traffic volumes and loads. While the technologies for collecting automated vehicle classification (AVC) and weigh-in-motion (WIM) data were commercially available when the LTPP program began, their implementation was varied, and there were no standards for data quality, analysis, or interpretation.

Truck approaching a WIM installation in Arkansas.

In the program's early years, significant unknowns related to AVC and WIM data collection included the accuracy and reliability of the wide range of available equipment—both portable and permanent. Since then, the LTPP program has been instrumental in advancing the technology of AVC and WIM data collection. Several States, including Washington, Arizona, and Texas, have used LTPP test sections as a means to incorporate automated data collection into their standard operations.

The LTPP program has developed standards and products to address variability in the data collected from the various AVC/WIM technologies:

- Equipment calibration protocols.
- Smoothness specifications for the pavement in the vicinity of the monitoring equipment, along with an associated software application—the WIM Smoothness Index Software—to help optimize WIM equipment locations.
- Software that imports data records and provides both quality control checks and computed parameters.

Based on LTPP work, *Smoothness of Weigh-in-Motion Systems* (AASHTO provisional specification MP 14-05) was developed to assess the smoothness of pavement approaches at WIM sites. There are both long and short wavelength pavement contributions to vehicle dynamics, and this specification helps agencies to determine whether the pavement smoothness at existing locations will introduce significant errors in the resulting WIM data, as well as to identify the optimal location for new WIM installations.

Considering the importance of the SPS projects—with multiple sections at the same location to allow comparison of various design features and rehabilitation

"It is important to note that the obtained data had previously been checked for accuracy and summarized into the Microsoft Access format. If this had not been the case, extensive time would have been required to manually process and edit the large amount of traffic data."

M.S. Buchanan, Ph.D.
Traffic Load Spectra Development for the 2002 AASHTO Design Guide

strategies—the SPS Traffic Data Collection Pooled Fund Study was established to install, calibrate, and validate continuous traffic data. The study guidelines require a site to have data that pass the LTPP quality control standards for at least 210 days a year, including field validations. Highway agencies have contributed more than $2.7 million to this effort, and the LTPP program has significantly improved the availability and quality of monitored traffic data as a result.

Quality Control/Quality Assurance

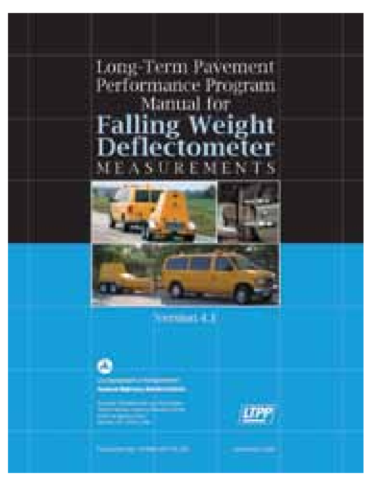
QC/QA have been integral components of the LTPP program since its inception. Quality control plans are in place for every field data element, and while processes are in place for office processing software and detailed QC checks in the LTPP database, the LTPP program has long recognized that collecting high-quality data expedites subsequent data processing activities. Many of the LTPP products, such as the DIM and the FWD calibration centers, are the direct results of the program's emphasis on QC/QA. In 2001, when the Office of Management and Budget issued government-wide guidelines regarding data quality standards, the LTPP program already had policies in place that ensured compliance.

FWD Calibration Centers

Reliable and precise measurements of pavement strength enable pavement engineers to design and schedule appropriate repairs at cost-effective intervals. Errors in FWD data lead to errors in pavement analysis. Securing accurate data depends on the periodic calibration of these complex hydraulic-electrical-mechanical devices.

In the early days of the LTPP program, calibration procedures and regional calibration centers were identified as priority needs. The original FWD calibration protocol was finalized in 1992, and calibration centers were established in Pennsylvania, Texas, Minnesota, and Nevada (the Nevada center was eventually moved to Colorado). These centers provided calibration services not only for LTPP FWDs, but also for FWD equipment owned by highway agencies and consultants. In the first 3 years of center operations, many of the non-LTPP FWD units were found to be significantly out of calibration. The LTPP calibration centers thus provided an essential public service that resulted in significant construction savings. These savings were most notable in situations where design is driven by FWD measurements, such as in flexible pavement overlay designs and jointed rigid pavement load-transfer rehabilitation designs.

With advances in technology, FHWA recognized the need to update the FWD calibration system and initiated a pooled fund study, Falling-Weight Deflectometer Calibration Center and Operational Improvements (TPF 5(039)), for that purpose. The study resulted in a new calibration system that takes advantage of improvements in technology; an updated FWD calibration protocol: AASHTO Standard Practice R 32-09: Calibrating the Load Cell and Deflection Sensors for a Falling Weight Deflectometer; and arrangements for ongoing support of the calibration centers, ensuring that they will remain available to the pavement community.



Left: Calibrating an FWD. The reference load cell is positioned under the FWD load plate.

Right: The LTPP program periodically updates its data collection guidelines for use of FWD equipment (available at http://www.fhwa.dot.gov/pavement/ltpp/pubs/06132).

The upgraded hardware and software in the new system allow calibration to be completed in about 2 hours, about a third of the time previously required. The system is compatible with all brands of FWDs available in the United States. Changes in the new system include the use of an accelerometer for deflection sensor calibration, the ability to calibrate all deflection sensors simultaneously by using a multiple sensor stand, use of a Windows-based programming language that can read native data formats from each brand of FWD, and use of modern data acquisition techniques to eliminate sensitivity problems.

Extensive research has established that the new procedure is as accurate and repeatable as the old one. All State DOT–operated calibration centers have implemented the procedure, as have three manufacturer-run centers in the United States and Europe.

To encourage State highway agencies and other FWD users to use the calibration facilities, FHWA has produced a video, "Calibrating the Falling Weight Deflectometer," which can be viewed at www.fhwa.dot.gov/multimedia/research/infrastructure/calibration. Also available on CD, the video illustrates the new calibration procedure, explains how to prepare for a successful calibration, describes how calibration improves the quality of backcalculated data, and explains the impact of proper calibration on overlay design.

The LTPP program also developed a maintenance manual that provides instructions on reconditioning an FWD: *The Long-Term Pavement Performance Program Falling Weight Deflectometer Maintenance Manual.* Addressed to FWD owners, operators, and technicians, the manual describes the process of disassembling and reassembling the components and subcomponents of an FWD to extend its service life.

Since 1997, more than 500 FWD and heavy-weight deflectometer calibrations have taken place at the FWD calibration centers. The centers provide an important service to the highway community, particularly when FWD-derived inputs are used for rehabilitation design. With support services from the AASHTO Materials Reference Laboratory, the centers continue to serve public and private agencies.

State-Operated FWD Calibration Center Contacts

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Data Variability

An important element to consider in pavement management systems and many research applications is the variability associated with a data point. LTPP data has been analyzed to develop typical variability ranges for manual distress surveys[5, 6, 7] and longitudinal profiles.[8] Pennsylvania used LTPP data to verify its own acceptance limits for pavement distress data.[9] Variability associated with data collection equipment has also been studied, particularly in longitudinal profile where three different makes of high-speed profilers have been used over the years. An in-depth analysis comparing profiles by equipment type, completed in 2005, determined that changes in profiler equipment did not impact the overall variability in LTPP smoothness data.[10]

Objective Comparisons Between Geographic Locations

Researchers must determine how much confidence to assign information obtained from different sources, particularly if those sources are from different parts of North America, where collection and testing procedures can vary. The LTPP program has established strict guidelines for data collection and processing that require specific equipment, accredited distress raters, standardized processing software, and thorough QC/QA practices that enable analysts to utilize data from sections around the country without introducing additional sources of uncertainty.

Laboratory Testing

The ability to accurately and consistently quantify material properties is an important step in pavement selection, design, and construction. The LTPP program has made significant contributions in characterizing material properties by improving test protocols, as well as in providing a database of properties that are linked to actual field performance—both of which have furthered the development and use of mechanistic approaches in pavement engineering.

Resilient Modulus Testing of Bound and Unbound Layers

When establishing characteristics in the unbound layers—including subgrade, subbase, and base materials—resilient modulus is the property most relevant to pavement design. It is no surprise that establishing granular-layer resilient modulus values has been a priority activity for the LTPP program. In the program's early days, researchers, observing that samples from the same location yielded wide variations in test results regardless of which lab was used, recognized that there was no concise test protocol for resilient modulus testing.

LTPP made a considerable investment in establishing Test Protocol P46—Resilient Modulus of Unbound Materials.[11] This protocol has been widely adopted, a process that was accelerated first by a series of videos directed to administrators, engineers, and lab managers and technicians, followed by a CD-ROM containing both the videos and documentation for the LTPP *Guide for Determining Design Resilient Modulus Values for Unbound Materials.*[12] The LTPP program also adopted a highly repeatable test protocol to determine asphalt resilient modulus: Protocol P07.[13]

A dynamic modulus testing apparatus (courtesy North Carolina State University).

Equipment Startup Procedures

For both bound and unbound resilient modulus testing, a key element for ensuring uniformity is the LTPP startup procedure. The LTPP resilient modulus CD-ROM contains a 15-minute video describing the startup and quality control processes. The startup procedures were developed specific to the resilient modulus protocols, but could broadly be applied to setting up closed-loop, servo-hydraulic testing equipment. This procedure has been adopted by equipment manufacturers as a quality control check during equipment production.

Innovations and New Products

In both the field and lab, LTPP measurement innovations and related products are benefiting the pavement community. Direct measurements at SMP projects and automated weather station locations have provided designers and researchers with an abundance of high-quality environmental data. The further step of developing virtual weather stations has already paid significant dividends (an estimated $50 million per year for LTPPBind alone), and all environmental data will support significant future savings.

Improving material characterizations for bound and unbound layers is critical for advancing mechanistic-based designs. The LTPP program has provided many advances across this spectrum—from establishing testing protocols and increasing uniformity between testing labs to providing quality data sets used in analysis activities.

Tools such as LTPP WIM Cost Online and the LTPP WIM Smoothness Index software provide agencies with the means to optimize their entire traffic data collection program—and further guidelines on calibrating and validating equipment allow loading and classification information to be utilized with confidence. Anecdotally, Arizona has reported saving $2 million in construction costs on a single project by utilizing the LTPP WIM data.

"The AASHTO MEPDG is based on engineering mechanics principles as much as possible. However, the heart of the design procedure is key distress and smoothness prediction models that required calibration with measured performance data. The LTPP database provided such long-term performance data for hundreds of asphalt, concrete, and rehabilitated pavement sections that were used in the national calibration. Without LTPP data for the national calibration, the MEPDG distress models could not have been validated for use throughout the country. In addition, LTPP data is invaluable to each State highway agency for its own local validation and calibration purposes."

M. I. Darter, Ph.D.
Applied Research Associates, Inc.

An original LTPP objective was to acquire data for use in evaluating existing design methods and in developing new ones. The program has achieved this objective. LTPP data have been used in numerous studies tasked with evaluating or developing design procedures, the most recent being the *Mechanistic-Empirical Pavement Design Guide* (MEPDG). The LTPP program has also supported the implementation of, and advancements in, pavement management systems for agencies throughout the country.

The Mechanistic-Empirical Pavement Design Guide

Since the late 1990s, one of the pavement research community's single largest investments has been in the development of the MEPDG. Development of the new guide required detailed information about pavements located across the country and representing a wide range of loading, climate, and subgrade conditions with varying structural compositions. The LTPP database was critical to the development of the MEPDG, as it is the only source of comprehensive pavement data representative of national conditions. In fact, the MEPDG could not have been completed without the type and national extent of data provided by the LTPP studies. All of the traffic loading defaults provided in the MEPDG, for example, were derived from the LTPP traffic database using WIM sites across the United States and Canada, and all of the distress and smoothness models in the MEPDG were calibrated using LTPP data.

The MEPDG models evaluate the impact of traffic, climate, materials, and subgrade stiffness on performance and account for the interactions among these components. The MEPDG predicts individual performance measures (i.e., transverse cracking, fatigue, smoothness, rutting) based on site condition input for a given trial pavement section. These prediction techniques can be used in pavement evaluation studies, as well as in forensic investigations.

MEDPG Development

National Cooperative Highway Research Program (NCHRP) Project 1-37A (Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures: Phase II) was undertaken to develop a new pavement design guide based on mechanistic-empirical relationships and utilizing accepted and proven technologies. The new guide was developed to address the many limitations of the existing design procedure, which was based on data collected at the American Association of State Highway Officials (AASHO) Road Test in Illinois in the late 1950s. That design procedure has served the industry well, but has deficiencies due to some of the limitations of the AASHO Road Test:

- Today's traffic loads are much higher than they were six decades ago.

- Rehabilitated pavements were not monitored.
- Only one climatic condition and one subgrade type were included in the road test.
- Only one hot-mix asphalt and one PCC mixture were studied.
- Test pavements did not include drainage.
- Only 2 years of monitoring were conducted, rather than the entire pavement life of every section (some sections did, however, fail within 2 years).

Local Calibration

The LTPP database is serving as a critical tool in implementing the new design guide. The MEPDG was delivered with the prediction models calibrated to average national conditions. For the guide to be an effective resource for individual agencies, the national models need to be evaluated against local and regional performance. The results of these evaluations are being used to determine if local calibration is required. In addition, LTPP sites provide typical values for many of the MEPDG inputs.

Additional studies have been initiated as a direct result of the MEPDG. NCHRP 1-40A (Independent Review of the Recommended Mechanistic-Empirical Design Guide and Software) investigated the assumptions, evaluated the reasonableness and reliability, and assessed the implementation opportunities of the new design procedure.

The objectives of the NCHRP 1-40B project (Local Calibration Guidance for the Recommended Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures) were to develop a user guide and a manual on local calibration of the MEPDG. Local validation and calibration will rely heavily on the LTPP database as many agencies do not otherwise have the data necessary to complete this endeavor.

Sensitivity Studies of Models

Data from the LTPP SPS-5 project in New Jersey have been used to study the sensitivity of the MEPDG to weather and traffic inputs.[14] The initial analysis compared the predicted outputs of the Enhanced Integrated Climatic Model for Pavement Design and found that the predicted moisture content for unbound material and temperature profiles of bound layers were significantly different from those measured on the SPS-5 project.

LTPP and the Texas Flexible Pavement Database

Pavement data from the LTPP program were essential to the development of the MEPDG. Now those same data are proving critical to the development of local and regional pavement design models. Calibrated for national standards, the MEPDG models cannot be assumed to apply to specific locales—researchers have noted that in some cases the software produces unreasonable results, partly due to regional differences in soil, construction materials and practices, climate, and traffic loads.

Recognizing the need for data that can be used to develop, validate, and calibrate flexible pavement design models, the Texas DOT (TxDOT) recently sponsored a 3-year project at the University of Texas at Austin to develop and deploy a flexible pavement database, with two objectives:

- To build a reference database comprising design, construction, structural, and performance data for selected flexible pavement sections in Texas.
- To develop guidelines for local calibration of the MEPDG.

A major challenge for the project researchers was to design a database of sufficient size and complexity to fulfill pavement design needs—yet not so large or complex as to be too burdensome to maintain.

The project resulted in the online Texas Flexible Pavements Database with pavement sections spanning the climate, traffic, and structure types found in Texas. LTPP data were critical to the development of the database, providing the long-term performance data necessary for initial calibration. Of the 86 pavement sections housed, 45 are LTPP sections in Texas. Each has information on traffic, materials, structure, and performance history. The other 41 sections are relatively new sections recommended by TxDOT. When sufficient performance data have been collected on the newer sections, they will become the primary data source for validation and calibration of pavement design and performance models.

"The database is delivering what it was designed for. There is no doubt that the interim calibration factors recommended by this study are more accurate for predicting pavement performance in Texas than the default national values," says Jorge Prozzi, the principal investigator. "The database will evolve over time. We recommend that Texas continue to monitor these sections annually for at least the next 10 years, and add new sections as newer materials like recycled asphalt and warm-mix asphalt come into wider use in the State. New sections with thin asphalt surfaces and surface treatments should also be added."

The procedures followed and the calibration factors determined in the calibration methodologies—one for calibration of mechanistic rutting models and the second for empirical roughness models—are available in the project's final report, *Development of the Texas Flexible Pavements Database,* available at www.utexas.edu/research/ctr/pdf_reports/0_5513_2.pdf.

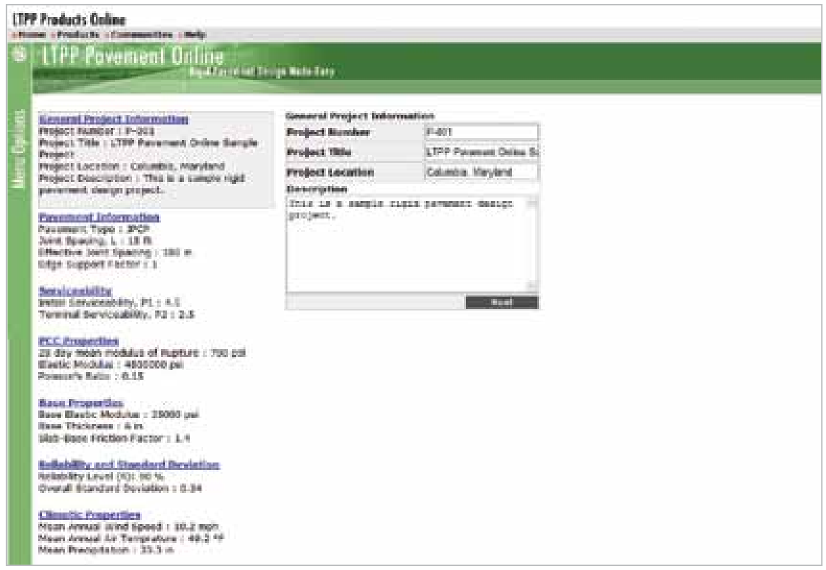

FIGURE 3. Screen capture of LTPP Pavement Online—Rigid Pavement Design software.

These differences prompted additional research on the sensitivity of the MEPDG performance predictions using climatic inputs from different weather stations.

This study stands as a testament to the critical role LTPP data will play in evaluating, calibrating, and validating the MEPDG on a local level. The results indicate that the MEPDG will need to be refined for use in New Jersey's conditions, and the refinement process will likely rely heavily on LTPP data.

Other studies are being performed in support of the MEPDG at the State and national levels. One example is NCHRP 1-42A (Models for Predicting Top-Down Cracking of Hot-Mix Asphalt Layers), which is investigating models to predict top-down cracking, a damage function included in the MEPDG as a placeholder for this observed but not fully understood distress. The LTPP SPS-1 projects will serve as an excellent resource for studying the effect of pavement thickness in the development of top-down versus bottom-up cracking. Forensic analysis of the SPS-1 projects can provide valuable information on the factors influencing the origins of top-down cracking.

Evaluation and Modification of Design Methods

Understanding how design methods relate to actual performance is extremely valuable. Design procedures can be modified based on research findings, and better decisions on design policy can be made.

AASHTO Rigid Pavement Design Spreadsheet

A study was undertaken to make improvements to the 1993 AASHTO Rigid Pavement Design Guide. The improvements included enhanced k-value selection techniques, curling and warping considerations, guidance on joint spacing, inclusion of slab/base friction, and new performance prediction capabilities.

These advancements led to more cost-effective and reliable pavement designs. The research utilized LTPP data to conduct the most critical portion of the study—validation of the new methodologies. Based on the findings, AASHTO adopted the new techniques as part of the 1998 Supplement to the *AASHTO Guide for Design of Pavement Structures*.

In addition, the LTPP program sponsored the development of a software application to automate the new and improved design process. Not only does the software incorporate all of the new features of the Rigid Pavement Design Guide, it can also perform sensitivity analyses. This capability has contributed to improved pavement designs as engineers have better information regarding the effects of variability in design inputs. The software has been Web-enabled—LTPP Pavement Online—and is available through the LTPP Products Online Web site, free of charge (see figure 3).

Continuously Reinforced Concrete Pavement Performance Study

The LTPP GPS-5 experiment provides performance, design, climatic, and traffic information for 85 continuously reinforced concrete pavement (CRCP) test sections located in 29 States across the country.[15] This information was used to study CRCP performance and to identify the characteristics of sections that are performing well.

Using the September 1999 LTPP database, inventory and performance information was used to evaluate CRCP test sections. High-severity transverse cracking, average crack spacing, total punchouts and patches (i.e., localized failures), and smoothness were of particular interest to the researchers. This information was beneficial in evaluating current CRCP design practices as well as understanding key design factors in performance.

Further analysis was conducted to evaluate the characteristics of the GPS-5 test sections that were performing extremely well. Pavements that were 20 or more years old and that exhibited an International Roughness Index measurement of less than 1.5 m/km, no localized failures, and no high-severity transverse cracks were defined as excellent performers. Of the 85 GPS-5 test sections, 13 fell into this category.

The results from this study are useful to pavement designers, materials engineers, and others who make the critical choices that will determine level of service and return on investment when building CRCP pavements. The data available through LTPP will continue to provide a means of evaluating pavement performance to enhance design, construction, and maintenance activities. These analyses will lead to improved performance at reduced overall cost.

Improved Predictive Capabilities

Using the models developed as part of pooled fund study TPF-5(013), Effect of Multiple Freeze–Thaw Versus Deep Frost Penetration on Pavement Performance (Final Report, FHWA-HRT-06-121), a software application, LTPP Performance Forecast Online, was developed that provides pavement performance predictions (i.e., smoothness and distress) for both flexible and rigid pavements. Each of the models provided in the Performance Forecast application incorporated data from LTPP test sections and is completely described and documented in the report. The predictions/forecasts are based on user-defined inputs for environment, traffic, structure, and subgrade conditions.

> "Indeed, LTPP is providing one of the most important elements in technology development through field validation and calibration. The use of LTPP data helps demonstrate to the user community that the models and technologies being developed really match real-world problems."
>
> **M. W. Witczak, Ph.D.**
> *Professor of Civil Engineering, Arizona State University*

The online application (www.ltpp-products.com/Predictor/index.aspx) can be used by State, county, and local highway agencies to forecast or estimate performance trends for pavement sections within their jurisdictions. These estimates are useful in evaluating the prediction capabilities of the MEPDG to determine whether local calibration is necessary for the validation and implementation process. The predictions are also beneficial in updating pavement family performance curves within pavement management systems, allowing decision makers to optimize investment choices and improve overall pavement network conditions.

Understanding Factors That Contribute to Pavement Performance

Traffic loading and environmental conditions are the two major causes of pavement deterioration. Therefore, accurately capturing both elements—as done in the LTPP program—is paramount in analyzing pavement performance. Other critical elements in pavement performance include the materials used in the bound and unbound layers, as well as the selection and timing of preventive maintenance activities.

Pavement engineers consider many alternatives when designing a pavement system. The LTPP database has been used to sort out these alternatives and establish optimal design features for use in certain situations. The data has also been used to change design policy at State and local agencies.

An extensive study, LTPP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements, was conducted under NCHRP[16] on all SPS-1, SPS-2, and SPS-8 projects to evaluate the influence of site conditions and design factors on pavement response and performance. SPS-1 projects consist of multiple flexible pavement test sections constructed consecutively with various layer thicknesses, base types, base thicknesses, and drainage configurations. Similarly, test sections on an SPS-2 project are composed of various slab thicknesses of the PCC, base type, PCC flexural strength, drainage, and lane width combinations. Both of these projects provide an excellent source of data to evaluate the effectiveness of various design features and the impact of in situ conditions. The SPS-8 experiment was designed to study the influence of environment in the absence of heavy loading.

This study can be used by those interested in the contribution of design factors on flexible and rigid pavement performance. The present benefit of this study is an understanding of the interaction between design parameters and climate and the resultant changes in pavement performance. The LTPP database provides a means of conducting this type of study on a national scale. The findings from this study can be used to optimize cost-effective design alternatives and will be useful in transferring mechanistic evaluations to field performance for various design parameters.

Maintenance and Rehabilitation Insights

Before the LTPP program, there was limited information on the performance of rehabilitation and maintenance activities. The experimental design of the LTPP database ensured that information on maintenance and rehabilitation strategies and their deterioration rates was collected (SPS-3 and SPS-4 maintenance studies; SPS-5 and SPS-6 rehabilitation projects; GPS-6 and GPS-7 asphalt concrete overlay sections). Thus the database provides performance data for various maintenance and rehabilitation alternatives.

Some of the LTPP experiments offer side-by-side comparisons of treatment alternatives that allow direct comparison while keeping selected factors (such as subgrade, traffic, and climate) constant. The results can be used to determine the most cost-effective treatments based on life cycle cost analysis. These experiments can also be used to predict the expected service life of treatments based on in situ conditions. By knowing the expected life, pavement management engineers can develop proper timing intervals and determine budgetary needs.

As part of the LTPP data analysis program, an NCHRP study, LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options,[17] evaluated the performance of various maintenance and rehabilitation strategies on immediate improvements in pavement condition, as well as their long-term effects. In addition, the impact of climate, traffic, and pre-treatment pavement condition were analyzed. For flexible pavements, both maintenance and rehabilitation strategies were studied; for rigid pavements, only rehabilitation strategies were considered. Data from LTPP SPS-3, SPS-5, SPS-6, GPS-6B, and GPS-7B experiments were utilized in the NCHRP study. The findings from this study can be used to understand the impact of maintenance and rehabili-

LTPP experiments have contributed to more cost-effective pavement preservation strategies.

Above: A pavement test section with a 2-in. recycled asphalt overlay.

Left: LTPP rehabilitation experiments included jointed concrete pavements.

tation treatments. With this understanding, engineers can make informed decisions on treatment types based on the existing condition of the pavement, expected traffic, and climate. Findings such as these are very useful to pavement decision makers in evaluating the cost effectiveness of alternative strategies, materials, and methods.

Use of Reclaimed Asphalt Pavement

The growing demand for materials to rehabilitate the highway infrastructure in the United States and the increasing need for sustainable and environment-friendly alternatives have substantially increased the demand for recycling materials. The most common application of material recycling in pavements is RAP, reclaimed asphalt pavement.

Research was done under LTPP SPS-5 to determine the effects of design and construction features on pavement response and performance and to establish their importance in predicting the future performance of rehabilitated pavements. The performance data from LTPP SPS-5 revealed that RAP and virgin hot-mix asphalt mixes used in overlays of flexible pavements show approximately the same performance across a wide range of climates, traffic, and existing pavement conditions over a service life ranging up to 17 years.[18] The evaluation of the deflection data suggested that when thick overlays are designed for pavement sections, the likelihood that the performance will be similar for both types of mixes increases. This major finding should give agencies confidence in specifying RAP mixtures for overlays when economic and other conditions warrant.

The inventory of MRL materials is available at www.ncenet.com/ltpp/mrl. The facility has shipped more than 17,000 lb of material to pavement researchers in seven countries.

Materials Reference Library

From the onset of the LTPP program under SHRP, administrators planned to store test site materials to make them available for future research. As such, the Materials Reference Library (MRL) was established, initially in Austin, Texas. Now located in Reno, Nevada, the MRL stores more than 1,000 tons of pavement materials—portland cement, asphalt cement, natural aggregates, and combinations of these materials—in both loose and core forms. Collected from across the United States, the samples represent a wide variety of physical, chemical, and geologic properties and field performance histories. Although most of the materials are from LTPP projects, there are also materials from WesTrack and a few other federally funded research activities. The MRL also houses film and distress maps produced during the collection and interpretation of automated surface distress data collection on LTPP sites.

The MRL continues to grow. A significant re-sampling effort was recently completed on the SPS projects to ensure that sufficient material is available to the pavement community. In addition, recycled asphalt and warm-mix asphalt samples are being collected and stored at the MRL as the Asphalt Research Consortium, under a cooperative agreement with FHWA, constructs pavement test sections using those materials.

The MRL will enable future analysts to compare new test methods to actual performance using materials from LTPP projects. It will provide a critical link between field performance and material properties for new test methods and will support a variety of other materials-related research efforts.

Colorado Implements Proven PCC Pavement Practices

The Colorado Department of Transportation (DOT) has been a strong supporter of LTPP by being proactive in examining performance at its LTPP test sections and making improvements based on these evaluations. A 2006 report[19] documented the implementation of improved PCC pavement practices based on LTPP test sections. The LTPP data confirmed that widening a slab from 12 ft to 14 ft (3.7 m to 4.3 m) provides the structural equivalent of increasing slab thickness by 1 in. (2.5 cm); and that a single 1/8-in. (0.32-cm) cut is as effective as Colorado DOT's previous standard 3/8-in. (0.95-cm) double cut for PCC joints, thereby providing a savings of $0.57 per linear foot of joint ($1.87/m). These results were derived from the SPS-2 and SPS-4 projects, respectively.

Many aspects of the LTPP program that are clearly beneficial to the highway community are difficult to quantify monetarily—such as procedures for QC/QA for research-level data collection, data collection techniques and practices, test methods, and database management. Other programs are benefiting from the extensive experience of the LTPP program, as well. For example, plans for the Long-Term Bridge Performance Program emphasized lessons learned in LTPP: the importance of standardizing data collection procedures and documenting data cleaning and analysis in rigorous reports. The plan also recommended using the LTPP program as a model for organization structure and oversight.[20]

Other aspects of the LTPP program can be defined monetarily as cost savings recognized through implementation and can serve as a basis for determining the return on investment of the LTPP program.

LTPP by the Numbers

The numerous innovations that have directly resulted from the LTPP program—procedures, software tools, manuals, and research findings—have been implemented across the United States and abroad. A partial listing of LTPP resource statistics is shown in table 2.

Opportunity Cost

From an agency perspective, cost savings do not contribute directly to an increased bottom line, but rather to an optimized opportunity cost. Almost invariably there are significantly more projects to be completed than funding will allow. Funds that do not have to be used on one project can thus be shifted to another. As an example, the design of a project in Arizona was being based on existing tables of equivalent single-axle loads. However, because of the presence of an LTPP WIM site, measured traffic data were available. These data clearly showed traffic loads to be much less than the design table indicated. This resulted in a cost savings of more than $2 million for the project—extra funds that could then be allocated to other priority projects. Nationwide, these "save/extra" moneys serve to improve the overall pavement network without incurring additional costs.

"The true benefit of the LTPP database will come from its use in developing new pavement designs and methods for building and maintaining pavements."

Preserving and Maximizing the Utility of the Pavement Performance Database, Transportation Research Board, 2009

Table 2. Long-Term Pavement Performance (LTPP) Resources

LTPP Resource	Statistics
Requests for data	50,000+ requests filled
LTPP Products Web site	3,000+ registered users (in 77 countries)
Published documents resulting from LTPP data	500+ publications
American Society for Civil Engineers/LTPP International Contest on LTPP Data Analysis	60 entries
Distress manuals	20+ State agencies use in operations
Falling-weight deflectometer calibration centers	500+ calibrations performed
Weigh-in-motion systems	550+ installations
SPS Traffic Data Collection Pooled Fund Study	28 Specific Pavement Study sites
Materials Reference Library materials	2,000,000 lb available for future research
Materials Reference Library shipments	17,000 lb delivered for other research

Table 3. Estimated Annual Expenditures for Highways and Roads in 2006 Dollars Under SAFETEA-LU[1]

	Expenditures (billions)		
Type of Expenditure	Federal	State and Local	Total
Capital	$34.0	$40.6	$74.6
Operation and maintenance	$1.2	$58.5	$59.7

[1]Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users, Public Law 109-59.

Projected Cost/Benefit Ratios

In 2007, the Congressional Budget Office published a paper documenting "Trends in Public Spending on Transportation and Water Infrastructure, 1956 to 2004."[21] This report provides public expenditures (on the Federal, State, and local levels) for both capital spending and operation and maintenance spending, and it also breaks these expenditures down by type of infrastructure, including highways and roads. Annual expenditures under current legislation[22] are provided in table 3. Using numbers from the 2007 report as a base and subtracting the amount spent on bridges, one can extrapolate that more than $114 billion is spent each year on roadways and highways. Typically 40 percent of that amount is dedicated to pavement construction and maintenance; thus the annual investment in pavements totals about $45.6 billion.

Quantification of the return on research investments can prove quite challenging. In most instances, the

Better estimates of traffic volumes and loads support more rational allocations of construction and rehabilitation dollars.

Table 4. Projected Savings as LTPP Data Are Utilized

	Projected Future Savings (2015–2024)*			
	Annual		Cumulative	
Savings to Date	No additional monitoring	Continued monitoring	No additional monitoring	Continued monitoring
$1.7 billion	$228 million	$456 million	$2.28 billion	$4.56 billion

*Assumes that future annual pavement costs remain steady at $45.6 billion/year.

research does not include a discussion of cost implications, and assumptions must be made. This scenario utilizes cost information whenever possible and is very conservative in assessing the benefit. Simply providing a cumulative savings is not realistic since independent findings do not necessarily provide a 1:1 cumulative relationship. For instance, it is not practical to suggest that 10 separate findings, each resulting in "saving" a single half inch in a pavement design, would cumulatively provide 5 inches of savings.

Suppose the return on investment (savings) from the LTPP data since program inception in 1989 is one-quarter of 1 percent (0.0025), or $1.7 billion. As LTPP monitoring is continued past 2009, the annual savings, beginning in 2015, is expected to be about $456 million per year, or about 1 percent of the total pavement investment—double what could be expected if monitoring ended today (table 4). Over a 10-year span (2015 to 2024), the savings achieved as a result of continued monitoring will total $4.56 billion.

To reiterate, the estimated savings shown are extremely conservative. Considering that the MEPDG team estimates *$1 billion in annual savings* from implementing the new design procedure, and—as demonstrated herein—that LTPP's benefits range much more broadly than supporting development and implementation of the MEPDG, it could be argued that future LTPP cost savings should start at 10 figures.

By any measure, the LTPP program has already provided a substantial return on investment, with a benefit–cost ratio exceeding 6:1. Put in the context of other large research programs, this number is quite reasonable. For instance, the estimated return on research investment for MnROAD is 8.9:1,[23] and Washington DOT has documented returns on its State research funds at over 18:1 when considering all funding sources in the State.[24] In fact, the benefit–cost ratio for LTPP over the 2015–2024 period is projected at over 50:1, using recent AASHTO and TRB estimates for proposed levels of funding support. Furthermore, even greater returns can be achieved through expanding future monitoring activities to pavement materials and design methods that have been developed since 1987.

THE ROAD AHEAD

The key drivers for establishing the LTPP program still exist today, more than 20 years after the initiation of test section monitoring. High-value sections remain in the program, and there is much to be gained by continuing to monitor them. There is a rich base of information still to be harvested from LTPP studies that will aid in improving the performance of pavements. The LTPP program will provide benefits and deliver accomplishments for the foreseeable future.

As such, TRB published a report in 2009 titled *Preserving and Maximizing the Utility of the Pavement Performance Database*.[26] This document recommends a multi-year strategy designed to leverage LTPP's strengths to deliver high-priority results. On a similar track, AASHTO has formally endorsed the LTPP program and publicly championed for enhanced funding.

In support of these endorsements, FHWA has issued a policy document, *LTPP Beyond FY 2009, What Needs to Be Done*,[27] which describes the activities to be undertaken by the program to reap additional returns on the Nation's significant investment in LTPP. This document provides a framework of work to be done during the 2010–2015 time period and outlines the additional benefits that will accrue from these actions.

The LTPP program is an ongoing and active program. Looking forward, there are literally thousands of additional potential benefits LTPP can provide. The overarching benefits are increased service life for all types of pavements, lowered life cycle costs, and improved safety. Following are a few of the specific ways in which the LTPP program will contribute to improving pavement programs across the country:

- Optimizing treatment selection.
- Assessing the impact of the environment on performance.

A Critical Role

There is no doubt that the LTPP database has played a critical role in the development and evaluation of every major pavement design methodology developed over the past 20 years. These include the 1993 and 1998 AASHTO design procedures, Superpave, and—most recently—the MEPDG, which the developers indicate will generate annual savings of $1 billion. Calibrated nationally with LTPP sections, the MEPDG has shown significant reductions in the initial cost for heavily trafficked pavement designs. Beyond overall design procedures, the LTPP data has supported and will continue to support model development and validation for a wide array of performance predictors and indicators.

The LTPP program has generated savings across a wide range of pavement management activities—from improving data collection equipment and operations and establishing data variability and reliability to providing quality data sets to be used for baseline comparisons against agency data. As one example of potential savings, the Indiana DOT has estimated that a 1-mil (0.0254 mm) error in FWD calibration will result in additional costs of $17,900 per lane-mile ($11,187 per lane-kilometer).[25]

Looking to the future, the largest component of highway pavement programs and budgets is likely to involve rehabilitating and maintaining existing pavements, rather than new construction. The LTPP program has many rehabilitated test sections that were monitored for several years before rehabilitation and have continued to provide service since rehabilitation. Capturing the full performance life of these projects will require continuing monitoring into the future if the benefit of future savings based on lessons learned is to be realized.

Furthermore, considering that the SPS-1 and SPS-2 experiments are most relevant to establishing the influence of specific design features on pavement performance, and many of these projects are not close to the end of their design lives, determining the influence of specific design features requires continued monitoring. Data exist to support early conclusions, but additional information is necessary to learn the true impacts of these features over a section's entire design life.

- Providing baseline data sets for agencies to evaluate performance internally.
- Allowing year-to-year checks against agency pavement management system/pavement condition index data.
- Calibrating new field data equipment.
- Comparing the performance of new materials with conventional materials.
- Evaluating the performance effects of specific design features.
- Allowing local calibration and model refinement for the MEPDG.

The benefits and accomplishments of LTPP to date, as discussed in this document, have already provided a significant return on investment to the Nation. In the future, the LTPP program will yield additional information of tremendous value to pavement engineers and managers, who will translate this information into strategies and procedures for building better, safer, more cost-efficient roads for the Nation.

"LTPP is a major contributor toward assuring that we will have good pavements into the 21st century."

Charlie Churilla
"An Investment in the Future"
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Accessing LTPP Information and Products

Accomplishments and Benefits Database: This document highlights the accomplishments and benefits of the LTPP program over the first 20 years of data collection. During development of this report, an extensive database of existing LTPP reports, products, and research results was compiled. The LTPP Literature Database can be accessed here: http://ltpp.org/user_corner.shtml.

FHWA LTPP Web Site: FHWA maintains an LTPP Web site to disseminate information resulting from the LTPP program. www.fhwa.dot.gov/Pavement/ltpp

LTPP Customer Support Service Center: LTPP data requests, technical questions, and data user feedback can be submitted to the LTPP Customer Support Service Center via email at LTPPinfo@dot.gov or by calling 202-493-3035.

LTPP Products Web Site: Many of the products mentioned in this document can be found online at the LTPP products Web site, which also contains online access to the LTPP database. www.ltpp-products.com

Materials Reference Library: More than 1,000 tons of sample materials are held at this site for research purposes. Included are pavement cores, asphalt cement, portland cement, aggregates, and other materials. www.ncenet.com/ltpp/mrl

Strategic Plan for LTPP Data Analysis: Since 1999, analysis of the LTPP data at the national level has been guided by the Strategic Plan for Data Analysis. The Strategic Plan was developed by the TRB Expert Task Group on LTPP Data Analysis, recommended by the TRB LTPP Committee, and adopted by FHWA as the basis for selecting LTPP analysis projects and evaluating progress in LTPP data analysis. www.fhwa.dot.gov/pavement/ltpp/stratplan/strategic.cfm

ASCE-LTPP International Contest on LTPP Data Analysis: The contest is designed to encourage university students, professors, and highway department engineers from around the world to get involved in using the LTPP database. www.fhwa.dot.gov/pavement/ltpp/contest.cfm

SPS Traffic Data Collection Pooled Fund Study: This study includes two phases. Phase I consists of assessing, evaluating, and calibrating the current weigh-in-motion and vehicle classification systems used to collect traffic data at SPS sites across the country. Phase II consists of installing and maintaining new weigh-in-motion equipment as necessary to ensure high-quality data collection. More information is available at www.fhwa.dot.gov/pavement/ltpp/spstraffic/index.cfm.

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