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THE LONG-TERM PAVEMENT PERFORMANCE PROGRAM



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Foreword

Why read this report? For highway professionals the answer is obvious. This report is a treasure trove of information about pavements and their performance. But why should others read it? Because the report details how a *long-term, strategically oriented* research program was conceived, initiated, and successfully carried out. In the 1980s such research had disappeared from the transportation field, displaced by short-term efforts aimed at narrowly focused problem solving or policy adjustments. Such research is needed of course, but it cannot answer fundamental questions about the performance of transportation infrastructure—the very questions that the “infrastructure crisis” of the 1980s brought to the fore. Such questions require well-organized, interconnected programs of research such as the Long-Term Pavement Performance program, better known as LTPP.

To understand LTPP, one must first understand the discontent and frustration among transportation agencies during the latter part of the 1970s and 1980s. Public works of all kinds seemed to be falling into disrepair at an alarming rate. The popular press dubbed it “the Infrastructure Crisis.” Roadways, especially roadway pavements, seemed to be most prominently afflicted.

Highway pavements, whether on country lanes or modern expressways, were simply not living up to the expectations of motorists and freight carriers. Nor were they living up to the expectations of the transportation agencies. No one was quite sure why this crisis arose or how it might be overcome. What was certain was that investments in highway research had fallen to a historic low. In the late 1970s, the U.S. Congress began to focus on the infrastructure crisis and the role of research in providing solutions. The key legislative action was the passage of the Surface Transportation and Uniform Relocation Assistance Act in 1987. This act significantly increased funds available for highway research and specifically funded a Strategic Highway Research Program (SHRP) previously recommended by a select committee of the Transportation Research Board. A key element of SHRP was the studies of the LTPP program. These studies were explicitly designed to address concerns about the long-term behavior of highway pavements and how that behavior was influenced by climate, materials properties, traffic, design, construction, and maintenance.

The pages that follow recount the history and outcomes to date of the LTPP program. The program’s

studies have tracked the performance of more than 2,500 pavement test sections located throughout the United States and Canada, in some cases for more than 20 years. What might not be evident in this history is how daunting a task it all seemed at the beginning, considering what was expected of the program.

LTPP was intended to be the largest pavement research effort ever—transcontinental in its scope. It was expected to involve the active collaboration of the transportation agencies of the 50 American States, Puerto Rico, the District of Columbia, and, ultimately, all 10 Canadian Provinces. The individual test sites would be widely dispersed, and the research teams would have to be masters of logistics. One part of LTPP would study the past and future performance of in-service test sections typical of pavements in current use. The second part of the effort would study specially constructed pavements where factors deemed important to pavement performance could be carefully controlled.

LTPP was expected to be truly “long term,” lasting at least 20 years. This expected longevity also posed a host of concerns about funding, continuity of the research, materials sample storage, data storage and access, and the like. Most of all, it required long-range research and management plans.

The studies were to be comprehensive, considering how variations in climate, materials, designs, maintenance activities, and other factors augment or limit pavement life. Also, a host of practical outcomes were expected, including new, more reliable pavement design procedures and standards, cost allocation methodologies, improved pavement management techniques, and pavement maintenance policies.

These grand goals, grand expectations, and grand plans were seen as too grand by skeptics. They held that LTPP would wither before the studies were completed and would not meet the grand goals. Turn now to *The Long-Term Pavement Performance Program* and judge for yourself.

Neil F. Hawks

SHRP-LTPP Director, 1987–1992

Acknowledgments

A great deal of gratitude is owed those who gathered in the 1980s to not only discuss the condition of the Nation's highway system but to also articulate a vision for its improvement and to develop a plan to make the vision a reality. Thus, the Long-Term Pavement Performance (LTPP) program came to be.

Thank you to the many authors of this history for taking time to record the facts about the program's development so that future generations can have a good understanding of how the LTPP program began, has been managed, and has overcome the many challenges inherent in a long-term pavement monitoring effort. Staff members of the National Academy of Sciences' Transportation Research Board (TRB) who work with the program are due thanks for helping to sustain the LTPP vision through the many changes in volunteer and staff participation over the years. The Federal Highway Administration's Division Offices are also recognized for their role in maintaining communications between the LTPP program office and the highway agencies.

Acknowledgement is given to the many efforts and contributions of the LTPP program staff, its contractor staff, and the supporting TRB LTPP committees who have devoted countless hours to review the contents of

this book for accuracy and completeness, and for providing the pictures displayed throughout the pages.

Leading the effort to assemble this book has been both a challenge and pleasure over the past several years. The primary goal for this document is to provide a detailed, written record of the LTPP program that serves the needs of different readers—from the chief engineer in the highway agency who wants a better understanding of the origins of the program (chapter 1) to the pavement engineer who wants to learn more about the different LTPP products (chapter 10) to the student who needs to know the different types of pavement performance data collected by the program (chapter 6). Thank you to management for the privilege of working on this assignment. Thank you to those who offered encouragement on those challenging days, but sincerest gratitude goes to the communications director who worked diligently to help resolve the big issues and tiniest details to complete this book. Read on, to learn about the LTPP program's rich history and its future direction.

Deborah Walker

Research Civil Engineer, LTPP Team Member

Federal Highway Administration

LONG-TERM PAVEMENT PERFORMANCE

Knowledge into Action... Performance Data for Pavement Innovation



The Long-Term Pavement Performance program partners, data elements, and data collection, storage, and analysis activities. (Concept by Eric Weaver, Federal Highway Administration; executed by Jim Elmore, CSI.)

Welcome to LTPP

The mission to study pavement performance systematically across the United States and to promote extended pavement life had been advanced since the late 1950s by the National Academy of Sciences' Transportation Research Board, the American Association of State Highway and Transportation Officials, and the U.S. Department of Transportation's Federal Highway Administration (FHWA). By the 1970s, deterioration of the highway systems built two and three decades earlier was a growing concern, and highway budgets were increasingly devoted to maintenance, rehabilitation, and reconstruction. By the 1980s, the bill coming due for pavement repair and replacement by the year 2000 was estimated at \$400 billion.^{1,2} Highway agencies were creating pavement management programs to help them invest public funds more strategically, but lacked historical data to support those programs. Although many highway agencies were conducting pavement research, a broader, long-term, coordinated effort was needed to understand better how to design, build, and maintain long-lasting, high-performing pavements.

Congress, in the Surface Transportation Assistance Act of 1978, directed the Secretary of Transportation, assisted by the Congressional Budget Office, to “investigate . . . the need for long-term or continuous monitoring of roadway deterioration to determine the relative damage attributable to traffic and environmental factors.”³ The Congressional Budget Office responded with Guidelines that outlined the effort needed:

Many of the uncertainties about pavement...can be unequivocally resolved only by carefully monitoring the volume and mix of traffic on selected roads over an extended period and by monitoring changes in the serviceability of the pavement over the same period. . . . This undertaking would also produce information that could improve practices followed in the construction and maintenance of pavement. The selection of the roads to be monitored should be made in such a way that the study will include a representative set of climatic and environmental conditions. In addition, it is important that a wide range of road types be monitored, including roads on every functional system and both urban and rural roads. To the greatest extent possible, wide variations in the mix of traffic should be sought at otherwise similar monitoring points, so that additional assessment of the relative effects of heavy and light vehicles can be made.⁴

Nearly a decade later, with passage of the Surface Transportation and Uniform Relocation Assistance Act



The goal of the Long-Term Pavement Performance program is to increase pavement life by investigation of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices.

of 1987, Congress authorized the Long-Term Pavement Performance (LTPP) program as part of the first Strategic Highway Research Program (SHRP), a 5-year applied research program funded by the 50 States through a dedicated share of the Highway Trust Fund.⁵ The program was joined by Canada, whose leaders were also seeking to advance highway research and were closely involved in planning for SHRP. Canada's 10 Provincial highway agencies participated in SHRP and the LTPP program. The mission of the LTPP program was ambitious:

- Collect and store performance data from a large number of in-service highways 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.

After extensive planning, data collection officially began in 1989. Four LTPP regional offices and a small national office were established to coordinate the collection of data within 17 scientifically designed experiments. Eventually, 2,509 pavement test sections on in-service highways were selected or constructed to address specific questions about how differently constructed and maintained pavements perform under the wide range of climatic, soil, and traffic conditions in the United States and Canada. Such an ambitious program required identifying the constituent materials and structural design of each test section and its maintenance history, monitoring weather conditions, deter-

mining traffic loads and volumes, and monitoring the resultant pavement performance. This vast store of information had to be carefully collected and safeguarded for future analysis.

At the end of SHRP 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 as well as the District of Columbia and Puerto Rico. Pavement 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 highway agency. By following these test sections over time, researchers are gaining insight into how and why pavements perform as they do, which provides valuable lessons on how to build and maintain longer lasting, more cost-effective pavements.

New experiments are being added to monitor the performance of pavement materials and technologies that were not yet in use when the LTPP program began, such as warm-mix asphalt and pavement preservation. As highway agencies implement other pavement materials and technologies, the LTPP program will consider whether they should be added to the program for long-term monitoring.

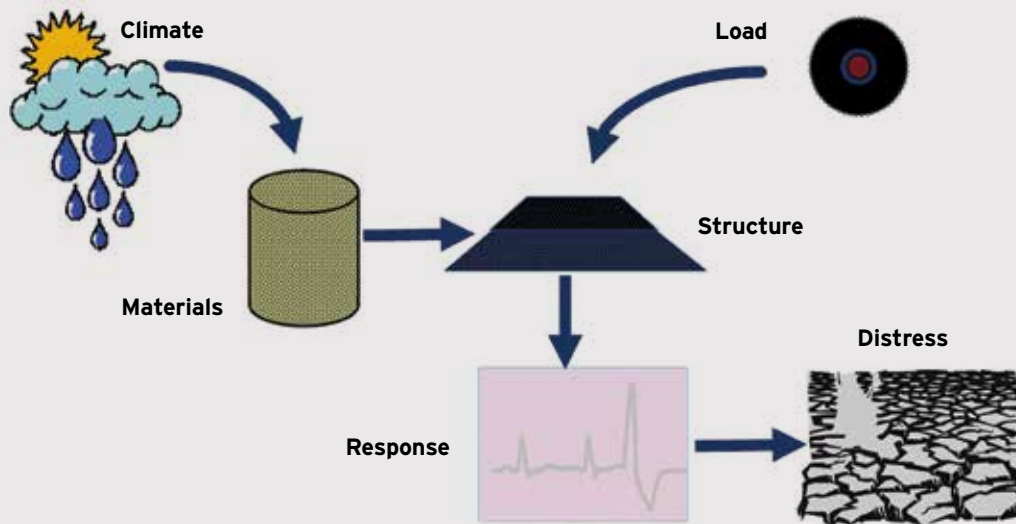
The LTPP program has generated a broad array of benefits across the pavement engineering and performance spectrum. Numerous applications now make use of LTPP data, and the utility of the data is increasing. LTPP benefits and products fit broadly within three categories:

- The largest and most comprehensive pavement performance database (approximately 280 million records of data and climbing) in the world.
- Advances in pavement performance measurement.
- Contributions to pavement design and management.

Because of the foresight of leaders in the highway community three decades ago and the resolve of all parties involved in the program, LTPP-related findings continue to benefit the highway community and ultimately the taxpayers and driving public. In some cases, highway agencies have seen cost-savings in the millions of dollars on their highway systems as a result of these findings.

To make the best use of the LTPP data, some understanding of the history of the program and the decisions that shaped it is needed. Many people and

TYPES OF DATA COLLECTED AT LTPP TEST SECTIONS



The LTPP program continues to improve its data collection and quality control procedures through lessons learned and by adapting to changes in equipment and pavement technology. Although data collection and quality control procedures have varied over time, the principal data types

collected since the beginning of the program, shown in the graphic above, have not. The program has collected these data in a consistent and systematic manner over the years, and they will be the primary source for evaluating pavement performance for the foreseeable future.⁶

organizations have participated in this extraordinary data collection, analysis, and product development effort. Program decisions have evolved over time to implement what has been learned and to adopt advances in technology. This report was prepared to document the history of the LTPP program as a foundation for future work, to review lessons learned, and to consider how future pavement managers, researchers, and engineers can benefit further from the program. The report is organized in three parts:

I. Building and Managing the LTPP Program

Chapter 1. Origins of the LTPP Program—the program’s conception, pre-implementation studies, and early development.

Chapter 2. Management of the LTPP Program—the program’s organizational structure, peer review and advisory functions, and communication and coordi-

nation activities, and an introduction to the program’s managers.

Chapter 3. LTPP Program Partnerships—the major collaborators in the program and their contributions.

Chapter 4. Federal Investment in the LTPP Program—the U.S. Federal legislative mandates for the program, its budgetary support, and the impact of funding reductions on program activities.

II. Developing the Studies and the Pavement Performance Database

Chapter 5. Design and Recruitment of the LTPP Experiments—the planning process that determined what variables would be studied at the test sites that were to be chosen for the General Pavement Studies and constructed for the Specific Pavement Studies.

Chapter 6. Collection of the LTPP Data—data-gathering efforts, technologies, and procedures.

Chapter 7. Special LTPP Data Collection Efforts—data collected through special programs that were not in the original experiment designs—the Seasonal Monitoring Program, Traffic Data Collection Pooled-Fund Study, Materials Action Plan, and forensic studies.

Chapter 8. Storage, Growth, Security, and Dissemination of the LTPP Data—history of the data storage and distribution technologies and procedures.

Chapter 9. LTPP Data Quality Efforts—manual and automated quality control and assurance processes established to ensure that the data stored are of research quality.

III. Creating Products, Learning From the Past, and Preparing for the Future

Chapter 10. Turning LTPP Data Into Results—data analysis activities, LTPP products, research findings, and realized economic and performance benefits.

Chapter 11. Lessons Learned From the LTPP Program—lessons learned from some of the thornier problems that the program wrestled with, their outcomes, and insights gained.

Chapter 12. Paving the Way to the Future—preservation, refinement, and analysis activities required of the program to maximize the LTPP investment, and plans for monitoring the performance of new pavement materials and technologies.

Three appendices outline the program’s advisory bodies, technical contracts, and data collection equipment and software.

References are provided throughout this history, many with links to the World-Wide Web. Over time, these links may become obsolete. Readers seeking these source documents or more up-to-date information about the program and its future should refer to the LTPP home page and the LTPP InfoPave™ Web site.

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Building and Managing the LTPP Program



The LTPP program began with a high level of support from the U. S. Congress and from a wide array of organizations that were represented in formulating the program.



Origins of the LTPP Program

The LTPP program officially began in 1987, after much planning and preparation. Its purpose was simple: gather high-quality data needed to understand pavement performance—and the variables affecting it—and make the data available for research and development of high-value products well into the future. The execution of this mandate, however, has been exceedingly complex, involving dozens of organizations, hundreds of participants, thousands of decisions, and volumes upon volumes of data and analysis. Several decades later, the program continues to positively impact the highway community.

INTRODUCTION

The LTPP program is an ongoing effort to collect and understand information about how and why pavements behave as they do. The program consists of experiments that were carefully designed to answer specific questions about how certain variables—pavement design, construction, and materials; maintenance and rehabilitation practices; traffic loading; and climate—affect pavement performance over time. Pavement test sections are established throughout the United States and Canada with the cooperation and support of the State and Provincial highway agencies. Some test sections are selected from existing highways and others are constructed to the program's specifications. Information on the design, construction methods, materials, and

maintenance and rehabilitation activities are collected for each test section. The program monitors the performance of these sections, their traffic loads and climatic conditions, and the data collected are made available to the highway community. The LTPP program is the largest and longest lasting pavement monitoring program, and it has assembled one of the most comprehensive national and international pavement performance databases in the world.

The LTPP program evolved from long-term pavement monitoring studies that were conducted in the early 1980s. Planning for a long-term monitoring program gained momentum as supporters of the concept realized the potential return that investment in long-

Key Milestones in the Origins of LTPP

- 1978** Surface Transportation Assistance Act calls for long-term roadway monitoring
- 1982** FHWA implements the Long-Term Pavement Monitoring Study
- 1984** AASHTO approves recommendations from Strategic Transportation Research Study
- 1984** Office of SHRP interim director established
- 1985** AASHTO Task Force approves research plans
- 1985** Contractors chosen for SHRP research areas
- 1985** FHWA funds the Pavement Condition Monitoring Methods and Equipment Study
- 1986** SHRP research plans published
- 1987** U.S. Congress authorizes SHRP-LTPP program

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term pavement research would ultimately bring. After years of preparation, the LTPP program officially began as part of the 5-year Strategic Highway Research Program (SHRP) authorized by Congress in 1987.¹ A critical component of the multi-pronged SHRP effort, the LTPP program carried an initial price tag of \$50 million over 5 years. The ultimate return on investment would be the economic benefits realized from better design, construction, monitoring, and management of the Nation's pavements—the anticipated outcome of long-term pavement performance monitoring and the research it would enable. Before the launch of such an ambitious research program, extensive planning and preparation were necessary.

This chapter focuses on the conception, planning, precursor studies, and early coordination activities that laid the groundwork and prepared the management structure for implementation of the LTPP program.

THE NEED TO UNDERSTAND PAVEMENT PERFORMANCE

At the time SHRP was conceived, the United States had reached a low point in highway research investment at the State and Federal levels and in private industry. By comparison with other developed countries, other industries, and its own previous levels of investment, the country was falling behind in its commitment to highway research.^{2,3} At the same time, the Nation faced an impending crisis in the aging of its highway infrastructure, which was due for massive investments in repair and replacement. Accountability for the use of public funds was becoming a much greater priority for government agencies. Highway expenditures were \$50 billion annually at the time,⁴ and it was estimated the Nation would spend \$400 billion replacing and rehabilitating pavements by the year 2000.⁵ People recognized that improved understanding of how pavement design, materials, construction techniques, maintenance practices, traffic loads, and climate affected the life cycle of pavements would lead to longer lasting pavements and a more efficient use of public funds.

The need to improve design methods was pressing. Pavement design guides in wide use by highway agencies between the 1960s and 2000s^{6,7,8} largely relied on models of pavement behavior developed primarily from the American Association of State Highway Officials (AASHTO) Road Test,⁹ conducted in the late 1950s. The AASHTO Road Test had a very small inference space of monitored pavements and loading parameters. By the mid-1980s, truck traffic loads far exceeded the levels experienced 30 years prior, and the AASHTO Road Test was no longer applicable to the design of modern pavements. No other long-term, nationwide research had been conducted on pavement performance. Despite their limitations, in some cases the design models in use worked reasonably well, and they were enhanced with professional judgment and calibration factors to more accurately predict true performance. In other cases, however, predictions of design performance varied drastically from observed performance, resulting in overdesigns and underdesigns that taxed highway agency budgets. Legislators demanded better, more reliable methods of budgeting available transportation

dollars, with some assurances that a major failure would not occur to derail years of planning.

A secondary impetus for long-term monitoring of pavements in service came from the need for models to make pavement management systems more accurate in their predictive capabilities. In the mid-1980s, pavement management was becoming recognized as a valuable tool. Improvements were needed in pavement performance models, and standards for collecting research-quality pavement performance data were lacking.^{10,11}

Leaders in the highway community called for a large-scale, national approach to learning how best to design, build, and maintain long-lasting highway infrastructure. Highway managers and engineers at the time were convinced that the opportunity to make vast improvements in the understanding of pavement performance was a prudent fiscal investment. In the United States, the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) strongly supported the initiative, and Canada joined in the planning and implementation phases of the program, with representation on the SHRP Task Force and on each of its seven technical area advisory committees. State and Provincial agencies worked together to locate suitable test sections for monitoring and helped in numerous workshops and meetings to guide the development of the program in the mid-1980s. AASHTO, FHWA, and the Transportation Research Board (TRB) of the National Research Council, together with leaders in the international highway community and the pavement industry, began a dialogue about the need to collect pavement performance data over an extended period. The remainder of this chapter describes the research and planning that led up to implementation of the SHRP-LTPP program.

LONG-TERM PAVEMENT MONITORING IDEA

In Section 506 of the Surface Transportation Assistance Act of 1978 (Public Law 95-599), the Congress of the United States directed the Secretary of Transportation to study and investigate “. . . the need for long-term or continuous monitoring of roadway deterioration to determine the relative damage attributable to traffic

and environmental factors.”¹² This provision offered an opportunity to begin a serious initiative.

The initiating agencies in the highway community—FHWA, AASHTO, representing the State highway agencies, the Road and Transportation Association of Canada, and TRB—began preparations for SHRP and its long-term pavement monitoring component. These preparations extended from 1980 through the 1987 SHRP authorization and included two major studies: the Long-Term Pavement Monitoring Study and the Strategic Transportation Research Study. In connection with these studies, the partners began forming an organizational structure to carry out the LTPP program and to formulate plans for the pavement experiments. The FHWA also funded the Pavement Condition Monitoring Methods and Equipment Study in 1985 to evaluate and select the best available equipment for the data collection effort. These preparations are described below.

Long-Term Pavement Monitoring Study

The FHWA's Office of Highway Planning developed concepts for a long-term pavement monitoring study, drawing strongly on opinions and ideas from other offices of FHWA. It was decided to shape the proposed effort as a cooperative program among FHWA, an AASHTO Advisory Panel, and participating highway agencies. In June 1981, a joint meeting of the TRB Pavement Management Task Group, AASHTO Joint Task Force on Pavements, and FHWA was held to plan for pilot studies to assess the feasibility of conducting a large-scale, long-term pavement monitoring program and the potential opportunities and challenges in building a national database that could be used to improve understanding of pavement damage relationships. The initial study, the Long-Term Pavement Monitoring Study, a cooperative program among FHWA, AASHTO, and eight States, was implemented in 1982 to monitor selected pavements in those States (Arkansas, California, Colorado, Idaho, Iowa, New Mexico, Pennsylvania, and Washington).¹³

The primary objectives of the pilot effort were to assess the problems associated with building a database that could be used to improve existing design procedures, evaluate rehabilitation techniques, examine the effectiveness of construction techniques and maintenance procedures, and respond to questions asked by

Congress on pavement issues. Funding for the pilot study was provided under an FHWA contract managed by the Office of Research and Development. The FHWA's Office of Highway Planning provided support and additional oversight.

One of the first efforts undertaken in this study was to develop a guide for data collection.¹⁴ Findings revealed that while within the States a significant body of knowledge was available, across the States methods used to collect and record pavement information varied widely, making use of the data on a national scale difficult or impossible. The *Data Collection Guide*, developed over several years, sought to bring consistency to the collection of both project-specific and network-level data. This guide used the Concrete Pavement Evaluation System¹⁵ as a starting point, and then added significant detail with input from recognized professionals in the industry.

In October 1984, FHWA sponsored the Long-Term Pavement Monitoring Workshop, where experts from Federal, State, and private agencies reviewed the States' experiences in the pilot program. Looking ahead to the proposed LTPP program, the industry experts refined the stated objectives, data needs, and data collection processes associated with long-term pavement monitoring. Participants agreed that, to be successful, the proposed program must have "a long-term commitment of money and dedicated permanent staffing."¹⁶ They also called for better uniformity in data collection, better historical records of performance, standardized data definitions, and standardized procedures for collecting the data, as well as extensive training in collecting and processing data. The results of the Long-Term Pavement Monitoring Study showed that it was feasible to identify a set of test sections in multiple States, implement a standardized data collection procedure, and collect key information that could be used to satisfy the objectives of the study.

Strategic Transportation Research Study

Concurrent with the Long-Term Pavement Monitoring Study, FHWA commissioned TRB to conduct a study to develop a strategy for a major new research emphasis on key technological gaps with a potential for high payoff. The results of this effort, called the Strategic Transportation Research Study, were published in 1984 in the "Stars" report, TRB Special Report 202,

America's Highways, Accelerating the Search for Innovation (figure 1.1).¹⁷ One of the primary recommendations from this study was for long-term pavement monitoring. As it became clear that the major agencies involved in pavement design, construction, and management were recognizing the need for a national database of long-term data from highway monitoring, they joined together to develop these plans.

A committee of highway leaders directed the Strategic Transportation Research Study. This committee focused on developing a national research program aimed at high priorities that were not being adequately addressed by existing programs. They compared the distribution of highway agency expenditures with that of highway research expenditures to identify research areas that were being neglected relative to their importance to the agencies. Materials, paving technology, and maintenance emerged as areas of high agency investment that were being neglected in research. The committee chose six technical research areas in which focused, accelerated, results-oriented research promised significant benefits.

The committee recommended that \$150 million be spent over 5 years, funded by 0.25 percent of Federal-Aid Highway Program funds. The committee also presented a brief assessment of several administrative options under which the proposed program could be managed.

In July 1984, AASHTO approved the recommendations of the Strategic Transportation Research Study and SHRP was established to carry out the proposed 5-year research program.¹⁸ The objectives for the six technical areas for the SHRP study in the Stars report were developed further during SHRP planning (see sidebar on facing page).

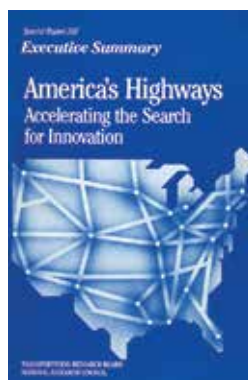


FIGURE 1.1. Report of the Strategic Transportation Research Study, TRB Special Report 202 (1984) or "Stars" report, which identified high-priority areas for a national highway research program.

The FHWA-sponsored Long-Term Pavement Monitoring Study and the Strategic Transportation Research Study generated enthusiasm for the SHRP proposal and its LTPP component. FHWA, with the SHRP office and its Advisory Committee, began developing a transition plan to transfer FHWA's monitoring activities to SHRP. FHWA funded these pre-implementation activities, outlined in the next section, to maintain the momentum until SHRP was officially authorized and funded by Congress, which occurred in the 1987 highway authorization bill, the Surface Transportation and Uniform Relocation Assistance Act.¹⁹

FHWA Maintains Monitoring Momentum Until SHRP-LTPP Begins

The FHWA and contractor staff had been involved in the Long-Term Pavement Monitoring initiative for 3 years (1982–1984) when FHWA decided to support

SHRP in planning the LTPP study. LTPP transition activities were undertaken through increased scope and revision of FHWA's ongoing Long-Term Pavement Monitoring contract. As previously stated, this project had demonstrated that a national data collection effort was feasible and that uniform data collection procedures would allow the creation of a uniform database of information, which in turn would allow the objectives of the SHRP-LTPP study to be realized.

In October 1984, under the auspices of TRB's National Cooperative Highway Research Program (NCHRP) Project 20-20, "SHRP Research Plans," the office of the SHRP interim director was established and plans were set in motion to implement SHRP under the guidance of a special task force. Six contractors were selected in early 1985 to develop the specific research plans for the six technical areas, including Pavement Performance. The technical assistance con-

OBJECTIVES OF THE SHRP TECHNICAL AREAS

Asphalt: To improve pavement performance through increased understanding of the chemical and physical properties of asphalt cements and asphaltic concretes. The research results would be used to develop specifications, tests, and construction procedures needed to achieve and control the pavement performance desired. . . .

Long-Term Pavement Performance: To increase pavement life by investigation of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soils, and maintenance practices. . . .

Maintenance Cost-Effectiveness: To develop elements of pavement maintenance management systems, which establish budgets, administer programs, and allocate resources more efficiently. In addition, the development of equipment, materials, and processes that will increase the productivity and reduce service life costs of pavement maintenance are also sought. . . .

Concrete Bridge Component Protection: To provide methods to protect existing chloride-contaminated concrete components against deterioration and to rehabilitate and protect those components that are already exhibiting corrosion-induced distress. . . .

Cement and Concrete: To increase service life through an improved understanding of the chemistry of cement hydration, the properties of concrete, and the performance of concrete in the highway environment. Particular attention will be given to improving the understanding of the mechanisms of setting and strength development, and the chemical processes during hydration of the cementitious component. Attention will also concentrate on improving the production, placement, quality control, nondestructive testing, and durability of concrete. . . .

Snow and Ice Control: To provide more cost-effective ways to remove the buildup of snow and ice on highways and streets during winter conditions; reduce deterioration of bridges, pavements, and vehicles; and mitigate adverse environmental consequences of snow and ice control.²⁰

tractor and staff for the pavement performance technical area were involved in the planning, and later the implementation, of the LTPP program.

The AASHTO Task Force on the Strategic Highway Research Program was appointed, and the Task Force established advisory committees for each of the technical research areas of SHRP. The SHRP-LTPP Advisory Committee included about 30 representatives from highway agencies, industry, academia, FHWA, a city, and a county (appendix A). The Advisory Committee met for the first time in February 1985, and members were briefed by the interim director for SHRP on SHRP planning, by FHWA on the plan for transitioning from the Long-Term Pavement Monitoring Study to the LTPP component of SHRP, and by the contractors relative to their proposed approach to the experimental design. The findings and recommendations from the 1984 Long-Term Pavement Monitoring Workshop were reviewed. The Advisory Committee discussed issues such as what types of pavements should be studied, developed a set of objectives, made decisions on management of the program, and decided what portions of the transition plan they supported.

A procedure was developed at this meeting for iterative review and guidance, with Advisory Committee meetings occurring approximately every 2 months. The approach was for the FHWA and contractor team to proceed with the experimental design and other assignments and to present the results of these studies to the Advisory Committee. The Advisory Committee would then discuss these presentations and other issues that surfaced and provide decisions and guidance for the team to follow as the work progressed to the next checkpoint. This procedure became a very effective means of gaining input from the highway community and guidance from those selected to supervise the planning of the LTPP study.

A national SHRP workshop was held in Dallas in September 1985 to provide a preview of the research plans under development for the technical areas. U.S. and foreign professionals were invited. At the end of October 1985, the Advisory Committee held its fifth meeting to finalize the research plan. The resultant plan was presented to the AASHTO Task Force in November 1985, and received unanimous approval. The plan for pavement monitoring included three

potential types of studies: General Pavement Studies (GPS), Specific Pavement Studies (SPS), and Accelerated Pavement Testing. It was later decided to pursue Accelerated Pavement Testing research through avenues other than SHRP. Development of the experimental design matrices for the GPS and SPS experiments are detailed in chapter 5.

Following adoption of the research plans, detailed presentations were made at the 1986 TRB Annual Meeting to broaden awareness of SHRP among highway representatives in the United States and abroad. The research plans were published in a document, *Strategic Highway Research Program Research Plans, Final Report*, May 1986.²¹ This publication is known as the “Brown Book” to many (figure 1.2), and it laid the foundation for all of the research work to be conducted under SHRP, including the LTPP studies. It is a valuable reference for anyone seeking to learn about the program, providing a comprehensive list of the organizations and people involved in the development, review, and oversight of the program. The Brown Book established the goals and objectives for each of the six technical research areas. A year after its publication, SHRP officially began.

Pavement Condition Monitoring Methods and Equipment Study

Meanwhile, in 1985, FHWA funded the Pavement Condition Monitoring Methods and Equipment Study contract. The study was designed to serve both the pre-implementation needs of LTPP planning and the industry in general by evaluating deflection and pavement distress survey equipment and methods offered at the time.

The study included a comprehensive comparison of deflection equipment, conducting the first side-by-side

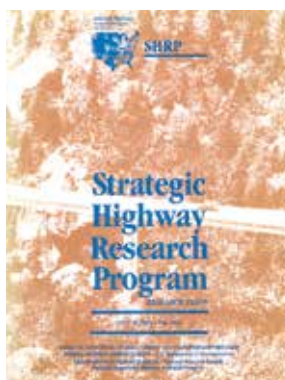


FIGURE 1.2. The 1986 *Strategic Highway Research Program Research Plans*, known as the “Brown Book.”

field tests of the Dynatest falling weight deflectometer (FWD), Kuab FWD, Phoenix FWD, Benkelman Beam, C.E.B.T.P. (France's Center for Experimental Research and Studies of Building and Construction) Curvimeter, Dynaflect, and Road Rater. The results of this comparison were published in *Evaluation of Pavement Deflection Measuring Equipment*.²²

To get a better understanding of state-of-the-practice pavement distress survey methods and to improve upon them, a companion track of the study evaluated, on a common set of test sections, the results of the following distress survey technologies:

- Manual distress mapping.
- Detailed visual surveys using manual recording and automated data logging.
- PASCO ROADRECON survey vehicle.
- GERPHO survey vehicle.
- ARAN (Automatic Road Analyzer) survey vehicle.
- Laser Road Surface Tester survey vehicle.

PASCO was at the time a Japanese firm; the GERPHO vehicle was of French origin and widely used in Europe in the 1980s.²³

The results of this comparison study were published in *Improved Methods and Equipment to Conduct Pavement Distress Surveys*.²⁴ This study set the course for the rigorous equipment performance specifications that the LTPP program has maintained to ensure consistency and accuracy in data collection.

Early Coordination Activities

By the time these preliminary studies had reached their conclusions and the LTPP study under SHRP officially began in 1987, the structure to carry it out was in place. People from different organizations had joined in a concerted effort to develop a sound research program. Management was in the hands of the SHRP interim director, later director, assisted by SHRP engineers assigned to the four LTPP regions established by SHRP. Day-to-day LTPP operations were carried out by the technical assistance contractor (in later years called technical support services contractor) and four regional coordination office contractors (in later years called regional support contractors), who had assisted with preparations for the program prior to 1987.

The highway agencies were heavily involved in these initial phases, for they provided the pavements with which the experiments could be carried out, as well as some of the required data. The basic structure of the program and the roles and responsibilities of these participants are described in chapter 2 for both this SHRP-LTPP period and the program's continuation under FHWA from 1992 forward.

LONG-TERM PAVEMENT PERFORMANCE GOAL AND OBJECTIVES

The goal established for the SHRP-LTPP studies was “to increase pavement life by the investigation of long-term performance of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices.”²⁵ This goal was established by the Strategic Transportation Research Study and adopted by the SHRP-LTPP Advisory Committee. The Advisory Committee identified six specific objectives to support the goal:

1. Evaluate existing design methods.
2. Develop improved design methodologies and strategies for the rehabilitation of existing pavements.
3. Develop improved design equations for new and reconstructed pavements.
4. Determine the effects of (1) loading, (2) environment, (3) material properties and variability, (4) construction quality, and (5) maintenance levels on pavement distress and performance.
5. Determine the effects of specific design features on pavement performance.
6. Establish a national long-term pavement data base to support SHRP objectives and future needs.²⁶

Building the LTPP database, the final objective, is key to achieving the first five objectives. Although research to answer key performance-related questions can be conducted at any time, monitoring the changes as they develop in the pavement is a time-critical mission. In addition, the monitoring data must be collected systematically and consistently over the life of the pavement, as demonstrated by the findings from the early studies that

were conducted. As such, the LTPP program's efforts were initially focused on obtaining equipment, developing protocols, and maintaining schedules for routine data collection to populate the national pavement performance database with research-quality data.

SUMMARY

By the 1980s, substantial knowledge had been accumulated related to the design and construction of highways. A variety of materials had been employed in many ways to reflect the experience of pavement engineers as to the best ways to support transportation needs as economically as possible. Numerous design procedures had evolved over time, each representing some form of model for pavement performance, and construction techniques and specifications had also been developed and refined. Although the traveling public had generally been well served, the service life expectations of the pavements constructed were sometimes not achieved, and the successes were not always cost effective. By the mid-1980s, a lot had been learned, but managers and engineers realized that more could be done to predict with greater confidence how different designs would perform and how new technologies could benefit the science of pavement engineering.

The LTPP program began with a high level of support from the U.S. Congress and a wide array of organi-

zations—State, Provincial, and local highway agencies and departments of public works; engineering firms and consultants; manufacturers of pavement materials and highway-related trade groups; highway engineers; university departments of civil engineering; research institutes; and other agencies—who were represented in formulating the program through the SHRP research advisory committee. Considerable advance research, including the pilot Long-Term Pavement Monitoring Study, the Strategic Transportation Research Study, and the Pavement Condition Monitoring Methods and Equipment Study, provided important preparation activities. Most notably, the SHRP research plans, funded by FHWA, laid the groundwork for the LTPP study and the many years of work that would follow.

This preparation and additional work during the early years of the program resulted in the final formulation of the LTPP experiments (table 1.1), a process described in chapter 5. As new technologies and high-performance materials emerge, the LTPP framework can be used to address the performance questions these advances elicit. In 2012, for example, the LTPP program began plans to monitor the performance of different warm-mix asphalt technologies. Recruitment began in 2014 with the expectation that a warm-mix site will be monitored in each of the 50 States and 10 Canadian Provinces.

The next chapter discusses the management of the LTPP program since its inception to its present day.

TABLE 1.1. LTPP General and Specific Pavement Study experiments.

General Pavement Study (GPS) Experiments	Specific Pavement Study (SPS) Experiments
GPS-1 Asphalt Concrete Pavements on Granular Base	SPS-1 Strategic Study of Structural Factors for Flexible Pavements
GPS-2 Asphalt Concrete Pavements on Bound Base	SPS-2 Strategic Study of Structural Factors for Rigid Pavements
GPS-3 Jointed Plain Concrete Pavements	SPS-3 Preventive Maintenance Effectiveness of Flexible Pavements
GPS-4 Jointed Reinforced Concrete Pavements	SPS-4 Preventive Maintenance Effectiveness of Rigid Pavements
GPS-5 Continuously Reinforced Concrete Pavements	SPS-5 Rehabilitation of Asphalt Concrete Pavements
GPS-6 Asphalt Concrete Overlay of Asphalt Concrete Pavements	SPS-6 Rehabilitation of Jointed Portland Cement Concrete Pavements
GPS-7 Asphalt Concrete Overlay of Portland Cement Concrete Pavements	SPS-7 Bonded Portland Cement Concrete Overlay of Portland Cement Concrete Pavements
GPS-8 Bonded Portland Cement Concrete Overlay (discontinued, later replaced by SPS-7)	SPS-8 Study of Environmental Effects in the Absence of Heavy Loads
GPS-9 Unbonded Portland Cement Concrete Overlay of Portland Cement Concrete Pavements	SPS-9 Validation of Strategic Highway Research Program Asphalt Specification and Mix Design (Superpave®)
	SPS-10 Warm-Mix Asphalt Overlay of Asphalt Pavements (2014)

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Managing the LTPP program presents budgetary, administrative, and technical challenges, requiring the cooperation of 62 transportation agencies and involving the concerns of numerous stakeholders in the highway community.

2

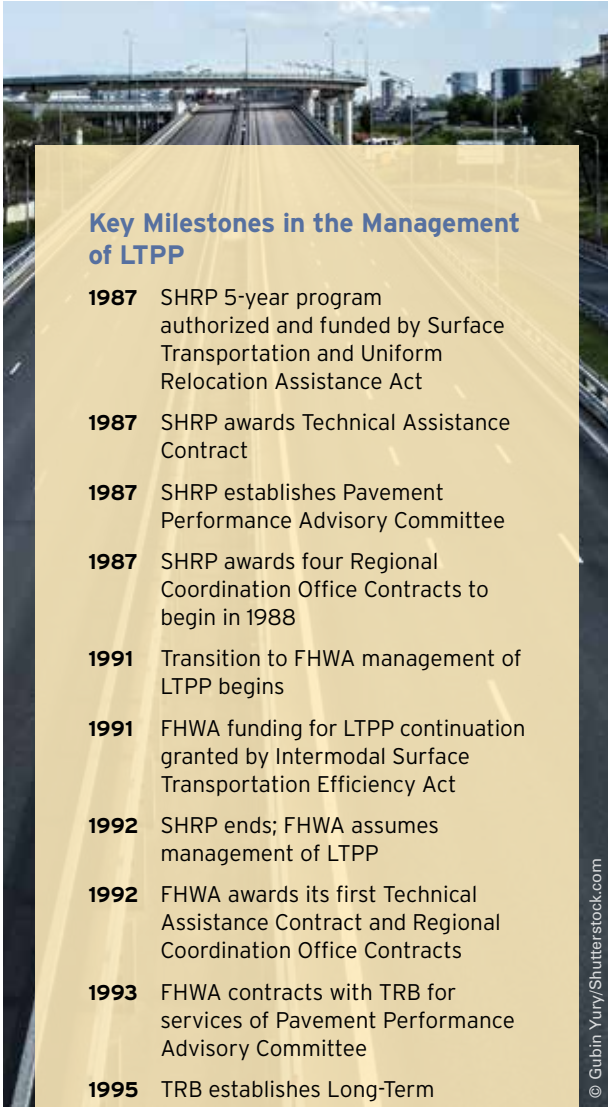
Management of the LTPP Program

Ambitious objectives were set for the LTPP program from the start, whose achievement has been challenged by multiple internal and external factors including transitions between two management agencies and five highway legislations. The program's success can be attributed to the support and investment of the participating highway agencies, the expertise of the advisory structure, and the tenacity and focus of management staff who guided and executed the program with the support of its professional contractors.

INTRODUCTION

The LTPP program began operations in 1987 under the 5-year, \$150 million, Strategic Highway Research Program (SHRP) administered by the National Research Council of the National Academy of Sciences. In 1991, the Federal Highway Administration (FHWA) made a commitment to assume LTPP management and administrative responsibilities when SHRP ended in 1992 to complete the pavement performance monitoring. From the program's inception, it was understood that realizing the full benefit of this research investment would require the program to continue over the long term. Experience has shown that even periods upwards of 40 years are needed to better characterize the performance of some types of pavement structures.

It was also understood that for the LTPP program to meet its objectives, the individual experimental studies in the program had to be carefully designed to yield verifiable conclusions, and the massive data collection effort had to be uniform and consistent from study to study and from place to place. The data had to be stored and made readily accessible to all LTPP participants and future researchers. These conditions required a nationwide level of cooperation among highway agencies, researchers, contractors, and national organizations seldom seen in pavement research. SHRP and then FHWA managed and coordinated this multi-organizational effort with the cooperation of the highway agencies, advisory groups, and sister organizations, and with the assistance of contractors at the regional and national levels.



Key Milestones in the Management of LTPP

- 1987** SHRP 5-year program authorized and funded by Surface Transportation and Uniform Relocation Assistance Act
- 1987** SHRP awards Technical Assistance Contract
- 1987** SHRP establishes Pavement Performance Advisory Committee
- 1987** SHRP awards four Regional Coordination Office Contracts to begin in 1988
- 1991** Transition to FHWA management of LTPP begins
- 1991** FHWA funding for LTPP continuation granted by Intermodal Surface Transportation Efficiency Act
- 1992** SHRP ends; FHWA assumes management of LTPP
- 1992** FHWA awards its first Technical Assistance Contract and Regional Coordination Office Contracts
- 1993** FHWA contracts with TRB for services of Pavement Performance Advisory Committee
- 1995** TRB establishes Long-Term Pavement Performance Committee

- 2006** Customer support functions transferred from contract to LTPP Team and General Administration Support Contract
- 2006** Six TRB LTPP ETGs merged into two
- 2011** First LTPP Webinar held
- 2013** Two TRB LTPP ETGs merged into one

It was thought that data collection activities would be most effectively managed on a regional basis provided that adequate quality assurance (QA) programs were in place to ensure quality and consistency. Four regions were defined in the United States and Canada—North Atlantic, North Central, Southern, and Western—each with an office established and staffed by contracted firms with expertise in pavement performance monitoring. The LTPP regional offices served as collection and validation centers for pavement section data. In addition, a technical assistance contractor assisted SHRP and, later, FHWA management in overseeing the program. Figure 2.1 shows the four LTPP regions, their boundaries, and the locations of the LTPP offices.

This chapter describes the program’s management through national and regional contracts and staffing arrangements, first under SHRP (1987 to 1992), then under the transitional period when SHRP was ending (1991 to 1992), and finally under FHWA’s management (1992 through the present). During the latter period, funding levels under U.S. highway legislation have varied. Priorities and activities are often driven by the availability of funds, and reductions in Federal funding have had a major impact on the LTPP program. Additional management issues related to these changes in Federal funding are discussed in chapter 4. This chapter also discusses the various communication, coordination, and outreach practices followed by the LTPP program throughout the years.

UNDER THE STRATEGIC HIGHWAY RESEARCH PROGRAM (1987-92)

The Surface Transportation and Uniform Relocation Assistance Act of 1987 authorized and provided funding to SHRP. That same year, under the sponsorship of the National Research Council, a SHRP program office was established in Washington, DC, continuing the pre-implementation work and contractual relationships that had been ongoing since 1984 for a long-term monitoring study (discussed in chapter 1). Of the six research areas proposed for SHRP, operations began in

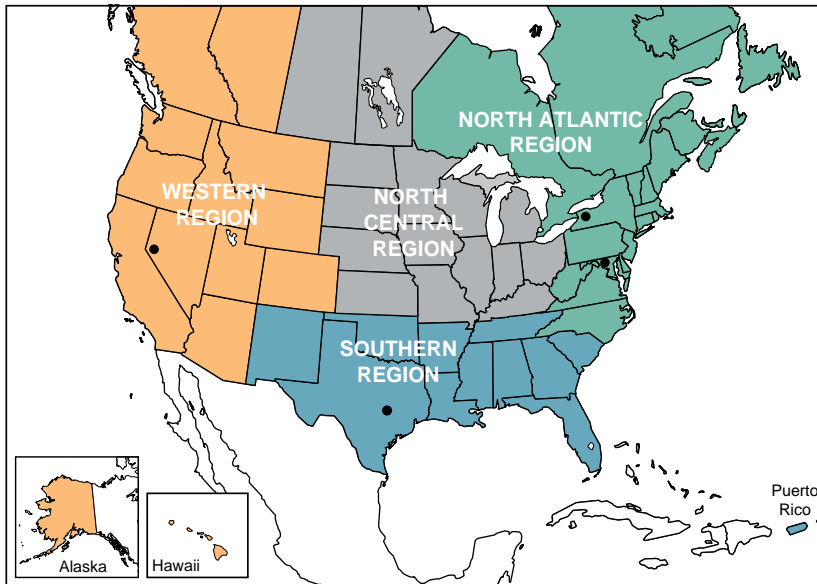


FIGURE 2.1. The four LTPP regions and current regional offices (North Atlantic and North Central: Buffalo, NY; Southern: Austin, TX; Western: Reno, NV). In 2003, Buffalo, NY, became the regional office for both the North Atlantic and North Central regions. The office for the central technical support services contractor is also shown: Beltsville, MD.

four: Asphalt Characteristics, Concrete and Structures, Highway Operations, and Long-Term Pavement Performance.^{1,2} (The proposed Snow and Ice Control and Maintenance Cost-Effectiveness research areas were combined in the Highway Operations area, which also addressed work zone safety. The proposed Concrete Bridge Component Protection and Cement and Concrete research areas were combined within the Concrete and Structures area.)

The SHRP executive director was responsible for overall program management, while four SHRP program managers were responsible for the daily operations in their respective focus areas with the support of a small staff of engineers and loaned staff, who played a major role in the program. Collectively, the SHRP executive director, program managers, and support staff represented the central management staff for the four SHRP program areas.

For the LTPP program area, a senior engineer, the SHRP-LTPP director, was responsible for all technical activities, and four other engineers in the SHRP central office were individually responsible for pavement monitoring activities, field sampling and materials testing activities, database operations, and traffic mon-

itoring activities. The management structure is shown in figure 2.2.

In addition, four engineers contracted to SHRP served as extensions to the central LTPP management staff, each based at one of the four regional coordination offices. The SHRP regional engineers were responsible for overseeing and reporting on the regional contractors' activities to the central management staff in Washington, DC, as well as for providing overall support to the regional offices in a variety of activities including program marketing and test section recruitment. Specific activities carried out by regional engineers included the following:

- Providing administrative and technical review of regional contractor functions.
- Providing written and verbal comments and recommendations on various technical and administrative aspects of the existing program and proposed new program elements.
- Representing the LTPP program at various meetings, seminars, and training sessions held within their respective regions.
- Representing the LTPP program at various meetings for recruitment and development of LTPP test sites.

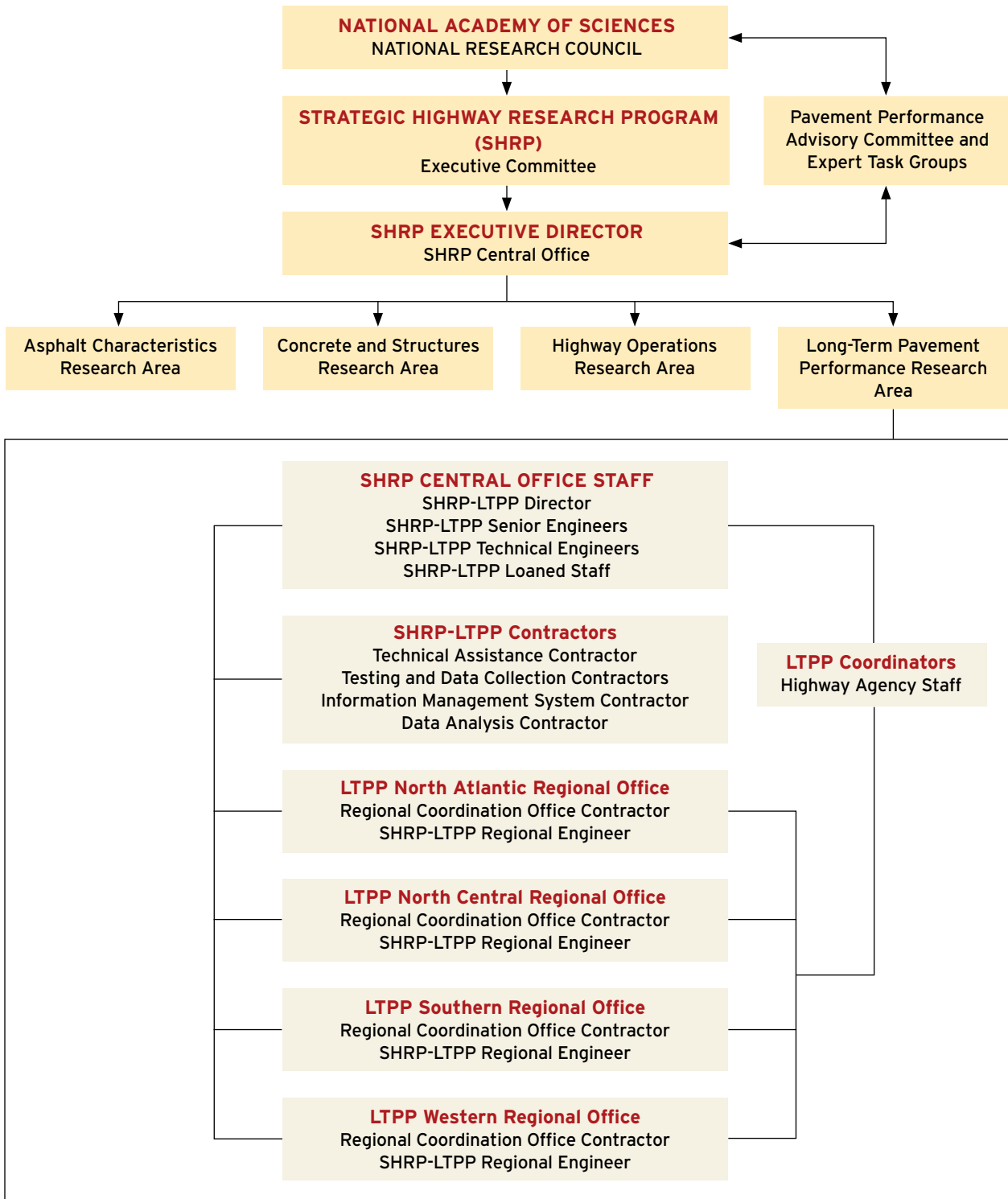


FIGURE 2.2. Structure of the LTPP organization during the SHRP-LTPP years (1987-92).

- Serving as the focal point for public information and comments concerning the LTPP program.
- Promoting LTPP program activities, goal, and objectives, and the products of SHRP.
- Reviewing and validating payment claims from materials testing contractors.

Additional staffing was provided to the LTPP program through the loaned staff program (see sidebar), which allowed employees of highway and transportation agencies (both national and international) to assist in program implementation while bringing their agencies' perspectives to program management at the national level. FHWA had staff on loan to SHRP from the program's inception. For example, in May 1987, six of the 10 SHRP-LTPP staff were on loan: one from FHWA, one from Sweden, one from Canada, and three from highway agencies. Other professional experts who contributed to the LTPP program through the loaned staff program were university professors and researchers. In some cases, professors were on sabbatical while working with the LTPP program staff. When SHRP ended and FHWA assumed management, the practice continued. Nearly 100 individuals have participated in the LTPP program through these inter-agency loans, providing both practical support and an essential cross-fertilization of ideas to the program.

Technical Assistance Contractor Responsibilities

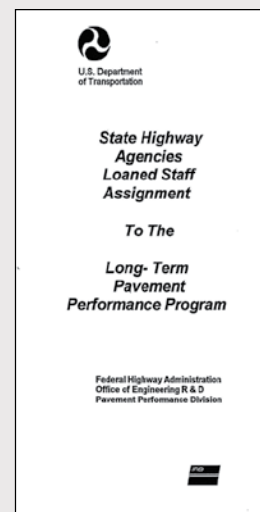
The P-001 LTPP Technical Assistance Contract, awarded in 1987, was the first contract under the LTPP program. The central LTPP management staff retained the services of this contractor to provide technical and management services in support of SHRP in the development and conduct of the LTPP studies. The contractor was referred to as the "technical assistance contractor" under SHRP. The activities provided by this contract included the following:

- Completing the General Pavement Study experimental designs, building upon the framework that was developed during the 1985–87 SHRP pre-implementation effort.
- Assisting highway agencies and the LTPP regional contractors in the selection of monitoring sites.
- Assisting in the selection and procurement of equipment and services for data collection, materials testing, and other tasks.

LOANED STAFF PROGRAM

The LTPP program has been enriched through the direct participation of staff from highway agencies in the States and Provinces and abroad since the early SHRP years. To encourage participation, a loaned staff program was developed under which a highway agency employee, nominated by his or her agency, could complete a 1-year or longer tour of duty working with the LTPP Team. The sponsoring highway agency supported the employee's salary during the loan period, and SHRP and later FHWA supplied a housing allowance.

The program allowed the loaned staff to broaden their technical expertise and interact with the pavement community at the national and international levels, while giving their agencies a voice in the direction of the program. Typically, loaned staffers tended to focus their efforts on specific technical activities such as traffic monitoring and seasonal monitoring. The LTPP program benefited as the team gained first-hand knowledge of the operations, perspectives, and priorities of highway agencies. This mutual arrangement benefited both the LTPP program and the highway agencies.



- Developing and implementing methods and procedures for data collection, sampling, and testing, with necessary provisions for updating manuals and organizing additional training to ensure continued, consistent, and accurate data collection by State personnel and other SHRP research contractors.
- Developing and implementing QA and quality control (QC) procedures for collecting data and for collecting and testing samples.
- Assisting central SHRP staff in the coordination of activities of other participants in the LTPP studies.
- Developing procedures for processing and entering data into the national pavement performance database (i.e., LTPP database), including the processing of test section distress records to quantify distress data.
- Conducting periodic QC evaluations of all contractor and highway agency data collection activities.
- Developing the Specific Pavement Study (SPS) experiments in coordination with highway agencies, other SHRP contractors, and advisory groups.
- Performing periodic analyses and statistical studies on simulated and real data to evaluate the study designs and the utility of the database for producing the anticipated results and to highlight avenues of promising research.
- Developing procedures to obtain environmental data.
- Assisting the highway agencies in the assembly of all necessary test section inventory data describing existing and past conditions regarding design, traffic, construction, maintenance, rehabilitation, environment, and skid resistance.
- Inspecting all candidate sites to verify the accuracy of inventory data, adherence to experiment requirements, and proper identification of the sites with signs.
- Utilizing SHRP-LTPP data collection procedures.
- Scheduling and coordinating data collection activities with highway agencies that provided traffic control during data collection.
- Scheduling emergency data collection when conditions required it, such as during unexpected maintenance.
- Scheduling and supervising the field testing and sampling of test sections, which were performed by highway agencies, and forwarding the samples obtained to the designated testing facilities.
- Collecting deflection data from each site using falling weight deflectometer (FWD) equipment provided by SHRP and collecting profile data using the road profiling systems provided by SHRP.
- Collecting distress and transverse profile data with other contractors selected by SHRP to collect these data.
- Performing data reduction and data input for all test section measurements into the LTPP database using computer equipment and software provided by SHRP.
- Coordinating with highway agencies to obtain monitoring data on maintenance, rehabilitation, traffic counts, vehicle classification and weight, and friction measurements (friction data were collected for a short period).
- Training highway agency personnel on LTPP data collection, monitoring procedures, and QC to ensure adherence to the stipulated requirements.
- Coordinating and conducting other similar LTPP activities as these evolved during the program.
- Coordinating with SHRP and the other regional coordination office contractors to assure that the overall program was efficiently and consistently executed.
- Providing field data collection services to other SHRP research activities.

Regional Coordination Office Contractor Responsibilities

After the Technical Assistance Contract was awarded in 1987, several additional contracts were awarded to advance full implementation of the LTPP program. Many of these were directly associated with the four LTPP regions.

Together with the LTPP Technical Assistance Contract, the four LTPP regional office contracts, implemented in 1988, represented the primary and largest (cost-wise) LTPP contracts (P-004, North Atlantic; P-005, Southern; P-006, North Central; and P-007, Western). The objective of the regional contracts was to provide technical and management services to SHRP in the collection of high-quality data and related activities in the development and conduct of the LTPP studies. The activities provided by these contractors included the following:

- Maintaining SHRP-provided equipment, including computers and testing equipment.
- Coordinating with highway agencies and SHRP contractors to ensure that all safety standards and legal requirements were met.
- Working with highway agencies in the recruitment and construction of SPS test sites.
- Hosting SHRP-LTPP regional meetings.

Other Contractor Responsibilities

Other major LTPP contracts were awarded during the 1987 to 1992 SHRP era (appendix B) to perform the following activities at the LTPP test sections:

- Conduct photographic pavement surface distress surveys and provide digital conversions of the film records (P-002 Pavement Distress Record Contract).
- Provide road surface profiling equipment used by the regional coordination office contractors (P-003 Road Profiling System Contract).
- Perform laboratory testing of Portland cement concrete materials (P-008 Portland Cement Concrete Laboratory Materials Testing Contract).
- Perform laboratory testing of asphalt, aggregate, and soil materials for each region (P-012, P-013, P-014, and P-015 Regional Soil and Asphalt Testing Contracts).
- Develop a management system to store data and information (P-016 Information Management System Development Contract).
- Reimburse highway agencies for the purchase of traffic data collection equipment (P-017 Traffic Data Collection Equipment Contract).
- Operate and maintain the Information Management System (IMS) (P-019 Information Management System Operations Contract).
- Perform initial data analysis studies for the first five LTPP program objectives (P-020 Data Analysis Contracts).
- Provide structural evaluation equipment used by the regional coordination office contractors (P-021 Falling Weight Deflectometers Contract).
- Perform drilling and materials sampling for each region (P-022, P-023, P-024, and P-025 Regional Drilling and Materials Sampling Contracts).
- Provide technical advice and guidance for collecting traffic classification and weight data at LTPP test sites.

Although not of the financial magnitude of those listed above, a few other contracts were awarded during the SHRP-LTPP era. Examples include the development and implementation of FWD calibration centers, which became a major SHRP product, and the evaluation of ground-penetrating radar technology for use in layer thickness determinations at LTPP test sections.³ The Materials Reference Library was established under a SHRP contract and later transferred to the LTPP program.

Expert Peer Review Groups

During the SHRP-LTPP years, the Pavement Performance Advisory Committee (hereafter Advisory Committee) provided oversight and guidance for the LTPP program. This was the first of two volunteer committees of the National Research Council of the National Academy of Sciences to provide advice pertaining to the LTPP program, and it performed its function until 1995. The Advisory Committee provided programmatic review and technical commentary on the program objectives, long-range plans, near-term operational activities, and progress of the LTPP research program. It also conducted external, nongovernmental reviews of, and comments on, the technical progress of ongoing pavement performance research, and it identified needs for further research projects.

The committee was also required to provide assistance to FHWA in its selection and implementation of SHRP research products. Accordingly, some of its tasks included monitoring the SHRP implementation activities of FHWA and providing written critiques of specific technology transfer efforts related to SHRP products. The committee developed advice on alternative technology transfer techniques and other actions needed to ensure effective deployment of and technical support for SHRP research products.

Various subcommittees to the Advisory Committee, known as the Expert Task Groups or ETGs, addressed specific program technical issues. Members of the ETGs were experts in their respective research areas and were drawn from highway agencies, industry, academia, SHRP, and FHWA. Eight ETGs existed during the 1987 to 1992 SHRP period of the LTPP program:

- Deflection Testing and Backcalculation ETG.
- Equipment Evaluation ETG.
- Experimental Design and Analysis ETG.
- Automated Distress Identification ETG.
- Traffic Data Collection and Analysis ETG.
- Weigh-in-Motion Equipment and Technology ETG.
- Environmental Data ETG.

The membership and scope of the ETGs are described in appendix A.

DURING THE SHRP-TO-FHWA MANAGEMENT TRANSITION (1991-92)

In 1991, as SHRP was approaching the completion of its mandate, a task force composed of high-level decision makers from the American Association of State Highway and Transportation Officials (AASHTO), FHWA, SHRP, and the Transportation Research Board (TRB) was assembled to evaluate and recommend the best approach for a seamless transition of the LTPP program from SHRP to a new management organization.

The consensus of this task force was to recommend FHWA as the rational option for assuming management of the LTPP program in 1992 and seeing it through to its conclusion. FHWA was recommended for three reasons:

- Logistics—Ability to work with the various players involved in the program, including highway agencies, industry, academia, contractors, and international participants.
- Personnel—Ability to assign full-time employees to the program without the need of contracts.
- Budget sustainability—Availability of funding to ensure long-term continuation of the program to its end.

The task force established a transition period of December 18, 1991 (date on which the Intermodal Surface Transportation Efficiency Act or ISTEA was enacted) to June 30, 1992. Transition activities during that 6-month period included the following:

- Hiring of SHRP-LTPP staff by FHWA following established agency procedures.

- Loaning FHWA staff members who were to become part of the new central management staff to SHRP during the transition period.
- Transferring paper and electronic files, data collection equipment, computer equipment and software, and 35-mm distress film from SHRP to FHWA.
- Contracting by FHWA with the National Research Council to continue providing the peer review functions of the LTPP Pavement Performance Advisory Committee and its supporting ETGs for a period of 15 months, from July 1, 1992, to September 20, 1993. As part of this contract, FHWA also retained the services of the LTPP regional engineers and took responsibility for the international coordination activities associated with the annual TRB meeting over the same 15-month period.
- Re-advertising and awarding, by FHWA, major LTPP contracts that were in place under SHRP but were coming to an end. These included the four SHRP-LTPP Regional Coordination Office Contracts, awarded in May 1992, and a new materials testing contract to help highway agencies with SPS testing, awarded in June 1992. Other major contracts, such as the LTPP Technical Assistance Contract, were awarded shortly after the conclusion of the transition period.

The last Pavement Performance Advisory Committee meeting under SHRP took place during the week of April 6, 1992, and the last SHRP Executive Committee meeting took place June 2–3, 1992. The seamless transition of LTPP program management and operation activities from SHRP to FHWA was completed on June 30, 1992, and FHWA began administering the program on July 1, 1992. Figure 2.3 shows the SHRP-LTPP and FHWA-LTPP staff members who served during the program transition.

It should be noted that FHWA also took over the responsibility of carrying on the activities and implementing the results and findings from the other three major SHRP research areas—Asphalt, Concrete, and Highway Operations. In addition, FHWA took over management of the Materials Reference Library established under the SHRP Asphalt research area, which over time would become an important repository of LTPP materials samples and 35-mm distress film as well



FIGURE 2.3. SHRP-LTPP and FHWA-LTPP staff members during the LTPP program transition.

Front Row (left to right): Cal Berge, Cheryl Richter, Rita Leahy, Neil Hawks, Brenda Buchbinder, Margie Sheriff, Karen Smith, Kris Gupta, Paul Teng, Vondell Little. *Second Row:* Marsha Barrett, Guy Hager, Cindy Baker, Monte Symons, Keizo Kamiya, Juliet Narsiah, Marty Laylor, Cindy Johnson, Harry Jones, David Esch, Carliss Parker-Smith, Homer Wheeler. *Third Row:* Shahed Rowshan, Ivan Pecnik, Joe Lamond, Bill Carr, Bob Kelley, Kathy Brosseau, Don Harriott, Stella White, Ray Torrey, Lisa McNeil, Harold Von Quintus, Amir Hanna. *Back Row:* Aramis López, Bill Bellinger, Dick Ingberg, Brian Cox, Shashikant Shah, Damian Kulash, Jack Youtcheff, Radu Andrei, John Hibbs, Robert Raab, Ed Harrigan, K. T. Thirumalai.

as the repository of materials samples from other important national research studies.

UNDER THE FEDERAL HIGHWAY ADMINISTRATION (1992-PRESENT)

Enacted December 18, 1991, ISTEA authorized continuation of the LTPP program and implementation of SHRP products under FHWA management (see sidebar). ISTEA also provided FHWA funding to support these activities. FHWA established the LTPP program office at FHWA's Turner-Fairbank Highway Research Center (hereafter, the FHWA highway research center) in McLean, Virginia.

The FHWA organizational structure has changed a number of times since the LTPP program began; however, the 2012 structure presented in figure 2.4 fairly represents the LTPP program's functioning within

FHWA. The LTPP Team falls under FHWA's Office of Infrastructure Research and Development. Figure 2.5 shows the organization of the FHWA-LTPP program.

The FHWA-LTPP team leader is responsible for overall program management and daily operations of the LTPP program. In addition to the team leader, the central FHWA-LTPP management staff includes these members:

- An engineer responsible for overseeing the LTPP regional support contractors and for managing LTPP materials sampling and testing activities, including the various contractors, Materials Reference Library contract, and the contract for the latest LTPP experiment (warm-mix asphalt).
- An engineer responsible for LTPP database operation activities, the Technical Assistance Contract (more recently named "Technical Support Services Contract"), and the contract that has developed the

TRANSITION OF LTPP PROGRAM FROM SHRP TO FHWA

In January 1992 at the 71st Annual TRB Meeting, Neil Hawks, SHRP-LTPP Program Director, and Paul Teng, FHWA LTPP Division Chief, announce the transfer of the LTPP program from SHRP to FHWA. This handshake marked the beginning of the transitional period, when the staff from both organizations worked together to ensure that the mission of the program would continue until the program's goal and objectives were achieved.⁴



LTPP Web-based system that allows users to access LTPP data and other program information.

- An engineer responsible for traffic data collection and communication and coordination activities.
- An engineer responsible for data analysis activities and profile operations.

The pavement performance monitoring activities as well as other LTPP functions not listed above, such as management of data collection equipment, product development, and customer support services, have been distributed among the team members based on their experience and the team's needs. While there have been some functional changes of responsibilities, the structure of the LTPP Team has been consistent over the years.

Between 1992 and 2002, the FHWA-LTPP central management staff also depended on the services of four FHWA engineers who were based at the LTPP regional coordination offices (although they are not shown in figure 2.5). These engineers performed the same functions assigned to the SHRP-LTPP regional engineers during the SHRP 1987 to 1992 period.

Like the SHRP managers, the FHWA-LTPP Team has also counted on the support of loaned staff from State, Provincial, and international highway agencies, especially during the 1990s. These individuals typically have rotated on a 1- to 2-year basis and have tended to focus their efforts on specific technical activities such as

deflection testing, traffic data collection, and the Seasonal Monitoring Program.

The States and Provinces continue to make significant contributions to the LTPP program under FHWA's management, as they did during the SHRP years. The highway agencies provide test section construction, materials testing, traffic control and other data collection management support, staff, and equipment required for the broad array of LTPP activities. In addition, groups of States have entered into pooled-fund agreements in support of several important LTPP activities for which no other financial support was available.

Technical Assistance Contractor Responsibilities

The first FHWA-LTPP Technical Assistance Contract was awarded by FHWA in July 1992 to provide all necessary facilities, equipment, services, supplies, materials, and personnel to perform pavement engineering, traffic engineering, and IMS technical activities in support of the FHWA-LTPP program. Specific activities required under this contract have included the following:

- Participating in the development, refinement, and assessment of pavement performance monitoring activities conducted in support of LTPP research and providing technical services in the conduct of those activities, including such items as quality and uniformity of field operations for pavement distress

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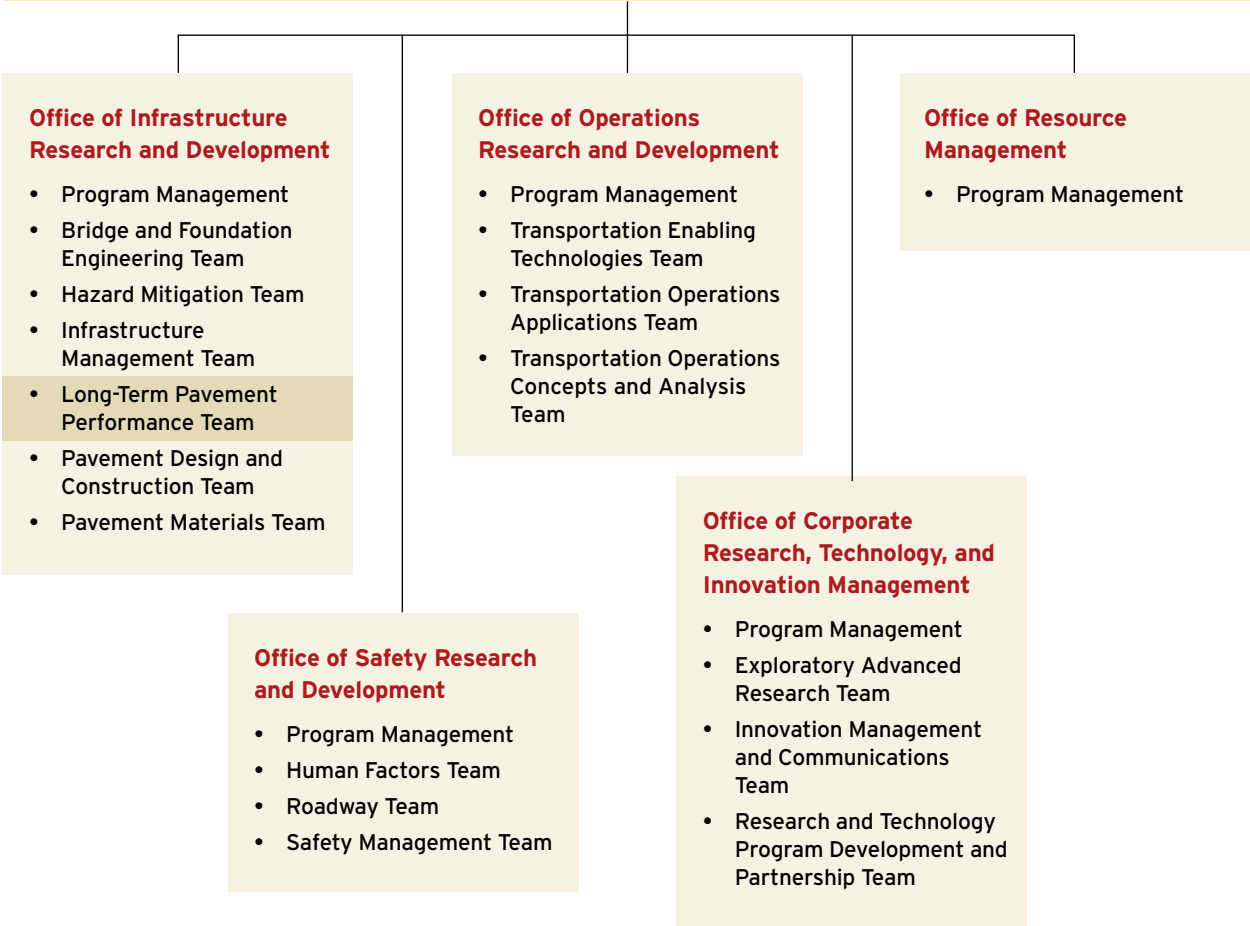


FIGURE 2.4. LTPP within the FHWA Turner-Fairbank Highway Research Center organizational structure (2012).

- data (both photographic and manual condition surveys), pavement profile data (both longitudinal and transverse), and deflection testing with FWDs, among other items.
- Providing support services in the collection of pavement response data using onsite instrumentation to monitor both environmental (i.e., temperature and moisture) changes and pavement response. Specific items covered have included dynamic load response, seasonal monitoring, and climatic data collection.
 - Participating in the development, refinement, and assessment of LTPP traffic data collection activi-

- ties. Specific items covered have included providing the facilities and manpower to house and maintain the LTPP Central Traffic Database hardware and software, developing and maintaining standards for traffic data collection, developing procedures for QC review of data collection, developing specifications for the traffic data processing program, and documenting traffic data collection and processing procedures.
- Providing technical services in support of the LTPP materials characterization program. Specific items covered have included developing QA criteria and precision statements, evaluating testing procedures,

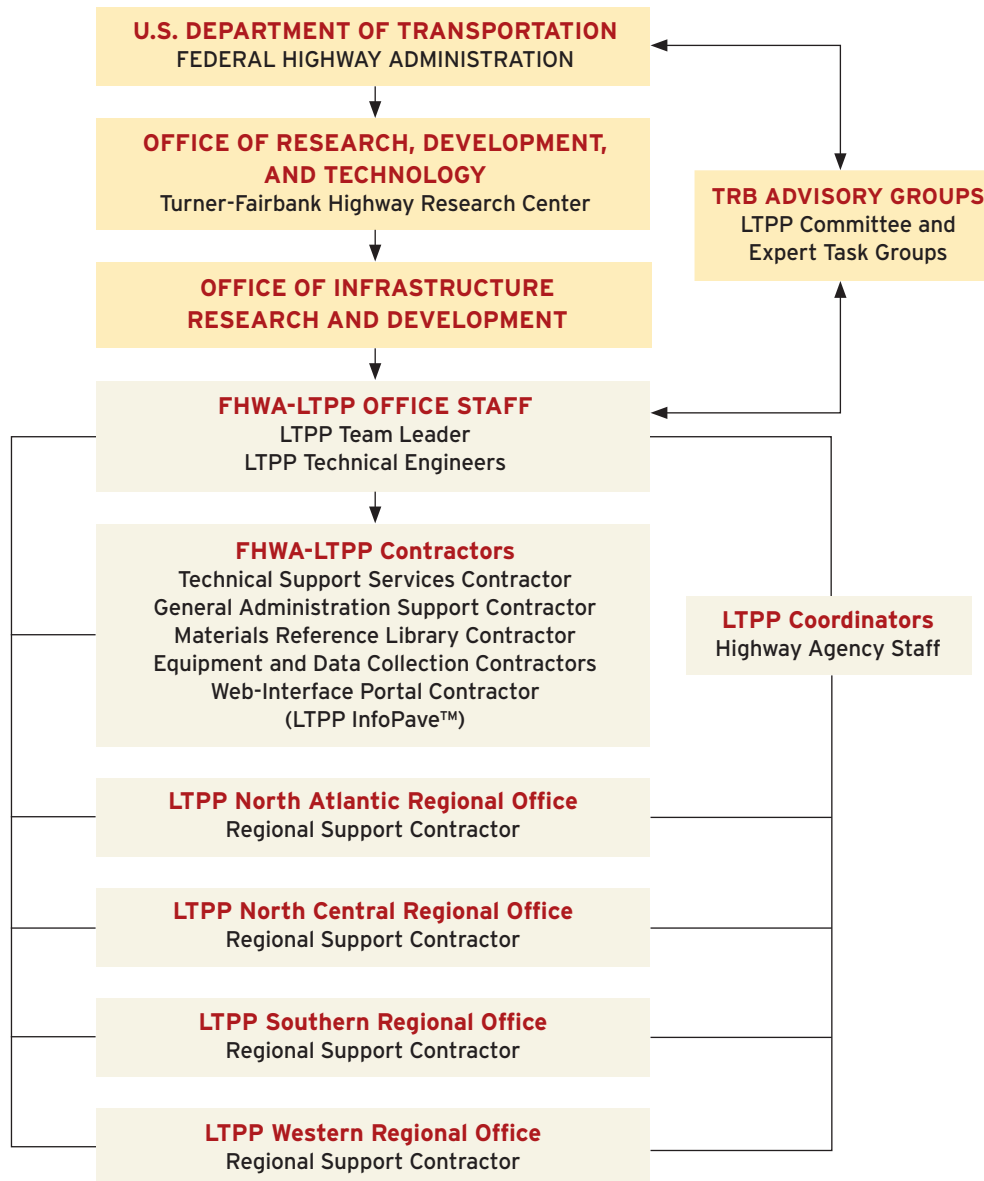


FIGURE 2.5. General structure of the LTPP organization during the FHWA-LTPP years (1992–present).

- and assisting with other activities related to materials testing.
- Providing technical support to the LTPP staff in the development of procedures and specifications for QC/QA on data in the LTPP IMS, including these activities:
 - Providing specifications for software coding or database structure for the LTPP database for software development.
 - Assisting with QC/QA procedures and checks.
 - Assisting the LTPP regional and other contractors with data entry and processing, QC/QA checks, procedural issues, and data extraction.
 - Developing and modifying software to help LTPP regional contractors track data.
 - Assisting in the review and revision of existing IMS manuals, procedures, and documentation

and in the development of new IMS policies, procedures, documentation, and reports; assisting in tracking the status of new and existing test sections.

- Ensuring that status changes are properly recorded in the database, evaluating the LTPP database as development continues, and providing recommendations for enhancements and improvements.
- Providing technical support in several areas: review and assessment of LTPP experimental designs and status, general planning and coordination of the experiments, special needs that arise, and LTPP regional field operations. The contract also has provided for periodic assessments of the LTPP program and for the services of the four LTPP regional offices.
- Providing general support to FHWA for the maintenance and operation of the LTPP database and its customers. Specific items have included housing, staffing, and maintaining the database hardware and software operations and providing general technical support to LTPP participants and, later, customers, developing software coding, developing hardware specifications, periodically updating the Data User's Guide,⁵ evaluating new software or software upgrades, and periodically releasing LTPP data to the public.
- Coordinating activities with other LTPP contractors, FHWA, participating States and Canadian Provinces, and LTPP customers as required.
- Providing technical support services on other special projects.

The 1992 LTPP Technical Assistance Contract was in place until 1997. It was re-advertised and awarded by FHWA in 1997, 2002, and 2009. The name of the contract changed to LTPP Technical Support Services Contract or TSSC in 1997 and remains as such today. Other historical facts with regard to the objectives for the LTPP Technical Assistance and Technical Support Services contracts include the following:

- Maintenance and operation of the LTPP database and support for its customers were formally incorporated into the contract in 1993, a year after FHWA awarded the initial contract.

- LTPP customer support functions were transitioned to the FHWA-LTPP Team and FHWA's General Administration Support Contractor in 2006.
- Development, refinement, and assessment of traffic data collection activities were not formally incorporated into the contract until 1997, when the second FHWA-LTPP Technical Support Services Contract was awarded.
- As noted earlier, FHWA entered into a contract with SHRP to, among other things, retain the services of the original four SHRP-LTPP regional engineers for a period of 15 months, from July 1, 1992, to September 20, 1993. At the end of that contract, the functions of the LTPP regional engineers were incorporated into the 1992 FHWA-LTPP Technical Assistance Contract, and they remained in place until the award of the 2002 FHWA-LTPP Technical Support Services Contract.
- Assistance in relocating database equipment to FHWA. Prior to 2011, responsibility for housing the computer hardware for the LTPP program's IMS and databases remained with the Technical Assistance/Support Services contracts. As discussed in chapter 8, in 2011, this equipment was secured at FHWA's highway research center, and the support contract retained responsibility for the production databases.

Regional Support Contractor Responsibilities

The first regional office contracts under FHWA management were issued in May 1992 for a 4-year period during the transition of the LTPP program from SHRP to FHWA. As the contracts were ending, they were re-advertised and awarded for additional 5-year periods in 1996, 2001, 2006, and 2011 (appendix B).

The objective of the LTPP regional contracts is to provide technical services in support of the development and conduct of LTPP studies, including all data collection, data processing, and data quality activities for LTPP project sections within each region's geographical boundaries, as previously defined under SHRP. Not only are the regional contractors responsible for day-to-day operations and maintaining a high level of data quality, but they play an important part in sustaining the program through their active coordination with the highway

agencies. Specific activities that have been required under these contracts are listed below:

- Working with participating highway agencies to recruit test sections, oversee and document SPS test section construction, and assemble required data (inventory, design details, traffic, construction, maintenance, rehabilitation, environment, and skid resistance).
- Conducting tests and collecting field data, including periodic deflection testing, profile testing, manual distress surveys by accredited raters, Seasonal Monitoring Program measurements, and automated weather station data collection. Providing support for traffic, maintenance, and rehabilitation data collection by the highway agencies; materials sampling and testing by the highway agencies and other LTPP contractors; and ensuring the uniformity and consistency of the data they collect.
- Managing the data handling and database including processing data for input into the LTPP database, and implementing data QC processes, including checks and correction of errors, data uploads, database system management, and response to data quality concerns.
- Developing QC/QA procedures, including implementation of written QC programs, cooperation with and participation in the LTPP QA review program, and development of biannual work plans addressing the quantity and frequency of data to be collected as well as quantities of that data to reach QC Level E, the highest assigned quality level (see chapter 9 for a description of the database QC levels and checks).
- Assisting in coordination and communication, including:
 - Reviewing and commenting on LTPP documents and proposed activities.
 - Cooperating and coordinating with other LTPP participants.
 - Participating in meetings, conferences, and workshops.
 - Hosting regional LTPP meetings (until the early 2000s).
 - In later contracts, developing and maintaining up-to-date regional operations Web sites.
- Maintaining and repairing government-furnished equipment; establishing and implementing compre-

hensive equipment preventive maintenance programs, calibrations, and checks to ensure equipment meets operating standards; and providing secured storage space for the equipment.

- Carrying out other miscellaneous LTPP program support activities on an as-needed basis such as special data collection and testing, special database management, computer software development, and technical services.
- Collecting additional data to support other FHWA studies, as needed.

Other Contractor Responsibilities

As SHRP had done earlier, FHWA has awarded other major LTPP contracts (appendix B) to perform the following activities:

- Collecting material samples and testing these samples (Materials Sampling and Test Contracts).
- Overhauling or providing new equipment for FWDs and high-speed profilers (Equipment Contracts).
- Providing a permanent, high-resolution record of the pavement condition for the entire length and width of each LTPP test section (Photographic Distress Contract).
- Analyzing data collected at LTPP test sections to answer specific pavement issues (Data Analysis Contracts).

In addition, other contracts have been awarded by FHWA to further meet the goal and objectives of the LTPP program. These contracts provided or are providing the following services:

- Providing onsite administrative support (General Administration Support Contract).
- Maintaining a facility to store LTPP material samples (Materials Reference Library Contract).
- Developing and distributing LTPP products to the highway community (LTPP Products Contracts).
- Determining layer thickness of test sections and collecting ground penetrating radar data (Determining Layer Thicknesses Using Ground Penetrating Radar Contract).
- Performing video inspections of edge drains for select SPS projects (Video Edge Drain Inspections Contract).

- Collecting high-quality traffic data at select SPS projects (LTPP SPS Traffic Data Collection Pooled-Fund Study Contracts).
- Improving the FWD calibration procedures (FWD Calibration Center and Operational Improvements Pooled-Fund Study Contract).
- Improving the level of integrity for ride quality measurements by developing calibration processes and verification procedures (Improving the Quality of Pavement Profiler Measurement Pooled-Fund Study Contract).
- Examining the effects that multiple freeze-thaw events versus deep frost penetration has on pavement performance (Effect of Multiple Freeze-Thaw Versus Deep Frost Penetration on Pavement Performance Pooled-Fund Study Contract).
- Developing an automated pavement distress analysis system (Automated Distress Analysis for Pavements Contract).

More information for each of these contracts is discussed in appendix B.

Expert Peer Review Groups

As noted earlier, FHWA entered into a contract with SHRP to continue to provide the peer-review functions of the LTPP Pavement Performance Advisory Committee and its supporting ETGs for a 15-month period ending September 20, 1993. Subsequently, the FHWA entered into a direct contract with TRB to provide formal peer review regarding LTPP program matters. This contract has been renewed throughout the life of the LTPP program.

Once SHRP ended in 1992, the Pavement Performance Advisory Committee provided its counsel to FHWA and AASHTO until 1995, when the committee was retired. The TRB Long-Term Pavement Performance Committee (LCOM) was then established to provide advice on LTPP's program planning and operations, review progress, and coordinate work conducted by various ETG subcommittees on specific technical issues. Thus, LCOM became the second of two committees of the National Research Council to provide advice pertaining to the LTPP studies. The charge to LCOM by TRB is as follows:

This committee, acting through the National Research Council, will advise the Federal Highway Administra-

tion (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) on the planning and execution of the Long-Term Pavement Performance (LTPP) studies. The LTPP studies are a set of operational activities consisting of compiling and analyzing data that is being collected on more than 2,500 in-service pavements in the United States and Canada. The principal objective of this data collection and analysis is to further the understanding of how and why pavements deteriorate when subjected to traffic loadings and environmental conditions. Data collection and analysis began in 1987 and will continue beyond 2013 for a substantial number of test sections that are still providing valuable data. The program is also adding test sections to investigate the performance of warm-mix asphalt and other pavement topics. The committee will prepare reports, including letter reports, containing the committee's evaluations and suggested mechanisms to enhance the utility to the states of the studies' outcomes.⁶

This charge is in line with the objective established under FHWA's contract with TRB, which is to continue to conduct and document a program to assist in the guidance of current and future activities related to the conduct and operation of LTPP data collection, analysis, product development, delivery, coordination, evaluation, and communication activities. Furthermore, the contract stipulates that accomplishing this objective is the responsibility of LCOM. This group convenes twice a year to develop and provide strategic recommendations that assist in the guidance of current and future activities related to the conduct and operation of the LTPP program (figure 2.6). These recommendations are sent in the form of a letter report to the FHWA Administrator and AASHTO Executive Director after each meeting.

As was the case with the TRB Pavement Performance Advisory Committee, various subcommittees or ETGs were formed to address specific program technical issues in support of LCOM. These groups enlisted experts from highway agencies, industry, academia, and FHWA. Through 2006, five ETGs provided support to LCOM:

- LTPP Automated Distress Identification ETG.
- LTPP Materials Data Collection and Analysis ETG.
- LTPP Data Analysis ETG.
- LTPP Database Development and Operations ETG.
- LTPP Traffic Data Collection and Analysis ETG.

The scope and membership of the ETGs are described in appendix A.

In addition to these ETGs, two subcommittees served LCOM. The Subcommittee for Product Development and Delivery was established in 1999 to define a future course for the LTPP program to maximize its outcomes and products (chapter 10).⁷ The Program Improvement Subcommittee, composed of selected members from LCOM, was established in 1997 to review and oversee FHWA's implementation of the results of the 1996 Program Assessment—a formal evaluation of the program's achievements in relation to its goal, objectives, and future direction.⁸ Activities identified as a result of that assessment, which became part of the subcommittee's purview, included the following:

- Clearing data backlog.
- Addressing missing data.
- Classifying test sections.
- Adjusting schedules for monitoring.
- Formulating analysis and product development plans.
- Implementing data studies and preliminary analyses.

This subcommittee ended in 1999, when the program improvements were well underway.

In 2006, as a direct result of the budget constraints imposed on the LTPP program by the 2005 highway legislation (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users), the number of ETGs providing support to LCOM was reduced to two. The TRB ETG on LTPP Traffic Data Collection and Analysis was continued, and a multi-purpose TRB ETG on LTPP Special Activities was created that assumed many of the technical functions of the ETGs that were discontinued.

Between 2006 and 2013, LCOM, with the support of the Traffic Data Collection and Analysis and Special Activities ETGs, provided the formal peer review func-



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FIGURE 2.6. LTPP Committee meeting held in Washington, DC, on October 29, 2013. Left to right, clockwise: Randy Iwasaki (Contra Costa Transportation Authority), Gary Hoffman (Pennsylvania Asphalt Pavement Association), Jorge Pagán-Ortiz (FHWA), Pat Hu (Office of Secretary of Transportation), Larry Wiser (LTPP Program), Aramis López (LTPP Program), Olga Selezneva (Applied Research Associates, Inc.), William Temple, Chair (Concrete and Aggregates Association of Louisiana), and Robert Raab (TRB).

tions for all LTPP-related activities. In 2013, the Traffic ETG was retired, and its functions were assigned to the Special Activities ETG.

COMMUNICATION, COORDINATION, AND OUTREACH

The LTPP program's longevity and success is due to the open dialogue and constant feedback that has been in practice since the SHRP years. The planners of the program had the foresight to know that clear communication and a well-coordinated effort with many people and organizations would be required to achieve the goal and objectives of such a detailed and grand research program. The communication and coordination practices of the LTPP program have distributed important information about the program, and allowed a feedback mechanism for the program's stakeholders, partners, and data users to share their input to improve the research being conducted.

Communication With Stakeholders

Disseminating information to stakeholders has been a high priority for the LTPP program. The program has used different communication mechanisms throughout the years, from holding national meetings and workshops, to meeting with individual highway agencies, to participating in agency-sponsored LTPP meetings. In addition, reports, articles, newsletters, and other publications have been made available. The methods used to communicate with LTPP stakeholders have changed over the years with changes in technology and resources.

Meetings

Communicating the benefits of the LTPP program and listening to stakeholder input concerning its plans and progress have been of paramount importance to SHRP and FHWA. A key piece of this communication has involved participating in national and regional conferences over the years. Highlights include many different events at the annual TRB meetings in Washington, DC, such as the LTPP State Coordinators' Meeting, International Coordinators' Meeting, LTPP Technical Session, and presentations during other technical sessions. The LTPP sessions held each year during the TRB annual meeting discuss different topics relating to the program and often feature presentations from a highway agency perspective or from a university that has used LTPP data in its curriculum.

In addition to participating in the TRB annual meeting, the LTPP program has held national meetings through the years with stakeholders to discuss data collection and monitoring issues and provide an update on the program's progress and plans. These national meetings include the Colorado Mid-Course Assessment Meeting in 1990, California LTPP National Meeting in 1996, Rhode Island LTPP Specific Pavement Study Workshop in 2000, LTPP Pavement Analysis Forum in 2010, and many others. The LTPP program has also been represented in many AASHTO meetings, including those of the Standing Committee on

Research, Research Advisory Committee, and Subcommittee on Materials.

Coordination meetings have been held with individual highway agencies since the program began. The LTPP program staff and its contractors often meet with representatives of State and Provincial agencies and FHWA Division Offices, for example, to discuss data collection, equipment installation, and traffic control issues, as well as other LTPP-related issues specific to the highway agency. In the early years of the program, these coordination meetings focused on recruitment and nomination of LTPP test sections. In the last several years, the agency visits have focused on plans to establish two new SPS experiments (warm-mix asphalt and pavement preservation).

The LTPP regional support contractors held meetings for many years to bring together the LTPP Coordinators from the highway agencies within their respective regions to discuss progress within their agencies and to hear presentations on big-picture items within the LTPP program. These meetings were phased out in the early 2000s as program funds became more limited and out-of-state travel became more difficult for highway agency personnel. Later, the LTPP program began to hold face-to-face meetings at State/Provincial highway agency offices with agency staff, regional contractors, and LTPP program staff. Figure 2.7 shows a meeting held in 2011 with the Connecticut Department of Transportation.

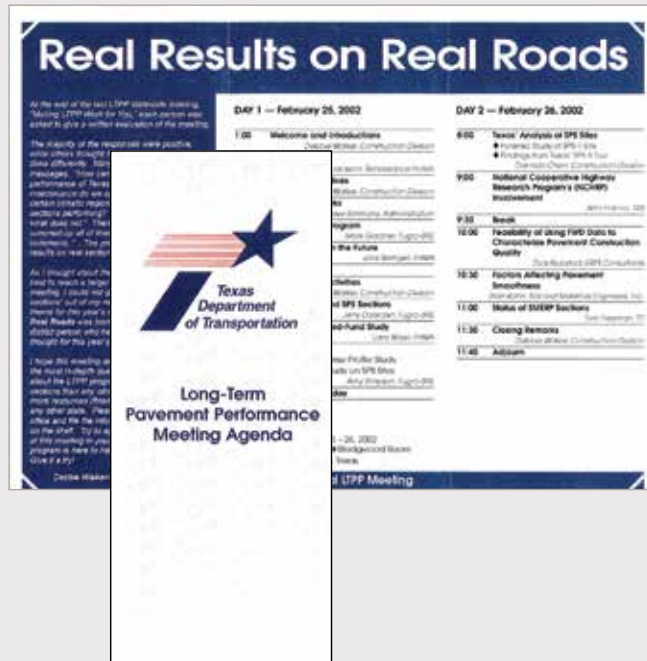


FIGURE 2.7. Connecticut Department of Transportation (CT DOT) staff meet with the LTPP program and regional support contractor staff. Pictured from left to right: Edgardo Block, Thomas Harley, Anne-Marie McDonnell (LTPP State Coordinator), Ravi Chandran (CT DOT); Frank Meyer (LTPP North Atlantic Region); Aramis López (LTPP Program); Amy Jackson-Grove (Connecticut FHWA Division Office); Jack Springer (LTPP Program); and Basel Abukhater (LTPP North Atlantic Region).

HIGHWAY AGENCY COORDINATORS' MEETINGS

Achieving Real Results on Real Roads

Some highway agencies have held their own LTPP meetings to discuss the importance of the LTPP program with their field staff. These meetings proved to be beneficial to both the highway agencies and the program. For example, in the mid-1990s, the LTPP State Coordinator for the Texas Department of Transportation met every 12 to 18 months with the 25 district offices to discuss Texas' role in and commitment to the LTPP program. These meetings brought together the district contacts, LTPP program staff, regional support contractors, other contractors, and the FHWA Division Office staff. Recognizing the benefits of national pavement research, Texas established more LTPP test sections than any other highway agency and continues to be an active partner in the program.



LTPP meetings held by the highway agencies have helped to sustain agency commitment to the program. The meetings have kept agency staff informed and encouraged fruitful exchanges between agency staff and the program. For example, in the State of Texas, each district office met every 12 to 18 months with someone from the LTPP program staff, regional support contractors, and other contractors to learn more about the program and why it is important at the State and national levels (see sidebar). Because the meetings kept the State's field staff informed about the test sections in their respective districts, the staff understood why it is necessary to monitor the test sections until the end of their design life, without jeopardizing the safety of the driving public. State efforts like the Texas meetings possibly allowed many LTPP test sections to remain in the program for continued monitoring longer than they otherwise would have.

LTPP team members also participate in a variety of other national meetings, including the annual North American Travel Monitoring Exhibition and Conference, TRB's biannual Data Analysis Working Group, and the annual Road Profiler User Group and Falling Weight Deflectometer User Group meetings. The participation of team members in these meetings allows them to collaborate with others on technical issues, keeping the program abreast of the latest in data collection and information technologies, and to offer face-to-face assistance to highway agencies.

The LTPP Web site and, in more recent years, Web conferencing technology have enabled a much larger number of people to participate in direct learning about the program and database and to do so with more frequency than face-to-face conferences would allow. The technology also enables the LTPP Team to benefit from a broader range of stakeholder feedback about the

program and its products and a wider collaborative network as the program moves into the future. The first LTPP Webinar was held in September 2011 to give an overview of the program (see sidebar). Recorded Webinars are available on the LTPP Web site.

Publications

Special reports, brochures, exhibits, and various print and Web documents have been used to relay program information to wider audiences. Examples of reports include:

- *The Long-Term Pavement Performance Program Roadmap: A Strategic Plan.*⁹
- LTPP: The Next Decade.^{10,11}
- *An Investment Benefiting America's Highways: The Long-Term Pavement Performance Program.*¹²
- *LTPP Product Plan.*¹³
- LTPP and the 2002 Pavement Design Guide.¹⁴
- *LTPP Beyond FY 2009: What Needs to Be Done?*¹⁵
- *Long-Term Pavement Performance Program: Accomplishments and Benefits 1989–2009.*^{16,17}

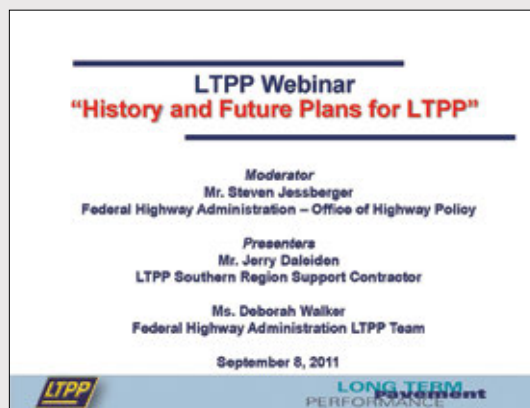
In addition, the program has published articles in highway publications, such as *Focus*, TRB's *TR News*, *Research & Technology Transporter*, *Roads & Bridges*, *Public Roads*, and *EDC News* to present important pavement engineering issues to the broader community. The LTPP Web pages bring LTPP research and products directly to data users and also serve as an archive for program activities. The Web pages carry the LTPP Newsletter,¹⁸ communicating directly with stakeholders, the Year in Review articles that summarize activities and progress in the program, Key Findings reports that summarize LTPP data analysis projects,^{19,20} and hundreds of research reports that provide the findings from different studies.

Communication Within the Program

While the success of the LTPP program is largely attributable to the partnerships that exist between the program and the highway engineering community, internal communication between the LTPP program staff and its supporting contractors has also played a vitally important role in the program's achievements. LTPP management holds regular team meetings and teleconferences to maintain clear communication and

COMMUNICATING WITH LTPP STAKEHOLDERS VIA THE WEB

The first LTPP Webinar was held September 2011 to provide more direct contact and interaction between the LTPP Team and program stakeholders. The team conducts informational Webinars, usually bimonthly, that are open to highway agencies, pavement industries, contractors, vendors, university professors and students, consultants, metropolitan planning organizations, and others with an interest in the program. Topics range from the general (future plans, program updates) to the very specific (demonstration of the dynamic modulus software, how traffic data are used) and include LTPP products and case studies.



coordinate program activities with the FHWA-LTPP staff and contractors both onsite at FHWA's highway research center and offsite. These activities include a weekly staff meeting attended by FHWA-LTPP Team members, onsite contractors, and key offsite contractors, as well as personnel from other FHWA offices on occasion. Meetings feature briefings on the progress of program activities, discussion of pending and future issues, and planning and review of future LTPP Newsletter articles and Webinars.

As the LTPP technical support services contractor and the regional support contractors are primarily responsible for the program's data collection and processing, data QC/QA, equipment maintenance, and

other field activities, it has been particularly important to hold regular meetings with them to ensure consistency in various procedures and technical issues throughout the four LTPP regions. The FHWA-LTPP staff holds a 2-day formal meeting twice a year with the program's core contractors to discuss many of the program's large-scope issues and identify actions to resolve these issues (figure 2.8). Earlier in the program, these meetings were held quarterly. Another critical and very important communication tool used to ensure consistency among the LTPP regions is the use of program directives. Directives provide written instructions to the regions for collecting, processing, and managing LTPP data, equipment, and software.

In addition, the FHWA-LTPP staff holds routine meetings and teleconferences with the technical and regional support contractors to discuss issues specific to various program areas, such as distress, deflection, profile, traffic, automated weather stations, the Seasonal Monitoring Program, and the IMS. Targeted meetings and teleconferences are also held to discuss special projects. In the past, these have included projects such as the Materials Action Plan, the database, and forensic studies, as well as FHWA pooled-fund studies that involve the LTPP program.

SUMMARY

Managing the LTPP program presents a number of challenges—budgetary, administrative, and technical. The program spans two countries, requires the cooperation of 62 transportation agencies, and involves the concerns of numerous stakeholders within the highway community. Implementation challenges have been met with the expert advice and support of professional groups, industry organizations, and research institutions through the National Research Council advisory committees and related expert task groups. A significant management challenge arose when SHRP ended in 1992 and the objectives of long-term pavement performance monitoring had not yet been fulfilled. FHWA's commitment to the program and assumption of its management enabled it to continue, and the management transition from SHRP to FHWA in 1992 was carefully planned and smoothly executed.

Throughout the program, a rigorous emphasis on quality has been maintained. To achieve a consistently high level of data quality across the program required planning and coordinating the activities of the many technical contractors who have served the program in various capacities, and addressing the concerns of the



FIGURE 2.8. LTPP program staff and core contractors meet to discuss the status of different program activities including data collection, database management and development, and future plans of the program. *Front Row (left to right):* William Bellinger, Kevin Senn, Larry Wiser, Deborah Walker, Miriam Pitz, Basel Abukhater, Jane Jiang, Jerry Daleiden. *Second Row:* Jack Springer, Tommy Clark, Gary Elkins, Sarah Tarpgaard, Frank Meyer. *Third Row:* Aramis López, Jason Puccinelli, Gabe Cimini, Jonathan Groeger, Mark Gardner (2011 in Austin, Texas).

highway agencies. Consistent and constant communication and coordination with stakeholders and within the program are vital to meeting the program's objectives.

As the program grew, management had to adapt to rapid technological changes in pavement monitoring and data management while also facing painful reductions in Federal funding (discussed in chapter 4) that have jeopardized the program's completion. Nonetheless, the program has weathered these difficulties with the wisdom and guidance of the program managers, who are introduced in the following pages, and the support and commitment of its partners, whose contributions are acknowledged in chapter 3. On this solid foundation, the LTPP program is prepared to address the pavement research needs and technologies of the future.

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LEADERS OF THE LTPP PROGRAM



NEIL F. HAWKS

*SHRP-LTPP Program Manager,
1987–1992*

Neil Hawks, P.E., recently retired from the Transportation Research Board (TRB) of the National Academies, where he was the Director of the second Strategic Highway Research Program (SHRP 2). SHRP 2 was a concentrated, focused program seeking to make strategic advances that will improve the safety, planning, travel-time reliability, and renewal of America's highway system.

Mr. Hawks joined the staff of the National Academies in 1982. From 1982 to 1987, he was the TRB Engineer of Soils, Geology and Foundations. From 1987 through 1992, Mr. Hawks was with the first Strategic Highway Research Program. At SHRP, he directed the Long-Term Pavement Performance Program and initiated the SHRP Asphalt Research Program. In 1992, he rejoined TRB as the Director of Special Programs. In this role, he provided direction to the five TRB Innovations Deserving Exploratory Analysis (IDEA) programs and to committees advising on the conduct of research and technology implementation.

Prior to joining TRB, Mr. Hawks worked for the Pennsylvania Department of Transportation for 14 years in geotechnical engineering, highway design, and construction.

He is a graduate of Columbia University and a registered professional engineer.



T. PAUL TENG

LTPP Division Director, 1991–1995

Paul Teng, P. E., started his highway engineering career conducting paving materials research while pursuing a graduate degree at the University of Mississippi in 1964.

Prior to joining the Federal Highway Administration (FHWA) in 1981, he held a range of engineering positions with the Mississippi State Highway Department, where he was the Department's Research and Development Division Engineer from 1974 to 1981.

At FHWA, Mr. Teng was assigned to a number of engineering, operations, and research and development positions and worked with industries, universities, trade associations, State highway agencies, and FHWA Division Offices on pavement engineering, rehabilitation, and management practices. In 1991, he established the Long-Term Pavement Performance Division, and was responsible for the transition of SHRP activities from the National Research Council to FHWA in 1992. He was selected into the U.S. Senior Executive Service and appointed as FHWA's Chief Pavement Engineer in 1994. In 1999, Mr. Teng became Director, Office of Infrastructure Research and Development.

He has received numerous commendations and awards including the FHWA Administrator's Award for Superior Achievement and the Secretary of Transportation's Meritorious Achievement Award. As a professional engineer, Mr. Teng has authored many authoritative technical publications in the highway pavement and materials areas. He retired from FHWA in 2005.



CHARLES J. CHURILLA

LTPP Team Leader, 1995–1999

Charles Churilla, P.E., has had a professional career of more than 40 years in the materials, geotechnical, and pavement engineering disciplines. During those years he worked for the Pennsylvania Department of Transportation, Federal Highway Administration (FHWA), and as a Principal Engineer for Applied Research Associates, Inc. He was the lead in the development of the FHWA Highways for LIFE concept and saw it through to fruition. He also led the FHWA Infrastructure Team in the development of the first-ever Infrastructure Research and Technology Plan. Mr. Churilla led the Long-Term Pavement Performance (LTPP) program from 1995 to 1999. Working with other FHWA headquarters and field offices he was instrumental in beginning the development and delivery of the LTPP technical products. He was responsible for the development and implementation of FHWA's Full Scale Accelerated Testing Program using the ALF (accelerated loading facility) pavement testing machine.

Mr. Churilla was a member of the National Academy of Sciences, the American Association of State Highway Transportation Officials, and the Transportation Research Board. He is a registered professional engineer and an Honorary Member of Chi Epsilon, a civil engineering fraternity.



MONTE SYMONS

LTPP Team Leader, 1999–2001

Monte Symons, P.E., received his B.S. and M.S. degrees in Civil Engineering from the University of Illinois and joined the Federal Highway Administration (FHWA) in 1975. In his career with FHWA, Mr. Symons served as Geotechnical Engineer in the Federal Lands Highway Program, Materials and Research Advisor to the Kuwait Ministry of Public Works Motorway System, Regional Pavement and Materials Engineer in Region 5, Team Leader for the Long-Term Pavement Performance research program, and Team Leader of the Infrastructure Team in the Midwest Resource Center. He finished his FHWA career as Team Leader for the National Pavement and Materials Resource Center Team.



Mr. Symons' accomplishments included completing over 200 reports on pavement condition and design as well as subsurface reports for landslides and bridge foundations; developing and implementing the initial roadway inventory program for the U.S. National Park Service; assisting State highway agencies with pavement and materials issues; directing research programs to improve pavement performance and design life; and leading efforts to implement the latest pavement technologies.

After retiring from FHWA in 2005, he joined Auburn University as Director of the Airport Asphalt Pavement Technology Program, a 5-year, \$4.8 million effort that completed 19 projects. He is currently the CEO of Montista Consulting LLC.

ARAMIS LÓPEZ

LTPP Team Leader, 2001–Present

Aramis López, P.E., was a Civil Engineer with the Puerto Rico Department of Transportation before joining the Federal Highway Administration (FHWA) in 1978 as a participant in the FHWA Highway Engineer Training Program. Mr. López has held several different engineering positions within FHWA in the areas of construction, design, research, and management in the Oregon, California, Texas, and Louisiana FHWA Division Offices, and at headquarters. In 1991, he was assigned to assist in the transition of the Long-Term Pavement Performance (LTPP) program from the Strategic Highway Research Program to FHWA. He is currently the Team Leader of the LTPP program in the Office of Infrastructure Research and Development at the Turner-Fairbank Highway Research Center.

Mr. López earned a Bachelor's of Science in Civil Engineering from the University of Puerto Rico at Mayagüez. He has received numerous awards and commendations including the FHWA Administrator's Award for Superior Achievement for his vision and leadership of the LTPP program, the U.S. Department of Transportation Secretary's Volunteer Service Award, and the U. S. Department of Transportation Excellence in Teamwork Award. His leadership and commitment to pavement research and the LTPP program since 1991 has produced the most comprehensive pavement performance database in the world.





Partnerships with the highway agencies, academia, and industry not only keep the LTPP program relevant and responsive, but also enable it to draw on the highest levels of technical and managerial expertise.

3

LTPP Program Partnerships

Since its inception, the LTPP program has relied on a close working relationship with many organizations and individuals. The unique blend of expertise among the partners brings focus to every area of the research study. The open and often very candid interaction with the partners has had a positive impact on the program's direction. The dedication and commitment of those in this partnership arrangement has strengthened the LTPP program and has supported the program's efforts to provide resources that benefit the highway community.

INTRODUCTION

Since the LTPP program began, partnering with the highway engineering community has been another key to the program's longevity and success. Even as the program was being planned as part of the Strategic Highway Research Program (SHRP), it benefited from the international outreach and involvement of industry and academia that were integral to the SHRP-LTPP planning process.

In particular, the LTPP program depends on the cooperative efforts of the American Association of State Highway and Transportation Officials (AASHTO), the Canadian Strategic Highway Research Program (C-SHRP), the highway agencies in the States and Provinces, the National Research Council (NRC) through SHRP and the Transportation Research Board (TRB),

the Federal Highway Administration (FHWA), and the international highway community. By extension, LTPP partners also include the various paving industries, trucking industry, highway user groups, material suppliers, equipment manufacturers, and the engineers and researchers who use LTPP research results. Each of these partners has played and will continue to play a key role in helping the LTPP program achieve its full potential.

The illustration on the facing page represents the LTPP program's primary partners (1987 to the present) and their areas of participation, while the summaries below describe how the partners contribute to the program.



Meeting of the TRB Expert Task Group on LTPP Special Activities held in Washington, DC, on October 15, 2013. From bottom left, clockwise: Dean Wolf (Applied Research Associates, Inc.), Rebecca McDaniel, Chair (Purdue University), Robert Raab (TRB), Rick Reel (Florida DOT), Deborah Walker (LTPP Program), Gary Taylor (Professional Engineer, Michigan), Olga Selezneva (Applied Research Associates, Inc.), Barbara Ostrom (AMEC), and Catherine Lawson (State University at New York).

"I have had the good fortune to be associated with the Long-Term Pavement Performance program in various ways since its inception. While the extensive database and the many products stand out of course, the importance of partnerships, direct and indirect or implicit, represents both an evolution and a legacy of accrued benefits. State, Federal, and local agencies and researchers are direct beneficiaries. The organizations and the individuals involved have gained experience and expertise, and the state of knowledge and practice has advanced substantially. In turn, the LTPP program itself can justifiably take pride in the many achievements of having more and better trained people in the program and in the partnerships; as well in the receptiveness shown to the needs of the partners. But the ultimate beneficiaries are really the public, who are served by better and safer roads, by skilled people, and by good management of the assets."

Ralph Haas
The Norman W Mcleod Engineering Professor
and Distinguished Professor Emeritus
University of Waterloo

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

AASHTO is the national representative of State transportation agencies in the United States. Through funding from participating agencies, AASHTO lobbies the U.S. Congress on transportation-related issues, conducts national and regional meetings with State representatives on transportation-related topics, publishes materials and testing specifications and standards of practice, and provides reference material services and accreditation to materials testing laboratories.

AASHTO has played a critical role in the LTPP program from its start. From working with States to establish the LTPP program using Federal-Aid highway funds to recruiting test sections to the adoption of LTPP-developed methods, procedures, and guidelines as standards for pavement engineering, AASHTO has provided the collective leadership for many of the program's successes to date. For example, in 1996, AASHTO passed a Memorandum of Understanding on the LTPP Program, to help in obtaining the remaining Specific Pavement Study (SPS) test sections (figure 3.1). It was not until an AASHTO resolution was passed in April 1998 seeking the States' help that the effort began in earnest to resolve LTPP data deficiencies identified during a 1996 Program Assessment.¹ Likewise, in 2003, LTPP management worked with the AASHTO Subcommittee on Materials to address issues related to the resilient modulus for unbound materials. In addition, through its Standing Committee on Research, AASHTO provided \$13.83 million to the LTPP program through the National Cooperative Highway Research Program (NCHRP) to supplement data collection and data analysis activities during a severe funding shortfall (chapter 4). AASHTO was represented on the various SHRP planning committees and the Pavement Performance Advisory Committee, and continues to be represented on the LTPP Committee.

CANADIAN STRATEGIC HIGHWAY RESEARCH PROGRAM

Representatives of Canada were involved with SHRP and the LTPP program from the earliest planning stages. In the spring of 1985, Transport Canada, the country's national transportation agency, funded a study to explore Canadian involvement in SHRP. Canada's participation was coordinated by the Roads and Transportation Association of Canada (RTAC) (known as "Transportation Association of Canada" since 1990) through its Council on Highway and Transportation Research and Development.

RTAC worked closely with AASHTO and SHRP, and Provincial officers represented Canada on the SHRP Task Force, SHRP Advisory Committee on Overview and Integration, and on the SHRP technical area advisory committees, including the Advisory Committee on Long-Term Pavement Performance (appendix A), which developed the initial SHRP-LTPP plans. Canada's highway agencies were also represented in early SHRP workshops in 1985 and 1986, and RTAC conducted meetings and a workshop in the fall of 1985 involving key highway agency and research representatives. In 1986, Canada established its own Strategic Highway Research Program—C-SHRP—with initial funding of \$5 million CAD, with 10 percent of the costs covered by the Federal government and the balance by the Provinces.^{2,3}

The Canadian approach to highway research included monitoring SHRP research, pursuing technology transfer related to SHRP and C-SHRP, and conducting two separate research programs:

- Integrated Program—Canadian sites and facilities were incorporated into the SHRP program, with SHRP contractors conducting the testing as in the United States. Canadian highway agencies retained responsibility for traffic control and coordinating



**MEMORANDUM OF UNDERSTANDING
ON
THE LTPP PROGRAM**

October, 1996

WHEREAS, representatives of AASHTO and its Task Force on Strategic Highway Research Program (SHRP) Implementation met with representatives of the American Concrete Pavement Association (ACPA), the American Trucking Associations (ATA), the Federal Highway Administration (FHWA), the National Asphalt Pavement Association (NAPA), the National Stone Association (NSA), and the Transportation Research Board (TRB) to discuss the Long Term Pavement Performance (LTPP) program and the various Specific Pavement Studies (SPS) sections that remain uncommitted for the study; and

WHEREAS, the industry organizations' representatives were given an overview of the history of the LTPP program and the statistical justification and the specifications for several of the SPS sections; and

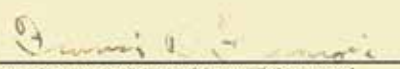
WHEREAS, the meeting highlighted the State Highway Agencies' (SHA) remarkable feat of providing approximately two-thirds of the required study sections and explained the barriers which restrict the SHA's ability to construct the remaining SPS sections; and

WHEREAS, several possible approaches utilizing the cooperative efforts of the attending organizations and public-private partnerships were explored as possible means of filling the voids in the LTPP study; and

WHEREAS, mutual understandings and consensus were reached between the attending organizations concerning the national importance of obtaining the remaining SPS sections and of obtaining all of the technical tools and information originally anticipated to be delivered under the LTPP program; and

WHEREAS, commitment was given by each of the organizations present to work cooperatively with SHAs, local governmental entities, universities, and private enterprise firms in an effort to explore and exhaust all possible avenues for gaining the missing sections in the LTPP study; and


NOW, THEREFORE, BE IT COOPERATIVELY AGREED UPON that AASHTO, ACPA, ATA, FHWA, NAPA, NSA, and TRB support the vision and objectives of the LTPP program and jointly agree to actively participate, both independently and cooperatively, in the solicitation of commitments for the remaining SPS section and the completion of the LTPP program.



American Association of State Highway and
Transportation Officials (AASHTO)



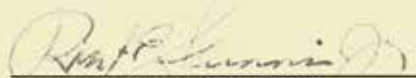
American Concrete Pavement Association (ACPA)



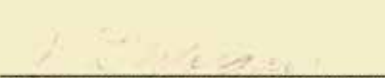
National Stone Association (NSA)



American Trucking Associations (ATA)



Transportation Research Board (TRB)



National Asphalt Pavement Association (NAPA)



Federal Highway Administration (FHWA)

FIGURE 3.1. Memorandum of Understanding for the recruitment of LTPP SPS test sections.

site visits. The Provinces were part of LTPP's North Atlantic, North Central, and Western regions, and data from 127 sections across the 10 Provinces are contained in the LTPP database. As SHRP began operations, RTAC was represented on the SHRP-LTPP staff through the loaned staff program; this staff participation continued into the FHWA-LTPP years.

- C-LTPP—In 1989, Canada funded a separate, small-scale research program, structured to be compatible with and complementary to SHRP-LTPP, to examine factors of particular interest to Canada that were not addressed in SHRP. Focused on rehabilitation practices, this program consisted of 24 test sites with a total of 65 test sections constructed between 1989 and 1992 to investigate various thicknesses and types of asphalt overlays, with particular consideration of frost action and seasonal variations.⁴ C-LTPP was continued until 2004 and resulted in a database and numerous research reports. The data and other information for the test sections monitored by Canada are available on the LTPP InfoPave™ Web site.

C-SHRP has played a major role in the achievements of the LTPP program by providing sponsorship and support for LTPP test sections in Canada, supporting LTPP data collection efforts in Canada, participating on the Pavement Performance Advisory Committee and LTPP Committee, and sponsoring LTPP-related data analysis projects. During a period of reduced LTPP program funding, C-SHRP contributed \$120,000 to cover digitization of distress survey film and also funded an LTPP publication. Due to Canada's close support and coordination, it is the only country other than the United States with test section data in the LTPP database.

STATE AND PROVINCIAL HIGHWAY AGENCIES

The LTPP program began as part of SHRP, which was a “State’s” initiative, and it included the departments of transportation for the 50 States, the District of Columbia, and Puerto Rico. These agencies, along with the 10 Provincial transportation agencies of Canada, are both owners and customers of the program.

As owners, highway agencies have made significant investments in the program by investment of funds, designating test sites, constructing and monitoring test sections, supplying test materials, collecting traffic and other data, and providing traffic control. In addition, these agencies have optimized the benefits from their investment in the LTPP program (and their highway networks) by sponsoring and submitting LTPP-related NCHRP research problem statements for data analysis, product development, and implementation activities; participating in LTPP-related pooled fund studies; sponsoring LTPP-related data analysis with agency funds; and participating on AASHTO, TRB, and NCHRP committees, expert task groups (ETGs), and task forces. Many agencies have also loaned staff to work directly with the LTPP program in certain technical areas of the program. These arrangements gave the agency detailed insight about the everyday operations of the program and the opportunity to affect decisions made at the national level.

As customers of the program, the highway agencies are the primary users of the results garnered and yet to be garnered from the program. LTPP data and products are a resource for pavement designers, materials engineers, maintenance engineers, traffic forecasters, and pavement management engineers. For example, the LTPP data will be important to the local and regional calibration of the AASHTOWare® Pavement ME Design software. In addition, with the ready availability of LTPP data via the Standard Data Releases and online support (LTPP InfoPave), agencies can more easily gain access to the data to address their local and regional pavement information/technology needs.

The active participation of highway agencies in the program was largely driven by their expectation that the tools and knowledge that the LTPP program generated would provide answers to issues of importance to them. In formal interviews conducted with chief engineers in the highway agencies as part of the LTPP Program Assessment (chapter 11), the engineers voiced the following expectations:

- We need to know what maintenance treatments are effective. What do they cost? When should they be used? How much do they extend the life of the pavement?

- We need to know what the best rehabilitation design is for a given road structure. How can we minimize the risk of our choice? What are the life-cycle costs?
- We need better designs, developed from models that predict with assurance that the newly built or reconstructed pavements based on these designs will last a specified number of years.
- We need dramatic improvements in technology, not incremental changes.
- We need to know what performance trends are discernable from the LTPP data.
- We need improvements in WIM technology. We need to measure equivalent single-axle loads more accurately.

The States' concerns echo strongly those cited in the AASHTO *Interim Guide for Design of Pavement Structures*, known as the “Blue Book,”⁵ and the *Strategic Highway Research Program Research Plans, Final Report*, known as the “Brown Book,”⁶ but have a more tangible feel. In essence, the agencies want useful engineering tools and an enhanced knowledge base on which to base management and engineering decisions—these are their high-priority needs in terms of answers from the LTPP program.

To ensure that general program information and research results are communicated consistently, each of the highway agencies has designated an LTPP State Coordinator, who serves as liaison and point of contact between the agency and the LTPP program staff. Each year during the annual TRB meeting, an LTPP State Coordinators' meeting is held at which the coordinators learn about the status of the program and LTPP program staff learn how highway agencies are using LTPP data and products at the agency level. Each LTPP State Coordinator has been important to the success of the LTPP initiative.

The highway agencies have been critical to the LTPP program's achievements and will continue to play a pivotal role in the future.

NATIONAL RESEARCH COUNCIL/ TRANSPORTATION RESEARCH BOARD

As previously discussed, the LTPP program originated and operated for 5 years within SHRP, an independent unit of the National Research Council. From 1987 to 1992, SHRP managed the day-to-day operations of the LTPP program. Specific activities included development of guidelines for recruiting test sections, testing materials, collecting and processing data, establishing the database, and orchestrating and coordinating LTPP activities. The National Research Council also provided peer advisory committees to the LTPP program through SHRP. Later, TRB, a sister entity to SHRP under the National Research Council's umbrella began operating several committees that have provided an independent forum in which the States, Provinces, industry, and academia have contributed input and advice on the conduct of LTPP research and implementation activities.

As part of the partnership with the LTPP program, TRB has sponsored special LTPP events. In September 2010, for example, the LTPP Committee sponsored an LTPP Pavement Analysis Forum that brought together pavement design, management, preservation, and traffic data experts to update the Strategic Plan for LTPP Data Analysis. Jointly planned and implemented by FHWA's LTPP Team and the LTPP Committee, the forum was designed to identify, define, and prioritize the analytical studies that will produce results that can be further developed and combined into products that highway agencies can use to help design, build, and maintain—on a mechanistic/empirical basis—existing and future highways.⁷ In addition, many of TRB's research projects, such as NCHRP Project 1-37A (Mechanistic-Empirical Pavement Design Guide) and NCHRP Project 1-34D (Effects of Subsurface Drainage on Performance of Asphalt and Concrete Pavements: Further Evaluation and Analysis of LTPP SPS-1 and SPS-2 Field Sections), have been strengthened through the use of LTPP data.

The work of all of the LTPP advisory committees and ETGs exemplifies the dedication of individual stakeholders who have offered advice and provided guidance to the program.

FEDERAL HIGHWAY ADMINISTRATION

The FHWA has been a prime mover behind the LTPP program, from investing in preliminary research in long-term pavement monitoring in 1984, before SHRP-LTPP began, through its sponsorship and extension of the LTPP program beginning in 1992 and continuing into the future. The agency has provided a permanent “home” for the program by securing the LTPP Information Management System, performance data, and other program products at FHWA’s Turner-Fairbank Highway Research Center, and by continually upgrading the software and hardware required for accurate and reliable data collection and management. The FHWA has also provided budgetary support to supplement congressional authorizations and in-kind staff and overhead throughout much of the LTPP program’s existence.

INDUSTRY, ACADEMIA, PROFESSIONAL ASSOCIATIONS, AND USER ORGANIZATIONS

From the earliest landmarks in the LTPP program’s formative years, a broad range of viewpoints and areas of expertise has been represented on planning and decisionmaking bodies. The “Stars” report, the first official call for SHRP and LTPP, was prepared by a 13-member steering committee that included two academic institutions and two major corporations as well as a county executive and a public policy group. In the formulation of the SHRP Research Plans, although the State and Provincial highway agencies were the predominant groups, university departments of civil engineering and transportation research institutions were also well represented, and engineering firms and trade organizations comprised the balance. The LTPP advisory committees and expert task groups have continued this practice of providing diverse input into program planning and management.

Highway industry and user groups have also been providing input since the beginning of the LTPP program, for example:

- Paving associations (e.g., National Asphalt Pavement Association, American Concrete Pavement Association, Association of Asphalt Paving Technologists,

The Asphalt Institute, International Grooving and Grinding Association, Asphalt Recycling and Reclaiming Associations).

- Manufacturers of paving materials (e.g., National Stone, Sand, and Gravel Association; Concrete and Aggregates Association).
- Highway users (e.g., American Automobile Association; American Trucking Associations, Inc.; Roadway Express, Inc.).

The LTPP program has enjoyed a unique partnership with the American Society of Civil Engineers (ASCE). Since 1998, ASCE and FHWA-LTPP have jointly sponsored a series of international contests on LTPP Data Analysis to recognize the use of LTPP data by university students and professors. 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. ASCE’s participation is managed by its Task Committee on the Long-Term Pavement Performance Contest, which is a subcommittee of the Highway Pavement Committee of ASCE’s Transportation and Development Institute.

The contest usually makes awards in four categories (Undergraduate students, Graduate students, Partnership, and Challenge) with a theme that changes each year. Prizes have included expense-paid attendance at the TRB Annual Meeting, cash awards, and publication of winning papers (figure 3.2).^{8,9,10}



FIGURE 3.2. Reports of the winning papers from the 2001-2002 and 2003-2004 international data analysis contests.

INTERNATIONAL COMMUNITY

Other governments around the world were facing pavement issues similar to those in the United States when the LTPP program was first envisioned. Consequently, SHRP invited collaboration from international highway agencies during the pre-implementation phase to obtain information about research and to solicit suggestions for future cooperation. SHRP also sponsored a number of international workshops and conferences. After the first workshop, held in 1986 in Alexandria, Virginia, SHRP adopted a formal policy of international cooperation, and several other conferences followed. In 1988, LTPP was one of two themes at a SHRP International Technical Workshop held in Bath, England. Delegates representing 17 countries¹¹ exchanged information and plans for data collection testing procedures, information management systems, laboratory accreditation, and other issues related to measuring long-term pavement performance.

By 1994, more than 10 countries were conducting their own LTPP studies, while others were planning to do so, and 30 countries had each identified an international coordinator to facilitate the exchange of information about the LTPP program and pavement research. Researchers from other countries also use LTPP data to address their research needs. Members of highway agencies in many countries have participated in the LTPP loaned staff program (Australia, Canada, Denmark, Finland, France, Germany, Japan, Norway, Romania, Slovenia, South Africa, Sweden, Venezuela, and the United Kingdom during the SHRP years alone)¹² and have served as members in one or more of the TRB LTPP committees or ETGs (e.g., Canada, Denmark, Germany, Sweden, The Netherlands, and the United Kingdom). From time to time, international

organizations, such as the International Road Federation, Pan-American Institute of Highways, USAID, World Road Association-PIARC, and The World Bank, have also been represented in forums and on committees. International exchange of information and onsite visits have continued throughout the LTPP program.

INTERNATIONAL PARTICIPATION



International Coordinator Meeting, Washington, DC, 1990

Face-to-face meetings were one avenue of participation for the international highway community. The international coordinators reported on their own highway research programs at SHRP-sponsored workshops and TRB's Annual Meeting and contributed their expertise through on-site staff assignments in Washington, advisory committees, and ETGs. Represented at the pictured meeting were Canada, Australia, Finland, Germany, Sweden, Norway, Austria, Denmark, and the United Kingdom, with others. Participation came from as far as South Africa, Egypt, and Japan.

SUMMARY

The LTPP program has flourished within a cooperative structure that from the program's beginning has involved the State and Provincial highway agencies, their representative organizations AASHTO and C-SHRP, TRB's research advisory capacity by way of its advisory committees and ETGs, the participation of professional organizations and researchers from other countries, continuous support from FHWA, a dedicated management corps, and experienced contractor staff. With a commitment to fulfill the program's goal through changes in management and funding, including financial contributions that are discussed in the next chapter, this productive collaboration among the partners has moved the LTPP program forward for more than 25 years. Continuing these partnerships into the future will assure that the program remains relevant to the needs of highway agencies and the pavement research community.

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The ultimate return on investment from the LTPP program is the economic benefit realized from better design, construction, and management of the Nation's pavements.

4

Federal Investment in the LTPP Program

The Federal investment in the LTPP program through fiscal year 2014 (over a period of 27 years) is \$311.56 million. This investment includes funding allocated over five highway authorizations. In addition to the Federal investment, the program has benefited from significant direct and indirect support from AASHTO, C-SHRP, and individual States and Provinces.

LTPP UNDER FIVE HIGHWAY LEGISLATIONS

Since 1987, the LTPP program has been fortunate to have dedicated funding to carry out its goal and objectives (chapter 1) through five Federal transportation statutes: Surface Transportation and Uniform Relocation Assistance Act of 1987 (STURAA), which implemented the program; Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA); Transportation Equity Act for the 21st Century (TEA-21); Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU); and continues now under Moving Ahead for Progress in the 21st Century (MAP-21). Table 4.1 shows Federal funding for the program from 1987 through 2014.

Funding Variations

LTPP funding levels have varied over the life of the program and have relied on Federal and other sources. Although this section focuses primarily on the Federal investment that has been dedicated to the program through authorizing legislation, other funds have been used to perform program activities. Table 4.2 details annual LTPP funding and funding sources from the program's beginning through 2014. Figure 4.1 illustrates the variation in funding received from the highway bills and compensatory contributions received to support LTPP activities after dedicated Federal funding was reduced in 1999. Added to these contributions are resources that the Federal Highway Administration (FHWA) has supplied, which are not included in the summaries of Federal expenditures in tables 4.1

TABLE 4.1. LTPP program Federal funding (fiscal years 1987-2014).

Fiscal Years	Authorizing Highway Legislation	Funding (in millions of dollars)
1987-1991	Surface Transportation and Uniform Relocation Assistance Act (Public Law 100-17, April 2, 1987)	\$50.00
1992-1997	Intermodal Surface Transportation Efficiency Act (Public Law 102-240, December 18, 1991)	87.29
1998-2003	Transportation Equity Act for the 21st Century (Public Law 105-178, June 9, 1998)	75.52
2004-2009	TEA-21 Extension + Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (Public Law 109-59, August 10, 2005)	53.44
2010-2014	SAFETEA-LU Extensions + Moving Ahead for Progress in the 21st Century (Public Law 112-141, July 6, 2012)	45.31
TOTAL		\$311.56

and 4.2. These contributions include the cost of engineering and clerical staff salaries, travel funds, equipment, supplies, and routine overhead.

Initially, in 1987, the LTPP program received \$50 million of the \$150 million provided to the Strategic Highway Research Program (SHRP) by STURAA. In 1992, the administration of the program was transferred to FHWA, and ISTEA provided \$37.52 million through 1997, with FHWA contributing an additional \$49.77 million from its research and technology funds. The combined funds averaged \$14.55 million per year, approximately the amount that was estimated would be needed to sustain the LTPP studies when the program was transferred from SHRP to FHWA. From 1998 through 2003, funding from TEA-21 and the Revenue Aligned Budget Authority (RABA) of TEA-21 plus contributions to the program from the American Association of State Highway and Transportation Officials

States and Provinces have contributed resources estimated to be in excess of \$500 million to LTPP in services and direct expenditures. Their contributions to pooled-fund studies have sustained critical LTPP activities, and their support through AASHTO has been critical to the program.

(AASHTO) provided on average \$12.59 million per year for the LTPP program. From 2004 through 2009, funding through extensions of TEA-21, SAFETEA-LU and its associated technical corrections bill, and the FHWA Innovative Pavement Research and Deployment Program (IPRD) provided approximately \$8.91 million per year for the LTPP program. Finally, from 2010 through 2014, funding through extensions of SAFETEA-LU, the passage of MAP-21, and FHWA's IPRD funds is estimated to provide \$7.47 million per year to continue the LTPP mission.

States and Provinces have contributed resources estimated to be in excess of \$500 million to the program in services and direct expenditures. Their highway agencies have provided construction of the test sections, materials testing, traffic control, traffic data collection, management, loaned staff, and equipment supporting the broad array of LTPP activities. During periods of reduced Federal funding, their contributions to pooled-fund studies have sustained critical LTPP activities.

Canada's Strategic Highway Research Program, known as C-SHRP, also contributed to the program during funding shortfalls. Between 1999 and 2001, C-SHRP funded the data interpretation of film images collected during the automated distress surveys, contracting with the survey vendor to interpret about 490 LTPP test sections in the United States and Canada at a cost of \$120,000. C-SHRP also funded the publication of *Preserving and Maximizing the Utility of the Pavement*

Performance Database. In this document addressed to the highway community, the Transportation Research Board (TRB) LTPP Committee stated its view of what would be needed beyond 2009 (the anticipated end of the program) to complete LTPP data collection, data analysis, and product development and to preserve and make accessible LTPP data for future researchers.¹

The distribution of LTPP program expenditures by cost element can only be roughly estimated. Expenditures have varied from year to year in response to program priorities set in consultation with the advisory

committees, the maturing of the program, and varying levels of Federal investment. Some costs are difficult to quantify, for example, the activities supported financially by the States and Provinces (estimated at more than \$500 million), product development covered by non-LTPP funds, and overhead costs and staffing supported by FHWA. Excluding expenditures such as these, the distribution of the Federal investment by cost element, averaged over the years, is estimated as follows: program management, outreach, and coordination, 8 percent; data collection (equipment, person-

TABLE 4.2. LTPP Timeline—Highway legislated and other funding sources (in millions of dollars).

Highway Legislation	FY	Legislated Funding	AASHTO Funding ¹	RABA Funding ²	IPRD Funding ³	Total Funding per Year	Total Funding
<i>SHRP Management</i>							
STURAA	1987	\$10.00				\$10.00	
	1988	10.00				10.00	
	1989	10.00				10.00	
	1990	10.00				10.00	
	1991	10.00				10.00	\$50.00
<i>FHWA Management</i>							
ISTEA	1992	13.78				13.78	
	1993	12.14				12.14	
	1994	14.94				14.94	
	1995	14.80				14.80	
	1996	15.83				15.83	
	1997	15.80				15.80	87.29
TEA-21	1998	10.00				10.00	
	1999	8.83	\$4.70			13.53	
	2000	8.71	5.03			13.74	
	2001	8.77	3.55			12.32	
	2002	9.04	0.55		\$3.10	12.69	
	2003	8.94			4.30	13.24	75.52
TEA-21 Extension	2004	9.40				9.40	9.40
SAFETEA-LU	2005	8.23				8.23	
	2006	7.14			\$0.16	7.30	
	2007	7.45			1.23	8.68	
	2008	8.70			0.90	9.60	
	2009	8.82			1.41	10.23	44.04
SAFETEA-LU Extension	2010	8.81			0.61	9.42	
	2011	8.72			1.60	10.32	
	2012	8.53				8.53	28.27
MAP-21	2013	8.32				8.32	
	2014	8.72				8.72	17.04
Total		\$284.42	\$13.83	\$7.40	\$5.91	\$311.56	\$311.56

(1) A significant portion of the LTPP funding during the TEA-21 highway legislation years came from AASHTO. AASHTO's Standing Committee on Research passed a resolution to use National Cooperative Highway Research Program project funds to support LTPP program activities from 1999 to 2002.

(2) Significant funding was also provided by RABA, a provision of TEA-21 that adjusted transportation funding to match actual revenue from gas and vehicle taxes.

(3) The FHWA IPRD provided non-LTPP funds to the program during the SAFETEA-LU years for product development.

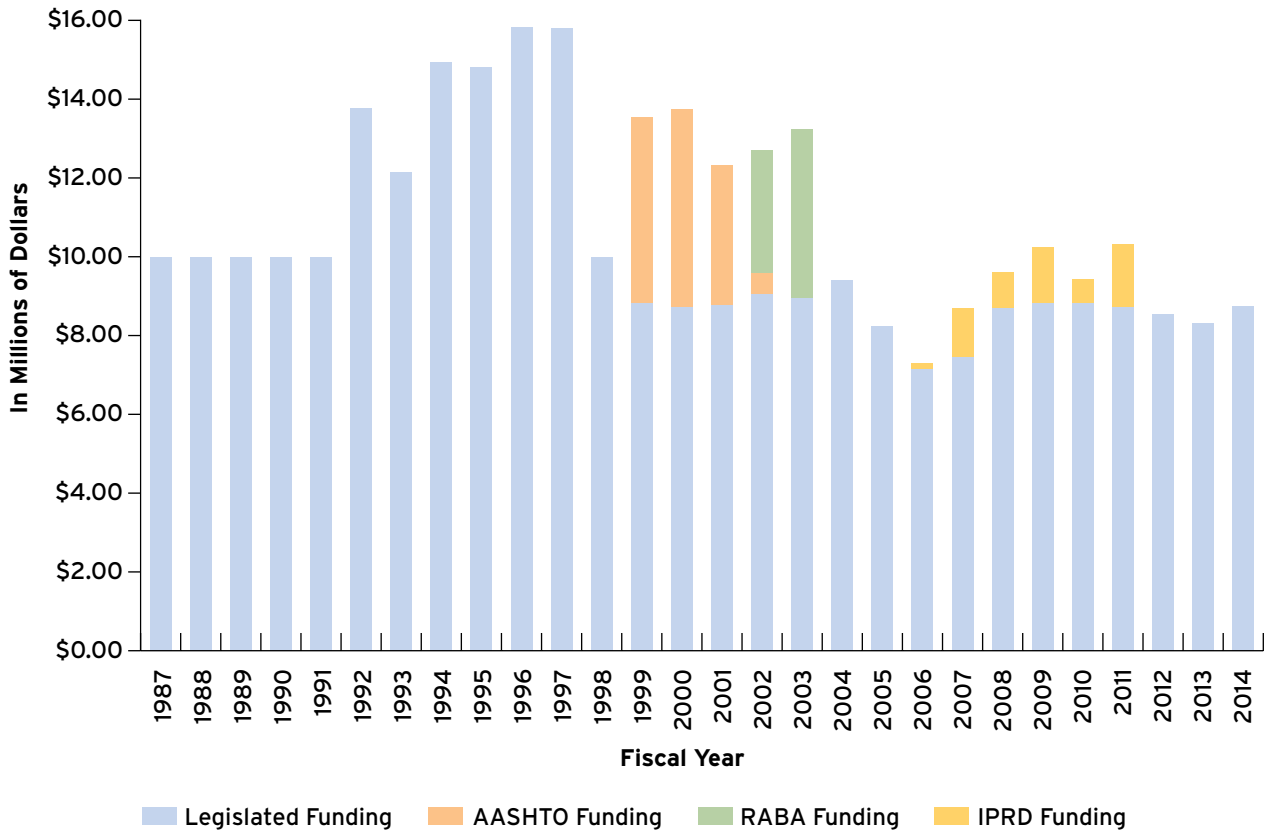


FIGURE 4.1. LTPP funding in fiscal years 1987-2014.

nel, data processing and quality assurance, laboratory testing, and training), 52 percent; database management (information management systems, data storage and distribution, and customer service), 30 percent; data analysis and product development, 10 percent.

The following sections, and tables 4.3 through 4.7, provide more detailed information about funding during the STURAA, ISTEA, TEA-21, SAFETEA-LU, and MAP-21 highway legislation periods associated with the LTPP program, including period covered, funding, legislation requirements, impact on operations, and, where applicable, delays in legislation passage.

SURFACE TRANSPORTATION AND UNIFORM RELOCATION ASSISTANCE ACT

STURAA, which was enacted April 2, 1987, as Public Law 100-17, authorized SHRP and provided \$30 mil-

lion per year or a total of \$150 million for carrying out the program, which the States paid for by contributing 0.25 percent of their Federal-Aid Highway Program funds.² The STURAA legislation covered LTPP operations for a period of 4 years and 8 months, from April 2, 1987, to December 18, 1991, when the next highway legislation was enacted (see the sidebar for excerpts from the legislation).

Of the funding provided to SHRP, \$10 million per year or a total of \$50 million was dedicated to the LTPP program (table 4.3). This projection matched the funding called for in the preliminary LTPP plans contained in the *Strategic Highway Research Program Research Plans, Final Report*, May 1986 or “Brown Book.”³ However, once implementation of the program commenced, it became apparent fairly quickly that the funding level provided was not sufficient to carry out all of the planned activities. The budget realities had an impact on a number of program

issues, such as reductions in the types and numbers of pavement layer materials tests that could be performed, but perhaps no impacts were as significant and long lasting as the following two:

- Under the General Pavement Study (GPS) suite of experiments, the materials testing activities were centralized through sampling and testing contractors under the direct control of the program. Because of budget limitations, however, the pavement layer materials testing program was decentralized for the Specific Pavement Study (SPS) experiments. Thereby the responsibility for sam-

pling and testing many of these projects was handed over to the participating agencies. However, as the LTPP program began to review the materials data from the SPS test sections, considerable variation was discovered among the States and Provinces in their sampling and testing procedures, and the SPS materials test results were found to be inconsistent and incomplete relative to the program's standards.

- Responsibility for traffic data collection for the GPS and SPS test sites was assigned to the individual participating highway agencies. However,

SURFACE TRANSPORTATION AND UNIFORM RELOCATION ASSISTANCE ACT OF 1987

SEC. 128. Strategic Highway Research Program.

Section 307 of title 23, United States Code (relating to research and planning), is amended by redesignating subsections (d) and (e) (and any references thereto) as subsections (e) and (f), respectively, and by inserting after subsection (c) the following new subsection:

“(d) STRATEGIC HIGHWAY RESEARCH PROGRAM.—

“(1) ESTABLISHMENT. —The Secretary, in consultation with the National Academy of Sciences and American Association of State Highway and Transportation Officials, shall carry out such research, development, and technology transfer activities as the Secretary determines to be strategically important to the national highway transportation system.

“(2) COOPERATIVE AGREEMENTS.—The Secretary may make grants to, and enter into cooperative agreements with, the American Association of

State Highway and Transportation Officials and the National Academy of Sciences to carry out such activities under this subsection as the Secretary determines are appropriate. Advance payments may be made as necessary to carry out the program under this subsection.

“(3) PERIOD OF AVAILABILITY.—Funds set aside to carry out this subsection shall remain available for the fiscal year in which such funds are made available and the three succeeding fiscal years.

....

“(5) ANNUAL REPORT.—The Secretary shall transmit a report annually beginning on January 1, 1988, to the Committee on Environment and Public Works of the Senate and the Committee on Public Works and Transportation of the House of Representatives which provides information on the progress and research findings the program conducted under this subsection.”

TABLE 4.3. LTPP program funding under STURAA (fiscal years 1987-91).

Funding Source	Funding by Fiscal Year (in millions of dollars)					Total Funding
	1987	1988	1989	1990	1991	
STURAA	\$10	\$10	\$10	\$10	\$10	\$50
Total	\$10	\$10	\$10	\$10	\$10	\$50

traffic-monitoring technology never fulfilled early expectations that it would be economically and technically feasible to install reliable weigh-in-motion equipment at every LTPP test site. The lack of appropriate equipment, coupled with problems that arose regarding data quality and timely monitoring, led to large gaps in traffic data in the LTPP database.

The impact of the materials and traffic data issues on LTPP operations became quite evident in the mid-1990s and led to the development and implementation of important materials testing and traffic monitoring action plans to address data deficiencies. These remedial actions, discussed in chapter 7, required a significant level of additional funding.

INTERMODAL SURFACE TRANSPORTATION EFFICIENCY ACT OF 1991

ISTEA was enacted December 18, 1991, as Public Law 102-240.⁴ The legislation provided funding for implementation of SHRP products as well as continuation of the LTPP program (see sidebar).

Enactment of the ISTEA legislation defined the end of SHRP and the beginning of LTPP under FHWA management, and the legislation covered LTPP operations for a period of 5 years and 8 months, from December 18, 1992, to June 9, 1998. ISTEA provided \$37.52 million for continuation of the LTPP program, and FHWA assigned an additional \$49.77 million from its research and technology funds; together these resources averaged \$14.55 million per year (table 4.4).

INTERMODAL SURFACE TRANSPORTATION EFFICIENCY ACT OF 1991

SEC. 6001. Research and Technology Program.

Subsections (a), (b), and (c) of section 307 of title 23, United States Code, are amended to read as follows:

...

“(b) MANDATORY CONTENTS OF RESEARCH PROGRAM. –

....

“(2) SHRP RESULTS.–

“(A) IMPLEMENTATION.–The highway research program under subsection (a) shall include a program to implement results of the strategic highway research program carried out under

subsection (d) (including results relating to automatic intrusion alarms for street and highway construction work zones) and to continue the long-term pavement performance tests being carried out under such program.

“(B) MINIMUM FUNDING.–Of amounts deducted under section 104(a) of this title, the Secretary shall expend not less than \$12,000,000 in fiscal year 1992, \$16,000,000 in fiscal year 1993, and \$20,000,000 per fiscal year for each of fiscal years 1994, 1995, 1996, and 1997 to carry out this paragraph.”

TABLE 4.4. LTPP program funding under ISTEA (fiscal years 1992-97).

Funding Source	Funding by Fiscal Year (in millions of dollars)						Total Funding
	1992	1993	1994	1995	1996	1997	
ISTEA § 6001 ¹	\$4.00	\$6.00	\$8.00	\$6.00	\$7.52	\$6.00	\$37.52
FHWA GOE ^{2,3}	9.78	6.14	6.94	8.80	8.31	9.80	49.77
TOTAL	\$13.78	\$12.14	\$14.94	\$14.80	\$15.83	\$15.80	\$87.29

(1) Section 6001 provided \$108 million to FHWA for SHRP implementation and the continuation of LTPP (\$12 million in FY 1992, \$16 million in FY 1993, and \$20 million per fiscal years 1994 through 1997).

(2) FHWA GOE = General Operating Expenses. These amounts do not include staff salaries for eight engineers, one clerk, travel, equipment, and supplies at an approximate cost of \$750,000 per year or \$3.75 million for fiscal years 1992 to 1997. Routine overhead costs were also provided by FHWA.

(3) Over the 5-year period, \$5.4 million was deducted from this total for management and coordination activities.

This budget represented a 45 percent increase compared to STURAA funding during the 1987 through 1991 SHRP years. More importantly, this budget increase permitted the LTPP program to make important adjustments as well as to implement new initiatives that would later prove to have a positive impact on the program. These adjustments and initiatives included:

- Increased monitoring frequencies on LTPP test sections, particularly for falling weight deflectometer (FWD) deflection testing and longitudinal profile surveys.
- Formal introduction of manual pavement surface distress surveys (in addition to the photographic distress surveys).
- Implementation of the Seasonal Monitoring Program to study the impact of seasonal climate variations on pavement performance.

- Planning and initial implementation of the Dynamic Load Response Program at select SPS-1 and -2 projects (structural factors for flexible and rigid pavements, respectively).

TRANSPORTATION EQUITY ACT FOR THE 21ST CENTURY

TEA-21 was enacted June 9, 1998, as Public Law 105-178.⁵ The legislation provided funding for continuation of the LTPP program and, unlike ISTEA, also required that the LTPP program “prepare products to fulfill program objectives and meet future pavement technology needs” (see sidebar).

TEA-21 covered LTPP operations for a period of 7 years and 2 months, from June 9, 1998, to August 10, 2005. The LTPP program operated under the TEA-21

TRANSPORTATION EQUITY ACT FOR THE 21ST CENTURY

TITLE V—TRANSPORTATION RESEARCH

Subtitle A—Funding

SEC. 5001. Authorization Of Appropriations. . . .

(c) ALLOCATIONS.—

(1) SURFACE TRANSPORTATION RESEARCH.—Of the amounts made available under subsection (a)(1)—

(A) \$10,000,000 for each of fiscal years 1998 through 2003 shall be available to carry out section 502(e) of title 23, United States Code (relating to long-term pavement performance);

Subtitle B—Research and Technology

SEC. 5102. Surface Transportation Research.

Chapter 5 of title 23, United States Code (as added by section 5101 of this title), is amended by adding at the end the following:

“§ 502. Surface transportation research

“(e) LONG-TERM PAVEMENT PERFORMANCE PROGRAM.—

“(1) AUTHORITY.—The Secretary shall complete the long-term pavement performance program tests initiated under the strategic highway research program established under section 307(d) (as in effect on the day before the date of enactment of this section) and continued by the Intermodal Surface Transportation Efficiency Act of 1991 (105 Stat. 1914 et seq.) through the midpoint of a planned 20-year life of the long-term pavement performance program.

“(2) GRANTS, COOPERATIVE AGREEMENTS, AND CONTRACTS.—Under the program, the secretary shall make grants and enter into cooperative agreements and contracts to—

“(A) monitor, material-test, and evaluate highway test sections in existence as of the date of the grant, agreement, or contract;

“(B) analyze the data obtained in carrying out subparagraph (A); and

“(C) prepare products to fulfill program objectives and meet future pavement technology needs.”

Perhaps the most critical impact of the TEA-21 extensions to achievement of the program's objectives was the program's inability to monitor aging pavement test sections at the needed intervals.

legislation for the longest period of any legislation, which had impacts on operations due to its reduced funding level. In contrast to ISTEA, which increased the LTPP budget by 45 percent from that provided under STURAA, TEA-21 reduced LTPP funding more than 30 percent, from \$14.50 million per year to approximately \$9.00 million per year after the yearly appropriations takedown (or rescission), which varied each year, was applied to the authorized funding for the program (table 4.5). There was no takedown in 1998.

From October 1, 2003 (anticipated end of TEA-21 legislation), until August 10, 2005 (actual passing of the next highway legislation), the LTPP program operated under a series of extensions to TEA-21 and continuing resolutions. These extensions incrementally provided funding in the amount of \$940 million per year.

Program Adjustments Due to Funding Constraints Under TEA-21

The budget cuts had an impact on the LTPP program's ability to effectively plan and execute key activities required to complete the program's mission. While many of the core activities continued, the decreased level of funding required that LTPP make some significant program adjustments, taking into consideration contractual obligations and programmatic issues. Those adjustments included the following:

- Basic data collection (manual distress and profile surveys, deflection testing, and other field evaluations) and processing activities were reduced to levels below those under the ISTEA legislation.
- Important data collection activities were either postponed or delayed, including drainage surveys, forensic investigations, within-test-section thickness surveys (using ground penetrating radar) and some quality assurance review activities such as the profiler and FWD comparisons. The purchase of much-needed replacement equipment also had to be postponed.
- The Seasonal Monitoring Program was terminated.
- Development and population of key computed parameters for storage in the database were postponed. The most important of these parameters was the dynamic modulus of hot-mix asphalt concrete mixtures (often referred to as $|E^*|$), which was considered essential in the calibration of AASHTO's Mechanistic-Empirical Pavement Design Guide at the regional and local level. Other affected computed parameters included the moisture content of unbound layers from time-domain reflectivity readings, frost/thaw depth determinations from resistivity measurements, and elastic layer moduli backcalculation from deflection data.
- The ability to plan for future procurements stopped due to budget uncertainties. In addition, two major planned contract procurements ready for advertisement were put on hold—the photographic distress survey contract and a centralized materials testing contract.
- Minimal task order work assignments were made to the data analysis contracts awarded during the original TEA-21 legislation.

TABLE 4.5. LTPP program funding under TEA-21 (fiscal years 1998-2003).

Funding Source	Funding by Fiscal Year (in millions of dollars)						Total Funding
	1998	1999	2000	2001	2002	2003	
TEA-21	\$10.00	\$8.83	\$8.71	\$8.77	\$9.04	\$8.94	\$54.29
AASHTO	–	4.70	5.03	3.55	0.55	–	13.83
RABA	–	–	–	–	3.10	4.30	7.40
TOTAL	\$10.00	\$13.53	\$13.74	\$12.32	\$12.69	\$13.24	\$75.52

- No new product development activities were started.
- Key activities in support of the Ancillary Information Management System were either cut back or postponed, including work on the LTPP library and on information not contained in the database (e.g., raw profile and deflection data and distress photographs and images).
- Vital communication and coordination activities were hampered due to limited funds, especially those involving the TRB LTPP Committee and expert task groups (ETGs). A number of important meetings could not be held, and attendance at others was limited. Visits with State partners for coordination activities had to rely more on teleconferences rather than face-to-face meetings.

The TEA-21 adjustments were clearly painful cuts for a long-term program to endure and still deliver the products it was designed to produce. Perhaps the most critical impact of the TEA-21 extensions on achievement of the program's objectives was the program's inability to monitor aging pavement test sections at the needed

intervals. Cutbacks in monitoring frequency resulted in sections being dropped from the study without the final round of condition measurements being recorded.

Were it not for the contributions made to the program by AASHTO, which provided \$13.80 million during fiscal years 1999 through 2002, and funding derived from RABA, which amounted to \$7.40 million during fiscal years 2002 and 2003, the adverse impact of TEA-21 on LTPP operations would have been much more severe.

SAFE, ACCOUNTABLE, FLEXIBLE, EFFICIENT TRANSPORTATION EQUITY ACT: A LEGACY FOR USERS

SAFETEA-LU was enacted August 10, 2005, as Public Law 109-59 (see sidebar).⁶ This legislation was to take the LTPP program to its formal conclusion at the end of fiscal year 2009—the end of the 20-year period considered to be the minimum period required to realize the benefits of long-term monitoring. At the time of

SAFE, ACCOUNTABLE, FLEXIBLE, EFFICIENT TRANSPORTATION EQUITY ACT: A LEGACY FOR USERS (PUBLIC LAW 109-59)

(i) Long-Term Pavement Performance Program.—

(1) **IN GENERAL.**—Section 502(f) of such title (as redesignated by subsection (b) of this section) is amended to read as follows:

“(f) **LONG-TERM PAVEMENT PERFORMANCE PROGRAM.**—

“(1) **AUTHORITY.**—The Secretary shall continue to carry out, through September 30, 2009, tests, monitoring, and data analysis under the long-term pavement performance program.

“(2) **GRANTS, COOPERATIVE AGREEMENTS, AND CONTRACTS.**—Under the program, the Secretary shall make grants and enter into cooperative agreements and contracts to—

“(A) monitor, material-test, and evaluate highway test sections in existence as of the date of the grant, agreement, or contract;

“(B) analyze the data obtained under subparagraph (A); and

“(C) prepare products to fulfill program objectives and meet future pavement technology needs.”

(2) **FUNDING.**—Of the amounts made available by section 5101(a)(1) of this Act, \$10,120,000 for each of fiscal years 2005 through 2009 shall be available to carry out section 502(f) of such title.

SAFETEA-LU’s enactment, however, much additional work remained to be done to fulfill the LTPP mission.

LTPP program funding under the SAFETEA-LU legislation was set at \$10.12 million per year. However, after a reduction was applied to correct for the Title V—Surface Transportation Research Development and Deployment overdesignation, the program received the amounts shown in table 4.6. Moreover, as was the case under the previous TEA-21 legislation, SAFETEA-LU required that the program “prepare products to fulfill program objectives and meet future pavement technology needs.”⁷ Additional funds were provided to the LTPP program in fiscal years 2006–2009 from FHWA IPRD Program funds and from the SAFETEA-LU Technical Corrections Act of 2008 (Public Law 110-244) in fiscal years 2008 and 2009 (table 4.6). These additional funds brought the average annual LTPP budget under this legislation to around \$8.8 million per year.

To put these numbers into perspective, in 2001 the TRB LTPP Committee had projected that the funding required to fulfill the LTPP mission from fiscal year 2004 through fiscal year 2009 was \$120 to \$125 million, or approximately \$20 million per year.⁸ This figure included activities that FHWA had planned to accomplish by the end of the legislation and those designed to address some of the program’s high-priority needs. With the budget provided by SAFETEA-LU, however, it was not possible to perform many of the actions proposed by the TRB LTPP Committee. Furthermore, whether LTPP operations would be extended past 2009 was uncertain. Like previous legislation, SAFETEA-LU extended authority for the program’s operation only for the 5 years the act covered. Since the future of the LTPP program was not clear, FHWA

decided that the most responsible course of action for use of program funds was to prepare simultaneously for both a transition of LTPP activities past 2009 and possible program termination in 2009.⁹

Program Adjustments Due to Funding Constraints Under SAFETEA-LU

As the LTPP program prepared for the unknown outcomes of the delayed legislation, the uncertainties led to the adoption of the following statement to describe the primary program deliverable come September 2009: “a quality pavement performance database and supporting ancillary information and document warehouse that enables researchers to better fulfill the goals of understanding pavement performance on which the program was founded.”¹⁰ Five specific attributes of the database were defined as necessary to achieving the primary programmatic goal by 2009:

- A database containing complete data sets (i.e., inventory, materials, traffic, climate, maintenance and rehabilitation, and pavement performance data) for most LTPP test sections.
- A database whose contents have been reviewed and checked through quality control/quality assurance (QC/QA) processes and data studies and that is as error-free as time and the program budget will allow.
- A database that is documented not only in terms of its content but also in how those data were collected and their quality.
- A database that is accessible to the public.
- A database that conforms to Federal Government information dissemination quality guidelines.

TABLE 4.6. LTPP program funding under SAFETEA-LU (fiscal years 2004-2009).

Funding Source	Funding by Fiscal Year (in millions of dollars)						Total Funding
	2004	2005	2006	2007	2008 ¹	2009 ¹	
TEA-21 Extension	\$9.40	–	–	–	–	–	\$9.40
SAFETEA-LU	–	\$8.23	\$7.14	\$7.45	\$8.70	\$8.82	40.34
FHWA IPRD Program	–	–	0.16	1.23	0.90	1.41	3.70
TOTAL	\$9.40	\$8.23	\$7.30	\$8.68	\$9.60	\$10.23	\$53.44

(1) Includes the SAFETEA-LU Technical Corrections Act of 2008 (Public Law 110-244, June 6, 2008).

Working towards this deliverable, it was decided that LTPP program funds provided by the SAFETEA-LU legislation would be used for the following high-priority program needs:

- Completing data sets:
 - Continue implementation of the Traffic Data Action Plan at SPS project sites to collect missing traffic volume and load data (chapter 7).
 - Continue implementation of the Materials Data Action Plan at SPS project sites to collect missing materials property data (chapter 7).
 - Perform one more round of pavement performance measurements on selected LTPP test sections.
- Refining database and ancillary information:
 - Continue the database QC/QA activities and investigation of discrepancies.
 - Complete the database and program documentation.
 - Improve direct user access to the database and ancillary information.
 - Provide annual data releases.
- Coordinating program activities:
 - Continue program coordination with TRB, highway agencies, AASHTO, and other FHWA offices.
 - Continue internal program coordination.
- Developing and publishing a post-2009 plan to secure the legacy of the LTPP program. This plan would provide for the continuation of essential LTPP activities:
 - Storage, maintenance, and user support for the LTPP database and associated information.
 - Storage and user support for the LTPP Materials Reference Library.
 - Collection of missing data and monitoring of LTPP test sections that had not reached the end of their performance life.
 - Implementation of the LTPP Strategic Data Analysis Plan (chapter 10).
 - Implementation of the LTPP Product Development Plan (chapter 10).

The decision to make use of available LTPP resources for the designated high-priority needs, listed above, required significant adjustments to other program activities. Similar to adjustments made under TEA-21, activities were either reduced or eliminated in data collection, database development, data analysis, product development, and coordination as follows:

- Data collection activities:
 - Frequency of pavement condition data collection was reduced.
 - More than 300 active test sections were placed in the out-of-study category (i.e., no future monitoring would be performed). These sections were in the SPS-3 (preventive maintenance of flexible pavement), -4 (preventive maintenance of rigid pavement), and -7 (bonded Portland cement concrete (PCC) overlay) experiments and the GPS-4 (jointed reinforced concrete), -5 (continuously reinforced concrete), and -9 (unbonded PCC overlay on PCC) experiments.
 - On the remaining active test sections, monitoring would only be performed on a subset of priority test sections.
 - Quantitative pavement surface images (photographic images) for distress interpretation would not be obtained.
 - Structural response measurements with the FWD were suspended.
 - LTPP program funds were not used to support the regional FWD calibration centers.
 - Aging materials tests previously planned for inclusion in the SPS Materials Action Plan were eliminated.
 - Planned activities to characterize test section drainage features were eliminated.
 - Additional ground penetrating radar measurements to obtain layer thickness measurements within the monitoring portion of the test section were eliminated.
 - Activities planned to address deficiencies in traffic volume and load data at GPS project sites were eliminated.
 - No program funds were used to replace or update field data collection equipment.

- Database development activities:
 - Development of an analysis database was suspended.
 - Overhaul of the LTPP database automated quality checks was suspended.
 - Development of a complete metadata database for all offline LTPP ancillary information was suspended.
 - LTPP data releases were reduced to an annual cycle.
 - Conversion of LTPP data element units to a common standard was suspended.
 - LTPP funding was not provided to support DataPave Online (user-friendly software for working with the LTPP database) and database user training.
- Data analysis activities:
 - Limited LTPP program funds were dedicated to formal data analysis projects through 2009.
- Product development activities:
 - No LTPP program funds were allocated to product development from 2006 to 2009.
- Coordination activities:
 - LTPP-sponsored national and regional meetings were eliminated.
 - National coordination meetings with LTPP data collection contractor staff and meetings between the data analysis contractors and operations staff were reduced.
 - TRB ETGs were reduced in number and membership size.

MOVING AHEAD FOR PROGRESS IN THE 21ST CENTURY ACT

On July 6, 2012, MAP-21 (Public Law 112-141) was signed into law (see sidebar).¹¹ MAP-21 emphasizes performance measurement and evaluation and sets the stage for a more long-term, nationally coordinated approach to investing in the Nation's transportation needs. With the removal of most earmarks and the con-

solidation of Federal transportation programs from about 90 to fewer than 30, the act is designed to focus resources on key goals, reduce duplication of effort, and provide more flexibility in managing infrastructure investment.¹²

The first long-term highway authorization to be enacted since 2005, MAP-21 included an additional extension of SAFETEA-LU to the end of fiscal year 2012. Thus, new provisions of the law took effect October 1, 2012. For fiscal years 2013 and 2014, MAP-21 reauthorized the Federal-Aid Highway Program at \$40.40 billion and \$41.00 billion, respectively, equal to current funding levels plus inflation.

Under Sections 52003 and 52013 of the act, related to Transportation Research and Development Strategic Planning, the Secretary of Transportation is directed to develop a 5-year strategic research and development plan to address the following purposes: promoting safety, reducing congestion and improving mobility, preserving the environment, preserving the existing transportation system, improving the durability and extending the life of transportation infrastructure, and improving goods movement.¹³

MAP-21 continues authorization for LTPP program activities under Title 23, Section 503(b), Highway Research and Development Program, of the United States Code. The act provides \$115 million per year for the Highway Research and Development program, emphasizing research and development activities that maintain infrastructure integrity, meet user needs, and "link Federal transportation investments to improvements in system performance."¹⁴ Research areas include highway safety, infrastructure integrity, planning and environment, highway operations, exploratory advanced research, and support for the Turner-Fairbank Highway Research Center. "Long-term infrastructure performance programs addressing pavements, bridges, tunnels, and other structures" are among the activities to be carried out under the program. With the exception of adding two new LTPP experiments, the program continues to perform the same activities as it did during the SAFETEA-LU period. LTPP's resources under SAFETEA-LU extensions and MAP-21 are detailed in table 4.7.

MOVING AHEAD FOR PROGRESS IN THE 21ST CENTURY ACT

SEC. 52003. Research and Technology Development and Deployment.

(a) IN GENERAL.—Section 503 of title 23, United States Code, is amended to read as follows:

“§ 503. Research and technology development and deployment

“(a) IN GENERAL.—The Secretary shall—

“(1) carry out research, development, and deployment activities that encompass the entire innovation lifecycle; and

“(2) ensure that all research carried out under this section aligns with the transportation research and development strategic plan of the Secretary under section 508.

“(b) HIGHWAY RESEARCH AND DEVELOPMENT PROGRAM.— . . .

“(3) IMPROVING INFRASTRUCTURE INTEGRITY.—

“(A) IN GENERAL.—The Secretary shall carry out and facilitate highway and bridge infrastructure research and development activities—

“(i) to maintain infrastructure integrity;

“(ii) to meet user needs; and

“(iii) to link Federal transportation investments to improvements in system performance. . . .

“(B) OBJECTIVES.—In carrying out this paragraph, the Secretary shall carry out research and development activities— . . .

“(iii) to increase the reliability of lifecycle performance predictions used in infrastructure design, construction, and management;

“(iv) to improve the ability of transportation agencies to deliver projects that meet expectations for timeliness, quality, and cost;

“(v) to reduce user delay attributable to infrastructure system performance, maintenance, rehabilitation, and construction;

“(vi) to improve highway condition and performance through increased use of design, materials, construction, and maintenance innovations; . . .

“(C) CONTENTS.—Research and technology activities carried out under this paragraph may include—

“(i) long-term infrastructure performance programs addressing pavements, bridges, tunnels, and other structures; . . .”

TABLE 4.7. LTPP program funding under MAP-21 (fiscal years 2010-2014).

Funding Source	Funding by Fiscal Year (in millions of dollars)					Total Funding
	2010	2011	2012 ¹	2013	2014	
SAFETEA-LU Extension	\$8.81	\$8.72	\$6.45	–	–	\$23.98
FHWA IPRD Program	0.61	1.60	–	–	–	2.21
MAP-21	–	–	2.08	8.32	8.72	19.12
TOTAL	\$9.42	\$10.32	\$8.53	\$8.32	\$8.72	\$45.31

(1) Fiscal year 2012 was funded by extensions of SAFETEA-LU and, for the last 3 months, by MAP-21.



SUMMARY

Although FHWA management submits a budget to Congress, the final decision on funding is made by the Congress. With a Federal investment of more than \$300 million, the LTPP program has had some years of generous funding that led to advances in pavement research, while in the leaner years, the program has had to make some tough decisions on what could and could not be accomplished and what had to be postponed. Even though funding levels for the program have declined over the years, the program's goal and objectives have not changed.

FHWA's commitment to support the LTPP program is still strong today. The LTPP program is helping to answer the questions of how and why pavements per-

form as they do. With an aging highway infrastructure facing the Nation, the need continues for a robust research pavement program to help current and future transportation officials in their decision making. As shown throughout this report, the LTPP program has created standard practices that are commonly used by highway agencies and has developed a pavement performance database that is renowned worldwide. Although there have been significant returns on this Federal investment in the program, many dividends are still to be gained in the years ahead.

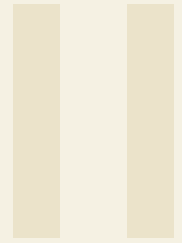
The next section in this report describes how the studies were developed, and the manner in which the data are collected, stored, and checked for quality. The section begins with the design and recruitment of the research experiments.

“LTPP research is significantly advancing the pavement engineering process nationwide. The better the process, the better the product. That’s why the LTPP investment is so essential—it yields the kind of substantive, long-lasting improvements the public expects for its transportation dollars.”

—Mary E. Peters, Federal Highway Administrator 2001-2005¹⁵

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Developing the Studies and the Pavement Performance Database



The shaping of the LTPP experiments was a lengthy process that was already underway before the program officially began and has extended through both the SHRP and FHWA management periods.

5

Design and Recruitment of the LTPP Experiments

At the heart of the LTPP program were the pavement experiments. The design of the experiments was an integral part of the planning and preparation for the program, and ultimately critical to its success. Highway agency, industry, and university representatives collaborated to design experiments located across various climates that would use different materials and carry different traffic loads to assist in understanding how and why pavements perform as they do.

INTRODUCTION

The shaping of the LTPP experiments was a lengthy process that was already underway before the program officially began and has extended through both the Strategic Highway Research Program (SHRP) and Federal Highway Administration (FHWA) management periods. In the early 1980s, FHWA had been working on design plans to field test different pavements and materials to evaluate their performance over time.

Experts in the pavement engineering and statistics areas, including those on the Expert Task Group (ETG) on Experimental Design and Analysis (appendix A), helped to formulate the LTPP experiments. The ETG worked with the Pavement Performance Advisory Committee to identify the types of experiments they envisioned would accomplish the different objectives

for the pavement performance monitoring program.^{1,2,3} In the mid-1980s when planning began, three study types were considered: General Pavement Studies (GPS), Specific Pavement Studies (SPS), and Accelerated Pavement Testing.

The GPS experiments sought to use in-service pavement sections to examine general performance by pavement type. It was thought that these sections would provide relatively quick and cost-efficient insights into the performance of pavement designs generally used in the United States and Canada at the time. In contrast, the SPS studies were designed to investigate the influence on performance of specific features, such as drainage, layer thickness, and rehabilitation or maintenance treatments. These sections were to be constructed specifically for the LTPP study.

Key Milestones in the Design of the Experiments

- 1985** First meeting of the Pavement Performance Advisory Committee to discuss LTPP objectives, experiment designs, and management of the program
- 1988** Selection of first GPS test site
- 1988** First FWD and materials data collection, in North Carolina
- 1989** Selection of SPS test sites begins
- 1990** Construction of first SPS project
- 1990** First SPS maintenance and rehabilitation sections selected
- 1992** First pilot for SPS-9, in Arizona
- 2000** Construction of last SPS project under original LTPP experiments
- 2012** Planning for warm-mix asphalt experiment begins, first new LTPP experiment in 20 years
- 2014** Recruitment begins for new warm-mix asphalt experiment (SPS-10)
- 2014** Planning for pavement preservation experiment begins

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In the third type of study proposed, Accelerated Pavement Testing, sections would be constructed and loaded using a machine simulating traffic for rapid study results. After consideration and deliberation, it was ultimately decided to proceed with the GPS and SPS experiments as part of the SHRP-LTPP program and to pursue accelerated pavement testing under separate efforts. As highway agencies adopt new pavement technologies, new experiments are designed to evaluate the long-term performance of these technologies.

The remaining sections in this chapter briefly discuss the original experiment designs and recruitment of the test sections, as well as the roles that SHRP, FHWA, and the program's contractors had in implementing the LTPP experiments. The general design criteria and design issues specific to the GPS and SPS experiments are discussed in the sidebar. A more thorough discussion of the evolution of the LTPP experiments is found in *SHRP-LTPP Overview: Five-Year Report*.⁴

DESIGN OF GPS EXPERIMENTS

As mentioned previously, the purpose for monitoring GPS test sections was to observe the performance of in-service pavement sections to the end of their design lives. This approach had both advantages and disadvantages.



Early program planners meet to discuss the experiment designs and vision for the LTPP program (left to right, Ralph Haas, John German, Virgil Anderson, and Ed Pensok).

GENERAL DESIGN CRITERIA

In formulating the design criteria for the GPS and SPS experiments, certain criteria were common for both experiments. For example, all GPS and SPS test sections are in the outside single lane (“slow lane”) of the roadways. In addition, the original test section length was planned to be 1,500 ft (457.2 m), but at the SHRP-LTPP Advisory Committee meeting in February 1988, it was agreed to shorten the section length to 500 ft (152.4 m). Reasons for this change included the difficulty in finding homogeneous sections 1,500 ft in length and the acknowledgment that perfor-

mance should be sufficiently consistent over a 500-ft length to account for general roadway conditions. In addition, 500 ft was the shortest length permitting measurement of 250-ft (76.2-m) longitudinal profile wavelengths.⁵ In practice there are some exceptions: some SPS-6 sections (rehabilitation of jointed Portland cement concrete) are 1,000 ft (304.8 m) long, and some “supplementals” are shorter or longer than the prescribed 500 ft. “Supplementals” are test sections added to SPS sites by the States and Provinces to examine features of particular interest to them.



LTPP test site 331001 in New Hampshire (GPS-1: asphalt concrete on granular base). In the unique six-digit identifier, the first two digits indicate the State or Province where the test site is located.

vantages. It allowed for relatively rapid implementation, as no construction was required, and it provided data to begin populating the LTPP database. On the other hand, the structural condition of the pavement when it was first built, or its condition prior to overlay for some experiments, was sometimes unknown, making it extremely difficult to consider this important information in analysis of the data.

Nine pavement types or studies were originally planned for the GPS experiments. Preliminary work in these studies focused on finding pavement test sections meeting the defined criteria for each of the studies. Experimental matrices were developed to help encourage a distribution of primary experimental factors, such as layer thickness, traffic level, and subgrade type (figure 5.1).

It became clear from early efforts that many of the factorial combinations did not exist. Certain pavement types had not been built in some parts of the country, and highway agencies did not build relatively thin roadways for relatively heavy traffic. As a result of the initial section recruitment efforts, modifications to the GPS experiment plans were considered. After review, pavement experts and statisticians recommended changes to seven of the nine original experiments.

Evolution of the GPS Experiments

Following review and discussion by the Advisory Committee with expert input from pavement engi-

neers and statisticians, several changes were made to the GPS experiments. Table 5.1 outlines the basic experiments as originally called for, the changes recommended, and the decision to implement the changes by SHRP. Each experiment had sub-experiments not shown in table 5.1. For example, the variations in the design of asphalt concrete (AC) thickness, AC stiffness, and base and subbase characteristics were examined in the GPS-1 test sections (as shown in figure 5.1). Details of the design process and the final GPS designs are available in the SHRP 5-year and midcourse assessment meeting reports.^{7,8,9}

At subsequent meetings of the LTPP Advisory Committee, two other significant changes were made:

- The minimum truck traffic requirement was relaxed to make finding suitable projects easier.
- The GPS-6 and -7 overlay experiments were split into two experiments each. One set, the 6A (existing AC overlay of AC) and 7A (existing AC overlay of Portland cement concrete (PCC)) experiments, would include sections with existing overlays, where the condition prior to overlay was not known. The second set, 6B (planned AC overlay of AC) and 7B (planned AC overlay of PCC), would include sections where the condition prior to overlay was known, which would make the information gained from this study much more valuable. In this way early results could be obtained, and later studies from overlays with known prior condition would provide stronger long-term understanding.

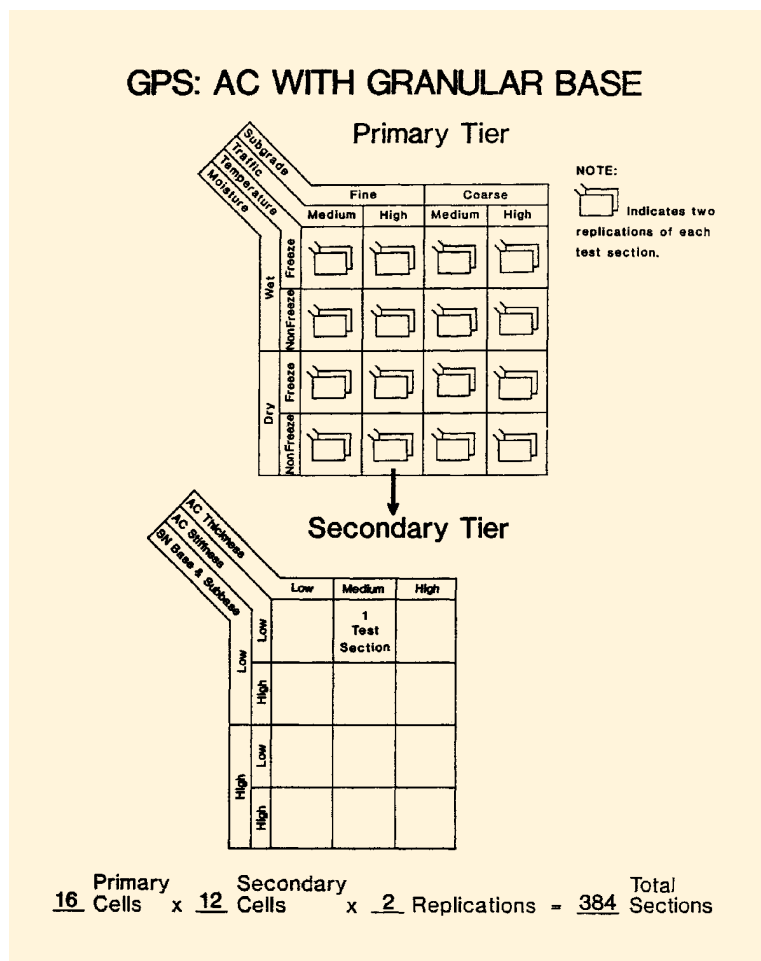


FIGURE 5.1. Example of the research matrices used to plan the GPS experiments (AC = asphalt concrete, SN = structural number).⁶

Later in the program, the GPS-6 and -7 overlay experiments were further divided as a result of the Program Assessment undertaken in 1996 (chapter 11). This assessment determined that the program lacked rehabilitation test sections and that this area of the program needed

TABLE 5.1. Evolution of the General Pavement Study experiment designs.

Original GPS Experiments	Changes Recommended	Were Changes Implemented?
Asphalt Concrete (AC) Over Granular Base	<ul style="list-style-type: none"> • None. 	No. Final experiment name: <ul style="list-style-type: none"> • GPS-1: AC Pavements on Granular Base.
AC Over Stabilized Base	<ul style="list-style-type: none"> • Expand acceptable base types and classify as bituminous and nonbituminous. • Expand acceptable binder types. • Include coarse-grained subgrades. • Add traffic level and subgrades as factors. • Remove AC stiffness as a factor. • Consider plant mix bases. • Consider soil cement and sand asphalt. 	Yes. In addition, the experiment was further modified to allow delineation of asphalt-treated base and cement-treated base. Final experiment name: <ul style="list-style-type: none"> • GPS-2: AC Pavements on Bound Base.
Jointed Plain Concrete (JPC)	<ul style="list-style-type: none"> • Consider pavements in dry-no freeze zone placed directly on subgrade. 	No. JPC placed directly on treated or untreated subgrade was not permitted in the experiment. Final experiment name: <ul style="list-style-type: none"> • GPS-3: Jointed Plain Concrete Pavements.
Jointed Reinforced Concrete (JRC)	<ul style="list-style-type: none"> • None. 	No. Final experiment name: <ul style="list-style-type: none"> • GPS-4: Jointed Reinforced Concrete Pavements.
Continuously Reinforced Concrete (CRC)	<ul style="list-style-type: none"> • Add dry-no freeze region as a factor level. • Remove base type as a structural factor and replace with percentage of reinforcement as the structural factor. 	Yes. Final experiment name: <ul style="list-style-type: none"> • GPS-5: Continuously Reinforced Concrete Pavements.
AC Overlay of AC	<ul style="list-style-type: none"> • Add condition of pavement before overlay as a factor in planned overlays. • Delete AC stiffness as a design factor. 	Yes. The experiment was divided into existing and planned overlays, and AC stiffness was deleted as a factor. Final experiment name: <ul style="list-style-type: none"> • GPS-6: AC Overlay of AC Pavements.
AC Overlay of Jointed Portland Cement Concrete (PCC)	<ul style="list-style-type: none"> • Combine dry-freeze and dry-no freeze into one combined dry environmental zone. • Eliminate JRC as original pavement in the dry environmental zone due to lack of projects. • Add condition of pavement before overlay as a factor in planned overlays. • Delete AC stiffness as a design factor. 	Yes. However, the dry environmental zones were not combined, but JRC pavement was eliminated. The experiment was divided into existing and planned overlays, and AC stiffness was deleted as a factor. Final experiment name: <ul style="list-style-type: none"> • GPS-7: AC Overlay of PCC Pavements.
Bonded Jointed Concrete Pavement (JCP) Overlay of JCP and CRC Pavements	<ul style="list-style-type: none"> • Eliminate due to lack of projects. 	Yes. The SPS-7 (bonded PCC overlay of PCC pavements) experiment was later formulated to address this rehabilitation alternative.
Unbonded JCP Overlay of JCP and CRC Pavements	<ul style="list-style-type: none"> • Delete traffic level, subgrade type, and original pavement condition as design factors. • Allow overlay type as a structural factor and CRC pavement as an overlay type. • Include both existing and planned overlays. • Accept virtually any project that fits the title of the study. 	Yes. Final experiment name: <ul style="list-style-type: none"> • GPS-9: Unbonded PCC Overlay of PCC Pavements.

improvement. To remedy this deficit, it was decided that once a highway agency rehabilitated a test section to address safety or deterioration issues, the LTPP program would move the test section to one of the following GPS-6 or -7 sub-experiments, with the concurrence and continued support of the highway agency:

- GPS-6C (AC overlay using modified asphalt of AC pavement).
- GPS-6D (AC overlay on previously overlaid AC pavement using conventional asphalt).
- GPS-6S (AC overlay of milled AC pavement using conventional or modified asphalt).
- GPS-7C (AC overlay using modified asphalt on PCC pavement).
- GPS-7D (AC overlay on previously overlaid PCC pavement using conventional asphalt).
- GPS-7F (AC overlay using conventional or modified asphalt on fractured PCC pavement).
- GPS-7R (concrete pavement restoration treatments with no overlay).
- GPS-7S (second AC overlay, which includes milling or geotextile application, on PCC pavement with previous AC overlay).¹⁰

RECRUITMENT AND SELECTION OF GPS TEST SECTIONS

In the recruitment of GPS test sections, participating highway agencies were advised of the section needs and asked to review their records for pavements meeting the study criteria. Agency personnel reviewed many potential roadways to find sections that met the needs of the program and submitted them to their respective LTPP regional coordination office contractor (later called “regional support contractor”) for consideration. The LTPP regional coordination office contractors were firms with expertise in pavement monitoring and testing. Under SHRP management of the LTPP program, a SHRP regional engineer was also assigned to each regional office. The SHRP regional engineer and the regional coordination office contractor staff sorted the candidate sections into the experimental matrices to ensure that

the variation in experimental factors desired was actually achieved. SHRP program staff, assisted by the technical assistance contractor (later called “technical support services contractor”), reviewed the potential candidates and provided recommendations for acceptance or rejection of a candidate section. Once this was done and sections meeting the stated criteria were identified, the highway agencies were advised of the selections. Wherever there were multiple projects meeting needs of the same cell, the test sections were sorted and information was maintained for substitution if needed.

After the highway agencies identified the sections, the regional coordination office contractors made field trips to confirm section characteristics and to find and mark out 500-ft (152.4-m) sections for study (figure 5.2). These field trips were an eye-opening experience, as in many cases it was found that the actual section characteristics were vastly different from what was expected. In some cases, layer types and thicknesses varied, and in others the cut/fill transitions or traffic generators (on/off ramps or intersections) prevented the identification of suitable sections for study. During these field visits, cores were obtained at the ends of each section, to confirm layer types and thicknesses. Wherever possible, a section location was found, documented, marked out, and confirmed for study.

Once the field visits were completed, the sections were re-sorted in the experiment matrices based on actual field conditions. This process resulted in many sections changing experiment cells. To fill in the cell gaps, additional sections were recruited and selected. In this iterative process, the GPS experiments were populated with test sections for study. Figure 5.3 shows an example of a GPS sampling template used to populate the LTPP experiments.

In the end, many cells were devoid of sections. Many of these empty cells had extreme criteria, for example, thin sections with high traffic and fine subgrade. These sections simply had not been built, since the highway agencies knew that they would fail in a short time. It was also found that certain pavement types did not exist in certain parts of the country, making the combination of pavement type and environmental zone difficult to achieve in some places.

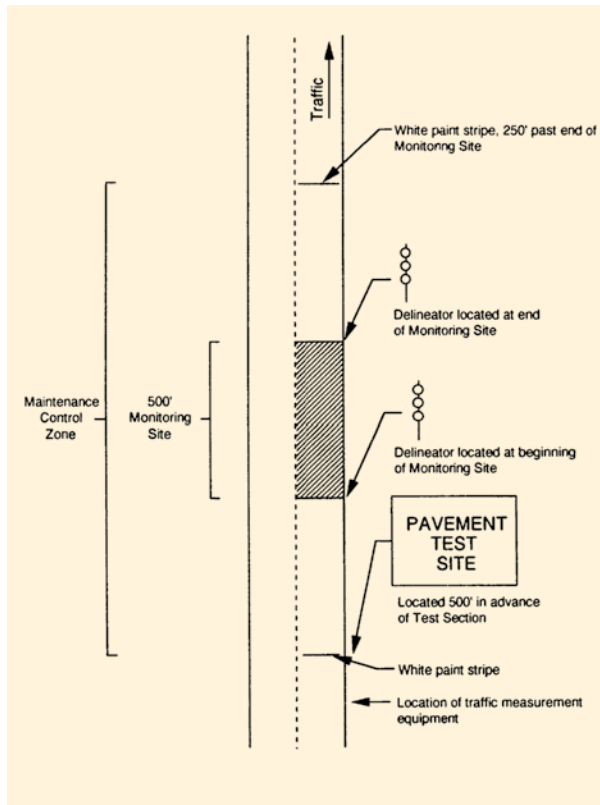


FIGURE 5.2. Designated layout for GPS test sites.¹¹

Consequently, some GPS experimental cells were destined to remain empty. Some of these needs could be addressed through the SPS experiments, where sections would be constructed, but in other cases, there was no practical way to address the gap.

Later in the program, as the pavement performance of some of the test sections began to decline and highway agencies needed to restore performance through rehabilitation activities, many of the pavements in the flexible (GPS-1 and -2) and rigid (GPS-3, -4, and -5) experiments moved to the GPS-6 (AC overlay of AC pavement) and GPS-7 (AC overlay of PCC on concrete pavements) experiments after rehabilitation. Continued monitoring of these sections provided ample data before and after rehabilitation.

MOISTURE	TEMPERATURE	SUBGRADE TYPE	TRAFFIC RATE	AC STIFFNESS	BASE THICKNESS	WET				DRY								
						FREEZE		NO FREEZE		FREEZE		NO FREEZE						
						F	C	F	C	F	C	F	C					
						L	H	L	H	L	H	L	H					
L	L	L	1	13	25	37	49	61	73	85	97	109	121	133	145	157	169	181
		H	2	14	26	38	50	62	74	86	98	110	122	134	146	158	170	182
	H	L	3	15	27	39	51	63	75	87	99	111	123	135	147	159	171	183
		H	4	16	28	40	52	64	76	88	100	112	124	136	148	160	172	184
M	L	L	5	17	29	41	53	65	77	89	101	113	125	137	149	161	173	185
		H	6	18	30	42	54	66	78	90	102	114	126	138	150	162	174	186
	H	L	7	19	31	43	55	67	79	91	103	115	127	139	151	163	175	187
		H	8	20	32	44	56	68	80	92	104	116	128	140	152	164	176	188
H	L	L	9	21	33	45	57	69	81	93	105	117	129	141	153	165	177	189
		H	10	22	34	46	58	70	82	94	106	118	130	142	154	166	178	190
	H	L	11	23	35	47	59	71	83	95	107	119	131	143	155	167	179	191
		H	12	24	36	48	60	72	84	96	108	120	132	144	156	168	180	192

Quantitative Factor Midpoints





Traffic rate: 85 KESALS/year
AC stiffness: 650 ksi/
Base thickness: 10 Inches
AC thickness: 3 and 8 Inches

FIGURE 5.3. Sampling template and cell identification numbers for GPS-1 (asphalt concrete on granular base).¹²

DESIGN OF SPS EXPERIMENTS

The GPS experiments were to be augmented by research into the impact of specific design features in the SPS experiments. The two study types share a symbiotic relationship, in that the findings from each complement the other. The primary difference in the two is that the SPS experiments generally involve some type of construction and tighter control of experimental parameters. Construction focused on providing specific design features for study, such as drainage features, layer thicknesses, base types, or treatment prior to rehabilitation. It was recognized that in some cases SPS results would take longer to realize, but the insights offered would be worth the wait.

SPS: PRE-TREATED JCP WITH AC OVERLAY Primary Tier

Subgrade Traffic Temperature Moisture		Fine		Coarse	
		Medium	High	Medium	High
Wet	Freeze				
	NonFreeze				
Dry	Freeze				
	NonFreeze				

Secondary Tier

Pvt. Type Pre-Treat. OL Thickness		JPCP		JRCP*	
		None		None	
Thin	SS				
	C/S				
Thick	None				
	SS				
	C/S				

C/S = Crack & Seat
SS = Subseal

* NOTE: JRCP not included in
Dry-Nonfreeze Zone.

Primary Secondary JRCP not Total
4 Cells x 12 Cells x 2 Replications - 12 included = 84 Sections

FIGURE 5.4. Example of the research design matrices created for the Specific Pavement Study experiments (JCP = jointed concrete pavement; AC = asphalt concrete; JRCP = jointed reinforced concrete pavement).¹⁵

Efforts began with a “shopping list” of potential studies, gathered over a period of time. In the original plans for the SPS experiment designs, 18 general topics were selected for intensive experiments for flexible and rigid pavements, and design matrices were formulated for many of them in the *Strategic Highway Research Program Research Plans* (“Brown Book”) (see example in figure 5.4).¹³

The SHRP technical assistance contractor developed preliminary designs based on the matrices and details presented in the Brown Book. The preliminary designs were reviewed by a working group that included representatives from highway agencies, FHWA, SHRP, and the contractors. Drawing on the observations of the working group, the SHRP contractors then prepared a draft design, and the draft was presented in study workshops for review by representatives of State and Provincial highway agencies, the pavement industry, and FHWA. As many as 26 highway agencies were represented in the study workshops, and the recommendations from the workshop reviews were incorporated in the final experimental designs.¹⁴

Evolution of the SPS Experiments

In 1987, an effort was undertaken to reduce the number of original SPS design plans and to define the methods required to analyze the data from each. At that time a decision was made to divide the SPS into five major categories: Structural Factors, Preventative Maintenance, Pavement Rehabilitation, Environmental Factors, and Load Equivalencies. These major categories were further subdivided into specific experiments (table 5.2).

During 1989 and 1990, a number of analytical studies were undertaken to further define the SPS experiment designs. In particular, Strategic Pavement Design Initiatives for SPS-1 (structural factors for flexible pavements) and SPS-2 (structural factors for rigid pavements) were considered, and the value of sub-experiments to explore and isolate the relative effects of different factors and combinations of factors was investigated. These investigations led to the development of experiment designs and research plans for SPS-1 and SPS-2. During the same time, guidelines were developed for nomination and evaluation of candidate projects for SPS-5 (rehabilitation for asphalt concrete

TABLE 5.2. Evolution of the Specific Pavement Study experiment designs.

Original SPS Experiments	Changes Recommended	Were Changes Implemented?
<ul style="list-style-type: none"> Asphalt Concrete (AC) Subdrainage New Concepts for Flexible Pavements Portland Cement Concrete (PCC) Subsurface Drainage High-Strength PCC PCC Shoulder Design PCC with Non-Erodible High-Strength Bases New Concepts for Rigid Pavements 	<p><i>Structural Factors</i></p> <ul style="list-style-type: none"> Study structural factors for flexible and rigid pavements. 	<p>Yes. Resulted in two experiments:</p> <ul style="list-style-type: none"> SPS-1: Strategic Study of Structural Factors for Flexible Pavements. SPS-2: Strategic Study of Structural Factors for Rigid Pavements.
<ul style="list-style-type: none"> AC Preventive Maintenance PCC Preventive Maintenance 	<p><i>Preventive Maintenance</i></p> <ul style="list-style-type: none"> None. 	<p>No. Preventive maintenance studies were given specific names:</p> <ul style="list-style-type: none"> SPS-3: Preventive Maintenance Effectiveness of Flexible Pavements. SPS-4: Preventive Maintenance Effectiveness of Rigid Pavements.
<ul style="list-style-type: none"> AC Hot Recycling AC Cold Recycling Pretreated Jointed Concrete Pavement (JCP) with AC Overlay PCC Retrofit Shoulder PCC Restored JCP 	<p><i>Pavement Rehabilitation</i></p> <ul style="list-style-type: none"> Hot Recycling of AC. Restoration and Overlay of Jointed PCC Pavement. Bonded PCC Overlay of PCC Pavement. 	<p>Yes. Resulted in three experiments:</p> <ul style="list-style-type: none"> SPS-5: Rehabilitation of AC Pavements. SPS-6: Rehabilitation of Jointed PCC Pavements. SPS-7: Bonded PCC Overlay of PCC Pavements.
<ul style="list-style-type: none"> AC Environmental Distress PCC Environmental Distress AC Low-Volume Roads 	<p><i>Environmental Factors</i></p> <ul style="list-style-type: none"> Study environmental effects on pavements under light loads. Each test site location to include two flexible and two rigid pavement sections. 	<p>Yes. Resulted in one experiment:</p> <ul style="list-style-type: none"> SPS-8: Study of Environmental Effects in the Absence of Heavy Loads.
<ul style="list-style-type: none"> AC Load Equivalence Factors PCC Load Equivalence Factors 	<p><i>Load Equivalencies</i></p> <ul style="list-style-type: none"> None. 	<p>No. At the time, separating traffic to study true load equivalencies was impractical, so the experiment was not considered beyond the conceptual phase in spite of the perceived relative importance of the result.</p>

pavements), SPS-6 (rehabilitation of jointed concrete pavements), and SPS-7 (bonded PCC overlays). Ultimately, a suite of guidelines was developed—for nomination and evaluation, data collection, material sampling and testing, and construction—for each of the SPS experiments.

Concurrent with the development of the LTPP GPS and SPS experiments, the asphalt research area under SHRP was developing the Superpave® mix design method. Once the method was developed and ready for field implementation, it was deemed prudent to study the performance of the new mix designs

in the field in controlled experiments. In the 1990s, the SHRP Asphalt Research Group worked with the LTPP program to develop an SPS experiment (SPS-9: Validation of Strategic Highway Research Program Asphalt Specification and Mix Design (Superpave®)) for the long-term study of performance of the Superpave mixtures. This experiment design included placement of three test sections: a control section using the highway agency’s normal mix design, a section with a Superpave mix designed for the climate in question, and a section with a Superpave mix designed one grade lower than optimum. The Superpave proj-

AGENCIES' USE OF SUPPLEMENTAL SPS TEST SECTIONS

Many highway agencies chose to construct supplemental sections on SPS projects. Recognizing the value of consistent long-term monitoring on these sections, a variety of approaches were taken in their design. For example, many agencies used their standard mix design and structural section on the pavement adjacent to the 12 core sections on an SPS-2 project to compare the performance of their standard practice with that of the core sections.

The Arizona Department of Transportation took this strategy a step further and constructed nine supplemental sections that examined alternative joint configurations, structural sections, and even pavement types. The department is currently studying the performance, after 20 years, of the supplemental

sections relative to each other and to the core sections—recognizing that all 21 sections are still in the study and there is more to be learned going forward.

Typical variations between the core sections and supplemental sections involve changing material properties, structural thicknesses, and design properties (e.g., lane width). In another example of supplemental sections, several States in the western part of the country—Arizona, California, Colorado, Nevada, and Utah—collaborated on a study of joint sealants as part of the SPS-4 experiment. This study included more than 100 supplemental sections. As future SPS projects are constructed, the opportunity to include supplemental sections is an excellent incentive for participation on the part of highway agencies.

ects were both new construction and rehabilitation projects that covered an array of asphalt aggregate mixture specifications and were recruited consistent with the methods used to find sites for the other SPS experiments.¹⁶ The data were collected as part of the LTPP program and stored in the database.

Supplemental SPS Test Sections

Unlike the GPS test sections, highway agencies were permitted to construct supplemental sections for all SPS projects, in addition to the core experimental sections to monitor factors specific to their agency. Two such examples are described in the sidebar. Data from these supplemental sections are collected as part of the LTPP program and included in the database.

RECRUITMENT AND SELECTION OF SPS TEST SECTIONS

Recruitment of sites for the SPS test sections was even more involved than for the GPS sections. For the SPS experiments, the test sections were to be constructed, meaning that suitable projects and a commitment from

the highway agency to incorporate special provisions for construction into a planned project had to be obtained. The SPS sections also differed in that each SPS project incorporated several test sections at a location. Given the complexity of the studies and the importance of the results, intensive planning was required. Because of these requirements, and because agencies must work construction activities into their existing programs, some SPS projects were constructed as late as 2000.

Although the SPS experiments had been generally defined, construction details had not been finalized to the point that construction documents could be developed from them. A series of national meetings was held in the late 1980s to obtain input from all of the involved partners and to develop draft construction guideline documents for each of the high-priority SPS experiments: SPS-1, -2, -5, and -6. (The final guidelines are listed in table 9.1.) These particular experiments were considered high priority because they were new sites with specific design and construction criteria to meet a particular research need for the LTPP program. The other LTPP experiments were just as important to the overall goal of the program, and were equally impor-

tant in meeting the program's objectives. SHRP program staff and the LTPP technical assistance contractor gathered all of the input and worked this information into comprehensive construction guidelines that highway agencies could use to develop project plans. These documents also served as the basis for the project recruitment guidelines, since they essentially outlined project needs. The guidelines generally covered nomination and evaluation, data collection, materials sampling and testing, and construction. The guidelines also provided clear instruction for field activities and data forms for recording required information through the site evaluation and construction process. An example of an SPS test section layout for SPS-1 and -2 is shown in figure 5.5. It is important to note, however, that the number of test sections monitored for other SPS experiments may differ from what is shown.

The other SPS experiments that were new construction included SPS-8 (environmental factors in absence of heavy loads) and some SPS-9 sites. SPS-3 and -4 were maintenance studies of flexible and rigid pavements, respectively, and SPS-7 and some SPS-9s were overlays. All of these experiments followed a similar but less restrictive process of nomination and construction than the high-priority SPS experiments. On the high-priority sites, deviations from the design and construction guidelines were not permitted.

The project nomination and screening process was organized and methodical, designed to select the best candidates for study from the available construction projects. Test section locations were to be selected to minimize or avoid altogether transitions from cut to fill or unusual variations in distress along the project length. On ramps, off ramps, or other traffic generators were also to be avoided. With these and other considerations to be met, selection of projects became a challenging task. Still, in the end, recruitment and selection efforts resulted in a majority of the required experiment design needs being filled.

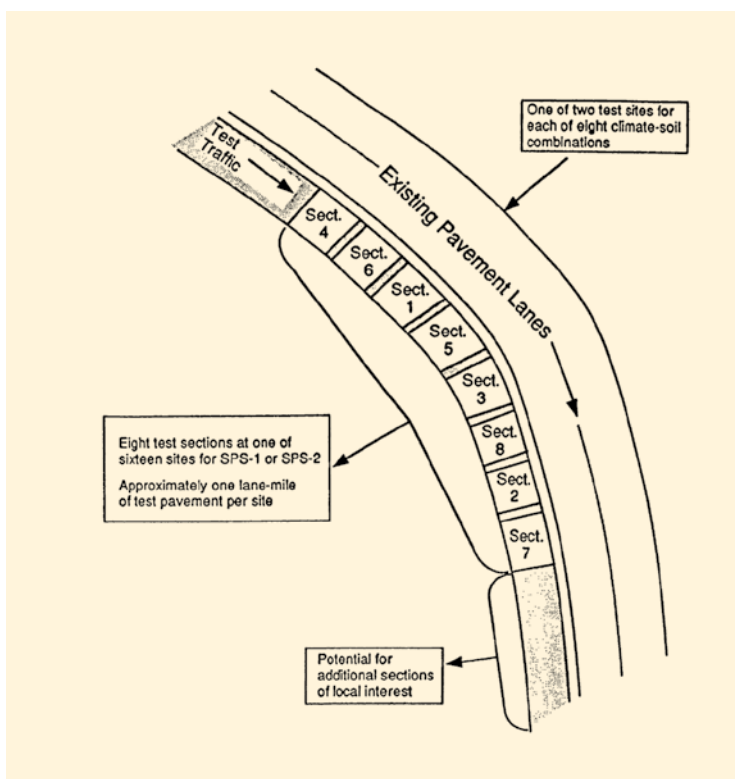


FIGURE 5.5. Test section layout for SPS-1 and SPS-2 projects (Strategic Studies of Structural Factors for Flexible and Rigid Pavements, respectively).¹⁷

In response to feedback from highway agencies regarding concerns about increased costs for items such as traffic control needed during field testing, collection of traffic data, and costs associated with more detailed materials testing, FHWA agreed to monetary incentives for agency participation in the construction of SPS projects. Agencies were provided \$50,000 for each SPS-1 or SPS-2 project they constructed and \$35,000 for each SPS-5 or SPS-6 project they constructed. The roles and responsibilities of the highway agencies had to be understood and agreed to, as part of the data collection requirement fell on their shoulders (mainly materials testing and monitored traffic data collection).

With all of these pieces in place, highway agencies started the process of identifying projects best suited to the construction for the SPS test sections. This process was a slow one, starting in about 1989 and ending in about 2000. Suitable projects were identified, construction plans developed and altered to include the

TABLE 5.3. LTPP General and Specific Pavement Study experiments.

General Pavement Study (GPS) Experiments	Specific Pavement Study (SPS) Experiments
GPS-1 Asphalt Concrete Pavements on Granular Base	SPS-1 Strategic Study of Structural Factors for Flexible Pavements
GPS-2 Asphalt Concrete Pavements on Bound Base	SPS-2 Strategic Study of Structural Factors for Rigid Pavements
GPS-3 Jointed Plain Concrete Pavements	SPS-3 Preventive Maintenance Effectiveness of Flexible Pavements
GPS-4 Jointed Reinforced Concrete Pavements	SPS-4 Preventive Maintenance Effectiveness of Rigid Pavements
GPS-5 Continuously Reinforced Concrete Pavements	SPS-5 Rehabilitation of Asphalt Concrete Pavements
GPS-6 Asphalt Concrete Overlay of Asphalt Concrete Pavements	SPS-6 Rehabilitation of Jointed Portland Cement Concrete Pavements
GPS-7 Asphalt Concrete Overlay of Portland Cement Concrete Pavements	SPS-7 Bonded Portland Cement Concrete Overlay of Portland Cement Concrete Pavements
GPS-8 Bonded Portland Cement Concrete Overlay (discontinued, later replaced by SPS-7)	SPS-8 Study of Environmental Effects in the Absence of Heavy Loads
GPS-9 Unbonded Portland Cement Concrete Overlay of Portland Cement Concrete Pavements	SPS-9 Validation of Strategic Highway Research Program Asphalt Specification and Mix Design (Superpave®)
	SPS-10 Warm-Mix Asphalt Overlay of Asphalt Pavements (2014)

test sections, and specifications developed for pay items not part of normal agency practice (e.g., permeable asphalt-treated base).

Construction coordination frequently involved participation of the LTPP regional coordination office contractor in a pre-construction meeting with the agency staff and its contractor to discuss the importance of the experimental test sections and adherence to the plans and specifications. Agreement also had to be reached on the function of the LTPP regional coordination office contractor staff on site, typically during the construction process, to monitor the progress and record key pieces of information during construction. In many ways this was a difficult process for highway agency construction contractors to understand, and success depended on their, as much as the agency's, understanding and accepting the requirements.

The need for monitoring of the original SPS experiments continues into the future. In addition, the LTPP program is adding new SPS experiments to address 21st century pavement needs, such as warm-mix asphalt concrete (SPS-10) and the monitoring of pavement preservation treatments.

LTPP EXPERIMENTS AND TEST SECTION LOCATIONS

The new experiments that were ultimately designed for the program are listed in table 5.3. The test sections cover a broad spectrum of pavement types. The even-

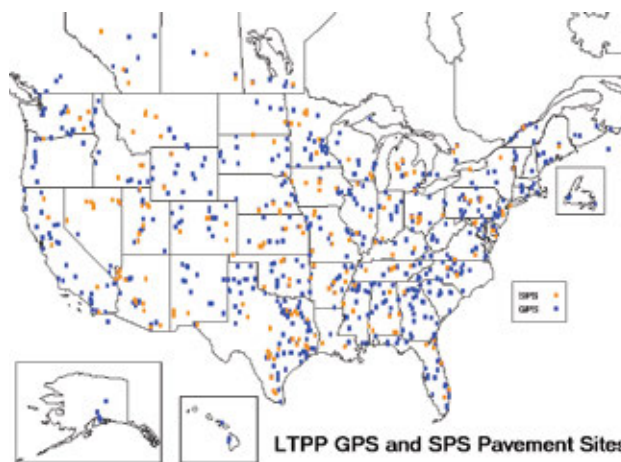


FIGURE 5.6. Locations of the 2,509 pavement test sections across the United States, Puerto Rico, and Canada: 791 in the General Pavement Studies (GPS) and 1,718 in the Specific Pavement Studies (SPS) over the course of the LTPP program. In 2014, 372 GPS and 360 SPS test sections were still being monitored.

tual distribution of test sections across the United States and Canada, including Puerto Rico and the District of Columbia, is shown in figure 5.6.

SUMMARY

Establishing the LTPP experiments and selecting the appropriate test sections was not an easy task for those involved. However, the data that have been collected and the results obtained, as will be discussed later in

this report, have been worth the effort. The careful planning, close collaboration among the LTPP program, highway agencies, industry, and contractor staff, and careful attention to the design details of the experiments have resulted in a sound research program that continues today. The following chapter covers the types of data collected at the LTPP test sections, the collection methods, and the equipment and instrumentation used since the beginning of the program.

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The challenge in LTPP data collection is to capture research-quality data of diverse types using highly specialized, state-of-the-art equipment with the involvement of many people across different geographical areas.

6

Collection of the LTPP Data

Since 1989, millions upon millions of discrete data have been gathered and collected from pavement test sections across North America by highway agency personnel and the LTPP program through its contractor staff using a myriad of methods and equipment. The procedures and equipment used in the collection process were subject to careful planning and systematic quality controls designed to ensure that the data would be as consistent, comparable, and useful as possible for future research.

INTRODUCTION

LTPP data collection focuses on understanding the performance of pavements from a mechanistic engineering perspective—the attempt to define a structure’s performance by modeling the factors that lead to performance degradation and the need for maintenance, rehabilitation, or reconstruction. Figure 6.1 illustrates the relationships between data collection categories for mechanistic-based pavement performance modeling. Climate and traffic loading are two primary factors affecting a pavement structure’s performance. Climate affects mainly the properties of the materials contained in the pavement structure. Traffic loads are directly supported by the pavement structure. Traffic loads and climate create responses in the materials contained in the pavement structure

and subgrade that lead to various forms of distress. The data collection design for the LTPP program aims to measure, characterize, and quantify the factors that explain how and why a pavement performs as it does.

Providing high-quality data is of paramount importance to the LTPP program. Thus, collecting data with careful quality control/quality assurance (QC/QA) processes in place has been and continues to be a primary focus of the program (chapter 9). This chapter describes the development of LTPP’s data collection procedures. The key data collection activities that have been adopted and continuously refined over the course of the program are the following:

- Maintaining data collection procedures, guides, and protocols.

Key Milestones in Data Collection

1987	First edition of <i>Distress Identification Manual</i> published	2003	GPR study of SPS test section layer thicknesses conducted
1987	Inventory data collection begins	2003	FWD maintenance and overhaul manual developed
1988	First manual distress survey performed	2004	FWD Calibration Center and Operational Improvements Pooled-Fund Study initiated
1988	First FWD equipment purchased	2005	GPS data updated for test sites, weather stations, and weigh-in-motion scales
1989	FWD Operational Field Guidelines published	2008	Automated Weather Station data collection phase-out begins
1989	FWD data collection begins	2009	LTPP protocols adopted for AASHTO FWD calibration standard
1989	First inertial profiling equipment purchased	2010	Operation of FWD calibration centers transferred to AASHTO MRL
1989	First automated distress surveys (PASCO) performed	2011	FWD calibration protocol updated
1991	First FWD calibration protocol published	2013	FWD equipment and software upgraded
1991	First manual distress workshop conducted	2013	Profiling equipment and software upgraded
1992	First FWD calibration center opens	2013	Climate data upgraded
1992	Climate data collection begins	2014	Fifth edition of <i>Distress Identification Manual</i> published
1994	Automated Weather Station installations begin		
1994	Global Positioning System units purchased		
2001	LTPP SPS Traffic Data Collection Pooled-Fund Study initiated		

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- Ensuring that personnel in different geographic regions receive the same data collection and process training.
- Using properly maintained and calibrated state-of-the-art equipment.
- Training personnel to correctly use the equipment and meticulously follow procedures.
- Documenting problems to provide input, feedback, or answers for enhancing data collection efforts or for future data analysis work.
- Tracking all efforts to ensure that data are not lost nor efforts wasted and to allow steps to be retraced should issues develop.
- Checking, inspecting, and following up to ensure that data are of high quality.

Who Collects the Data?

The data collection processes have involved both the highway agencies and the LTPP program's contractors. The highway agencies agreed to collect the materials and traffic data as well as friction data. In some cases, the highway agencies were not able to provide all of the data needed by the LTPP program to perform critical data analysis projects or studies. Therefore, the program initiated special data collection efforts such as the Materials Action Plan and the LTPP Specific Pavement Study Traffic Data Collection Pooled-Fund Study to collect these critical data elements (chapter 7). The remaining pavement-related data were collected by LTPP's contractor staff: regional support contrac-

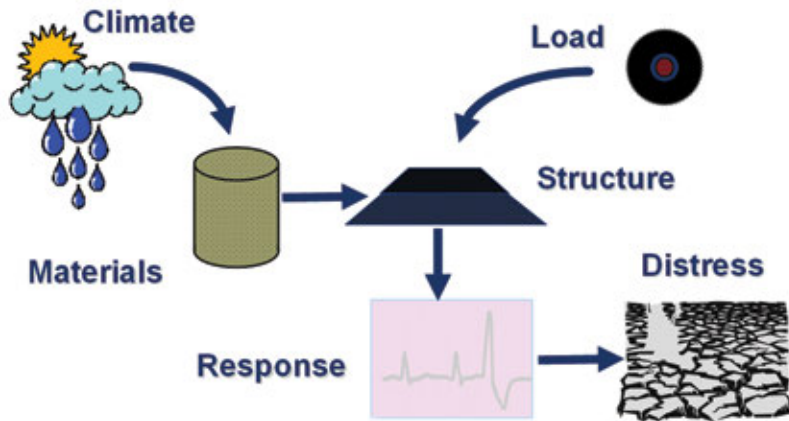


FIGURE 6.1. LTPP data collection categories.

tors, the technical support services contractor, equipment vendors, and service contractors.

Data QC was integral to data collection activities. Each regional support contractor is required to have a Quality Control Plan and Working Guide covering all aspects of data collection and review. The plan must be implemented and maintained. Through the years, the LTPP program has managed quality issues using various mechanisms such as unannounced field or office visits to observe data collection and processing procedures, conference calls, Data Analysis and Operations Feedback Reports, Operational Problem Reports, and Software Problem Reports.

What Types of Data Are Collected?

The different data types described in this chapter are collected at both the General Pavement Study (GPS) and Specific Pavement Study (SPS) experiments with few exceptions. Early in the LTPP program, most of the data elements were collected annually. However, as the funding levels for the program were reduced, the frequency of data collection was reduced.^{1,2} Some data elements have been collected more frequently for certain LTPP experiments, but nearly all of the experiments have annual monitoring data (e.g., distress, deflection, profile) in addition to inventory, and maintenance and rehabilitation data. These data elements are stored in the LTPP database in tables that are organized by modules, listed in table 6.1.

The source, type, method of capture, quality, and quantity of the different data elements are quite varied. With the exception of the Administration module, which contains no performance-related data and therefore is not discussed here, the remainder of this chapter describes each of the LTPP database modules and its associated data element(s).

It is important to mention that LTPP data are also used to develop special data sets. One example is the Mechanistic-Empirical Pavement Design Guide (MEPDG) data sets, used by highway agencies to calibrate the design models for their local pavement conditions. The MEPDG data sets, which are part of the Traffic data module, are computed data. Nearly all of the LTPP data modules have computed data—not collected or measured data—such as dynamic load response data, falling weight deflectometer backcalculation, and equivalent single-axle load values. Also, the SPS data module actually refers to inventory data for the SPS projects (as discussed later in this chapter).

TABLE 6.1. LTPP database modules (circa 2014).

Database Modules
Administration (ADM)
Automated Weather Station (AWS)
Climate (CLM)
Dynamic Load Response (DLR)
Ground Penetrating Radar (GPR)
Inventory (as-built) (INV)
Maintenance and Rehabilitation (MNT and RHB)
Materials Testing (TST)
Monitoring (MON)
• Deflection (MON_DEFL)
• Distress (MON_DIS)
• Drainage (MON_DRAIN)
• Friction (MON_FRICTION)
• Profile (MON_PROFILE)
• Rutting (MON_RUT)
• Transverse Profile (MON_T_PROF)
Seasonal Monitoring Program (SMP)
Specific Pavement Studies (SPS) Inventory
Traffic (TRF)

Data collection for the LTPP program aims to measure, characterize, and quantify the factors that explain how and why a pavement performs as it does. Consequently, data collection was established to support the envisioned data analyses and product development.

AUTOMATED WEATHER STATION DATA

Automated weather station (AWS) data collected from the LTPP test sections include site-specific weather information: air temperature, humidity, precipitation, solar radiation, wind direction, and wind speed. To understand the influence of various environmental conditions on the performance of a specific type of pavement, one must first learn what those conditions are.

Weather stations with remote data collection capabilities were installed at newly constructed SPS-1 (structural factors for flexible pavements), -2 (structural factors for rigid pavements), and -8 (environmental effects in the absence of heavy loads) projects. At some locations, particularly in Delaware, Nevada, Ohio, and Wisconsin, multiple SPS projects were located within a short distance of each other, reducing the number of weather stations required. Thus, it was cost beneficial to install a single AWS at these study sites.

The weather stations collected data at 15-minute intervals: air temperature, relative humidity, precipitation, solar radiation, and wind speed and direction. These data were accumulated into hourly, daily, and monthly statistics. Measurements began in August 1994 and continued through December 2008, with the start and end of data collection varying from one weather station to another. The automated weather stations were also intended to validate the data from the virtual weather stations (discussed in the climate data section).

Before data collection began, a review of commercially available weather stations was conducted, after which a Campbell Scientific, Inc. (CSI) unit was selected

and installed on the grounds of the Federal Highway Administration (FHWA) research center for further evaluation. During the evaluation period, the LTPP technical support services contractor developed an automated weather station manual covering the installation of the weather stations, data collection, and maintenance.³ The initial training for installation occurred near Phoenix, Arizona, in July 1994. In September 1994, the LTPP program issued a directive (a written communication circulated program-wide to ensure uniformity in data collection) for its contractors to follow that described the installation, data collection, and maintenance activities required for the weather station.⁴ As weather station activities changed, the program issued subsequent directives to update procedures and complement or change instructions provided in the AWS Installation and Data Collection Guide.⁵ These directives covered such topics as parts replacement, sensor calibration, remote data collection, and preventive maintenance plans.

The weather instrumentation and equipment were centrally purchased by FHWA and shipped to the LTPP regional support contractors to install at the SPS sites. In addition to providing the instrumentation, the LTPP program also performed the data collection and maintenance activities through the regional support contractor staff. The highway agency sponsoring the site provided the concrete pad for the weather tower, the tipping bucket base, and compound fencing (figure 6.2). In most cases, telecommunication and



FIGURE 6.2. Complete automated weather station installation with protective fencing.

power costs were assumed by the highway agency. See appendix C for more information on the type of AWS equipment and software used to collect, store, and process the weather data.

AWS Maintenance Issues

Maintenance became a major issue for the weather stations. One of the problems encountered at the weather stations was the tipping buckets would become clogged with various types of debris. Similarly, the relative humidity probe filter would become plugged, retain moisture, and provide false high readings. Remote access was often an issue, as the modems used to connect the dataloggers with the LTPP regional support contractor's office computers were prone to lightning damage. The onsite storage modules were also prone to data retrieval problems that required returns to the office for data extraction.

Site visits were needed more frequently than had been anticipated. Maintenance was performed on the weather stations every 2 years, and exchange of instrumentation was part of the maintenance procedure. In addition, when collecting other LTPP data elements at a site, the regional support contractors visited the weather stations to inspect the equipment and perform minor maintenance (such as unclogging a tipping bucket rain gauge). However, at some locations, the highway agencies assisted with minor maintenance. Any instrumentation that needed to be returned to the regional support contractor's office was checked for accuracy using the manufacturers' guidelines. Out-of-tolerance instruments were either calibrated in-house (figure 6.3) or returned to the manufacturer for calibration. Most of the regional support contractors purchased equipment and spare parts for servicing the tipping bucket rain gauges and the wind monitors, but preferred to return the relative humidity/air temperature probe units and pyranometers to the vendor for calibration. In addition to maintaining the instrumentation, there was often a need to service the dataloggers, storage modules, and modems or to replace batteries.

AWS Quality Control Programs

Two DOS-based programs were developed to check the quality of the AWS data. The first was AWSScan, which performed basic data checks in the field includ-



FIGURE 6.3. Prototype automated weather station used by the LTPP regional support contractors for in-house training of staff and to calibrate equipment components.

ing range, time-series consistency, and required data elements. One of the key functions of the AWSScan program was to make sure the measurement equipment was operating properly and alert the field technician to potential issues that could be corrected in the field. AWSScan was used at the time data were being downloaded, whether onsite or remotely. The second program, AWSCheck, was developed for office processing purposes and was used to combine raw data files, edit/remove invalid data, allow for time stamp corrections (that correspond with standard/daylight saving time), view additional graphical outputs for time-series consistency and logical ordering of climate statistics (i.e., maximum \geq average \geq minimum), generate upload files for entry into the LTPP database, recompute daily statistics when bad hourly measurement values were deleted, and replicate the QC checks that would be performed after the data had been uploaded

into the database. The time stamps needed adjustment because the time in the dataloggers did not change with standard/daylight saving time. All of the AWS data in the database are in local time (based on the location of each station's time zone). User guides for AWSScan and AWSCheck were developed in 1995 and 1996, respectively.⁶

Decision to Decommission AWS

The LTPP automated weather stations received regular maintenance and instrumentation replacement at 2-year intervals until 2006, when the decision was made to continue servicing only those stations that could be maintained with minimal investment of time and expenditure. As stations started to require maintenance due to component failure, they were dismantled or turned over to the respective highway agencies. Phase-out was completed in December 2008, and all sites were decommissioned. At the conclusion of the AWS data collection activities, 9 to 13 years of weather data had been collected from the SPS-1, -2, and -8 projects and stored in the LTPP database.

CLIMATE DATA-VIRTUAL WEATHER STATIONS

Unlike the AWS data which cover detailed data for a subset of the LTPP test sections, the climate data—precipitation, temperature, wind, and humidity—cover all test sections. The climate conditions at the GPS and SPS test sites have been obtained from the United States National Climatic Data Center (NCDC) and the Canadian Climate Center (CCC). The climate module includes data from both operating weather stations and “virtual” weather stations. However, efforts are underway to improve the coverage, completeness, and quality of the LTPP climate data through the use of Modern Era-Retrospective Analysis for Research and Applications (MERRA)⁷ data from the National Aeronautics and Space Administration (NASA). These efforts are still ongoing, and hence the focus of this section is on the legacy approach that relied on NCDC and CCC data.

Because the LTPP test sites were not typically co-located with operating weather stations, it was necessary to extract data from nearby operating weather stations and, using a distance-weighted averaging function, create virtual weather statistics for each LTPP test site. One of the first steps in creating a virtual (i.e., statistical) weather station was to identify up to five operating weather stations (see example in figure 6.4) that met the following criteria in the order listed:

1. Type of station, first order stations being preferred over cooperative stations.
2. Operating weather station(s) coverage time period relative to the pavement test section construction date.
3. Distance between the test site and operating weather station(s).
4. Elevation difference between the test site and operating weather station(s).
5. Location of mountains.
6. Microclimate effects.

In the early years of the program, the services of a climate specialty contractor were used to obtain NCDC and CCC data, perform initial weather station selection based on the above criteria, and provide daily data from the operating weather stations to the LTPP program in ASCII format. Subsequent processing created the daily, monthly, and annual summaries for the virtual weather stations.



FIGURE 6.4. A virtual weather station (VWS). This example shows the locations of five operating weather stations used to create the VWS for GPS section 831801 on Trans-Canada Highway 1 in southwestern Manitoba.

(Source: Esri, Digital Globe, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, and the GIS User Community; created in ArcGIS 10.1)

The climate data provided by the LTPP program are “computed parameters.” In other words, they are estimates derived from measured values. Daily statistics (temperature, rainfall, wind speed, and humidity) are obtained from the operating weather stations and subjected to range and logic checks as defined in the LTPP QC Manual.⁸ Only data passing all data checks are used to compute the daily virtual weather station statistics. The daily statistics are aggregated into monthly and annual statistical summaries. Automated QC checks are performed on the monthly and annual statistics to verify reasonable ranges and logical relationships.

The last update of the climate data was performed in 2013 and included data through 2012, the most up-to-date data available at the time. This update used the raw data collected from the NCDC and CCC. The LTPP program has also incorporated into the Climate module data from NASA’s MERRA project, which provides much finer spatial resolution and offers more data elements that can be implemented without the use of virtual weather station interpolation concepts.

DYNAMIC LOAD RESPONSE DATA

The LTPP database contains data that measure the pavement response under controlled loading conditions for two SPS projects. These data, known as dynamic load response or DLR data, were collected in North Carolina and Ohio from 1996 to 1997.

In North Carolina, four Portland cement concrete (PCC) pavement sections at the SPS-2 project were instrumented to collect DLR data. In Ohio, asphalt concrete (AC) and PCC pavement test sections from the SPS-1 and SPS-2, respectively, were instrumented to monitor the DLR of vehicles with known weights.

Three types of instrumentation were installed at the project sites:

- Instruments to measure pavement response including vertical displacements, vertical pressures, and strains at selected locations within the pavement structure.
- Instruments to collect environmental data such as temperature with depth, moisture content of the various pavement layers, water table depth, and

frost/thaw depth (i.e., the same subsurface moisture and temperature equipment installed at the LTPP test sections making up the Seasonal Monitoring Program (SMP)). The only LTPP test section instrumented with environmental condition sensors was test section 370201 in North Carolina.

- Instruments to collect air temperature, precipitation (rain and snow), wind speed, wind direction, relative humidity, and incoming solar radiation as described in the section on AWS.

Thus, at each project site, a comprehensive set of data was collected—DLR measurements within the pavement and on the pavement surface, subsurface moisture and temperature conditions, and ambient conditions.

Results of the DLR initiative are discussed in *LTPP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements*.⁹ The North Carolina DLR data are included in the LTPP database. An update and reinterpretation of the DLR data collected between 1996 and 1997 from the SPS-1 and -2 sites in Ohio were made available in the LTPP database starting in 2013.

GROUND PENETRATING RADAR DATA

Pavement structure is one of the four primary factors whose separate and combined effects influence the performance of a pavement. To understand how pavement thicknesses vary along LTPP test sections, which are generally 500 ft (152 m) long, ground penetrating radar (GPR) measurements were performed on a subset of LTPP test sections. GPR is a nondestructive technique based on reflection of radio waves transmitted in the ground to determine subsurface changes in material properties. For pavement applications GPR is typically used to determine the thickness of pavement layers and the dielectric constant of paving materials. Among other potential applications are detection of subsurface voids and moisture concentrations.

The primary interest in GPR technology by the LTPP program was to measure pavement layer thicknesses. In 1994, a study of 10 GPS LTPP asphalt test sections in the southern and eastern United States concluded that GPR could be used to accurately character-

ize asphalt thickness.¹⁰ In 2002, the LTPP program initiated plans to collect GPR measurements on all SPS-1 test sections and at 1 jointed plain concrete pavement section at the Arizona SPS-2 site, 10 AC overlay sections at the Oklahoma SPS-5 (rehabilitation of AC pavements) site, and 5 test sections at the Oklahoma SPS-6 (rehabilitation of jointed PCC pavements) project site. Nineteen SPS sites consisting of multiple test sections were surveyed in 17 States within a 6-week timeframe in 2003.¹¹

To ensure the collection of high-quality data, GPR measurements took place only on dry pavement surfaces. GPR data were collected along both wheelpaths at posted highway speeds. To precisely locate the GPR data for each pass, a photo-reflective laser switch, mounted to the rear of a survey vehicle, transmitted and received a signal pulse from polarized reflectors set up along each test section. These position pulses were automatically recorded in the GPR data files for each pass. The depth of the AC, treated base, and aggregate layers can be shown in a GPR report.

Only the interpretations of the GPR data from the 2003 measurements were included in the DLR module in the LTPP database; data from the 1994 study were not included. While no report on the findings from the 2003 GPR measurements was published, the LTPP program did not implement GPR measurement technology as a routine pavement measurement device on LTPP test sections.

INVENTORY DATA

Inventory data include location (e.g., latitude, longitude, state, county, route, milepost) of the test section, pavement type, layer thicknesses and types, material properties, composition, previous construction improvements, and other background information. Inventory information was collected for all GPS test sections and for SPS sections originally classified as maintenance and rehabilitation experiments. The inventory data in the LTPP database are supplied by the State and Provincial highway agencies. Structural information, such as shoulder width and milepost, was derived from highway agency project records or measurements taken at the test sections by the LTPP program. The inventory data includes:

- Location information that identifies the test section.
- Site information from the time of construction (or rehabilitation) such as the composition and temperature of the paving mixture, aggregate and cement properties, and ambient conditions; joints, reinforcement, compaction, strength, drainage features; properties of the subgrade and base; completion and opening dates; and other characteristics of the pavement at the time of construction or rehabilitation.
- Geometric details of the test section.
- Initial cost data for the construction or maintenance of the section, as well as information on snow and ice control.

Inventory data collection began in 1988 and continues with the inclusion of the latest LTPP experiments (warm-mix asphalt and pavement preservation experiments). Because some inventory data were incorrect or missing, various efforts have been undertaken to collect or correct the missing data. This was the case with the Program Assessment and Improvement Campaign in the mid-1990s, which looked at the availability of data for the LTPP test sections (chapter 11). The regional support contractors have worked very closely with the highway agencies to collect this information, and they continue to obtain inventory data from highway agencies whenever a maintenance or rehabilitation activity occurs at a test site. The inventory data module contains structural and location data for each LTPP test section, which are discussed below.

Structural Data

Collecting the structural data (layer types and thicknesses) presented challenges. Significant time and effort were needed to process huge amounts of data onto forms. Highway agencies often did not have the resources (staff, time, or funds) to locate data and complete data forms. Some data elements had not been collected by agencies, and some historical data had been discarded over time and were no longer available.

The LTPP program worked with the highway agencies to retrieve as much data as possible. Some agencies sent all of their data to the LTPP regional support contractor, who completed the required forms for the agencies. In other cases, the regional

support contractors visited agencies to help collect data and complete the LTPP forms.

Agency data were not necessarily representative of the test sections—the data covered highway lengths of from 1 to 10 mi (1.6 to 16.1 km) while the LTPP sections were only a 500-ft (152-m) segment of that distance. Data had to be processed to determine a “best fit” scenario for LTPP use.

Location Data

The purpose for this data element was to establish accurate location information for every LTPP test section using maps, satellite technology, and other methods. The effort began with the agencies collecting latitude and longitude coordinates, and elevation data. After some initial investigations, discrepancies were found; for example, some data had been interpolated from maps that were only approximations of accurate measurements.

In 1994, first-generation Garmin® Global Positioning System units were purchased, and a new inventory form was developed to collect data onsite.¹² Around 2001, newer generation global positioning units were acquired, as the technology had improved dramatically. Magellan® global positioning tracking devices were used. Then, in 2005, updated coordinates were collected from pavement test sections using modern global positioning system receivers.¹³ A test section’s coordinates were also collected for AWS and weigh-in-motion (WIM) scale installations. The Garmin eTrex® Global Positioning System receiver (GPSr) with trip and waypoint (Model Legend C) was employed for this purpose. Data were typically collected by the LTPP regional support contractors, coinciding with manual distress surveys. Measurements were verified by comparing the coordinates with previous measurements and plotting the locations on digital maps. In cases where field measurements could not be performed, up-to-date mapping software (MapSource® 6.0 or Google Earth™ mapping service) was used. Measurements and location estimates were based on the World Geodetic System 84 datum. The original latitude, longitude, and elevation data were replaced with the new and more accurate data, which are stored in the LTPP database.

In 2007, the global positioning component of the location data was moved from the Inventory module and placed in the Administration module. Accurate global positioning coordinates are now available for all LTPP sites. In 2013, the LTPP program began collecting location data using the new GPSr equipment connected to the falling weight deflectometer and profile units.

MAINTENANCE AND REHABILITATION DATA

The maintenance and rehabilitation data tables in the LTPP database have been consolidated in a single module. The maintenance tables contain information about treatments—seal coats, patches, joint resealing, grinding, milling less than 25 mm (1 inch), and grooving—applied to test sections after (and in some cases before) the section’s inclusion in the LTPP program. The rehabilitation tables contain information on resurfacing, reconstruction, joint repair, and similar activities, which typically alter pavement structure.

Maintenance Data

Maintenance-type treatments that are reported by highway agencies and stored in the LTPP database include thin surface treatments, crack sealing, joint sealing, and patching performed on in-service test sections. Obtaining the data elements that are needed to accurately and completely document maintenance activities performed on GPS and SPS test sections has been a challenge throughout the LTPP program. This effort has been complicated by the wide variations in maintenance policies, practices, and data collection procedures among agencies, and the need for coordination between the agencies and the LTPP program.

LTPP maintenance data document surface treatments that do not change pavement structure—seal coats, crack sealing, patching, joint sealing, grinding, grooving, and shallow milling.

The highway agencies were asked to follow a maintenance policy that required coordination with the LTPP regional support contractor responsible for data collection at sections located within their State or Province. Through this coordination and advanced notification that a maintenance activity is scheduled to take place, the value of the data obtained from a test section after it had been monitored for a number of years would be increased significantly because a set of performance data could be obtained prior to and after the maintenance treatment. Maintenance decisions and agreements between each agency and the LTPP program were worked out with a cooperative spirit, with consideration for the needs of the agency. The agency was asked to provide all details of the maintenance activity on the LTPP maintenance data sheets to facilitate entry into the LTPP database.

Although this cooperative spirit existed between the highway agency and the LTPP program, on many occasions a maintenance activity was completed without the program's knowledge. As a result, the last data point before maintenance took place, which is critical to understanding a pavement's long-term performance, was not collected. Also, sufficient data were not always available to establish a new starting point for the LTPP section after maintenance took place. In these cases, the LTPP regional support contractor made every effort, working with the highway agency, to obtain the details of the maintenance activity that had been performed. These efforts included visiting agencies, searching through files and archives, and talking with staff who were at the job site when maintenance was performed. Often, further information was retrieved, but some maintenance data remain missing.

The collected maintenance data provide information such as when the activity was performed and the materials, construction equipment, and practices used. The following guides have been used in collecting the data: *Long-Term Pavement Performance Maintenance & Rehabilitation Data Collection Guide*;¹⁴ *Specific Pavement Studies, Data Collection Guidelines for Experiment SPS-3, Maintenance Effectiveness for Asphalt Concrete Pavements*;¹⁵ and *Specific Pavement Studies, Data Collection Guidelines for Experiment SPS-4, Maintenance Effectiveness for Portland Cement Concrete Pavements*.¹⁶ LTPP program directives also provide additional information.¹⁷

LTPP rehabilitation data document a change to the pavement's original structure.

Rehabilitation Data

Most rehabilitation procedures, such as recycling or placing overlays, produced a test section with a modified pavement structure. Other procedures, such as undersealing, were considered to restore the existing pavement structure. Reworking shoulders and placement of edge drains are other examples of improvements that could be made without changing the primary pavement structure.

Highway agencies were asked to notify the LTPP program whenever rehabilitation was planned, so that the condition of the pavement could be observed and recorded prior to the rehabilitation activity. They were also responsible for providing the program with information about the treatment.

The LTPP program had to ensure that all rehabilitation data were complete and processed promptly and thoroughly because these data were key to successful data analyses. In many cases, not all of the required information was provided to give a new starting point for the LTPP test section. More intensive searches on the part of the LTPP regional support contractors, as with maintenance data, yielded positive results. However, rehabilitation data for many LTPP test sections are still missing. Although this missing data can be added to the LTPP database if the highway agencies are able to provide it, the rehabilitation test sections where data continues to be lacking may provide little to no value for certain data analysis studies.

LTPP documents provide guidelines regarding when a section that had undergone rehabilitation could continue to be monitored by the program. These documents include the *Long-Term Pavement Performance Maintenance & Rehabilitation Data Collection Guide*,¹⁸ guidelines specific to SPS sections,¹⁹ and LTPP program directives.²⁰ Some of the rehabilitation treatment types caused a section to be removed from further study. Others resulted in the test section being moved to a new experiment. In some cases, there was overlap between SPS-5, -6, -7 (rehabilitation studies), and GPS-6 and -7 (overlays of AC and PCC) rehabilitation data. Some data for the SPS rehabilitation experiments are stored

in the maintenance and rehabilitation module and not in the respective SPS module. Access to these data has been streamlined in the new LTPP InfoPave™ system.

MATERIALS DATA

The LTPP database has materials sampling and testing information for all test sections. The primary objective for performing materials sampling and testing was to provide a comprehensive evaluation of the pavement layer structure and layer thicknesses of the pavement materials used in each section or project. The material testing data represent the condition of the material at the time of sampling and testing. The work was accomplished by core drilling, augering, test pit opening, sampling, and nuclear density testing, followed by performing a suite of laboratory material characterization tests (see sidebar, next page). To help with data collection, standard material sampling and laboratory testing protocols with data entry sheets were developed to record the data collected in the field and in the laboratory.

The GPS and SPS experiments followed different approaches to materials sampling. For GPS experiments, FHWA contracted out this task, and a drilling supervisor from the LTPP regional support contractor's office was responsible for QC. For SPS experiments, the highway agencies were tasked with the drilling. In addition, the sampling approach for each SPS experiment was different. A material sampling guide was prepared for the GPS experiments, and specific sampling guides were prepared for each of the SPS experiments.

The initial GPS Materials Sampling and Testing Guidelines were issued in May 1990²¹ and finalized in February 1991.²² A series of SPS Materials Testing and Sampling Guidelines was developed between November 1989 and February 1996. The Laboratory Testing Guidelines were finalized in May 1992, but a series of revisions was issued between October 1992 and September 2001. In 2007, the *Long-Term Pavement Performance Project Laboratory Materials Testing and Handling Guide* was issued.²³

For projects that received overlays that were still to be monitored by the LTPP the program, the agencies would obtain the materials with assistance from the

LTPP regional support contractors, who were responsible for getting the right materials to the right location for testing. The regional staff assisted the agencies' drilling crews during the sampling operations to ensure that the onsite sampling operations were completed accurately, efficiently, and safely. The safety of the operating crews as well as the traveling public was of the utmost importance.

Before going to each of the LTPP sites to collect samples, a formal plan was prepared indicating the sections, locations of the samples, and different layers that were to be collected from each location. The location numbers and sample numbers also needed to be defined. For each SPS project, a unique sampling and testing plan had been prepared before the project was constructed. The SPS experiment-specific guidelines provided the approach to be used in preparing the project-specific plans before, during, and after construction of the SPS sections. The advance planning ensured a smooth process of sample collection, labeling, wrapping, and transportation to the designated labs.

All samples collected were marked with a pen or labeled with a keel chalk immediately after sampling. Blue (AC samples), white (PCC samples), or yellow (granular material) labels were also prepared for each sample and taped or inserted inside the bag or the box where the sample was to be stored. Labels contained the State code and LTPP test section ID, sample location, sample number, sample date, and field set number.

While the core samples were set aside to dry, the regional staff measured and recorded the length of the cores and the quality of the samples before they left the site. Cores were also marked to indicate the direction of traffic. Once the cores had dried, they were wrapped with transparent plastic film and bubble wrap to prevent damage and packaged for shipment to the designated laboratories.

Materials data included information necessary to characterize the various layers of each test section. The testing was performed by highway agency laboratories and by laboratories contracted by FHWA. For example, a laboratory hired by FHWA performed all of the resilient modulus tests. In addition, the concrete laboratory at FHWA's highway research center performed the PCC coefficient of thermal expansion testing. Each laboratory has an ID number in the LTPP database.

MATERIALS SAMPLING AND STORAGE

Sampling Activities

Materials sampling activities are performed at the LTPP test sections using special equipment such as the dynamic cone penetrometer, shown below. The materials collected are tested in a laboratory, the data are stored in the LTPP database to provide information for pavement analyses, and the samples are stored in the Materials Reference Library (MRL).



Materials Reference Library

The MRL was created in the late 1980s under the Strategic Highway Research Program (SHRP) in Austin, Texas, to provide a central storage facility for asphalt cement and aggregate samples collected under the Asphalt Research program and for pavement and subsurface materials samples collected from the LTPP test sites across the United States and Canada. One of the facility's main objectives is to address a problem associated with the original American Association of State Highway Officials Road Test, conducted in Ohio in the 1950s, where there was a shortage of materials available for subsequent research.

In 1993, the FHWA-LTPP program took over management of the MRL facility and moved it from Austin, Texas, to Reno, Nevada. The MRL continues

to be managed by FHWA to store materials samples for the LTPP test locations. Over the years, other pavement research programs, such as the Asphalt Research Consortium, WesTrack, the FHWA Crumb Rubber Modifier Project, and the WesTrack Project have sent samples from their test sections for storage in the MRL. Materials from the research conducted at the National Center for Asphalt Technology and the Western Research Institute are also stored there.

The MRL stores over 1,000 tons of asphalt cement, Portland cement, natural aggregates, and combinations of these materials in both loose and core forms. In addition to storing the samples, the MRL maintains a temperature-controlled room to house photographic film records of distress collected from the LTPP test sites. Most of the materials at the MRL are from LTPP projects, including samples taken during construction of the SPS test sections. The materials samples have been used to support more than 30 national highway research projects. The samples enable the application of as-yet undeveloped test methods to LTPP materials, thereby enabling updates of the LTPP data to reflect new technologies. The MRL will continue to provide a common pool of materials for future research.

The samples are available to the public, and more detail is available at the MRL Web site (<http://192.186.205.27/ltppt/mrl>).



In the early stages of the LTPP program, all samples collected from GPS sites were sent to LTPP contractor laboratories to perform the required laboratory tests. Later, when an overlay was placed at a site, some of the cores were sent to the highway agency's laboratory for testing in addition to the LTPP contractor laboratory that ran resilient modulus tests on these cores.

The samples collected from the SPS projects before, during, and after construction were sent to both the agency lab for testing and to the LTPP contractor laboratory that ran resilient modulus testing and other tests. It is important to note that the quality of the SPS materials test data was always a concern for the LTPP program as testing was done by numerous laboratories (i.e., a different laboratory for each highway agency or, in many cases, agencies had more than one laboratory perform the testing). As a result, the LTPP program kept the option open to repeat some of the tests performed by the highway agencies. Some SPS projects were still missing materials data, as was discovered during an LTPP program assessment,²⁴ so the LTPP program developed a plan to collect this missing data. The details of the Materials Action Plan are described in the following chapter, Special LTPP Data Collection Efforts.

Just south of Winston-Salem in North Carolina, a pilot study was conducted to field test the Materials Sampling and Testing plan and the falling weight deflectometer protocol testing patterns. The pilot took place December 7, 1988, but due to a rare snow storm that hit Winston-Salem that day, the testing was completed on December 8. This GPS test section, 373807, was the first site where data were collected for the LTPP program. Officially, LTPP data collection began in 1989.

MONITORING DATA

The monitoring data module contains pavement performance information that is collected primarily by LTPP contractors. Since 1988, with the first materials and falling weight deflectometer data collected at LTPP test section 373807 in North Carolina, the LTPP program has been collecting distress, drainage, friction, rutting, and longitudinal and transverse profile data, with some exceptions. (Friction data were collected by the highway agencies and submitted to the program for inclusion in the LTPP database. The drainage data were collected by LTPP contractors for only a subset of LTPP test sections for a few months.) More information about each data type is discussed in this section.

Deflection Data

One of the six objectives of the LTPP program is to improve pavement prediction and design models (as discussed in chapter 1). A variable needed to accomplish this objective is the change in seasonal and long-term response to pavement loads. For both GPS and SPS sections, the LTPP program uses the falling weight deflectometer (FWD) to measure the deflection response of a pavement to a load of known magnitude. The program has conducted basin tests on AC and PCC pavements and load transfer tests on PCC pavements.

LTPP program efforts have significantly improved the accuracy and precision in measuring pavement strength. Ultimately, efforts within the program to achieve greater reliability and precision in FWD data resulted in the establishment of calibration centers around the country and the development of much-improved nationwide calibration standards: LTPP protocols formed the basis for American Association of State Highway and Transportation Officials (AASHTO) Standard Recommended Practice R 32-09, Calibrating the Load Cell and Deflection Sensors for a Falling Weight Deflectometer, adopted in 2009 by AASHTO, and updated as Standard Recommended Practice R 32-11.^{25,26} This section highlights some of the activities that culminated in those advancements, which are detailed in chapter 10.

LTPP activities in FWD calibration led to the adoption of a national FWD calibration standard: AASHTO Standard Recommended Practice R 32-11.

FWD Data Collection and Equipment

Parts of the FWD data collection process are automated—the computer controls the operation, acquiring and processing the data at high speed. In addition to sensing and recording load and deflection data, the system measures and collects air and surface temperature, time, and distance traveled on the roadway data. Some manual measurements are required, however: the FWD operator uses a probe to measure the subsurface temperature. Initially in the LTPP program, the subsurface temperature measurements were taken at three depths, but later these measurements were taken at five depths depending on the pavement structure. In 2003, the FWD gradient temperature data collection changed from drilling temperature holes at 25 mm from the top, at the middle, and 25 mm (1 inch) from bottom of the pavement surface layers to set intervals of 25, 50, 100, 200, and 300 mm (1, 2, 4, 8, 12 inches) from the top of the pavement surface. The operator also measures the width of joints when testing load transfer efficiency on rigid pavements. Any cracks or surface distresses that might affect the measurements are included in the operator's report.

During the early years of the LTPP program, under the Strategic Highway Research Program (SHRP) and later under the management of FHWA, each LTPP regional support contractor was responsible for storing, maintaining, and operating an FWD unit and its towing vehicle. The first four FWD units were purchased in 1988. The FWD equipment has been replaced or upgraded four times over the course of the program (in 1995, 2000, 2002, and 2014), and when FWD data collection was expanded in 1995 to meet the added demands of the SMP and new SPS sites, one additional FWD was purchased for each region to permit the expanded data collection resulting from these new demands.

Figure 6.5 shows an FWD used by the LTPP program to collect deflection data. See appendix C for

more information on the type of FWD equipment and software used to collect, store, and process the data over the years.

FWD equipment comparisons were held periodically, where the FWDs from the four LTPP regions were brought together to assess their performance. Referred to as “FWD thump-offs,” these comparisons were used to qualify newly purchased equipment for acceptance and program use, to perform periodic evaluations of the equipment's operational status, and to conduct cross-training exercises for regional contractor staff (figure 6.6). The thump-offs were later dropped in favor of FWD User Group meetings, where regional FWD operators and coordinators had an opportunity to review problems and exchange information on the



FIGURE 6.5. Van-towed falling weight deflectometer equipment used in the LTPP program.



FIGURE 6.6. Falling weight deflectometer equipment at the first LTPP “thump-off,” which was held at Purdue University in November 1988.

operation and maintenance of the FWD equipment and analysis of FWD data.

FWD Maintenance

Continuous preventive maintenance is necessary to keep the complex hydraulic-electrical-mechanical FWDs operating under demanding conditions to collect high quality data and pass rigorous annual reference calibrations. The LTPP program developed a preventative maintenance plan to ensure that the FWDs (and other equipment) are maintained to a high standard. The manufacturer's owner's manual provides guidance on most repairs and troubleshooting; however, eventually, after years of service, FWDs require a complete overhaul, which the program has successfully done in recent years.

In spring 2003, the LTPP Southern Regional Support Contractor overhauled one of the FWDs operated for the LTPP program, documenting the complete disassembly and reassembly with instructions and photographs. This maintenance and overhaul manual provides FWD owners, operators, and technicians with instructions and guidelines that supplement the Dynatest 8000 owner's manual (figure 6.7).²⁷ In 2014, the LTPP regional support contractors completely overhauled all of the FWD equipment with the Southern Region playing a key role in this activity.

FWD Quality Control Checks

Five validity checks (roll-off, nondecreasing deflections, overflow, load variation, and deflection variation) were built into the FWD software to alert the operator of possible problems.²⁸ To further check the integrity of the data, the FWDScan software was created for use in the field and again in the office to check data files for completeness and readability and to flag potential problems before data are loaded to the LTPP database. Similarly, the LTPP program developed FWDCheck to allow for subdividing the FWD deflections into uniform sections and provide statistical information on the FWD readings. This check was developed because earlier backcalculation exercises lacked uniform sections, which influenced the FWD results. FWDCheck also generated



FIGURE 6.7. The cover of the FWD maintenance manual, used to keep the units operating at peak performance.

an overall structural capacity in terms of effective Structural Number.

Another QC check used by the LTPP program is a deflection sensor location program called SLIC (an acronym for the authors Stubstad, Lukanen, Irwin, Clevenson).²⁹ This program was developed and tested on FWD data collected by the LTPP program. Its LTPP use is summarized in *Study of Long-Term Pavement Performance (LTPP): Pavement Deflections*.³⁰ SLIC was a QC check for the sensor locations. The LTPP regional support contractors used engineering judgment to determine whether or not to use the FWD data based on the data's overall quality.

Because the FWD data are intended for research use, the collection protocols required many more data than would be needed for routine pavement evaluation and rehabilitation purposes. Four drop-heights of equivalent 6,000-, 9,000-, 12,000-, and 16,000-lbf loadings (26, 40, 53, and 71 kN) were selected for AC pavements and three drop-heights of 9,000-, 12,000-, and 16,000-lbf loadings for rigid pavements. Random errors in readings were handled by taking four drops at each height. Sensor history data were collected for each sensor and the load cell at the fourth drop of each height. A 60-millisecond window was used to capture the history data.³¹ Just as the FWD equipment has been updated over the years to improve data collection, the various software procedures used to ensure quality deflection data have also been updated as needed (appendix C).

Establishment of FWD Calibration Centers

At the first FWD thump-off, in 1988, SHRP recognized the need to ensure that data being collected from each FWD unit be comparable across the LTPP program. As a result, the early program managers developed a methodology to calibrate FWDs to an independent reference standard and established centers to carry out the calibrations.

The Dynatest FWD, which has been used by the program, repeats itself very well, but comparison of the FWDs among the regions revealed statistical differences. Efforts were begun to reference-calibrate the FWDs by adjusting the sensor readings to a reference sensor to reduce significant statistical differences between the units. The prototype for this calibration procedure was developed at Cornell University in Ithaca, New York, in 1988.³² Initial trial comparisons were conducted at Purdue University with the participation of all four LTPP regional FWDs. The results of the comparisons showed that, when calibrated, the four SHRP FWDs could be used interchangeably. A calibration protocol was published in 1991,^{33,34} updated in 1994,³⁵ and revised in 2011.³⁶

The first production calibration center was built at the Pennsylvania Department of Transportation (PennDOT) Bridge and Maintenance Office in Harrisburg and operations began in 1992. In the same year and using the same protocol, additional calibration centers were opened in Texas, Nevada, and Minnesota. At the completion of the calibration centers, a round robin “Cal Off” was conducted with all four SHRP-LTPP regional FWDs. This comparison indicated there was minimal difference between the calibration centers, although some problems specific to individual centers were noted. This activity also allowed the FWD operators to compare their regions’ procedures with the other regions and refine them, if needed.

The LTPP program provided the calibration centers (1) annual QA review and certification of the center operators and (2) technical services—training, troubleshooting, equipment replacement, and annual reference load cell calibration. Figure 6.8 shows an FWD readied for testing in an LTPP calibration center.

When the need to upgrade the calibration centers exceeded LTPP program resources, FHWA initiated, in 2004, Transportation Pooled-Fund Study TPF-5



FIGURE 6.8. An FWD being calibrated at the PennDOT regional calibration center early in the LTPP program.

(039): Falling Weight Deflectometer (FWD) Calibration Center and Operational Improvements.³⁷ This study resulted in new, highly portable calibration equipment and in updates and improvements in the FWD calibration procedure.³⁸ The new procedure is demonstrated in a video available at the LTPP program’s InfoPave Web site.

Also among the pooled-fund study’s several objectives was to identify a source of support for the calibration centers over the long term. The study determined that the AASHTO Materials Reference Laboratory (AMRL) was qualified to continue providing these calibration center support services in the future. FHWA and AASHTO worked together on transitional activities over 2 years, resulting in a complete transfer of calibration center support to AMRL on September 1, 2010.^{39,40} AMRL now provides the centers the review, certification, and technical services previously provided by the LTPP program.

Frequency of FWD Calibrations

The LTPP program requires the regional FWDs to have annual reference calibrations, every 9 to 14 months and following any repairs or major maintenance of FWD sensors or processor.^{41,42}

While the FWD calibration procedures have been updated over the years, the load cell calibration remained unchanged. However, the deflection sensor calibrations were modified to allow for a group of sensors to be calibrated in a stand with an accelerometer versus the linear variable differential transformer (a deformation measurement device) used as the reference device. This simplified the procedure and made it less dependent on soil and slab condition.

FWD Manuals

In 1989, the *SHRP-LTPP Manual for FWD Operational Field Guidelines, Version 1.0*, was published, outlining the requirements for test setups for both flexible and rigid pavements, monthly relative calibrations, and temperature data collection requirements.⁴³ In 1992, six sets of SPS site-specific guidelines were also issued. Interim changes in protocol were provided to the LTPP regional support contractors in the form of program directives, and the FWD manuals were updated to incorporate the SPS-related guidelines, revised calibration procedures, software changes, and step-by-step instructions for FWD data collection in 1993 (version 2.0),⁴⁴ 2000 (versions 3.0 and 3.1),⁴⁵ 2005 (version 4.0),⁴⁶ and 2006 (version 4.1).⁴⁷

Major changes in the guidelines were occasioned by implementation of the Dynatest25 (Dyna25) software in 2000 and FWDWin in 2005. After the Texas 1996 reference center calibration comparisons and operator exchange session, the LTPP regions performed follow-up testing with the Dyna25 software, and in September 2000 were directed to fully implement the new software and *Operational Field Guidelines, Version 3.1*. Subsequent versions simplified some of the earlier instructions and incorporated LTPP program directives into the text.

FWD Meetings

FWD comparisons were conducted and provided an opportunity to review problems and allow for exchange of information among FWD operators. These comparisons were later dropped in favor of attendance by the LTPP regional FWD coordinators at FWD User Group meetings, which were also a venue for FWD calibration center meetings. These annual meetings were

formed as a means for the exchange of information on the operation, maintenance, and analysis of FWD data. These meetings gave the LTPP program an opportunity to meet with highway agency staff which was very important in the early days of the program.

Distress Data

Distress surveys are performed to document the condition of the surface of LTPP test sections in terms of visible distresses—such as cracking, defects, deformations, joint deficiencies, rutting—by severity and quantity. Distress data have been collected using both photographic (film-based) surveys and manual surveys. Photographic surveys were the priority with manual surveys serving as backup at the start of the LTPP program. However, significant differences were noticed between the two methods, and so the program gradually began to depend more on the manual survey because of the known limitations with the photographic survey and the increased confidence in the distress rater accreditation process.

Photographic Distress Surveys

The photographic distress survey's objective was to provide a record of distress for data interpretation and archival purposes. Under SHRP management, a contract was awarded in 1989 to Pacific Aerial Survey Company (PASCO USA) of Japan to collect the permanent distress records for all test sections in each of the four LTPP regions beginning in the fall of that year. PASCO was the only vendor able to record cracks as small as 1 mm in width using backlit cameras and 35-mm film. Between contracts, PASCO sold their North American rights and equipment to Cumberlandedge, Gramling and Hunt (CGH) around 2000, who subsequently bid and were successful in retaining the contract with FHWA.

In the early part of the LTPP program, photographic surveys were conducted once every 2 years. As time passed, surveys were subject to budget constraints and typically occurred once every 3 to 5 years. Due to funding limitations, 2004 was the last year that CGH performed photographic surveys. At the conclusion of the last photographic survey contract, the LTPP program began collecting detailed photographs of the test sec-

tions with each manual survey, so in effect the program is still collecting a photographic record of the LTPP test sections.

The photographic distress permanent record systems in the early 1990s were housed in vans (figure 6.9). The distress was recorded on high-resolution 35-mm black-and-white motion picture film from overhead cameras directed at the pavement. Testing was conducted at night using artificial lighting to produce the highest quality images and minimize disruption to traffic.

Photographic distress or permanent record surveys had to be performed under dry conditions and were not taken at remote locations (e.g., Hawaii, Alaska, Puerto Rico, and Newfoundland). Also if the PASCO unit was not able to get to a test section prior to maintenance, rehabilitation, or closeout activities, then a manual distress survey was performed. Due to limitations with the PASCO data collection system (such as not being able to detect low-severity hairline cracking (< 1 mm) or to rate joint seal damage and crack sealant, faulting, and severity of potholes), the LTPP regional support contractors began to concentrate on doing manual distress surveys when visiting the test sites for other reasons, such as FWD testing. This ensured that distress data would be available and that data elements that were not available from the PASCO film could be obtained.

Photographic Distress Interpretation

PASCO/CGH performed the initial distress rating, and sent the film to the technical support services contractor, who performed the secondary review and QA, performed distress ratings, and electronically logged the resulting distress types, severities, and quantities. The electronic copy of the data was provided to the regional support contractors for additional QA and to load into the LTPP database, and hard-copy outputs were provided for review and historical records. Computer-generated distress maps were also produced (figure 6.10).

The SHRP *Distress Identification Manual* (described in the Manual Distress Surveys section) for rating distress was used to determine the severity and extent of each distress. Some distress types could not be easily determined from the film. These are listed below by pavement type:

- AC—bleeding, polished aggregate, raveling, lane/shoulder drop-off.



FIGURE 6.9. Mobile equipment used to photograph pavement distress. Mounted on a boom extending from the front of the vehicle is the motion picture camera, synchronized with vehicle speed for continuous filming; flood lights are mounted on the custom front bumper. On a boom extending from the rear of the vehicle is a 35-mm pulse camera, which collects transverse profile. The camera is controlled by a distance measuring instrument that can trigger the camera at preset intervals; a strobe projector is mounted on the rear bumper.

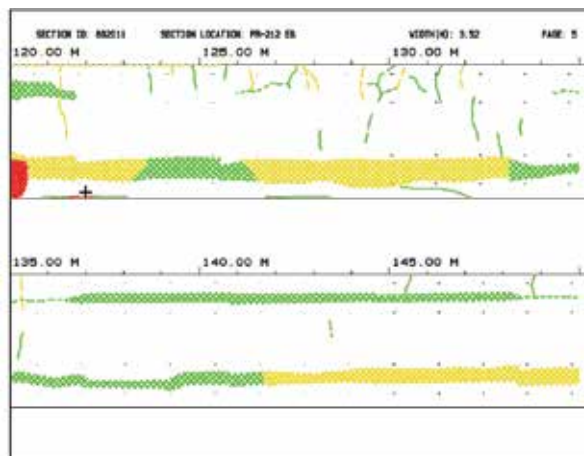


FIGURE 6.10. Sample of a computer-generated distress map from PADIAS 4.2 software.

- PCC—joint seal damage, polished aggregate, faulting, lane/shoulder drop-off, lane/shoulder separation.
- Continuously reinforced concrete pavement (CRCP)—polished aggregate, lane/shoulder drop-off, longitudinal joint seal damage.

The film images were rated using the Film Motion Analyzer (figure 6.11) which PASCO USA had developed for the LTPP program. This device projected the film image onto a digitizing board. Because the film was on spools, the apparatus included a system to move the film through the projector. Initially a grid system, Pavement Distress Analysis System (PADIAS) 1.0, was used to determine the area and length of distresses; later a vector system, PADIAS 4.2, was developed. A study of LTPP distress data variability in the late 1990s found that “Although differences in data interpreted with the PADIAS v1.x and v4.x systems exist, there is excellent overall agreement between the two systems for all pavement types, especially for total distress quantities and for cracking-related distresses.”⁴⁸

Photographic Distress Quality Control Checks

The four LTPP regional support contractors performed a QA check on 10 percent of the distress data interpreted by the technical support services contractor from the film images before accepting it for loading to the database. The regions had a similar but somewhat less sophisticated apparatus and setup for checking the film as compared to the technical support services contractor. Three copies of the film were produced: a copy retained by PASCO, a copy provided to the technical support contractor for rating (which was then forwarded to the regions for secondary review and storage), and a third copy for the highway agency. Due to the sensitive nature of the film and to preserve the film’s images, the canisters that were stored at the regional offices early in the program were later transferred to an environmentally controlled room at what is now the LTPP Materials Reference Library in Sparks, Nevada. (The reference library was begun under the SHRP asphalt program and later transferred to FHWA-LTPP management.)

QC/QA procedures were put in place with the automated distress survey contractor. Initial data reviews found discrepancies in the database between the pho-



FIGURE 6.11. Film Motion Analyzer.

tographic and manual distress ratings. This was particularly noticeable when using Distress Viewer and Analysis (DiVA), a stand-alone software tool developed in 2000 by the LTPP program to plot the historical changes in distress over time.⁴⁹ This resulted in a decision to redo the ratings on all the film (except SPS-3 and -4) using the PADIAS 4.2 software.

As part of the QC/QA procedures, film distress raters were required to attend distress rater accreditation workshops to become accredited FHWA-LTPP distress raters. This was to ensure that qualified personnel were performing the distress interpretations and that the ratings would be similar to those of the manual distress surveys. Due to the different data collection methods, some discrepancies were still sometimes evident between the photographic and manual distress survey methods.

Manual Distress Surveys

Manual distress surveys were initially instituted as a backup to the permanent film record distress method. These “walking surveys” were performed by trained and accredited raters. Before becoming a designated scheduled LTPP activity, manual distress surveys were not routinely performed by the LTPP regional support contractors except in the Southern Region, where manual distress surveys were performed at all sites as part of the site selection and verification process and later at sites visited for FWD testing. In 1995, the LTPP program issued a directive that outlined the measurement frequency and priorities for manual distress surveys.⁵⁰

Stringent guidelines for the identification, interpretation, measurement of the quantity, and determi-

nation of the severity of the distress, and documentation of the findings were followed. Raters were also required to provide manually prepared distress maps, photographs, videos, and distress data forms as needed to record the conditions at the time of the survey and any unusual distresses observed. These requirements were described in the SHRP *Distress Identification Manual (DIM)*, which was used to conduct the surveys. Development of the initial manual was funded by FHWA prior to the launching of SHRP, to be used in the distress data collection that would be performed under the original SHRP program. The manual was written by SHRP's technical assistance contractor and drew on various Federal and State/Provincial manuals. The photographs included came mainly from these documents.⁵¹ The manual contains the forms that surveyors use to record and summarize cracks, faulting, and other surface distresses observed on the pavement during a manual survey (figure 6.12). These forms provide input to the LTPP manual distress data module.

After a second DIM was published in 1990,⁵² ratings became more consistent among all of the LTPP regions. The third version of the DIM was issued in 1993,^{53,54} and the fourth version, released in 2003, incorporated refinements, changes, and LTPP program directives that had been issued since the previous edition.^{55,56} The DIM was updated in 2014 in its fifth version.⁵⁷

Following release of the fourth version, the LTPP program developed four pocket editions to assist field engineers in conducting manual distress surveys. Plasticized and durable, the pocket guides covered distress identification for AC, PCC, and CRCP, with an additional AC guide designed for local agencies.⁵⁸ The pocket guides were developed by the North Dakota Local Technical Assistance Program Center for use by local agencies with funding from FHWA. The Baltimore FHWA Resource Center reprinted a modified version. Both the tech-

Revised Dec 1992; Jan 1999; Feb 2002; Aug 2010

SHEET 1

DISTRESS SURVEY STATE CODE 26

LTPP PROGRAM SHRP SECTION ID 0116

DISTRESS SURVEY FOR PAVEMENTS WITH ASPHALT CONCRETE SURFACES

DATE OF DISTRESS SURVEY (MONTH/DAY/YEAR) 04/24/12

SURVEYORS: JL PHOTOS, VIDEO, OR BOTH WITH SURVEY (P, V, B) P

PAVEMENT SURFACE TEMP - BEFORE 29°C; AFTER 29°C

DISTRESS TYPE	SEVERITY LEVEL		
	LOW	MODERATE	HIGH
CRACKING			
1. FATIGUE CRACKING (Square Meters)	<u>314.2</u> ✓	<u>0</u> ✓	<u>0</u> ✓
2. BLOCK CRACKING (Square Meters)	<u>0</u>	<u>0</u>	<u>0</u> ✓
3. EDGE CRACKING (Meters)	<u>0</u>	<u>0</u>	<u>0</u> ✓
4. LONGITUDINAL CRACKING			
4a. Wheelpath (Meters)	<u>0</u>	<u>0</u>	<u>0</u> ✓
Length Sealed (Meters)	<u>0</u>	<u>0</u>	<u>0</u> ✓
4b. Non-Wheelpath (Meters)	<u>183.0</u> ✓	<u>122.0</u> ✓	<u>0</u> ✓
Length Sealed (Meters)	<u>183.0</u> ✓	<u>122.0</u> ✓	<u>0</u> ✓
5. REFLECTION CRACKING AT JOINTS	Not Recorded		
6. TRANSVERSE CRACKING			
Number of Cracks	<u>0</u>	<u>0</u>	<u>0</u> ✓
Length (Meters)	<u>0</u>	<u>0</u>	<u>0</u> ✓
Length Sealed	<u>0</u>	<u>0</u>	<u>0</u> ✓
PATCHING AND POTHOLES			
7. PATCH/ PATCH DETERIORATION (Number)			
(Square Meters)	<u>0</u>	<u>0</u>	<u>0</u> ✓
8. POTHOLES (Number)			
(Square Meters)	<u>0</u>	<u>0</u>	<u>0</u> ✓

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JCB

FIGURE 6.12. Example of the multipage forms used to record distresses observed during LTPP manual distress surveys. For each pavement type, a different form is used to record surface distresses. This is page 1 of the form for asphalt concrete pavement.

nical assistance program center and resource center versions were printed in 2005.

The DIM is also used in workshops to provide examination and accreditation to LTPP distress raters in identifying various pavement distresses. These workshops were initiated early in the program to ensure consistency in data collection among different raters throughout the LTPP regions.

Over the course of the LTPP program, procedures for manual surveys changed as technical developments occurred or funding was adjusted. Some examples follow:

- Documentation of distress in photos during surveys, made mandatory later in the LTPP program to provide a permanent visual record of the survey.⁵⁹
- Population of a Distress Image/Photo database software table by LTPP regional support contractors with detailed information of all distress photographs taken since the beginning of their contracts.⁶⁰
- Cessation of night time (artificially illuminated) manual distress surveys, to reduce concerns over the safety of raters performing the surveys and the agency traffic control crew members, as well as the quality and consistency of the data being collected.
- Clarification of procedures for surface patches, creating the need to review map sheets and summaries before they are uploaded to the LTPP database.

Manual Distress Workshops

The first manual distress workshop was conducted in Arlington, Texas, in 1991, with representatives from all four LTPP regions attending. There were many discussions on what constituted distress, how it should be categorized, and what parameters should be used for ratings. There was also a distinct difference between how individuals from the north perceived distress and severity levels versus those coming from the south. Based on this workshop, it was evident that work would be required to get a consensus on what distresses would be categorized and how. For example, some of the more significant issues that required resolution were how to rate the distresses in the wheelpath, identify the cracks (e.g., longitudinal, fatigue), and rate the extent and severity of each distress.

Early reviews of regional distress surveys for consistency between raters indicated a need for training and standardization. Therefore, the LTPP program developed a workshop for accreditation of the LTPP regional distress raters.⁶¹ The raters were to be trained within the region and would attend the workshop to be accredited to conduct distress surveys for the LTPP program. Distress accreditation workshops were conducted every 2 years and included a distress presentation, field review of distresses, distress rating on flexible and rigid pavements, and the accreditation. The distress workshops were rotated among the regions, and accreditation expired after 24 months (or

could be extended to the next available workshop). Other requirements, such as the need to conduct a minimum of 15 manual distress surveys each year, were added to ensure that only experienced raters were performing the manual distress survey duties, thus ensuring research-quality results.⁶² Between 1991 and 2014, the LTPP program has held 38 manual distress workshops, 32 for LTPP regional support contractor raters, and six for PASCO/CGH raters. In the early years of the program, two to three workshops were held each year; currently one workshop is held each year. Figure 6.13 shows a field exercise at a manual distress workshop.

Office Review of Surveys

Internal LTPP regional office reviews of distress surveys are also conducted. They include detailed checks for errors in math, summarization, and visual comparison with previous surveys regarding distress types and quantities.

After the initial mathematics checks and overall review, the manual distress survey is compared to the last visit for a time-series check. When noticeable discrepancies from survey to survey were found, a program directive was issued allowing the rater to take the prior survey maps into the field. Once the survey had been performed and summed, it was checked against the prior survey while on site. This allowed an explanation of the differences in distress before leaving the site.⁶³



FIGURE 6.13. Participants in a field review of distresses at an LTPP distress accreditation workshop.

Back in the office, the LTPP regional support contractors conducted reviews of the distress data entered into the database. In 2004, the DiVA software was issued for use as an integral part of the regional office QC/QA activities, as well in the time-series evaluation of distress data (figure 6.14).⁶⁴ The purpose for this software has been served, and it is no longer being used by the LTPP program for distress reviews.

Drainage Data

The drainage data contain information on the inspection of drainage features and, more specifically, information on the condition of the edge drain systems and the location of the lateral-side drainage structures. Drainage information gathered includes the presence and type of subsurface drainage features, such as permeable layers, transverse drains, and longitudinal drains. The best source of information on the effect of in-pavement drainage systems will be from comparison of the drained and undrained sections on SPS-1 and SPS-2 projects.

Two investigations were performed to explore the condition of the edge drains at the SPS-1, SPS-2, and SPS-6 projects. Although some GPS projects contain edge drains, they were not included as a primary experimental factor.

The first investigation included a video survey, wherein a camera on the end of a semi-flexible cord was inserted into the outlet and pushed into the drain pipe, recording the condition of the outlet itself as well as the drain pipes' condition (figure 6.15). Observations included crushed pipes; sags; ponding water; pipes clogged with dirt, silt and construction debris; and numerous animals and their nests. The intent of this investigation was to determine the degree to which the pipes were properly constructed, and, if it was necessary to clean them out to ensure proper operation. Edge drain videos and reports were sent to the respective highway agencies, and the completed inspection forms (and associated data) were entered into the LTPP database.

The second drainage investigation conducted at the LTPP test sites included field investigations to evaluate the effectiveness of the drains themselves.

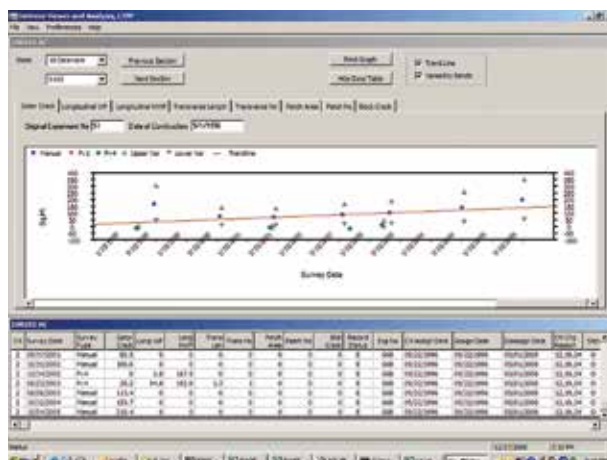


FIGURE 6.14. Screen shot from DiVA software showing a time-series chart of a pavement distress along with the table for all distresses for a test section.



FIGURE 6.15. Edge drain inspection using videography.

As part of the study, Effects of Subsurface Drainage on Performance of Asphalt and Concrete Pavements: Further Evaluation and Analysis of LTPP SPS-1 and SPS-2 Field Sections (NCHRP 01-34D), liquid with dye was injected into holes drilled in the pavement surface at a set distance from the drain outlet, and the length of time required for the dyed water to be detected exiting the drainage outlets was measured. In some cases the dye appeared very quickly, and in others it never appeared at all.⁶⁵ This information may help explain anomalous findings in pavement performance and drainage effectiveness predictions.

Friction Data

The LTPP database contains the results of friction tests on pavement sections where the State/Provincial highway agency was willing to provide the data. Because friction data hold the potential risk for litigation, submission was made voluntary.

The LTPP data collection guidelines for friction data recommend using the ASTM E-274 (AASHTO T 242) procedure as the preferred method for obtaining data. The ASTM E-274 procedure uses a locked-wheel skid tester in a trailer assembly (figure 6.16). Friction test results are reported as Skid Numbers. It should be noted that although the LTPP program provided guidelines for friction testing, the program has no control over the data collection method, measurement equipment, or calibration of the equipment used for these measurements. In addition, prior to 2014, the LTPP database did not contain surface texture data or related information that are traditionally used to link pavement properties to measured friction levels.

Longitudinal Profile Data

Profile data are collected because pavement smoothness/roughness is perhaps the most important user parameter (i.e., level of service). Profile data and smoothness indices are used to track the performance of the section and provide input to the development of models, especially models that are related to user cost and benefits. Research-quality data require a state-of-the-art profiler to collect ride statistics and longitudinal profiles for long-term comparisons and the development of future smoothness indices.



FIGURE 6.16. Locked-wheel skid tester currently in use for collecting friction data.

Longitudinal profile data are collected almost exclusively by automated profilers, and manual Dipstick® measurements as well as rod and level measurements are sometimes used as a backup. The Dipstick is the backup device in the event an inertial profiler is unable to be scheduled or for remote sections that can not be visited due to distance (e.g., Hawaii and Puerto Rico). The Dipstick is still used for longitudinal profile comparisons because it is an ASTM standard profile measuring device. A list of profile data collection equipment used by the LTPP program over the years is shown in appendix C.

Inertial Profiler and Dipstick Equipment and Verification Tests

Inertial profiling equipment was first purchased in 1989 and was replaced in 1996, 2002, and 2013 as technologies improved and as equipment deteriorated. The profilers, purchased by SHRP and then FHWA, underwent rigorous testing to ensure that they met the requirements specified in the contract documents. After each LTPP regional support contractor took delivery of a replacement profiler, a comparison of the new and old profilers was performed before the new profiler was put into service. These verification tests compared the output from the old and new equipment.

When the first profilers were delivered to the LTPP regional support contractors in 1989 (shown in figure 6.17), some of the regions added video cameras to the equipment to provide backup evidence of pavement condition at the time of survey. The videotaping also helped in determining if maintenance had occurred at the test sections.



FIGURE 6.17. The first (DNC 690) Profilometers used in the LTPP program. Three were mounted in the Champion motor home chassis with Ford underpinning with dual rear wheels, and the fourth in a Ford E350 van chassis.



FIGURE 6.18. The T6600 Profiler, in use from 1996 to 2002.



FIGURE 6.19. ICC profiler MDR 4086L3 (Ford E350 van), in use from 2002 to 2013.



FIGURE 6.20. Ames profiler in Ford E150 van, acquired in 2013.

The T6600 Profiler and the ICC profiler are pictured in figure 6.18 and figure 6.19, respectively. In 2013, through a competitive process, the LTPP program replaced the ICC profilers with state-of-the-art Ames Engineering, Inc. profilers with added capabilities: macrotexture measurements are a new data collection element, and all of the data, including ambient and surface temperature, are referenced with Global Positioning System coordinates (figure 6.20). The new system's software was designed through a collaborative manufacturer/LTPP program process.

As stated earlier, the LTPP program has used the Dipstick over the years in addition to the high-speed

profilers to collect profile data. (A manual Dipstick is shown in figure 6.21.) A comparison study of the profiler, the manual Dipstick, and a portable rolling surface profiler manufactured by Face was conducted at the Virginia I-95 LTPP test section (511023) to provide data for use in developing software for the manual collection of longitudinal profile data. The portable rolling profiler was found not to be an ideal tool for the LTPP program's purposes. Safety issues arose with the collection of transverse profiles because it was necessary to roll the profiler past the centerline in the adjacent lane to capture the profile at the centerline.

In 2003, issues were identified with the distance as recorded from the various Dipsticks and the actual length of a section. To compensate for these differences, the LTPP program developed a procedure to determine the "effective Dipstick footpad spacing" as determined by applying the difference between the foot pad distance and actual distance. The Dipstick survey for the MnROAD profile comparison used the "effective" spacing and determined that it provided a more accurate distance when collecting Dipstick profiles.⁶⁶

Comparison studies (sometimes called profile rodeos or rough-offs) are conducted at regular intervals to compare the output from the four LTPP profilers. For each study, several test sections are laid out, and reference profile measurements along each wheelpath are obtained using the Dipstick. Thereafter, profile measurements are performed on the test sections by the inertial profilers. The primary method for checking if the profilers are functioning accurately is to compare the International Roughness Index (IRI) values computed from Dipstick data with the values computed from the data obtained from the profilers. The repeatability of the profilers is evaluated by analyzing the standard deviations of the IRI, which are computed using the IRI values obtained from repeat measurements on a test section. In the profiler comparison studies that have been performed since 1998, in addition to comparing the IRI values, profiles obtained by the profilers are compared to evaluate profiler repeatability and reproducibility. These are just some of the activities that the profile rodeo data analysis covers. The LTPP program has held 10 profiler rodeos in various locations across the country (see sidebar). Some of

the rodeos have led to improvements, such as the integration of an updated calibration oscillator into the ICC profiler processor in 2003. Profilers and profile coordinators at the 2007 rodeo are shown in figure 6.22. A summary of the profiler comparisons, *Guide to LTPP Profiler Comparison Resource* (2010), is available from the LTPP Customer Support Service Center (Email: ltppinfo@dot.gov). In 2013, the program held a training session in College Station, Texas, to accept delivery of the new profilers and teach the profile coordinators how to operate them (figure 6.23). In addition to the rodeos, in 2004, an analysis was undertaken to quantify and resolve the differences in the longitudinal

profile and roughness indices that are attributable to the different profilers that have been used in the LTPP program. The analysis indicated good agreement of IRI values among the different inertial profilers.⁶⁷

The highway agencies often use FHWA-LTPP profile data as a reference for checking or calibrating their own profilers. Numerous profile comparisons have been performed among the FHWA-LTPP, agency, and contractor profilers.

Profiler Quality Control Checks

The LTPP program developed ProQual, which is a DOS-based software used to QC profilometer data collected at LTPP test sections. The major features were the ability to check for repeatability between runs (as 5 error-free runs were required) and to generate ride quality indices other than IRI.⁶⁸ ProQual was later updated to have the ability to identify spikes due to “lost lock” and “saturation” (which was a common problem with the incandescent profile system) and to accept longitudinal and transverse Dipstick data. Issues with the calculation of IRI (related to smoothing) and slope variance (related to sample interval and sharp slopes) were identified and addressed in 1996 (Tech Memo, March 1996). ProQual was further developed to incorporate office QC and calibration routines, and updated with additional features.



FIGURE 6.21. Manual Face® Dipstick® used to collect profile data in the LTPP program.

LTPP Profiler Rodeos

- 1990 in Austin, Texas.
- 1991 in Ann Arbor, Michigan.
- 1992 in Ames, Iowa.
- 1996 at LTPP Regional Support Contractor Offices.
- 1998 in Urbana, Illinois.
- 2000 in College Station, Texas.
- 2002 at LTPP Regional Support Contractor Offices.
- 2003 at MnROAD, Minneapolis, Minnesota.
- 2007 in Minneapolis, Minnesota.
- 2010 in Minneapolis, Minnesota.



FIGURE 6.22. Profile coordinators with four ICC profilers and the last K. J. Law Profilometer (center), gathered for a rodeo at MnROAD in 2007.



FIGURE 6.23. Profile coordinators gather in College Station, TX, in 2013 to receive training from the LTPP program on the new Ames profiler units.

A Windows-based version of ProQual with additional features was issued in 2002. In particular, the ability to handle multiple years of data and the refinement of sub-sectioning SPS projects were added.⁶⁹ ProQual 2002 was updated again in 2005 to add the ability to backup data and files and to address issues identified by the LTPP regional support contractors to further enhance the software.⁷⁰ ProQual became the basis for FHWA's profile processing software package, ProVAL, which was first released in 2001.^{71,72} ProXport was developed to create 25-mm data in the new industry-accepted text file format (.erd) developed by the Michigan Transportation Research Institute's Engineering Research Division.⁷³ ProQual 2012 was designed to efficiently and effectively process all data being collected with the latest profilers, Dipstick, and SurPRO; this version introduced the Sidekick® program to process the new macrotexture measurement data elements as well as the new temperature and GPS coordinate data. ProQual 2014 is the latest version of the ProQual software. This version combines all of the previous exterior programs (ProXport, Sidekick) into one robust modern language software package.

Profile Manual

In 1989, the first profile manual, *Manual for Profile Measurement: Operational Field Guidelines*, was developed and distributed to the LTPP regions for their use in collecting pavement longitudinal and transverse profile data.⁷⁴ As profile equipment changed and data collection activities improved with technology, the LTPP program updated the manual to reflect these changes in 1994,⁷⁵ 1997,⁷⁶ 1999,⁷⁷ and 2002.⁷⁸ Subsequent updates of the manual in 2004,⁷⁹ 2008,⁸⁰ and 2013^{81,82} carry the title "LTPP Manual for Profile Measurements and Processing." The manual contains procedures for collecting data using automated profiler equipment, the Dipstick, and the rod and level; performing calibration tests and calibrating and maintaining the equipment; recordkeeping; office processing of data collected in the field; and guidelines for performing interregional comparison tests.

Rutting Data

While rutting information derived from PASCO's semi-automated transverse profile methods was the primary method at the start of the LTPP program, the backup manual method was initially based on a 4-ft (1.2-m) straightedge (figure 6.24). The straightedge rut-depth method is based on positioning the straightedge at various locations in each half of the lane until the maximum displacement from the bottom of the straightedge to the top of the pavement surface is found. Only the maximum rut depths in the left and right wheelpath are reported from this measurement and stored in the LTPP database.

The 4-ft straightedge method was based on the rut measurement protocol from the American Association of State Highway Officials (AASHTO) Road Test. It is important to note that the wheelpath locations at the road test were marked with paint to channelize this early form of accelerated pavement test. In the early implementation tests of the automated transverse profile measurement equipment, it was discovered that on public highways, it was not uncommon for the depressions in the wheelpaths to be wider than 4 ft (1.2 m). This was particularly noticeable on wider lanes. Because the baseline reference of the 4-ft straight edge would sometimes fit inside the wheelpath depression, the resulting rut depth measurement was less than the actual depth.

Although the eventual manual backup method to the semi-automated procedure to measure transverse profile was through the use of a Dipstick, rut data measurements using the 4-ft straightedge method were required for all SPS-3 (preventive maintenance of flexible pavements) test sections. The 4-ft straightedge method was only in use in the LTPP program from 1989 to 1991.

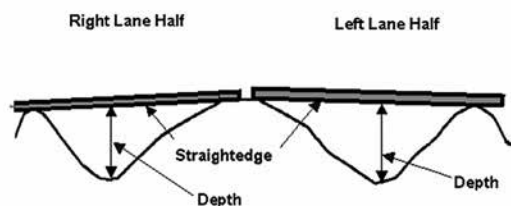


FIGURE 6.24. Measuring rut depth with the 4-ft straightedge.

Transverse Profile Data

In the early stages of the LTPP program, transverse profile was determined from 35-mm picture frames by the string line method/algorithm. A string was stretched over the high spots and the vertical distance measured at the deepest depression in the wheel-paths. This interpretation was performed by PASCO.

Photographic and manual techniques have been used to represent the transverse profile of the test section pavements and to calculate rut depth and cross slope. With photographic techniques, images are obtained using an automated film-based profiler system mounted on the back of the PASCO/CGH survey vehicle, and these images were translated into points of data. With manual techniques, Dipstick measurements must also be translated to be comparable with profiler data. The LTPP regional support contractors are responsible for collecting manual transverse profile data for their regions. The national data collection contractor that took the photographic distress measurements also took the photographic transverse profile measurements. Measurements were typically taken at 15.25-m (50-ft) intervals. The data collected from photographic transverse profiling were used to compute the rutting data found in the LTPP database.⁸³

Automated Transverse Profiling

Initially, the primary method used by the LTPP program to capture distortions in a pavement's transverse profile was photographic, using the ROADRECON-75 equipment manufactured by PASCO. The system used a 35-mm black-and-white optical imagery photographic technique. A pulse camera mounted on the survey vehicle photographs hairline optical bars projected onto the pavement surface (figure 6.25). The camera shutter and hairline projector are synchronized with vehicle speed, allowing the distance between measurement locations to be specified.

The initial analog-to-digital conversion of the transverse surface profile was obtained by projecting the recorded image of the hairline on the pavement onto a digitizing table and tracing its shape using a high precision mouse (figure 6.26). Up to 30 transverse and vertical (X-Y) points in the transverse profile shape were captured. As illustrated in figure 6.27, the elevations in

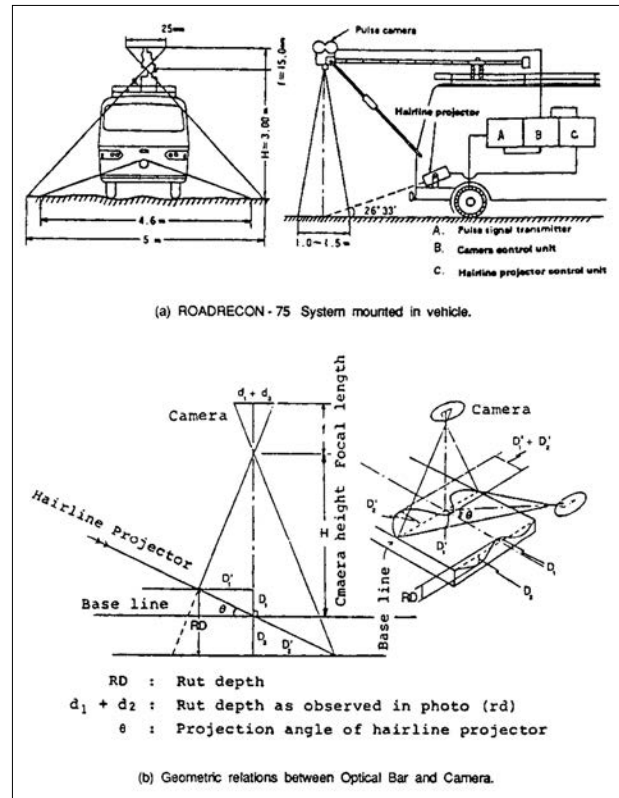


FIGURE 6.25. Diagrams of the PASCO/CGH ROADRECON-75 showing (a) the transverse surface profiler system mounted in a vehicle; and (b) the geometric relations between the system's optical bar and camera.



FIGURE 6.26. Translating photographs produced by the automatic profilers into digital format. Transverse profile/rutting was determined from 35-mm picture frames by the string line method/algorithm. Generally 30 points defined the transverse profile.

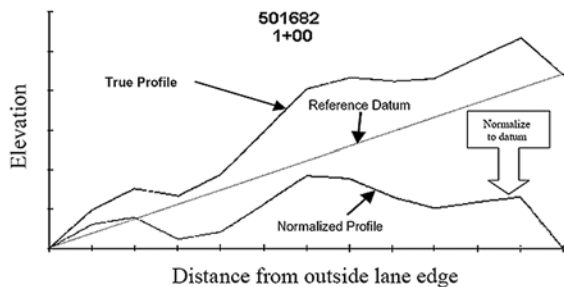


FIGURE 6.27. Normalization of transverse profiler measurements to lane edges. The transverse elevations are adjusted to a reference line through the endpoints so that the elevations of the endpoints are zero.

the initial digital profile are then converted to “normalized” elevations using the geometric relationships between the hairline projector and camera, simple trigonometry relationships, and proprietary calibration factors to account for optical distortions from the camera lens. Due to the limitations of this technology, the shape of the transverse profile from these measurements is normalized so that the beginning and end points of the profile are assigned a zero elevation. Thus while these measurements provide information on many aspects of the characteristics of the distortion in the shape of the transverse profile, they do not provide an indication of the pavement’s cross slope.

Dipstick Becomes Choice for Collecting Transverse Profile and Cross-Slope Information

As noted earlier, simple rut-depth measurements using a 4-ft (1.2-m) straightedge did not sufficiently measure the actual rut depths in all cases or capture all features of interest in the transverse profile. In an early comparison of rut depth indices derived from PASCO and Dipstick measurements on a sample set of test sections, the two devices were found to provide repeatable results within the realm of engineering accuracy.⁸⁴ Consequently, the Dipstick was adopted by the LTPP program in 1992 as the manually operated measurement device to perform transverse profile measurements because it is an ASTM standard profile measuring device.

Dipstick data were collected in conjunction with manual distress surveys. The Dipstick’s principle of

operation is that it measures the difference in elevation between its two reference elevation feet located 1 ft (305 mm) apart. For transverse profile measurements, each transverse profile measurement start point is assigned a zero elevation. By adding the cumulative elevation differences between readings this measurement device is capable of recording the elevation difference between the beginning and end points of a transverse pavement surface profile. To conform to the transverse measurement protocol from the PASCO ROADRECON-75 system initially adopted by the LTPP program, all Dipstick transverse profile measurements are stored as normalized elevations in the LTPP database. Three different models of Dipstick have been used during the program, Face® models 1500, 2000, and 2200, as shown in figure 6.28.

Dipstick calibration is performed on a per-site basis, using the zero check (to ensure meter’s elevation reading is the same when rotated 180°) and the calibration block check (if elevation reading is zero, the result from this check should be 3.2 mm or very close to the height of the block) before and after each site visit. The calibration procedures followed are detailed in an LTPP program directive,⁸⁵ the *Distress Identification Manual*,⁸⁶ and *Profile Manual*.⁸⁷

Dipstick data are entered to update the transverse profile database using the ProQual software. Header information and graphical displays of the forward and backward passes and of the normalized elevations can be reviewed. Output files of the normalized elevations (rounded to the nearest millimeter) and cross slope are stored in the LTPP database.

In 2003, the LTPP program decided to capture the pavement cross-slope information contained in the Dipstick manual transverse profile measurements by reinterpreting the raw data from previous measurements and performing one round of manual transverse profile measurements using the Dipstick on PCC-surfaced pavements. The objective was to extract the cross-slope information contained in the raw dipstick measurements to enable translations of the normalized profiles into actual transverse pavement profiles. The motivation for this action was to provide an analytical basis on the potential of ruts to hold water within the cross-elevation profile and to provide



FIGURE 6.28. Three Face® Dipstick® profile measuring devices with carrying cases. Left to right are the 1500, 2000, and 2200 models.

cross-slope data for other analysis objectives. The first release of the cross-slope data was in 2004. In 2012, another round of transverse profile measurements was begun on active PCC test sections.

PCC Transverse Profiles

In the early years of the program, transverse profile measurements were performed on both AC- and PCC-surfaced test sections using the PASCO automated measurement device. In more recent years, transverse profile images on PCC-surfaced test sections have not been interpreted due to program budget cuts. A little-known fact is that the LTPP program has collected data which show that PCC pavements also exhibit depressions in the wheelpath. The LTPP database contains information on distortion in the transverse profile of PCC-surfaced pavements that is not available elsewhere.

SEASONAL MONITORING PROGRAM DATA

Temperature and moisture-related changes in pavement structures, both within a day, from season-to-season, over the course of a year, and from year-to-year, can have significant impact on the structural characteristics of pavement layers, thus affecting the pavement's response to traffic loads and, ultimately, its useful life. To attain a fundamental understanding of the magnitude and impact of temporal (daily, seasonal, and annu-

al) variations in pavement response and material properties due to the separate and combined effects of temperature and moisture variations, SHRP envisioned the SMP. The study concept received strong support from the LTPP stakeholder community and was also endorsed by the Transportation Research Board (TRB) LTPP Pavement Performance Advisory Committee.

Because the SMP was not part of the original LTPP program plan and has involved a large investment of resources, its development and implementation under FHWA are discussed in chapter 7. The chapter describes the scope, equipment, data collection procedures, data collected (onsite air temperature and precipitation data, subsurface temperature and moisture content data, and frost-related measurements), and monitoring frequency.

SPECIFIC PAVEMENT STUDIES INVENTORY DATA

SPS experiments that were newly constructed (SPS-1, -2, -8, and some -9) made it possible for the LTPP program to collect the construction and materials data for these test sites. Therefore, a separate data module was created in the LTPP database specifically for the SPS experiments to store what is essentially inventory data.

Because the constructed SPS test sections were built to meet specific requirements, data associated with the construction of each project were recorded for the purpose of evaluating the performance of each test section within the project. After each SPS project was completed, a report was prepared by the LTPP regional support contractor with information collected during the different stages of construction. Many of the construction reports included details of meetings that took place in preparation for the construction of the SPS sections as well as sampling and testing performed before, during, and after the new pavement layers were constructed. Any data collected and pertinent drawings were included in the reports, which are available on the LTPP InfoPave Web site. The reports' appendices included a correspondence section, any materials or QC data provided by the agency or the contractor on site, photos of the different equipment and activities performed during construction, and a

summary explaining any deviation from the experiment guidelines that was documented during the different stages of construction.

In addition to the data collected on site by the LTPP regional support contractor, the highway agency had the responsibility of submitting information about the SPS experiments: for example, inventory forms for overlay SPS experiments, construction sheets from all SPS experiments, and information about the asphalt or concrete plant and other equipment and procedures used during construction. The submitted inventory and construction data were not always complete. In some cases, the LTPP regional support contractors, through agency visits and archive searches, retrieved further information, but some SPS construction data are still missing and are likely to remain missing despite many attempts to collect these data.

TRAFFIC DATA

Since the beginning of the LTPP program, highway agencies have committed to provide traffic loading (weight), classification, and volume data for each LTPP test site. The LTPP database contains historical and monitored traffic data, which are discussed in the following sections. A special traffic data collection effort, initiated by FHWA under a pooled-fund study that was supported by the State/Provincial partners, is discussed in chapter 7.

Historical and Monitored Data

“Historical data” is defined as data collected during a period beginning at the initial opening of the pavement to traffic (or the most recent overlay or rehabilitation project) and extending through 1989 and applies only to GPS test sections. The purpose of collecting historical traffic data was to determine the best estimate of annual traffic levels at each test section before LTPP performance monitoring began at the pavement section. “Monitored data” is defined as data collected at the initiation of LTPP performance monitoring of the pavement test section to date.

Historical traffic data on sections in service before and after the start of LTPP monitoring in 1990, were provided by the highway agency. There were occasions when the traffic characteristics of a site were either not known or questionable, and this required effort from the LTPP program and the highway agency, working together, to obtain this information. Figure 6.29 shows an LTPP traffic data sheet that the highway agencies use to submit historical traffic data.

Monitored traffic data are usually collected separately for each lane being monitored. For the LTPP program, data collection was planned only for the outside lane (test lane) in one direction. Earlier in the program, the highway agencies were encouraged to provide traffic data from all lanes to populate the average annual daily traffic (AADT) tables. Monitored traf-

SHEET 1 LTPP TRAFFIC DATA SUMMARY TRANSMITTAL FORM		*STATE ASSIGNED ID [_____]
		*STATE CODE [__]
		*SHRP SECTION ID [_____]
STATE OR PROVINCE _____	COUNTY _____	
HIGHWAY ROUTE NO. _____	MILEPOST# _____	
NEAREST CITY/TOWN _____	NEAREST INTERSECTION _____	
*FUNCTIONAL CLASS _____ NO. LANES EACH DIRECTION _____		TOTAL NO. LANES _____
*DIRECTION OF TRAVEL LTPP LANE _____ [N S E W]		
*DATE OPENED TO TRAFFIC ____-____-____		
FIPS COUNTY CODE _____	FHWA STATION IDENTIFICATION NO. _____	
HPMS SAMPLE NO. _____	HPMS SUBDIVISION _____	
*TYPE OF PAVEMENT: 1- AC ____ 2- PCC ____ 3- OTHER ____		
CONTROL OF ACCESS: YES ____ NO ____ MEDIAN: YES ____ NO ____		
CURRENT (1990) SURROUNDING DEVELOPMENT:		
URBAN ____ SUBURBAN ____ RURAL ____		
DID INTENSITY OF ROADSIDE DEVELOPMENT INCREASE BETWEEN 1980 AND 1990?		
YES ____ NO ____		
IF YES, DESCRIBE CHANGES _____		
NEW FUNCTIONAL CLASS: _____ DATE FUNCTIONAL CLASS CHANGED: _____		
NOTE: ATTACH ALL RELATED FORMS AND COUNT DATA AND SUBMIT TO THE SHRP REGIONAL OFFICE. ATTACH MAP INDICATING THE LOCATION OF EACH TRAFFIC COUNT, VEHICLE CLASSIFICATION COUNT, OR WEIGHT STATION RELATIVE TO THIS LTPP SITE.		
NAME OF PREPARER _____ PHONE # _____		
DATE PREPARED _____		rev. February 28, 2000

FIGURE 6.29. A sample data transmittal form used by the highway agency to submit historical traffic data to the LTPP regional support contractor.

fic data are submitted on a monthly, quarterly, or annual basis depending on the practices of the individual agencies.

Traffic data include distribution of traffic by vehicle classes, days of data collected, and distribution of axle loads for single, tandem, tridem, and quad axles by vehicle class. For locations where traffic data have been submitted for all lanes, the data could include AADT and percent trucks. Beginning in 1990, data have been submitted in one of the electronic record formats documented in FHWA's *Traffic Monitoring Guide*, second through fifth editions, issued in 1992, 1995, 2001, and 2013.⁸⁸

Highway agencies submit traffic information on individual data reporting forms, 16 in all, which provide historical and estimated volume and load data for the test site. The LTPP regional support contractor is responsible for tracking the data transmittal sheets, soliciting them from agencies when required, checking them for reasonableness, and entering them into the LTPP database.

Although every effort has been made by both the highway agencies and the LTPP program, there are still gaps in the traffic data. Collecting traffic data at the LTPP test sections has not been as straightforward as collecting the other data described in this chapter. Many challenges existed, such as different types of traffic data collection equipment used by different highway agencies and the lack of equipment calibration. These are just two of the challenges which the LTPP program sought to remedy in the early to mid 2000s. One approach was to collect at least 1 week of continuous classification data at those sites where no traffic data existed in the LTPP database (internal memorandum, "Minimum Standards for Traffic Monitoring Data Collection on LTPP Sites," January 21, 2009). The other approach required partnering with as many agencies as possible because it involved substantial funding and personnel resources to successfully carry out. This particular effort, better known as the LTPP SPS Traffic Data Collection Pooled-Fund Study, TPF-5(004), is covered in more detail in chapter 7.

Data Collection Equipment

Equipment used to collect traffic data by the highway agencies varied from different kinds of piezoelectric

cables to bending plates to load cells. In the design of the LTPP program, the expectation was that all sites would be instrumented with reliable, low-cost (\$5,000) weigh-in-motion (WIM) scales. However, the original estimated cost and assumed reliability of equipment were not realistic. Therefore expectations for traffic data collection were redefined, and were described using three levels of effort:⁸⁹

- Preferred—Continuous WIM data.
- Desirable—Continuous automatic vehicle classification (AVC) with site-specific seasonal WIM.
- Minimum—1 year's worth of continuous AVC at some time within a 5-year period, with seasonal WIM within that same period.

Data collection was to occur near the test section wherever possible. Where the pavement section under study and the traffic monitoring equipment were not co-located, which was true for nearly 15 percent of the pavement test sections, highway agencies were asked to provide measured data to determine the differences in traffic between the two locations. This information was not provided, however, by every highway agency.

Several years into the program it became clear that many agencies did not have the resources to meet even the minimum option at most locations. For sites for which monitored traffic data are not being collected, highway agencies are asked to provide the LTPP program with estimates of the traffic at the site using the traffic data sheet shown in figure 6.30.

Equipment Calibration

Two new LTPP protocols, detailing the guidelines and procedures for traffic data collection and calibration of data collection equipment, were issued in April 1998.^{90,91} The equipment calibration protocol was issued because of significant anecdotal information that equipment was being installed without calibration or subsequent validation.

Because high-quality traffic data collection requires verification of what is being collected, suggested practices were developed for agency use. After further minor revisions, in April 2000, the LTPP program implemented the *Guide to LTPP Traffic Data Collection and Processing*.⁹² Updated in 2001,⁹³ and 2009,⁹⁴ the guide contains all sheets required to be

submitted with historical, calibration, and electronic traffic data submissions.

The LTPP program encouraged the highway agencies to check and calibrate, if necessary, their equipment every time it was used to collect data for the LTPP program. In addition, permanent WIM scales are expected to have their calibration settings field validated (and updated as necessary) at least twice a year, and data were to be monitored on a monthly basis to ensure that the scales remain calibrated. This calibration check was to include both the weight and vehicle classification data produced by the equipment. It was recommended that data collected from an improperly functioning WIM device not be sent to the LTPP program for inclusion in the database. However, it was apparent to the LTPP program that some data were sent for uncalibrated traffic data collection equipment.

By the late 1990s, it had become clear that the spatial distribution, timeliness, quantity, and quality of the traffic monitoring data needed to be improved. Issues included non-uniform data collection equipment between highway agencies, infrequent or no calibration of the equipment, and insufficient checking of collected data. These deficiencies in the data motivated the LTPP program to develop a plan to collect traffic data of the quality that would be needed for future data analysis studies. This data collection effort was managed by the program from 2001 to 2014 and is covered in more detail in chapter 7.

SUMMARY

Data collection is the primary activity in the LTPP program, which supplies the information from which all productive activities follow—data analysis, product development, and standards. The challenge—to capture research-quality data of diverse types using highly specialized, state-of-the-art equipment with the involvement of many different people spread

SHEET 2 LTPP TRAFFIC DATA		*STATE ASSIGNED ID [] [] [] []			
TRAFFIC VOLUMES AND LOAD ESTIMATES		*STATE CODE [] []			
		*SHRP SECTION ID [] [] [] []			
*YEAR	1 ESTIMATED TOTAL VEHICLES AADT (TWO-WAY)	2 ESTIMATED TOTAL TRUCK AADT (TWO-WAY)	3 ESTIMATED TOTAL VEHICLES AADT LTPP LANE	*4 ESTIMATED TOTAL TRUCKS AADT LTPP LANE	*5 ESTIMATED ESAL*YEAR LTPP LANE (1000'S)
1989					
1988					
1987					
1986					
1985					
1984					
1983					
1982					
1981					
1980					
1979					
1978					
1977					
1976					
1975					
1974					
1973					
1972					
1971					
1970					
1969					
1968					
1967					
1966					
NAME OF PREPARER _____					PHONE # _____
DATE PREPARED _____					Rev. March 12, 2001

FIGURE 6.30. A sample data transmittal form used by the highway agency to submit traffic estimates to the LTPP regional support contractor.

across North America—is great. Documentation of the processes used has been essential, and as the LTPP program advanced, data collection guidelines, QC procedures, and equipment specifications have been created of necessity to assure the integrity of the data. These program documents have become models for other data collection efforts and have led in several cases to national industry standards. The program has kept pace with advances in technology by investing in improved data collection equipment and software, and has undertaken major efforts over the years to assure that the LTPP data are of sufficient quality and quantity to support pavement performance research. These efforts are discussed in the next chapter.

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The LTPP program has mounted three major data collection efforts that have improved the quality and quantity of its climate, traffic, and materials data, and has led the way in investigating pavement performance through forensic studies.

7

Special LTPP Data Collection Efforts

Only data of the highest quality, in sufficient quantity, can be relied upon to yield true and useful answers to research questions. The LTPP program, with the assistance of expert peer groups, has continually reviewed and expanded its collected data to make the LTPP database more valuable to pavement researchers.

INTRODUCTION

The LTPP program has planned and executed three major efforts to enrich the LTPP database or to address areas where data did not meet the program's expectations for quality or sufficiency. These programs went beyond the original experiments in the General Pavement Studies (GPS) and Specific Pavement Studies (SPS). So that pavement responses can be correlated with climatic conditions and traffic loads, the Seasonal Monitoring Program (SMP) gathered daily and seasonal weather data. To remedy the program's lack of consistent, high-quality monitoring traffic data, the LTPP SPS Traffic Data Collection Pooled-Fund Study, supported by the highway agencies, collected continuous classification and weight data at SPS projects where various design and rehabilitation strategies were being monitored. To supplement and correct incomplete materials data,

the Materials Action Plan was carried out. This chapter describes these "special" multiyear data collection efforts and the forensic investigations that have been conducted to increase understanding of pavement performance.

SEASONAL MONITORING PROGRAM DATA

Temperature and moisture-related changes in pavement structures, both within a day, from season to season, over the course of a year, and from year to year, can have significant impact on the structural characteristics of pavement layers, thus affecting the pavement's response to traffic loads and, ultimately, its useful life. To attain a fundamental understanding of the magnitude and impact of temporal (daily, seasonal, and annual) variations in



Key Milestones in Special Data Collection Efforts

- 1992** Seasonal Monitoring Program begins
- 2001** LTPP SPS Traffic Data Collection Pooled-Fund Study initiated
- 2003** Traffic data collection begins for traffic pooled-fund study
- 2004** Seasonal Monitoring Program ends
- 2004** Materials Action Plan implementation begins
- 2004** LTPP develops framework for forensic investigation
- 2008** LTPP conducts four forensic studies
- 2009** Materials Action Plan completed
- 2014** LTPP SPS Traffic Data Collection Pooled-Fund Study ends

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ments as well as measurements of surface elevation, joint openings in Portland cement concrete (PCC) pavements, and various in situ surface and subsurface moisture and temperature parameters. The instrumented sites were widely distributed and represented a variety of climatic and soil conditions (figure 7.1).

It was envisioned that the products from the seasonal monitoring study would provide the means to link pavement response data obtained at random points in time to critical design conditions; the means to validate models for relationships between environmental conditions (e.g., temperature and precipitation) and in situ structural properties of pavement materials; and expanded knowledge of the magnitude and impact of the changes involved. When this study was terminated in 2004, it represented the end to perhaps one of the most successful undertakings within the LTPP program. The seasonal study provided input on the effects of temperature on falling weight deflectometer (FWD) deflection data, seasonal changes in performance of pavements, and the effects of heave (frost) and swell (expansive soils) on pavement performance. This information allowed for better decision making in the use of FWD data and update of current analytical models.

Detailed information about the SMP such as the scope, equipment, data collection procedures, data collected (onsite air temperature and precipitation data, subsurface temperature and moisture content data, and frost-related measurements), and monitoring frequency is discussed below.

pavement response and material properties due to the separate and combined effects of temperature and moisture variations, the Strategic Highway Research Program (SHRP) envisioned the SMP. The study concept received strong support from the LTPP stakeholder community and was also endorsed by the LTPP Pavement Performance Advisory Committee.

Unlike the GPS and SPS experiments, the SMP, which began in 1992, was not a planned experiment during formulation of the LTPP program in the 1985–87 pre-implementation phase. Rather, the study evolved as an extension of the ongoing LTPP deflection testing activities that began in 1989. The original study concept was to perform deflection testing on a more frequent basis on a subset of LTPP test sections to provide the data necessary to “conquer the last frontier” in the structural evaluation of pavements—understanding the daily and seasonal variations in pavement deflections. However, the scope increased to include not only more frequent deflection basin and joint load transfer testing, but also more intensive profile and distress measure-

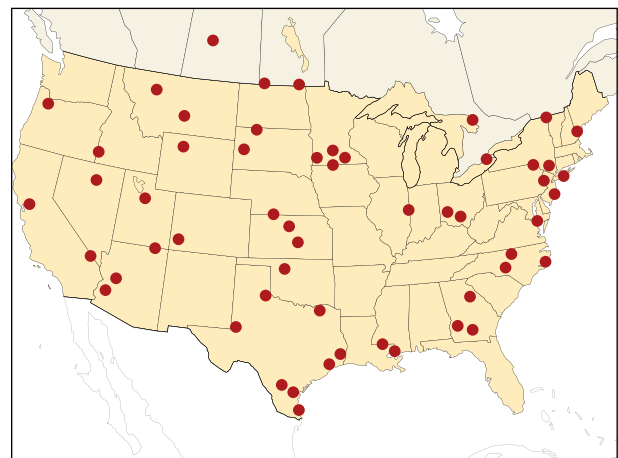


FIGURE 7.1. Distribution of instrumented sites in the LTPP Seasonal Monitoring Program.

Scope

Resource limitations made it impossible to monitor all LTPP test sections on a seasonal basis. Consequently, an experimental matrix of 32 cells was established addressing the following key pavement factors:

- Pavement type—Thin asphalt concrete (AC), thick AC, jointed plain concrete pavement, and reinforced PCC.
- Subgrade—Fine and coarse soil.
- Precipitation—Dry and wet conditions.
- Frost—Freeze and no-freeze conditions.

Traffic was not considered in the experimental matrix, as it was not felt critical to achieving the study objective.

During the test section recruitment effort, 3 sections were sought for each of the 16 AC pavement experiment cells and 1 section for each of the 16 PCC experiment cells—a total of 48 AC pavement test sections and 16 PCC pavement test sections. To cover different soil and environmental conditions, the LTPP program identified 16 sites in each of the four LTPP regions. Ultimately, 63 of the targeted 64 test sections were selected from the GPS and SPS studies to populate the SMP experimental matrix.¹ These test sections were part of the SMP Phase I or Phase II monitoring frequency, as described later in this section.

Monitoring Equipment

At the start of the SMP only minimal funds were available, which meant that most of the options to be considered for instrumentation had to be “low tech” with manual data collection. Moisture data was collected with time domain reflectometer (TDR) probes connected to a Tektronics 1502B cable tester. Thermocouples connected to a precision multi-meter were used to collect temperature readings, and similarly, a resistivity probe was used to determine frost/thaw activity. A piezometer monitoring well (figure 7.2) was chosen to monitor water levels. Rod and level surveys were also conducted at the time of FWD data collection to determine any pavement movement due to frost/thaw activates or swelling of cohesive soils. Figure 7.3 shows the SMP mobile monitoring equipment. Details of the evaluation, selection, and development of probes and other equipment used and challenges encountered are available in appendix C.

Validation of Data Collection Procedures

From 1990 to 1992, pilot studies and training sessions were held to select the instrumentation to be used for surface and subsurface moisture and temperature measurements, as well as to finalize the instrumentation installation, and data collection guidelines. GPS test section 361011 which is a flexible pavement on I-481 near Syracuse, New York, was selected as the first pilot. The New York State Department of Transportation (NYSDOT) had conducted various temperature and frost/thaw studies in the past and had in-house expertise that could help with assembly of the instrumentation. The pilot installation on October 22–25, 1991, was attended by the LTPP program and contractor staff, NYSDOT, and CRREL (the U.S. Army Corps of Engineers’ Cold Regions Research and Engineering Laboratory). During the installation, CRREL provided insight on the instrumentation data collection along with the algorithms to analyze the voltage outputs from the thermocouples.



FIGURE 7.2. A piezometer monitoring well and cap, used to determine ground water levels.



FIGURE 7.3. Mobile monitoring equipment for downloading data collected at seasonal monitoring sites.

The LTPP regional support contractors had the opportunity to review the different instrumentation and procedures. A major consideration coming out of the pilot and subsequent data collection at this site was the need to refine the instrumentation and to automate the data collection process.²

Following the initial pilot, the selection and development of instrumentation proceeded as plans were put in place for additional pilots, which were conducted at test section 163023, a rigid pavement near Boise, Idaho, in November 1991; and test section 308129, a flexible pavement near Billings, Montana, in August 1992.^{3,4} A Campbell Scientific, Inc. (CSI) CR10 Datalogger was purchased, and software was developed to automate the data collection. After the evaluation of the TDR alternatives, a 3-prong, 203-mm-long, stainless steel tube probe was selected because of its accuracy, repeatability, and ease of installation. However, to reduce the instability of the electronic signal caused by differences in cable length, staff from the LTPP program and the Electronics Laboratory at the Federal Highway Administration's (FHWA) Turner-Fairbank Highway Research Center designed a special TDR

probe. This probe was designed to accurately measure the apparent length of the probe that is used to calculate the dielectric constant of the material surrounding the probe. The dielectric constant is an input to the calculation of moisture content in unbound base and subgrade materials. The final design was fabricated by the Electronics Laboratory specifically for the SMP data collection (figure 7.4 and figure 7.5).



FIGURE 7.4. The moisture probe designed at the FHWA highway research center.

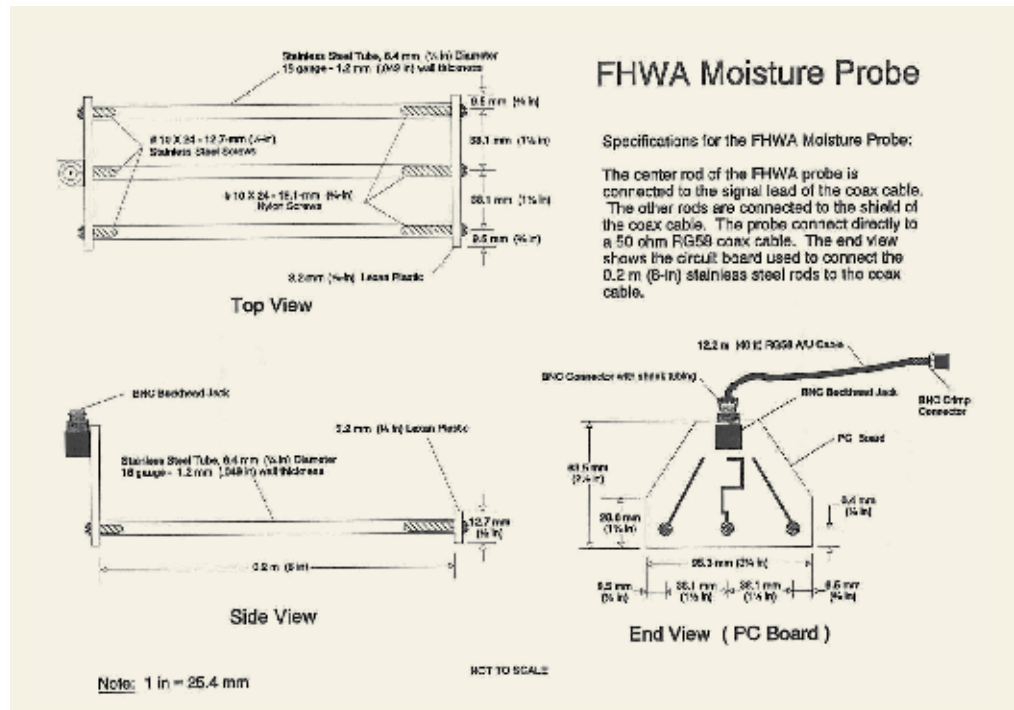


FIGURE 7.5. Schematic of the moisture probe that was used to obtain moisture content in unbound base and subgrade materials in the SMP, designed at the FHWA highway research center.⁵

Data Collected and Monitoring Frequency

Monitoring of select LTPP test sections that were also part of the seasonal study began in 1992 and had a more extensive and more frequent data collection monitoring schedule than the other LTPP test sections. The 63 seasonal sites were monitored in SMP Phase I and 24 of them were monitored in SMP Phase II. Although the two phases were monitored at different times throughout the year, the frequency of the data collected was monthly. However, in the spring and fall, the data were collected twice a month.

Regardless of the monitoring phase, the same data elements were collected for each SMP site. The core data elements collected were deflection, profile, and distress data. In addition, surface elevations, ambient temperature, precipitation, sub-surface moisture, sub-surface temperature, frost depth, and ground water table elevation were also collected.⁶ It should be noted that procedures for cold weather FWD testing were developed specifically for the SMP.

SMP Phase I Monitoring

Approximately half of the seasonal test sections were monitored in alternate years—one loop of test sections in 1992, 1994, 1996, and 1998 and the other loop of test sections in 1993, 1995, 1997, and 1999. This data collection schedule was used because of the limited availability of the instrumentation, equipment, and LTPP program contracting resources. Once one loop of testing was complete, the instrumentation and equipment were rotated to the second loop of test sections for monitoring. However, the initial data collection cycle was extended by a year to compensate for problems encountered early in the SMP, including battery pack failures. The D-cell battery packs were replaced with gel cell batteries that could be recharged or continuously charged through a solar panel.

It was originally envisioned that seasonal monitoring would be performed on three alternate years per test section, from 1992 to 1997, but the instrumentation performed better than expected and there was a great deal of interest in the study by the participating highway agencies, so monitoring was extended until 1999. This period of monitoring would eventually be called the SMP Phase I monitoring, and it extended over an 8-year period.

SMP Phase II Monitoring

As a result of the success of the SMP Phase I data collection activities, many highway agencies supported the continuation of the program, and planning began in 1998 for a second phase (see sidebar). The objective of the SMP Phase II monitoring, which began in 1999, was to continue to provide the data needed to attain a fundamental understanding of the magnitude and impact of diurnal, seasonal, and annual variations in pavement response and properties due to the separate and combined effects of temperature, moisture, and frost penetration. However, unlike Phase I, this phase was limited to test sections that had available the full suite of data (i.e., monitoring,

In April 1999, the LTPP program and its contractor staff held a Phase II pilot at the LTPP 510114 test site in Danville, Virginia, to install the instrumentation that was to be used in the Phase II monitoring and to perform a trial test (internal document, “LTPP Seasonal Monitoring Program, Phase 2 Installation and Monitoring Activities,” April 2006). Based on the results from this pilot, the LTPP program developed a manual to upgrade SMP sites to Phase II instrumentation. The photograph below shows a completed installation of monitoring equipment at the SMP Phase II pilot.





FIGURE 7.6. SMP Phase II seasonal monitoring equipment installation at the Lake Ontario State Parkway site on SR 947A in western New York.

materials, and inventory data) required for pavement performance monitoring. Figure 7.6 shows the monitoring equipment installed at a Phase II seasonal site.

Twenty-four of the SMP Phase I monitoring test sections were selected for the SMP Phase II monitoring on the basis of data completeness, instrumentation condition, and willingness of the highway agency to support the effort. Data collection requirements remained largely the same as in the first phase, but the frequency of deflection testing was reduced, and the option was provided for either fixed-interval testing or direct-event testing, depending on the climatic regime at the site. The direct-event option was made possible in part because at 10 of the 24 test sections, equipment was upgraded to automate collection of moisture and frost/thaw data when triggered by precipitation or specified soil temperatures. Unlike temperature measurements, which were continuously collected during SMP Phase I monitoring, moisture and frost/thaw depth measurements had been collected manually at 4-hour intervals on the days of deflection testing, using the mobile monitoring equipment. During SMP Phase II, moisture and frost/thaw depth data were collected continuously when the new equipment was triggered by conditions (i.e., when the temperature reached a certain degree, frost information was collected). This direct-event testing equipment was rotated among the 24 test sections.

Quality Control Software

Software was developed for field quality control (QC) and review of the SMP data. In 1995, during Phase I, the LTPP program developed the ONSFIELD software to QC and review onsite data (temperature and rainfall),

and the MOBFIELD software to review the mobile data (moisture and frost/thaw).⁷ In addition, Seasonal Monitoring Program Check, or SMPCheck, was developed for central office processing and loading of data into the LTPP database, with a manual released in 1996.⁸

During Phase II, the CR10 operating software was updated to the PC208 Windows version. This resulted in changes to the data collection routines and provided a better user interface, eliminating the need for the CR10 procedural routines developed in the DOS version.⁹ A CR10 procedural program along with documentation was developed to provide a systematic approach for the SMP data collection,¹⁰ and later a comprehensive data collection guidelines document was created to ensure high-quality data would be collected.¹¹ LTPP program directives were issued to provide resolutions for data collection and processing issues from October 1993 to November 2002 and to document changes in procedures.

Training and Data Interpretation

Training sessions were held throughout the SMP when new versions of the equipment or software were made for processing and interpreting SMP data. Editing of the plots to “null” timeframes that contained no data, the removal of bad data, and the interpretation of TDR traces were part of the training. This training was often conducted in conjunction with data training for the automated weather stations (chapter 6).

An evaluation of the moisture determination from TDR methods was also done. This method of developing and identifying inflection points, along with the Topp et al. procedure for determining the volumetric moisture content of soils from dielectric constant,¹² was adapted by the LTPP program.¹³ As both manual TDR traces on paper and automated traces were collected, an interpretation manual was developed for the TDR traces. This manual outlined the procedures on how to interpret different trace types and generate volumetric moisture values from manual traces.¹⁴

The evaluation of the automated resistance/resistivity data to determine frost/thaw depths was more difficult, as no mathematical solution could be applied (since the input voltage was not recorded). As such, manual interpretation of the traces was required. Evaluating the 2-point and 4-point resistivity, manually collected

at the time of site visits, had the same limitations. Using the 4-point resistivity to determine soil moisture and other conditions was also considered impractical as soil volume changes with weather and seasons.

TDR and resistivity data collected from the seasonal monitoring sites do not directly provide information useful to pavement engineers. Rather, the data must be interpreted to develop subsurface moisture content and frost condition information. The LTPP program has sponsored four studies to compute these parameters. Two initial studies were conducted to compute frost conditions and moisture content from data collected through 1998.^{15,16} After these studies were completed, additional data were collected but were not routinely interpreted. Considering this, FHWA sponsored two other studies to evaluate the methodologies used in the initial studies and to compute frost and moisture content for all of the data in the LTPP database. The procedures used were modified from the original studies, and computations were made for all collected SMP data.^{17,18}

SMP data collection ended in October 2004, for reasons ranging from failing sensors, sections being rehabilitated or going out of study, and financial constraints.¹⁹ At the completion of Phase II data collection, the instrumentation and equipment from most of the SMP sites were removed and returned to the LTPP regional offices (with the exception of the in-ground instrumentation). Exceptions were in Arizona and Ohio, where the SMP site/equipment was transferred to the highway agency. At some of the sites, a forensic study of the condition of the instrumentation was undertaken in which the in-ground instrumentation was removed and examined. The installation, decommissioning, and re-commissioning of seasonal monitoring sites are documented in reports that detail the instrumentation, its location within the pavement layers, material properties, and any problems.²⁰

The SMP projects have provided pavement designers and researchers with an abundance of research-quality environmental data. Combined with measurements taken at the automated and virtual weather stations, these data have already proven useful in evaluating and modifying rigid pavement design procedures, refining the selection of performance-graded binders, evaluating seasonal load restrictions, and defining moisture and frost penetration prediction models.

LTPP SPS TRAFFIC DATA COLLECTION POOLED-FUND STUDY

A 1996 program assessment (chapter 11) revealed major traffic data deficiencies in the LTPP database. To address this issue, the LTPP program and the Transportation Research Board Expert Task Group (ETG) on LTPP Traffic Data Collection and Analysis studied the problem and developed an action plan.²¹ This 1999 action plan provided guidelines to improve traffic monitoring by assuring uniformity of data collection equipment across States and Provinces, establishing regular equipment calibrations, and ensuring that a sufficient quantity of data would be collected to support research and product development.²²

Around this time, weigh-in-motion (WIM) technologies were greatly improved; however, their cost and the additional staff needed to maintain, calibrate, and operate the systems properly made it impossible to install a permanent WIM system at every LTPP test site. Therefore, the LTPP program and the Traffic ETG (figure 7.7) decided to collect traffic loading data only at SPS experiments, specifically SPS-1 (structural factors for flexible pavements), -2 (structural factors for rigid pavements), -5 (rehabilitation of AC pavements), and -6 (rehabilitation of jointed PCC pavements).²³ To implement the traffic monitoring action plan, FHWA, with the support of the American Association of State Highway and Transportation Officials (AASHTO) and the participation of many highway agencies, initiated the LTPP SPS Traffic Data Collection Pooled-Fund Study, TPF-5(004), in 2001.

The objective of this study was to improve the quality and increase the quantity of monitored traffic data (volumes, classifications, and weights) at selected LTPP SPS test sites. Since 2003, this multiyear study has collected “research-quality data” for at least 5 years at

The LTPP SPS Traffic Data Collection Pooled-Fund Study aimed to improve the quality and increase the quantity of monitored traffic data at select LTPP SPS test sites.



FIGURE 7.7. Traffic ETG members who provided technical guidance and direction to the traffic pooled-fund study (left to right: Andrew Nichols, Elizabeth Stolz, Patricia Hu, David Cebon (Chair), Anne-Marie McDonnell, and Richard Reel). Not pictured but also instrumental in developing the study were members Larry Scofield (former Chair), Richard Quinley, Richard Rogers, and James Kramer.

TABLE 7.1. LTPP WIM system performance requirements.

Pooled-Fund Site Factor	95 Percent Confidence Limit of Error
Loaded Single Axles	±20 percent
Loaded Axle Groups	±15 percent
Gross Vehicle Weights	±10 percent
Vehicle Length	greater of 1.5 ft or ±3 percent
Vehicle Speed	±1 mi/h
Axle Spacing Length	±0.5 ft [150 mm]

28 of the 84 SPS sites using bending plate, load cell, and quartz WIM sensors. For the purpose of this study, research-quality data was defined to be at least 210 days of data (in a year) of known calibration meeting LTPP’s performance requirements for steering and tandem axles, gross vehicle weight, bumper-to-bumper vehicle length, vehicle speed, and axle spacing, as listed in table 7.1. In this study, the first contracted WIM equipment was installed in 2005 in Illinois; the last installation was in Indiana in 2008. These two locations along with others are still producing research-quality data.

Many pooled-fund studies use the funds contributed by participating States for any area of the study. In this study, however, each State’s contribution goes to its own data collection needs at its SPS projects. Six of the 28 participating States (figure 7.8) recognized the value of the study—as well as the potential for advancing their own traffic data collection activities—and decided to become donor States. Their contributions allowed the LTPP program to expand data collection.

Before the traffic pooled-fund study began, the LTPP program field-tested the installation of the WIM

equipment and the calibration and validation protocols at five pilot locations. These pilot studies are discussed in the next section.

Pilot Studies Conducted to Test Protocols

The LTPP program developed a series of protocols and guidelines to acquire uniformly collected, research-quality traffic data. The guidelines include a suggested performance-based equipment specification for equipment replacement, a

performance specification for validating equipment operation in the field, and pavement smoothness criteria. In addition, a field protocol addressing the calibration and validation procedures was prepared for all traffic data collection activities.²⁴

Over the summer and fall of 2001, LTPP staff oversaw five pilot studies to verify that the new performance specifications and field procedures were feasible. The pilots looked at both piezoelectric cable and bending plate sensor systems installed in AC and PCC pavements. One of the pilot sites was used to test the reinstallation process, and a side-by-side comparison of the principal sensor systems, piezoelectric cable, and bending plate was performed at another site.²⁵

The following sites were examined as part of the pilot studies in 2001:²⁶

1. Arizona SPS-6 site 040600. The traffic monitoring equipment included inductance loops and bending plates in all lanes installed in a PCC pavement about 500 ft (152 m) in length. The WIM installation process was tested at this location.
2. Florida WIM site not part of the LTPP experiment. The traffic monitoring equipment included inductance loops/piezoelectric cable sensors as well as inductance loops/bending plate installations in the northbound and southbound lanes in an AC pavement. A side-by-side comparison of the piezoelectric cable and bending plate sensors at this non-LTPP site showed that the piezoelectric cable did not perform as well as the bending plate.
3. Maryland SPS-5 site 240500. This site had a system with a pair of piezoelectric cable sensors without direct temperature compensation and a pair of



FIGURE 7.9. Load cell WIM installation.



FIGURE 7.10. Staggered bending plate WIM sensors installed in concrete pavement.



FIGURE 7.11. Installation of quartz piezoelectric WIM sensor spanning a full lane.

submitted the data on a weekly basis to the LTPP regional support contractors for further QC and processing. The second contractor performed field evaluation and validation of all WIM equipment installations, including equipment installed by highway agencies. Highway agencies that installed and maintained their

own WIM equipment sent the data directly to the LTPP regional support contractors for processing.

An extra step in processing the traffic data was to check for gross data changes over time. The LTPP regional support contractors used the LTPP Traffic Analysis Software to check the weekly data against a reference data set. The reference data set covers the 14 days immediately following a successful calibration and validation of the WIM system and provides the typical vehicle classification and loading conditions for the site. Data reviewed after the 14-day period are expected to reasonably match the reference data set (figure 7.12).

Although the pooled-fund study ended in 2014, its field validation, data collection, and other activities continue to be centrally managed by the LTPP program (at select sites) with the support of the contractors and highway agencies.

Products of the Study

Some of the products that have been developed as a result of the traffic pooled-fund study are the LTPP Field Operations Guide for SPS WIM Sites (WIM Data Quality Guidelines), a glossary of WIM terms, LTPP vehicle classification table, and new traffic defaults for use with the Mechanistic-Empirical Pavement Design Guide, as well as the AASHTO smoothness specification. Guidelines for equipment calibration checks and equipment model specifications were also developed and are available through the LTPP Customer Support Service Center (Email: ltppinfo@dot.gov). The information gathered, documentation produced, and lessons learned from this effort were shared with pavement and traffic engineers and traffic data collectors in WIM workshops that were held by the States. This study led to significant advances in the accuracy and reliability of permanent traffic monitoring equipment and has significantly improved the availability and quality of monitored traffic data for pavement, bridge, and other analysis studies.

MATERIALS ACTION PLAN

Collection of accurate and reliable materials data is a critical element of the LTPP program. As discussed in chapter 11, in 2004 the LTPP program undertook a major effort, the SPS Materials Action Plan, to fill iden-

New Mexico, SPS-1 Test Section 350100

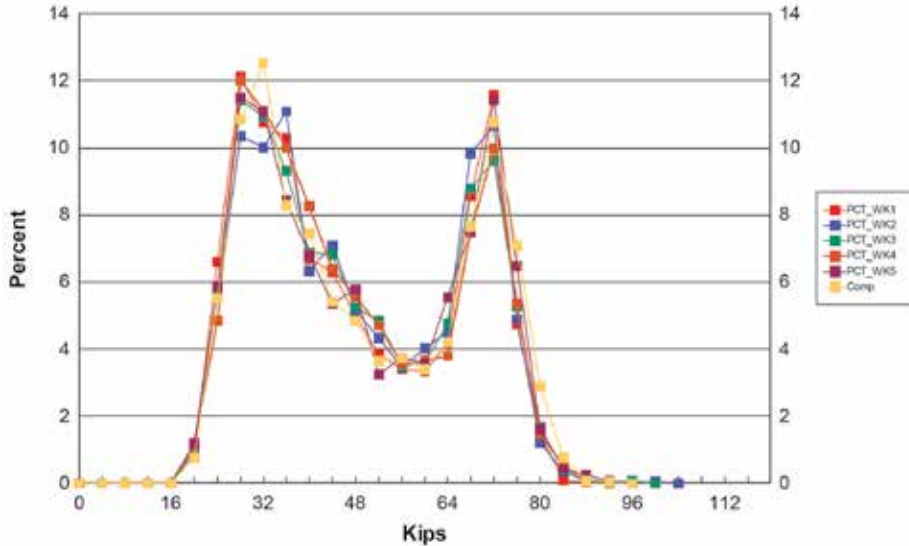


FIGURE 7.12. Screen shot from LTPP Traffic Analysis Software showing loadings of Class 9 traffic over a 5-week period in March 2011. “Comp” line represents the reference data set.

tified gaps in the materials data for the SPS projects. Efforts begun in 1997 had brought improvement, but serious gaps remained. The plan for resolving materials data deficiencies was laid out in an internal LTPP document, “LTPP SPS Materials Data Resolution: Update and Final Action Plan, August 2004.” The plan addressed three major areas of materials data needs for SPS-1, -2, -5, -6, and -8 projects:

- Resolution of materials data gaps—urgently required.
- Aging and new materials testing—highly desirable.
- Collection of materials samples—desirable.

The sampling and testing requirements that addressed these three areas were based on criteria defined in the internal Final Action Plan. These criteria were based on missing data per layer type and the requirement that three test results were needed for each layer. The initial Materials Action Plan pilot took place in Maryland in 2005.²⁸

To get the plan underway, the LTPP regional support contractors developed site-specific sampling plans and coordinated all activities with the highway agencies. The regional contractors were present during the sampling operations to ensure that the plans (approved by the LTPP program and the highway agencies) were followed. They identified and marked

all sampling locations, performed some of the field testing, and were responsible for labeling, packing, and shipping samples to the laboratories involved in the testing and for completing the sampling data sheets.

The highway agencies’ responsibilities were to provide traffic control, perform field sampling, and patch the holes where samples were taken. Due to the multiple activities at the site, coordination between the agency’s field crew and the regional support contractor’s crew was essential to ensure that samples were properly collected and tests were performed without interruption. A new, Web-based system was developed to track the layers and samples as they were collected, shipped, and tested, and as laboratory results were loaded into the database.

One challenge encountered during the SPS materials sampling was the lack of material to perform some of the laboratory tests. To resolve this, samples were combined for testing. A special form was used to log the different samples that should be combined for performing certain tests. For example, two or more bags of unbound granular material were combined to perform the resilient modulus testing (P46), and four cores were used to perform the asphalt resilient modulus testing (P07).

In the field, the regional contractor staff had the responsibility of performing some of the tests, mainly

the dynamic cone penetrometer for unbound layers, as shown in figure 7.13, and also thickness measurements and moisture determination.

The plan was to use two laboratories, one to perform the resilient modulus testing and one to perform the remaining tests. In the end, the contract for both testing functions was awarded to a single contractor; thus all testing was performed at one location with the exception of the coefficient of thermal expansion (P63) test, which was performed in the Concrete Laboratory at the FHWA highway research center.

The contracting laboratory was AASHTO-certified for performing standard procedures on soils, aggregates, asphalt binder, asphalt emulsion, and hot-mix asphalt and also had a current laboratory assessment from the ASTM Cement and Concrete Reference Laboratory. The contracted laboratory's quality management system was certified for compliance with AASHTO Standard Practice R 18, Standard Practice for Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories. The contractor was required to have a QC program to provide control over the activities that can affect the quality of materials laboratory testing. The LTPP program conducted a startup inspection visit in October 2005, with additional visits in the following years to inspect resilient modulus testing procedures and quality management compliance with AASHTO Standard Practice R18. Upon approval, data that passed the quality assurance (QA) review were transmitted to the LTPP regional support contractors for input to the

LTPP database. The primary objective of the QC/QA activities was to ensure that the required data collected were of high quality.

Under the Materials Action Plan, approximately 95 percent of the materials tests ordered from the LTPP contract laboratory were able to be tested using the rigorous LTPP test protocols, with a total of 10,863 tests performed. Although the collection of samples for future use was strongly supported by the LTPP program, it was assigned a lower priority due to financial constraints. Of the desired samples, 74 percent of the 12-inch (305-mm) core samples and 61 percent of the 4-inch (102-mm) core samples were delivered to the Materials Reference Library (1,544 cores in total), and 1,488 samples of bulk material were added to the collection. Data from tests not previously performed were added to the database, corrections were made to some pavement structure information from new field investigations, and, where possible, previous data deficiencies were corrected. The final report for this effort provides extensive detail on the amount of data collected and the reduction in missing data elements in the LTPP database.²⁹

FORENSIC STUDIES

Data that can be collected at the end of a test section's life can help to improve understanding of the causes of premature pavement failure and, in exceptionally long-lasting pavements, the reasons for superior performance. Ideally, whenever an LTPP pavement test section fails, is scheduled for replacement or rehabilitation, or is removed from an LTPP experiment for other reasons, a forensic study would be conducted to investigate in detail the processes of pavement deterioration and failure. By illuminating the causes and mechanisms of pavement distresses, forensic data can be used to design and implement an effective rehabilitation strategy for the pavement and prevent similar failures from occurring in the future. Forensic data are essential to improving design practices and updating construction techniques and can be valuable in the development or calibration of performance-prediction models. End-of-life evaluations also provide an opportunity to collect missing or incomplete test section data for the LTPP database.³⁰



FIGURE 7.13. LTPP regional support contractor staff use the dynamic core penetrometer to determine the strength and density of the subgrade at the SPS-5 site in Minnesota.

Forensic investigations are considered an important element of the LTPP program; however, funding constraints made implementation difficult. In 2004, the program developed a manual, *Framework for LTPP Forensic Investigations—Final*, to promote consistency in forensic studies and maximize their benefits.³¹ In 2008, FHWA funded four LTPP forensic studies. These studies examined hot-mix asphalt pavements that were exhibiting cracking and rutting:³²

- Arizona SPS-5 (rehabilitation of AC pavements)—To identify the cause of higher-than-expected rutting in the recycled sections (figure 7.14).
- Ohio SPS-1 (structural factors for flexible pavements)—To determine why the project had many more pavement distresses than the SPS-9 (Superpave™) project that is located in the same area.³³
- New York SPS-8 (environmental effects in the absence of heavy loads)—To investigate the observed early pavement distresses, which occurred in the absence of heavy loads.³⁴
- Texas SPS-5 (rehabilitation of AC pavements)—To determine why the project was performing substantially better than the surrounding pavement with similar pavement characteristics, and to examine reflection cracking and rutting in individual layers.³⁵

Other highway agencies have conducted their own forensic studies as well, notably Connecticut in connection with the Seasonal Monitoring Program, Texas (SPS-1), Colorado (SPS-5), Arizona (SPS-9, Superpave), Virginia (SPS-1), Quebec (GPS-3), and North Carolina (GPS-2).

In November 2012, in support of NCHRP Project 01-49, Guidelines for Conducting Forensic Investigation of Highway Pavements, the LTPP program sponsored a national workshop that brought together representatives of highway agencies to discuss their current agency practices and review the new national guidelines developed in Project 01-49.³⁶ The workshop presented the complete forensic investigation process that was established in the guidelines, from study initiation through the use of nondestructive and laboratory techniques to investigation closeout.

The LTPP program has played an important role in developing national guidelines that promote the effectiveness and efficiency of future forensic investigations of LTPP test sections as well as other pavement studies

by highway agencies. Future forensic investigation of LTPP test sections that have failed prematurely or have shown unexpectedly good performance will contribute great value to the understanding of the variables that affect pavement performance.

SUMMARY

The LTPP program mounted three successful multiyear data collection efforts to improve the quality and quantity of the program's monitoring of climate, traffic, and materials data. The SMP was a 12-year study with the goal of enriching the understanding of the effects of climatic variations in temperature and moisture on pavement responses. This program resulted in a wealth of new environmental data.

The LTPP SPS Traffic Data Collection Pooled-Fund Study was organized to improve the LTPP traffic data by providing uniformity in data collection equipment, regular equipment calibrations, and daily QC checks of the data. This 11-year data collection effort gathered upwards of 400 million vehicle records and 2.3 billion individual axle-load records—the largest quantity of research-quality traffic data ever assembled. These traffic data are now available to researchers in raw form or summarized as axle-load probability distributions.

The Materials Action Plan was carried out over 5 years to address priority materials data needs for SPS-1, -2, -5, -6, and -8 projects. Under this effort, 10,863 materials tests were performed under the rigorous LTPP test



FIGURE 7.14. Workers prepare a trench for forensic investigation of an SPS-5 test site in Arizona.

protocols. The materials data were improved significantly, and more than 3,000 cores and other samples were added to the Materials Reference Library.

Finally, a rich source of performance data is the forensic investigation of test sections as they reach the end of their useful lives. The LTPP program has developed a framework for forensic evaluation of pavements, participated in the development of national guidelines for forensic studies, and conducted four studies on hot-mix asphalt test sections.

The investment in the special efforts described above and the ongoing, routine data collection activities discussed in chapter 6 have yielded an unprecedented amount of pavement performance information. The systems developed to store, manage, secure, and distribute this information to the public are described in the next chapter.

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The LTPP database provides nearly three decades of pavement performance information and continues to evolve in size, content, and structure.

8

Storage, Growth, Security, and Dissemination of the LTPP Data

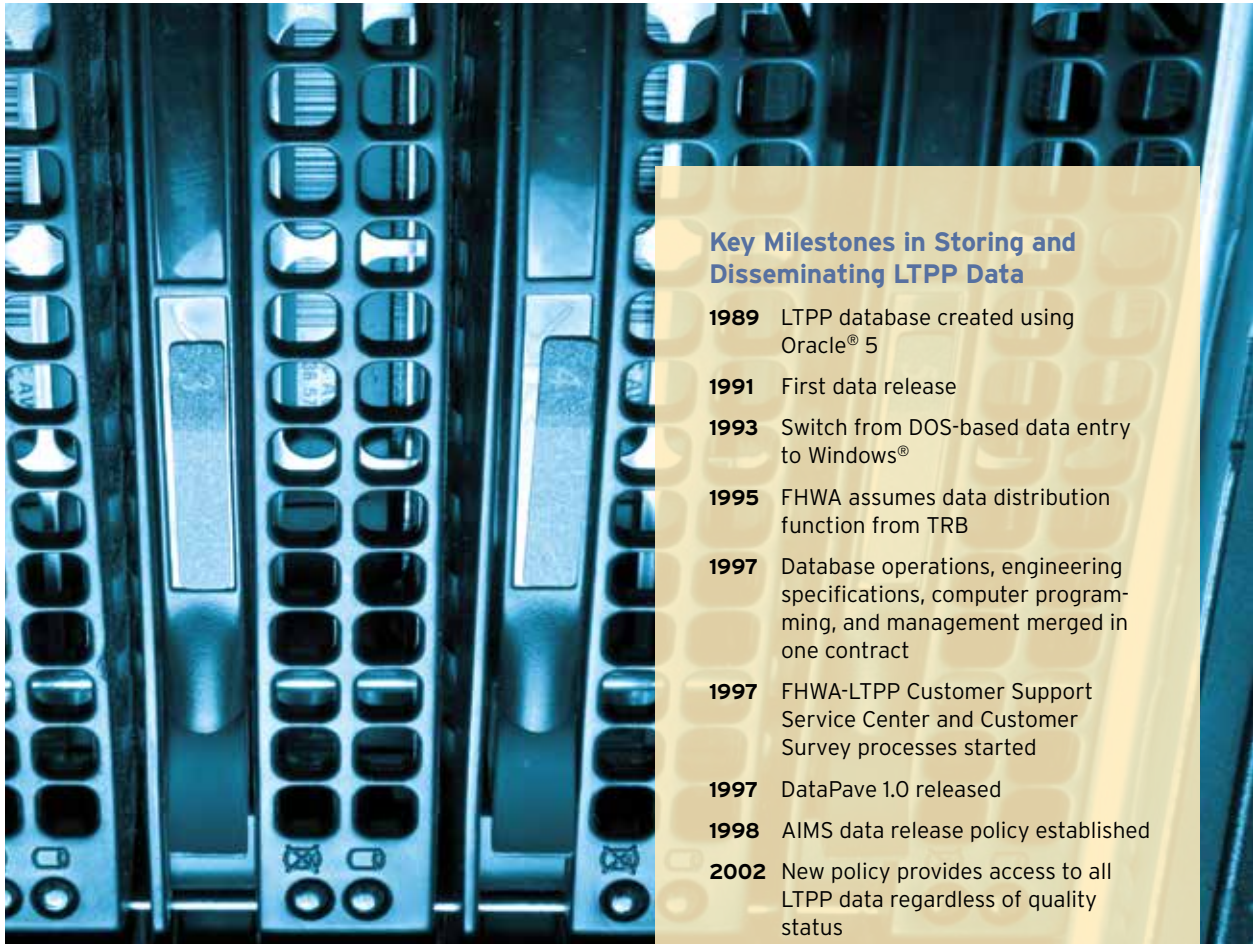
The extraordinary volume and complexity of pavement performance data present a real challenge to the LTPP program—providing quality control, security, and ease of access are the primary considerations. Fortunately, as the mountain of data grows, computer technology advances in ways that continue to benefit the program.

INTRODUCTION

The founders of the LTPP program knew that to achieve the primary engineering objectives of the program, it would be necessary to establish a robust pavement performance research database. Previous efforts to collect research-quality pavement performance data had been short-lived and geographically limited, and they did not secure the data for future use. The LTPP program has successfully accomplished the major challenge of developing, maintaining, and updating a database to support a national approach to improving pavement engineering and management tools.

Today the LTPP database is recognized by the Transportation Research Board (TRB) as LTPP's principal operational tool, its principal product, and its principal legacy to future highway researchers and practitioners.¹ The primary objective of the LTPP

database is to serve as a central repository for data collected by the program in a format that is secure, of known quality, easy to disseminate, and compatible with current database software. Successful completion of this objective has required many changes to the database over time. This chapter summarizes the development of the LTPP database and includes an overview of major structural and processing changes, improvements in computer hardware technology, and upgrades in database management and operating system software. Information on the state of the database with references to other information resources are also included. Although some of the procedures protecting data quality are described here, chapter 9 provides a full discussion of LTPP quality control/quality assurance (QC/QA) processes used by the program.



Key Milestones in Storing and Disseminating LTPP Data

- 1989** LTPP database created using Oracle® 5
- 1991** First data release
- 1993** Switch from DOS-based data entry to Windows®
- 1995** FHWA assumes data distribution function from TRB
- 1997** Database operations, engineering specifications, computer programming, and management merged in one contract
- 1997** FHWA-LTPP Customer Support Service Center and Customer Survey processes started
- 1997** DataPave 1.0 released
- 1998** AIMS data release policy established
- 2002** New policy provides access to all LTPP data regardless of quality status
- 2002** DataPave Online launched
- 2003** First Standard Data Release
- 2006** Customer Support Service Center moves to FHWA's highway research center
- 2008** IMS moves to FHWA's highway research center
- 2009** FHWA pledges to continue LTPP operations
- 2011** FHWA moves all LTPP data to FHWA research center
- 2011** Data entry centralized through online LTPP Data Entry Portal
- 2012** AIMS files centralized online with AIMS Data Entry Portal
- 2014** Debut of LTPP InfoPave™

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The overall system used to manage information intended for LTPP's public dissemination is called the Information Management System (IMS) (figure 8.1). The system's major components are LTPP products, the Pavement Performance Database (PPDB, or LTPP database), and the Ancillary Information Management System (AIMS). Products are program results and tools that can be used to improve pavement performance management and are discussed in chapter 10. At the time of this report, the LTPP database contained 330 million data records: pavement-related data, computed parameters, and summary weather and traffic data. The AIMS contains 2.7 million additional files: documents, videos, photos, and raw data files created in the LTPP program. Together these

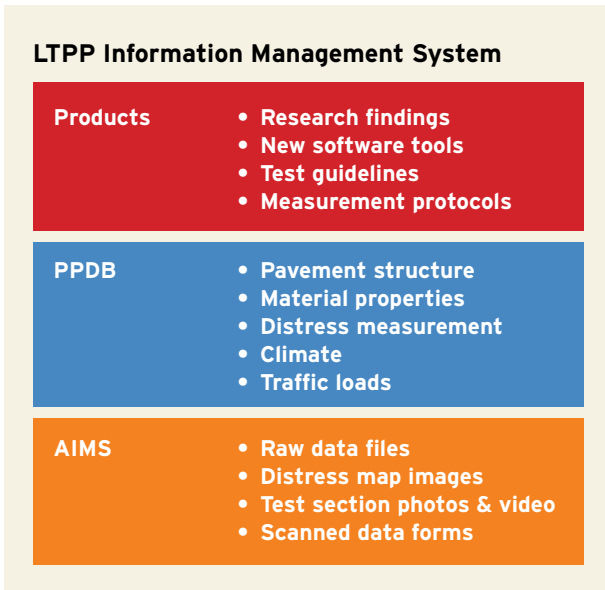


FIGURE 8.1. The LTPP Information Management System (IMS) includes Products, the Pavement Performance Database (PPDB), and the Ancillary Information Management System (AIMS).

collections occupy a significant amount of electronic storage (over 5 TB).

An introduction to the IMS is not complete without a review of the structure and development of the LTPP database. Most LTPP data are collected and processed by the four LTPP regional support contractors; other data are provided by central sources. Each regional support contractor is responsible for loading and processing data for the region’s test sections. These data are input into the national database, which is operated by the central technical support services contractor (referred to as the “technical assistance contractor” earlier in the program). The technical support services contractor is responsible for managing the IMS, loading data from other central data sources, performing extended central checks on all data, creating some central computed parameters, and creating data releases to the public on a periodic cycle. The LTPP Customer Support Service Center staff is responsible for data dissemination and data user support. The following sections describe how this data processing structure has matured over time.

DEVELOPMENT OF THE LTPP INFORMATION MANAGEMENT SYSTEM

Over the course of the LTPP program, changes in the program’s sponsorship and contractual relationships and advances in information technology have influenced the development of the program’s information management processes. This section briefly describes how the data were managed, from point of collection through dissemination to data users, during four time periods.

SHRP-LTPP Database Process (1989 to 1994)

After the national long-term pavement performance database was established under Strategic Highway Research Program (SHRP) management in 1989, the LTPP IMS, which included the LTPP data and its supporting information, consisted of a central node (the national IMS, or NIMS) located at the TRB office in Washington, DC, and the regional nodes (regional IMS, or RIMS), one at each of the four LTPP regional offices. Figure 8.2 illustrates the initial LTPP database process, dataflow, quality checks, and data releases under central operation of the LTPP database by TRB. The four SHRP-LTPP regional coordination office contractors (under the Federal Highway Administration (FHWA) called “regional support contractors”) had primary responsibility for collection and entry of the data into the RIMS. The data were then transferred into a “shadow database” at TRB where all of the regional databases were combined. The shadow database served as intermediate storage while QC checks were run centrally on the data by central SHRP-LTPP contractor staff. A feedback loop to the regional contractors was used to address issues with data failing a QC check. Data exchange between the RIMS and the NIMS was accomplished by mailing cassette tapes to avoid the high cost of telecommunicating large volumes of data.

The LTPP Information Management System includes LTPP Products, the Pavement Performance Database, and the Ancillary Information Management System.

Information supporting the data, such as distress photographs, laboratory data sheets, and core samples, was retained by the regional contractors for future reference. In the early years of the program, this information, which would evolve into the AIMS, was not stored centrally or made available for release.

Figure 8.2 also illustrates two data release categories. Category 1 was data released back to the participating agency where the test section was located. Category 1 data could be released without passing data quality checks. The category 2 data release was to the general public, and these data had to pass five levels of data quality checks. These data quality checks and their impact on how the LTPP program disseminated the data are discussed in the following Data Release Policy section.

The LTPP database is a relational database optimized for data storage and data entry. The database consists of records with multiple elements. Although one or more elements in a record may be subject to automated review, the record is tagged with the worst outcome of all data elements in the record. Data are released at the record level, not as elements from a record. In the release discussions that follow, data and records should be considered synonymous.

Data Release Policy

In the early years of the LTPP program, data released to the public were required to pass a series of data quality checks. In preparation for release of data to the public, five types of QC checks, labeled from A to E, were performed by the NIMS software as part of the level 1 processing. The checks were applied in series, and data did not proceed to the next check until satisfying the previous one. Not all data elements in a record were checked at every level.

- A**—Random checks to ensure correct RIMS-NIMS upload exchange.
- B**—Data dependency checks to ensure that basic section information (location, experiment, etc.) is recorded.
- C**—Minimum data search for critical elements (e.g., friction data should include skid number).
- D**—Expanded range checks to identify data elements that fall outside an expected range.

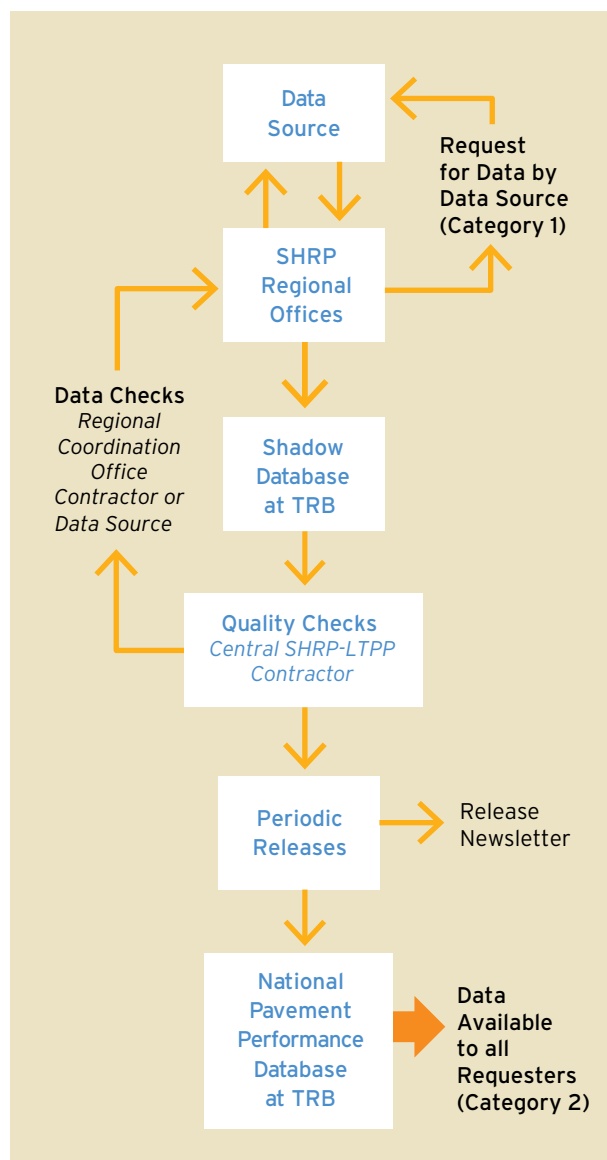


FIGURE 8.2. Overview of the initial SHRP-LTPP database process, data flow, and releases circa 1989 to 1994, with the database of the Strategic Highway Research Program (SHRP) offices residing at the Transportation Research Board (TRB). (Adapted from J. T. Maddock 1991.²)

E—Intramodular checks to verify consistency of data within or between records.³

Data passing all five level 1 checks, qualified as a level 1, category 2, data release to the general public. Data passing the level 1 checks were also called “level E” data

because the field named RECORD_STATUS contained an entry of E to indicate a record had passed.

A level 2 set of data QC checks, tied to what was called an “experiment release,” was planned but not implemented. The plan was for data passing level 1 checks to be subject to the following four types of additional global, cross-modular checks:

F—Intermodular cross checks to verify existence and consistency of data for related categories.

G—Experiment and cell assignment checks based on collected data.

H—Various checks involving frequency distributions and bimodal and variance checks.

I—Statistical checks for outliers, missing data, and completeness of experiment.

Although the full progression of QC checks to level 2 for all data was not realized, the planned level 2 checks have since been applied in a more limited way as part of some of the level 1 checks, other forms of post-upload checks, and formal data studies.

Beginning in January 1991, four data releases were made available to the public, upon request, at 6-month intervals. All were level 1 releases of data from the General Pavement Studies (GPS).⁴ Details of the QC/QA processing are discussed in chapter 9.

FHWA-LTPP Database Process (1995 to 1999)

Following the end of SHRP and transfer of the LTPP program to FHWA, management of the LTPP IMS remained with SHRP under a contract between the two parties from 1992 to 1995. In 1995, TRB transferred management of the LTPP IMS to FHWA. Operation of the central LTPP database became the responsibility of the LTPP pavement database contractor, and the central hardware was moved to the contractor’s location in Oak Ridge, Tennessee.

Also circa 1994 to 1995, a major shift of responsibility to the regional support contractors for primary QC processing of LTPP data was being implemented. This change was inspired by the relatively long time lag between the results of central QC checks from the central LTPP contractor and subsequent resolutions/data corrections by regional contractors. To provide automation and central review of QC check results, the central

LTPP contractor created a software program named “Browser.” The Browser program allowed the regional contractors to comment on data failing a QC check and provided rudimentary scripts to perform manual upgrades to a record’s QC status. In concept, all manual upgrades to data records failing a QC check would be reviewed by the central LTPP contractor and the comments explaining these manual QC upgrades would be made available to data users. Figure 8.3 illustrates the changes in data processing responsibilities and flow from the initial database model shown in figure 8.2.

In 1998, a new process was introduced to document the outcome of data review and correction processes. The Data Analysis/Operations Feedback Report (DAOFR) became a method by which any user of LTPP data could raise questions about data elements or data processes and initiate review and corrective actions by the LTPP program. The DAOFR became a method of systematically documenting issues identified by researchers and others about completeness and validity of data.

During this time period, supporting data to be associated with AIMS continued to be retained by the regional support contractors.

In 1997, FHWA combined the central technical assistance services for pavement engineering, database management, and traffic engineering into a single contract. This was a significant milestone for the LTPP database: it fostered effective, direct communications among these three technical professions that previously were split into three separate contracts. A true synergy developed among the pavement engineering staff, who understood what the pavement engineering data meant; traffic engineers, who knew what the traffic data meant; and the computer database staff, who knew how best to use available computer technology to store, process, and disseminate the combined pavement and traffic data that comprises the majority of the LTPP database. It was around this time that the program developed formal guidelines for adding new elements to the database, modifying existing elements, and resolving issues. The guidelines provided conventions and specifications to ensure that engineers and software programmers could communicate effectively and efficiently to develop the database.⁵

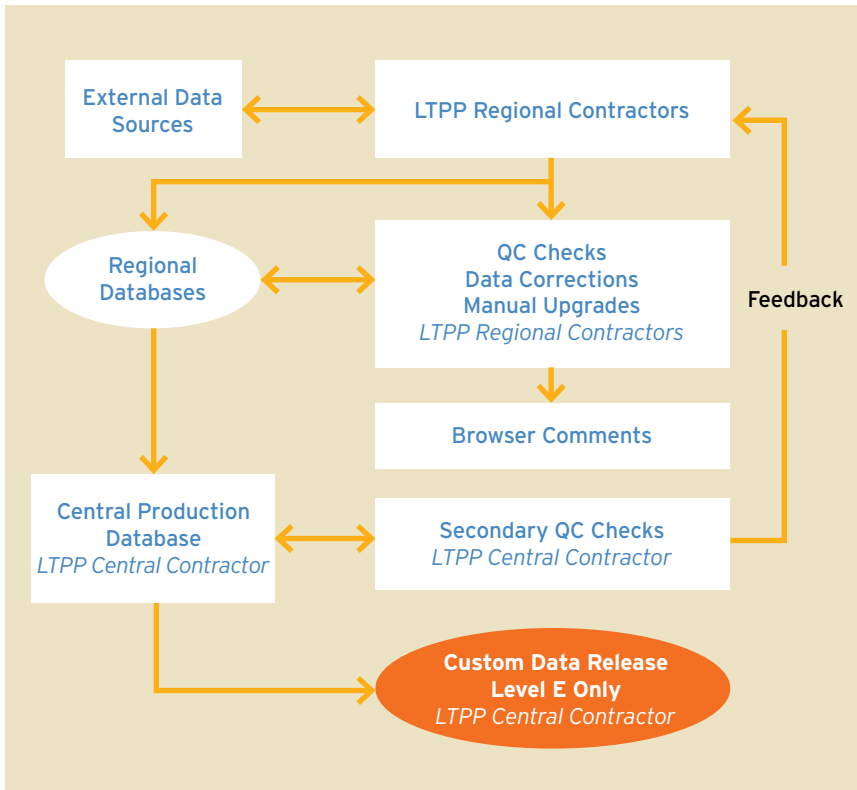


FIGURE 8.3. Functional diagram of LTPP data processing flow circa 1995 to 1999, which allowed regional support contractor offices to make manual quality control (QC) upgrades and explain them in the Browser software.

Data Release Policy

During the 1995 to 1999 time period, the data release policy for the NIMS remained the same as it was during the SHRP-LTPP years: data released to the public had to pass all level 1 QC checks and be at level E. The comments explaining manual upgrades made by the regional support contractors were provided to data users. In 1998, a policy for release of data contained in AIMS was established.

FHWA-LTPP Database Process (2000 to 2011)

An interesting LTPP database improvement was made in 2001, when the LTPP program began recording pavement structural changes by incrementing the test section construction number each time a maintenance or rehabilitation activity occurred on a test section. The construction number is a critical field in many LTPP database tables that links pavement performance measurements

to the physical pavement structure existing at the time. Adding the sequential numbering system to indicate all work activities performed on a test section during LTPP monitoring provided a convenient method to indicate these changes. Implementing this major change to the database required close collaboration between the LTPP program office and its contractor staff to review the technical details of the change and to resolve inconsistencies. This change was reflected in the database and in data releases from November 2001 forward.

During this period, there was explicit recognition of the value of LTPP information that exists outside of the database for researchers. Loss of AIMS-eligible data due to media failures led to a transition from floppy disks to CD-ROMs as the primary backup and storage medium in 2001.

This change created the foundation of the structure for AIMS and the first submissions for central distribution. In 2005, the types of ancillary data included were expanded, the structures revised, and the storage and distribution medium changed to DVD.

Data Release Policy

A database paradigm shift occurred in 2002 with a change to LTPP's data release policy. The decision was made to release all LTPP data contained in the database, regardless of its quality, to the public, free of charge.⁶ Previously, only data that had passed the automated QC checks or had been manually upgraded by LTPP contractor staff to level E (previously referred to as category 2) were generally available to the public. So, those interested in all LTPP data during that time period had to make a special request that needed to be approved by the LTPP program office. This policy cre-

ated problems of perception over the quality and amount of available LTPP data.

Level E records should not be considered better or worse than records at other levels for various reasons:

- Although the automated QC checks are extensive, they are not capable of detecting all types of data issues. The checks have changed and continue to evolve over time as new problems are discovered. Records that may have passed a QC level previously may not pass now.
- The structure of the LTPP database record contains multiple data fields of related data elements. Just because one data element fails a check does not mean that other values contained in the same record are not valid.
- There have been no direct means for a data user to know which records have passed all QC checks and which records have been manually upgraded in status. A plan was developed to provide this information to the data user, but it has not yet been implemented. A data user has to manually peruse the comments tables to understand previously recognized data issues.
- Releasing only level E data masked potential missing data issues: a data user did not know whether or not data were missing at level E.

By releasing all available LTPP data, the LTPP program gave data users the opportunity to evaluate data quality concerns relative to their intended analysis objective for themselves.

LTPP Standard Data Release

Another major milestone in LTPP database history, concurrent with the change in LTPP database release policy, was the development of the LTPP Standard Data Release (SDR) in Microsoft® Access®. The idea for the LTPP SDR started with a national review of data by the pavement engineers who were part of LTPP's technical support services contractor staff. Because of the high cost of licenses for Oracle® (the software used for the LTPP database) and the complexity involved in working with it, the LTPP regional support contractor

staff sent the data in Microsoft Access format to the technical contractor for review prior to releasing the data to the public. The Microsoft Access format allowed the pavement engineers to simply “look” at the data, sort the data by fields to find outliers, and perform other automated calculations to detect data anomalies without extensive Oracle knowledge.

The concept for the SDR was born from the recognition that pavement engineers performing research are not likely to have easy access to an Oracle license. Since the Microsoft Access database format was already being used to disseminate LTPP data to the program's pavement engineers, it was a simple step to make this format available to the public as a standard release format. The only drawback to using Access was that the LTPP database had to be divided into a series of smaller databases due to a 2-GB limit on the size of an Access database. The first LTPP SDR was distributed in January 2003 in CD-ROM format. This was LTPP data release 15 and contained data through summer 2002.

Figure 8.4 illustrates the functional LTPP database flow and QC checks that existed in 2011. Notice that the technical support services contractor no longer reviewed data generated by the Browser program or reran the automated QC checks at the national level. Central checks of the data were manual checks performed by the technical support services contractor based on data issues discovered since the last data upload, changes to existing data modules, new data modules, and verification of action taken by regional support contractors in the DAOFR process. AIMS data were submitted directly to the database archive at FHWA's Turner-Fairbank Highway Research Center in McLean, Virginia (hereafter called “FHWA's highway research center”) without formal quality data inspections by the technical support services contractor.

The first LTPP Standard Data Release was issued in January 2003 as SDR 15. It contained data collected through summer 2002.

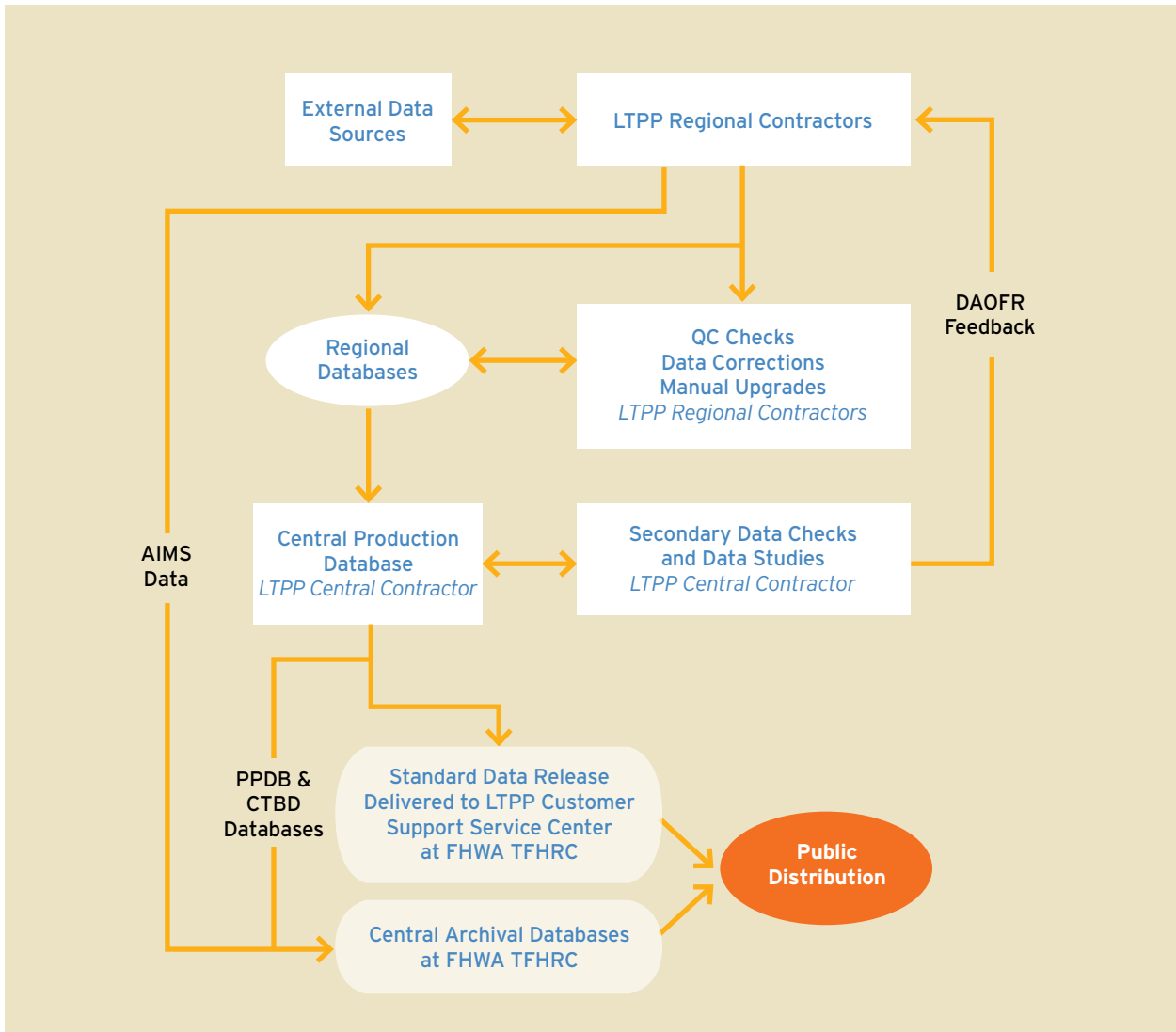


FIGURE 8.4. Functional diagram of LTPP data processing flow circa 2000 to 2011. The central contractor (technical support services contractor) performs secondary quality control (QC) checks before adding data to the Pavement Performance Database (PPDB) and the Central Traffic Database (CTDB) and preparing the Standard Data Release for delivery to the LTPP Customer Support Service Center (CSSC) at the FHWA Turner-Fairbank Highway Research Center (TFHRC) for distribution. The Data Analysis/Operations Feedback Report (DAOFR) form is used to document data issues and their resolution. Ancillary Information Management System (AIMS) data flow directly from the regional support contractors to the central archive.

FHWA-LTPP Database Process (2011 to present)

In 2009, FHWA developed a strategic plan to maintain and further develop the LTPP database. This internal document provided for continued customer support service to LTPP data users, public access to the LTPP database via the Internet, and use of the Internet for data submissions by the regional support contractors.

Development of a new LTPP Data Entry Portal (LDEP) began in 2010 and was completed in 2011.⁷ By creating a single central data entry portal accessible over the Internet, the LDEP reduces program costs for purchasing and upgrading software and equipment in the regional offices and allows for secure and efficient transfer of LTPP data from the regional support contractors through the portal. This change also keeps the LTPP database current with computer technology. To convert the LTPP database to an online system, the following migration process was used:

- A new server and associated hardware were purchased. (The history of database hardware is summarized in the following section.)
- The existing LTPP database, automated data entry software, LTPP Traffic Analysis Software (LTAS), and QC software were ported to Internet-compatible software platforms using a semi-automated process followed by a manual review of the code, debugging, and necessary changes.
- Approximately 95 manual data entry forms for currently active data modules were modified to a current version of Java to work on the new system and to extend their shelf life for future platform changes.
- Approximately 50 QC programs for active database modules were altered to change database referential code, alter mathematical algorithms, and adapt the report functions to the Internet platform.
- Approximately 28 programs that automate the process of reading electronic data and creating records in the database tables were altered.
- The LTAS software was set up in a separate but integrated portion of the data entry portal. Changes to accommodate the Internet-based computing

platform included modification of data loader programs, QC routines, and data graphing functions.

- Following traditional software testing procedures, the internal set of alpha tests performed by the technical support services contractor was followed up with beta testing by the regional support contractors.
- At the end of the alpha and beta test periods, the LDEP was opened for a validation test.
 - The validation test consisted of a limited period of dual data entry into the old and new systems.
 - At the end of the dual entry period, comparisons were made between the old and new systems to validate that the new system was performing correctly.
- The new Internet-based system was officially opened for full operation in 2011.⁸
- For security, the contents of the old system were electronically archived and stored in the central LTPP repository at FHWA's highway research center.
- A newly established automated software issue reporting and tracking system was developed to perform corrections, updates, and modifications to the system as new issues are discovered.

Figure 8.5 illustrates the greater centralization of data processing that currently exists. The shift from regional database servers to a central database server at FHWA's highway research center allows secondary central data QC functions to be performed continuously as the regional support contractors enter data. From a logistical viewpoint, centralization also simplifies rollout of new database software and central data updates since the need for consistency in software between the central server and four different regional database servers no longer exists. Updates to software and data are now done only on the central operational database server, and processing and QC checks are carried out in a secure Internet zone. Since the introduction to the Web-based LTPP database, operations are continually refined to keep current with computer technology and to improve overall operations.^{9,10,11}

The other significant operational change in LTPP electronic data file management allowed by the

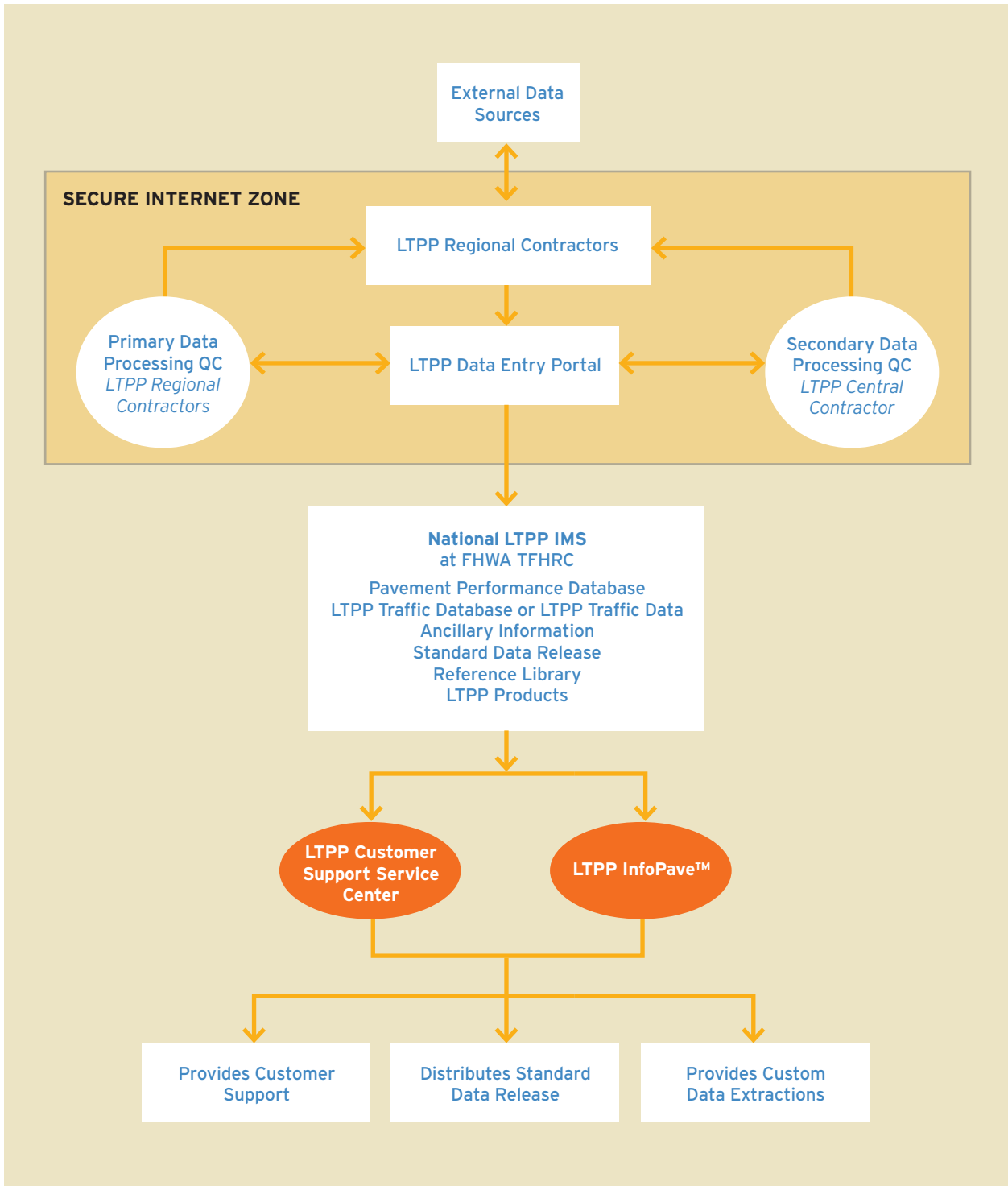


FIGURE 8.5. Functional diagram of LTPP data processing flow circa 2011 to present created by integration of LTPP regional databases into the LTPP central operational database. Processing and quality control (QC) checks are carried out in the secure Internet zone. The FHWA Turner-Fairbank Highway Research Center (TFHRC) maintains the Information Management System (IMS).

migration to a Web-based paradigm was creation of the AIMS Data Entry Portal (ADEP) within the LDEP. AIMS, which contains raw data forms, images, electronic recorded data, and interpreted data sets, is comprised of a set of electronic files organized into a logical file directory storage structure. It is updated over time as new documents are created from continuing data collection and operational activities. To support periodic updates and changes, the ADEP was set up within the LDEP using the TortoiseSVN open source version control system. Use of this file management software structure now allows the LTPP program to add new files as updates to the central archive instead of performing complete replacements.

HISTORY OF LTPP INFORMATION MANAGEMENT SYSTEM HARDWARE AND SOFTWARE

Changes in LTPP data storage and dissemination were driven by the rapid increase in data collected and by advances in computing technology. The rising capabilities and falling costs of computer hardware, accompanied by advances in database software, made it possible to keep pace with the challenges inherent in a program of this magnitude. This section describes the computer hardware and software used throughout the years to store LTPP data and information.

IMS Hardware

The history of the LTPP IMS hardware is outlined in table 8.1, and photographs appear in figure 8.6, figure 8.7, figure 8.8, and figure 8.9.

These changes in computer hardware technology are indicative of the technology challenges faced by the LTPP program. Servers that cost more than \$120,000 at the start of the program, with very limited capacity, now cost less than \$10,000 with capacities and capabilities that were hard to imagine in 1987.

Between 2006 and 2007, FHWA management began plans to consolidate operations of the LTPP Customer Support Service Center and the IMS from Oak Ridge, Tennessee, to FHWA's highway research center. This shift in operation started with locating a suitable space

at the research center to house the new national database server where the pavement performance data would reside. The AIMS data that support the pavement data were also consolidated at the research center—all of the raw data files, images of paper data forms, and video in electronic format. Relocation of the LTPP IMS was completed in spring 2008.^{12,13} In 2009, both the pavement performance database and AIMS were installed on the newly purchased, state-of-the-art server at the research center.

IMS Software

Software operating systems and database management systems have changed at a pace similar to hardware changes. The LTPP program has continually updated its software in response to these changes. The LTPP database is a relational database originally implemented in Oracle 5 format. As of this writing, the IMS operating system is Windows Server 2008 and the database is implemented in Oracle 11g. Due to its widespread use, Microsoft Access 2000 is used to distribute the SDR, and both Microsoft Access and Excel[®] can be used to download LTPP data online.

The Oracle relational database management system (RDBMS) was initially selected by SHRP in 1989 because it was the only RDBMS available at the time that supported different computer operating systems. The initial plan for development of the LTPP IMS was for the regional support contractors to operate the RIMS on Microsoft Disk Operating System (MS-DOS[®]) personal computers and for the NIMS to run on the VMS operating system used on the UNIX[®]-based computer operated by TRB. VMS[®] stands for Virtual Memory System, which provides a multiuser, multitasking environment, and was introduced in 1979 by DEC with the first VAX[®] minicomputer. The Oracle 5 RDBMS product was selected because it could run on both the MS-DOS and VMS operating systems and included Structured Query Language for data manipulation and maintenance, forms management, menu management, and reporting tools. Also, many third-party products were available at the time that interfaced with this software.¹⁴

Over the years, the LTPP program migrated the database software from the initial MS-DOS-based

TABLE 8.1. IMS computer hardware used in the LTPP program.

Year	Purpose	Model	Capacity	Cost* (each)
1989	RIMS NIMS	Compaq® 80386-25DX	25 MHz, 2 MB RAM, 300 MB hard drive; Everex Cartridge Tape Drive	\$12,500
1989	NIMS	Digital Equipment Corp. (DEC) MicroVAX 3900	33 MHz, 32 MB internal memory; maximum I/O rate 3.3 MB/sec; 9-track external tape drive; connected to the Compaq® 386-25 via high-speed Ethernet link	\$120,000
1992	Additional traffic data storage capacity in the RIMS	Optical disk drives	1,000 MB	\$5,000
1993	NIMS, to increase storage and computa- tional speed (about 3 times faster than MicroVAX)	DEC Alpha 3000 AXP 400 S	96 MB RAM, 1 GB internal SCSI disk drive; 10 GB external storage (hard drive chassis containing three 1.6-GB disk drives, Qualstar® 6250 bpi SCSI 9-track tape drive, and Winchester FlashDAT Turbo single-tape backup subsystem with 4 GB capacity 4 mm tape drive)	\$160,000
1993	RIMS, for database storage	Ideal 486DX2-50	50 MHz, 512 MB hard drive, 14,400-baud modem	\$7,000
1995	RIMS, for traffic data quality processing	Micron® Pentium®	90 MHz	\$6,700
1997	NIMS, for database server	Compaq ProLiant 1500 5/166P	Pentium®, 166 MHz, 4.3 GB hard drive storage	\$35,000
2001	NIMS, one each for production database and test database RIMS	Dell™ PowerEdge™ 4400	Dual Intel® Pentium III Xeon®, 1 GB SDRAM, 5 No. 36-GB 10,000 RPM SCSI hard drives in a RAID-5 array, DLT4000 40/80 GB internal tape backup, uninterruptible power supply	\$11,000
2001	NIMS RIMS	Dell Precision 530 Workstation	Dual Intel Pentium III 1 GHz processor, 786 GB of 800 ECC RDRAM, 40-GB hard drive, 12X.8X/ 32X CD read-write drive, 16X DVD read drive	\$3,200
2005	NIMS	Dell/EMC AX100SC external Storage Area Network Fibre Channel	1 TB storage	\$9,300
2007	NIMS, to replace PowerEdge 4400	Dell PowerEdge 2900	2 Dual-core Intel Xeon 5120 1.8 GHz processors, 2 GB RAM, internal RAID-5 hard drive array, 876 GB storage, PowerVault™ 110T-LTO2-L tape backup, 2200VA uninterruptible power supply, external 500 GB USB disk drive, 48X IDE CD-RW/ DVD-ROM drive	\$8,300
2009	NIMS, for both LTPP database and AIMS	Dell PowerEdge 2900III	Dual quad-core Intel Xeon 5450, 3.0 GHz processors, 32 GB RAM, internal RAID-5 hard drive array, 8 TB storage, external RD1000 USB drive with removable hard disks for data backup, 2200VA uninterruptible power supply, 16X DVD-ROM	\$10,500
2011	Central LDEP Web server	Dell PowerEdge R510	Dual 6-core Intel Xeon 5675, 3.06 GHz processors, 32 GB RAM, 1 TB RAID 1 hard drive array (two 1 TB drives) for the OS, 12 TB RAID-5 hard drive array (eight 2TB drives using one as a hot spare) for data, external RD1000 USB drive with removable hard disks for data backup, USB hub	\$16,700

RIMS = Regional Information Management System; NIMS = National Information Management System; AIMS = Ancillary Information Management System; LDEP = LTPP Data Entry Portal.

* Cost shown in dollar value for the year the equipment was purchased.



FIGURE 8.6. DEC MicroVAX 3900 computer running the UNIX® operating system, used as the first LTPP National Information Management System (NIMS) server from 1989 to 1993.



FIGURE 8.7. The LTPP DEC Alpha 3000 AXP 400 S computer system running the UNIX® operating system, used for NIMS server functions from 1993 to 1997.



FIGURE 8.9. Dell™ PowerEdge™ 2900III installed in May 2009 at FHWA's Turner-Fairbank Highway Research Center to serve as the secure central repository for LTPP electronic data into the future. The server contains 8 TB disk storage, dual quad core Xeon® 3 GHz processors, 32 GB RAM, and the Windows® Server 2008 64-bit operating system.

FIGURE 8.8. Compaq® ProLiant 1500 server running Windows® NT 16-bit operating system, used for the central database server 1997 to 2001.

computer operating system platform to Microsoft Windows® platforms. One of the first significant migrations occurred in 1993, when, with the conversion from Oracle 5 to 6, the DOS-based manual data input forms were converted to run under Microsoft Windows using a third-party software package. Some of the manual data entry forms programmed early in the program are still based on an MS-DOS sequential function key-based technology to reduce the programming costs associated with point-and-click technology.

LTPP's technical support services contractor maintains an internal Software Performance Report (SPR) database that documents all changes to LTPP database software performed by the contractor. The SPR database is an excellent tool that was developed to document and track software-related issues. It contains all critical information: problem description, problem resolution, submission and resolution dates, and other details. SPRs can be submitted by the regional support contractors for problems they have experienced using the LTPP database software or by the technical support services contractor for issues requiring correction.

The next upgrade challenge was to adapt the LTPP custom software to the new 64-bit Windows operating system and Oracle version for the new Dell PowerEdge 2900III installed at FHWA's highway research center in 2009. The LTPP program has developed a systematic approach based on quality management principles to meet the challenges of implementing new computer software, in order to continue to serve the program's changing software needs.

DATA STORAGE

The LTPP program stores the majority of the performance data collected from the LTPP test sections in an electronic relational database format. In addition, the program stores raw data files and other information about the test sections in AIMS.

Pavement Performance Database

The pavement performance data are stored in a relational database, meaning that it is composed of sepa-

rate, but related, tables of data. All data are stored in simple row/column format tables. Rows are referred to as records and columns as fields. Each row of data in a table is uniquely identified by the values in a primary key column or a combination of columns. In addition, relationships exist among the tables of the database that are represented by common data values stored in more than one table. For example, many data tables contain State code and SHRP identification columns, which uniquely identify the test sections and projects. These fields are used to locate or join data for a specific test section from different tables.

Database Modules

The data storage tables in the LTPP database are organized into modules containing similar tables. With the exception of the tables in the Administration module, the first part of the table name identifies the module to which a particular table belongs. In the LTPP SDR, the modules are as follows:

Administration (ADM)—The master test section control table consisting of metadata tables that describe the structure and content of the database, and the general comments tables.

Automated Weather Station (AWS)—Site-specific climatic information measured at automated weather stations installed near almost all Specific Pavement Studies (SPS) -1 (structural factors for flexible pavements), -2 (structural factors for rigid pavements), and -8 (environmental effects in the absence of heavy loads) project sites.

Climate (CLM)—General environmental information from government-operated weather stations located near test sections. Data may be from a single site within 7 mi (11 km) of the section or from a site-specific statistical estimate based on sites within a 50-mi (81-km) radius.

Data Compilation Views (DCV)—Data compiled from other existing tables with the primary intent of reducing the number of tables a user needs to examine for similar types of data elements.

Dynamic Load Response (DLR)—Dynamic load response instrumentation data from SPS test sections located in North Carolina and Ohio.

Ground Penetrating Radar (GPR)—GPR measurements performed on a subset of SPS-1, -2, -5 (rehabilitation of asphalt concrete), and -6 (rehabilitation of jointed Portland cement concrete) sections performed in 2003.

Inventory (INV)—Inventory information for all GPS test sections and for SPS sections originally classified as maintenance and rehabilitation experiments. Tables in this module contain general pavement information on the sections' pavement structure prior to their inclusion in the LTPP program.

Maintenance (MNT) and Rehabilitation (RHB)—Maintenance and rehabilitation data are combined into one module in the SDR because they are closely related. The data tables, however, are identified by MNT or RHB in the table names.

Monitoring (MON)—A series of submodules organized by data type. The submodules contained in the MON module are deflection, photographic distress, manual distress, drainage, friction, longitudinal profile, and transverse profile distortion (rutting).

Deflection (MON_DEFL)—Deflection measurements from falling weight deflectometer (FWD) testing, pavement temperature gradient data measured during FWD testing, and computed parameters based on FWD measurements. The names of all tables in this submodule begin with “MON_DEFL.”

Distress (MON_DIS)—Distress survey data from both manual and film-based surveys that include the amount and severity of cracking, patching, and potholes and the existence of surface deformation, joint defects, and other types of pavement surface defects.

Drainage (MON_DRAIN)—Information on the inspection of subsurface drainage features on selected SPS-1, -2, and -6 test sites.

Friction (MON_FRICTION)—Friction measurements performed by participating highway agencies.

Profile (MON_PROFILE)—Longitudinal profile data collected by automated inertial profiler or by manual Dipstick® measurements.

Rutting (MON_RUT)—Rutting data measured using a 1.2-m (4-ft) straightedge.

Transverse Profile (MON_T_PROF)—Transverse profile data and computed transverse profile distortion indices (rut depth) from manual Dipstick mea-

surements or the optical Pavement Distress Analysis System (PADIAS) method.

Seasonal Monitoring Program (SMP)—SMP-specific data, such as the onsite air temperature and precipitation data, subsurface temperature and moisture content data, and frost-related measurements.

Specific Pavement Studies (SPS)—Construction and general information for SPS test sites. SPS test sites that were newly constructed for the LTPP program are part of the SPS-1, -2, -8, and -9 (Superpave®) experiments. SPS-3 (preventive maintenance of flexible pavements), -4 (preventive maintenance of rigid pavements), -5, -6, -7 (bonded Portland cement concrete (PCC) overlay of PCC pavements), and -9 consist mainly of existing pavements with experimental maintenance or rehabilitation treatments. SPS-9 contains both newly constructed and pre-existing pavements.

Traffic (TRF)—Traffic load, classification, and volume data.

Test (TST)—Field and laboratory materials testing data from LTPP test sections.

Detailed technical information on all tables contained in these LTPP database modules is available in the *LTPP Information Management System User Guide*.¹⁵ Due to the changing nature of the LTPP database, this guide is updated for each data release and is also included in the SDR in the LTPP Reference Library. The IMS User Guide includes tutorials on common questions such as how to find linked materials data on SPS test sites. Prior to the release of SDR 28 in January 2014, the previous versions of this guide were referred to as the *LTPP Information Management System, Pavement Performance Database User Reference Guide*.¹⁶ The name of the guide was changed because information on AIMS and LTAS was added.

Computed Parameters

A primary consideration in the design of the LTPP database was to disseminate data in their most disaggregated “raw” form; however, occasionally computed parameters have been added to the database for the data user's convenience. Computed parameters are aggregations, computations, summarizations, or interpretations of raw data to derive new data ele-

Computed parameters are aggregations, computations, summarizations, or interpretations of raw data to derive new data elements.

ments. The LTPP program policy on incorporating computed parameters, which at one time were called “computed quantities,” was first established in 1996.¹⁷ In 2000, a new program policy changed the name to “computed parameters” and defined the roles of those involved with their creation.¹⁸

Some computed parameters are standard indices or data concepts with broad acceptance, such as soil classification following the methodology of the American Association of State Highway and Transportation Officials. Others are statistical representations of repeat measurements such as average and standard deviation. Still others are more complex derivations from multiple sources of raw data such as equivalent single-axle load, rut depth from transverse profile measurements, and backcalculated pavement layer moduli from FWD and pavement thickness measurements.

Most of the computed parameters contained in the LTPP database are internally computed. This means the parameters are computed by the database software as part of the normal processing and storage of raw data. Examples of internal LTPP computed parameter include:

- Roughness indices from longitudinal profile measurements.
 - International Roughness Index.
 - Slope variance.
 - Root mean squared vertical acceleration at various wavelengths.
- Material properties from laboratory tests.
 - Resilient modulus and creep compliance on hot-mix asphalt (HMA) materials.
 - Resilient modulus of unbound materials.
 - Compressive strength of PCC materials.
- Distortion indices from multipoint transverse profile measurements.

- 1.8-m (6-ft) straightedge rut depths.
- Lane-width wire reference rut depths.
- Positive, negative, and fill area distortion indices.
- Climate data.
 - Freeze index.
 - Number of freeze-thaw cycles.
 - Virtual weather station climate estimates.

External computed parameters contained in the LTPP database are those where data were extracted from the database at some point in time, calculations performed external to the LTPP program, and the resulting computed parameters entered into the database. The primary operational issue with external computed parameters is updating or changing quality labels for the computed parameters when changes are made to the input data. External parameters included in the LTPP database are those where significant engineering expertise and computation resources are needed that are not available to many data users. In concept, provision of these complex computed parameters will promote many types of analysis efforts using LTPP data at lower cost to the sponsoring agency. Examples of the external computed parameters in the LTPP database include:

- Moisture contents of unbound materials from time domain reflectometer (TDR) measurements on SMP sites.
 - Moisture estimates from automated TDR measurements using the traditional regression based dielectric constant approach.
 - Moisture estimates from manual TDR measurements using a speculative dielectric constant interpretation approach coupled with traditional regression-based dielectric constant-moisture content approach.
 - Moisture estimates from automated TDR measurements using the Transmission Line Equation approach coupled with a micro-mechanistic model to estimate moisture content.
- Subsurface frost penetration estimates on SMP sites.
- Backcalculated pavement layer moduli from FWD measurements.

- Dynamic modulus-based $|E^*|$ estimates for HMA materials using empirical- and mechanistic-based models derived from generalized material classification and LTPP resilient-modulus test measurements inputs.
- Climate data computed from the National Aeronautics and Space Administration's satellite-based Modern-Era Retrospective Analysis for Research and Applications, or MERRA, data.

Like the other tables in the LTPP database modules, detailed technical information on computed parameters is included in the IMS User Guide.¹⁹

Ancillary Information Management System

The LTPP database was intended to disseminate as much raw data as possible, but some raw data containing information on the performance of test sections were not included in the database due to cost and other practical reasons. The objective of AIMS is to provide a central source of information and data that are not available in the pavement performance database, are frequently requested by LTPP data users, or provide a historical record of data reported on paper data forms. Table 8.2 lists the data contained in AIMS.

AIMS data are stored in the LTPP IMS at FHWA's highway research center. The data and images are

TABLE 8.2. Contents of the Ancillary Information Management System.

Data Type	Electronic Files
Falling weight deflectometer data	<ul style="list-style-type: none"> • Raw files containing deflection-time history measurements • Raw files from reference and relative calibration tests
Longitudinal profile data	<ul style="list-style-type: none"> • Raw data files with 25-mm interval elevations • Profile measurements at weigh-in-motion sites • Files created by the ProQual pre-processing software
Transverse profile data	<ul style="list-style-type: none"> • Profile measurements
Pavement distress data	<ul style="list-style-type: none"> • Digitally scanned, hand-drawn distress maps from manual distress surveys • Digital images from manual distress surveys • Digital distress maps generated from photographic film interpretation • Digital images scanned from 35-mm black and white photographic film • Data summary forms from photographic film interpretation
Traffic data	<ul style="list-style-type: none"> • Binary data files for select weigh-in-motion sites • ASCII data files for select weigh-in-motion sites containing data to hundredths of a second • Site summary reports for ASCII data files • Volume, classification, and weight data in Traffic Monitoring Guide formats
Digitally scanned paper data collection forms	<ul style="list-style-type: none"> • Inventory • SPS construction • Seasonal Monitoring Program • Rehabilitation • Maintenance • Material sampling and testing forms • Traffic estimates • Traffic data equipment validation and calibration visits • Pavement gradient temperature measurement during FWD tests • Friction measurements • Faulting measurements • Dipstick measurements • Test section status change forms
Digitized test section videos	<ul style="list-style-type: none"> • Initial walking video inspections of test sections • Walking video inspections performed during manual distress surveys • Through-the-windshield video during profiler measurements • Drainage pipe inspections

stored electronically using a defined directory structure and file-naming convention.²⁰ Access to a large portion of these data is now available through the LTPP InfoPave™ Web interface.

In 2011, the Central Traffic Database became a component of AIMS, having been managed separately as a repository of agency-supplied data from the initiation of data collection. The database contains traffic data processed through LTPP software that was used to compute the annual estimates contained in the pavement performance database. Traffic data are reported in daily, hourly, and per-vehicle record formats for traffic volume, vehicle classification, and truck gross vehicle and axle weights.

GROWTH IN LTPP DATA

In a long-term research program, the number of data elements naturally increases over time as new observations are added. The following time-series graphs illustrate changes in some of the significant data elements that help to explain pavement performance.

The time-series graphs illustrate the general trend in increase of data over time; however, some decreases also occurred due to data quality concerns, changes in data collection/measurement technology, and changes in data release policies.

Another interesting point to note in the following graphs is the magnitude of LTPP data. The LTPP database now contains the most extensive source of detailed engineering data and information ever collected on the performance and properties of modern highway pavements.

Falling Weight Deflectometer Data

The history of FWD data in the public data release can be traced back to the beginning of the program. The first release of FWD data occurred in July 1991. Figure 8.10 illustrates the growth in LTPP FWD data sets over time based on record counts in the deflection master table. One record exists in this table for each set of FWD measurements performed on a test section during a calendar day. The apparent decrease in the 1992 data release represents a change in LTPP QC processing, since only level-E data were released during this time period. The flat line from 2005 to 2009 represents a reduction in FWD measurement frequency due to budgetary constraints. The increase in number of measurements after 2009 reflects the change in LTPP monitoring policy to renew FWD testing but at a lower intensity on fewer test sections.

To illustrate the large volume of data stored in the LTPP database, figure 8.11 shows the growth in the number of individual deflection measurement data

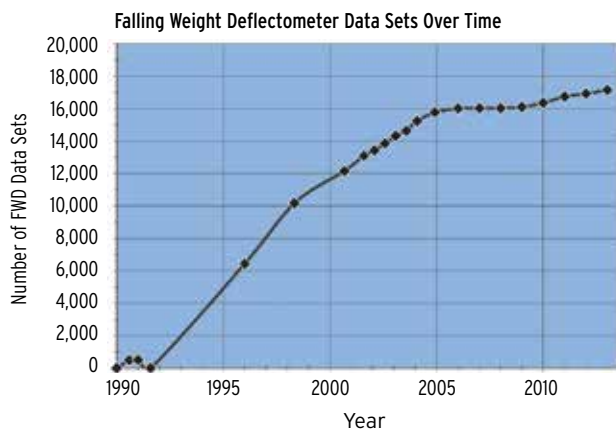


FIGURE 8.10. Historical changes in the number of FWD data sets contained in LTPP data releases.

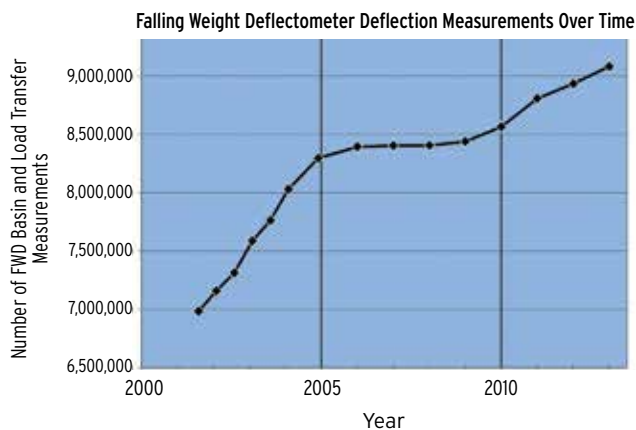


FIGURE 8.11. Growth in number of FWD basin and load transfer measurements contained in the LTPP database since 2002.

since 2002. At each test point, the LTPP FWD data set contains the measured deflection basins of up to four drops from up to four drop heights. Analyzing the more than 9 million FWD deflection measurements accumulated through 2013 is a significant task.

Longitudinal Profile Data

Measurement of the longitudinal profile of a test section is how the LTPP program computes pavement roughness parameters. Figure 8.12 shows the number of profile measurement data sets contained in the LTPP database. The LTPP measurement protocol requires five repeat profile measurements to be stored in the LTPP database for each measurement data set performed by high-speed road profilers, and one data set for manual measurements performed using the Dipstick® device. The amount of filtered profile elevation data stored in the database depends on the measurement device. A longitudinal profile measurement data set from a high-speed road profiler contains around 2,000 data points using a 6-inch (152.4-mm) or 5.9-inch (150-mm) moving average filter. Dipstick measurements are recorded every 12 inches (304.8 mm), however, so only 1,000 data points are stored in the database for a test section that is 500 ft (152.4 m) long.

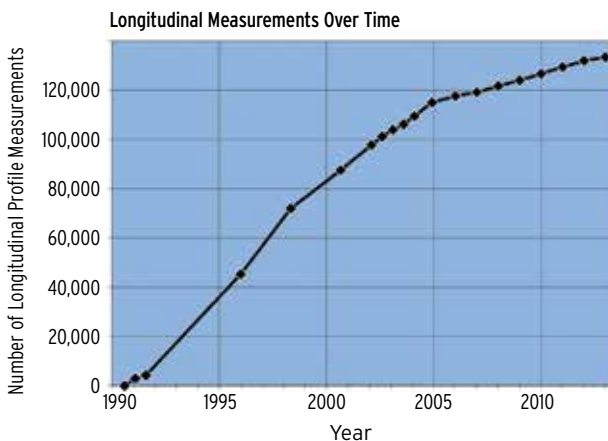


FIGURE 8.12. Growth in number of longitudinal pavement profile measurements.

Pavement Distress Data

Three different types of pavement surface distress data are stored in the LTPP database:

- PADIAS data are distress interpretations from 35-mm photography using the initial interpretation hardware.
- PADIAS 4.2 data are distress interpretations from the 35-mm photography using updated hardware and methods.
- Manual distress survey data are collected by LTPP regional contractors who record their observations during a physical field inspection of a test section.

Figure 8.13 shows the growth in number of pavement surface distress measurements contained in the LTPP database starting in 1992. The PADIAS 4.2 interpretation process for the 35-mm distress images was introduced in 1997. Over time, the images interpreted using the older PADIAS method were reinterpreted using the 4.2 method. The PADIAS method used a grid coordinate system for plotting and measuring surface distresses and the PADIAS 4.2 used a vector system. Data from the two methods were basically the same, and

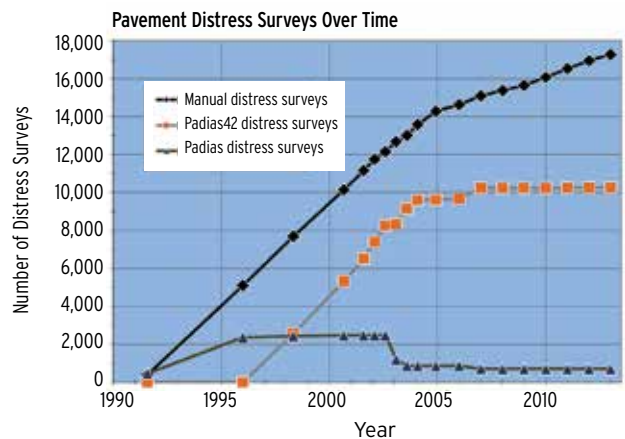


FIGURE 8.13. History of LTPP pavement surface distress surveys. Decline in PADIAS distress survey data is due to replacement with PADIAS 4.2 reinterpretations of the same images.

after a survey had been reinterpreted, the previous PADIAS data were removed from the database. Most of the PADIAS images that have not been reinterpreted are from test sections in the SPS-3 and -4 experiments for the period 1989 to 1992, due to funding limitations.

Transverse Profile Data

Transverse profile measurements are used to characterize different aspects of the pavement surface, such as rutting and pavement cross slope, on both AC- and PCC-surfaced pavements. As noted in chapter 6, two methods have been used by the LTPP program to measure transverse profile. Because the photographic method was not capable of measuring the cross slope, transverse profiles are stored normalized to the begin- and endpoints in the database.²¹ However, since the Dipstick does measure the true elevation difference between begin- and endpoints, starting in 2004, this elevation difference was added to the database in the transverse profile cross-slope table. This is why in figure 8.14 there is a spike in cross-slope data starting in 2004.

Climate Data

The LTPP program performed direct climate measurements at test sections included in the SMP and at SPS-1, -2, and -8 experiments that were instrumented with automated weather stations (AWS). The LTPP program developed QC software and data edit programs to check this data and make adjustments for daylight saving time shifts. As discussed in chapter 7, data collection for the SMP began in August 1992 and was terminated in October 2004.²² LTPP AWS data collection began in August 1994 and was terminated in December 2008.²³ The LTPP program attempted to provide as much data as possible, but the hourly data are not continuous over the collection period due to equipment malfunctions and breakdowns. Figure 8.15 illustrates the massive amount of hourly climate data collected by the LTPP program.

Materials Sampling and Test Data

Figure 8.16 shows the growth in the total number of records in the materials test data module starting in 1996. The total number of records is a relative indica-

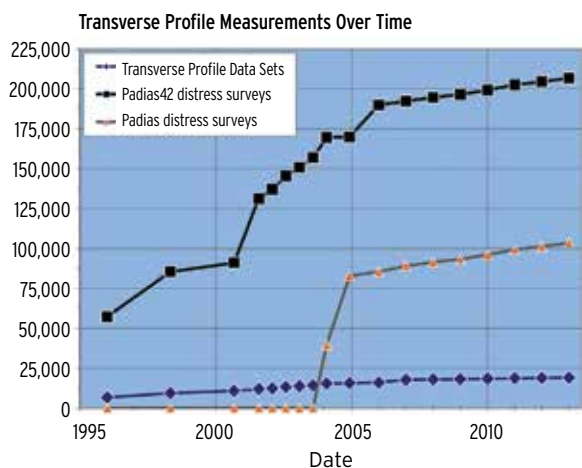


FIGURE 8.14. Increase in transverse profile measurements since 1996. The collection of cross-slope data began in 2004. Cross-slope data allow for evaluation of water retention, which has the potential to produce hydroplaning at the pavement surface.

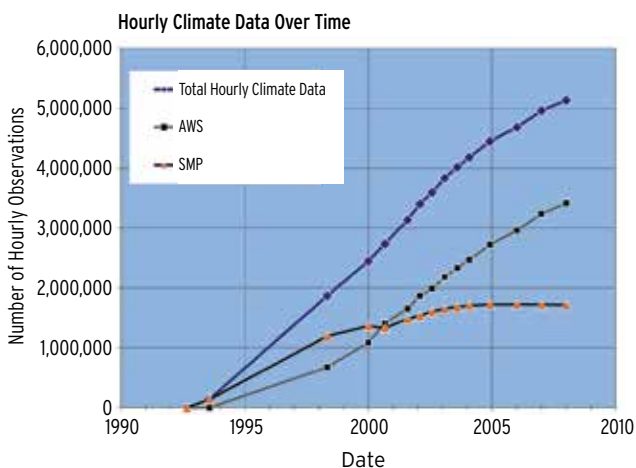


FIGURE 8.15. Growth in number of hourly climate data measurements collected by the LTPP program as part of the Seasonal Monitoring Program and automated weather station data collection efforts. Decreases in the time-series represent the result of quality control checks to remove suspect data.

tor in the growth in materials data because during this time period changes were made to some of the internal data tables that did not result in the addition of more data. An example of this is a drop in the number of records in 2004 caused by removal of administrative tables TST_L06 and TST_L07, which were used to track materials samples and did not contain usable material test data. However, the increase in the total number of records in the materials testing module clearly shows the impact of the Materials Action Plan that was implemented to address missing materials data on SPS projects.

The LTPP program invested significant resources in developing a research-quality test on the measurement of the resilient modulus of AC from field samples. (Development of the LTPP resilient modulus protocols is discussed in chapter 10.) Materials test data from the first LTPP P07 test protocol were removed from the database in 2000.²⁴ Version 2 of the P07 protocol had been developed, which in addition to resilient modulus includes creep compliance and indirect tensile strength measurements. Figure 8.17 shows the growth in the amount of P07 version 2 data.

DATA DISSEMINATION

Dissemination of information is one of the stated objectives of the LTPP program. The program's primary information distribution effort is the periodic macro release of "raw" data for use by scientist, engineers, and researchers for engineering-based analysis. The program also publishes and distributes research reports, data collection guidelines, and other documents related to pavement performance data collection and pavement research.

The LTPP program dissemination efforts comply with Federal information dissemination guidelines that were issued by the Office of Management and Budget on January 2, 2002, to implement the Data Quality Act, sometimes referred to as the "Information Quality Act" (title 5, section 515, Treasury and General Government Appropriations Act for Fiscal Year 2001).^{25,26} The purpose of the Federal guidelines is to ensure and maximize the quality, utility, objectivity, and integrity of information that is disseminated by Federal agencies.

The U.S. Department of Transportation consequently established policy on information quality for the department's agencies. This policy resulted in

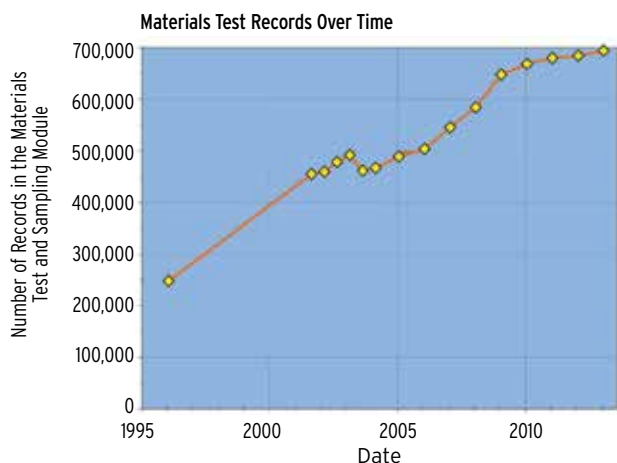


FIGURE 8.16. Increase in total number of records in the materials test module starting in 1996. The decrease in records in 2004 was due to removal of two administrative tables from the test module and not to a decrease in available measurement data.

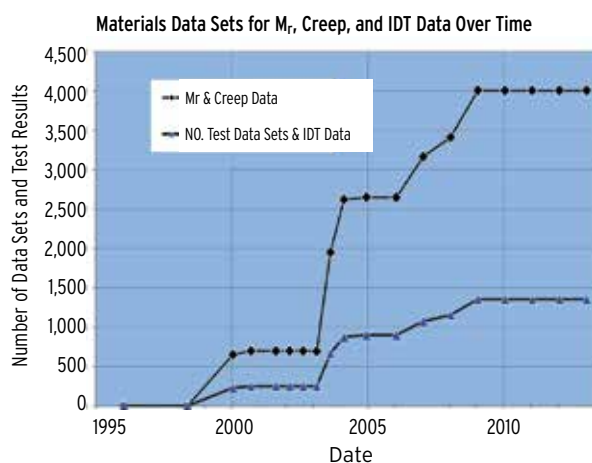


FIGURE 8.17. Growth in materials data for resilient modulus (M_r), creep compliance, and indirect tensile strength (IDT) using the P07 version 2 test protocol.

In response to the Data Quality Act, FHWA established the Information Quality Initiative, which promoted the Federal guidelines for dissemination of data and other information to the public.



FHWA developing its Information Quality Initiative (see sidebar).²⁷ In 2008, the LTPP program issued a formal report on compliance with the Federal guidelines (*Long-Term Pavement Performance Compliance With Department of Transportation Information Dissemination Quality Guidelines*) that includes issues related to publications and disseminated summaries of data, micro data releases, source and accuracy statements, and pre-dissemination reviews.²⁸

This section outlines LTPP data dissemination efforts through periodic releases of data, the development of software tools to aid data users, and, ultimately, online availability. As technology has changed, the program has adapted its methods to provide ease of access and improved functionality to users.

TABLE 8.3. Nominal dates for major LTPP data releases.

Release No.	Date	ZIP Size (GB)	Primary Format
1	January 1991 (data on 226 test sections)	N/A	N/A
2	July 1991	N/A	N/A
3	January 1992	N/A	N/A
4	July 1992	N/A	N/A
5	January 1994	N/A	N/A
6	September 1994	N/A	N/A
7	February 1996	N/A	N/A
8	September 1997	N/A	N/A
9	January 1999	N/A	N/A
10	October 1999	N/A	N/A
11	January 2001	N/A	N/A
12	January 2002	N/A	N/A
13	March 2002	N/A	N/A
14	July 2002	1.91	CD
15	January 2003 ¹	2.15	CD
16	July 2003	2.14	CD
17	January 2004	2.24	CD
18	July 2004	2.33	CD
19	January 2005	2.57	CD
20	October 2005	2.52	DVD
21	January 2007	2.56	DVD
22	January 2008	2.58	DVD
23	January 2009	2.85	DVD
24	October 2010 ²	4.02	DVD
25	January 2011	5.28	DVD
26	January 2012	4.47	DVD and thumb drive
27	January 2013	4.67	Thumb drive
28	January 2014 ³ (data on 2,509 test sections)	4.87	Thumb drive

¹ The January 2003 data release was the first Standard Data Release—the first release in Microsoft® Access® format and the first to contain data at all quality control levels.

² The October 2010 data release increased in file size due to the addition of traffic tables, which were removed in the January 2012 data release.

³ The January 2014 data release is the first Standard Data Release available on the LTPP InfoPave™ Web site. LTPP InfoPave contains the first public release of the LTPP AIMS data.

LTPP Data Release History

Table 8.3 provides the sequential release numbers assigned to the major LTPP database releases and their release dates. In the early years of the program, data releases contained partial data sets by module. For example, the first data release contained mostly inventory data from GPS test sections. In the mid-1990s, partial database uploads by module, assigned fractional data release numbers, were common. These fractional data release numbers are not shown in table 8.3.

The LTPP data release policy has also changed over the years. In the early years of the program, only data that passed all LTPP data quality checks were made available to the public, and a fee of \$77 to \$100 was charged for each extraction to partially defray the cost of fulfilling the request. Participating highway agencies could obtain all of the data from test sections in their jurisdiction at no charge. In November 2002, the LTPP program changed the data release policy to provide access to all data regardless of the quality level and to provide data in the standard release format free of charge.²⁹

While data users can still request custom extractions of data from the database in specific formats, these requests have been minimal since the introduction of the SDR in Microsoft Access format.

The following principles currently apply for release of LTPP data and information:

- LTPP data and information are distributed under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. Government assumes no liability for its contents or use.
- Understanding LTPP data collection procedures, principles, and practices is the responsibility of data users who interpret and draw conclusions based on LTPP data and information. Data users can contact the LTPP Customer Support Service Center to inquire about availability of documentation not distributed with the data or contained on the LTPP Web site.
- Although the LTPP program strives to provide data and information at no cost to the data user, program

funding limitations may limit the level of effort spent on user requests.

- Extractions from the LTPP database are provided free of charge to data users who request data in SDR formats.
- Custom extractions from the database may be requested.
- Delivery of data in raw data collection formats, access to internal documents, and access to other LTPP offline information are assessed on a case-by-case basis.

LTPP Standard Data Release

The LTPP SDR is an extraction of all data from the central LTPP database, split up and formatted as a series of Microsoft Access databases (based on the North American software version). In addition to the data, the SDR includes updated software and documentation specific to the contents of the data release, together with the following significant elements:

- Microsoft Access databases in compressed format that use long file names based on LTPP data module names.
- Data release notes that contain a historical record of significant changes starting with data release 16 in July 2003.
- Table Navigator software, which provides an intuitive point-and-click user interface to descriptions of all tables, all fields in each table, and the meaning of all code fields. The Table Navigator software is an automated metadata resource that all LTPP data users are encouraged to use to better navigate and understand the LTPP database.
- Updated Database User Reference Guide.
- LTPP Reference Library, containing electronic copies of LTPP program documentation.

Since the first SDR was issued in January 2003, the most up-to-date data from the LTPP program are distributed in this format on an annual basis free of charge to data requesters. Data at all quality levels, without restriction, are included in the release.

LTPP Data Dissemination Tools

As computer technology has evolved, the LTPP program has developed new and more efficient ways to make the data available to the pavement community. The program has engaged the State and Provincial agencies, industry, and academia partners in beta testing the software to ensure that users are able to access the pavement data provided in a format useful to them. The LTPP program continues to involve its partners and other users of the LTPP data in developing dissemination tools.

LTPP Data Sampler and Data Request Program

The earliest software developed to aid users of LTPP data was the Data Sampler and Data Request Program, developed by the LTPP program. Before the program started distributing the data, this software allowed pavement engineers, researchers, and others to select and request the data using a standard data request form. The form was submitted to FHWA via the technical support services contractor, who would follow up with the data requestor to make sure the data being prepared to send to the requestor was appropriate for the requestor's use.

Made available to the public in Version 5 on 5.25-inch floppy disk as early as January 1994, the sampler program helped users view and navigate the summary GPS data and request comprehensive data on selected sections. Version 7, released in early 1997, added features that allowed users to create their own data files using GPS data ordered from the LTPP program. It included a sample of the most up-to-date inventory, climate, traffic, layer material, and deflection data available for GPS sites.^{30, 31}

DataPave

DataPave was a CD-ROM-based product developed by the LTPP program to disseminate LTPP data in a user-friendly format. Its graphical user interface program was designed to help a data user select, view, and extract LTPP data of interest. Development of the DataPave program was based on the LTPP Data Sampler and Data Request Program.

Three versions of DataPave were produced by the LTPP program. Version 1 and 1.1 were released in 1997, Version 2 in 1999, and Version 3 and 3.1 in 2001. Version 3, released in November 2001, was the first to include the

new numbering system that reflected maintenance and rehabilitation activities performed at a section. Version 1 required a single CD-ROM; versions 2 and 3 required two CD-ROMs. Due to data storage limitations, the DataPave CD-ROM did not contain all available LTPP data. After production of DataPave 3.1, creation of the CD-ROM version of the program was discontinued due to the development of DataPave Online in 2002 and the LTPP SDR.

DataPave Online

The LTPP DataPave Online program provided access to LTPP data through a user-interactive format. It was designed as a training tool for users of LTPP data who may not have been acquainted with the use of database technology. The online version of DataPave limited a user to simple queries and downloads of a relatively small amount of data at a time. Users desiring access to large amounts of data were encouraged to obtain a copy of the SDR.

LTPP InfoPave™

The newest data dissemination tool, LTPP InfoPave, was released in January 2014 (figure 8.18). LTPP InfoPave is an interactive Web portal to the world of LTPP data, providing on-demand, integrated access to LTPP products and the entire scope of the LTPP IMS—the complete database, ancillary information in AIMS, and the LTPP Reference Library—through an interface that is easy and quick to use. LTPP InfoPave replaces DataPave and LTPP Products Online (discussed in chapter 10) and encompasses the SDR with the added option to obtain data releases for individual States/Provinces.

The system's software allows users to prepare customized searches, download data in Microsoft Access or Excel, generate customized reports, and personalize the LTPP InfoPave home page to their needs. The maps feature (figure 8.19) shows the LTPP tests sites throughout the United States and Canada and allows users to select data for one or multiple test sites. The contextual search feature connects the user to processed data, raw data, images, video, and reports. In addition, new features will include predefined, ready-to-use data sets that target specific analyses, prepared by expert data users; seamless activation of data analysis tools; and an interactive learning center to familiarize users with the system's features and use of LTPP data.

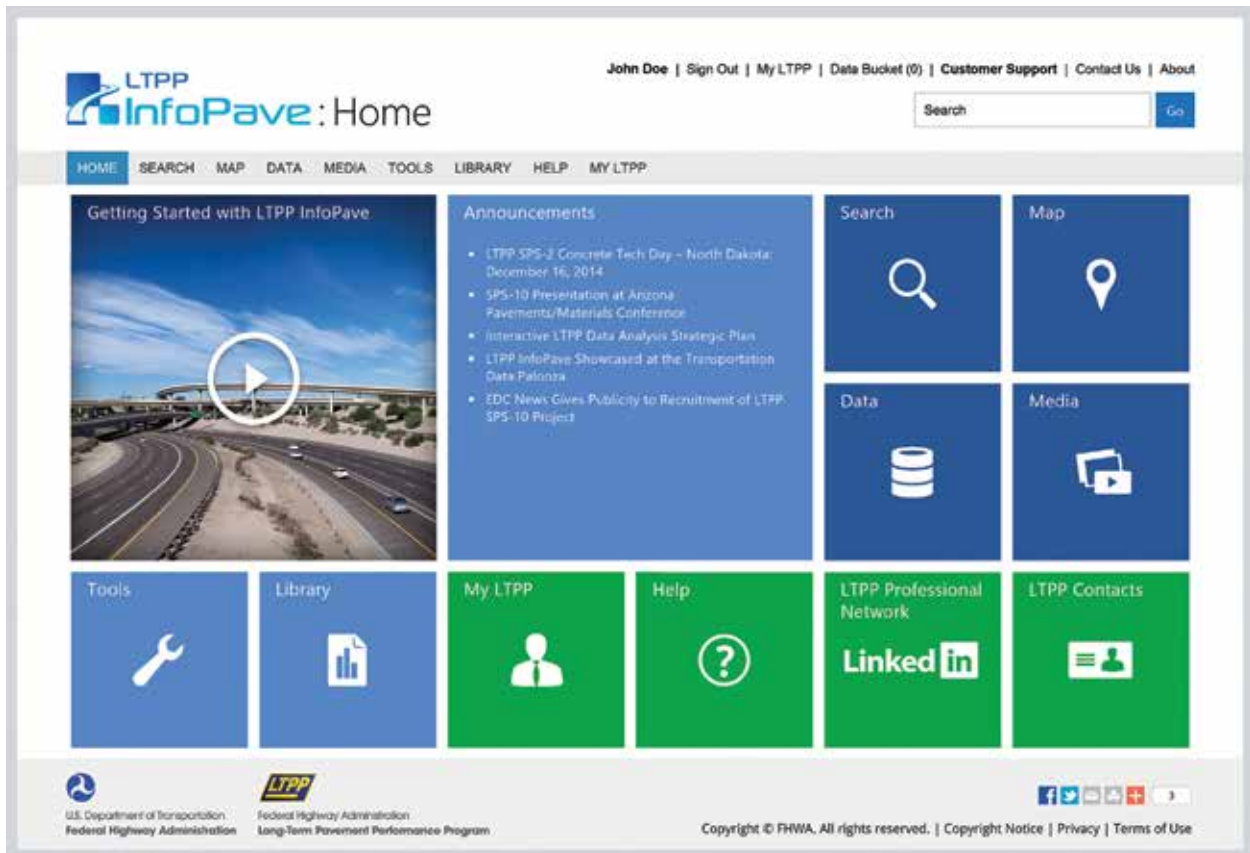


FIGURE 8.18. Home page of the LTPP InfoPave™ Web site.

Highway agency staff and other pavement researchers participated in the design of LTPP InfoPave through focused Webinars that solicited data users' opinions on the portal's features and functionality. Refinement of the system with user input will continue during the coming years.

LTPP Customer Support Service Center

Since the LTPP program started disseminating data, customer support has been vital in helping users understand what data are available, in what formats the data can be provided, and how the data can be used to answer their pavement performance questions. The program's customer support service function has changed over the years. After 1995, when responsibility for the database was transferred from TRB to FHWA, data distribution functions were transferred to the

technical support services contractor. In 1997, when the database operation, engineering specifications, computer programming, and management functions were merged into a single contract for central technical support of the program, the synergy of direct interactions among engineers, programmers, and data delivery staff led to rapid improvement in the quality of data delivery and user support functions.

It was not until 2002 that the LTPP customer support service function was formalized and assigned to the technical support services contractor. The purpose of the LTPP Customer Support Service Center is to provide a single point of responsibility for the program in responding to requests for data and technical questions from data users. The traditional customer support function was preparation of the SDR, support documentation, and user aids for release to the public.

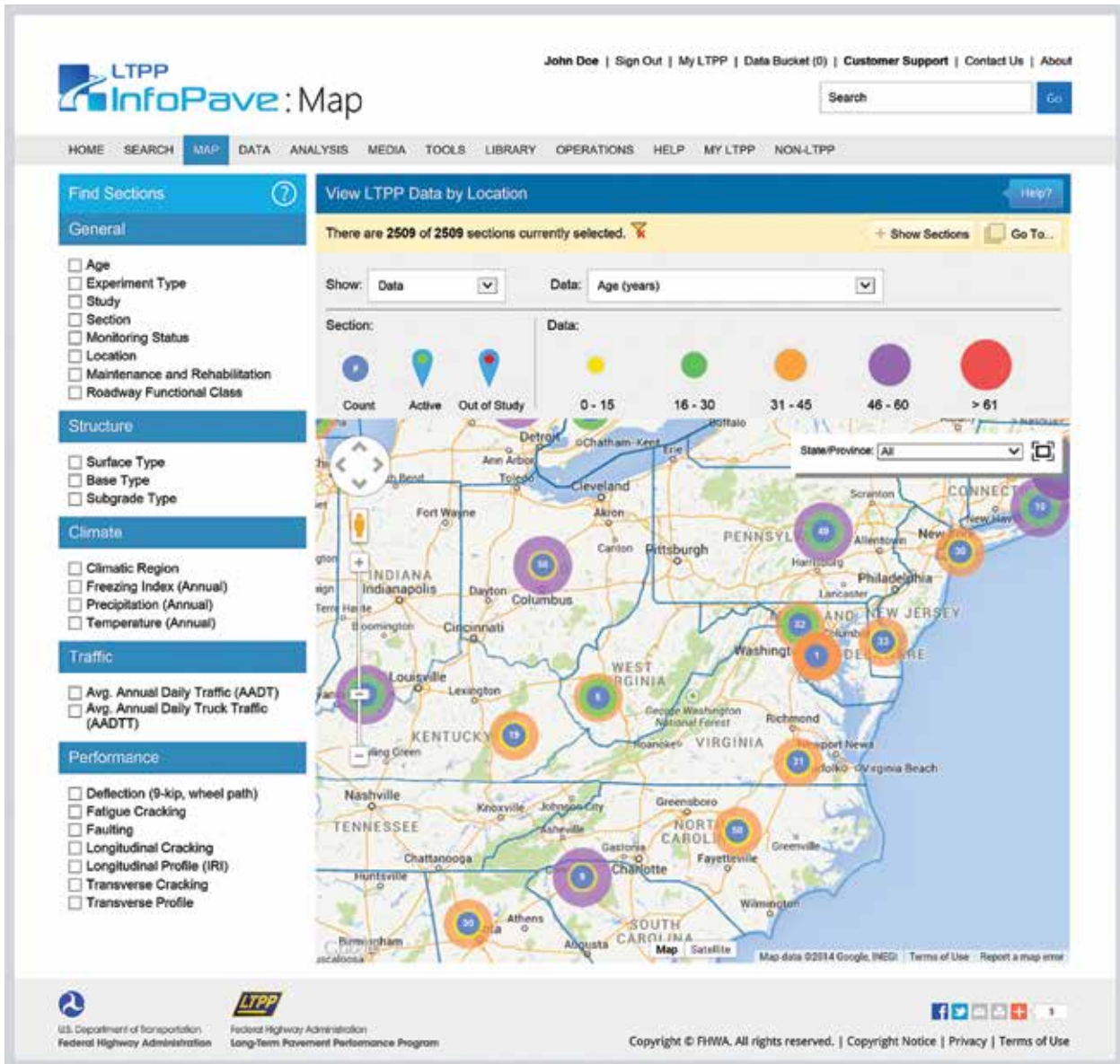


FIGURE 8.19. LTPP InfoPave’s interactive map feature, showing the locations of LTPP test sections.

In 2006, due to program funding limitations, FHWA management moved the LTPP Customer Support Service Center to its highway research center, where it is operated under supervision from the program staff with support from an onsite contractor. The support center still operates as the single point of contact for LTPP data and information requests. As

an onsite activity, the support center can provide reduced response times and access to other FHWA pavement resources.

LTPP Library

In addition to disseminating the pavement data, the LTPP program makes available a host of documents

that were created as part of the program that others can use or reference, such as data collection guidelines and reports from previous LTPP research projects. These documents are physically housed at FHWA's highway research center. The vision for the LTPP document collection is to have at least one hard copy of all LTPP program documents and publications along with an electronic copy of each. The current LTPP electronic library is distributed as the Reference Library in the SDR package on DVD and is available at the LTPP InfoPave Web site.

DATA SECURITY

Since the beginning of the LTPP program, data security has been a prime issue based on lessons learned from the American Association of State Highway Officials (AASHO) Road Test. Although some loss of LTPP data has occurred due to problems in field data equipment, LTPP data collection protocols contain instructions on data backup procedures to prevent data loss from faulty field data collection equipment. No significant loss has occurred to data entered into the LTPP IMS.

As described earlier, prior to fall 2011, the LTPP program used a distributed data collection structure that culminated in a central production database. The distributed data collection structure was operated by the four regional support contractors, who collected, processed, checked, and entered data into their respective regional databases. The regional databases were uploaded annually into the central, secure LTPP production database operated by the technical support services contractor. Security was maintained by the LTPP technical support services contractor and at the respective LTPP regional support contractor offices. Many of the earlier security measures are documented in *Long-Term Pavement Performance, Compliance with Department of Transportation Information Dissemination Quality Guidelines*.³² These protections continue.

In 2008, the LTPP program began to centralize the program's databases—pavement performance and central traffic databases—along with its AIMS data and other electronic and physical documents at FHWA's

highway research center to provide a secure central location for the invaluable information collected since the program began in 1987.

Since September 2011, LDEP, the central data entry Web portal leading to a production database, has been operated by LTPP's technical support services contractor. LTPP's regional support contractors are still responsible for collecting, processing, checking, and entering data. The data are now entered, however, through the centralized Web-enabled system and are uploaded on a continual basis instead of annually. This production database is used to update the central national archival IMS periodically at FHWA's highway research center. Security measures continue at the offices of the regional support and technical support services contractors, and additional security procedures have been established at FHWA's highway research center.

Safeguards for the LTPP Information Management System

In 2011, the LTPP program completed the transition to a new state-of-the-art server that has adequate storage capacity for the entire IMS—the central production and AIMS databases and the LTPP library—and an electronic archive of the IMS. To secure the system, the following measures are currently enforced:

- Entry and exit to FHWA's highway research center are secured by locked gates and security guards who control access.
- Physical access to the server room requires passage through two locked doors.
- People who enter the server room must sign in and sign out upon exiting.

LTPP compliance with the "Security of Federal Automated Information Resources" circular ensures that the data will be secure from unauthorized data modification, destruction, and loss. No significant loss has occurred to data entered into the LTPP IMS.

- The LTPP server hardware is housed in a covered and locked rackmount system (see figure 8.9).
- The server is not connected to any external networks at the research center.
- Procedures are in place to minimize production downtime in the event of hardware or software failure (“Data Processing Workstation Disaster Recovery (DR) and Continuity of Operations Plan (COOP),” internal document, December 14, 2012).
- Electronic backup media are stored offsite at a secure location.
- The IMS is archived and sent to the National Archives and Records Administration annually.

The Office of Management and Budget Circular A-130, Appendix III, “Security of Federal Automated Information Resources,”³³ requires agencies to perform a review of the security controls within each system and formally approve the system’s operation. The LTPP program has completed the security process and is following the established guidelines. Compliance with these extensive standards means that LTPP data will be secure from unauthorized data modification, destruction, and loss.

Hardware Security and Data Backup Procedures

Data backup procedures are in place at every level of the LTPP IMS. This section outlines the backup provisions for the program’s central server at FHWA’s highway research center.

The LTPP central server is currently a Dell PowerEdge 2900 server running Windows Server 2008, ser-

vice pack 2. It has two 3.0 GHz Xeon E5450 dual core processors. It contains one 8-disk RAID 5 array with 8 TB of storage. RAID 5 is able to recover from a single drive failure because parity information is striped across the disks. Therefore, if one, and only one, disk is corrupted, the system will continue to run. The drives are hot-swappable, so a faulty drive can be replaced, and it will be rebuilt automatically using the parity information stored on the other drives. The operating system, the Oracle software, and database instances are stored on this RAID 5 array. It also has two attached 15-disk RAID 5 arrays for a total of 50 TB of additional storage.

The server is protected from power failures by an uninterruptible power supply, Smart UPS 2200, which was purchased with the server. The server is on a circuit that is powered by an emergency generator to support uninterrupted operation.

The LTPP database system does not have critical uptime requirements; however, scheduled down time is minimized by doing the majority of the backup during nonbusiness hours. Daily backups are not deemed necessary due to the low volume of updates to the LTPP database. Major changes to software or the content of the database are received electronically and can be recreated in the case of system failure. Because recovery of every transaction to the point of failure is not necessary, all recovery is performed by restoring all the data files from a cold backup and restarting the database. The server is partitioned to contain different segments of the IMS, and the backup procedures for the segments vary according to the level of activity they experience, as outlined in table 8.4.

TABLE 8.4. Backup frequency for the LTPP Information Management System, 2014.

Server Segment	Update Cycle	Full Backup	Incremental Backup
Operating system	Daily	Biweekly	Alternate days
Working storage; workstation backup	Daily	Biweekly	Alternate days
Ancillary Information Management System	Quarterly	Quarterly	Not applicable
Traffic	Daily	Biweekly	Alternate days
Standard Data Release database	Quarterly	Biweekly	Not applicable
Production database	Daily	Biweekly	Alternate days
Test database	Daily	Biweekly	Alternate days
Recovery	Not applicable	Quarterly	Not applicable
Archive of historical data/software	Quarterly	Quarterly	Not applicable

SUMMARY

The LTPP database came into being in 1989 and has been successfully adapted to the many changes in computer hardware and software technology over the years. The database represents a significant investment of resources. The quality management features of the LTPP database, implemented before the development of formal quality management standards and mandated Federal quality and security guidelines, have resulted in a well-documented and robust national data archive of pavement research data. The database security procedures implemented by the LTPP program assure the preservation of all LTPP data; there will be no loss of data as occurred with the AASHO Road Test data, where many of the data were lost because they were not converted as technology changed over the years.³⁴

The LTPP program has amassed the largest and most comprehensive engineering data set on the performance of modern pavements in the world. The LTPP database spans the pavement engineering spectrum from time-series distress and roughness measurements to detailed measurements of changes in pavement materials due to climate and response of pavement materials under loading. LTPP InfoPave, launched in 2014, is a great leap forward in providing continuous access to the database, AIMS, pavement research, software, and other LTPP products.

Today, the LTPP database can be described as a complex, rich, research data warehouse that, to be used efficiently, requires some knowledge of the program. The LTPP program can claim successful accomplishment of the sixth major objective for the program listed in the 1986 research plan:³⁵ A national long-term pavement performance database has been established and is improving continually. Maintaining data quality is an important function of the program that is discussed in the next chapter.

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LTPP data requirements are based on achievement of the program's goal and objectives and, as a result, include literally thousands of measurement concepts.

9

LTPP Data Quality Efforts

The many quality control/quality assurance processes described in this chapter keep the focus of the people involved in the LTPP program on the quality of the work they do. Achieving a high level of data quality is a program expectation. This expectation created the environment that enabled development of cutting-edge quality control processes more than 10 years in advance of accepted industry standards and will enable continued improvements in quality control processes.

INTRODUCTION

Since the program's start, data quality has been a prime concern in the development and operation of LTPP activities. High-quality data have been critical to the program's success. Given the program's data requirements—a large number of data elements of varying complexity—as well as the available data acquisition and source options, achieving high-quality data is not only a major challenge, but also one that requires significant resources.

LTPP data requirements are based on achievement of the program's goal and objectives and, as a result, include literally thousands of measurement concepts. During the program planning process, experts in each associated engineering discipline participated in developing the data requirements, which were then reviewed and critiqued by other stakeholders. Like

the data requirements, the methods used to acquire LTPP data were developed by expert staff working in concert with program stakeholders and other authorities. A comprehensive planning process was used to examine and evaluate data acquisition methods that took into account budget, complexity, and time considerations.

Due to the complexity of many LTPP data elements, an early program decision was made to select qualified regional support contractors who had experience in operating technical data collection equipment and working with highway agencies to collect data. Increased planning was needed for data collection that requires special equipment, such as the falling weight deflectometers (FWDs) used in nondestructive deflection testing and the profilers used to collect profile



Key Milestones in Data Quality Efforts

- 1987** First *Distress Identification Manual* released
- 1989** SHRP-LTPP Customer Support Services established
- 1991** SHRP-LTPP reference calibration procedure for FWDs developed
- 1992** First Distress Accreditation Workshop held in Reno, Nevada
- 1992** ProQual developed
- 1993** Original LTPP Materials Testing and Handling Guide published
- 1993** Original Traffic Software used to process traffic data
- 1994** Software Problem Report form formally adopted
- 1995** Operational Problem Report formally implemented
- 1997** Comparisons with distress maps from prior manual surveys required
- 1998** FHWA regional operations audits formalized
- 1998** Data Analysis/Operations Feedback Reports process started
- 2002** LTPP Traffic Analysis Software (LTAS) first used by regional support contractors
- 2006** LTPP Materials Testing and Handling Guide revised
- 2012** Traffic Data Collection and Processing Guide (v. 3) issued

data. These early program planning efforts to establish data requirements, acquisition methods, and sources provided a solid foundation for achieving high-quality data, but they were just the beginning of the LTPP quality initiatives.

Data quality control/quality assurance (QC/QA) processes have been developed, updated, and implemented throughout the LTPP program. The processes fall into several categories:

- QC processes before data collection.
- QC processes during data collection.
- QC processes after data collection.
- Database checks and reviews.
- Regional quality management plans and Federal Highway Administration (FHWA) QA audits.
- Higher order data checks.
- Peer review.
- Feedback processes.

These processes are detailed over the remainder of this chapter. In addition, products that emerged from LTPP QC/QA development and implementation efforts are summarized in chapter 10. The various documents referenced in this chapter—directives, guidelines, manuals, and studies—are available at LTPP’s InfoPave™ Web site.

QUALITY CONTROL PROCESSES BEFORE DATA COLLECTION

After the selection of data collection equipment and regional support contractors, before data collection began, three elements were identified as critical to providing a solid foundation for high-quality LTPP data. These elements are data collection standards, personnel requirements, and equipment requirements.

Data Collection Standards

To promote uniform, consistent, and high-quality data, the LTPP program has published formal standards in the form of data collection guidelines, guides, and manuals that specify data collection frequencies, types

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FIGURE 9.1. Data collection guidelines published as manuals for profile measurements and processing, distress identification, and falling weight deflectometer measurements.

Some of the data collection guidelines have been compiled and published as manuals containing standards specific to the LTPP program. Examples include the highly requested *Distress Identification Manual for the Long-Term Pavement Performance Program*,¹ the *Long-Term Pavement Performance Manual for Profile Measurements and Processing*,^{2,3} and the *Long-Term Pavement Performance Manual for Falling Weight Deflectometer Measurements*⁴ (figure 9.1). These publications, like most of the many

of data collection, standard definitions, measurement procedures, test protocols, operation of electronic data collection devices, and data collection forms. These standards are implemented through the issuance of LTPP program directives, which present program policy to be followed by regional support contractors, materials laboratory contractors, and participating highway agencies. When guidelines are revised and updated, program directives are used to document changes in processes, procedures, equipment, and data collection activities.

other LTPP guides, manuals, and guidelines (some of which date back to 1988), have undergone major revisions and updates over the years. A list of the major LTPP data collection guidelines is presented in table 9.1.

A team process has been used to develop data collection guidelines. The process starts with the development of a draft guide by the central technical team. LTPP managers solicit review and comment from stakeholders—related expert task groups (ETGs), highway agencies, regional support contractors—on an initial draft. Feedback from the combined team obtained through written comments, teleconferences, Webinars, regional meetings, and national meetings is used to craft a proposed final version. The proposed guidelines are tested and refined through pilot activities and, when final, are issued through a formal LTPP program directive. Following implementation, data collection personnel can report equipment problems, issues with data collection forms, needed changes to procedures, and other issues using the formal Operational Problem Report (OPR) process. Changes and updates to the guidelines are also issued in a program directive.

In addition to providing standard definitions, measurement procedures, and data collection forms, guidelines also typically address equipment issues and, in the case of electronically collected data, software and data processing issues. For example, the latest version of the *LTPP Manual for Falling Weight Deflectometer Measurements* covers all aspects of measurement, from equipment setup through data handling procedures. Similarly, the *LTPP Manual for Profile Measurements and Processing* includes everything from equipment maintenance to inter-regional comparison tests and processing profile data in the office.

Data collection guidelines typically include and require the completion of data collection forms, whether data are collected using electronic means (which have comprised the bulk of LTPP data) or manual methods. These forms include written instructions on all requested pieces of information and pertinent information needed to complete the form. Also, all forms are numbered and dated for document control, and revisions to forms are issued by formal directives that document the changes. Most of the data collection guidelines within the LTPP program are implemented through formal issuance of directives.

TABLE 9.1. LTPP data collection guidelines.

Data Collection Guidelines	Date*
Distress Identification Manual for the Long-Term Pavement Performance Studies	1987
SHRP-LTPP Data Collection Guide	1988
SHRP-LTPP Interim Guide for Laboratory Materials Handling and Testing	1989
Framework for Traffic Data Collection for the General Pavement Studies' Test Sections	1989
SHRP-LTPP Guide for Field Materials Sampling, Handling and Testing	1990
Specific Pavement Studies Data Collection Guidelines for Experiment SPS-5: Rehabilitation of Asphalt Concrete Pavements	1990
Specific Pavement Studies Data Collection Guidelines for Experiment SPS-6: Rehabilitation of Jointed Portland Cement Concrete Pavements	1991
Specific Pavement Studies Data Collection Guidelines for Experiment SPS-7: Bonded Portland Cement Concrete Overlays	1991
Specific Pavement Studies Data Collection Guidelines for Experiment SPS-1: Strategic Study of Structural Factors for Flexible Pavements	1991
Specific Pavement Studies Data Collection Guidelines for Experiment SPS-2: Strategic Study of Structural Factors for Rigid Pavements	1992
Specific Pavement Studies Data Collection Guidelines for Experiment SPS-8: Study of Environmental Effects in the Absence of Heavy Loads	1992
Manual for Profile Measurement: Operational Field Guidelines	1994
LTPP Seasonal Monitoring Program: Instrumentation Installation and Data Collection Guidelines	1994
SPS-2 Seasonal and Load Response Instrumentation, North Carolina DOT	1994
Data Collection Guidelines Under Less Than Ideal Conditions (Seasonal Monitoring Program)	1995
Specific Pavement Studies Data Collection Guidelines for Experiment SPS-9A: Superpave® Asphalt Binder Study	1996
Guidelines for IMS Data Entry for SPS-9 Project	1997
SPS-1, SPS-2 and SPS-8 Data Collection Guidelines for Experiments	1997
Guide to LTPP Traffic Data Collection and Processing	2001
LTPP Inventory Data Collection Guide	2005
Long-Term Pavement Performance Maintenance and Rehabilitation Data Collection Guide	2006
Guidelines for the Collection of Long-Term Pavement Performance Data	2006
Long-Term Pavement Performance Program Manual for Falling Weight Deflectometer Measurements	2006
Long-Term Pavement Performance Program Falling Weight Deflectometer Maintenance Manual	2006
Long-Term Pavement Performance Project Laboratory Materials Testing and Handling Guide	2007
LTPP Field Operations Guide for SPS WIM Sites (Version 1.0)	2009
LTPP Traffic Data Collection and Processing Guide (Version 1.3)	2012
Long-Term Pavement Performance Program Manual for Profile Measurements and Processing	2013
LTPP Information Management System (IMS) Quality Control Checks (updated annually)	2013
Distress Identification Manual for the Long-Term Pavement Performance Program	2014

* Year published. Earliest and most recent versions released are listed. Intermediate versions have been published.

Personnel Requirements

Well-trained and knowledgeable data collection personnel are another critical element to achieving high-quality data. Accordingly, the data collection contractor selection process has included consideration of experience in operating various types of pavement data collection equipment, conducting field pavement data collection activities, or performing laboratory material tests, depending on the subject of the data collection contract. In addition, the LTPP program has established minimum criteria for data collection personnel, including previous experience in data collection, formal training with the data collection procedures using a training plan and syllabus approved by the LTPP program staff, and time spent assisting experienced personnel in performing data collection before doing so independently. Implementation of personnel requirements within the LTPP program is accomplished contractually with the data collection contractors or through formal program directives.^{5,6}

In the case of pavement distress data, for example, an accreditation program was established in 1992, requiring that all pavement distress data be collected by accredited raters. The regional support contractor staff are required to attend the distress accreditation workshops held by the LTPP program to receive and maintain their accreditation. To be eligible to attend, raters first have to be trained to a high level of competence in the knowledge and procedures contained in the *Distress Identification Manual* using a combination of classroom and field training activities. The regional support contractors are required to provide formal training based on the FHWA National Highway Institute's "Pavement Distress Identification Workshop" course. In addition, new raters are required to assist experienced personnel in performing distress data collection for asphalt and jointed concrete pavement (a minimum of two sections each) before becoming eligible to attend an accreditation workshop.⁷

The first distress accreditation workshops were held in 1992 in Reno, Nevada,⁸ and workshops were held at least annually early in the LTPP program. More recently, the workshops have been held less frequently due to budget limitations. The accreditation process consists of two major parts: a written examination to test the general knowledge of the rater and a field data collection or film interpretation examination to measure the



FIGURE 9.2. Distress raters evaluate a pavement surface in an LTPP accreditation workshop, where raters' proficiency is tested.

rater's capabilities in observing and recording distress data. Grading and accreditation are accomplished by comparing the rater's results to the reference values established by a team of experienced raters.

The distress accreditation workshops are intended for trained, experienced personnel only; they are not intended to train personnel. Their primary purpose is to assure high quality and uniformity in identifying pavement distress. Furthermore, to maintain their accreditation, distress raters have to meet minimum recertification requirements, including performing at least 15 surveys in a 12-month period—ideally evenly distributed throughout that time period—and successfully completing the accreditation workshop annually, or as required by the LTPP program. Figure 9.2 shows a distress accreditation workshop held in Columbus, Ohio, in May 2010.

Training sessions focused on the handling of weather and seasonal data were conducted as well. Personnel learned how to review the weather plots and identify and edit erroneous data collected from the automated weather stations, and they were trained in data processing QC procedures for the Seasonal Monitoring Program.

To promote consistency in data collection across the test sites, national and regional meetings of regional support contractor staff as well as teleconferences involving data collection personnel are conducted on each major data collection topic. These interactions, which vary in frequency according to the need and the maturity of each data collection activity, allow for the exchange of ideas and improvements as well as the discussion and resolution of issues.

TABLE 9.2. LTPP data collection equipment and components.

Georgia faultmeter
Rod and level
Seasonal Monitoring Program Mobile Unit (CR10 data logger, Tektronix time domain reflectometer cable tester, electrical resistivity function generator, and digital multimeters)
Megadac (dynamic load strain sensors, stress sensors, and displacement sensors)
Profilometers (laser sensors, accelerometers, data collection triggers, distance-measuring instrument, surface temperature sensors, macrotexture measuring lasers)
Dipstick® profile measuring devices
Falling weight deflectometers (air and surface temperature sensors, load plates, load cells, deflection sensors, high-accuracy distance-measuring instrument)
Climate and subsurface monitoring equipment (temperature sensors, rain gauges, subsurface temperature probes, moisture probes, frost/thaw probes, piezometers)
Traffic monitoring equipment (piezo electric sensors, inductive loops, pneumatic tubes, radar or infrared beams)
Materials testing equipment (closed-loop servo hydraulic test system–load frame, load cells, hydraulic system, deformation devices, triaxial pressure chamber, temperature chambers, computer, dynamic cone penetrometer)
Weigh-in-motion equipment (bending plate, load cell, and quartz sensor)

In addition, the regional support contractors' QC plans, mandated by the LTPP program, include processes for training new staff and reviewing the performance of existing staff, including some exchanges of equipment operators between the regions to review each other's efforts. The training requirements within these QC plans address not just the distress data collection, but all collection activities such as FWD, profile, and the Seasonal Monitoring Program. (Regional contractors' QC plans are addressed later in this chapter, along with FHWA QA audits.)

Equipment Requirements

In developing the LTPP data collection plans, it was determined that the program should own and operate specialized data collection equipment to best achieve the program's objectives. However, some data collection services were engaged due to consideration of the equipment cost, advanced operating requirements, or volume of data measurements to be performed. Contracted services have been used to collect photographic distress data, perform laboratory materials tests, and take ground penetrating radar measurements. The LTPP program has acquired FWD, inertial profiling, manual distress

survey, dynamic load response, seasonal monitoring, and traffic data collection equipment.

LTPP data collection activities rely on equipment that is often of a fairly sophisticated nature, which has been built using technologically advanced components to meet the program's specifications (table 9.2). The basic inertial profiler components, for example, include laser sensors, accelerometers, data collection triggers, a distance-measuring instrument, and a computer system that combines the measurements from each of the components to provide the longitudinal profile data. In 2013, texture measurements, surface temperature, GPSr (Global Positioning System receiver), and photo and video capabilities, were added.

Because properly functioning equipment is critical to achieving high-quality data, the maintenance, repair, checks, and calibration of equipment used in data collection have been an integral part of LTPP QC/QA efforts since the program's beginning. Most data collection guidelines address equipment maintenance, repair, checks, and calibration procedures, and each regional support contractor is required to establish and follow an equipment preventive maintenance plan that is accepted and monitored by LTPP program staff. Throughout the course of the program, many direc-

DAILY CHECKS OF INERTIAL PROFILERS

For inertial profilers, it is imperative that the individual components as well as the overall system be calibrated, where possible, to National Institute of Standards and Technology standards. In those cases where it is not possible to directly calibrate a component, checks are carried out to insure proper function. For example, these checks on the LTPP inertial profiler components are performed each day before data collection:

- Laser sensor checks, using a series of calibrated blocks of different heights to ensure that they are accurately measuring height.
- Tire examinations and pressure checks (the distance-measuring instrument is affected by the tire's rolling radius).
- Static/bounce tests to verify that the accelerometers and laser sensors are functioning together properly.
- Texture and pavement surface temperature sensor checks (a requirement with the newest LTPP profilers).

tives have been issued that address specific maintenance checks and calibration procedures for LTPP data collection equipment.

Calibrations and checks are performed on all data collection equipment to insure proper functioning before they are used in the field or laboratory. In those cases where it is not possible to calibrate a device, equipment checks are used. For example, temperature sensors (thermistor probes) in the Seasonal Monitoring Program were placed in substances of known temperature such as ice and boiling water. If the sensors were found to be outside an established range, they were either returned to the manufacturer for adjustment or replacement.

Although the LTPP program uses existing technology to the extent that is practical, in some cases it has had to develop calibration and check procedures for program equipment. For instance:

- The program developed the first reference calibration procedure for FWDs in the United States. This development process was independent of the equipment supply contractor, and Federal, State, and international highway agencies subsequently adopted the LTPP FWD reference calibration procedure.^{9,10,11}
- The program developed cutting-edge laboratory equipment calibration methods for highly sensitive tests for elastic response of pavement materials in 1997,¹² which were later expanded and modified in a 2005 publication.¹³ These tests, informally called startup procedures, involved expert instrumentation engineers who checked the internal functions of advanced laboratory electronic measurement equipment to identify sources of bias and error that could not be reliably detected through inspection of the output data. These checks measured the output from a controlled electrical input into the system to discern if the instrumentation was correctly calibrated to the manufacturer's specifications.

A number of software programs have also been developed and implemented to help identify potential equipment problems and to check calibrations. Examples include:

- *FWDCAL*—This program automates analysis of the relative calibration test procedure results for the FWD geophones and includes these functions: check FWD relative calibration data file for compliance with LTPP test setup requirements, calculate new relative gain factors for each geophone, check the ratios between existing and new relative gain factors to determine if they are within established tolerances, perform an analysis of variance on the data to determine the statistical significance of key test factors, provide a statistical summary of the test results, provide guidance to the user on needed gain changes or further testing needs, compute the gain factor for a replacement sensor, process up to three data sets in the same file, and compute an average new relative gain factor from relative calibration tests performed as a part of the LTPP reference calibration procedures.



FIGURE 9.3. Profiler rodeo held at the Minnesota Road Research Project (MnROAD) site in Albertville. From May 14 to 18, 2007, researchers performed a comparison test of the profilers used by the four LTPP regional support contractors.

- *MOBILE*—This program was used in the Seasonal Monitoring Program to perform measurements on the time-domain reflectivity calibration reference cable installed in a user-specified port and was intended to be an aid in diagnosing problems with the time-domain reflectivity data collection system whenever an anomaly was encountered.

Another important concept, introduced by the LTPP program in the early 1990s, was the use of equipment comparisons, which are referred to as “FWD thump-offs” and “profiler rodeos.” Such comparisons were used not only as a means of accepting equipment for program use, but also for performing periodic evaluations of the equipment’s operational status and for cross-training exercises. For example, upon delivery of the profilers now in use, a stringent acceptance procedure was conducted in February 2013 on reference test sections in College Station, Texas, and a week-long training was held in April 2013.¹⁴

In the profiler rodeos, the LTPP profilers were compared against each other as well as against a reference device, the Face Dipstick and rod and level, to ensure that the equipment was collecting high-quality profile data (as described in chapter 6). These rodeos required the establishment of multiple test sections. The profile of each test section was then measured by the Face Dipstick and profilers, and the resulting data were analyzed to determine compliance with established elevation bias and precision criteria along with the International Roughness Index (IRI) values.¹⁵ Figure 9.3 shows four profilers prepared for testing at a 2007 rodeo in Minnesota.

Ultimately, it is the responsibility of the regional support contractors to maintain the data collection equipment they use in good-working, calibrated condition. This equipment has included devices such as the levels used for surface elevation surveys and pavement and air temperature probes used in conjunction with FWD testing and profile surveys. Furthermore, as noted earlier, each regional support contractor is required to establish and follow an equipment preventive maintenance plan as accepted and monitored by LTPP program staff.

QUALITY CONTROL PROCESSES DURING DATA COLLECTION

While the data collection guidelines, personnel requirements, and equipment requirements described in the previous section provide an excellent foundation, additional QC elements are needed to assure that data are of high quality. Key elements to be considered during data collection are the ambient conditions, monitoring of data collection activities in the field by responsible personnel, and the use of QC tools to check equipment and data in the field.

Ambient Conditions

Ambient conditions must not be neglected when planning for or performing data collection because they can significantly affect data quality, as shown in these LTPP-specific examples:

- Hot-mix asphalt pavements in some southern States can show less cracking during the hot summer months

than in the winter. Likewise, temperature affects the distresses visible in Portland cement concrete pavement, including crack and joint openings. Thus the temperature of a pavement at the time distress measurements are performed is important to identify potential discrepancies in time-series trends.

- Inertial profiler laser height sensors can malfunction at very high and very low temperatures. At approximately 0 °C and 50 °C (32 °F and 122 °F), some lasers begin to produce errors, and at approximately -40 °C and 70 °C (-40 °F and 158 °F), a laser sensor can turn off to prevent damage.¹⁶
- The rolling radius of the tire, which is related to tire pressure and hence temperature, directly affects distance-measuring instrument measurements.
- The interior vehicle environment can be critical to the operation of on-board computers as many computers have a safe operating range of temperature that should be observed before power is applied.
- Inclement weather conditions, such as rain, snow, or heavy cross winds, can interfere with the collection of acceptable distress, FWD, and profile data.
- The ability to see and rate some types of distresses is very sensitive to lighting conditions, angle of the incident light, and light intensity.

These ambient condition considerations led to the issuance of formal LTPP program directives, such as these:

- Cessation of “Night Time” Manual Distress Surveys.¹⁷
- Special Provisions for Cold Weather FWD Testing.¹⁸
- FWD Surface Temperature Measurements in Cold Weather.¹⁹
- Data Collection Guidelines Under Less Than Ideal Conditions.²⁰

Most of these directives have been incorporated into the latest versions of the data collection guidelines discussed in the previous section.

Monitoring and Reviewing Data Collection in the Field

Reducing errors at the time of testing, when it is possible to correct a problem, is a priority within the LTPP

program. It is standard procedure for the regional support contractor’s staff carrying out data collection activities to follow program guidelines and to continuously monitor the data being collected to ensure that the equipment is functioning properly and the data appear reasonable. If either questionable data or improperly functioning equipment is suspected during data collection, activities are suspended until the issue in question is resolved.

In the case of field activities, data collection personnel are required to survey the test section area to ensure there are no obstacles or debris on the pavement surface that could affect data collection. They are also required to check and to ensure that the start and end of each test section are well defined so that measurements are taken at the appropriate locations.

Once data collection activities begin, a number of monitoring tools are available to determine whether the data appear reasonable and the equipment is functioning properly. For example, cameras are installed on all LTPP FWD units to aid in establishing the accurate location for joint deflection tests on rigid pavements. Another example is the automated data checks contained in the LTPP FWD data collection software, which includes the following error conditions:

- *Roll-off*—Deflection of the pavement surface, as recorded by a deflection sensor, does not return to near zero within 60 milliseconds of the trigger activation.
- *Nondecreasing deflections*—Deflections measured by the deflection sensors do not decrease with increasing distance from the load plate.
- *Overflow*—A measured deflection exceeds the range of the deflection sensor or 2030 μm (80 mils) for the FWDs operated by the program.
- *Load variation*—The peak load for repeat drops at the same drop height varies by more than the amount specified.
- *Deflection variation*—The load-normalized peak deflections for repeat drops vary by more than the amount specified.

If deflection errors occur, the operator is required to attempt to identify the source of those errors. If the

errors are determined to be due to problems with the FWD equipment, the problems have to be fixed before testing continues. If the errors are related to localized pavement conditions, the operator is required to reposition the FWD and comment on the condition. If the errors are determined to be due to pavement conditions that are representative of the test section as a whole or due to factors such as truck traffic that are out of the operator's control, then the operator is required to accept the error and comment on the condition.

As described, there are many valid reasons why some of these "errors" may actually be an accurate reflection of pavement conditions, such as a transverse crack between sensors leading to a nondecreasing deflection warning. This is another example of why the LTPP program stresses the importance of using trained and experienced field personnel.

Quality Control Tools to Check Equipment and Data

Once data collection has been completed, field personnel are required to review the collected data prior to leaving the site. In the case of longitudinal profile data, for example, profiler operators use the LTPP ProQual software (discussed in chapter 6) to evaluate the acceptability of the profile runs based on established criteria. ProQual uses collected profile data to compute IRI values for the left and right wheelpaths, as well as the average IRI of the two wheelpaths (figure 9.4).

Profiler operators are also required to use ProQual to perform a visual comparison of profile data collected by

the left, right, and center sensors for one profile run. As a further check on the data, the operator compares the current profile data with those obtained during the previous site visit. If there are discrepancies between profiles from the current and previous site visits, the operator is required to investigate whether these differences were caused by equipment problems or were due to physical pavement features such as those caused by maintenance or rehabilitation activities.

After the profile visual comparison is completed, an IRI comparison of current versus previous site visit data is also performed. If IRI values from the most recent profiler runs meet the LTPP criteria and the operator finds no other indication of errors, no further testing is needed at that site.

Other examples of automated field data collection QC tools used within the LTPP program include the following:

- *AWSSCAN*—A program developed to permit field checks on the integrity and quality of the automated weather station data collected as part of the Specific Pavement Study (SPS) -1 (structural factors for flexible pavements), -2 (structural factors for rigid pavements), and -8 (environmental effects in the absence of heavy loads) experiments.
- *ONSFIELD* and *MOBFIELD*—Programs developed to permit field checks on the integrity and quality of the onsite and mobile data collected as part of the LTPP Seasonal Monitoring Program. They were used in the field to identify data anomalies whenever onsite or mobile seasonal data were collected.

There are also instances within the LTPP program where data collection is not automated, as is the case with manually collected distress data. In those instances, efforts were made to develop and implement procedures that ensure consistent and uniform data. In the case of the manual distress surveys, for example, the regional support contractors were required to run the DiVA (Distress Viewer and Analysis) software on each section's data after the survey as part of the office review to identify inconsistencies among previous surveys. (The DiVA software is described in greater detail later in this chapter.) Furthermore, regional support contractor staff in the field are required to comply with the following policy:

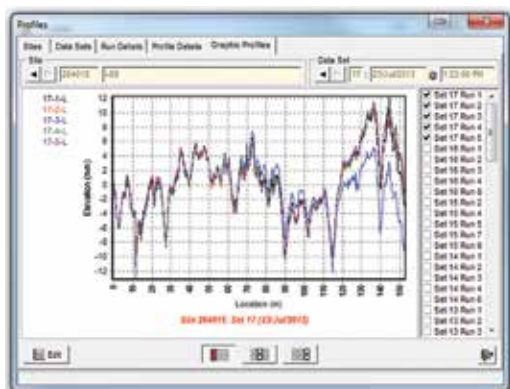


FIGURE 9.4. ProQual software, used to evaluate the acceptability of profile data.

- Raters assigned to perform a manual survey on an LTPP test section must obtain a copy of the distress map made during the prior survey. (This map would have undergone office review and had any discrepancies and questions resolved before it was made available.)
- The prior survey map is to be used by the rater to (1) become familiar with the types, severity, and quantities of distresses; (2) determine the survey limits; and (3) determine the wheelpath locations.
- The rater is then to map the test section independently: a new map, not an edited version of the prior map, is to be drawn.

The intent of this policy is to promote consistency, not to perpetuate errors. The rater is required to note disagreements with the prior map information and bring any issues to the attention of the office reviewer for resolution. In addition, inconsistencies with prior surveys are required to be documented by the rater using video or photographs.

QUALITY CONTROL PROCESSES AFTER DATA COLLECTION

After data have been collected, the regional support contractors carry out numerous quality checks before entering the data into the database. These checks range from basic—are profile data files readable and complete, is the manual distress data package complete, are survey date stamps correct—to sophisticated, as explained below. The primary objective of these data checks is to prevent “bad” (i.e., erroneous) data from being entered into the database. Examples of the data check tools developed by the LTPP program to avoid loading bad data into the LTPP database include:

- *AWSCHECK*—Used for automated weather station data. In addition to range and integrity checks, the program plotted the climate data, allowing for time-history consistency checks to be performed. This preprocessor program allowed deletion of bad measurement data and adjustments to data fields, corrected time stamps for daylight saving time, and prepared the data file for loading into the database.

- *FWDCHECK*—Used until about 1996 to analyze deflection data to determine test section homogeneity, the degree to which test pit data are representative of the section, the presence of data outliers within the section, and overall reasonableness from a structural capacity viewpoint.
- *FWDSCAN*—Scans electronic FWD data files to identify data collection rule violation issues, data file format integrity, and range values violations.
- *P46CHECK*—A preprocessor program that automates checks on the results of laboratory resilient modulus tests on unbound materials. In addition to all routine checks on data values, advanced statistically based checks are performed.
- *P07CHECK*—A preprocessor program and a computed parameter generator. While the primary function of this preprocessor program is to check the integrity of the results of resilient modulus measurements in indirect tension on asphalt concrete (AC) cores, it also uses an algorithm to calculate the test results from the raw measurement data to store in the database.
- *ProQual*—Both a pre-upload data check processor program and a computed parameter generator (like *P07CHECK*). *ProQual* processes, evaluates, and generates computed parameters for both longitudinal and transverse profile measurements. The output files from this program are used as input files to load data into the database.
- *SMPCHECK*—A preprocessor program allowing deletion of bad data and time-based adjustments. In addition to automated range and integrity checks on the data, time-history plots of this temporal data are also used to identify data inconsistencies. Output files created by this program were used as input files to the database.
- *LTAS*—LTPP Traffic Analysis Software, providing multiple functions (see sidebar).

Electronic data obtained from third parties are also evaluated and subjected to automated data checks before entry into the LTPP database. Two of the largest modules of data from other noncontract agencies are traffic monitoring data and climate data. The following

MIGRATION TO LTAS: EXAMPLE OF LTPP-DEVELOPED QUALITY CONTROL SOFTWARE

The LTPP Traffic Analysis Software (LTAS) provides multiple functions for evaluating and reviewing traffic data collected at the LTPP test sites by highway agencies and LTPP contractors. LTAS provides both graphical and automated range checks and statistical checks to identify suspect, invalid, duplicate, and erroneous traffic load and classification data.

Early in the program, each LTPP regional support contractor used in-house developed software to check the files received from highway agencies. These checks included detection of issues related to date gaps, lane identification, direction, station identification, start and end dates, times, left justification, optional agency data, blank lines, invalid line lengths, and the like, as well as sorting of the data. The files received were compared with the forms for classification and weight files submitted by the participating highway agency. Data identified as suspect were returned to the agencies for review and comment. Data identified as erroneous through this process were purged from the system before generation of annual traffic estimates.

Later in the program, LTAS was developed to ensure uniformity and consistency of processing traffic data between LTPP regions and to provide detailed QC checks of the data prior to making them available to the public. LTAS is used to perform a detailed review that is used to identify data that are atypical for the time period and test site. The software currently performs quality checks on automated vehicle classification (AVC) and weigh-in-motion (WIM) data, which are output graphically. These checks include:

AVC Data:

1. Missing Hours in a 24-Hour Period
2. 1:00 a.m. Volume > 1:00 p.m. Volume
3. 8 Plus Hours of Consecutive Zeroes Check
4. 4 Plus Hours of Static Non-Zeroes Volumes

WIM Data:

5. Gross Vehicle Weight Distribution Curves for Class 9 Vehicles (and Other Trucks)
6. Axle Distributions for All Vehicles
7. Equivalent Single Axle Load per Vehicle Variance Over Multiple Years
8. Tandem Axle Spacing
9. Class 9 Front Axle Weight Graph

Comparison of AVC and WIM Data:

10. Atypical Pattern
11. Average Volume Match
12. Match of Weight and Classification Volumes by Type of Vehicle

In addition to the QC graphs, LTAS has reports that can provide assistance in looking at the data to determine its accuracy. Some of these reports are:

1. Annual Summary Report
2. Annual Summary Report—Class by Lane
3. Annual Summary Report—Weight by Lane
4. Annual Estimate Statistics
5. Specific Pavement Studies Summary Report

The three Annual Summary Reports include monthly data, monthly statistics, and error summaries.

Since LTAS was first implemented in 2002, the software has evolved and continues to evolve to enable provision of high-quality data to LTPP data users.

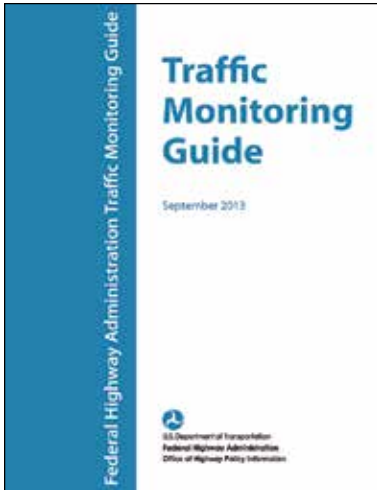


FIGURE 9.5. The Traffic Monitoring Guide, published by FHWA's Office of Highway Policy to assist States with collecting and submitting traffic data in a uniform format to FHWA.

explains the data checks that have been used by the LTPP program for these data:

- Traffic monitoring data are supplied by participating highway agencies in the standard data submittal formats described in FHWA's *Traffic Monitoring Guide*,²¹ shown in figure 9.5. Screening and processing of the traffic data submitted by the highway agencies are described in the LTAS sidebar.
- Until 2013, climate data were obtained from the National Climatic Data Center and Environment Canada. Due to their large volume, these raw data were loaded into an independent set of database tables. Automated checks on completeness, range, and logical statistics were performed on the data, and flags were set in the records to store the results. Records not passing the LTPP QC checks were excluded from use in the analysis process that creates temporal summary climate statistics for each LTPP test site. This summary information was then loaded into the database.

DATABASE CHECKS AND REVIEWS

As data are entered into the database by the regional support contractor, they undergo a hierarchy of automated, progressive QC checks. The results of these checks are recorded in the record status field. Every data record in the database starts with a record status

of A. When a data record with a status of A passes all level B checks, it is assigned a status of B, and so on. (Chapter 8 provides more detail about the different quality checks performed on the data.) Over time most of the level-B checks were removed, which left three major types of database QC checks:

- *Level C checks*—Determine if all required fields within a specific table have been populated. In some cases, level C checks were supplanted by non-null restrictions placed on critical fields during the table design that prevented a record from being created if a value for that field was not entered.
- *Level D checks*—Determine if the values entered in a field are valid and reasonable. For example, the range check for deflection data from the center sensor on an FWD is 5 to 2032 μm (80 mils).
- *Level E checks*—Determine if the value in one field of a table is comparable to the value in another field that may or may not be in the same table (commonly referred to as a “relational check”). For example, a level E check is used to see if pavement layer temperature gradient data exist for each FWD data set.

The QC level checks are performed sequentially. Level D checks are applied only to records passing level C checks, and level E checks are applied only to records passing level D checks. Record statuses of A and B are used for data that either have not undergone QC check processing or have not passed the level C checks. If a record fails a check, its record status remains at the next lower status. For example, records failing a level D check have a status of C. Alternatively, the record status can be manually upgraded if the record has been examined and has been found to be acceptable.

Records with level E status could mean either of the following:

- Records have passed all of the data checks.
- Records may have failed some data checks but were later manually upgraded after inspection.

In either case, level E records may contain errors that have not been detected by the data review process.

On the other hand, records with a non-level E status could be interpreted as any of the following:

- Records have not completed the QC process.
- Records have completed the QC process, but have been left at a lower level because they contain an anomaly.
- Records have not been subjected to the QC process by policy.

It is important to note that data users assume responsibility for conclusions based on their interpretation of the data collected by the LTPP program. Level E data should not be considered more reliable than non-level E data. Likewise, non-level E data should not be considered less reliable than level E data. The record status for non-level E data can be used as a relative indicator of potential issues or pavement anomalies that might exist for these data.

It was not practical, particularly when considering the wide variety of materials, climatic conditions, and local practices, to inspect all of the data for all types of potential anomalies. As the program evolved and improvements were made to the data QC checks, level E data included in previous releases may have been reclassified. It is also important to note that the LTPP program works diligently to identify and address critical data errors.

Likewise, it is important to recognize that the program has established standard and formal methods for the correction of data errors identified from the database checks. It is the LTPP program's policy to not load known "bad" data into the database, which is why the automated data check processors and screening methods were developed. Although steps are taken to prevent entry of erroneous data, with such vast quantities of data coming from multiple sources, there are instances when data in the database are still found to contain typographical errors.

When data errors are identified, the standard response is to correct the error if possible, to remove the data from the database, or to place the data at a lower data quality status. Error correction procedures are transmitted by LTPP program directives such as "Manual Upgrades to QC Checks," which describes the steps to take when data fail an automated check.²²

During the QC error resolution process, errors that are not possible to rectify are also identified. Some examples include:

- *Equipment measurement errors.* When a record failing a QC check can be traced to an identifiable equipment measurement error, manual upgrades cannot be employed to elevate a data element to a higher status.
- *Required data not available.* Circumstances can develop where critically required data are not available. There are instances when a required data element was not collected, was collected improperly, or is no longer possible to obtain or measure (e.g., thickness of an AC layer that was subsequently milled). In these exceptional circumstances, a test section may be removed from the LTPP study.
- *Issues requiring investigation.* When new tables are added to the database or new QC programs are issued, some records failing a QC check require further investigation to determine the cause. There are instances when it cannot be immediately determined if the error was a result of equipment malfunction, abnormal phenomenon, or program error. Some of these problems are resolved through the Software Performance Report (SPR) process, which is discussed later in this chapter.

The above database checks and review guidelines apply to data after entry into the LTPP database. Error correction guidelines are also contained in the field data collection and processing documents.

After the data have been entered into the LTPP database and have undergone checks by the regional support contractors, the technical support services contractor's staff reviews the contents of the entire database before releasing data to potential users. See chapter 8 for illustrations of the data flow and QC checks at different points in time. Data problems identified following release are documented using the Data Analysis/Operations Feedback Report (DAOFR) process, which is discussed later in this chapter.

LTPP QUALITY ASSURANCE EFFORTS

There are two types of QA procedures the LTPP program follows to maintain a high quality level in the database. These efforts, performed by the program staff, the technical support services contractor, and the regional support contractors, are discussed below.

LTPP Quality Assurance Audits

Since the early days, the LTPP program has performed QA audits of data collection contractor activities, including those of the regional support contractors, materials testing laboratories, central pavement distress data contractor, and FWD calibration centers. However, those audits were not formalized until 1998 through “LTPP Regional Operations Quality Assurance Reviews,” a program directive that enhanced and further standardized the data collection process used by the regional contractors.²³ This directive required, on a routine basis, the conduct of QA reviews of the regional data collection contractors in the areas of automated weather stations, distress, FWD, profile, and the Seasonal Monitoring Program.

After implementation of the directive, multiple QA reviews of regional support operations were conducted each year by teams consisting of four highly qualified individuals, typically including one from the LTPP program, two from the technical support services contractor, and one from a regional support contractor other than the one under review. These teams reviewed field and office operations during the course of their visits, sometimes together and at other times independently. Members of the review team were not allowed to interact with data collection or office personnel during the conduct of their activities; the reviewers could only observe and take notes.

Regional contractors were rated by the review team as being “Fully Compliant,” “Compliant—Minor Changes Required,” or “Non-Compliant—Major Changes Required,” depending on how closely LTPP guidelines and directives were followed. Individual personnel were also given a “Compliant” or “Non-Compliant” rating on the basis of the review results. In the event that one or more individuals were found to be “Non-Compliant,” the contractor was required to submit a remediation plan to the LTPP program office within

15 days of receiving such a rating. A follow-up review of “Non-Compliant” personnel was conducted within 6 months after the initial review and if at that time the individuals were still rated “Non-Compliant,” they were not allowed to collect data for the LTPP program until they were found to be compliant at a later review. Beginning in December 1998, only contractor personnel rated “Compliant” were permitted to collect LTPP data.

QA audits were also performed on FWD reference calibration facilities used by the program and operated under cooperative agreements with selected highway agencies. The facilities used LTPP-provided equipment and followed LTPP test protocols. Annual audits were performed in conformance to test protocols, audit results were documented, and certificates of compliance were issued.

QA audits for materials testing were performed independently by the American Association of State Highway and Transportation Officials (AASHTO). The LTPP program required that the materials testing contractors be certified by AASHTO standards.

In 2001, LTPP’s approach to QA audits was significantly revised with the re-letting of the four regional LTPP data collection contracts. As part of those contracts, FHWA required the regions to formally document their data collection and processing QC systems in accordance with ISO (International Organization for Standardization) 9001 quality management systems accreditation standards. The documents were referred to as “Regional Operations Quality Control and Data Flow Plans,” as described in the following section. Some of the relevant features of this management process include:

- Designation of a Regional Data QC Manager on each regional contractor’s staff, with the following responsibilities:
 - Conducting both regularly scheduled and impromptu internal audits of compliance with QC, data collection and data processing guidelines, and procedures.
 - Documenting internal audits.
 - Documenting corrective actions resulting from internal and external audit findings.
 - Conducting annual, or more frequent, reviews and updates of the QC and management procedures.

- The technical support services contractor established a QA audit team and process to assess compliance by the regional support contractors with their data QC and management guidelines and compliance with LTPP program requirements. The QA audits include the following:
 - Announced field or office visits to review designated sections of the QC and management plans. The different parts of the plans are rotated so that each part is reviewed on a 2-year cycle, budget permitting. Prior to an audit, a data review is conducted to identify data issues of concern to be investigated during the audit.
 - Unannounced audits of field data collection or office personnel. Auditors arrive unannounced to observe activities and compliance with both the contractor’s internal requirements and the LTPP program’s requirements.
 - A documented audit report that includes a description of audit activities, items reviewed, positive findings, corrective action requests, and improvement recommendations. All corrective action requests and improvement recommendations are discussed with the regional support contractor in order to reach an agreement on corrective actions to be taken. On each audit visit, all corrective action findings and improvement requests previously agreed to are reviewed.

Regional Quality Control and Data Flow Management Plans

Each region developed a formal Regional Operations Quality Control and Data Flow Plan circa 2001. These QC plans specified data collection, processing activities, data flow, and roles, responsibilities, and qualifications of staff members by position. QC activities were put in place to provide formal checks to identify bad, erroneous, and missing data prior to entry into the database. The regional contractors submitted QC and data flow plans for the following data elements:

- Deflection measurements.
- Longitudinal profile measurements.

- Distress surveys.
- Seasonal Monitoring Program data.
- Automated weather station data.
- Traffic data.
- Maintenance and rehabilitation data.
- Materials sampling and testing.
- Information Management System.

Plans varied among the regions; for example, the North Atlantic Regional Support Contractor developed the first LTPP QC plan for the automated weather station. Initially this region prepared a separate document for each data element, but later combined these into one document. In contrast, the Western Regional Support Contractor prepared a single document covering the QC processes for all of the data elements they collected and processed.

In 2004, the regional support contractors developed Working Guides as a means of standardizing regional procedures and ensuring consistency in training, field data collection, maintenance, calibration, and the processing and uploading of data. The purpose of these guides was to ensure compliance with the Data Quality Act.²⁴ In the North Atlantic Region, individual Working Guides were issued for each data element (like the initial QC and Data Flow Plans).

HIGHER ORDER DATA CHECKS

Although the QC processes discussed in the previous sections of this chapter can identify a wide array of data issues or problems, they cannot identify all of the potential data problems. Once these initial QC efforts have been completed, higher order data checks and reviews are used to identify other types of data issues. Important higher order review activities within the program include time-series checks, data studies, and engineering data analysis techniques. The term “data study” was introduced into the LTPP lexicon to indicate intensive higher order data reviews that employ a variety of analysis techniques performed against the entire LTPP data set and data subsets. While not in explicit alignment, these data studies tend to serve the same purpose as the level 2 QC checks described in the

Strategic Highway Research Program (SHRP) 5-year report on the LTPP Information Management System (IMS).²⁵ The final tier of higher order data checks comes from the results of formal analysis of LTPP data.

Time-Series Checks

An important higher order review activity performed within the LTPP program is the time-series review of pavement section performance data. In the case of distress data, for example, once data have been uploaded to the database, time-series checks are performed using the DiVA program. This software automates extraction, compilation, and time-series review of distress data from the database. The key subset of distresses included in the time-series review by pavement type is summarized below by pavement surface type:

- *Asphalt-concrete-surfaced pavements*—fatigue cracking, longitudinal cracking, transverse cracking, patch/patch deterioration, and block cracking.
- *Jointed concrete pavements*—corner breaks, longitudinal cracking, transverse cracking, and patch/patch deterioration.
- *Continuously reinforced concrete pavements*—longitudinal cracking, transverse cracking, patch/patch deterioration, and punchouts.

The DiVA software produces a graph of the selected distress versus time for each section and distress type,

starting from the time the test section was included in the LTPP program. An example is shown in figure 9.6. The graph includes both photographic and manual distress data for each test section along with error bands around the individual data points and a trend (best-fit) line to aid in the review. The variability bands are applied to the total quantity of distress—the sum of quantities over all severity levels. The upper and lower limits of each distress represent three standard deviations. Ninety-nine percent of the data from a given data set are expected to fall within three standard deviations of the mean of that data set.

Actions resulting from the time-series review vary from data being acceptable (most common outcome), to identification of issues that may be caused by correctable items such as unreported maintenance or rehabilitation activities on the test section (most common issue), to correction of individual distress data classification issues (infrequent occurrence).

Data Studies

In addition to the time-series checks, another important higher order review activity within the program is the conduct of data studies using data extracted from the database. Data studies are also used to develop, refine, or implement new or advanced data collection systems. Some examples of data studies conducted by the LTPP program include:

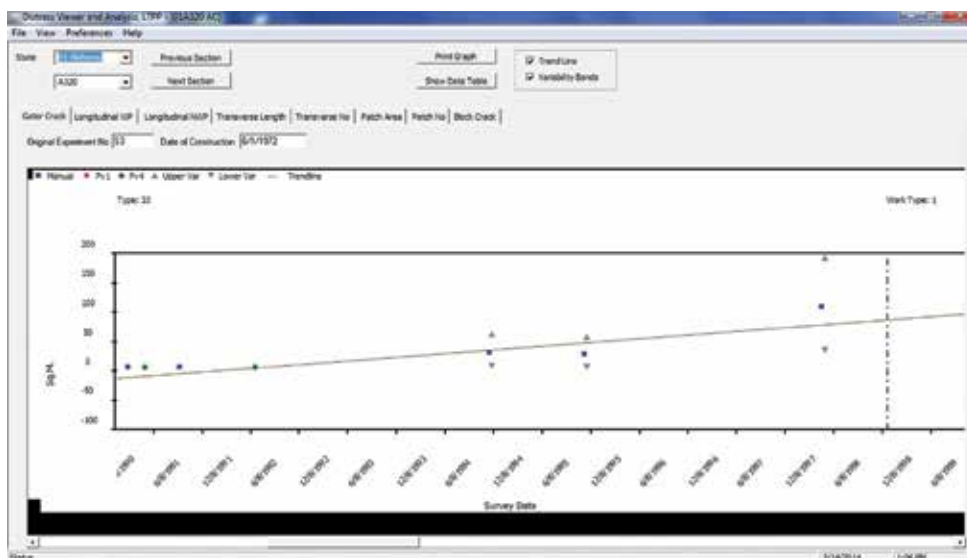


FIGURE 9.6. A distress-versus-time graph produced by the DiVA software.

- *LTPP distress data variability study*—Since the methods used to rate pavement distresses rely on subjective interpretation by trained personnel, a study was conducted in 1997 to examine variability between raters and between rating methods.²⁶ Based on a statistical sample of data obtained from nine distress rater accreditation workshops (and later updated and confirmed with data from an additional 13 distress rater accreditation workshops),²⁷ the study was conducted by engineering and statistical experts and peer-reviewed by the Transportation Research Board’s (TRB) ETG on Pavement Distress Monitoring. In addition to documenting probable ranges of uncertainty in distress measurements, the study provided recommendations on improving the rating methods that were implemented into the LTPP distress rater accreditation process, thereby reducing future distress data variability.
- *LTPP distress data consolidation study*—The objectives of this study were to produce a comprehensive consolidated distress data set and to reconcile differences between data collected using photographic and manual methodologies. This study led to the implementation of the distress data time-series checks using the DiVA software, which, in turn, led to the identification and correction of numerous discrepancies: 17 percent were attributed to human error, 6 percent to data collection methodology, 36 percent to the strategies used in the study, and 41 percent were unidentifiable.²⁸
- *LTPP AC resilient modulus data study*—A data study was performed on the resilient modulus test, developed by the LTPP program, for AC mixes in indirect tension. Due to the severity of the problems found with the data from these tests and the uncertainty associated with test results, which had originally appeared reasonable, significant amounts of data were archived, removed from the database, and not distributed to the public.²⁹
- *LTPP field data collection equipment studies*—As a part of the QC process, data studies are routinely

performed on the LTPP FWDs and pavement profilers. These data studies typically consist of a statistically designed experiment that uses an analysis of variance approach to evaluate the results of side-by-side equipment comparisons. These procedures are also used to evaluate equipment during the procurement process.

- *FWD calibration center pooled-fund study*—A State-sponsored pooled-fund study, managed by the LTPP program, was established to investigate and improve the LTPP-developed FWD calibration protocols. The purpose of the study was to evaluate current methods, procedures, and instrumentation and develop an improved system compatible with current computer technology.³⁰

Data Analyses

The last tier of LTPP higher order review activities is associated with the performance of formal data analysis projects. A multiproject approach, by topic area, is used for analysis of LTPP data. The LTPP program, other FHWA program offices, the National Cooperative Highway Research Program, and the States have sponsored many research analysis projects that have used LTPP data. More detailed information concerning LTPP data analysis efforts is provided in chapter 10.

LTPP-sponsored analysis projects are primarily intended to yield insights, benefits, and products from analysis of the data. A fundamental requirement of any research investigation is evaluation of the empirical data used in the investigation. In recognition that the operational structure of the LTPP program serves to provide relevant data of known quality for achievement of program goals through analysis of the collected data, the DAOFR process, discussed below, was established in 1998.³¹ Over time, the DAOFR process has been used to report suspect data issues discovered in data analyses and studies by users both within and outside the LTPP program.

PEER REVIEW

An integral component of LTPP's data quality approach is extensive peer review, both external and internal, of the various program areas and activities. At the start of the program, an external peer review process was created to monitor the status and progress of the LTPP studies and provide technical assistance to SHRP and later to FHWA, as discussed in chapter 2 and appendix A. The TRB LTPP Committee and its ETG structure incorporated experts and practitioners from the highway pavement community and provided advice regarding the technical and managerial direction of the LTPP program. National outreach stakeholder meetings such as the 1990 SHRP Assessment Meeting in Denver, Colorado; 1996 SHRP LTPP National Meeting in Irvine, California; 2000 LTPP SPS Workshop in Newport, Rhode Island; and 2010 LTPP Pavement Analysis Forum in Irvine, California, provided additional external peer review input on LTPP program activities.

Internal peer review is also a major contributor to high-quality data and the program's success. Internal peer review touches on every element of the program, including the various QC/QA activities described in this chapter.

A few highlights of LTPP peer review activities, both external and internal, are summarized below:

- The LTPP experiment designs were developed and reviewed by statisticians with pavement research experience. These designs were also reviewed by an ETG consisting of statisticians and pavement research engineers.
- The LTPP data requirements were developed by experts in each of the engineering disciplines associated with the program. These requirements were reviewed and critiqued by other stakeholders through TRB-facilitated national meetings. This process continues.
- The LTPP data collection guidelines are developed by experts in each of the engineering disciplines

associated with the program. These guidelines are reviewed and critiqued by the appropriate TRB LTPP ETGs.

- Before the contents of the database are released, they are reviewed by experts and specialists on the technical support services contractor's staff. By design, these review staff are not involved with data collection or analysis.
- The LTPP Strategic Plan for Data Analysis was developed and continues to be refined based on input from program staff, highway agency personnel, industry stakeholders, and academicians through an outreach process.³² The plan was developed in concert with the LTPP ETG on Data Analysis, and it is periodically updated using the ETG peer review process. Review of LTPP-sponsored data analyses and reports is based on a formal peer review process. Data analysis documents that contain estimates and projections are required to contain a description of the analysis methodology, and they receive both an internal and an independent external review by subject matter experts before publication.
- All published LTPP reports use the FHWA publication process, which includes editorial review for conformance with FHWA publication standards and provides a report documentation page. Since the introduction of section 508 of the Rehabilitation Act, LTPP publications have been formatted in conformance with the Act and reviewed by individuals trained in section 508 compliance standards.

Furthermore, to allow input from both external and internal sources, better serve its customers, and determine customer satisfaction, the LTPP program provided customer support services and customer survey processes starting in 1989. In 2006, FHWA moved the formal LTPP Customer Support Service Center to its Turner-Fairbank Highway Research Center, in McLean, VA.

FEEDBACK PROCESSES

Another important data quality element is the feedback process. Initial LTPP feedback efforts were mostly limited to national and regional meetings involving LTPP State Coordinators and regional support contractors. Teleconferences were also held with the data collection staff from the regional support contractor offices. These meetings and conferences were scheduled as needed and allowed problems, ideas, and solutions to be shared among all participants. Later, more formal procedures (OPRs, DAOFRs, and SPRs) were established to ensure that the feedback processes contribute toward the improvement of data quality and to the LTPP program's success.

Operational Problem Reports

The first LTPP feedback mechanism, formally implemented by policy in 1995, was the OPR form, which enables personnel in the regions to report problem issues—equipment, software, and procedural problems associated with data collection, and, in particular, uncommon circumstances. This feedback mechanism provides a uniform way of reporting, handling, and tracking problems associated with the LTPP automated weather station, distress, FWD, profile, and seasonal monitoring data. Over time, LTPP program directives were issued extending and formalizing the OPR process to different data collection areas, such as materials sampling and testing.

A log of the OPRs is used to track the circumstances of the problems and their resolution. OPRs are reviewed, analyzed, and discussed by the LTPP program and contractor staff during teleconferences, and resolutions are provided by the regional support or technical support services contractors. Quarterly updates are sent to the program office and regions.

The OPR feedback process has resulted in several major benefits: standardizing the process for submitting problems associated with data collection activities; simplifying tracking when a problem was submitted, who was responsible for resolving it, whether or not it had been resolved, and how and

when it was resolved; and reducing the probability of issues being forgotten or resolutions not making it back to the problem's initiator. More than 400 OPRs had been submitted and resolved by 2014.

Data Analysis/Operations Feedback Reports


The second LTPP feedback mechanism formally instituted by policy (in 1998) was the DAOFR process,³³ which enabled users of the database to report issues encountered during data analysis that suggest or demonstrate the need for corrective actions or further investigation (figure 9.7). In an effort to examine all data in the database, the program developed a series of DAOFRs for use by the regional support contractors and data analysts to provide commentary and to load, edit, fix, clean, or remove any suspect data collected by the regions or received from the highway agencies. The approach to completing DAOFRs varies for each data collection element. For example, the Traffic DAOFR process started with the out-of-study sites (sites that were no longer being monitored) as well as the tables that had been completely populated (no new data were expected) or were part of the module close-outs. Data for active SPS and General Pavement Study sites were examined next.

The DAOFR form and DAOFR resolutions are available to LTPP data users online.³⁴ Situations in which use of the DAOFR process is appropriate include the absence of critical data for specific test sections; data that appear to be incorrect, contradictory, or otherwise suspect; data not collected but necessary to fill voids identified in the analysis; and recommendations arising from the analysis regarding data collection procedures that can be improved. By 2014, close to 1,400 DAOFRs had been submitted.

Software Performance Reports

An early program feedback effort was the implementation of the LTPP database SPRs, which the contractors used to report problems, comments, change requests, and document changes made to the database management software. Although suggestions for software diagnosis and correction are often provided via phone calls and emails, actual diagnosis

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 HRDI-30
 6300 Gecegetown Pike
 McLean, VA 22101-2296
 Facsimile: (202) 493-3161
 Email: LTPPINFO@dot.gov



LTPP Data Analysis/Operations Feedback Report			Report no.:
			Date:
Submitted by:			
Subject:			
Situation:			
Recommended action:			
Distribution			Urgency (check one)
Referred to:	Assigned to:	Information copies to:	Resolution needed by: <input type="checkbox"/> _____(Date) <input type="checkbox"/> Next public data extraction from the PPDB
			Comments
Action to be taken: As recommended _____ As outlined below _____			Date assigned:
			Date due:
Findings/actions taken:			
Date completed:			

Attach additional pages as necessary to describe situation, recommended action, and actions taken. When attaching a separate file to a DAOFR submital or resolution (for example a spreadsheet) please insert a header in the file with the DAOFR number and include the DAOFR number as part of the file name.

FIGURE 9.7. LTPP Data Analysis/Operations Feedback Report, used to provide feedback to the program regarding data that require investigation or correction.

(by re-creating the conditions and modifying the software) occurs via the SPR process. An SPR submitted on a specific version of software includes a concise description of the problem and relevant extractions of test section information.

The SPR process was put in place in the early 1990s, and an SPR form was adopted to report issues with the traffic software in 1996,^{35,36} but the SPR process was not formally implemented by policy until 2005.^{37,38} In 2011, the SPR form was Web-enabled.³⁹ In all, more than 4,300 pavement performance database and traffic SPRs have been submitted.

CONFORMANCE WITH DATA QUALITY SYSTEMS AND STANDARDS

Another important approach to data quality that was implemented by the LTPP program in the early years was to adopt existing concepts in other large databases to maintain consistency across the database. Such adoptions include the following:

- Federal Information Processing Standards for geographic codes.
- National Transportation Thesaurus for keywords.
- World Geodetic System 1984 for location coordinates.
- AASHTO classification system for soils and unbound base material.
- AASHTO materials testing standards.
- American Society for Testing and Materials test standards.

Still another data quality approach implemented from 2006 to 2008 was the self-assessment of the program relative to its compliance with U.S. Department of Transportation Information Dissemination Quality Guidelines, and the resulting report, as discussed in chapter 8.^{40,41}

SUMMARY

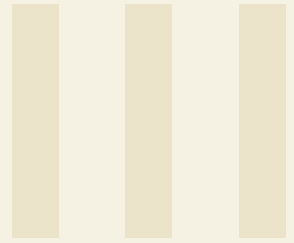
LTPP QC/QA practices have resulted in a high-quality pavement performance database. The program’s quality expectations have created an environment that promotes advancements in QC processes to help in understanding pavement performance. The program has developed an extensive and robust set of modern pavement engineering QC methods and tools, several of which have been adopted by the pavement engineering

community. These and other products are discussed in the next chapter. The next section also includes chapters on lessons learned and plans for the future.

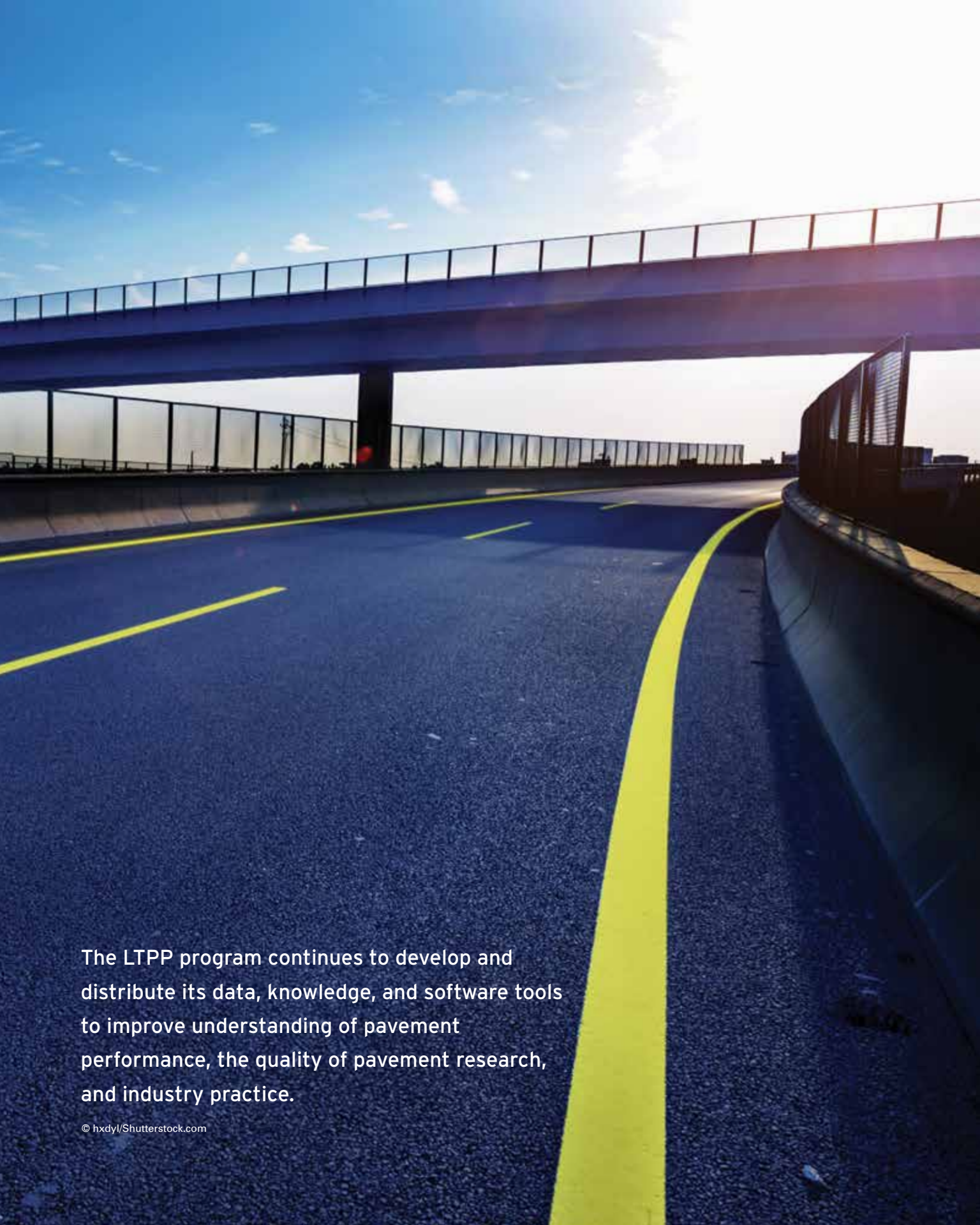
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**Creating Products, Learning From the Past,
and Preparing for the Future**



The LTPP program continues to develop and distribute its data, knowledge, and software tools to improve understanding of pavement performance, the quality of pavement research, and industry practice.

10

Turning LTPP Data into Results

While providing a treasure trove of information for researchers, the LTPP program also focuses on providing products to pavement practitioners at the local, State/Province, and national levels. By developing and following strategic data analysis and product development plans, the program has directly supported a wide range of improvements to pavement management, design, and construction practices. These benefits have resulted in cost savings in the millions of dollars for highway agencies.

INTRODUCTION

When pavement designers in Houston determine what materials and base structure an alternate truck route should incorporate, or when engineers ponder the effects of the hot dry climate on highways in Phoenix, the LTPP database is freely accessible to help them make crucial choices. Thanks to the foresight of a generation of engineers and administrators who knew the value that comprehensive pavement performance data would have for the future, the LTPP program has more than paid for itself in delivering dozens of products that have improved our highway system.

This chapter describes some of the more important contributions achieved through LTPP research, data analysis, and product development. In numerous studies over the years, pavement researchers have used LTPP data in the evaluation and development of design

procedures, most recently in the development of the *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures* (MEPDG). Analysis has led to improvements in pavement management systems, with new insights into the performance of rehabilitation and maintenance activities. LTPP data analysis has also led to many innovations and tools that pavement researchers and engineers are using to advance pavement quality and durability.

LTPP DATA ANALYSIS

Designing the experimental matrices, defining data collection procedures, and developing and populating the database are all critical steps to enable the LTPP



Key Milestones in Turning LTPP Data Into Results

- 1992** First calibration protocol for FWDs finalized
- 1994** First SHRP-LTPP data analyses published
- 1997** NHI develops LTPP-based distress rating course
- 1997** Vehicle Classification Report published
- 1998** ASCE-LTPP International Data Analysis Contest introduced
- 1998** NCHRP MEPDG project begins using LTPP data to develop new design software
- 1999** FHWA-LTPP updates SHRP Manuals of Practice
- 1999** AASHTO adopts LTPP-developed Standard Practice R 32
- 1999** LTPP Strategic Plan for Data Analysis adopted
- 2001** LTPP Product Plan published
- 2001** ProVAL software released
- 2006** Pavement Performance Forecast Online developed
- 2007** ProVAL software's data format becomes ASTM standard
- 2010** Major review and update of LTPP Strategic Plan for Data Analysis
- 2011** LTPP Dynamic Modulus Prediction software developed
- 2013** Update of the LTPP Strategic Plan for Data Analysis
- 2014** ProQual software updated

program to address its end objectives. Answering key questions requires a robust data analysis program. Although LTPP data analysis activities have been impacted by funding challenges over the years, nonetheless, significant resources have been invested into analyzing the data, and substantial returns have already been realized. Some notable examples are introduced in this section.

Early Analyses

SHRP-P-020 Contract—Data Analysis

As the first major effort under the Strategic Highway Research Program (SHRP) to use LTPP data for specific analytic purposes, the SHRP P-020 contract supported a number of studies to accomplish a variety of research objectives:

- To better understand the effects of a broad range of loading, design, environmental, materials, construction, and maintenance variables on pavement performance.
- To evaluate and improve the American Association of State Highway and Transportation Officials' (AASHTO) overlay design procedures.
- To evaluate and improve models included in the 1986 AASHTO *Guide for Design of Pavement Structures*.¹
- To plan for future analyses when the General Pavement Studies (GPS) and Specific Pavement Studies (SPS) time-sequence data would become more available.

The studies, conducted in 1992 and 1993, utilized GPS data collected during the first 5 years of the program, since collection of SPS data was just getting underway. The results were published in five volumes.² The fifth volume, *Lessons Learned and Recommendations for Future Analyses*,³ was notable in its identification of problems and deficiencies of the LTPP database and changes that would improve its utility for future researchers. The report identified procedures for developing predictive models and proposed procedures for evaluating design methods. The SHRP P-020 studies laid the foundation for later analyses using LTPP data.

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Pavement Maintenance Studies—SHRP-H-106 Reports
The SHRP H-106 project, Innovative Materials Development and Testing, 1991–93, was designed to evaluate the cost-effectiveness of pavement maintenance materials and procedures in the most extensive pavement surface maintenance experiment that had ever been conducted. The experiment studied the performance of unique combinations of materials and treatment methods for pothole repair (eight test sites, 1,250 potholes) and transverse and longitudinal crack sealing and filling (22,000 ft [6,700 m]) in asphalt concrete (AC) pavements and for joint resealing (1,600 joints) and partial-depth repair (four test sites, 1,600 partial-depth repairs) in Portland cement concrete (PCC) pavements. The study sites were distributed through the program’s four climatic regions, and the performance of the maintenance treatments was evaluated 18 months after the repairs were made. SHRP H-106 generated comprehensive reports and manuals of practice for each of the maintenance activities.^{4,5,6,7}

When the SHRP program concluded, the LTPP program under the Federal Highway Administration (FHWA) continued annual evaluations of the test sites between August 1993 and December 1997 through its Long-Term Monitoring of Pavement Maintenance Materials Test Sites study. At the end of the study, the LTPP program published extensive reports on PCC partial-depth spall repair,⁸ joint resealing,^{9,10} crack treatment,¹¹ and pothole repair.¹² In 1998, a 5-year data analysis review of the maintenance of SPS-3¹³ and -4¹⁴ was published, followed by an update of the original four SHRP Manuals of Practice in 1999 with information collected during the continued monitoring, as described in the LTPP Products section.¹⁵

FHWA Broad Agency Announcement

After the LTPP program transitioned from SHRP to FHWA, a series of LTPP data analysis contracts were funded under a Broad Agency Announcement (BAA). The BAA was issued before the development of the Strategic Plan for LTPP Data Analysis, discussed below, and the majority of the work was performed between 1994 and 1996. Examples of projects completed under the BAA include the following:

- *Design and Construction of PCC Pavements.* The study focused on the development of practical rec-

ommendations that could be implemented by highway agencies to increase pavement life.^{16,17,18}

- *Temperature Predictions and Adjustment Factors for Asphalt Pavement.* An analysis of data from 40 sites in the Seasonal Monitoring Program (SMP), this study led to the practical *LTPP Guide to Asphalt Temperature Prediction and Correction*, with a spreadsheet for use in implementation of the methods recommended.^{19,20}
- *Rehabilitation Performance Trends.* The earliest in-depth look at the SPS rehabilitation experiments, this study examined performance data from SPS-5 (rehabilitation of AC pavements), SPS-6 (rehabilitation of jointed PCC pavements), and SPS-7 (bonded PCC overlay on PCC pavements).²¹
- *Rutting Trends in Hot-Mix Asphalt Pavements.* Based on data from 575 GPS sites, this study found that pavements with high levels of rutting on average were constructed of asphalt mixes containing more fine aggregates than recommended by the Superpave[®] aggregate specifications; that hot weather, thin pavements, soft asphalts, and wet or low-density bases or subgrades also contribute to rutting; and that properly designed and constructed asphalt pavements can serve for 20 years or more without excessive rutting.²²

Following the BAA, FHWA began to use an umbrella data analysis contract or data analysis IDIQ—indefinite delivery/indefinite quantity—contract for most LTPP data analysis activities.

Strategic Plan for LTPP Data Analysis: The “Tablecloth”

With such a wide array of potential analysis efforts, the LTPP program recognized the need to develop a strategic plan for LTPP data analysis. Led by the Transportation Research Board (TRB) Expert Task Group (ETG) on LTPP Data Analysis and the program office, this focused effort in the late 1990s benefited from the participation of subject matter experts across the pavement spectrum.²³ The LTPP Data Analysis ETG took on responsibility for developing a strategic plan using LTPP data “to develop knowledge, relationships, and models to facilitate improved pavement design and reliable performance predictions.”²⁴ Soliciting input from academic, industry, agency, and other pavement experts, the ETG identified

a wide array of analysis topics and outcomes. Through a series of meetings and other interactions, these items were organized into seven strategic objectives:

1. Improve traffic characterization and prediction.
2. Improve materials characterization.
3. Improve consideration of environmental effects in pavement design and performance prediction.
4. Improve evaluation and use of pavement condition data in pavement management.
5. Evaluate existing and develop new pavement response and performance models applicable to pavement design and performance prediction.
6. Provide guidance for maintenance and rehabilitation strategy selection and performance prediction.
7. Quantify the performance impact of specific design features (e.g., presence or absence of positive drainage, differing levels of pre-rehabilitation surface preparation).

Each of these objectives had multiple “product outcomes,” further grouping the analysis activities to ensure optimum return on investment.

Upon reaching consensus on the Strategic Plan, the LTPP Data Analysis ETG formally voted to implement it at its meeting on November 8–9, 1999, and advocated that all partners and participants adopt it as well. The original plan is shown in figure 10.1 and figure 10.2. The LTPP program office assumed responsibility for maintaining the Strategic Plan, including periodically organizing in-depth reviews of the plan and its constituent problem statements.

In September 2010, a LTPP Pavement Analysis Forum was held in Irvine, California, where 50 pavement specialists from highway agencies, universities, and consulting firms met to review and refine targeted analytical outcomes under the Strategic Plan (see sidebar). The 3-day forum was a joint effort of the LTPP program office and FHWA management, along with the TRB LTPP Committee.²⁵ The group developed 122 analysis outcomes, project definitions, or research



LTPP Pavement Analysis Forum Participants at TRB Beckman Center in Irvine, CA, September 2010. *Front Row (left to right):* Larry Wiser, Ahmad Ardani, David Orr, Susan Tighe, Eric Weaver, Judith Corley-Lay, Steve Jessberger, Mike Heitzman, Shie-Shin Wu, Tahar El-Korchi, Nadarajah Sivanewaran, Gil Baladi, Newt Jackson. *Second Row:* Jane Jiang, Amelia Mathis, Deborah Walker, Wes Yang, Olga Selezneva, Julie Vandebossche, Bob Lytton, Lynne Irwin, Jerry Hajek, Cheryl Richter, Neil Hawks, Danny Dawood, Ralph Haas, Tom Yu, Amir Hanna, Andy Johnson, Ray Moore, Rick Reel, Karim Chatti, Robert Raab, Becky McDaniel, Jon Epps, Tom Baker, Luis Rodriguez. *Third Row:* Gary Elkins, Kevin Senn, Brian Schleppl, Andy Mergenmeier, Shelley Stoffels, Jonathan Groeger, Jack Springer, Ben Worel, Charlie Churilla, Mark Gardner, Aramis López, Tom White, Frank Meyer, John Donahue. *Not in the picture:* Mike Ayers. *Absent:* Carl Monismith.

STRATEGIC PLAN

FOR LONG-TERM PAVEMENT PERFORMANCE DATA ANALYSIS

November 9, 1999

PURPOSE AND GOAL

The purpose of this plan is to guide recommendations by the TRB LTPP Committee concerning the national-level analysis of data collected within the Long-Term Pavement Performance studies.

The goal for this plan is to develop knowledge, relationships, prototype performance models and other findings to facilitate improved pavement treatment strategy selection and reliable performance prediction.

The Committee will use this plan to help it determine whether the limited resources available for LTPP data analysis are used in the most effective manner. The Committee will evaluate newly proposed analyses, work currently in progress, and completed work for compliance with this plan. The Committee understands that the Federal Highway Administration intends to use this plan for similar purposes.

The Committee invites all agencies that are partners and participants in the LTPP studies to adopt this plan. If so adopted, this plan will provide uniform guidance for national-level LTPP data analysis.

The Committee formally adopted this strategic plan at its meeting of November 8-9, 1999. The plan is now in effect, and will be kept current by the Committee from this date forward to the completion of LTPP. The Committee will review the plan annually, and will update it when necessary.

EXPECTATIONS

It is anticipated that this plan will be used to:

1. Guide development of LTPP analysis problems by the TRB ETG on Data Analysis.
2. Guide selection of LTPP analysis problems by the TRB LTPP Committee.
3. Support the programming of national-level LTPP analysis by sponsors.
4. Guide the formulation of LTPP analysis project statements.
5. Support assessment of progress in analysis of the LTPP data.
6. Communicate products anticipated from LTPP analysis.

ANALYSIS OBJECTIVES

The objectives of the national-level analysis effort are as follows. Each objective is important to the achievement of the overall goal.

1. Improve traffic characterization and prediction.
2. Improve materials characterization.
3. Improve consideration of environmental effects in pavement design and performance prediction.
4. Improve evaluation and use of pavement condition data in pavement management.
5. Evaluate existing and/or develop new pavement response and performance models applicable to pavement design and performance prediction.
6. Provide guidance for maintenance and rehabilitation strategy selection and performance prediction.
7. Quantify the performance impact of specific design features (presence or absence of positive drainage, differing levels of pre-rehab surface preparation, etc.).

The specific LTPP analysis results leading to products expected to address these objectives are shown in the chart on the following page.

FIGURE 10.1. Introduction to the original LTPP Strategic Plan for Long-Term Pavement Performance Data Analysis, page 1, as adopted in 1999.

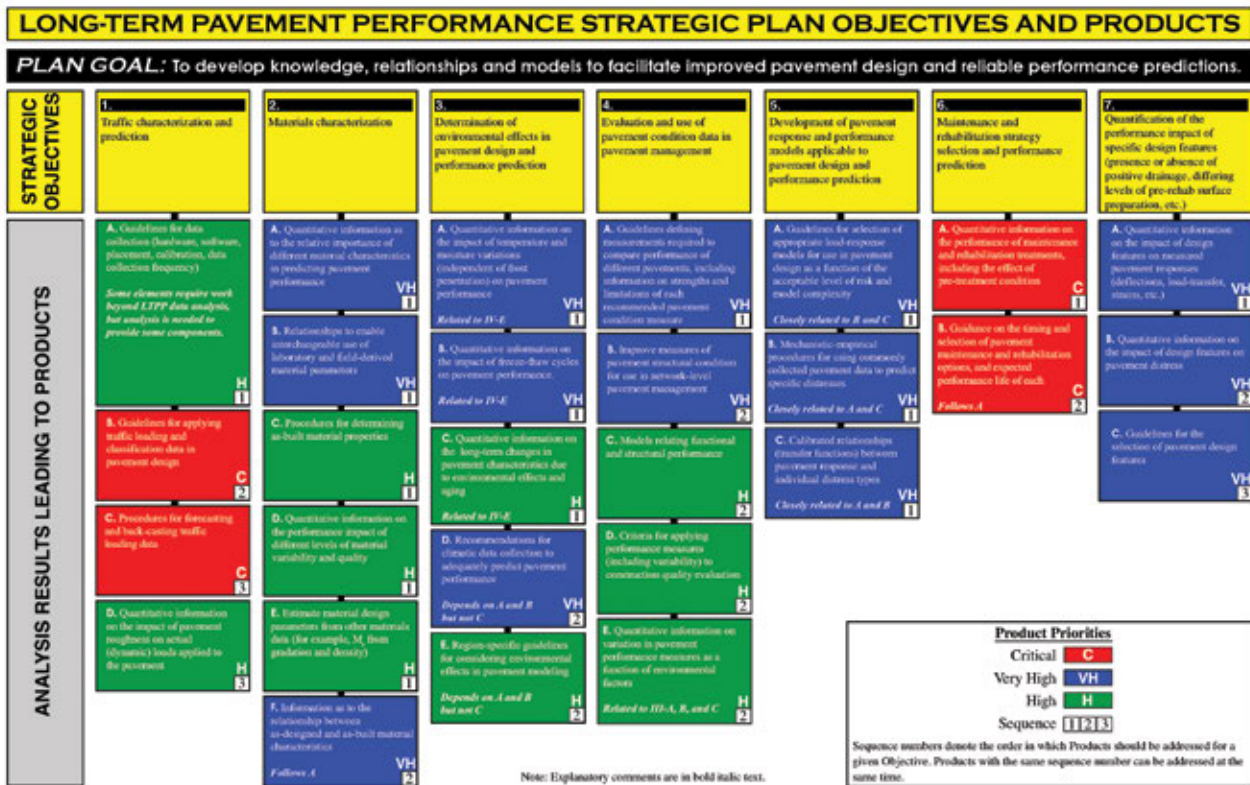


FIGURE 10.2. Graphical compilation of the 1999 LTPP Strategic Plan for Long-Term Pavement Performance Data Analysis, its strategic objectives and product priorities.

problem statements, which were provided to the TRB LTPP Committee for review and recommendation for implementation in future years.^{26,27}

During the pavement analysis forum, the Strategic Plan was expanded with the addition of two new strategic objectives:

8. Analyses Supporting and Enhancing the Use of the MEPDG.
9. Comprehensive Use of LTPP to Improve the Management of Pavement Assets.

The plan is a living document, and has been revised and updated regularly since its adoption to show the status of analysis projects.²⁸ Owing to the paper size required to legibly print the document on a single sheet of paper, the strategic data analysis plan was nicknamed the LTPP data analysis “tablecloth.” Figure 10.3 displays the plan, illustrating its size. Figure 10.4 and figure 10.5 show plan detail for Strategic Objectives 1 and 6.

Over the years, many projects have addressed areas within the Strategic Plan. The LTPP program supported some of these projects, while others were supported by non-LTPP funds from FHWA or through the National Cooperative Highway Research Program (NCHRP) (see table 4.2, LTPP Timeline—Highway legislated and other funding sources). The following sections present examples of NCHRP- and FHWA-funded analysis research; however, for a complete view of progress in LTPP data analysis—studies planned, completed, and underway—refer to the Strategic Plan for LTPP Data Analysis.

LTPP Analysis Research Funded by NCHRP

In 1999 and 2000, a series of LTPP data analysis projects were awarded and administered through NCHRP under Research Field 20—Special Projects. These projects, which have all been completed (results available online), are listed in table 10.1.

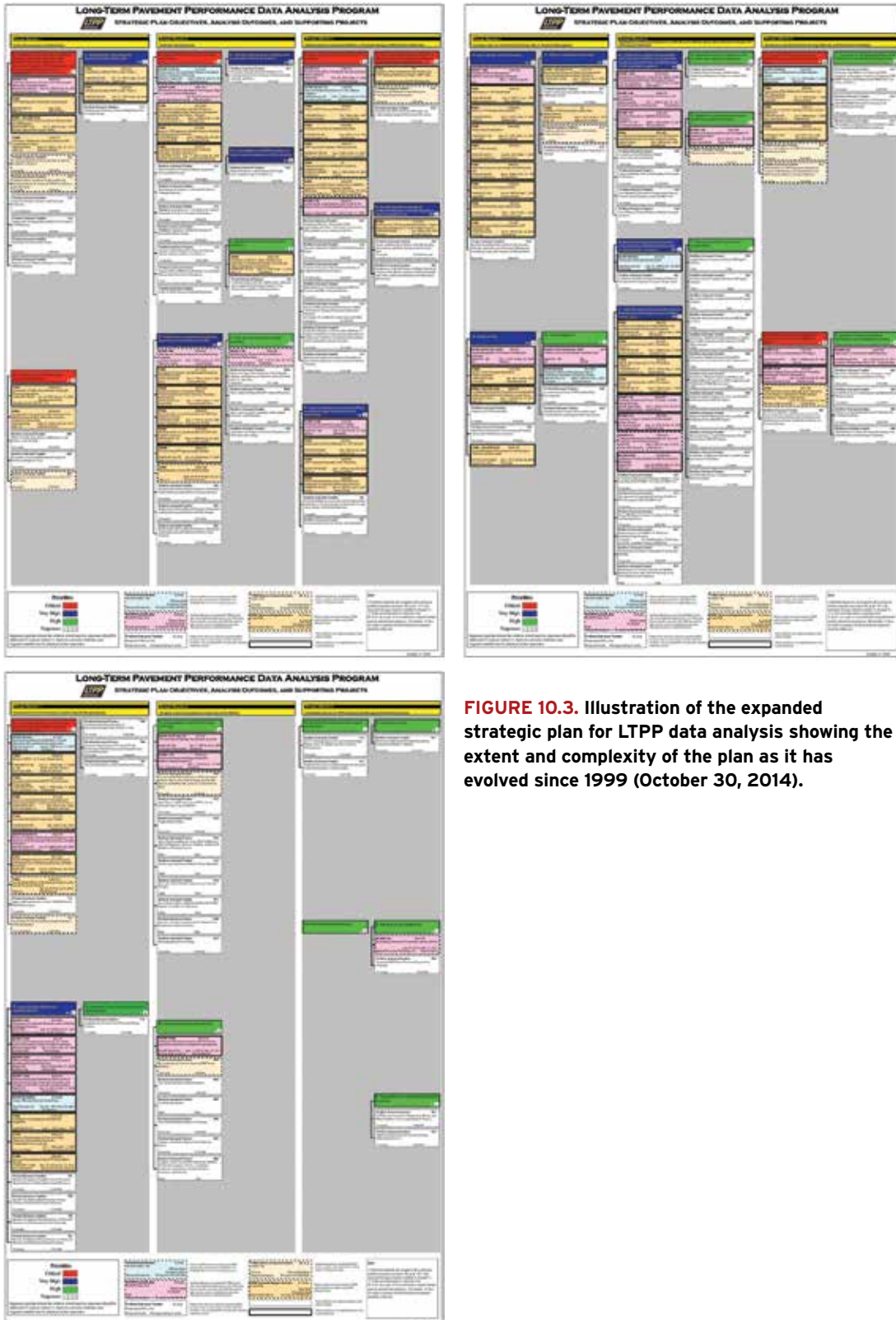
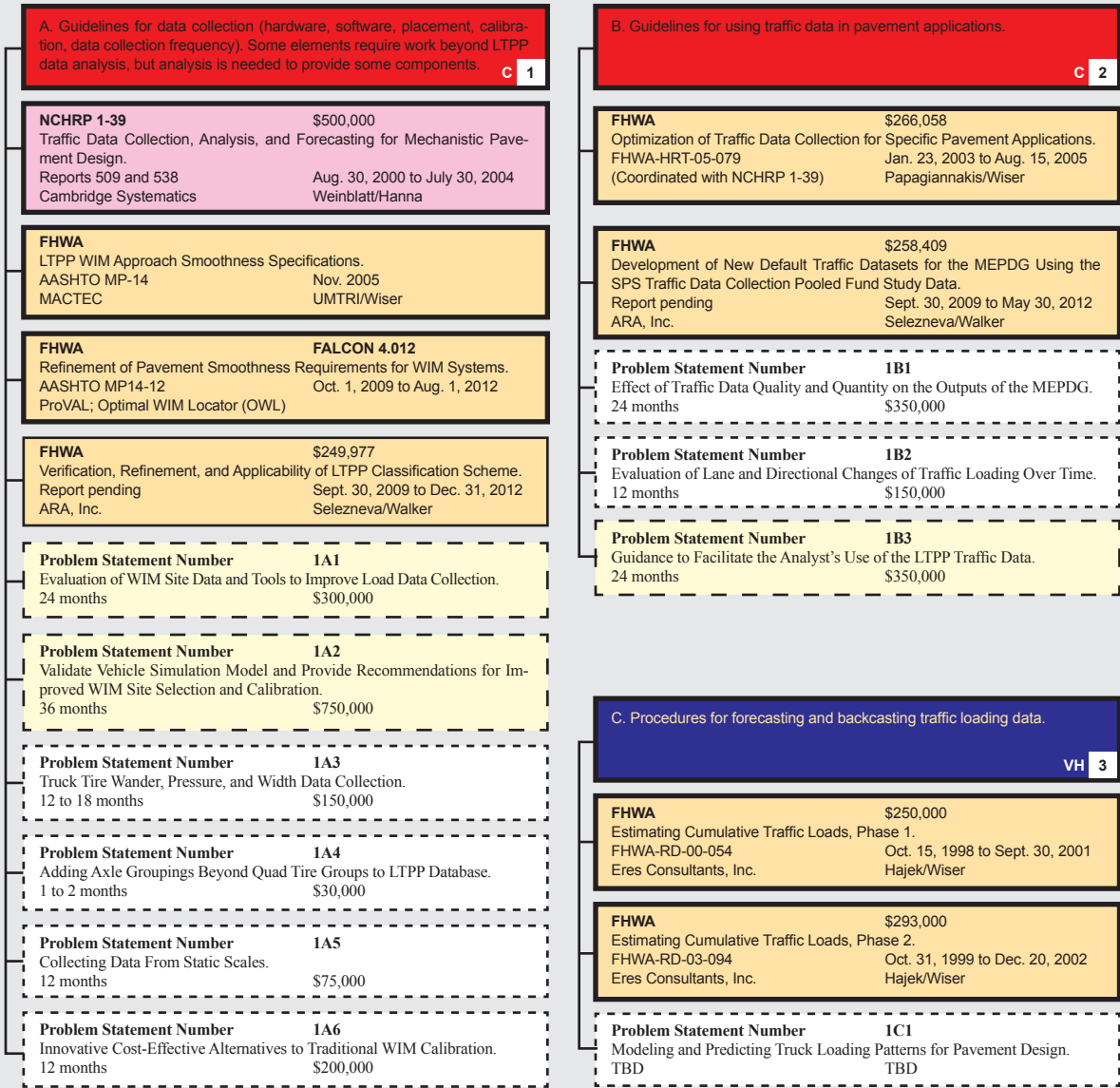


FIGURE 10.3. Illustration of the expanded strategic plan for LTPP data analysis showing the extent and complexity of the plan as it has evolved since 1999 (October 30, 2014).

Strategic Objective 1: Traffic Characterization and Prediction.



Priorities

- Critical ■
- Very High ■
- High ■
- Sequence 1 2 3

Sequence numbers denote the order in which analysis outcomes should be addressed for a given objective. Analysis outcomes with the same sequence number can be addressed at the same time.

 Boxes are ongoing NCHRP projects that were initiated by the LTPP ETG. Solid light blue boxes are completed projects.

 Boxes are ongoing NCHRP projects that were initiated by other agencies or work groups, but are directly associated with LTPP data analysis plan strategic objectives and analysis outcomes. Solid pink boxes are completed projects.

 Boxes are proposed research problem statements that were developed at LTPP workshops. See Note 1) for an explanation of the problem statement numbering scheme.

 Boxes are planned FHWA projects or data studies that will be funded using LTPP budgeted funds.

 Boxes are ongoing FHWA projects that were funded using LTPP budgeted funds.

 Boxes are completed projects with reports pending.

 Boxes are completed projects with reports published.

Note: 1) Problem statements are assigned a three-character number using the convention 'O_A_n'. 'O' is the associated strategic objective number (1 through 7); 'A' is the associated analysis outcome letter (A, B, C, etc.); and 'n' is an arbitrarily assigned number used for identification purposes. The number 'n' does not imply a sequence in which problem statements should be addressed.

FIGURE 10.4. Excerpt of the expanded strategic plan for LTPP data analysis, showing analysis outcomes, supporting projects, and problem statements for Strategic Objective 1: Traffic Characterization and Prediction (October 30, 2014).

Strategic Objective 6: Maintenance and Rehabilitation Strategy Selection and Performance Prediction.

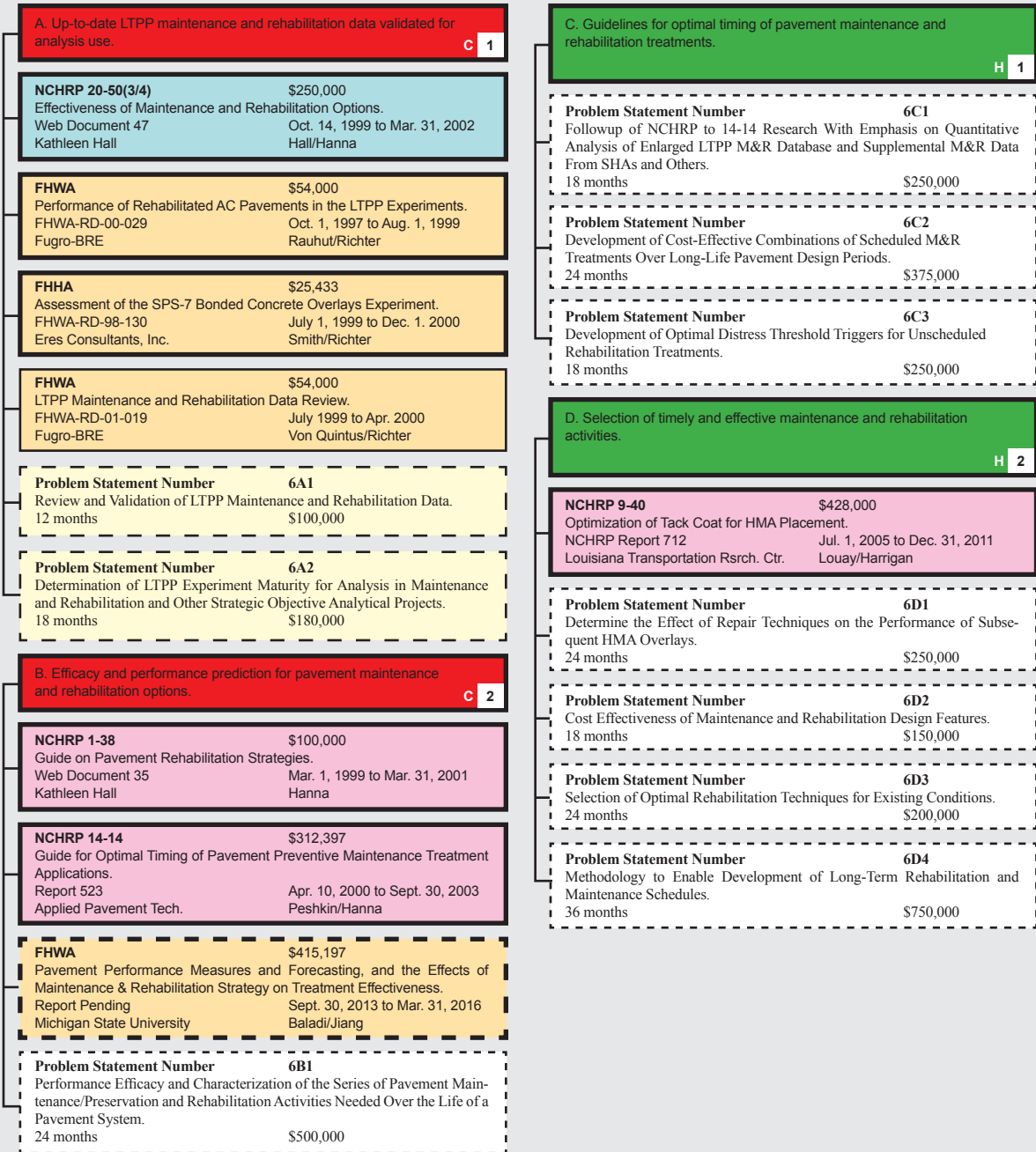


FIGURE 10.5. Excerpt of the expanded strategic plan for LTPP data analysis, showing analysis outcomes, supporting projects, and problem statements for Strategic Objective 6: Maintenance and Rehabilitation Strategy Selection and Performance Prediction (October 30, 2014). Refer to the legend in figure 10.4 for further explanation.

TABLE 10.1. LTPP data analysis research funded by the National Cooperative Highway Research Program.

Project Number(s)	Title
NCHRP 20-50(10&16)	LTPP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements ²⁹
NCHRP 20-50(10)	LTPP Data Analysis: Factors Affecting the Performance of Flexible and Rigid Pavements (folded into NCHRP 20-50(10&16))
NCHRP 20-50(14)	LTPP Data Analysis: Significance of "As-Constructed" AC Air Voids to Pavement Performance ³⁰
NCHRP 20-50(2)	LTPP Data Analysis: Relative Performance of Jointed Plain Concrete Pavements With Sealed and Unsealed Joints ³¹
NCHRP 20-50(3&4)	LTPP Data Analysis: Effectiveness of Maintenance and Rehabilitation Options, 2002 ³²
NCHRP 20-50(5)	LTPP Data Analysis: Variations in Pavement Design Inputs ³³
NCHRP 20-50(7&12)	LTPP Data Analysis: Daily and Seasonal Variations in Insitu Material Properties ³⁴
NCHRP 20-50(8&13)	LTPP Data Analysis: Factors Affecting Pavement Smoothness ³⁵
NCHRP 20-50(9)	LTPP Data Analysis: Feasibility of Using FWD Deflection Data to Characterize Pavement Construction Quality ³⁶

LTPP Analysis Research Funded by FHWA (Non-LTPP Funds)

Several research efforts sponsored or conducted by FHWA appear in the Products or Benefits section later in this chapter. Following is a sampling of specific studies undertaken in recent years.

- *LTPP Computed Parameter: Moisture Content (2005–2007)*. This project completed the interpretation of LTPP time domain reflectometry measurements and provided estimates of moisture contents from these measurements in the LTPP database in January 2008 on Standard Data Release 22.³⁷
- *LTPP Computed Parameter: Frost Penetration (2005–2007)*. With the completion of monitoring measurements on the SMP sections in October 2004, this project completed the interpretation of measurements not previously interpreted and added the results of these interpretations to the database.³⁸
- *LTPP Computed Parameter: Dynamic Modulus (2007–2009)*. The primary objective of this study was to develop estimates of the dynamic modulus of hot-mix asphalt (HMA) layers on LTPP test sections following the models used in the NCHRP Guide for MEPDG for storage in the LTPP database. A software tool was developed as part of this project.³⁹

- *Estimation of Key Portland Cement Concrete, Base, Subbase, and Component Engineering Properties From Routine Tests and Physical Characteristics (2007–2009)*. The results of this project enable pavement design and materials engineers to make well-founded decisions about materials and materials specifications to be used in pavement construction. Potential cost savings resulting from better materials selection, fewer premature pavement failures, and avoidance of overdesign are significant. The project report was published together with a user’s guide that summarizes the models developed, describes their application for specific project conditions, and lists their limitations.^{40,41}
- *Impact of Design Features on Pavement Response and Performance in Rehabilitated Flexible and Rigid Pavements (2007–2009)*. With new data available in the LTPP database, it was necessary to obtain a better understanding of the effects of design and construction features on pavement response and performance of rehabilitated flexible and rigid pavements. Published in 2011, this research provides preliminary information on the relationship between pavement response and performance, guidance for identifying appropriate features for different pavement types, and recommendations for improving data collection activities.⁴²

Fulfilling the LTPP Strategic Plan

Completing the research projects in the Strategic Plan for LTPP Data Analysis will require continued funding. Since the conception of the data analysis plan, a total of 211 projects have been identified (table 10.2). Although scores of analysis projects defined in the plan have been completed, more than 100 defined research projects remain to be performed, and new research needs will arise in the future. Some analysis projects are not ready for development of research problem statements because other underlying research has not been performed, or more data are needed. It is also recommended that many earlier findings derived from LTPP data be re-evaluated to determine if the short-term trends were correct. The additional data collection performed since early studies were finished (e.g., Effectiveness of Maintenance and Rehabilitation Options, completed in 1999⁴³) warrant consideration of follow-up investigations.

The TRB LTPP Committee continues to monitor the status of LTPP analysis projects and provide technical advice and assistance to FHWA concerning future direction of the projects. For example, in its 2011 letter report to FHWA and AASHTO, the Committee listed 22 analysis projects they considered to be of highest priority for early starts.⁴⁴

To continue the LTPP analysis research, FHWA issued a second BAA in June 2013, with the purpose of providing sponsorship for a series of research projects involving innovative analysis of data obtained through the LTPP program to better understand pavement performance. As stated in the BAA, the projects that comprise the LTPP data analysis program serve two broad functions that must be addressed if LTPP is to fulfill

expectations: (1) the projects provide the basis for identifying and developing products that engineers and managers can apply to design more cost-effective and better performing pavements; and (2) the projects check whether the data being collected are of the quality and completeness needed to answer questions about how and why pavements perform as they do.

LTPP Data Studies

While the “tablecloth” is the guiding document for most centralized LTPP data analysis activities, a number of additional investigations have been performed internally by the LTPP program office and LTPP contractor staff to improve the program’s overall operation.

One such example is the study of variability between distress raters (discussed in chapter 9).^{45,46} Using data from nine LTPP distress accreditation workshops, analyses regarding rater-to-rater variation were completed. It was found that significant variability was observed from one rater to the next, particularly with regard to severity levels for individual distresses, and that variability increased as distress quantities increased. Due to this study, the program implemented changes including adding time-series reviews and enhancing rater training activities.

Highway Agency Studies

Many State and Provincial highway agencies have performed analyses using LTPP data and have developed their own research programs incorporating LTPP standards as a basis for data acquisition and processing. The following pages describe a sample of these analyses.

TABLE 10.2. Status of research studies related to the Strategic Plan for LTPP Data Analysis (1999-2014).

Research Vehicle	Studies Completed	Studies Ongoing	Studies Planned	Unaddressed Problem Statements Remaining
FHWA-LTPP Data Analysis Contracts (using LTPP budgeted funds)	50	7	13	
National Cooperative Highway Research Program	26	11	0	
Total	76	18	13	104

Arizona SPS Analysis

Recognizing that much could be learned by analyzing the performance of the LTPP experiments within their own agency, the Arizona Department of Transportation (DOT) sponsored analyses of their SPS projects. These efforts were specifically targeted at evaluating pavement performance and determining “lessons learned.” Specific focus was given to the distress, longitudinal profile, and falling weight deflectometer (FWD) data sets. Distresses were grouped by failure mechanism (i.e., traffic/load-related and climate/materials-related) into structural and environmental damage indices, and these indices were tracked over time. Similarly, time-series investigations were made on deflection data to examine reductions in layer moduli and effective structural number, and on longitudinal profile data to track changes in International Roughness Index (IRI) values, power spectral density, roughness profiles, and filtered profiles (for short, medium, and long wavelengths) over time.

Cross correlations were also examined to study, for example, the impact of distress propagation on longitudinal profiles. One lesson learned was that roughness and roughness progression alone cannot be used to represent the health of a test section. Many test sections did not exhibit changes in roughness in proportion to the amount of fatigue cracking experienced, and sections that had clearly reached the end of their service lives did not necessarily have roughness values that would trigger a rehabilitation event. Arizona DOT, through the Arizona Transportation Research Center, is publishing these reports for their SPS-1 (structural factors for flexible pavements),⁴⁷ -2 (structural factors for rigid pavements), -5 (rehabilitation of AC pavements), -6 (rehabilitation of jointed PCC pavements), and -9 (Superpave) projects.

Colorado LTPP Implementation

Like Arizona, the Colorado DOT (CDOT) recognized that improvements to internal processes could be made by analyzing their LTPP test sections. CDOT was proactive in examining their SPS-2 (structural factors for rigid pavements) and SPS-4 (preventive maintenance of flexible pavements) projects, starting with the

construction practices. In the case of the SPS-2 experiment, a follow-up study found that using a 14-ft (4.3-m) slab width instead of a 12-ft (3.7-m) width was equivalent to adding 1 inch (25.4 mm) of slab thickness. Based on this finding, CDOT adopted the 14-ft slab in 1996 based on the results of the LTPP SPS-2 experiment, and continues to follow this practice today.^{48,49}

Before constructing the Colorado SPS-4 project, CDOT used a standard double cut for 3/8-inch (9.5-mm) joints. In building the SPS-4, CDOT learned that a single-cut, 1/8-inch (3.2-mm) joint was equally effective, while being less labor-intensive and requiring less sealant material. A cost-benefit analysis was performed, and it determined that going to the single-cut standard resulted in a savings of 57 cents per linear foot of joint, which equated to almost \$1.7 million in savings for 100 mi (161 km) of two-lane concrete pavement.⁵⁰

Kansas Binder Selection

When implementing the Superpave performance grade binder specifications, the Kansas DOT (KDOT) turned to a popular LTPP product to optimize binder selection: LTPPBind. KDOT uses the software as an integral part of their pavement design process. KDOT pavement designers use LTPPBind to determine the performance grades at the various depths of the pavement structure and for different traffic conditions. The software incorporates actual site temperatures, providing an improvement to the temperature information in the original SHRPBind software. In many instances, KDOT found that LTPPBind changed the binder grade, which provided improved pavement performance.⁵¹

MnROAD

Constructed near Albertville, Minnesota, in 1994, the MnROAD facility (figure 10.6) was designed to study cold weather pavement design, materials, and performance for both low-volume and interstate test sections. Primarily funded by the Minnesota DOT and the Minnesota Local Road Research Board, MnROAD activities have also been supported by industry, public-, and private-sector organizations at the State, national, and international levels.



FIGURE 10.6. MnROAD low-volume road and mainline test roadways owned and operated by the Minnesota Department of Transportation (2003).

The LTPP program and MnROAD staff work closely together, and many LTPP data collection activities have taken place on MnROAD sections, including manual and automated distress surveys (MnROAD uses a modified LTPP manual distress process), longitudinal and transverse profile measurement, and FWD testing. MnROAD has LTPP-like seasonal monitoring data, and once housed an onsite FWD calibration center. There are 11 LTPP test sections located at the MnROAD facility of which three remain active today.

MnROAD has gone through two phases since it opened to traffic in 1994. As the first set of MnROAD

studies was nearing completion, a second phase of research was begun that largely involved reconstructing many of the original test sections. Phase 2 activities are guided by the Transportation Engineering and Road Research Alliance (a research governance structure formed in 2004), and construction/reconstruction activities are nearing completion. Phase 3 will begin in 2016 with a focus on maintenance and rehabilitation. It is very possible that the LTPP test sections will be used during this phase.

Among key findings from the first generation of MnROAD studies were revised spring load restriction and winter load increase policies, improved low tem-

perature cracking resistance and pavement sealing practices, and mechanistic-empirical design methods for concrete and flexible pavements. These results save Minnesota \$33 million annually.

New Jersey Seasonal Monitoring Program

As part of its preparations to implement the MEPDG, the New Jersey DOT initiated a seasonal variation and material characterization study in 2001. Twenty-four test sections across the State were instrumented following LTPP SMP protocols. FWD and seismic testing were performed monthly over a 2-year period to supplement the continuous climatic data collection and to investigate the impact of environmental parameters on pavement response. Through regression analyses, temperature and seasonal correction factors were developed specific to New Jersey conditions.⁵²

New Jersey IRI Models for Pavement Management System

The New Jersey DOT has also used LTPP data to verify and refine models that are used in its pavement management system to determine when a pavement is in need of repair. The State's system had a default IRI performance model that triggered rehabilitation at 170 inch/mile (0.0027 m/km) or 9 years. To validate these criteria, the State accessed the data from its SPS-5 (rehabilitation of AC pavements) and SPS-9A (Superpave) test sites using DataPave Online. The results predicted pavement life as long as 20 years before an IRI of 170 inch/mile would be reached and any type of treatment would be required. Neither New Jersey's data set (using some of the State's 1999 construction projects) nor data from DataPave Online (using LTPP SPS test sites) ever reached the trigger IRI value of 170 inch/mile. Access to LTPP data allowed New Jersey to develop realistic IRI prediction models.⁵³

Pennsylvania Joint Design

The Pennsylvania DOT (PennDOT) has a pavement network with over 3,200 mi (5,150 km) of PCC pavements. Based on LTPP pavement performance data, PennDOT modified its PCC joint designs from using skewed joints to constructing perpendicular joints. Multiple benefits were realized with this modification, including reduced construction and maintenance

costs, fewer maintenance-related disruptions to traffic, and a smoother ride for motorists.⁵⁴

Texas SMERP—Supplemental Maintenance Effectiveness Research Program

The SMERP study was designed to “establish the effectiveness of typical and promising maintenance treatments used in Texas to prolong the life of asphalt pavements.”⁵⁵ The Texas DOT (TxDOT) allocated \$1 million to build test sections of preventive treatments that were of interest to Texas but were not being studied in the SHRP-LTPP national experiment. By analyzing the data from the LTPP SPS-3 experiment (preventive maintenance for flexible pavements), with 16 sites in Texas, and the SMERP studies, TxDOT hoped to identify the best treatment selection strategies and get the best return on its preventive maintenance funds. In designing the experiment, TxDOT followed the basic design of the LTPP SPS-3 experiment and used an ASCII data format that would be compatible with output from the LTPP database so that SMERP and LTPP data could be combined for analysis. In 1993, at each of 20 test locations throughout the State, six treatment sections and a control section were established: asphalt rubber chip seal, polymer-modified emulsion chip seal, latex-modified asphalt cement chip seal, unmodified asphalt cement chip seal, fog seal, and a microsurfacing treatment (two sites did not have a fog seal or control section).⁵⁶ The sites were inspected at 6 months and annually for 8 years, with nine sections surviving the full 8 years. The SMERP study resulted in treatment selection recommendations for TxDOT districts that were based on actual performance data. An important finding was that the pre-treatment condition of a pavement is a major determinant of a treatment's effectiveness when deterioration is measured over time.^{57,58,59}

Texas Evaluation of LTPP Data and Implementation of the Texas Transportation Institute Overlay Tester

Performance data from LTPP test sections were used by TxDOT to develop its performance prediction models for the Texas mechanistic-empirical flexible pavement design system. The proposed rutting model for HMA pavements was calibrated using rutting and traffic data from the Texas LTPP SPS-5 (rehabilitation of AC pavements) test sections and the National Center for Asphalt

Technology Pavement Test Track. Predicted rutting was compared with measured rutting in the LTPP database. In investigations of the use of the Overlay Tester in predicting fatigue cracking in HMA pavements, LTPP data were used to develop and calibrate the transfer function in calculating the amount of fatigue cracking.^{60,61}

The Texas Flexible Pavements Database

TxDOT used the LTPP database as an example to design its Texas Flexible Pavements Database.⁶² This database is being used to develop guidelines for local calibration of the MEPDG. A 5-year project was initiated to collect materials and pavement performance data on a minimum of 100 highway test sections around the State, incorporating both flexible pavements and overlays. Besides being used to calibrate and validate mechanistic-empirical design models, the data collected will also serve as an ongoing referencedata source and diagnostic tool for TxDOT engineers and other transportation professionals.

The Mechanistic-Empirical Pavement Design Guide

External to the LTPP program, NCHRP Project 1-37(A), Development of the 2002 *Guide for the Design of New and Rehabilitated Pavement Structures*,⁶³ was initiated to develop a replacement for the 1993 AASHTO Pavement Design Guide. Using increased computational speeds and improved understanding of key inputs (i.e., traffic loads, environment, and material properties), the project's objective was to develop a more mechanistic-based design methodology. It soon became apparent to the project team that developing a mechanistic-empirical pavement design guide was going to require pavement data from coast to coast, and the LTPP database provided access to this critical information.

The LTPP database has contributed significantly to the enhancement of pavement evaluation and design through the development of the MEPDG and, later, the AASHTOWare® Pavement ME Design software developed to implement the MEPDG.⁶⁴ It has been said that “without LTPP data for the national calibration, the MEPDG distress models could not have been validated for use throughout the country.” The distress and smoothness prediction models that are key to the MEPDG required calibration with measured

“Without LTPP data for the national calibration, the MEPDG distress models could not have been validated for use throughout the country. In addition, the LTPP data is invaluable to each State highway agency for its own local validation and calibration purposes.”

—Michael Darter, Applied Research Associates, Inc.⁶⁵

long-term performance data that were available only from the LTPP database. The database is also serving as an extremely valuable tool in implementation of the new guide. For the guide to be efficient for individual agencies, the national models will need to be evaluated against local and regional performance data. The LTPP test section data provide a resource for highway agencies to use in determining whether local calibration is required.

TRB LTPP Data Analysis Working Group

Twice each year the TRB Data Analysis Working Group (DAWG), sponsored by the TRB LTPP Committee, organizes an international forum on the analysis of pavement performance data in connection with a major highway pavement conference (appendix A).⁶⁶ Researchers are invited to informally present their work in progress, usually concerning the development of techniques for extracting and analyzing data and the early results of applying these techniques. Typical topics are model building, sensitivity analysis, and development of transfer functions linking structural response to distress. These forums have provided a venue where researchers can benefit from the input of others who are engaged in pavement research, design, maintenance, and rehabilitation and are interested in collecting, processing, and analyzing data and in developing insights into pavement performance. The analysis of LTPP data has frequently been the subject of research presented at DAWG forums, which serve to support and promote LTPP data analysis.

The ASCE-LTPP International Data Analysis contest is designed to encourage student involvement in analyzing LTPP data. As a result of the contest, several universities are using the LTPP data as part of their pavement curricula.

International Data Analysis Contest

As a means to both further LTPP data analysis activities and introduce the next generation of pavement engineers to the LTPP database, FHWA and the American Society of Civil Engineers (ASCE) teamed up in 1998 to create the LTPP International Data Analysis Contest.⁶⁷ The contest provides incentive for innovative use of LTPP data to solve common pavement engineering problems. Recently revamped, the contest offers general and challenge topics to contestants each year and has four entry categories (Challenge Topic, Partnership, Undergraduate Students, and Graduate Students). Winners are invited to present at the TRB Annual Meeting in Washington, DC, and winning papers are published by FHWA. The 2012 winner is pictured in figure 10.7.⁶⁸

This successful competition has resulted in many universities implementing the LTPP data in their undergraduate and graduate curricula, and use of the LTPP data has expanded significantly since the contest began. The success of the contest has been due to the partnership between the LTPP program and ASCE and a great number of contributions through the years from ASCE's Transportation and Development Institute's Pavements Committee and its many members.

Translating Analysis Results Into Products

As analyses are performed, whether by the LTPP program office, NCHRP, or highway agencies as discussed in the previous pages, the logical next step is to develop useful and usable highway engineering products from these analyses that help to explain how and why pavements perform as they do. The following section covers some of the key products that have been developed as a result of the program.



FIGURE 10.7. Daniel Franta, a graduate student at the University of Minnesota, receives the 2012 ASCE-LTPP International Data Analysis Contest Winner award for his winning paper "Classification of Features of Pavement Profiles Using Empirical Mode." Presenting the award is C. Michael Walton, then President of ASCE's Transportation and Development Institute.

LTPP PRODUCTS

After the first few years of data collection, the LTPP program began work on developing products that could be used by highway agencies to improve their practices. Product development became a requirement in 1998 under the Transportation Equity Act for the 21st Century (TEA-21). This act continued support of the program for 6 years with the following stipulation:

Under the program, the Secretary shall make grants and enter into cooperative agreements and contracts to (A) Monitor, material-test, and evaluate highway test sections in existence as of the date of the grant, agreement, or contract; (B) Analyze the data obtained in carrying out subparagraph (A); and (C) Prepare products to fulfill program objectives and meet future pavement technology needs.⁶⁹

Development of the LTPP Product Plan

In the early days of the program, when data collection, processing, and quality control/quality assurance (QC/QA) procedures were being established, many products were developed in support of LTPP operations. The program has played a major role in the development of pavement-related guidelines and standards

throughout its history. A partial listing of these achievements includes:

- Standardizing data collection and QC practices.
 - Pavement distress.
 - Automated profile.
 - FWD.
- Developing equipment calibration procedures.
- Standardizing automatic vehicle classification (AVC) and weigh-in-motion (WIM) data storage formats.
- Developing a methodology for AVC and WIM data QC.
- Developing a startup procedure for laboratory equipment and standardized laboratory and field testing protocols.

LTPP product development was elevated to a higher level by the language of TEA-21. In response to this charge, the program office with the support of FHWA management, requested that the TRB LTPP Committee evaluate five potential changes to the program:

- Establishment of an LTPP Product Subcommittee.
- Consideration of national pavement needs.
- Expansion of ETG responsibilities to address product development.
- Establishment of a new FHWA Product Development and Delivery Program.
- Development of an LTPP Product Plan.

The TRB LTPP Committee supported the LTPP Product Subcommittee recommendation and asked the subcommittee to assist in creating the LTPP Product Plan. This document was published in 2001 (figure 10.8), and identified five “national pavement needs” on which product development activities would be focused:⁷⁰

1. New and reconstructed pavements.
2. Maintenance and rehabilitation of pavements.
3. Pavement management system tools and techniques.
4. Traffic loading and environmental effects.
5. National pavement performance data services.

To achieve a fully integrated plan, the Product Subcommittee related these national pavement needs to the objectives in the Strategic Plan for LTPP Data Analysis.

LTPP products are ready-to-use guidelines, procedures, protocols, best practices, software, and equipment that are packaged for and delivered primarily to the management and technical staff in the highway agencies.

Research knowledge and findings contained in analysis reports are not ready to use and are only building blocks for future products. The goal articulated in the product plan, however, is to develop and deliver products that meet the following definition: LTPP products are ready-to-use guidelines, procedures, protocols, best practices, software, equipment, and other tools that are packaged for and delivered primarily to the management and technical staff in the highway agencies. It should be noted that a research report is not considered to be an LTPP product as defined in the plan.

As part of the LTPP Product Plan, FHWA's Office of Pavement Technology was charged with coordinating product development activities both internally with the LTPP program office and externally with supporting organizations such as the AASHTO Research Advisory Committee, Standing Committee on Highways, Subcommittee on Materials, and the Joint Task Force on Pavements. Funding issues have impacted the products area severely, with reductions in FHWA Office of Pavement Technology staffing and in dedicated moneys for product development. Nevertheless, the LTPP program has made significant advances in product development. In some cases, highway agencies have contributed money through pooled-fund studies for these activities (see sidebar). The program has frequently polled customers from highway agencies, industry, and academia to determine the needs of potential data users. In particular, chief engineers from the highway agencies have played a key role in identifying products needed to address national pavement needs.

LTPP products have benefited the pavement community by improving existing practices and providing tools to improve decisionmaking. Some of these products are described in the following sections. Although the listed products were developed both before and after the LTPP Product Plan was created, the prod-

TABLE 1: LTPP PRODUCTS

Identification and development of LTPP products is driven by national pavement needs. The LTPP Product table shows how current and future LTPP products address the national pavement needs.

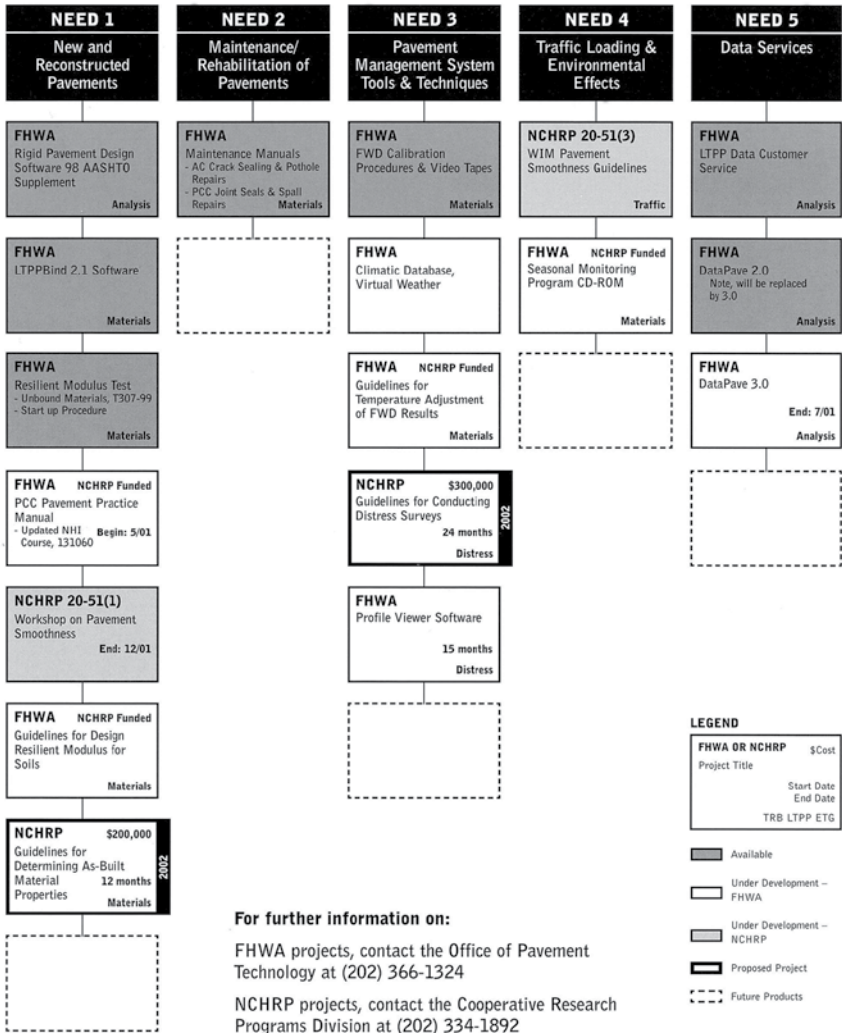


FIGURE 10.8. LTPP Product table from the 2001 LTPP Product Plan showing how existing and planned LTPP products address national pavement needs.

LTPP LEVERAGES FHWA'S TRANSPORTATION POOLED-FUND PROGRAM

The LTPP program and NCHRP were not the only sponsors of projects developing LTPP-related benefits. The transportation pooled-fund program is a way for FHWA, States, and other organizations to partner when significant or widespread interest is shown in solving transportation-related problems.⁷² Under this arrangement, the partners pool funds and other resources to solve problems through research, planning, and technology transfer activities. The quality and accessibility of LTPP data lends itself to supporting a wide range of pavement-related activities as in the pooled-fund studies named below.

- Effect of Multiple Freeze-Thaw Versus Deep Frost Penetration on Pavement Performance, TPF-5(013).

- Falling Weight Deflectometer (FWD) Calibration Center and Operational Improvements, TPF-5(039).
- Long-Term Pavement Performance (LTPP) Specific Pavement Study (SPS) Traffic Data Collection, TPF-5(004).
- Improving the Quality of Profiler Measurement, TPF-5 (063).

These are studies in which the LTPP program led the effort, but many other projects completed at the local, State/Province, and national levels have used LTPP data for the benefit of other operations and the pavement community as a whole.

ucts discussion is organized around the national needs and the goals included in the product plan. In addition, the objectives from the Strategic Plan for Data Analysis are listed for each national need. More products are listed in figure 10.8 and in the LTPP Benefits Report.⁷¹

NATIONAL PAVEMENT NEED 1: New and Reconstructed Pavements

GOAL: Identify improved designs and design features with more accurate service predictions, tendencies, or trends.

- **OBJECTIVE 5:** Development of pavement response and performance models applicable to pavement design and performance prediction.
- **OBJECTIVE 7:** Quantification of the performance impact of specific design features (presence or absence of positive drainage, differing levels of pre-rehabilitated surface preparation, etc.).
- **OBJECTIVE 8:** Analyses supporting and enhancing the use of the MEPDG.

To address the national need for improved design and construction of new and reconstructed pave-

ments, the LTPP program has created software tools and test procedures. In addition, the pavement performance data played an important role in the development of the MEPDG as discussed above. This section covers a few of the LTPP products related to pavement design.

Rigid Pavement Design Software 1998 AASHTO Supplement

The LTPP Rigid Pavement Design software was developed to facilitate the application of the *1998 Supplement to the Guide for Design of Pavement Structures*.^{73,74} The guidelines in this publication were developed based on studies conducted during NCHRP Project No. 1-30. The software automates the computations required to use the 1998 supplemental guidelines and includes separate tables for determining accumulated traffic loading, seasonally adjusted k-values, and depth to rigid layer, and for performing corner break and faulting checks. The magnitude of the cost savings from following the 1998 supplemental guidelines and using the software will vary with site conditions, with a 30 percent reduction being a reasonable average.

LTPPBind Software

Based on an analysis of the LTPP data and on the original binder selection software known as SHRPBind, LTPPBind is a Microsoft® Windows®-based program that can help highway agencies select the most suitable and cost-effective Superpave asphalt binder performance grade (PG) for a particular site. LTPPBind features a database of high and low air temperatures (minimum, mean, maximum, standard deviation, and number of years) for U.S. and Canadian weather stations, along with several modifications that provide users with the ability to (1) select PGs based on actual temperature conditions at their site and at the level of risk designated by their highway agency; (2) use either the original temperature models developed by SHRP or LTPP's revised temperature models for determining a site's binder PG; and (3) adjust PG selection for different levels of traffic loading and speed.⁷⁵

Resilient Modulus Test Procedures for Bound and Unbound Layers

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.

When establishing characteristics in the unbound layers—including subgrade, subbase, and base materials—resilient modulus is the property most relevant

to pavement design. Consequently, establishing granular layer resilient modulus values has been a priority activity for the program. In the program's early days, no concise test protocol existed for resilient modulus testing. This was observed when samples from the same location were tested (both in the same laboratory and in different laboratories) with wide variation in the test results.

To address variability in the laboratory equipment and procedures, the program developed the LTPP laboratory startup procedure. This comprehensive procedure was developed to test the ability of the equipment and personnel to perform resilient modulus testing.⁷⁷

At the same time, the program made a considerable investment in establishing LTPP Test Protocol P46—Resilient Modulus of Unbound Materials.⁷⁸ This protocol has been widely adopted,⁷⁹ a process that was accelerated first by a series of videos and then by a CD-ROM containing the videos and additional documentation.

Similar to its role in the development of Test Protocol P46, the LTPP program was responsible for developing a highly repeatable test protocol to determine asphalt resilient modulus—LTPP Protocol P07.⁸⁰ The LTPP asphalt resilient modulus CD-ROM contains a 15-minute video describing the startup and QC processes as well as a comprehensive package of information and data related to resilient modulus. The P46 and P07 CD-ROMs are available through the LTPP Customer Support Service Center (Email: ltppinfo@dot.gov).

Engineers use LTPPBind to more accurately determine the asphalt binder (cement) grade needed for their specific environmental conditions. A national review of LTPPBind shows it helps highway agencies save at least \$50 million in construction costs each year by reducing the need to apply modified binders, a factor that can drive up the costs of construction.⁷⁶

|E| Computation of LTPP Sites*

An FHWA-funded project was undertaken using the LTPP database to compute estimates of the dynamic modulus of HMA layers on LTPP test sections. Dynamic modulus, |E*|, is a fundamental property of AC mixtures that characterizes strain response as a function of loading rate and temperature. |E*| is one of the primary material property inputs in AASHTOWare® Pavement ME Design software;⁸¹ it is one of the primary properties measured in the Asphalt Mixture Performance Test protocol that complements volumetric mix design with mechanical properties; and it is one of the fundamental linear viscoelastic material properties that can be used in advanced pavement response models based on viscoelasticity.

Pavement Maintenance Manuals of Practice

As mentioned in the LTPP Data Analysis section, the SHRP-H-106 project (Innovative Materials Development and Testing) monitored 22 sites throughout the United States and Canada to evaluate the performance and cost-effectiveness of maintenance materials and procedures. The project resulted in the publication of a set of manuals on asphalt and concrete repair. In 1999, the LTPP program revised and updated the original four SHRP manuals with the latest long-term performance and cost-effectiveness information generated by its continued monitoring of the SHRP-H-106 project sites. The manuals cover the performance of repair materials and methods, the availability and relative costs of repair materials, and the planning, designing, construction, and performance monitoring for the repair activities.

- *Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements—Manual of Practice.*⁸⁸
- *Materials and Procedures for Repair of Potholes in Asphalt-Surfaced Pavements—Manual of Practice.*⁸⁹
- *Materials and Procedures for Repair of Joint Seals in Portland Cement Concrete Pavements—Manual of Practice.*⁹⁰
- *Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements—Manual of Practice.*⁹¹

NATIONAL PAVEMENT NEED 3: Pavement Management System Tools and Techniques

GOAL: Identify improved measurement and prediction tools.

- **OBJECTIVE 2:** Materials characterization.
 - **OBJECTIVE 4:** Evaluation and use of pavement condition data in pavement management.
 - **OBJECTIVE 9:** Comprehensive use of LTPP to improve the management of pavement assets.
-

The LTPP program is a project-level program, but the data collection guidelines and procedures and equipment protocols are also useful for network-level programs, such as pavement management systems. The following products have contributed to the quality of the pavement condition data collected by highway agencies to populate their pavement management systems and to help them determine which pavement sections should receive some type of treatment or rehabilitation.

Distress Identification Manual

The LTPP program developed the *Distress Identification Manual for the Long-Term Pavement Performance Program* (Standard Edition)⁹² to establish a consistent, uniform basis for collecting pavement distress data. The manual is divided into three sections, each focusing on one type of pavement: AC, PCC, and continuously reinforced concrete pavement (CRCP). It provides a common language for describing cracks, potholes, rutting, spalling, and other distresses being monitored by the program, and contains color photographs, drawings, and text that clearly label, describe, and illustrate each type of distress. Many highway agencies have adopted the manual's procedures and definitions.

The Local Technical Assistance Program, with assistance from the FHWA Resource Center, developed four pocket versions of the manual:

- AC Distress Identification Guide (Pocket Edition).
- PCC Distress Identification Guide (Pocket Edition).
- CRCP Distress Identification Guide (Pocket Edition).
- AC (for Local Agencies) Distress Identification Guide (Pocket Edition).⁹³

Created with the field technician in mind, the pocket editions are made of durable plasticized material (figure 10.10). They have not been updated, however, and do not reflect the most recent definition for every distress type.

The fifth and latest version of the standard edition was published in May 2014. The manual and the pocket

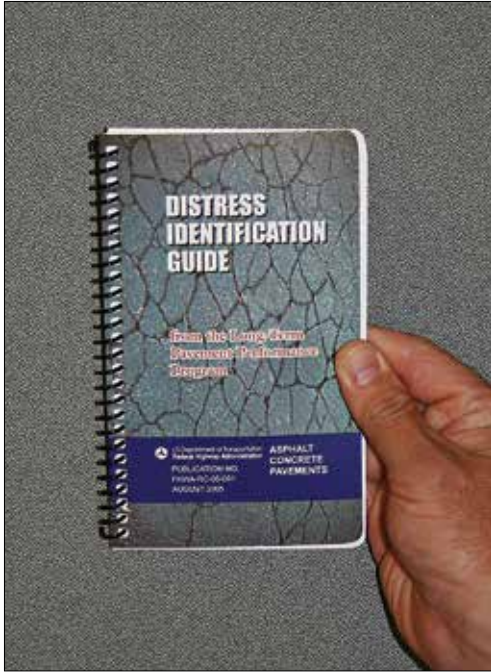


FIGURE 10.10. *Distress Identification Guide, Asphalt Concrete Pavements, one of the five pocket versions of the Distress Identification Manual that were created for use by field technicians.*

guides are available by contacting the LTPP Customer Support Service Center (Email: ltppinfo@dot.gov).

FWD Calibration Procedures

Early in the LTPP program, the need for FWD calibration procedures and regional calibration centers was identified as a priority. The original calibration protocol was finalized in 1992, and calibration centers were established in Pennsylvania, Texas, Minnesota, and Nevada (the latter eventually was moved to Colorado). These centers provided calibration services not only for LTPP FWDs, but also for FWDs operated by highway agencies and private consultants. In the first 3 years of center operation, many of the non-LTPP units were found to be significantly out of calibration. Hence, the LTPP calibration centers provided an essential public service that resulted in significant construction savings, especially in situations where design is driven by FWD measurements, such as flexible pavement

overlay design and jointed rigid pavement load transfer rehabilitation design. Since 1997, more than 500 FWD calibrations have taken place at these centers.

Considering that the LTPP FWD calibration centers had been operating with essentially the same equipment and procedures since 1992, the Falling Weight Deflectometer Calibration Center and Operational Improvements Pooled-Fund Study, TPF-5(039), was initiated in 2004 to improve the calibration process and update the calibration center equipment and software.⁹⁴ The study's reports contain the new protocol, equipment specifications, and other updated specifications of interest to engineers and technicians who perform structural evaluation of pavements.^{95,96} The new calibration equipment is highly portable and allows calibrations to be performed at a location of the FWD owner's choosing. The new protocol has been implemented at all of the FWD calibration centers operated by State highway agencies, for which technical support and QA audits have been assumed by the AASHTO Materials Reference Laboratory, as noted in chapter 6. These centers continue to be used by highway agencies and private consultants to calibrate their FWDs. Accurate data that are a direct result of the calibration procedure yield large dividends to stakeholders in the form of improved decisions and increased efficiency.

Perhaps the most significant outcome of the FWD pooled-fund study was AASHTO's adoption of the new calibration system as Standard Practice R 32-09, *Calibrating the Load Cell and Deflection Sensors for a Falling Weight Deflectometer*, in 2009 (updated in 2011).^{97,98} The new procedure is demonstrated in a video.⁹⁹ It has been adopted by Denmark and Australia, and other countries are considering using the procedure, as well.

The most significant outcome of the FWD pooled-fund study was AASHTO's adoption of the new calibration system as Standard Practice R 32, *Calibrating the Load Cell and Deflection Sensors for a Falling Weight Deflectometer*.

ProVAL is the first and only software application that can read data from different pavement profilers and unify them using a common data format.

Pavement Profiler Standards

In 2002, FHWA initiated a pooled-fund study, Improving the Quality of Profiler Measurement, TPF-5 (063), to assist in developing AASHTO standards for QA programs related to ride quality data collection, and to establish a level of integrity to pavement profiler measurements through calibration processes and verification procedures.¹⁰⁰ The resulting standards included:

- AASHTO M 328-10, Standard Equipment Specification for Inertial Profiler.¹⁰¹
- AASHTO R 56-10, Certification of Inertial Profiling Systems.¹⁰²
- AASHTO R 57-10, Operating Inertial Profiling Systems.¹⁰³
- AASHTO R 54-10, Accepting Pavement Ride Quality When Measured Using Inertial Profiling Systems.¹⁰⁴

One of the main objectives of this multiyear, multi-tasked, \$2.4 million study was to deliver a profile analysis software program. The Profile Viewing and Analysis (ProVAL) software was released in 2001, and its native data format became an ASTM International standard in 2007, E 2560-07, Standard Specification for Data Format for Pavement Profile. The free software enables users to view and analyze pavement profiles collected by profile measurement equipment.¹⁰⁵ Different equipment manufacturers use different data formats and standards, making it difficult to compare profiles collected by diverse brands of equipment. ProVAL is the first and only software application that can read data from numerous pavement profilers and unify them using a common data format.¹⁰⁶ The software is continually upgraded, and new features are added.

NATIONAL PAVEMENT NEED 4: Traffic Loading and Environmental Effects

GOAL: Identify improved weigh-in-motion (WIM) technology and data interpretation that will more accurately determine specific traffic volumes and determine the environmental effects on pavement performance.

- **OBJECTIVE 1:** Traffic characterization and prediction.
 - **OBJECTIVE 3:** Determination of environmental effects in pavement design and performance prediction.
-

Understanding the performance of pavements requires knowing the traffic loading and environmental conditions imposed on them. Over the years, the LTPP program has contributed to improving traffic data monitoring by objectively examining the types of traffic data collection equipment, developing standard equipment calibration and validation protocols, and identifying quality checks to perform on the data. In addition, the program has improved its climatic database by using data from the National Aeronautics and Space Administration's (NASA) Modern Era Retrospective Analysis for Research and Applications (MERRA) to establish weather data for the LTPP test sites. This section covers some of the LTPP products related to the impact of traffic and climate on pavement performance.

Traffic Data Collection Advancements

The LTPP program has been on the leading edge of traffic monitoring technology. The program has developed and continues to refine several procedures to address variability in traffic data that can be attributed to multiple factors: equipment type, calibration procedures (or lack thereof), and duration of monitoring. These procedures include the WIM calibration protocol and smoothness specifications for pavement in the vicinity of the traffic monitoring equipment. Also, work in improving how vehicles are classified continues to be an important aspect of LTPP's traffic data monitoring work.¹⁰⁷

mal location to install a WIM system to collect the best traffic data.¹¹⁰ OWL was developed as a new module of the ProVAL software to implement the method adopted in AASHTO M 331-13. ProVAL is an engineering software application used to view and analyze pavement profiles.¹¹¹

- The LTPP Classification Algorithm, the first national standard classification algorithm to classify vehicles in the FHWA scheme, was developed and verified by the LTPP program and adopted by the TRB Traffic ETG in January 2013.¹¹² In addition, the algorithm is being used as an example by FHWA's Office of Highway Policy Information for States to use in their own vehicle classification efforts.
- The LTPP program developed the LTPP Pavement Loading User Guide (LTPP-PLUG) software to assist highway agencies in selecting axle loading defaults to use with the MEPDG. These defaults can be used for pavement sites where site-specific traffic data collected by WIM equipment are limited or do not exist—helping transportation agencies to “plug” their traffic loading data gaps when designing pavements.^{113,114} LTPP-PLUG is available on the LTPP InfoPave Web site.

LTPP Seasonal Monitoring Program CD-ROM

The LTPP SMP was an intensive monitoring effort undertaken on a subset of the LTPP test sections to obtain data to improve understanding of seasonal variations in pavement structures and the factors that cause those variations. An SMP CD-ROM was created to provide a project summary and supporting documentation needed to facilitate future application of the LTPP data. The CD-ROM includes videos produced by the North Carolina and Colorado DOTs that show how the monitoring instrumentation was installed at the SMP test sections in both States. The CD-ROM can be obtained from the LTPP Customer Support Service Center (Email: ltppinfo@dot.gov).

Pavement Performance Forecast Online Tool

Funded through the pooled-fund study, Effect of Multiple Freeze-Thaw Cycles versus Deep Frost Penetration on Pavement Performance, TPF-5(013), and procured under the LTPP Data Analysis program, pavement performance comparisons were made for different frost climates using prediction models developed specifically for the study.¹¹⁵ In light of this analysis, a thorough review of agencies' standard practices for mitigating frost-related damage was conducted. Consideration was given to the new MEPDG. Additional analysis was performed to quantify the cost implications of maintaining pavements in frost areas. The final report has been published,¹¹⁶ and an online tool providing pavement performance predictions (i.e., roughness and distress) for both flexible and rigid pavements using the models developed in this project is available on the LTPP InfoPave Web site or by contacting the LTPP Customer Support Service Center (Email: ltppinfo@dot.gov). The online program can be used by State, Provincial, county, and local highway agencies to estimate performance trends for pavement sections within their jurisdictions.

Arizona SPS-2 Curl and Warp Report

An analysis was conducted of the roughness and roughness progression of 21 test sections on the SPS-2 (structural factors of rigid pavements) site in Arizona over the first 16 years of the experiment. Traditional profile analyses revealed roughness was caused by transverse and longitudinal cracking on some test sections and some localized roughness was caused by built-in defects. However, the analyses showed that curl and warp contributed to, and in some cases dominated, the roughness on many of the test sections. The study applied objective profile analyses to quantify the level of curl and warp on each section, using automated algorithms to estimate the gross strain gradient needed to deform each slab into the shape present in the measured profile. This study demonstrated the potential value of applying the methods used to other jointed concrete pavements, including other SPS-2 sites.¹¹⁷

NATIONAL PAVEMENT NEED 5: National Pavement Performance Data Services

GOAL: Establish and maintain an accurate, accessible, and high-quality database.

As the LTPP program continues, the database is and will continue to be the primary and pivotal product of the program. An important role for the program is to support this national need by providing pavement performance data that are accessible and usable not only to the pavement community, but other possible users such as bridge engineers, air quality researchers, freight policy makers, and transportation statisticians. In conjunction with the data, the program has developed tools to disseminate the data and to support potential users in working with the data effectively. The LTPP database is unique not only in its size and quality, but also in that access to the data is freely provided.

Dissemination Tools

As the database has matured, the LTPP program has improved access to the data with each advancement in computer and communications technology. This section briefly describes some of these dissemination tools in chronological order, with details provided in chapter 8.

- The LTPP Data Sampler and Data Request Program was used early in the program to distribute data to users.
- DataPave was a user-friendly interface adopted in the mid-1990s, distributed on CD-ROM. The DataPave CDs were quite popular in that they assisted users unfamiliar with the LTPP database to access a limited amount of data.
- The Data Dictionary was a searchable list of LTPP tables and fields that allowed users to identify the location within the numerous tables where specific data are stored. By searching a pavement engineering term, the user was not required to know specific table and field nomenclature.

- As the Internet came into wide use, DataPave was converted to a Web-based format called “DataPave Online.”
- The primary data delivery mechanism has been the Standard Data Release, typically timed for delivery at the TRB Annual Meeting. Distribution was first made by CD-ROM, then DVD, and later by thumb drive before being made available over the Internet. This annual release includes the database and new data collected over the course of the year, along with any new tables developed as part of data analysis projects or to assist end users.
- Products Online was established as a “one-stop shopping” Web site for multiple LTPP Products including DataPave Online, as well as other valuable program information. More than 40,000 downloads have been completed by upwards of 3,000 unique users worldwide.
- Moving beyond DataPave Online and Products Online, the LTPP program developed an integrated, comprehensive Web site—LTPP InfoPave—to make the LTPP data more accessible and functional for users. The Web site offers new and expanded features, not only to the pavement performance data (encompassing the Standard Data Release), but also to information that supports and extends the stored data—raw data, images, reference materials, guidelines, resource documents, and studies and analyses published by FHWA. LTPP InfoPave allows users to streamline their access by creating a “My LTPP” menu customized to their needs, and offers the added benefit of professional networking within a growing LTPP user community through linked social media. A smartphone application, LTPP InfoPave Mobile, developed in tandem with the Web site, allows users to map and select LTPP test sections using visual navigation, retrieve section detailed information, and access LTPP data collection guidelines such as the LTPP *Distress Identification Manual*.

LTPP Customer Support and Feedback Mechanisms

The LTPP program has always made it possible for users to obtain data—from the early days, sending out data on

floppy disks, to today, assisting customers with identifying and downloading data that meet their analysis needs. In 1997, the LTPP Customer Support Service Center was formally established to handle data requests and to also provide a feedback mechanism for data users. Since the center was established, more than 8,000 requests for data, research reports, products, software, and other LTPP program information have been received.

The program also plays a role in educating data users. With the development of DataPave, the program staff created a demonstration workshop to help data users transition to the new way of accessing LTPP data. In 1998, in partnership with ASCE, the LTPP program presented the workshop in 16 locations to an audience of highway agency personnel, practitioners, and university professors.¹¹⁸

In 2011, the program began hosting Webinars to provide updates and important information to users. Examples of Webinar topics include the history and future plans for the program, the program's impact on industry, roles and responsibilities of the LTPP State Coordinators, and LTPP's new initiative to construct and monitor warm-mix asphalt pavements. Most of the Webinar sessions are recorded and are available on the LTPP Web site.

LTPP BENEFITS AND BROADER IMPACT

The emergence of new technologies over time and the LTPP program's emphasis on continuously improving operations led to improvements in the program's practices that have benefited the entire pavement community. For instance, LTPP QC/QA processes were developed to fill a void in pavement engineering practice, as no formal procedures existed for many of the activities conducted by the program. These procedures were necessary because the size and scope of the program required the use of different pieces of equipment (although of the same make and model) and the involvement of multiple individuals in different locations. Standard equipment protocols, training, and data collection procedures were needed to assure reliability of the data. As the program addressed these needs, highway

agencies and the pavement industry benefited from the knowledge, improved standards, and QC procedures that resulted.

Key Findings From the LTPP Program

The LTPP data analyses have addressed a broad array of topics, from field validation of pavement design procedures, to the study of variability in traffic and materials data, to investigating pothole repair techniques. Many findings from these studies provide information that is critical for the improvement of pavement technology.

To identify some of the key findings, the LTPP program reviewed studies reported between 1990 and 1999 and published a roster of more than 60 key findings for that decade.¹¹⁹ The summarized results were organized by topic: site conditions, structural features, materials, initial roughness, pavement maintenance, pavement rehabilitation, AASHTO design validation, and performance modeling. In 2004, a second review and report drew on results published from 2000 to 2003. Again, more than 60 significant findings were identified and summarized, and scores of related publications were listed.¹²⁰ In the 2000–2003 report, local calibration of the 2002 Pavement Design Guide was added as a new topic area, but the AASHTO validation and performance modeling were not included.

The goal of these data analysis reviews was to provide LTPP partners with information that would help them in their efforts to design, build, and maintain cost-effective and long-lasting pavements, and to make the partners aware of the vast amount of information available to them. Most of the documents identified in the reports are available at the LTPP, NCHRP, and TRB Web sites.

The Benefits Study

To capture the wide array of benefits resulting from the LTPP program, a formal data analysis project was awarded in 2006. Multiple objectives were part of the project scope, including:

- Investigating the benefits derived from the LTPP program to traffic characterization and prediction.
- Studying the improvement in materials characterization originated from the LTPP program.

- Determining the environmental effects on pavement design and performance prediction contributed by the LTPP data.
- Evaluating the benefits of LTPP data in pavement management.
- Investigating the benefits of using the LTPP data in the evaluation of existing design methods and in the development of new pavement response and performance models applicable to pavement design and performance prediction.
- Studying the effects of LTPP data on the development of maintenance and rehabilitation strategies.
- Determining the influences of the LTPP data on the evaluation of specific design features on pavement performance.
- Investigating future benefits that can be cultivated from the LTPP program.

Hundreds of reports, products, and other information were collected and summarized, and in examining all this, three primary areas were identified within which benefits resulting from LTPP activities to date could be categorized.¹²¹

- The LTPP database.
- Improved measurement processes.
- Pavement design and management.

LTPP Database

As discussed in the previous section, the single most significant product of the LTPP program is the pavement performance database. The database supports 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 database will continue to be the primary source of information for future generations of pavement and other researchers.

An outcome that has benefitted the education community is the introduction and use of LTPP data in university engineering curricula. A number of engineering schools with pavement engineering classes have developed course curricula around the database. This application has dual benefits: students are challenged with computational problems based on actual

field data, and they learn to use database manipulation tools. Students emerge with conceptual and practical knowledge that will benefit the pavement engineering community into the future.

Improved Measurement Processes

The LTPP program has advanced data quality procedures in both the field and the office, as discussed in chapter 8 and chapter 9. This section highlights advances in equipment specifications and maintenance procedures, software, and laboratory and data collection protocols that have led to a higher quality standard for pavement performance measurement for the pavement community (see sidebar).

LTPP protocols have formed the basis for improved measurement standards, and the pavement industry has been proactive in using these standards to support their chartered objectives. For example, efforts within the LTPP program to achieve greater reliability and precision in FWD data resulted in the establishment of calibration centers and the adoption of much-improved nationwide calibration standards (chapter 6). In addition, traffic data collection equipment suppliers have improved their hardware and software, and some have incorporated more stringent data checks as a result of the program's requirements (chapter 7). Equipment manufacturers have also adopted the program's resilient modulus protocols as a QC check during equipment production.

The program has significantly improved other data collection practices for a wide range of operations including manual and automated distress surveys and longitudinal and transverse profiles. Numerous LTPP data collection procedures have been adopted by industry. The most widely implemented of these procedures is the *LTPP Distress Identification Manual*. The manual is used by more than 20 State highway agencies and numerous local entities. In 1997, the National Highway Institute (NHI) developed a distress training course using the *LTPP Distress Identification Manual* and LTPP distress accreditation procedures. The LTPP program funded the course, offering it to the States free of charge. Although the course is no longer offered by NHI, it was delivered to many domestic and international participants.

The program has purchased a variety of sophisticated data collection equipment and systems. The process by which the equipment specifications were

LTPP QC/QA RESOURCES

Software Programs

LTPP software QC/QA programs such as FWDCAL, ProQual, SMPCHECK, DiVA, and LTAS are discussed in earlier chapters. While much of this software was tailored specifically for LTPP operations, some of these programs have been used throughout the pavement community in processing and checking data for highway agency needs and research analysis projects.

Documentation

In the service of QC/QA, the LTPP program has developed a wide variety of reports, protocols, and other documents that are assisting highway agencies and researchers alike. Several of these have been addressed previously, including the *Distress Identification Manual for the Long-Term Pavement Performance Program and the LTPP Manual for Falling Weight Deflectometer Measurements*. The FWD calibration centers established under the program are a major benefit to the highway agencies and industry.

To capture the entire laboratory testing inputs and results as recommended during the peer review process, the LTPP program developed its own *LTPP Laboratory Materials Testing and Handling Guide*.¹²² For most elements, the laboratory protocols were modeled on ASTM and AASHTO standards. However, in the conduct of resilient modulus testing for both bound and unbound layers, existing protocols did not meet LTPP's data quality standards and therefore new protocols (LTPP Protocols P07 and P46, respectively) were developed. To supplement this development, the LTPP program prepared a

series of videos to instruct testing laboratory personnel not only on how to conduct the test procedures, but also on how to ensure that the equipment is functioning properly. Initially, an LTPP review found a large variability in test results from different laboratories, which was partially attributed to problems with laboratory equipment electronics. After implementing the startup procedures, the variability was greatly reduced.

Seeking to reduce variability is a constant part of the LTPP QC/QA process; eliminating variability entirely is rarely practical. Therefore, quantifying data variability is the subject of many analysis activities. A few of these analyses were discussed earlier in this chapter, and following is a partial list of additional studies:

- Accuracy of Weather Data in the LTPP Database.¹²³
- Use of LTPP Data to Verify the Acceptance Limits Developed for Penndot Pavement Distress Data.¹²⁴
- Quantification of Smoothness Index Differences Related to LTPP Equipment Type.¹²⁵
- Profile Data Variability in Pavement Management: Findings and Tools From LTPP.¹²⁶
- LTPP Data Analysis: Variations in Pavement Design Inputs.¹²⁷
- Preliminary Evaluation and Analysis of LTPP Faulting Data.¹²⁸

Understanding variability, bias, and precision allows practitioners to properly incorporate data points into their decision processes.

prepared, achievement of the specifications was confirmed, and the final selection of equipment was made have become a model for many highway agencies planning to acquire similar equipment for their own use. As a recent example, procurement for the current LTPP profilers involved developing a set of specifica-

tions for the vendors and then performing a field verification to prove the specifications could be met before moving forward with the selection process. Some highway agencies have expressed interest in using this model for future major equipment purchases.

Pavement Design and Management

An original LTPP objective was to acquire data for use in evaluating existing design methods and in developing new ones. The LTPP program is the only national research program that has collected pavement performance data reflecting different climates and different materials, using standard data collection protocols and equipment. This consistent manner of collecting long-term pavement performance data and ensuring its quality using verified QC/QA practices has had a tremendous impact in advancing new pavement design procedures, particularly the development and implementation of the MEPDG. In addition, LTPP data has been implemented by State/Province and local agencies in network-level and project-level pavement management systems to predict future performance and determine maintenance and rehabilitation needs.

LTPP CONTRIBUTIONS TO OTHER FEDERAL EFFORTS

The LTPP program lends support to various U.S. DOT and FHWA programs and initiatives. Data and processes developed during the program have been used and continue to be used in research efforts of national significance. Some examples include:

- U.S. DOT Research, Development, and Technology Strategic Plan, FY 2013–2018.
 - The LTPP program is named a key priority area for preserving existing highways and extending the life of future highways.¹²⁹
- Highway Performance Monitoring System (HPMS).
 - LTPP distress definitions provide the basis for ride, cracking, faulting, and rutting data for the HPMS database, which is maintained by FHWA's Office of Highway Policy Information.¹³⁰

- LTPP data enable mapping of HPMS with LTPP for modeling and performance measures.¹³¹
- Pavement Health Track (PHT) Analysis Tool—developed by FHWA's Office of Asset Management to calculate remaining service life for highway networks using data from HPMS and State pavement management systems.
 - The LTPP database supplies data that are missing in HPMS and State databases.
 - LTPP data from 40 sites in 20 States were used in an experiment to identify any significant differences between MEPDG version 0.8 (PHT Tool) and DARWin-ME 1.0 pavement performance predictions and how possible differences may impact PHT results.¹³²
- Highway Economics Requirement System (HERS)—used by FHWA's Office of Highway Policy Information to develop the highly influential bi-annual report to Congress, “Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance.”
 - LTPP data were used to calibrate the HERS pavement deterioration models.
 - LTPP data are used to fill gaps in the HPMS data set, which is used in HERS. Regionalized data provide specific inputs for different areas of the country.
- Long-Term Bridge Performance (LTBP) program—sponsored by FHWA's Office of Infrastructure Research and Development.
 - The LTPP program laid the groundwork for national-scale research programs such as the LTBP program.
 - The LTPP program shares its expertise and experience in this endeavor.
- Climate-related infrastructure research—conducted in various Federal agencies.

Beyond the benefits themselves, what is remarkable is how widespread—both geographically and throughout the public and private sectors—the use of LTPP products and data has become.

- The LTPP program developed procedures for the use of NASA's MERRA data to establish virtual weather stations at any location in the country, as noted above. This capability can yield high-quality climate data anywhere in the world in a consistent and high-quality format.

SUMMARY

Turning data into results that are of value and use to the highway community is an important function in understanding pavement performance. The LTPP program's return on investment, while challenging to fully quantify, is already estimated at over \$2 billion in savings and will continue to grow.¹³³ The many research studies and their products conducted under the program are too numerous to mention in this chapter, and their numbers continue to grow as the LTPP program continues to improve the functionality of the database and revisit the data with advancing knowledge. The program has had a significant positive impact on the quality of pavement construction and rehabilitation by influencing the AASHTO and ASTM standards. It has advanced the capabilities of modern pavement monitoring equipment through its equipment requirements and new software tools. The program continues to develop products needed by highway agencies and distribute the tools and knowledge gained through the program. Through these program activities, LTPP data can fulfill its potential to improve industry practices, pavement engineering studies, the quality of pavement research, and, ultimately, the performance and cost-effectiveness of the Nation's highways.

On the road to achieving the results reported in this chapter, the LTPP program encountered many obstacles and problems. As the first pavement performance data collection effort of its breadth and depth, the program often faced a steep learning curve, and lessons were dearly earned. The next chapter reviews some of the lessons learned in the program.

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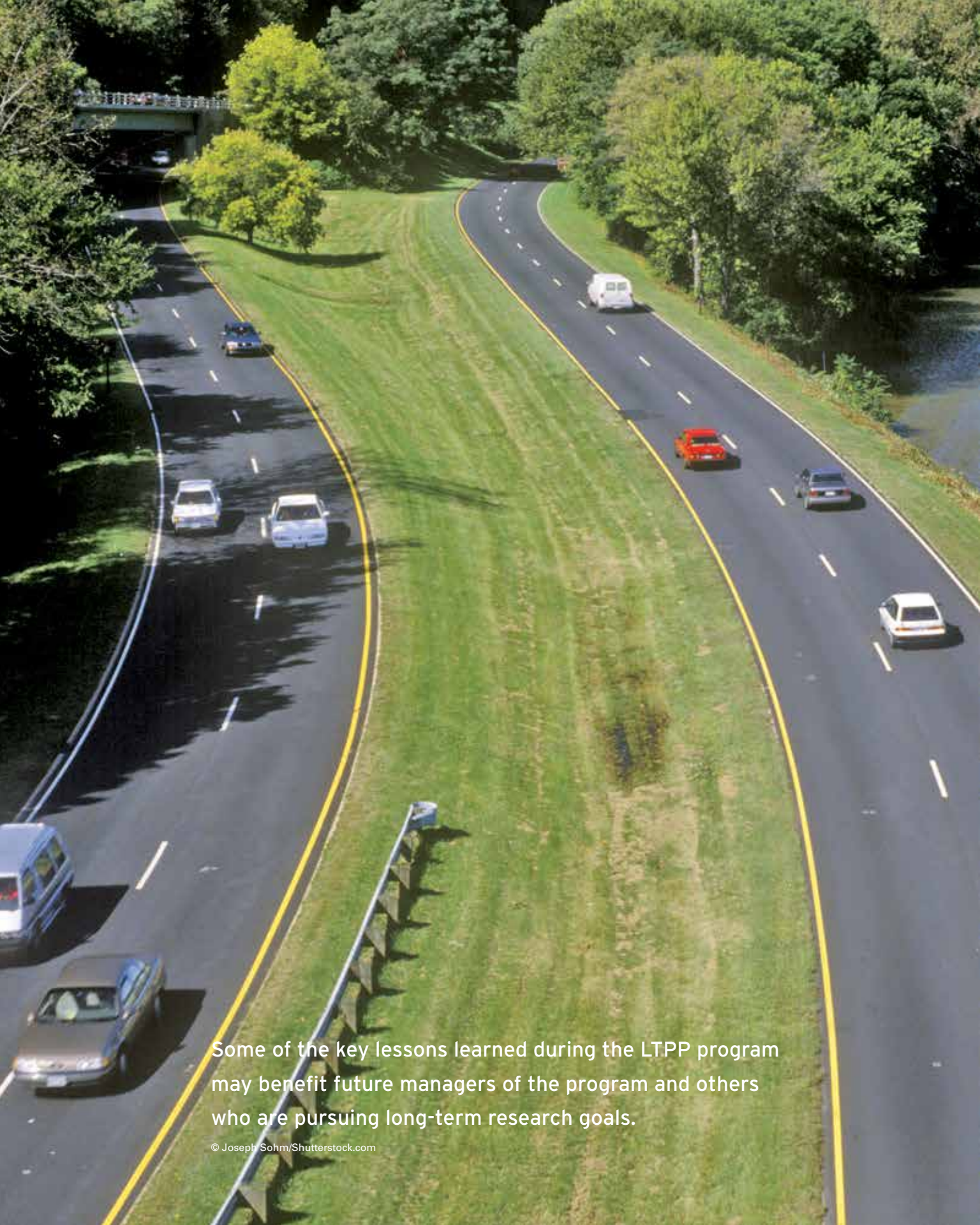
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Some of the key lessons learned during the LTPP program may benefit future managers of the program and others who are pursuing long-term research goals.

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11

Lessons Learned From the LTPP Program

Through the process of planning the experiments and executing the data collection activities in the LTPP program, many lessons have been learned. While the technical research findings are interesting and useful, the lessons learned and observations along the way are equally interesting and potentially useful.

INTRODUCTION

The task of the LTPP program managers has been to build and maintain a viable, reliable, and credible long-term research program that can provide highway agencies with the resources they need to better manage their aging roadways. These resources include the data and tools needed to develop better pavement design methods and maintenance and rehabilitation procedures. In the beginning, the LTPP program was not an “easy sell.” There were many obstacles as implementation began, and challenges continue to arise along the way. Although the problems have sometimes been painful to work through, valuable lessons have been learned by everyone in the program.

This chapter highlights some of the most pressing issues encountered since the LTPP program was authorized by Congress in 1987 and the ways in which

these issues have been addressed while keeping in mind the goal and objectives established for the program.^{1,2} This written account presents some of the key lessons learned over the years with the hope that others planning short- or long-term research programs can benefit from these experiences.

QUESTION ALL ASSUMPTIONS

One of the key elements to any successful program, short- or long-term, is preparation. The early LTPP program planners and managers provided a solid foundation on which to build the program. Their effort is evident not only in the longevity of the program, but also in how the program has contributed to the pavement community. The early planners, however, could not anticipate every challenge that would need to be



“You did then what you knew how to do.
When you know better, you do better.”

Attributed to Dr. Maya Angelou

Test Site Information Assumptions

When the program started, it was widely believed by the organizers that general information about the test sites proposed for the General Pavement Study experiments was readily available. Field visits and exploration of candidate project locations, however, showed that specific information about material types and properties, layer thicknesses, construction dates, traffic, and other test site details was difficult to obtain. Furthermore it was discovered that some plan sheets were not nearly as accurate as was expected. These findings resulted in shuffling sites between experiments or removing them from the program altogether.

Although a body of knowledge did generally exist, it was usually scattered in various offices or divisions within the highway agency. The autonomy of many highway agency departments and divisions resulted in communication and coordination challenges in finding the historical data for the LTPP test sites. In some agencies, interaction between the district or field offices and the main office was limited, and project records were difficult to find. Often they were thought to be in transit, when they were actually stored in one place or the other, and no one really knew where to look. The LTPP program made a concerted effort to collect the missing data by working at times in the highway agency office reviewing plan sheets and inventory documents, and completing the necessary forms to include the data in the LTPP database. There are still some test sites where the historical data remain incomplete despite the program working closely with the agencies to collect this information.

Traffic Data Assumptions

Collection of climatic, materials, and performance time-history data was useful, but of limited impact if the progression of pavement condition could not be tied to the traffic loading. During planning, some major and grossly inaccurate assumptions were made in the traffic area.

First, it was assumed that wherever sites were selected, historical traffic information would be readily available. Second, since highway agencies routinely collected traffic data as part of their normal operations,

addressed by the program’s managers, partners, and contractor staff. Early assumptions were that selection of site locations would be relatively easily accomplished using highway agency information from as-built plans and pavement management systems. As implementation of the program began, the highway research community learned that we did not know nearly as much about the state of the pavements existing on the roadways as we thought we knew.

Although the idea of advance planning can be applied to each lesson discussed in this chapter, this section speaks to the issue of not having adequate information on which to proceed with implementation. Specifically, the program found that in some cases the basic design, construction, and maintenance information and other test section data needed to populate the LTPP database were unavailable or did not accurately reflect the characteristics of the test section.

it was assumed that they would be able to instrument the selected test sites to provide monitored data for future years. And, third, it was assumed that equipment would be available to accurately collect weigh-in-motion (WIM) data at a reasonable cost. As a result, little consideration was given to the need for traffic data during the site selection process. No consideration was given to the availability of historical information until after the fact. No consideration was given to the utilities and pavement conditions required for installation and proper operation of data collection equipment. These assumptions created a serious road block for the LTPP program until they were resolved by the traffic pooled-fund study (chapter 7), initiated following the Campaign for Program Improvement discussed below.

ESTABLISH CLEAR PRODUCT DEVELOPMENT EXPECTATIONS

Those who managed the LTPP program and those who supported the program in its infancy understood that several years would be needed to develop data collection protocols, identify and test the data collection equipment, and build the database. All of these program activities were essential for the future development of useful and usable tools and products to address highway agencies' needs. The planners also knew that many years would need to pass before sufficient data were collected to produce any meaningful results. This inevitable delay was a problem because results were urgently needed by the highway agency partners.

The expectation that products would not be quickly available was not communicated to the highway agency partners early on and probably not often enough, resulting in misunderstandings and frustration. The LTPP program has since improved its communication with the highway agency partners by providing frequent program updates through its newsletter and Webinars. In addition, the program has performed and initiated data analysis studies that have the potential to address some of the pressing needs of the agencies, such as the study on effectiveness of maintenance and

rehabilitation options.³ Many other examples are described in the data analysis and product descriptions in chapter 10. As monitoring continues on in-service pavement structures, more data are collected, and more analyses are conducted, additional knowledge, tools, and useful products will result to help the entire highway community.

MANAGE FROM THE CENTER TO SUCCEED

The LTPP program requires a centralized management structure to effectively and efficiently perform the activities and functions of the program. The benefits from such a structure were first realized when the program was managed by the Strategic Highway Research Program (SHRP) of the National Research Council in the early years, and since then by the Federal Highway Administration (FHWA). Operating such a large program also requires collaboration among many partners in different types of organizations and among different levels of management, which both SHRP and FHWA have successfully supported. Direct communication and close coordination among multiple parties is only possible through a centralized management structure that can provide the funding and personnel resources needed to properly carry out the program's many activities.

Dedicated Funding

Efficient execution of a program such as LTPP requires considerable planning and a predictable, uninterrupted stream of funding. Given that highway bill funding usually lasts for a period of 4 to 5 years, and is renegotiated each time, the program has had to survive the passage of five highway bills over its more than 25 years of existence. With each new highway bill, LTPP program staff had to justify the value of the program and the logic of continuing its funding. Although the program has enjoyed continuous funding, there has been considerable disruption and uncertainty as to how much money would be available and when. In response to these situations, the program's managers have learned to adjust its short-

and long-term program plans and priorities, which are set based on multiple levels of possible funding. The reality, however, is that such funding uncertainties have led to missed opportunities in pavement performance monitoring and to the delay of critical activities such as correcting program weaknesses and addressing emerging pavement-engineering needs.

Central management of the LTPP program has provided the flexibility to strategically carry out the program activities during funding reductions. For any long-term research program, it is important to seek dedicated and uninterrupted funding.

Dedicated LTPP Program Staff

The program has had the good fortune to have nearly the same core staff for much of its 25-plus years, which is extraordinary. The program, however, has seen its share of changes in leadership and staffing levels, resulting in changes in the approach to moving the program forward.

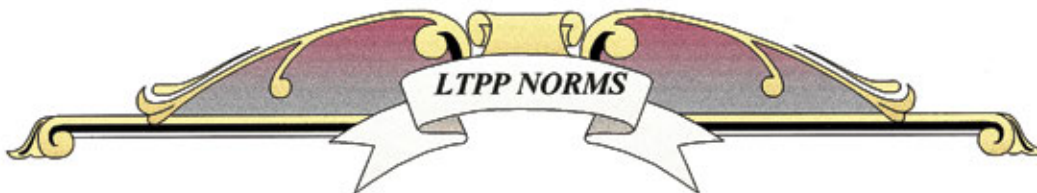
During the years when the LTPP study was part of SHRP, the challenge faced by the SHRP-LTPP management was finding the right “home” for the pavement research study where the work would continue after the SHRP program ended in 1992. Having a vested interest in long-term pavement monitoring well before the LTPP program was implemented, FHWA was identified as the most logical “home” for the program to live out its intended purpose. However, in more recent years given the uncertainty of the future of the LTPP program, the partners have feared that the program functions—particularly the housing of the database and the core program staff—would be dispersed across different offices within FHWA.

The highway agency and industry partners strongly voiced their concerns that decentralization of the LTPP program could result in neglect, lack of communication, the inability to properly manage critical activities remaining to be done, and a gradual loss of interest in the program itself.⁴ One such example can be shown in the transfer of LTPP product development from the core staff to another office within FHWA, which has left the program staff not knowing the status or delivery of products to the highway community. While

efforts have been made to correct this problem, it is still a concern and not the ideal solution for the program. In response to the partners’ concerns, FHWA management has committed to provide the staff required to fulfill the LTPP program’s needs.

The program’s history has shown that having a dedicated program staff provides coherency, close communication, and clear and firm control over priorities. Having the support of core staff through this centralized management structure, the LTPP program has been able to collect consistent, high-quality data. A case in point is the resolution of the Specific Pavement Studies (SPS) materials and traffic data gaps as discussed in chapter 7. SPS materials testing and traffic data collection were the responsibility of the individual highway agencies. The agencies made good faith efforts to discharge these responsibilities, but the dispersion of responsibility resulted in problems with timeliness, completeness, and consistency in the data provided. For this reason, efforts to correct the SPS materials and traffic data gaps were managed centrally and have successfully resulted in these data gaps being filled. Achieving consistent, high-quality data requires central management.

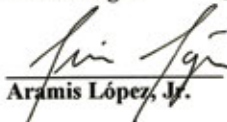
Having a dedicated staff to work on the LTPP program has been ideal, as demonstrated in the many accomplishments described in this report. The program’s staff, however, has not always been in agreement. Each staff person has had the best interest of the program in mind, but misunderstandings, disagreements, and frustrations have existed among members of the LTPP Team as would occur with any complex operation. In 1997, at an internal LTPP meeting, members of the LTPP program staff and its contractor and loaned staff discussed and positively resolved this issue by agreeing to operate under the “LTPP Norms” (see sidebar). This signed resolution by the parties emphasizes the importance of putting differences aside by being respectful and staying focused on moving forward. The resolution also shows the importance of people with different backgrounds, expertise, and interests coming together to work toward the good of the whole program. Synergy at its best was demonstrated by this group and has since continued within the LTPP program.

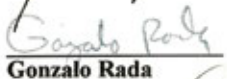



- Supporting Decisions -** *We commit to support decisions made in accordance with the LTPP Program Decision Making Process.*
- Communication -** *We will exchange information to achieve a mutual understanding of issues.*
- Cooperation -** *We will seek, offer, and provide assistance.*
- Respect -** *We will be polite and considerate of each other.*
- Accountability -** *We hold ourselves and each other responsible for our actions.*

We, the undersigned, commit to abide by these norms.


Bill Bellinger


Aramis López, Jr.

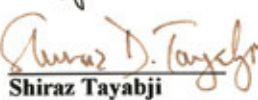

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December 9, 1997



Dedicated Highway Agency Staff

There were a number of meetings at the beginning of the program to inform participating highway agencies of plans and to solicit their support for activities. Given the support of highway agencies through the American Association of State Highway Transportation Officials (AASHTO) and the Transportation Association of Canada, senior management staff supported the program objectives, which trickled down to mid-level managers who provided their support as directed. Under SHRP-LTPP management, each highway agency was asked to provide an LTPP State Coordinator who would serve as the liaison between the agency and the LTPP program office. This practice continues under FHWA's leadership.

Over time, agency personnel changed positions or left agency employment as a result of career moves and retirement. This attrition meant that those who supported the program at the outset were no longer available to encourage continued participation. LTPP program resources were continually required to educate those moving into positions of influence, and to encourage them to continue support for the program. The effect of attrition was especially felt in the solicitation of candidate projects for the SPS experiments. Participation in the SPS experiments, which involved new construction, was costly, and results were not to be realized for many years. Obtaining and maintaining enthusiastic support under these circumstances was extremely difficult.

Efforts to support the program were all voluntary, with agency staff already committed to performing their regular job duties, so it was often difficult for them to make time for the tedious and time-consuming tasks involved in researching available test sections for site selection, locating historical data, or planning construction of SPS projects. The LTPP program had its own way of doing things, with specific test protocols, design constraints suited to SPS construction, and data forms requiring detailed information about discrete points on the roadway where very little specific information existed. In order to fully support LTPP program activities, agencies had to make some adjustments to their normal operations. These changes were met at times with some resistance. As the program matured and the expectations of the highway agency were bet-

ter defined, the LTPP program became a higher priority for the agency staff.

In addition, Federal funds for the program cover only part of its real cost, and highway agency staff and resources have been needed to assist in meeting the LTPP objectives. Some agencies have even allotted funding in their budgets to support LTPP program activities such as providing traffic control for data collection, materials sampling, or construction activities; installing instruments to measure traffic; and performing laboratory materials testing.

REASSESS PERIODICALLY

Since 1987, the LTPP program managers have been hard at work establishing the experiments, preparing for implementation of the program, identifying and collecting the right pavement performance data for future data analysis and product development, and developing a secure database to store the data. Given these and other key program activities, the program managers have learned to pause and reflect on the condition of the program and to identify what improvements can be and should be made. Such periodic assessments or reviews of the state of the program have happened through internal meetings, meetings with the program partners through the expert task group committee structure, and national meetings. This section focuses on the information gathered from key national meetings that have helped to make the LTPP program what it is.

SHRP Midcourse Assessment Meeting

Denver, Colorado (August 1990)

More than 400 invited representatives of highway agencies, industry, and research organizations gathered in Denver, Colorado, August 1–3, 1990, to take a close look at SHRP's progress to date, and to suggest adjustments that would maximize the potential for delivery of immediately useful products when SHRP would end in 1992. The presentations looked at the strengths and weaknesses of current planning, and sought to gain input that would ensure that the LTPP program would remain in line with the stated goal and objectives. There was also a heightened awareness of international participation, as

presentations provided input from international perspectives, and data analysis topics provided insight to the potential capabilities of the very early SHRP-LTPP data. The proceedings from this assessment meeting were published as SHRP Report No. 91-514, as a collection of the LTPP papers and presentations.⁵

States Convey Their Needs to LTPP

Interviews at Eight State Highway Agency Offices (1995)

The AASHTO Task Force on SHRP Implementation provided valuable assistance to the LTPP program by making arrangements for the program manager at the time to meet with eight senior State officials (at least one from each of the AASHTO regions) in order to hear their pavement performance needs. The purpose of these discussions was to obtain guidance on the future direction of the program and to get an understanding of the States' expectations on the program deliverables.

The 1-hour, face-to-face meetings initiated by the LTPP program took place in 1995 in Arkansas, California, Kansas, Maryland, New York, Pennsylvania, Texas, and Wisconsin. These senior State officials revealed that their active participation in the program was largely driven by their expectations that the tools and knowledge produced by the program would yield answers to and address issues such as the ones listed below:⁶

- What maintenance treatments are effective? What do they cost? When should they be used? How much do they extend the life of the pavement?
- What is the best rehabilitation design for a given road structure? How can we minimize the risk of our choice? What are the life-cycle costs?
- We need better designs, developed from models that predict with assurance that the newly built or reconstructed pavements based on these designs will last a specified number of years.
- We need dramatic improvements in technology, not incremental changes.
- What performance trends are discernable from the LTPP data?
- We need improvements in WIM technology. We need to measure equivalent single-axle loads more accurately.

These thoughts strongly echo those cited in the “Blue Book”⁷ and “Brown Book,”⁸ but have a more tangible feel. In essence, the States want useful engineering tools and an enhanced knowledge base on which to base management and engineering decisions—their high-priority needs in terms of answers from the LTPP program. The program fell short of this expectation because initially the program was focused on data collection. Little effort was put on product development, which has had a negative impact on the program's image. To understand why some pavements provide superior service beyond a 20-year design life, monitoring must be extended beyond 20 years, but States needed answers immediately. This posed a problem then and in some ways it still does now. Although many valuable data analysis studies have been performed by the LTPP program which have resulted in useful products (that would not have otherwise been developed) that have benefited the States and the broader highway community, there are still unanswered questions posed by the States that need resolution.

LTPP National Meeting

Irvine, California (March 1996)

The FHWA assumed stewardship of the LTPP program in 1992, when SHRP ended. Collection, management, and analysis of the data, and planning for continued operations moved seamlessly ahead during the transition from SHRP to FHWA.⁹ In recognition of the fact that the LTPP program was approaching the midpoint of planned pavement monitoring, it was prudent to plan a national meeting where participants could learn from those that had made use of the data collected to date, and provide input on any needed midcourse corrections.

The LTPP National Meeting was held at the TRB facilities in Irvine, California, March 26–28, 1996. This meeting drew participation from most highway agencies, industry, academic institutions, and FHWA. Presentations provided background information on the status of the various aspects of the program, and on results of data analyses. Breakout groups discussed program needs and high priority objectives.

Throughout the course of the meeting it was recognized that major gaps existed in the LTPP database, predominantly in traffic and materials test data. Those

in attendance agreed that these critical data gaps must be filled if the program was to deliver on its stated objectives. It was also recognized that of the pavement types being studied, highway agencies were most interested in the result of rehabilitation studies, since the bulk of their construction efforts were in maintenance and rehabilitation of existing roadways. Concerns were expressed about studies focusing on pavement technologies and material types that were no longer used. All of these observations and many more provided strong feedback to the LTPP program managers, giving them much clearer direction as to what they should focus their efforts on.

LTPP Program Focus: Assessment and Corrective Actions

In 1996, as the LTPP program was approaching the 10-year mark, FHWA decided to embark on an overall assessment to review the program goal and objectives, and to see in what direction the program was really heading. This assessment was accomplished by evaluating the impacts of deviations from the program's plans, the number and types of test sections ultimately included for monitoring, data collection deficiencies, and resources. The ultimate objective of the assessment was to develop a revised strategic plan that focused on high-payoff products that would meet agencies' needs, improve program efficiency, and provide better quality data for product development.¹⁰

The assessment was conducted by a team composed of LTPP program and contractor staff, in concert with a special peer review subcommittee made up of highway agencies, TRB, and AASHTO representatives. In addition, through the TRB advisory mechanism, stakeholders in agencies were contacted to obtain input on agency needs as related to the goal and objectives of the program established 10 years earlier.

Early on in the assessment it became evident that data quantity issues overshadowed other program considerations. Specifically, large data gaps in the LTPP database and questions regarding the data were identified, which precluded addressing other issues such as data quality and test section coverage. In turn, this issue led to concerns about the ability of the LTPP program to fully deliver on its intended goal and objectives.

The Campaign for Program Improvement (1997–1999)

As a result of the assessment in which data completeness and data improvement were identified as the highest priorities for the LTPP program to address immediately, a highly publicized “Campaign for Program Improvement” (often referred to as the Program Improvement Campaign) was initiated in 1997 with support from the TRB LTPP Committee.¹¹ This 2-year campaign consisted of five interrelated tracks of activities:

- Operations Backlog.
- Test Section Classification.
- Monitoring Schemes.
- Analysis and Product Development Plan.
- Data Studies/Preliminary Analyses.

Special mention to the operations backlog track is given here since it was intended to address the gaps and questions regarding the data collected but not processed and entered into the LTPP database, which was identified as a major program issue during the assessment. Preliminary data resolution began in early 1998, and in April, when AASHTO passed a resolution seeking the agencies' help in resolving the LTPP data issues, the effort began in earnest.¹² As a result of the AASHTO resolution, face-to-face meetings similar to the ones held with the senior State officials in 1995, were held but this time with each individual agency during the summer of 1998. In all, 60 meetings took place involving more than 1,200 highway agency and FHWA personnel. These meetings led to the development and endorsement of agency action plans, and implementation of these plans resolved many of the LTPP data issues.

The 2-year Program Improvement Campaign significantly improved the LTPP program's ability to better deliver on its goal and objectives through several accomplishments:

- Cleared data processing backlog.
- Systematically assessed data availability and deficiencies.
- Initiated work to resolve deficiencies and obtain needed data.
- Established framework for development of improvement quality measures.

- Revised monitoring guidelines in response to data availability and importance of test sections to program priority goals.
- Developed a strategic plan for data analysis.
- Developed a product development plan linked to data analysis.
- Established clear lines of feedback from analysis to data collection activities to resolve data anomalies and errors as they are identified.
- Initiated formal data studies.
- Rejuvenated highway agency commitment to the program.
- Took actions to develop a plan for management of ancillary data and data archival at the end of the program.

The LTPP program learned about its strengths and weaknesses as a result of the campaign and this resulted in a fundamental shift in program operations and management. The campaign aligned the program with modern quality management principles and practices, and it brought needed focus to product development and data analysis, as identified in the list above. However, despite its many accomplishments and successes, it is important to note that at the conclusion of the Program Improvement Campaign, data issues remained to be resolved. In particular, large data gaps remained in the LTPP database in terms of the SPS traffic and materials data, which necessitated the development and implementation of action plans. These action plans are discussed in the following section. The LTPP program has been proactive in its assessment of itself, and has continued to take steps to improve the manner in which the program is managed.

Major Data Resolution Initiatives

Due to budgetary restrictions early in the LTPP program, funding responsibility for traffic and materials data collection was assigned to the individual participating highway agencies. Although the highway agencies made a good faith effort to fulfill this responsibility at the LTPP test sites, problems of data quality and timely monitoring and testing arose. And while highly successful, the Program Improvement Campaign, which concluded in 1999, did not resolve these two

major data issues that still existed at the SPS test sites. Consequently, in the early 2000s, the program undertook two major data resolution initiatives to address the traffic and materials data gap issues.

LTPP SPS Traffic Data Collection Pooled-Fund Study. Traffic data collection within the LTPP program has always been a challenge, in large part because the associated technology has not lived up to the early expectation that it would be economically and technically feasible to install reliable WIM equipment at every LTPP test site. By the late 1990s it was clear that, as a consequence of mistaken assumptions about the availability of traffic data and the WIM equipment as described earlier in the chapter, traffic data were incomplete relative to original expectations. Complete, high-quality traffic data were available for some sites, while little or no traffic data were available for others. For the majority of LTPP test sites, traffic data availability fell somewhere in between.

Clearly, something had to be done with regard to the traffic data, particularly at the SPS projects, and it was. In response to the large SPS traffic data gap, the LTPP program, with support from the Expert Task Group (ETG) on LTPP Traffic Data Collection and Analysis, developed and implemented an action plan for closing the gap. Specifically, a pooled-fund study between the highway agencies and FHWA was initiated in 2001. The Long-Term Pavement Performance (LTPP) Specific Pavement Study (SPS) Traffic Data Collection Pooled-Fund Study, TPF-5(004), was designed to fill in existing data gaps and improve the quality and quantity of monitored traffic data for the SPS-1 (structural factors for flexible pavements), -2 (structural factors for rigid pavements), -5 (rehabilitation of asphalt concrete), -6 (rehabilitation of jointed Portland cement concrete), and -8 (environmental effects in the absence of heavy loads) projects. FHWA managed the study and oversaw the work of two independent contractors to resolve the traffic data gap. Although its implementation began later than anticipated due to various technical issues, in 2003 the traffic pooled-fund study began to generate the high-quality data needed to close the traffic data gap. At least five years of research quality traffic data were collected during the study for 28 of the 84 SPS projects and are available in the LTPP database.

The LTPP program made a significant financial contribution toward the pooled-fund study, but the bulk of the funding came from contributions by the highway agencies. A majority of the highway agencies with SPS projects (28 of 38) participated in the study, and some highway agencies with no SPS projects also contributed, essentially making their funds available for the good of all. The traffic pooled-fund study ended in December 2014, but the LTPP program has committed to continue collecting weight and classification data from as many of these projects as the budget will allow. As a result of this centralized data collection and review effort, a significant portion of the SPS traffic data gap was resolved, and the LTPP program is applying the methods from this initiative to collect traffic data at the new LTPP warm-mix asphalt projects. See chapter 7 for more information about the traffic pooled-fund study.

SPS Materials Action Plan. SPS materials data were collected by the highway agencies according to materials sampling and testing guidelines developed by the LTPP program and site-specific sampling plans adapted by the LTPP regional support contractors working closely with each highway agency. The State and Provincial highway agencies took responsibility for sampling and testing the materials from their respective SPS projects, with two exceptions: the LTPP program performed the resilient modulus testing of unbound and hot-mix asphalt materials and the coefficient of thermal expansion testing for Portland cement concrete layers. Under this primarily decentralized approach, data collection practices were not consistent among the highway agencies. This inconsistency was in contrast to the materials sampling and testing for the General Pavement Studies test sections, where the LTPP program performed all of the associated activities with support from the highway agencies.

The program assessment revealed that nearly 48 percent of the required SPS materials test data were missing, which clearly limited the ability of the LTPP program to meet its goal and objectives. Starting in 2002, the program, with support from the ETG on LTPP Materials Data Collection and Analysis, began taking steps to address the SPS materials data gaps. This effort led to the further pursuit of missing materials data from the responsible highway agencies, the

search for missing data at the LTPP regional support contractor offices, and the acceleration of hot-mix asphalt and unbound granular resilient modulus testing by the LTPP laboratory contractor. An SPS materials data resolution action plan was developed to provide standard procedures for collecting and testing the samples. This plan, known within the program as the SPS Materials Action Plan, was specific to the SPS-1, -2, -5, -6 and -8 projects and addressed three major areas:

- Resolution of materials data gaps.
- Aging and new materials testing.
- Collection of materials samples.

A significant reduction in the missing SPS materials data, from 48 percent to 35 percent, resulted from the efforts started in 2002, but large materials data gaps still existed and they needed to be addressed. Therefore in 2004 the LTPP program, with the support of the Materials ETG, updated the action plan and began a concerted effort to resolve the remaining materials data gaps. The updated Materials Action Plan, implemented in 2004, called for nearly 10,000 laboratory material tests and included nine major tasks.

The quality of the SPS materials test data was also investigated to determine the need for repeating tests performed by the highway agencies as part of the final action plan. Major findings from this investigation were that (1) the biggest difficulty in assessing the quality of the SPS materials data is the lack of data; and (2) where data are available, the majority met the criteria used in the quality review. Accordingly, the decision was made that repeat testing was not necessary and therefore did not have to be included in the action plan. Despite the financial challenges faced by the LTPP program, in 2008, the program successfully resolved approximately 90 percent of the missing SPS materials data issues.¹³ See chapter 7 for more information about the SPS Materials Action Plan.

LTPP SPS Workshop

Newport, Rhode Island (April 2000)

On April 27, 2000, the LTPP program held a workshop in Newport, Rhode Island, to discuss the status of the program's SPS-1, -2, -5, and -6 experiments. Nearly 150 participants were on hand to discuss the progress of

these experiments, which were designed to explore how climate and cumulative traffic loading affect pavements of different compositions and cross sections. The LTPP contractor staff presented comparative studies on the performance of the test sections to date and the highway agencies presented their observations and opinions from the construction experience. There was active discussion about missing data, including traffic and materials information, and the critical need to obtain this information if the experiments were to be successful. The workshop provided yet another forum for the involvement of stakeholders in the program to voice opinions and observations, and to provide input for the planning and direction of LTPP program operations.

KEEP PARTNERS INFORMED

As discussed throughout this report, the LTPP program has benefitted from the close collaboration and collective efforts from different organizations, and also from the individual expertise from many individual professionals. Working in partnership with these organizations and professionals has always been integral to the program and began well before program implementation. However, during funding cuts that began in 1998, the partners became concerned that keeping them informed was no longer a high priority of the program staff. The budget constraints resulted from highway legislations passed in 1998 and 2005 (see chapter 4).

The budget provided by these legislations was not able to meet every need of the LTPP program. So, some tough decisions were made by the program based on the budget given. One such decision was to not only reduce the frequency of meetings with the ETGs and the LTPP Committee, but to also reduce the number of ETGs from six to two. So, instead of meeting every 6 months with six ETGs and the LTPP Committee to discuss the status and future work of the program, the LTPP Team began meeting annually with two ETGs and the LTPP Committee.

This was an uncomfortable time for both the LTPP program and the partners. Uncomfortable for the program because the managers thought they were

"There is a need for person to person communication, and for user involvement in technology transfer. The ways in which we do it are as important as doing it."

—Lynne Irwin, Cornell University¹⁴

making the right decisions at the time. Uncomfortable for the ETG and LTPP Committee members because they felt they were not being kept informed, and they were also frustrated that their input was not being sought to help in influencing the direction of the program, especially since the program was nearing the end of its planned 20-year data collection period. There was uncertainty as to whether or not the program would be extended beyond the 20 years even though hundreds of test sections still had not reached the end of their design life, and the LTPP database still needed to be further developed and maintained. It was vital that the partners through the LTPP Committee structure hear from the LTPP program what was being considered for the future and to be part of these discussions.

As the LTPP Committee voiced their concerns, the LTPP program and FHWA's senior management listened and made changes to correct the lack of communication between the program office and the partners.^{15,16} Since then, the semi-annual frequency of the face-to-face meetings has resumed. In addition, the *LTPP Newsletter* was established to keep the program partners informed during the time when meetings were not possible. The newsletter is still being distributed at regular intervals to hundreds of people across highway agencies, researchers, academia, and other interested parties.

The LTPP program knows that continued involvement of its stakeholders is vital to its ultimate success. Routine coordination and communication with participating highway agencies, for example, are of paramount importance—without their support, performance monitoring and other data collection activities on the LTPP test sections would not be possible.

DOCUMENT CONTINUALLY

The LTPP program has developed, written, and published thousands of formal and informal program documents over the years. The references cited in this very report show the magnitude and variety of communications produced and used by the program. The program staff has learned the importance of having a written account of the various decisions made, not only for those involved in working directly with the program but also for those who may want to learn about how the program is managed. To achieve high-quality data consistently throughout the United States and Canada, clear direction and guidance are needed by those collecting and processing the LTPP data. Having a written account of the program's activities also provides future LTPP program managers and senior FHWA management with insight into the program. The permanent record of the program's data collection procedures, calibration activities, and other important documentation used to manage the program will serve as valuable resources for the pavement industry for years to come. It is very important for any type of research program, long- or short-term, to have a plan to document its program along the way.

PREPARE TO CHANGE WITH TECHNOLOGY

One of the frequent criticisms heard by the LTPP program managers was that the program studied "past" technology. The implication was that by the time sections were constructed and their performance had been monitored over a long period of time, the use of that material or construction technology would have evolved to the point where the findings were no longer appropriate to current practices. This potential problem is fundamental with a long-term study of any type. In the LTPP program, efforts were made to include a broad enough "inference space" of material properties and practices, such that results could be reasonably expected to reflect behaviors that would be encountered.

Another concern has been change in technology over time. Since the program began in 1987, there have been amazing advancements in electronics, equip-

ment, and computing technologies. The program had to periodically update its pavement performance monitoring equipment and software as equipment became obsolete or worn out and as software was no longer supported. These changes each required updates in other areas and notifications in the resulting data to ensure that users were aware of the changes and their potential impacts on measurements. For example, the program has used four different pieces of equipment from three different vendors to collect longitudinal profile measurements. Although the end results should be the same, different electronic technologies and filtering techniques result in differences in the data. The LTPP program has conducted comparison and calibration activities for each equipment upgrade to minimize the impacts of such changes and noted the changes in the data set where appropriate to do so. In some cases, where equipment had not advanced to meet specific needs of the program, manufacturers adapted equipment to the program's specifications.

Data processing and communications equipment and software were another area where continuous effort and investment are needed to keep pace with change. As the LTPP database is the program's principal operational tool, its most strategic product, and its legacy to future generations of highway researchers and practitioners, a paramount program priority has been to keep the Information Management System secure and current with computing and communications software and hardware. Over 25 years, the program has moved from magnetic tapes and floppy disks to centralized data entry and data user access via the Internet to keep the data accessible. Equipment and software have been upgraded several times. Particular attention is directed to system security, and backups of the entire database are performed routinely (see chapter 8). Long-term research efforts must be prepared to adapt to a changing technological world.

SUMMARY

Every chapter in this report tells part of the LTPP story. In this chapter, it was important to document some of the challenges so that others understand that the pro-

gram has not done things perfectly or made the right decisions all the time; mistakes and adjustments have been made. Perhaps others will learn from what has been done, and appreciate the effort, hard work, and dedication of those who have made the program better with each lesson mentioned in this chapter, lessons that were not mentioned, and lessons that will come as the LTPP program looks forward to future research efforts, which are discussed in the final chapter.

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The LTPP processes and database can serve as a springboard to monitoring the long-term performance of new pavement materials and technologies in the future.

12

Paving the Way to the Future

The LTPP program was born in the 20th century, but it has already provided knowledge that is improving the design, construction, rehabilitation, and maintenance of pavements that are serving the 21st century. The performance data gathered in the LTPP experiments over the past quarter century, and data yet to be gathered from the program's high-performing sections and new experiments, will provide insight into designing, constructing, and maintaining pavements that last long into the future.

INTRODUCTION

More than 25 years after the LTPP program began, the benefits and products resulting from the program continue to advance pavement design and management worldwide. The LTPP database has played a critical role in the development and evaluation of every major pavement design methodology developed over the past two decades, including the 1998 American Association of State Highway and Transportation Officials (AASHTO) design procedures, Superpave[®], and, most recently, the *Mechanistic-Empirical Pavement Design Guide* (MEPDG), implemented in the AASHTOWare[®] Pavement ME Design software. Beyond overall design procedures, the data have supported model development and validation for a wide array of pavement performance

predictors and indicators. The program has also influenced industry practices and has raised the bar for data collection and laboratory analysis standards worldwide.

Although the LTPP program's achievements have been many, to realize the full potential of the world's most comprehensive pavement performance database and capitalize on the investment that has been made to date, much work remains to be done. As the national focus in transportation systems moves to performance standards and measures, as mandated by the Moving Ahead for Progress in the 21st Century Act (MAP-21),¹ the program brings to the table data and data-related capabilities that are needed to support the understanding of pavement performance measures.



“To learn the lessons required to design long-life, high-performance pavements, we must continue to track the performance of the more structurally robust test sections. It is their performance that will yield the requisite knowledge to develop, verify, and calibrate designs demanded by 21st century highway networks; their performance that will teach us how to manage and maintain these new pavements. If LTPP stops now, we will have only learned how to build and maintain 20th century pavements better.”

Transportation Research Board LTPP
Committee, 2001²

The program is committed to a fluid planning process with a 30-year horizon to keep pace with a changing world. Looking to the future, major areas of program activity will include the following:

- *Securing and enhancing LTPP resources.* Provide access, functionality, user support, and security for the pavement performance data, ancillary electronic data, film, and materials specimens that the program has collected. Continue to upgrade the database, user interfaces, and user support to keep pace with advances in data analysis methods and computing and communications technologies.
- *Collecting pavement performance data.* Monitor active LTPP test sections through a complete performance cycle. Design, implement, and monitor new LTPP experiments as pavement technologies change and new materials and technologies are introduced.
- *Conducting analyses and developing products.* Pursue new insights and understanding by conducting research to fulfill the prioritized objectives of the Long-Term Pavement Performance Data Analysis Program.³ Building on the results from the research, develop products and tools that are aligned with national pavement engineering priorities as outlined

in the LTPP Product Plan⁴—products and tools that pavement engineers and managers can use to design, construct, maintain, and rehabilitate pavements for better performing, longer lasting, and more cost-effective highways.

- *Contributing to national initiatives.* Work with other highway data collection initiatives to assure the availability, reliability, and validity of data used for research into pavement performance measures.

The road ahead for the LTPP program continues to be a long one with these future activities paving the way.

SECURING AND ENHANCING LTPP RESOURCES

The LTPP program has assembled massive amounts of information that are freely available to the pavement community (see sidebar). As described in chapter 8, researchers can now select and download LTPP performance data and ancillary information via the Internet and can request samples of paving materials from the Materials Reference Library. To maintain the usefulness of these resources to highway agencies and other pavement researchers, these assets must be

LTPP RESOURCES FOR DATA USERS

The LTPP program has assembled and made available two major bodies of electronic data, the Pavement Performance Database and an archive of information that supports the performance data known as AIMS—Ancillary Information Management System. In addition, the program maintains a huge and varied store of materials samples in the Materials Reference Library in Reno, Nevada. Together, the electronic data and physical specimens are a vital resource for future pavement research and are available through LTPP's InfoPave™ Web site, where data can be downloaded, or by contacting the LTPP Customer Support Service Center (Email: ltppinfo@dot.gov).

- **The LTPP Database**—The LTPP program's principal operational and product-enabling tool. The database is the program's legacy for current stakeholders and future generations of highway researchers and practitioners seeking to learn how and why pavements perform the way they do. Currently containing more than 330 million records of data in 14 data modules, 484 data tables, and 11,906 data fields, the searchable and downloadable database is a complex data warehouse. The program recently invested in improvements with the end user in mind: simplifying the database structure, adding more commonly used computed parameters for analysis, improving access, and creating a ready-for-analysis data structure.

- **The Ancillary Information Management System**—A central, downloadable, electronic archive of raw data, information, documents, research reports or briefs, and tools that support the LTPP database. AIMS includes a collection of more than 1 billion raw traffic classification and weight measurement records, test section photographs, videos, reports, raw data files, construction plans, data collection protocols, data processing guides, and other program documentation.
- **Materials Reference Library**—The repository for material samples from the General Pavement Study and Specific Pavement Study test sections across the United States and Canada—asphalt cement, Portland cement, natural aggregates, combination materials—as well as more than 12,000 35-mm film distress records. The facility also contains specimens from the Strategic Highway Research Program and Federal Highway Administration's (FHWA) Crumb Rubber Modifier Project and Accelerated Loading Facility. Materials samples are available for evaluation and verification of new pavement designs and materials tests.
- **LTPP Documentation**—More than 600 documents related to the LTPP program are housed in a central library at FHWA's Turner-Fairbank Highway Research Center in McLean, Virginia, and are available in the LTPP Reference Library, which is distributed with the Standard Data Release, and at the LTPP InfoPave™ Web site.

properly secured, maintained, and upgraded with changing technology to assure continued access.

Providing Security and Maintenance

The LTPP data have been available to all potential users since the first public release of data in 1991. These data will remain an important resource for pavement performance research for many years to come. Without adequate investment in security and maintenance activities, however, the potential of the LTPP database to contribute to advancements in pavement engineering could be gradually eroded and eventually lost altogether. Ensuring that the database and its supporting information remain accessible, yet secure, has required the program to take some important steps, which are outlined in chapter 8. The program will continue to maintain the security, functionality, and accessibility of the database and to upgrade the database software and hardware to keep pace with future changes in data storage, security, and communications needs and technologies.

Maintenance of the Materials Reference Library is also vital, as it is the repository for materials samples from the LTPP test sections and other pavement programs of national significance, and it also provides climate-controlled storage conditions for the LTPP 35-mm film distress records. Many of the materials samples are from projects with performance data, which makes the samples especially valuable to researchers. The samples have been used to support 32 national highway research projects. By continuing to maintain the Materials Reference Library, the LTPP program will enable researchers to link the results of past, present, and future pavement research. Researchers will be able to use samples from the test sections, for example, in evaluating future test methods, thereby enabling updates of the data to reflect new technologies.

Improving the Database

Refining and improving the LTPP database so that it is aligned with users' needs is critical to achieving the full future value of the LTPP program. Additional refinement of the database will make it easier and more effective to use. Several planned database improvements, many of which are currently underway, have the potential to accomplish this goal:

- Create a custom data extraction that is formatted and contains all data needed for analysis using specified falling weight deflectometer backcalculation computer programs.
- Add a new table that provides a unique index of the location for all pavement monitoring measurements performed on each joint or transverse crack location on Portland cement concrete (PCC) pavements and rehabilitated pavement structures.
- Create a unified set of pavement distress data that presents a logical progression of key pavement distress types over time, taking into account the different methods the LTPP program has used to measure distress, variability inherent in each measurement method, and timing of field pavement construction and maintenance activities.
- Create a calibration data set that is specific to the MEPDG and can be used by highway agencies to perform pavement performance calibration from LTPP test sections located within or near their jurisdictions.
- Create a performance measure data set to include distress, profile, faulting, and rutting compatible with Highway Performance Monitoring System requirements. This data set will support implementation of the performance-based surface transportation program mandated by the current highway legislation, MAP-21.
- Provide a set of basic time history of pavement performance observations of pavement distress, roughness, friction, and falling weight deflectometer measurements that include matching cumulative load values, pavement material property characterizations, pavement structure, and climate.
- Interpret available data, expand project-level sample data to recommended test-section-specific characterizations, impute needed time-dependent properties from other measurements, and provide a characterization of the relative estimated error for the following material properties:
 - Hot-mix asphalt (HMA) volumetric measures.
 - HMA resilient and dynamic properties.
 - PCC temporal indices.

- PCC thermal coefficient.
- Resilient modulus of unbound materials.
- Other parameters related to drainage and climate.

Supporting LTPP Data Users

Given the complexity of the LTPP database, continuing to provide technical support to data users will be crucial to maximizing research results. Researchers around the world have successfully used the data to address an array of pavement engineering challenges. Vital to this success has been the availability of LTPP technical support to answer questions, point researchers to the documentation they need to understand the data applicable to their problems, and otherwise help users navigate and manipulate the database structure to select the appropriate data.

Future user support will take different forms, depending on the intended use of the data. The LTPP program's primary customer, highway agencies using the LTPP database to address pavement issues of concern to them, will receive support to ensure clear understanding of the data being provided and to assist them with any problems. Such support may focus on generating data sets for selected locations that could be used to calibrate the MEPDG for a State or Province's local conditions. In the future, when national pavement performance measures are established, the LTPP database is likely to be the prime resource for highway agencies' use.

For studies of national significance, such as the National Cooperative Highway Research Program (NCHRP) project that developed the MEPDG, support will often entail face-to-face meetings to communicate fully the data needs and required formats and to identify the best source of the data within the LTPP database. Custom extractions from the database can then be performed to provide the needed data in the appropriate format, followed by ongoing technical support to ensure clear understanding of the LTPP data and to clarify any issues that may arise.

Support will also include training for Federal, State/Province, and local agencies, as well as members of industry and academia. For example, the LTPP program has developed a workshop to familiarize pavement engineering professors with the database and engage them in using the data to solve

real-world pavement analysis problems. For university students working on theses, dissertations, or other research projects, support will include providing them with the latest LTPP Standard Data Release, recommendations on where to find the needed data within the database structure, and clarification of data-related questions.

COLLECTING PAVEMENT PERFORMANCE DATA

The LTPP program's pavement performance data collection effort is the largest and most comprehensive ever undertaken for in-service highway pavements. The program has monitored 2,509 test sections located throughout the United States and Canada. The test sections that are still being monitored include many that are part of the program's rehabilitation and structural factor experiments; long-life, high-performance pavements; and sites where traffic monitoring continues.

Changes in technology will also expand the types and quantity of performance-related data that can be captured. For example, variations in the quality of construction have a vital impact on pavement performance. As technologies evolve, new tools are becoming available to capture more comprehensive data during construction, enabling highway agencies to know whether pavements are built as planned. Some examples of these technologies are magnetic tomography systems for checking dowel bar alignment⁵ and full-width infrared thermography scanning systems for measuring HMA placement temperatures in real time.⁶ With additional information that these technologies can provide, "noise" in the data may be reduced and clear trends may appear. As it pursues new experiments, the LTPP program will be examining technologies that can help to identify and separate the many variables affecting pavement performance.

LTPP data yet to be collected will contribute valuable new information to pavement performance research. The future of LTPP data collection will include completion of the original experiments, forensic studies of selected test sections that can shed light on specific performance questions, and new experi-

ments designed around emerging technologies, such as warm-mix asphalt (WMA) and pavement preservation.

Completing the Original LTPP Experiments

As of 2014, 732 of the original LTPP test sections were still being monitored—372 in the General Pavement Study (GPS) experiments, and 360 in the Specific Pavement Study (SPS) experiments. To achieve the objectives for each experiment, it is critical that data be collected for the remaining sections over a full performance cycle, especially in view of the shortage of test sections in some experiments when the designs were implemented.

Some of these active test sections have been constructed or rehabilitated within the past decade, some are long-life sections still in good condition, and others have been monitored as LTPP test sections both before and after rehabilitation. Traffic data also continue to be collected on most SPS test sections. Many GPS and SPS sections whose performance cycle monitoring has

been completed have been moved to the GPS-6 (asphalt concrete (AC) overlay of AC pavements) and -7 (AC overlay of PCC pavements) experiments. Some of the experiments were designed to complement each other, for example, GPS-1 and -2 (AC on granular and bound base pavements, respectively) and SPS-1 (structural factors for flexible pavements). GPS-9 (unbonded PCC overlay of PCC pavements) represents the only available long-term data on composite pavement structures and has been given priority due to a request from the Strategic Highway Research Program (SHRP) 2. The LTPP program will continue monitoring these sections to fully answer the critical pavement performance questions they were designed to address.

One future opportunity that merits consideration is to collect permanent distress records for those test sections that remain in service, as recommended by the Transportation Research Board (TRB) LTPP Committee. Table 12.1 outlines the benefits of monitoring active test sections throughout their performance lives.

TABLE 12.1. Importance of completing the long-term monitoring of the original LTPP experiments.

LTPP Experiment	Benefits of Additional Data Collection
SPS-1 (structural factors for flexible pavements) SPS-2 (structural factors for rigid pavements)	Improved ability to derive definitive results, based on complete performance histories, concerning the impact of design features on long-term pavement performance.
SPS-8 (environmental effects in the absence of heavy loads)	Assessment of the effects of loading and environment on pavement life, information that is critical for pavement design and performance models. This work can begin when sufficient distress (serviceability loss) has accumulated on the SPS-8 test sections.
GPS-6 (AC overlay of AC pavements) GPS-7 (AC overlay of PCC pavements) SPS-5 (rehabilitation of AC pavements) SPS-6 (rehabilitation of jointed PCC pavements) SPS-9 (Superpave®)	Improved design, construction, and maintenance procedures for asphalt concrete overlays, which will result in longer and more economical renewed pavement life.
GPS-1 (AC on granular base pavements) GPS-2 (AC on bound base pavements) GPS-3 (jointed plain concrete pavements) GPS-4 (jointed reinforced concrete pavements) GPS-5 (continuously reinforced concrete pavements) GPS-9 (unbonded PCC overlay of PCC pavements)	Performance data required to develop, verify, and calibrate designs for long-life, high-performance pavements and to manage and maintain those new pavements.
Permanent distress records (photographs) for still-active test sections	Future analysts will have the opportunity to revisit test section condition on the basis of objective records. Potential for interpretation/reinterpretation of images based on improved distress definitions and criteria.

Note. Adapted from *LTPP Beyond FY 2009: What Needs to Be Done?*, p. 12.⁷

Conducting Forensic Studies

Another significant source of data for the program are forensic studies at selected LTPP test sections when they are removed from the study. Close examination of these mature sections before they are replaced or rehabilitated can yield new data and analyses that will contribute much to the understanding of pavement deterioration processes.⁸ Although forensic evaluations are an important element in the LTPP program, funding constraints delayed implementation. As described in chapter 7, the program published the *Framework for LTPP Forensic Investigations* in 2004 and conducted four forensic studies, funded by the Federal Highway Administration (FHWA), in 2008. Several highway agencies have also conducted forensic evaluations of LTPP test sections.

Forensic investigation of LTPP test sections that have failed prematurely and sections that have shown unexpectedly good performance are of particular value in understanding the variables that affect pavement performance. With national guidelines in place, the

foundation has been laid for future forensic investigations of LTPP test sections as well as other pavement studies by highway agencies.

Implementing New LTPP Experiments

Alongside the continued monitoring in the original LTPP experiments to achieve the program's original objectives, the program's leaders and advisors recognize that new technologies have been introduced and implemented since the program was planned in the mid-1980s. Some examples are Superpave, the MEPDG, in-place recycling, and alternative construction materials such as aggregates from waste sources, composite materials, precast concrete pavements, and nano particles. In addition, the impact of climate on infrastructure is of increasing importance. The LTPP program is addressing these changing needs in its short- and long-range plans.

In the near term, the foundation has been set for a new LTPP field experiment to collect short-term and long-term research-grade performance data on WMA



pavements. With support from FHWA management and as part of a multiteam effort, this experiment is designed to determine whether there is any significant difference between the performance of WMA and that of HMA. The FHWA is partnering with States and Provinces to construct projects in support of this national experiment. Test section recruitment and selection for the new SPS-10 experiment, Warm-Mix Asphalt Overlay of Asphalt Pavements, began in 2014, with construction slated for 2014 and 2015.⁹

The LTPP WMA experiment will be followed by other new field experiments in the years to come. There is, for example, a real need today to understand pavement preservation and its impact on pavement performance. Planning is underway for a pavement preservation experiment. Planning activities for a cold-in-place recycling experiment will follow next, and other current topics of interest—hot-in-place recycling, composite pavements, precast pavements, and fast-track pavement construction—are being considered. As technologies evolve and are implemented in the field under real conditions, the need to perform long-term monitoring will continue.

CONDUCTING ANALYSES AND DEVELOPING PRODUCTS

Data analysis and product development have been integral to the LTPP program from its early days. Focused analysis has led to many program improvements in data collection practices and interpretation over the years and revealed the need for new software and engineering tools to improve the uniformity and validity of the data being collected. Data analysis and product development will take on even greater importance in the future with the maturity of data collection and the database itself.

New Insights and Understanding Through LTPP Data Analysis

Analysis of LTPP data began in 1992 with the evaluation of the then-current version of the *AASHTO Guide for the Design of Pavement Structures*. That analysis showed large discrepancies between predicted and actual pavement performance, confirming the need

for a new design guide. More recently, LTPP data and data analyses were critical in the development of the MEPDG under NCHRP Project 1-37A. LTPP data analysis reports have been published by SHRP, FHWA, and NCHRP. States, Provinces, and universities have also published hundreds of reports, theses, and dissertations based on the analysis of LTPP data.

FHWA worked with the TRB Expert Task Group on LTPP Data Analysis to develop the Strategic Plan for LTPP Data Analysis in 1999, as described in chapter 10.¹⁰ The plan, which has been expanded and maintained with the support of the TRB LTPP Committee, presents a long-term strategy for data analysis that takes into account both internal and external analytical needs, the current or anticipated data availability, and the process for developing major LTPP products. It may be useful to repeat here the current plan's nine strategic objective areas:

- Traffic characterization and prediction.
- Materials characterization.
- Determination of environmental effects in pavement design and performance prediction.
- Evaluation and use of pavement condition data in pavement management.
- Development of pavement response and performance models applicable to pavement design and performance prediction.
- Maintenance and rehabilitation strategy selection and performance prediction.
- Quantification of the performance impact of specific design features.
- Analyses supporting and enhancing the use of the MEPDG.
- Comprehensive use of LTPP to improve the management of pavement assets.¹¹

By 2014, under the plan, 76 studies had been completed, 18 studies were ongoing, and 13 were planned. An additional 104 problem statements on the plan awaited funding. In addition, the program recommends that early findings from LTPP data be re-examined to determine if the short-term trends were correct. The

LTPP program will support continued data analysis that is aligned with the objectives outlined in the plan.

The greatest benefit from the LTPP database will be realized by applying the data and then developing products from what is learned through this application. To achieve the most immediate impact and capture the full value of the data, a coordinated and integrated approach to analysis will be accompanied by a similarly coordinated product development program.

New Tools and Resources for Pavement Researchers, Practitioners, and Managers

Products resulting from the LTPP data have benefited highway agencies and other segments of the highway community. These products include new methods, guidelines, and procedures for standardized pavement testing and performance data collection. As more pavement performance data are added to the database from the original and new experiments, and if highway legislations continue to be driven by performance and asset management imperatives, the LTPP program will remain in the forefront of providing the data, resources, and technical expertise needed to develop future products for highway agencies and the pavement industry. What these new products will be is still to be determined.

Other significant products of the LTPP program will continue to be issued. The Standard Data Releases are available via the Internet at LTPP's InfoPave™ Web site, so that users can easily access the wealth of information available in the LTPP database. The program's guidelines for data collection and distress rating, such as the *Distress Identification Manual*, will be updated as needed.

Another benefit that will continue into the future is the introduction and use of LTPP data in university engineering curricula. This curricula application will introduce both professors and students to the use of database manipulation tools, which is a necessary skill that is not currently covered in most engineering programs. As in the past, future undergraduate and graduate students will use the LTPP database and monitoring procedures as part of their pavement engineering coursework. Many students will be introduced to the database and to pavement research through the ASCE-LTPP International Data Analysis Contest.

Long-term monitoring of pavement performance continues to be a key need nationwide, just as it was in the 1980s when the LTPP program began. The LTPP processes and database can serve as a springboard to monitoring the long-term performance of new pavement materials and technologies in the future.

The LTPP program has created many products to date, but the most significant products are yet to come, after the full performance history of the test sections has been documented and complete suites of quality data are available in the LTPP database.

POTENTIAL FUTURE INSIGHTS AND BENEFITS

With regard to its ultimate potential, the LTPP program has barely started to advance the knowledge of researchers and practitioners—yet it already has contributed to saving billions of dollars in construction and maintenance costs.¹² Pavement engineers and designers will rely on the LTPP database, a kind of “virtual highway” to improved pavement performance, for decades to come.

Although it is not possible to envision every possible future use and insight, the larger the pool of analysts using LTPP data and other ancillary information, the greater the chances are that the data will support major breakthroughs. Some of the resources that future users may investigate to gain better insight into pavement performance include the following:

- LTPP test sections will be a valuable resource within the States/Provinces, particularly for those looking to support their own performance monitoring programs. Comparing LTPP information to similar data elements collected within the agency (e.g., pavement distress) at the same location will allow

an agency to correlate its own data with LTPP, thereby expanding the utility of its in-house data.

- LTPP test sections will provide national data needed to calibrate current mechanistic-empirical models and the new, improved models that will be developed.
- LTPP pavement deterioration trends can be used by highway agencies that do not have the data or resources to develop their own. These trends are needed for efficient pavement design and management.
- The results from the traffic data analyses, such as investigating the effect of different axle configurations and loading sequences on pavement distress accumulation, can be used to check the validity of MEPDG models and assumptions and to refine future mechanistic-based design procedures.
- Access to materials samples housed at the Materials Reference Library will provide a critical link between field performance and materials properties for new test methods and will support a variety of other materials-related research.
- Detailed surface roughness profiles and distress maps can be used to investigate relationships between roughness development and distress accumulation.
- Future forensic analysis of LTPP test sections will provide valuable information. For example, the LTPP SPS-1 projects (structural factors for flexible pavements) will serve as an excellent source for studying the effect of pavement thickness and the development of top-down versus bottom-up cracking.
- Prediction of remaining pavement life will be improved by revisiting the relationships between pavement response during falling weight deflectometer testing and future pavement performance, and by exploring the use of next-generation embedded self-powered strain sensors to measure continuous strain pulses under actual traffic, combined with damage transfer functions.

In addition, the international community will look to the LTPP program in establishing their own long-term research programs (most recently, Brazil has requested several FHWA visits to discuss how such a program can be implemented there), and other domestic programs, such as the Long-Term Bridge Performance Program, will benefit from LTPP's models of data quality standards and coordination necessary to successfully meet their objectives.

Contributing to National Initiatives

The LTPP program is one of several programs and initiatives that collect or use highway data in planning and policymaking related to different aspects of the Nation's transportation systems. For example, data from the LTPP program complement the data of the Highway Performance Monitoring System, which is used in highway policymaking. The LTPP program is in a position to share knowledge, data, and research facilities with other highway data collection initiatives to assure the availability, reliability, and validity of data used for research into pavement performance measures. Collaboration at this level can maximize budgetary resources and assure that the data secured are of the highest quality possible. The LTPP program will continue working with the highway agencies, AASHTO, and TRB to provide research-quality data that meets the present and future needs of the pavement community.

LTPP AND A FUTURE OF OPPORTUNITY

The LTPP database has enormous potential as the foundation for improvement in pavement engineering and management procedures and practices. Some of that potential has already been realized, but additional work will be required to take full advantage of the investment made in the program.

For the LTPP program, the road ahead is one of opportunity. By continuing to invest in the database and the Materials Reference Library and by continuing to collect data, conduct data analyses, and develop

products, the program will carry forward benefits and rewards for a new generation of highway engineers and researchers facing new challenges. Building on the lessons learned to date is also vital to achieving the program's full potential. While much has been accomplished, the LTPP data still offer the key to even better performing pavements tomorrow. Even as the LTPP data and products change today's pavement design and management worldwide, the LTPP story continues, and the best is yet to be discovered.

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Long-Term Pavement Performance Program Team receives FHWA's Administrator's Excellence in Teamwork Award (November 5, 2010). *Front Row (left to right):* Antonio Nieves (LTPP Product Development), Victor Mendez (then FHWA Administrator), Deborah Walker (LTPP Team Member), Jane Jiang (LTPP Team Member), Jorge Pagán-Ortiz (Director of Office of Infrastructure). *Second Row:* Michael Moravec (LTPP Product Development), Larry Wiser (LTPP Team Member), Aramis López (LTPP Team Leader), Jeff Paniati (FHWA Executive Director), Jack Springer (LTPP Team Member), Eric Weaver (former LTPP Team Member), Michael Trentacoste (Associate Administrator for Research, Development, and Technology).

The picture above shows the LTPP Team members with FHWA management as the team is recognized for its exemplary team spirit in the pursuit of excellence in the LTPP program. Past members of the FHWA-LTPP Team (not shown in the picture) who have contributed to the program are William Bellinger, Charlie Churilla, John Klemunes, Kris Gupta, Cheryl Richter, Shahed Rowshan, Jean Sexton, Monte Symons, and Paul Teng.



Appendix A

Planning and Advisory Committees Supporting the LTPP Program

INTRODUCTION

Well before the LTPP program began in 1987 and continuing into the present, the input of stakeholders and the guidance of experts in the highway community have been critical to the success of the program. This appendix documents to the extent possible some of the committees and expert task groups (ETGs) that have planned the program, guided its implementation, and, through a Data Analysis Working Group (see page 264), helped to promote analysis of LTPP data.

Between 1987 and 1992, when the LTPP program was part of the Strategic Highway Research Program (SHRP), an independent agency of the National Research Council (NRC), LTPP management was guided by an arrangement among the Federal Highway Association (FHWA), American Association of State

Highway and Transportation Officials (AASHTO), and the NRC. The NRC provided formal, external, peer review and advisory support for the LTPP program through an advisory committee assisted by specialized ETGs and subcommittees.^{1,2} When SHRP ended, in 1992, NRC continued to provide these advisory functions through SHRP's sister organization, the Transportation Research Board (TRB), and continues to do so.

Members of the planning and advisory committees and ETGs bring expertise in pavement engineering and performance monitoring, statistics and data analysis, information technology, and other specialized areas associated with the LTPP program's goal and objectives. The members are drawn from highway agency staff, academia, pavement industries, consulting firms, and research institutions from across the United States and Canada. In addition, committee liaisons from AASHTO,

C-SHRP (the Canadian SHRP), FHWA, international agencies, and other organizations provide important linkages. These liaisons are included in the membership lists.

The following sections list, to the extent they are available, the approximate dates the committees and ETGs served, their scopes, and the individuals who have participated during three periods (see sidebar):

- SHRP planning and pre-implementation advisors (circa 1982–86).
- Pavement Performance Advisory Committee (1987–95).
- TRB Long-Term Pavement Performance Committee (1996–present).

The service of some ETGs and many members has spanned these timeframes. Members of the advisory committees and ETGs during these periods are listed below (where known, chairpersons are shown in italics). Please note that these lists are incomplete and undoubtedly contain inaccuracies. Although an extensive search has been conducted, records were not always accessible. Some committees morphed into others, some had very short lifespans, and for some, documentation is no longer available. Any omissions of individuals who have contributed to the program, misattributions, or other errors are unintentional and deeply regretted.

SHRP PLANNING AND PRE-IMPLEMENTATION ADVISORS (1982-86)

The Strategic Transportation Research Study: Highways,³ was one of a series of studies that paved the way for implementation of the SHRP-LTPP program. The study was sponsored by FHWA and carried out by TRB. Additional research planning studies for SHRP were sponsored by the National Cooperative Highway Research Program and, in the case of the long-term pavement performance program, FHWA. These studies culminated in the publication in 1986 of *Strategic Highway Research Program Research Plans: Final Report*,⁴ in which the foundation for the LTPP program was laid. Following are the advisory groups that helped to shape the LTPP program through these pre-implementation studies.

Steering Committee for the Strategic Transportation Research Study: Highways

Duane Berentson	Daniel T. Murphy
Donald W. Collier	William A. Ordway
Francis B. Francois	Richard S. Page
Robert N. Hunter	Bruce H. Pauly
<i>Thomas D. Larson</i>	Daniel Roos
Harold L. Michael	Joseph L. Schofer
Thomas D. Moreland	

LTPP ADVISORY GROUPS/SUPPORTING EXPERT TASK GROUPS FOR EACH TECHNICAL AREA

Planning and Pre-implementation Advisors (1982-86)

- Steering Committee for the Strategic Transportation Research Study: Highways
- SHRP Task Force
- SHRP Advisory Committee, Pavement Performance

Pavement Performance Advisory Committee (1987-95)

- Deflection Testing and Backcalculation
- Equipment Evaluation
- Experimental Design and Analysis
- Automated Distress Identification
- Traffic Data Collection and Analysis

- Weigh-in-Motion Equipment and Technology
- Environmental Data

TRB Long-Term Pavement Performance Committee (1996-present)

- Automated Distress Identification/Distress Data Collection and Analysis
- Data Analysis
- Database Development and Operations
- Materials and Falling Weight Deflectometer Data Collection and Analysis
- Product Development and Delivery
- State Usage of the LTPP Data
- Traffic Data Collection and Analysis
- LTPP Special Activities

Strategic Highway Research Program Task Force

Ray A. Barnhart	Lester P. Lamm
Duane Berentson	<i>Thomas D. Larson</i>
Thomas B. Deen	Harold W. Monroney
Francis B. Francois	Thomas D. Moreland
Mark G. Goode	David K. Phillips
David J. Hensing	Robert J. Reilly
Boris Hryhorczuk	Charley V. Wootan
Robert N. Hunter	

Strategic Highway Research Program Advisory Committee, Pavement Performance

Richard D. Barksdale	William N. Lofroos
<i>Byron Blaschke</i>	Joel Marcuson
Tom Christison	Brooks Nichols
Leland Fletcher	Frank P. Nichols, Jr.
Raymond A. Forsyth	Charles A. Pagen
Dave Gendell	Art Peters
Wade Gramling	Dale Peterson
Kevin Heanue	Roger Petzold
R. G. Hicks	Randell Riley
Ronald W. Houska	Harry A. Smith
W. Ronald Hudson	Dick Sullivan
Paul E. Irick	Shiraz D. Tayabji
Mike Jaskaniec	Harry H. Ulery, Jr.
W. H. Jorgenrud	Fred Van Kirk
Robert Joubert	George B. Way
Roger LeClerc	Thomas D. White
Richard A. Lill	Matthew W. Witzcak

PAVEMENT PERFORMANCE ADVISORY COMMITTEE (1987-95)

Scope

The major objective of the Pavement Performance Advisory Committee (PPAC), which reported to the SHRP Executive Committee,⁵ was to review the LTPP research plans for conformance with the established goal and objectives, for practicality and applicability to the technical needs of the operating highway agencies, and for engineering technological accuracy and feasibility. In addition, the committee was charged with identifying significant highway engineering products emerging from the LTPP studies and assisting the

SHRP Executive Committee in developing priorities and recommendations for implementation.

The committee provided programmatic review and technical commentary on the program objectives, long-range plans, near-term operational activities, and progress of the LTPP research program; conducted external, nongovernmental reviews of research; and identified needs for further research projects. Planning and implementation of the LTPP program were emphasized, but other pavement performance research was also reviewed to identify gaps and overlaps, encourage cooperation, and foster the synthesis of further results. PPAC served from approximately 1987 to November 1995, a period that included the 5-year term of SHRP and the early years of the program under FHWA's management.⁶ Following are the committee members and the ETGs that assisted the committee.

Members

<i>Allan L. Abbott</i>	Frank R. McCullagh
David Albright	Kenneth H. McGhee
Roger Almond	Raymond K. Moore
Richard Barksdale	Richard D. Morgan
James L. Brown	William R. Moyer
Albert J. Bush III	David E. Newcomb
Charles J. Churilla	Louis M. Papet
Robert L. Clevenger	Olga Pendleton
Ronald Collins	Charles A. Pryor, Jr.
Guy Doré	Cesar A. V. Queiroz
Charles E. Dougan	Rolands L. Rizenbergs
Ted R. Ferragut	Gary K. Robinson
McRaney Fulmer	Frederic R. Ross
John P. Hallin	Ted M. Scott II
Neil F. Hawks	Gary D. Taylor
Newton Jackson	T. Paul Teng
Marlin J. Knutson	Marshall R. Thompson
Hans Jorgen Ertman Larsen	Kenneth R. Wardlaw
Rita Leahy	Stella White
William J. MacCreery	Marcus Williams

LTPP Benefits Subcommittee

Scope

This subcommittee was created by PPAC to review the outcomes that have resulted from the LTPP program and how these outcomes can benefit highway agencies

in the design, construction, and maintenance and rehabilitation of their pavements.

Members

Allan L. Abbott	Gary Sharpe
Larry Cole	Carl Monismith
Gary D. Taylor	Ray Moore

Expert Task Group on Deflection Testing and Backcalculation

Scope

The ETG assisted in developing the SHRP backcalculation program by recommending criteria for the selection of software for use in the program, participating in the evaluation of six candidate backcalculation programs, and recommending Poisson's ratio values for use in the backcalculation procedure.^{7,8}

Members

Paul Anderson	Robert L. Mikulin
Robert C. Briggs	Richard J. Nelson
<i>Albert J. Bush III</i>	Larry A. Scofield
Billy G. Connor	Ken Stokoe
William Edwards	Richard N. Stubstad
John Hallin	Marshall R. Thompson
Frank L. Holman, Jr.	Per Ullidtz
William J. Kenis	Jacob Uzan
Roger M. Larson	Wes Yang
Joe P. Mahoney	

Expert Task Group on Equipment Evaluation

Scope

The ETG provided guidance to SHRP staff on monitoring equipment used to collect pavement performance data for network- and project-level pavement management.

Members

Robert C. Briggs	Rudolph R. Hegmon
James K. Cable	P. G. Jordan
Gaylord Cumberledge	Robert McQuiston
Harold Dalrymple	Kenneth H. McGhee
Leo DeFrain	Anand Prakash
Bob Guinn	Gerry Wrong
James P. Hall	William A. Young
Sonya Hill	

Expert Task Group on Experimental Design and Analysis

Scope

The ETG provided guidance to SHRP staff, consultants, and LTPP regional staff in the overall design of the experiments in the General Pavement Studies and Specific Pavement Studies by evaluating the analysis plans and recommending specific changes in the experiments. The ETG periodically reviewed the analysis procedures over the course of the studies, together with the SHRP Data Analysis Working Group, PPAC, SHRP staff, and technical contract staff.

Members

Paul E. Benson	Roger M. Larson
James L. Brown	Richard A. Lill
Lyle Calvin	Joe P. Mahoney
Samuel G. Carmer	Michael Markow
Judith B. Corley-Lay	Robert L. Mason
Morris de Groot	John R. Olds
John P. Hallin	William D. O. Paterson
Newton Jackson	James A. Sherwood
Alex Kazakov	Marshall Thompson
Walter P. Kilareski	Richard M. Weed

Expert Task Group on LTPP Automated Distress Identification

Scope

The ETG provided assistance to SHRP in its effort to evaluate pavement distress on LTPP test sections and to suggest mechanisms for implementation at the State level. This ETG played a key role in the development of the SHRP *Distress Identification Manual*, which is one of the LTPP program's most highly used products.

Members

Janice Arellano	Loren Hill
Michael E. Ayers	Colleen Kissane
Carl Bertrand	Donald Larsen
<i>James K. Cable</i>	Charles Larson
Lawrence W. Cole	Daris Ormesher
Gaylord Cumberledge	Joy Portera
Jon A. Epps	Richard B. Rogers
Tahar El-Korchi	Brian Schleppe
Roger Green	Shelley M. Stoffels
Wouter Gulden	James Walls III
Kent Hansen	Shie-Shin Wu

Expert Task Group on LTPP Traffic Data Collection and Analysis

Scope

The ETG provided guidance to SHRP staff, consultants, and LTPP regional staff for the traffic data collection program. The Traffic ETG played an active role in the program and was instrumental in several decisions regarding traffic and data collection requirements, site-specific data collection, database needs, weigh-in-motion requirements, guidelines in traffic variability and precisions, equivalent single-axle load calculations, traffic data analysis, and adoption of the FHWA vehicle classification system.^{9,10}

Members

David Albright	William Lofroos
Wiley Cunagin	Bill McCall
Curtis Dahlin	George Novenski
Ralph E. Folsom	Alan Pisarski
Jerry J. Hajek	Larry Schoenhard
John Hamrick	Ronald Tweedie
Andrew Horosko	George Wass
Bruce Hutchison	Richard Weed
Ed Kashuba	

Expert Task Group on Weigh-in-Motion Equipment and Technology

Scope

The Weigh-in-Motion Equipment and Technology ETG was charged with determining the availability, uses, cost, and accuracy of equipment to fulfill the needs of the LTPP program to measure load on the pavement test sections.¹¹

Members

Lloyd Henion	John Van Berkel
Perry Kent	Doug Warpoole
Billy M. McCall	John Wyman
Tom Neukam	

Expert Task Group on Environmental Data

Scope

The ETG assisted SHRP in the development of the climatic database, advising on the establishment of on-site weather stations to complement the “virtual” weather stations, the retention of both raw and com-

posite climatic data obtained from the Canadian and U.S. weather services, data elements to be included, and the algorithm for deriving site-specific estimates from the climatic data.^{12,13}

Members

Richard L. Berge	John Griffith
Tom Christison	David W. Phillips
Walter Dabberdt	Eugene Rasmusson
Barry J. Dempsey	

LONG-TERM PAVEMENT PERFORMANCE COMMITTEE (1996-PRESENT)

The FHWA contracted with TRB for provision of formal peer review regarding LTPP program matters. This contract has been renewed periodically and supports the continuation of the advisory committee, renamed the Long-Term Pavement Performance Committee (currently referred to as the LTPP Committee or LCOM), and its ETGs. The committee is appointed by, and acts through, the NRC.

Scope

The role of the TRB LTPP Committee is to advise FHWA and AASHTO on the planning, implementation, and development and delivery of products of the LTPP studies. The committee also prepares reports, including letter reports, containing its “evaluations and suggested mechanisms to enhance the utility to the States of the studies’ outcomes.”¹⁴

Traditionally, individuals who are actively employed by highway agencies in the United States and Canada have occupied slightly more than half of the Committee’s membership seats, and one of these State appointees has served as chairperson. Participation in the development of the Committee’s advice to FHWA and AASHTO on the plans, operations, and accomplishments of the LTPP program affords the States and Provinces the opportunity to affect the future of this research program in which they are heavily invested.

Currently, the LTPP Committee is a TRB Policy Study Committee that meets regularly to receive reports from the LTPP program staff, deliberate, and develop recommendations regarding current and

future activities related to the conduct and operation of the program. All members are required to comply with the conflict of interest and bias disclosure procedures of the NRC of the National Academies. Since 1997, the committee has submitted its findings to FHWA and AASHTO in the form of a formal review letter. The review letters are archived and available at the TRB Web site.¹⁵ At various times, the LTPP Committee has formed subcommittees to address specific issues, such as the Subcommittee on Program Improvement (March 1997 to March 1999). The committee also sponsors the LTPP State Coordinators' meetings and semi-annual meetings of the TRB Data Analysis Working Group.¹⁶

The TRB LTPP Committee has served since August 1996. In 2006, however, the size of the committee and the number of ETGs were trimmed back, reflecting a reduction in LTPP activities and TRB funding.¹⁷ The ETGs are described separately for the periods before and after 2006.

Members

<i>Allan L. Abbott</i>	<i>Victor M. Mendez</i>
Roger Almond	Carl L. Monismith
Michael E. Ayers	Raymond K. Moore
<i>Thomas E. Baker</i>	Richard D. Morgan
Gary S. Carver	Carol A. Murray
Charles J. Churilla	David E. Newcomb
Lawrence W. Cole	Olga J. Pendleton
R. Ronald Collins	Charles A. Pryor, Jr.
Judith B. Corley-Lay	Robert Raab
Dale S. Decker	Frederick R. Ross
Charles E. Dougan	Robert L. Sack
Theodore R. Ferragut	Larry A. Scofield
Donald H. Freeman	Ted M. Scott II
Ralph C. G. Haas	Gary W. Sharpe
Amir Hanna	Richard K. Smutzer
Neil F. Hawks	Monte Symons
Gary L. Hoffman	A. Haleem Tahir
John R. Hosang	Gary D. Taylor
Patricia S. Hu	<i>William H. Temple</i>
Randell H. Iwasaki	Robert Walters
Henry G. R. Kerali	C. Michael Walton
Russel W. Lenz	Kenneth I. Warren
Joseph M. Leonardo	Sarah Wells
Aramis López	Gary C. Whited
William J. MacCreery	James McFarland Yowell
Jim McDonnell	

TRB LTPP Committee Expert Task Groups, 1996-2006

Expert Task Group on LTPP Automated Distress Identification / Distress Data Collection and Analysis

Scope

The ETG on LTPP Automated Distress Identification advised FHWA on planning and implementation of the collection and processing of 35-mm photographic records of pavement distress at LTPP test sections. The ETG provided advice intended to help solve operational problems with this activity; enhance the productivity of recording, identifying, and extracting the distress data; and assuring that the results addressed high-priority needs of State highway departments. Specific areas of activity included (1) programmatic review of the automated distress identification project's objectives, priorities, and work plans; (2) technical assessment of ongoing work; (3) project-wide and task-specific progress assessment; and (4) recommendations to enhance project success.

The ETG's members were selected for their expertise with equipment and methods used for automated recording of visual images of pavement surfaces and extraction from these records of distress data suitable for analysis of pavement performance, and for their experience in pavement engineering, statistics, and data analysis.

In 1999, at the ETG's request, the LTPP Committee broadened the scope of this ETG and changed its name to the ETG on LTPP Distress Data Collection and Analysis. Although the ETG would continue to focus on automated identification of distress, its charge was widened to include "all aspects of collecting, processing, and uploading in the LTPP database data quantifying the type and extent of distress experienced by LTPP's test sections."¹⁸ The ETG served from July 1996 until November 2005.

Members

Janice Arellano	Loren Hill
Michael E. Ayers	Colleen A. Kissane
William Bellinger	Donald Larsen
Carl Bertrand	Charles Larson
<i>James K. Cable</i>	Daris Ormesher

Lawrence W. Cole	Joy F. Portera
Gaylord Cumberledge	Robert Raab
Tahar El-Korchi	Richard B. Rogers
Jon A. Epps	Brian Schleppe
Roger Green	Shelley M. Stoffels
Wouter Gulden	James Walls III
Kent Hansen	Shie-Shin Wu

Expert Task Group on LTPP Data Analysis

Scope

The ETG on LTPP Data Analysis was organized to advise FHWA on matters related to the development, through analysis of LTPP data, of research products that are needed and will be used immediately by State highway agencies. Specific areas of activity include (1) development and prioritization of data analysis objectives; (2) technical assessment of work plans for specific analysis projects; (3) technical review and advice regarding ongoing analytical efforts; (4) program-wide and project-specific progress assessment; (5) participation in periodic assessment and update of the LTPP Data Analysis Plan; (6) technical review of LTPP data analysis reports; and (7) referral of data analysis products to the LTPP Implementation Technical Working Group.¹⁹ Members were selected for their technical expertise in the analysis of pavement performance data and experience in pavement engineering, statistics, and data analysis.

Members

<i>Paul E. Benson</i>	Michael Murphy
Lawrence Cole	Neville Parker
<i>Judith B. Corley-Lay</i>	Linda Pierce
Guy Doré	Patricia Polish
Marc Eijbersen	Robert Raab
Steve Goodman	Cheryl A. Richter
Eric Harm	Susan L. Tighe
Lynne Irwin	Julie M. Vandenbossche
Heikki Jamsa	William Vischer
Andrew M. Johnson	James Walls
Henry Kerali	Randy West
Bill Maupin	Thomas White
Karen McClure	Larry Wiser
Raymond K. Moore	Wes Yang

Expert Task Group on LTPP Database Development and Operations

Scope

The ETG provided advice to the LTPP Committee and FHWA on (1) the further development of the LTPP database including the refinement of existing data tables and the addition of new data tables, including “computed parameters” tables and tables for data currently stored offline; (2) the further development of tools (such as the DataPave software, or Web-enabled versions of the database) for improving the accessibility of the LTPP data; (3) priorities, plans, and options for improving the accessibility of LTPP data not currently included in the LTPP database that may be of interest and value to users of the LTPP data; (4) plans for long-term maintenance and operation of the LTPP database; and (5) storage and dissemination of offline data following the sunset of the LTPP research program. Members were familiar with pavement performance data, data analysis, information technology, the fundamentals of relational databases, and the LTPP database.

The ETG’s purview included review of planning, implementation, and progress of LTPP database activities and advice regarding operational problems. Together with the TRB LTPP Committee, its other ETGs, and the Subcommittee on LTPP Product Development and Delivery, this ETG oversaw the planning and progress of LTPP projects to assure that their outcomes would lead to products addressing the high-priority pavement-related needs of State highway departments. The ETG served from October 2002 until November 2005.

Members

Roger L. Green	Deborah Walker
Leonnice Kavanagh	Eric Weaver
David P. Orr	John R. Weaver
Robert Raab	Benjamin Worel
Shelley M. Stoffels	

Expert Task Group on LTPP Materials Data Collection and Analysis/Falling Weight Deflectometer Data Collection and Analysis

Scope

The ETG reviewed and advised the TRB LTPP Committee on matters relating to the collection, processing, and uploading materials properties data in the LTPP database. Established by the TRB LTPP Committee in 1999 because of the high level of materials data issues being brought to the attention of the Automated Distress Identification ETG, the new ETG addressed materials-related questions such as the robustness of techniques for backcalculation of resilient modulus from nondestructive testing, the repeatability of laboratory testing of resilient modulus, the precision and bias of resilient modulus testing, and the pros and cons of resilient modulus versus dynamic modulus. The scope of this ETG later expanded to include the review and analysis of falling weight deflectometer data. Thus, the name changed to Expert Task Group on Materials and Falling Weight Deflectometer Data Collection and Analysis. The ETG served from December 1999 until October 2006.

Members

Ahmad Ardani	Rebecca S. McDaniel
Thomas Baker	Samuel Miller
Ramon Bonaquist	David Newcomb
Bruce Dietrich	Robert Raab
Jon Epps	Stephen Shober
Michael A. Heitzman	Jack Springer
Said Kass	A. Haleem Tahir
Richard Kim	Marshall Thompson
Mark McDaniel	

Expert Task Group on Product Development and Delivery

Scope

The ETG provided technical advice to the TRB LTPP Committee on matters related to identification of LTPP products, the efforts to develop these products, and the plans to deliver these products to the State highway agencies. The ETG's advice helped solve operational problems encountered in these activities, enhanced the productivity of the LTPP program, and assured that the program's results address the high-priority needs of the States. Members included several members of the TRB

LTPP Committee and other individuals who are well acquainted with the potential of the LTPP program to generate products of value to the highway community, including representatives of State transportation departments, transportation technology associations, consulting engineering firms, and universities. The ETG served from August 1999 to October 2003.

Members

James K. Cable	A. Haleem Tahir
Ewa Flom	Gary D. Taylor
Antonio Nieves	Robert Raab
Michael Moravec	Monte Symons
Charles A. Pryor, Jr.	Bing Wong
Larry A. Scofield	

Expert Task Group on State Usage of the LTPP Data

Scope

The ETG on State Usage of the LTPP Data provided advice to the FHWA and AASHTO on the unique needs of State departments of transportation (DOT) regarding access to and use of data residing in the LTPP database. Activities of this committee included (1) evaluation of database users' service procedures, (2) evaluation of database user guides and other documentation, (3) evaluation of specific data delivery formats to afford ease of use, and (4) appraisal of the capacity of State DOTs to use LTPP data in DOT-staffed research and management activities.

Members

Judith Corley-Lay	Jamshid Armaghani
Andrew Johnson	John Hallin
Ben Worel	Linda Pierce
Danny Dawood	Robert Raab
Gary Sharpe	Shakir Shatnawi
George Cochran	Wes Yang
Guy Doré	

Expert Task Group on Traffic Data Collection and Analysis

Scope

The ETG advised the TRB LTPP Committee, FHWA, and AASHTO on matters related to collection, processing, uploading in the LTPP database, and analysis of

traffic data collected at LTPP test sites in the United States and Canada. The ETG provided comments and advice intended to help solve operational problems encountered in these activities. The work of the ETG was to facilitate the accumulation in the LTPP database of high-quality traffic data in quantities sufficient to support LTPP analysis projects. These projects are designed to produce outcomes that lead to products addressing the high-priority pavement-related needs of State/Province highway departments. The work of the ETG also included reviewing those parts of the plans, activities, and progress of the LTPP program's data analysis and product development activities that pertain to the use of LTPP traffic data, and reporting its findings and suggestions to the TRB LTPP Committee. The ETG served from 1992 to 2013.

Members

Allan L. Abbott	<i>Anne-Marie McDonnell</i>
David Albright	Andrew Nichols
<i>David Cebon</i>	George Novenski
Wiley Cunagin	Olga Pendleton
Curtis Dahlin	Alan Pisarski
Ralph E. Folsom	Richard Quinley
Ralph Gillmann	Robert Raab
Kris Gupta	Richard L. Reel, Jr.
Ed Green	Richard Rogers
Jerry J. Hajek	Larry Schoenhard
John Hamrick	<i>Larry A. Scofield</i>
Andrew Horosko	Elizabeth Stolz
Patricia S. Hu	Ronald Tweedie
Bruce Hutchinson	John Van Berkel
Frank Jarema	Deborah Walker
Steven Jessberger	George Wass
Ed Kashuba	John Weaver
James Kramer	Richard Weed
Catherine T. Lawson	Larry Wisner
William Lofroos	Clyde Woodle
Bill McCall	

TRB LTPP Committee Expert Task Groups, 2006-2013

In 2006, as a result of budget constraints imposed on the LTPP program, the number of ETGs providing support to the TRB LTPP Committee was reduced to two: the TRB ETG on LTPP Traffic Data Collection and

Analysis continued to provide the same functions as it had since 1992, and a multipurpose ETG on LTPP Special Activities was created to encompass many of the functions of the ETGs that were discontinued. Thus, between 2006 and 2013, the TRB LTPP Committee, with the support of the Traffic Data and Special Activities ETGs, provided the formal peer review functions for all LTPP-related activities. In 2013, the Traffic Data ETG was retired and its remaining responsibilities were folded into those of the Special Activities ETG.

Expert Task Group on LTPP Special Activities

Scope

The Special Activities ETG, referred to as LSPEC, advises the TRB LTPP Committee on matters related to collection, processing, uploading into the LTPP database, and analysis of all data, including traffic data as of 2013, that have been recorded at or determined from samples collected at LTPP test sites. The work of the ETG facilitates the accumulation in the LTPP database of high-quality data in quantities sufficient to support LTPP analysis projects. These projects were designed to produce outcomes addressing the high-priority, pavement-related needs of State highway agencies. The ETG's scope of work includes reviewing the plans, activities, and progress of various aspects of the LTPP studies, including materials data collection and analysis, distress and profile data collection and analysis, data analysis, product development and delivery, and database development and operations.

Members

<i>James K. Cable</i>	Robert Raab
Judith B. Corley-Lay	Richard L. Reel, Jr.
Tahar El-Korchi	Jack Springer
Michael Alan Heitzman	Shelley M. Stoffels
Yan "Jane" Jiang	Gary D. Taylor
Andrew M. Johnson	Susan L. Tighe
Catherine T. Lawson	Deborah Walker
Aramis López	Larry Wisner
<i>Rebecca S. McDaniel</i>	Benjamin James Worel
David P. Orr	Wei-Shih Yang

Expert Task Group on LTPP Traffic Data Collection and Analysis (see 1996-2006 ETG section above; retired in 2013)

DATA ANALYSIS WORKING GROUP

First DAWG Agenda

LTPP DATA ANALYSIS WORKING GROUP MEETING
JANUARY 16, 1992
SUITE 2023
SHERATON WASHINGTON HOTEL

1:00-1:10	Opening Remarks	Neil Hawks, Robert Raab
1:10-1:20	P-020a - Flexible Pavement Status	Brent Raahut
1:20-1:30	P-020a - Rigid Pavement Status	Mike Darter
1:30-1:50	P-020a Status	Olga Pendleton
1:50-2:00	DAWG Action Item Status	Brent Raahut
2:00-2:20	Contending With Zero Distress Data	Olga Pendleton
2:20-4:00	Brainstorming on Clustering of Terms and Equation Forms in Pavement Performance Models	Brent Raahut, Mike Darter
4:00-4:20	Statistical Remarks on the SHRP Long-Term Pavement Performance Studies	Tony Lawrence
4:20-4:40	UK Data Analysis Findings	Henry Kerali
4:40-5:00	Status of Other Data Analysis Activities	(TBD)
5:00-6:00	Break - Informal Discussion	
6:00-	Continuation of DAWG Meeting at Dinner	

Created under the Pavement Performance Advisory Committee in the early 1990s and still supported by the LTPP Committee, the TRB Data Analysis Working Group (DAWG) provides a continuing forum for discussion of methods of analysis of pavement performance data. The first DAWG meeting was held in January 1992 at the Annual TRB Meeting. Presentations at DAWG meetings emphasize the development of techniques for extracting and analyzing data, results of model building, and development of transfer functions linking structural response to distress. The usual DAWG meeting has a minimum of formality to encourage open discussion and minimize the time between preparation and dissemination of analytical results. DAWG meetings are held twice each year: immediately preceding the TRB Annual Meeting in Washington in January, and approximately at the midyear at another location in conjunction with a major conference that DAWG members are likely to attend in large numbers.

Members

Gabriel Assaf	Ahmed Samy Nouredin
Harold Augustin	Emmanuel Owusu-Antwi
Gilbert Baladi	A. Thomas Papagiannakis
Paul Benson	William D. O. Paterson
Allesandra Bianchini	Olga J. Pendleton
Karim Chatti	John F. Potter
Charles Copeland	Jorge A. Prozzi
Brian Cox	Robert Raab
Michael Darter	Brent Raahut
Jerome Daleiden	James Rosenberger
Gianluca Dell'Acqua	Shahed Rowshan
A. G. Dumont	Luis de Picado Santos
Brian Walter Ferne	James Sherwood
William O. Hadley	Gordon Sparks
Amir Hanna	Mate Sršen
Neil F. Hawks	Wynand Jacobus van der Merwe Steyn
Heikki Jämsä	Govert Sweere
Keizo Kamiya	Rafiqul Alam Tarefder
Henry Kerali	Shiraz Tayabji
Anthony Lawrence	Paul Teng
Bojan Leben	Thorkild Thurmann-Moe
Johann Litzka	Francesca La Torre
Kang-Won Wayne Lee	Waheed Uddin
Robert Lytton	Gerhard Van Blerk
James William Maina	Larry Wiser
Robert Mason	Haifang Wen
Louay N. Mohammad	Greg Williams
Jostein Myre	
Athanassios Fotios Nikolaidis	

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SOLICITATION, OFFER AND AWARD

2. CONTRACT NUMBER

3. SOLICITATION NUMBER

1. THIS CONTRACT IS A RATED ORDER UNDER DPAS (15 CFR 700)

RATING

7. ISSUED BY

CODE

4. TYPE OF SOLICITATION
 SEALED BID (IFB)
 NEGOTIATED (RFP)

5. DATE ISSUED

6. REQUIS

8. ADDRESS OFFER TO (If other than item 7)

NOTE: In sealed bid solicitations "offer" and "offeror" mean "bid" and "bidder".

9. Sealed offers in original and hand carried, in the depository located in _____ copies for furnishings the supplies or services in the Schedule will be received at the place specified in _____

SOLICITATION

CAUTION - LATE Submissions, Modifications, and Withdrawals: See Section L, Provision No. 52.214-7 or 52.215-1. All offers are subject to all terms and conditions contained in this solicitation.

10. FOR INFORMATION CALL:

A. NAME

B. TELEPHONE (NO COLLECT CALLS)
 AREA CODE NUMBER EXTENSION

C. E-MAIL ADDRESS

(X) SEC.

DESCRIPTION

11. TABLE OF CONTENTS

(X)	SEC.	DESCRIPTION	PAGE(S)	(X)	SEC.	DESCRIPTION
	A	SOLICITATION/CONTRACT FORM				PART I - THE SCHEDULE
	B	SUPPLIES OR SERVICES AND PRICES/COSTS				PART II - CONTRACT CLAUSES
	C	DESCRIPTION/SPECS./WORK STATEMENT				PART III - LIST OF DOCUMENTS, EXHIBITS AND OTHER
	D	PACKAGING AND MARKING				PART IV - REPRESENTATIONS AND INSTRUCTION
	E	INSPECTION AND ACCEPTANCE				STATEMENTS OF OFFERORS
	F	DELIVERIES OR PERFORMANCE				INSTRUCTIONS, CONDITIONS, AND NOTICES TO OFFER
	G	CONTRACT ADMINISTRATION DATA				EVALUATION FACTORS FOR AWARD
	H	SPECIAL CONTRACT REQUIREMENTS				

OFFER (Must be fully completed by offeror)

NOTE: Item 12 does not apply if the solicitation includes the provisions at 52.214-16, Minimum Bid Acceptance Period.

12. In compliance with the above, the undersigned agrees, if this offer is accepted within _____ calendar days (60 calendar days unless a different period is inserted by the offeror) from the date for receipt of offers specified above, to furnish any or all items upon which prices are offered at the set opposite each item, delivered at the designated point(s), within the time specified in the schedule.

13. DISCOUNT FOR PROMPT PAYMENT (See Section I, Clause No. 52.232-8)

14. ACKNOWLEDGMENT OF AMENDMENTS (The offeror acknowledges receipt of amendments to the SOLICITATION for offerors and related documents numbered and dated):

10 CALENDAR DAYS (%)	20 CALENDAR DAYS (%)	30 CALENDAR DAYS (%)	CALENDAR
AMENDMENT NO.	DATE	AMENDMENT NO.	DATE

15A. NAME AND ADDRESS OF OFFEROR

CODE

FACILITY

16. NAME AND THE TITLE OF PERSON AUTHORIZED TO SIGN (Type or print)

15B. TELEPHONE NUMBER
 AREA CODE NUMBER EXTENSION

15C. CHECK IF REMITTANCE ADDRESS IS DIFFERENT FROM ABOVE - ENTER SUCH ADDRESS IN SCHEDULE.

17. SIGNATURE

18. OFFER DA

19. ACCEPTED AS TO ITEMS NUMBERED

AWARD (To be completed by Government)

20. AMOUNT

22. AUTHORITY FOR USING OTHER THAN FULL OPEN COMPETITION:
 10 U.S.C. 2304 (c) 41 U.S.C. 3304(a) ()

21. ACCOUNTING AND APPROPRIATION

24. ADMINISTERED BY (If other than item 7)

23. SUBMIT INVOICES TO ADDRESS SHOWN IN (4 copies unless otherwise specified)

25. PAYMENT WILL BE MADE BY

CODE

ITEM

26. NAME OF CONTRACTING OFFICER (Type or print)

27. UNITED STATES OF AMERICA

(Signature of Contracting Officer)

28. AWARD DATE

IMPORTANT - Award will be made on this Form, or on Standard Form 28, or by other authorized official written notice. Previous edition is unusable

AWARD/CONTRACT

2. CONTRACT (Proc. Inst. Ident.) NO.

5. ISSUED BY

7. NAME AND ADDRESS OF CONTRACT

CODE

11. SHIP TO/MARK FOR

13. AUTHORITY FOR

10 U.S.C. 2304

15A. ITEM NO.

(X) S

Identify rights and obligations, the following documents: (1) provisions, representations, certifications, incorporated by reference herein. (Attach) AND TITLE OF SIGNER (Type or Print)

Appendix B

Contract Services Acquired to Operate the LTPP Program

INTRODUCTION

The LTPP program relies upon technical, scientific, and management expertise in the private sector to carry out different aspects of its mission. Under the program's leadership, contractors provide the skilled personnel needed to implement a research program of this magnitude. Contractual relationships with engineering and consulting firms, testing laboratories, and equipment manufacturers have been essential in planning the program's experiments, managing the collection and quality assurance of the data, building the program's Information Management System (IMS), conducting analyses, and producing results.

This appendix lists briefly the key contracts that have been instrumental in achieving the program's objectives and acknowledges many of the firms that

have contributed to the LTPP program. The list is not comprehensive, and many equipment, instrumentation, and data analysis contract services used by the program may not be described below due to the difficulty of retrieving historical information. Contracts in place under the leadership of both the Strategic Highway Research Program (SHRP) between 1987 and 1992 and the Federal Highway Administration (FHWA) from 1992 through the present are listed. More detail on the types of activities carried out by some of the contracts listed below is provided in chapter 2.

PEER REVIEW CONTRACTS

During the transition of the LTPP program from SHRP to FHWA, a 15-month contract with the National

Research Council, National Academies, continued the services of the Pavement Performance Advisory Committee, its supporting expert task groups, and the LTPP regional engineers. The contract also assigned responsibility for the international coordination activities associated with the Transportation Research Board (TRB) annual meeting to FHWA. Later, the services of the LTPP regional engineers were included in the technical support services contract. After this transitional period, FHWA contracted with TRB to continue advisory services to the LTPP program, and the committee was renamed the LTPP Committee. This contract has been modified and renewed periodically. The National Research Council has been the primary conduit for peer exchanges among the LTPP Team, its senior management, and the program's stakeholders and partners. Appendix A provides a detailed description of the advisory committees and expert task groups.

TECHNICAL SUPPORT CONTRACTS

Objective

The original objective for this contract during the SHRP management years was to provide the technical and management services needed to develop and conduct the LTPP studies and to build and maintain the LTPP database. These same services and more have been required during the FHWA management years. In particular, from 1992 until 2002, the services of the LTPP regional engineers were included in the contract. In 1997, the development, refinement, and assessment of traffic data collection activities were added. The contract also provided customer support services until 2006, when this function was transferred to the LTPP Team and its onsite General Administration Support contractor. The technical support contract, however, continues to provide support, as needed, for customer-related data requests and information.

SHRP-LTPP Contractor

Texas Research and Development Foundation (prime)/
University of Texas Center for Transportation
Research/Pavement Consultancy Services, Inc.

FHWA-LTPP Contractors

Pavement Consultancy Services (prime), later acquired by
LAW Engineering; LAW later acquired by MACTEC
Engineering and Consulting, Inc.; MACTEC later
acquired by AMEC Environment & Infrastructure,
Inc./Science Applications International Corporation/
Soil and Materials Engineers, Inc.

REGIONAL SUPPORT CONTRACTS

Objective

The objective for these contracts during SHRP management and now under FHWA management is to implement consistent data collection, data processing, and data quality activities to support the LTPP program objectives for test sections across each of the four LTPP geographical boundaries: North Atlantic, North Central, Southern, and Western Regions. The contract services also require close coordination with the highway agencies to carry out these primary activities.

In each region, an LTPP engineer was assigned to oversee the daily operations of the regional staff. These regional engineers were employees of SHRP, and later FHWA continued their services through a mix of contractual and employment arrangements. Ivan Pecnik (North Atlantic Region), Dick Ingberg (North Central Region), Homer Wheeler and Morris Reinhardt (Southern Region), and Calvin Berge (Western Region) all served in this capacity until they retired or the regional engineer staffing was ended in 2002.

SHRP-LTPP Contractors

Pavement Management Systems, Ltd. (prime)/
Austin Research Engineers, Inc. (LTPP North
Atlantic Region)
Braun Pavement Technology (prime)/Soil and
Materials Engineers (LTPP North Central Region)
Brent Rauhut Engineering, Inc. (LTPP Southern Region)
Austin Research Engineers, Inc. (LTPP Western Region)
Nichols Consulting Engineers, Chtd. (LTPP Western
Region)

FHWA-LTPP Contractors

Pavement Management Systems, Ltd., later acquired by Stantec (LTPP North Atlantic Region)
Braun Pavement Technology (prime)/Soil and Materials Engineers (LTPP North Central Region)
ERES Consultants (LTPP North Central Region)
Stantec (LTPP North Central Region)
Brent Rauhut Engineering, Inc., later acquired by Fugro Consultants; Fugro now Fugro Roadware (LTPP Southern Region)
Nichols Consulting Engineers, Chtd. (LTPP Western Region)

GENERAL ADMINISTRATION SUPPORT CONTRACTS

Objective

To accomplish the program objective, this contract provides onsite engineering and technical support services to the LTPP program manager at FHWA's Turner-Fairbank Highway Research Center. The services under the contract include technical support activities such as teaching the LTPP distress workshops; updating and maintaining the Data Analysis/Operations Feedback Report activities; maintaining the LTPP program documents and files, publications, Reference Library, Strategic Plan for LTPP Data Analysis, Web page, and mailing and email distribution lists; assisting in drafting and reviewing the LTPP newsletter; working at the LTPP exhibit booth at the TRB Annual Meeting and other conferences; and more recently, in 2006, handling all data and information requests from users sent to the LTPP Customer Support Service Center. This type of contract did not exist under SHRP management.

FHWA-LTPP Contractors

EBA Engineering, Inc.
LENDIS Corporation
ECOMPEX
Engineering & Software Consultants, Inc. (ESCINC)

DATA COLLECTION EQUIPMENT CONTRACTS

The equipment and instrumentation contracts provide the engineering and technical support services needed to collect the various types of data at the LTPP test sections. The contract services during the SHRP management years focused on developing, testing, and establishing standard protocols for the equipment used to collect the pavement data. In the early years of the LTPP program, some of the data collection equipment simply did not exist, and the contractors selected played a major role in developing the first-generation data collection equipment used by the program. The LTPP program has raised the bar for collecting quality data which has encouraged industry to improve not only how they collect the data, but also how they manufacture the equipment used to collect the data. As a result, many equipment manufacturers and vendors have changed their practices and are continually improving their technology, when necessary. With the passing of time, technology has improved, providing FHWA management more equipment options from which to choose.

The services provided by the many equipment manufacturers and vendors over three decades are too numerous to discuss in this appendix, but those relating to major data collection efforts are briefly described.

Photographic Pavement Distress Contract

Objective

The services provided under this contract were to perform periodic surface distress surveys using continuous 35-mm black-and-white photography for the purpose of obtaining a permanent historical record of the pavement condition over the full length and width of the LTPP test sections, and to interpret the distress data (type, severity, and quantity) from these photographic records. To achieve this, survey vehicles operated at highway speeds and all surveys were done at night under controlled, artificial lighting. The reduction of distress data from the film was done in the office using a software and film-handling system, which consisted of a computer, a film transport device with a digitizing tablet for viewing and digitizing images from the 35-mm films, a printer for preparing reports, and

an inkjet plotter for producing color distress maps. The actual film interpretation was comparable to performing a typical manual distress survey; that is, the type, amount, and severity of the distresses existing in the test section were observed and recorded.¹

Contractor

PASCO USA was the contractor under both SHRP and FHWA management. The company later sold their North American rights and equipment to Cumberlandledge, Gramling and Hunt, which was later acquired by Applied Research Associates, Inc.

Falling Weight Deflectometer Contract

Objective

The services required under this contract are to provide new falling weight deflectometer (FWD) systems or to refurbish existing systems to perform structural evaluation of the LTPP test sections, calibration, scheduled and unscheduled maintenance and repair; provide replacement parts; and provide updated software, training, and technical support to the LTPP regional FWD operators. The contract agreements have provided either complete overhaul of the FWD units used by the LTPP program or complete replacement of the units.

Contractor

Dynatest USA was the contractor under SHRP management and has continued under FHWA management.

Falling Weight Deflectometer Calibration Center and Operational Improvements Contract

Objective

The objective of this contract was to upgrade the existing FWD calibration system hardware and software to take advantage of improvements in technology. These upgrades would make calibration sustainable for the next decade without a loss of quality while ensuring that any new procedures are compatible with all brands of FWDs sold in the United States. The contract also provided a plan for permanent support of the four LTPP calibration centers through the American Association of State Highway and Transportation Officials (AASHTO) Materials Reference Laboratory. This contract did not exist under SHRP management.

FHWA-LTPP Contractor

Cornell Local Roads Program, Cornell University

Inertial Road Profiling Contracts

Objective

The services required under this contract are to provide noncontact inertial road profiling equipment capable of measuring and recording the road surface profile in both wheelpaths at normal highway speed, perform scheduled and unscheduled maintenance and repair, and provide training and technical support to the LTPP regional profiler operators. Later, under FHWA management, the latest profiler units were also equipped to collect pavement macrotexture data and ambient and surface temperatures with Global Positioning System coordinates.

SHRP-LTPP Contractor

K. J. Law

FHWA-LTPP Contractors

K. J. Law

International Cybernetics Corporation
Ames Engineering, Inc.

TRAFFIC DATA COLLECTION CONTRACTS

Objective

Traffic data collection contracts awarded by FHWA in the early 2000s address the missing traffic data at the Specific Pavement Study (SPS) -1 (structural factors for flexible pavements), -2 (structural factors for rigid pavements), -5 (rehabilitation of asphalt concrete pavements), and -6 (rehabilitation of jointed Portland cement concrete pavements) projects. Funding limitations restricted the LTPP program from collecting quality, monitored traffic data at the SPS-8 (environmental factors in the absence of heavy loads) projects which were included in the original data collection plan (see chapter 7).

The contractual services provide a central mechanism to ensure that the traffic data collection equipment is routinely calibrated, validated, and, when necessary, replaced and that the data collected by the

equipment installed at the SPS sites are uniformly checked on a regular basis. These contracts are conducted under two concurrent phases with a separate contractor for each phase. The Phase I contractor performs the field calibration and validation activities for the traffic data collection equipment, and the Phase II contractor installs and maintains the equipment. The contracts were initiated under the LTPP SPS Traffic Data Collection Pooled-Fund Study, which was an outcome of the LTPP Program Improvement Campaign (see chapter 11), and thus did not exist under SHRP management.

Weigh-in-Motion Field Calibration and Validation Contracts

The services provided under these contracts are to verify that the weigh-in-motion (WIM) systems at the SPS sites are operating at peak performance and to document the reliability of the data being collected. If the WIM systems are not meeting the LTPP accuracy requirements, the contractor must identify the problems and recommend corrective actions, as well as supporting rationales for these actions.

FHWA-LTPP Contractors

MACTEC Engineering and Consulting, Inc.
Applied Research Associates, Inc.

Installation, Maintenance, and Data Services for Weigh-in-Motion Systems Contracts

The services provided under these contracts are to install and calibrate WIM systems that would provide research-quality traffic data (defined to be at least 210 days a year of data of known calibration, meeting LTPP's accuracy requirements) for 5 or more years at SPS sites that either did not have an operational WIM system, or that had been recommended by the contractor performing the WIM field calibration and validation activities to replace the equipment. The services also include maintenance of the WIM systems installed and replacement of the systems, if necessary. In addition, daily verification checks are also part of the contract services.

FHWA-LTPP Contractor

International Road Dynamics, Inc.

MATERIALS CONTRACTS

Objective

Materials contracts awarded by SHRP and FHWA cover the collection of materials samples at the LTPP test sections and laboratory testing of the collected samples. The contract services are performed either regionally or centrally and the laboratory testing results are entered into the LTPP database.

Materials Drilling and Sampling Contracts

The services provided under these contracts were to perform drilling and materials sampling at the LTPP test sections and to label with source information, package, and ship the collected samples to the appropriate laboratory testing facility. During SHRP management, these services were performed by firms within each region rather than through one central contract.

SHRP-LTPP Contractors

Westinghouse Environmental and Geotechnical Services
Professional Service Industries, Inc. (LTPP North Atlantic Region)
Braun Engineering Testing (LTPP North Central Region)
LAW Engineering (prime)/Southwest Labs (LTPP Southern Region)
Chen-Northern (LTPP Western Region)

FHWA-LTPP Contractor

Braun Intertec

Materials Reference Library Contracts

The services provided under these contracts are to store loose and core forms of highway materials (asphalt concrete, Portland cement concrete, natural aggregates) from the LTPP test sections and provide a climate-controlled room to house 35-mm films that contain images of the LTPP test sections. Other pavement research programs have also stored their materials at the Materials Reference Library (MRL). The SHRP Asphalt program contract established the MRL at a facility in Austin, Texas. This contract ended in

1993, and the materials were relocated to a facility in Reno, Nevada, under FHWA management.

SHRP-LTPP Contractor
University of Texas at Austin

FHWA-LTPP Contractors
Nichols Consulting Engineers, Chtd.
Sierra Transportation Engineers, Inc.

DATA STORAGE AND DISSEMINATION CONTRACTS

Objective

The original objectives for these contracts during the SHRP management years were to provide the technical and management services needed to build and maintain the IMS and to ensure continuity, stability, and access to the LTPP data. Under FHWA management years, the contract services have been expanded to include new data elements collected from the LTPP test sections and the creation of a Web-based data entry portal that allows for real-time loading of data from the LTPP regional support contractor offices directly to the national LTPP database. In more recent years of the LTPP program, a contract independent of the IMS contracts was put in place to improve user access to the LTPP data and other program information.

Information Management System Contracts

The services provided under these contracts have been to organize and implement the LTPP IMS, its national node in Washington, DC, and the four LTPP regional nodes. The specific services include installation of the National IMS (NIMS) at the TRB, National Research Council, facilities in Washington, DC, and the necessary interfaces between the program and contractor offices to allow flexible access to the data for a national analysis program; installation of the regional IMS (RIMS) nodes at the four regional contractor offices, and the necessary interface and quality control subsys-

tems among the regional, LTPP program, and IMS contractor offices; and documentation and training to allow operation of the RIMS and NIMS by the program and contractor staff. Under FHWA, these services have been provided from locations in Oak Ridge, TN; Beltsville, MD; and McLean, VA.

SHRP-LTPP Contractor
Science Applications International Corporation

FHWA-LTPP Contractors
Pavement Consultancy Services, later acquired by LAW Engineering (prime); LAW later acquired by MACTEC Engineering and Consulting, Inc.; MACTEC later acquired by AMEC Environment & Infrastructure, Inc./Science Applications International Corporation/Soil and Materials Engineers, Inc.

DataPave Online Contract

The services provided under this contract were to develop a Web-based system to provide continuous user access to LTPP data, documents, and related program information. This type of contract did not exist under SHRP management. The contract covered the development of DataPave Online and its expanded system, Products Online, which included other LTPP products (see chapter 10).

FHWA-LTPP Contractor
iENGINEERING Corporation

Web Interface Portal Contract

The services provided under this contract have been to develop, enhance, maintain, and support an effective Web interface program for the LTPP IMS. This Web-based system, known as LTPP InfoPave™, provides on-demand access to the LTPP database, Ancillary Information Management System, and products and tools to help maximize understanding and use of the data and other program information. This type of contract did not exist under SHRP management.

FHWA-LTPP Contractor
iENGINEERING Corporation

DATA ANALYSIS CONTRACTS

Objective

The LTPP program has contracted with many consultants, researchers, private firms, and universities—too many to list in this appendix—to examine the LTPP data over its nearly three decades. Details on the contractors that have conducted LTPP data analysis can be found by viewing the Strategic Plan for LTPP Data Analysis at <http://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/pavements/ltppl/analysis-plan/index7print.cfm>.

The objective for the key data analysis contract during SHRP management was to perform the initial analysis studies for the first five LTPP program objectives. The activities for this first data analysis contract included the evaluation of existing design methods, improved design equations, effects of load and environment on pavement distress and performance, effects of specific design features on pavement performance, and evaluation of the design equations in the AASHTO Pavement Design Guide² in light of empirical-mechanistic analysis techniques. In the principal data analysis contract, LTPP data were extracted and processed to create analytical databases tailored to the planned calculations. During this process, data gaps, overlaps, and other inconsistencies were identified for correction in the LTPP database portion of the IMS. Also, preliminary distress-specific pavement performance models were developed and sensitivity analyses were conducted to identify those variables having the strongest influence on specific distresses. In the secondary, smaller data analysis contract, efforts focused on the mechanistic evaluation of the AASHTO flexible pavement design equation and led to the identification of procedures in the AASHTO Pavement Design Guide that were inconsistent with a mechanistic model for pavement structures.

FHWA has used the Broad Agency Announcement (BAA) contract mechanism twice to award research projects involving innovative analysis approaches, novel ideas, and new methods of using LTPP data and

information that will result in a better understanding of pavement performance. The primary objective of the BAAs was to derive useable and useful interim advances, with immediate applications in the areas of pavement design, construction, and evaluation practice, through analysis of the LTPP data.

The BAA projects provide the basis for identifying and developing products that engineers and managers can apply to design more cost-effective and better performing pavements. Four projects were performed under the first BAA between 1994 and 1996, and 12 projects will be performed under the second BAA between 2014 and 2016.

SHRP-LTPP Contractor

Brent Rauhut Engineering, Inc. (prime)/ERES
Consultants

FHWA-LTPP Contractors

AMEC Environment & Infrastructure, Inc.
Applied Research Associates, Inc.
Braun Intertec Corporation
Brent Rauhut Engineering, Inc.
ERES Consultants, Inc.
Fugro Roadware, Inc.
Michigan State University
Nichols Consulting Engineers
Quality Engineering Solutions, Inc.
Soil & Materials Engineers, Inc.

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Appendix C

Data Collection Equipment, Instrumentation, and Software Used in the LTPP Program

INTRODUCTION

The LTPP program has used state-of-the-art equipment and technology to collect high-quality data. In many cases, the devices and software used to collect, process, and perform quality control/quality assurance (QC/QA) on the data have been created by the SHRP-LTPP and FHWA-LTPP contractors because the technology either did not exist or did not meet the performance needs of the program.

The following sections describe some of the equipment used by the program over the years. In addition, this appendix also covers the software used for processing and performing QC checks of the data collected. Please note that the information contained in the following pages is not a complete list of the equipment or the software used by the program, but this addition-

al information is being provided because it may be of value. More complete information about each type of data collection equipment and software used to process the data can be found in other documents published by the LTPP program, many of which are referenced throughout this report, particularly in chapter 6 and chapter 7.

AUTOMATED WEATHER STATION EQUIPMENT

The automated weather station (AWS) equipment installed at the SPS-1 (structural factors for flexible pavements), -2 (structural factors for rigid pavements), and -8 (environmental factors in the absence of heavy loads) projects included:

- UT3 weather tower with a Vaisala HMP 35 RH/ATP probe (measured air temperature and relative humidity).
- R. M. Young 05103 wind speed and wind direction probe.
- Licor LI-200x pyranometer (measured solar radiation).
- Model 380-L and 385-L (electrically heated) tipping bucket rain and snow gauges.
- CSI CR10 Datalogger (collected and stored the instrumentation data).
- 12-volt DC PS 12 LA storage battery.
- MSX10 solar panel.

The LTPP regions with SPS projects in freeze zones were provided with heated tipping buckets (figure C.1) that required 110-volt service to power the heater.

AWS Datalogger and Storage Units

Software routines for the Campbell Scientific, Inc. (CSI) CR10 Datalogger were developed as a DOS-based program that was downloaded to the CR10 Dataloggers.¹ This program complemented the field data collection and calibration activities by controlling the field data collection functions and providing the file format for storage of the instrumentation data. In 2004, the DOS-based program was updated to work with CSI's PC208W program, which was based on Microsoft Windows®.

In 1997, the installation of modems at each AWS location to allow for remote data download became a requirement.² Modems were added to sites that could be provided with landline telecommunications at a reasonable cost (figure C.2), and cellular packages were added to sites that were not phone-line accessible.

FALLING WEIGHT DEFLECTOMETER EQUIPMENT

Prior to the implementation of the SHRP program, very little falling weight deflectometer (FWD) data had been collected. Since deflection data were to be a key data element in the LTPP program, FWD units were purchased and evaluated for deflection data collection.

The first four FWD units for the LTPP program were procured from Dynatest® in 1988. The FWDs



FIGURE C.1.
Heated tipping bucket rain gauge.



FIGURE C.2. Modem attached to Datalogger for transmitting data via landline to the respective LTPP regional support contractor's office computer.

were towed by a 1988 GMC diesel van (figure C.3) and were equipped as follows:

- An 8000 series processor.
- A laptop computer.
- A Dynatest DOS v20 FWD field program.
- A load cell.
- Two solid load plates (300 mm and 600 mm).
- Seven deflection sensors.
- Eight 55-lb (25-kg) weights.
- A trailer with dual axles.
- An enclosed body (a special-order item to allow the units to travel to numerous locations and remain secure when parked at hotel or airport parking lots).

Five-year maintenance programs were included with the procurement, requiring the FWDs to be delivered annually to the manufacturer for service.



FIGURE C.3. One of the four original FWD van and trailer units.

Since the purchase of the first set of FWD units in 1988, the LTPP program has made a concerted effort to maintain the equipment. Driven by budget restrictions, in some years, the program found it more economical to refurbish the units instead of replacing them altogether. The manufacturer refurbished the FWD units in the early years of the LTPP program, but in later years, the LTPP regional support contractors were given the option to refurbish the units using the expertise of their staff or by sending the units to the manufacturer. All units, whether new or refurbished, are required to pass the reference calibration at one of the regional calibration centers (see chapter 6 for more detail) prior to collecting deflection data at the LTPP test sites. Table C.1 lists the FWD equipment used in the LTPP program from 1988 to 2014.

FWD Buffers

The Dynatest DOS v20 FWD field program had the option of smoothing the FWD load and deflection peaks, as typically a 2-point peak occurs at the time of initial impact and full loading of the buffers. For the LTPP program, no smoothing was applied as the desire was to provide data in an unadjusted state. The flat buffers that initially came with the FWD units were problematic in that they provided too harsh a contact, which resulted in a very uneven peak. To alleviate this, Dynatest conducted a rotating knife cut on the buffers to provide a tapered buffer that would cushion more on impact due to the reduced contact area. The first modified buffers had too much of a taper such that their warming would cause the weight assembly to bounce back into the catch. Two additional versions of the buf-

fers were developed (100 mm and 110 mm) that had a mild curvature to the bottom. These buffers were used for the remainder of the program.

FWD Temperature Issues

The LTPP program developed procedures for cold weather testing as part of the Seasonal Monitoring Program (see chapter 7). To keep the FWD units operating during the winter months, the LTPP regional support contractors added block heaters to keep the hydraulic fluid warm so the hydraulics would continue to operate. However, the AC current from the heaters created a spike in the peaks, which was noticed at the time of reference calibration. Procedures were then developed to ensure that the heaters were turned off at the test site and that testing would be terminated if temperatures dropped below 15 °C (5 °F).

Pavement temperatures were initially measured using the Williamson infrared temperature sensors provided with the FWDs. They were problematic in that they were intermittent in their operation. These infrared sensors were replaced with a Raytec infrared surface temperature probe. Regional calibration of the infrared sensors also determined an issue with the consistency of temperature output. After each calibration, the temperature coefficients changed, although slightly. It was decided that this change resulted in unreasonable differences. The procedures were modified in 2005 to allow the regions to perform calibration checks, while temperature calibration changes would only be performed by the manufacturer.³

TABLE C.1. Falling weight deflectometer equipment used in the LTPP program.

Year	Equipment
1988	Purchased 4 FWDs, equipped with Laptop computer—8000 series processor Dynatest® DOS v20 FWD field program Load cell 7 deflection sensors 8 weights, 55-lb (25-kg) each 5-year maintenance contract requiring annual service at manufacturer 1988 GMC diesel vans and dual-axle trailers with enclosed bodies
1995	Refurbished 4 LTPP regional FWDs and purchased 4 new FWDs: ¹ 9000 series processor 5-year maintenance contract for annual service at LTPP regional office or manufacturer Purchased 8 Ford diesel vans
2000	Upgraded FWDs: 9 deflection sensors Dyna25 operating system Database modified and output file formats created for read (*.F25) and historic (*.H25) data Training in Dyna25 for regions Replaced FWD vans
2002	Refurbished FWDs
2005	Upgraded FWD software to FWDWin Changed file format to Microsoft® Access®
2006	Disposed of 1 FWD in each region (transferred to other FHWA operations and the National Center for Asphalt Technology in Auburn, AL)
2013-2014	Refurbished FWDs Purchased 4 diesel Chevrolet 2013 Express 3500 passenger vans Upgraded FWD software to new CP-15 system

(1) The additional FWDs were needed to meet the demands of the Seasonal Monitoring Program and the addition of many SPS projects.

Automated Temperature Datalogger

In 2008, the LTPP program developed the automated temperature data logger (ATDL) and the software used to determine surface and thermal gradient temperature measurements at FWD test locations (figure C.4 and figure C.5). The ATDL process was developed to replace the manual method, which used a handheld temperature reader and probe to collect temperature data at the time of FWD data collection. The automated process allows for collecting temperature data at the same time each FWD data point is collected. The previous practice for collecting this information was at 30-minute and 1-hour intervals. Although the setup was proven to be successful and some 16 units were assembled, this method was not implemented by the LTPP regional support contractors due to funding reductions that resulted in the suspension of FWD data collection at most LTPP test sites (with the exception of some SPS projects).

FWD Quality Control Tool

A 60-millisecond (ms) window was used to capture the loading and response history data. However, there were requests from researchers for 100-ms histories. The LTPP program investigated this request at the time of the Dyna25 implementation and, based on the added time required to store the histories, decided to continue with the 60-ms histories. The Dynatest program produced output files in the *.FWD format with the history data embedded in the binary file. So, the LTPP program developed a field QC software tool—FWDScan—to ensure that the FWD data met the minimum requirements (number of drops and repeatability) before sending the data to the office.^{4,5}

The LTPP program began to migrate the FWD data from U.S. customary units to the International System of Units (SI) in 1999. The FWD setup was modified to output in SI units.

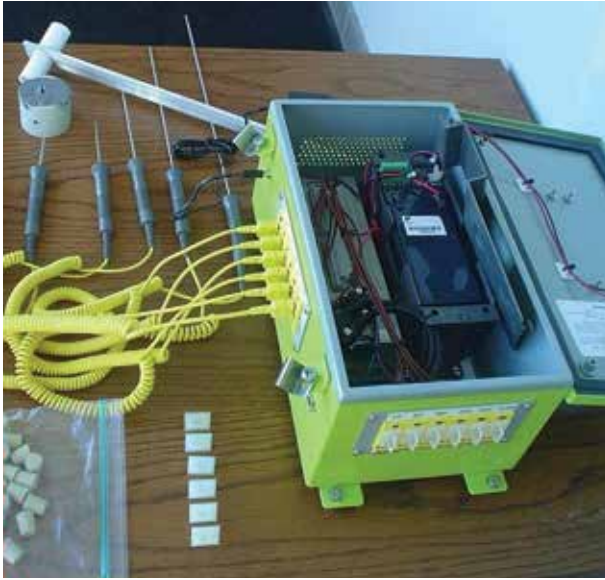


FIGURE C.4. Automated Temperature Datalogger with temperature probes attached.

PROFILING EQUIPMENT

In 1989, SHRP purchased three DNC 690 Profilometers from K. J. Law to collect longitudinal profile data. The profilometers used a Champion motor home chassis with Ford underpinning with dual rear wheels. These Profilometers used:

- Two incandescent sensors (centrally mounted and shrouded).
- Two accelerometers.
- A distance measuring instrument.
- Photocell initiation.

A fourth Profilometer, mounted in a Ford E350 van chassis, was obtained from FHWA and delivered to the LTPP North Central Regional Coordination Office Contractor. This van had the same profiling system but was mounted in a smaller unit. The data collection and computing were handled by a PDP 1184 with disk drive and tape backup. Profile elevations were sampled at 1-inch (25-mm) intervals, averaged over 12 inches (305 mm), and reported at 6-inch (152-mm) intervals.

As the technology for profiling equipment improved, the LTPP program upgraded its units. New units were subsequently purchased in 1996 and then again in 2002.



FIGURE C.5. Automated Temperature Datalogger setup in the field. The Datalogger is powered by a 12-volt SLA battery. The solar panel charges the battery to sustain 12 volts during data collection.

Starting in 1996 with the purchase of the K. J. Law T6600 Profilometers, SI units have been used for collecting and storing the profile data. In 2013, the LTPP program took delivery of four new, state-of-the-art inertial profiling units manufactured by Ames Engineering that meet LTPP's stringent acceptance criteria. The competitively procured profilers replaced LTPP profilers that were in service since 2002 and collectively logged more than 1.2 million miles (1.9 million km). Table C.2 lists the profiling equipment used in the LTPP program since delivery of the first profilers in 1989.

Data Filtering

Sample data were collected and stored at 1-inch (25-mm) intervals with the conversion to the K. J. Law T6600 Profilometer. A 12-inch (305-mm) running average was being applied to the 1-inch (25-mm) data output at 6-inch (152-mm) intervals. In discussion with K. J. Law, no filtering was to be applied to the 1-inch (25-mm) data. It was later discovered that a running average was applied on the 1-inch (25-mm) data. Since data were additionally being filtered by the LTPP regional support contractors, the profiles were being double-filtered. Researchers using these data should be aware that this was never rectified, and this double filtering is still present in the data in the LTPP database.

Capabilities and Acceptance Testing of Latest Units

Capabilities

The latest LTPP profilers (purchased in 2013) were specified and manufactured so the results from the test-

TABLE C.2. Profiling equipment used in the LTPP program.

Year	Equipment
1989	Purchased 3 K. J. Law DNC 690 Profilometers DEC PDP 1184 computer processor with disk drive and backup 2 incandescent sensors, centrally mounted and shrouded 2 accelerometers Distance-measuring instrument Photocell initiation Elevations sampled at 1-in. (25-mm) intervals, averaged over 12 in. (305 mm), and reported at 6-in. (152-mm) intervals 3 mounted in Champion motor home chassis with Ford underpinning, dual rear wheels 1 mounted in a Ford E350 van (DNC 690 Profilometer obtained from FHWA) Video cameras added after delivery in some regions
1996	Purchased 4 K. J. Law T6600 Profilometers IBM-compatible computer, integrated MS-DOS®/Windows® system 3 infrared sensors Mounted in Ford E350 extended vans Change from U.S. customary units to SI units
2002	Purchased 4 International Cybernetics Corporation MDR 4086L3 Profilers 3 laser/accelerometer sensors Vertical and horizontal photocell Distance-measuring instrument integrated with speedometer pickup Air temperature probe Mounted in Ford E350 vans
2003	Updated calibration oscillation integrated into processor
2013	Purchased 4 Ames Engineering, Inc. Profilers 3 laser/accelerometer sensors 2 texture sensors Vertical and horizontal photocell Wheel-mounted quadrature optical encoder distance-measuring instrument Air temperature sensor Pavement temperature sensor Global Positioning System (GPS) Wide Area Augmentation System (WAAS) enabled GPS receiver Mounted in Ford E150 vans

ing regimen closely match legacy LTPP data collection parameters. The new units not only collect longitudinal profile data, but have added capabilities. Pavement macrotexture measurements are a new data collection element, and all of the data, including ambient and surface temperature, are now referenced with Global Positioning System coordinates. The cockpit of the vehicle has been designed to minimize driver distractions and provide ease of access to all controls and testing switches. As compared to the old LTPP profilers that used 2002-era computer technology, the new system's hardware requirements are minimized, resulting in a very low

computer rack footprint. System software has been designed through a collaborative manufacturer/LTPP program process to be user-friendly and intuitive.

Acceptance Testing

The new LTPP profilers were procured and accepted for service using a very strict procedure. This procedure could be leveraged by other agencies that are procuring inertial profilers to check the ability of the equipment to collect consistent, accurate profile and macrotexture data. The acceptance procedure, conducted in February 2013, consisted of the following checks:

- **Static Sensor Test:** Researchers evaluated the precision and bias of the profile and texture height sensors in the static mode.
- **Bounce Test:** Researchers checked whether the accelerometers were cancelling out vehicle motion, and as an overall test on the integrity of the profiling system.
- **Test on Distance Measuring Instrument (DMI):** Researchers evaluated the precision and bias of the DMI.
- **Profile Initiation Test:** Researchers evaluated the ability of the vertical and horizontal photocell to initiate data collection.
- **Ability of Devices to Detect Profile Features:** Researchers investigated the ability of the profiler to correctly detect profile features.
- **Repeatability of Profile Data:** Researchers analyzed the ability of the devices to collect repeatable profile data.
- **Repeatability of International Roughness Index (IRI) Values:** Researchers compared IRI values computed from the profile data collected by the devices to determine the ability of the devices to obtain repeatable IRI values.
- **Cross Correlation Analysis—IRI Repeatability of Profile Data:** Researchers performed this check to evaluate the repeatability of IRI values along the section.
- **Comparison of IRI Values with Reference Device IRI:** Researchers performed this check to compare the IRI values obtained by the test devices with IRI values computed from the data collected by a reference device.
- **Cross Correlation Analysis—IRI Accuracy of Profile Data:** Researchers performed this check to evaluate the accuracy of IRI values along the section compared to IRI from data collected by the reference device.
- **Waveband Analysis of Profile Data:** Researchers performed this check to compare the spectral distribution of the profile data collected by the test devices with data collected by a reference device.
- **Evaluation of Accuracy of Texture Laser in the Dynamic Mode:** Researchers evaluated the accuracy of the texture lasers in the dynamic mode by utilizing

the texture laser evaluation tool provided by the manufacturer.

- **Evaluation of Data Collected by the Texture Lasers:** Researchers compared mean profile depth (MPD) values computed from macrotexture data collected by texture lasers to MPD values obtained from a reference device.

To conduct the acceptance testing, several reference test sections were established near College Station, Texas. These sections consisted of two asphalt concrete, two Portland cement concrete, and one chip seal surface. The sections were selected to obtain a range of roughness and MPD values. The results were analyzed and it was found that all four profilers met the stated requirements. Following acceptance testing and analysis of the data, a week-long training exercise held in April 2013 for the LTPP regional support contractors paved the way for the LTPP program to incorporate the new devices into production mode for data collection.

SEASONAL MONITORING PROGRAM EQUIPMENT

The instrumentation and data collection equipment used as part of the seasonal monitoring program (SMP) included:

- Tektronics 1502B cable testers.
- PS12LA power supply with charging regulators.
- Solar panels.
- CSI CR10 Dataloggers and multiplexers.
- TE525 and TE525MM tipping bucket rain gauges.
- CSI 107 air temperature probes.
- MRC 15 thermistor probes (soil gradient temperature probes) from Measurement Research Corporation (MRC).
- 330-mm surface probe containing three thermistors.
- CRREL resistivity probe from the U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory (CRREL).
- FHWA time domain reflectometer (TDR) moisture probes.
- Equipment cabinets and electronics.

Equipment Challenges

Thermistor and Resistivity Probes

Thermocouple and resistivity probes were assembled in Albany, New York, at the State highway agency. The agency had experience with the thermistor probes, and information on the resistivity probe was provided by CRREL. Thermistor probes were considered but decided against based on problems CRREL had using this technology in Vermont and New Hampshire. At this time, thermistor probes manufactured by MRC were in their infancy and little was known regarding their performance. A Troxler moisture probe was loaned from the vendor who was working with New York on the use of this device. The LTPP program purchased a precision Hewlett-Packard multi-meter for the thermocouple and resistivity probe data collection and an Omega channel selector to multiplex through the various thermocouples. An oscillator (developed from plans provided by CRREL) was assembled for resistivity probe data collection. Some other methods were considered for frost/thaw determination, but time limitation eliminated these from the initial installation.

A function generator and multiplexer developed by FHWA's Turner-Fairbank Highway Research Center replaced the initial manual 2-pt and 4-pt resistivity multiplexers. The instrumentation for measuring air and pavement temperature and precipitation was connected to a CR10 Datalogger and mounted in a cabinet at the site location.

The MRC surface thermistor probes that were contained in the 330-mm stainless steel probe had a high failure rate. It was suspected this was due to the flexing of this probe under traffic loading (since they were placed in the surface layer in the wheelpath). Replacement probes, which contained three "piglet" style mini probes, were installed to replace the failed probes for Phase II SMP sites (figure C.6). Each probe was placed independently within the surface layer at a defined depth.⁶

Time Domain Reflectometer

TDR probes were used to obtain the moisture content in unbound base and subgrade materials. The TDR technique is based on the measurement of the travel time of an electromagnetic wave induced into a wave-

guide, in this application, a moisture probe. The apparent length is the length between the beginning and end points on the waveform, which correspond to the beginning and end of the metal tube portion of the moisture probe. This apparent length of the probe can be used to calculate the dielectric constant of the material surrounding the probe. The dielectric constant is an input to the calculation of moisture content.

The LTPP program evaluated TDR probes of various configurations (2-prong, 3-prong, short and long probes, straight or curved probes, with or without baluns, etc.) using Sonotubes™ with various soils and moisture levels to select the type of probe and using the Topp, Roth, and Paterson analytic procedures.

Problems were encountered with TDR activation when using the CR10X Dataloggers. Support was sought from CSI, but this issue was never resolved. It was never determined if the issue was a problem with the CR10X Datalogger or if the program was too complicated for the CR10X processor. CSI had indicated that they had problems with the crystal in some of the CR10X Dataloggers, but the ones they delivered to FHWA for the SMP Phase II program were not part of this group. The solution was to regularly check the Datalogger outputs and reload the program if the TDR system went idle. This resulted in some of the early data sets being incomplete.



FIGURE C.6. "Piglet" style mini-probes installed to replace failed thermistor probes in Phase II of the Seasonal Monitoring Program.

Equipment Improvements in SMP Phase II

The continuous moisture and frost/thaw data collection in SMP Phase II was accomplished by integrating a Tektronics cable tester and an ERB20 resistivity multiplexer (manufactured by ABF, Inc.) with the existing onsite instrumentation at select sites and in the mobile units. The ERB20 multiplexer, which replaced the CRREL multiplexer, recorded the input voltage, which allowed for the mathematical interpretation of the automated resistivity data.

In addition to the Tektronics cable tester and ABF multiplexer, the Dataloggers were upgraded to the CSI CR10X-2M along with CSI multiplexers, cabinet, and remote telecommunication capabilities. The software, OnsPlus, incorporated an “Agency Machine” to initiate the TDR system based on the level and intensity of rainfall, and initiated the resistivity system based on below-freezing gradient temperatures from the MRC temperature probe. To extend the period between site visits, CSI SM-192 data storage modules were added. The SM-192 storage modules had 5-volt lithium batteries that provided reserve power to the memory chip to help prevent data loss.⁷

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Acronyms

AADT	average annual daily traffic	C-SHRP	Canadian Strategic Highway Research Program
AASHO	American Association of State Highway Officials	CSI	Campbell Scientific, Inc.
AASHTO	American Association of State Highway and Transportation Officials	CSSC	Customer Support Service Center
AC	asphalt concrete	CTB	cement-treated base
ADEP	AIMS Data Entry Portal	CTDB	Central Traffic Database
AIMS	Ancillary Information Management System	CTDOT	Connecticut Department of Transportation
AMRL	AASHTO Materials Reference Laboratory	CTE	coefficient of thermal expansion
APT	accelerated pavement testing	DAOFR	Data Analysis/Operations Feedback Report
ASCE	American Society of Civil Engineers	DAWG	Data Analysis Working Group
ASCII	American Standard Code for Information Exchange	DCP	dynamic cone penetrometer
ASTM	ASTM International, formerly American Society for Testing and Materials	DIM	Distress Identification Manual
ATB	asphalt-treated base	DiVA	Distress Viewer and Analysis
ATDL	automated temperature data logger	DLR	dynamic load response
AVC	automatic vehicle classification	DMI	Distance Measuring Instrument
AWS	automated weather stations	DOT	Department of Transportation
BAA	Broad Agency Announcement	ESAL	equivalent single-axle load
CCC	Canadian Climate Center	ETG	expert task group
CDOT	Colorado Department of Transportation	FALCON	Focus Area Leadership and Coordination
COPEs	Concrete Pavement Evaluation System	FHWA	Federal Highway Administration
CRCP	continuously reinforced concrete pavement	FWD	falling weight deflectometer
CRREL	Cold Regions Research and Engineering Laboratory	FWDUG	FWD User Group
		GOE	General Operating Expenses
		GPR	ground penetrating radar
		GPS	General Pavement Study
		GPSr	Global Positioning System receiver

HERS	Highway Economics Requirement System	PADIAS	PAvement DIstress Analysis System
HMA	hot-mix asphalt	PCC	Portland cement concrete
HPMS	Highway Performance Monitoring System	PennDOT	Pennsylvania Department of Transportation
ICC	International Cybernetics Corporation	PG	performance grade
IDIQ	indefinite delivery/indefinite quantity	PHT	Performance Health Track
IMS	Information Management System	PLUG	Pavement Loading User Guide
IPRD	Innovative Pavement Research and Deployment Program	PPAC	Pavement Performance Advisory Committee
IRI	International Roughness Index	PPCP	precast prestressed concrete pavement
ISO	International Organization for Standardization	PPDB	Pavement Performance Database
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991	QC/QA	quality control/quality assurance
JCP	jointed concrete pavement	RABA	Revenue Aligned Budget Authority
JPCP	jointed plain concrete pavement	RAC	rubberized asphalt concrete
JRCP	jointed reinforced concrete pavement	RAP	recycled asphalt pavement
KDOT	Kansas Department of Transportation	RCOC	regional coordination office contractor
LCOM	LTPP Committee	RDBMS	relational database management system
LDEP	LTPP Data Entry Portal	RIMS	Regional Information Management System
LSPEC	LTPP Special Activities Committee	RSC	regional support contractor
LTAS	LTPP Traffic Analysis Software	RTAC	Roads and Transportation Association of Canada
LTBP	Long-Term Bridge Program	SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
LTM	Long-Term Pavement Monitoring	SCOR	AASHTO's Standing Committee on Research
LTPP	Long-Term Pavement Performance Program	SDR	Standard Data Release
LTPP-PLUG	LTPP Pavement Loading User Guide	SHRP	Strategic Highway Research Program
MAP-21	Moving Ahead for Progress in the 21st Century Act	SI	International System of Units
MEPDG	Mechanistic-Empirical Pavement Design Guide	SMERP	Supplemental Maintenance Effectiveness Research Program
MERRA	Modern Era–Retrospective Analysis for Research and Applications	SMP	Seasonal Monitoring Program
MPD	mean profile depth	SOM	Subcommittee on Materials
MRC	Measurement Research Corporation	SPR	Software Performance Report
MRL	Materials Reference Library	SPS	Specific Pavement Study
MS-DOS®	Microsoft Disk Operating System	STAA	Surface Transportation Assistance Act of 1982
NASA	National Aeronautics and Space Administration	STRS	Strategic Transportation Research Study
NCDC	National Climatic Data Center	STURAA	Surface Transportation and Uniform Relocation Assistance Act of 1987
NCHRP	National Cooperative Highway Research Program	TAC	technical assistance contract/contractor
NDT	nondestructive deflection testing	TEA-21	Transportation Equity Act for the 21st Century
NHI	National Highway Institute	TDR	time domain reflectometer
NIMS	National Information Management System	TFHRC	Turner-Fairbank Highway Research Center
NOAA	National Oceanic and Atmospheric Administration	TRB	Transportation Research Board
NRC	National Research Council	TSSC	technical services support contract/contractor
NYSDOT	New York State Department of Transportation	TxDOT	Texas Department of Transportation
OPR	Operational Problem Report	VMS®	Virtual Memory System
OWL	Optimal WIM Site Locator software	WAAS	Wide Area Augmentation System
		WIM	weigh-in-motion
		WMA	warm-mix asphalt



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