Fulfilling the Promise of Better Roads

A Report of the TRB Long-Term Pavement Performance Committee

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Contents

Executive Summary 1

1 Introduction 3
LTPP's Mission 3
LTPP's History 4

2 LTPP's Current Status 5
Data Collection 5
Data Analysis 6
Products 7
Potential Products 8

3 The Work Still to Be Done 9
Funding Concerns 9
Data Concerns 9

4 Beyond 2009 11
Data Collection, Storage, and Management 11
Data Analysis 12
Product Development 12

5 What Will Be Lost If the Job Is Not Completed 13

6 Recommendations 14

Appendixes
1 LTPP Background 16
2 LTPP Funding 21
3 LTPP Data Collection Status 30
4 LTPP Data Analysis Status 39
5 LTPP Product Development Status 57

Figures and Tables

Figure 1-1 Variation in number of LTPP test sections over time 19
Figure 2-1 Previous LTPP funding 22
Figure 2-2 Projected LTPP work, FY 2004–FY 2009, expressed in dollars. 25
Figure 3-1 Number of active LTPP GPS test sections, 1989–2009 31
Figure 3-2 Number of active LTPP SPS test sections, 1989–2009. 32

Table 2-1 LTPP Annual Cost Projections, FY 2004–FY 2009: Preliminary Estimates Provided by FHWA LTPP Research Team. 22
Table 2-2 Projected Increases in Cost per Section, FY 2004–FY 2009. 27
Table 2-3 Projected Work Effort, 2004–2009, for All LTPP Components, Expressed in Dollars (Millions) 29
Table 3-1 LTPP GPS Experiments 31
Table 3-2 LTPP SPS Experiments. 31
Table 3-3 Completeness of Available LTPP Materials Test Data as of January 2000 33
Table 3-4 LTPP Monitoring Requirements: Desired 34
Table 3-5 LTPP Monitoring Requirements: Current 35
Table 4-1 Projects Related to Strategic Objective 1: Traffic Characterization and Prediction 41
Table 4-2 Projects Related to Strategic Objective 2: Materials Characterization . . 42
Table 4-3 Projects Related to Strategic Objective 3: Determination of Environmental Effects in Pavement Design and Performance Prediction 43
Table 4-4 Projects Related to Strategic Objective 4: Evaluation and Use of Pavement Condition Data in Pavement Management. 44
Table 4-5 Projects Related to Strategic Objective 5: Development of Pavement Response and Performance Models Applicable to Pavement Design and Performance Prediction 45
Table 4-6 Projects Related to Strategic Objective 6: Maintenance and Rehabilitation Strategy Selection and Performance Prediction. 46
Table 4-7 Projects Related to Strategic Objective 7: Quantification of the Performance Impact of Specific Design Features 47

Acronyms

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
CD	compact disc
DOT	department of transportation
ETG	expert task group
FHWA	Federal Highway Administration
FWD	falling weight deflectometer
GPR	ground-penetrating radar
GPS	General Pavement Studies
IRI	International Roughness Index
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
LTPP	Long-Term Pavement Performance
NCDC	National Climatic Data Center
NCHRP	National Cooperative Highway Research Program
OPT	Office of Pavement Technology
PCC	portland cement concrete
PG	performance grade
RPD	rigid pavement design
SHRP	Strategic Highway Research Program
SPS	Specific Pavement Studies
TDR	time domain reflectometry
TEA-21	Transportation Equity Act for the 21st Century
TRB	Transportation Research Board
WIM	weigh-in-motion

Executive Summary

The United States invests approximately $30 billion per year in building, maintaining, and repairing highway pavements. The Long-Term Pavement Performance (LTPP) program, North America's most comprehensive highway research program, addresses the best ways to use and protect this annual investment. With more than a decade of data collection and analysis now available, valuable insights, innovations, and products will emerge from the LTPP studies in the next several years. What is needed to realize the promise of the 20-year LTPP effort is identified in this report.

The LTPP studies—17 scientifically designed field experiments—collect and analyze pavement performance and other data to determine how and why pavements perform as they do. From the findings, new pavement design, management, and maintenance systems can be developed to extend pavement life and serve a new generation of highway users.

Originally part of the Strategic Highway Research Program, the LTPP program is now administered by the Federal Highway Administration (FHWA) with active input from the state departments of transportation and with the cooperation of the Canadian provincial transportation agencies. In June 2000, the FHWA LTPP Research Team asked the Transportation Research Board's (TRB's) LTPP Committee for guidance on the appropriate content and focus of the LTPP studies for 2004 through 2009—the period likely to be covered by congressional legislation reauthorizing the Federal-Aid Highway Program.

The TRB LTPP Committee monitors the status and progress of the LTPP studies and provides guidance on ongoing and prospective activities to FHWA and the American Association of State Highway and Transportation Officials. In keeping with its task and in response to FHWA's request, the committee in this report reviews the history of LTPP, assesses the program's status, identifies crucial needs for 2004 through 2009, and recommends that FHWA take the following actions:

- Develop research plans and budgets for the years 2004 to 2009 consistent with the view of the future described in this report.
- Give the highest priority to closing potential gaps in data collection for three areas of major significance:
  - Traffic volume and load data at the Specific Pavement Study (SPS) sites;
  - Selected materials testing on certain SPS projects; and
  - Performance-monitoring data identifying the onset of distress at each test section.
- Assess the program in FY 2006 to
  - Determine if data collection can conclude before or during FY 2009, or if it will have to continue beyond FY 2009 to capture performance data from SPS test sections built in the late 1990s; and
  - Determine if remaining gaps in the database compromise the completion of the mission and warrant further efforts to close the gaps.
- Develop post-LTPP plans covering
  - Storage, maintenance, and user support of the LTPP database;
  - Storage and user support of the LTPP off-line Auxiliary Information Management System;

– Storage and user support of the LTPP Materials Reference Library;
– Continued implementation of LTPP data collection;
– Continued implementation of the Strategic Plan for LTPP Data Analysis; and
– Continued implementation of the *LTPP Product Plan* (*1*).

Chapter 1
Introduction

The United States invests approximately $30 billion a year in building, maintaining, and repairing highway pavements.[1] The Long-Term Pavement Performance (LTPP) program, North America's most comprehensive highway research program, addresses the issue of how best to use and protect this recurring investment. With more than a decade of data collection and analysis to work from now, valuable insights, innovations, and products will continue to emerge from the LTPP studies over the next several years. In this report, what is required to realize the promise of a 20-year effort is identified. The brief overview is supported by detailed reports attached as Appendixes 1 through 5.

The LTPP studies, a set of 17 scientifically designed field experiments, seek to collect and analyze pavement performance and other data to determine how and why pavements perform as they do. From this knowledge, new pavement design, management, and maintenance systems can be developed that will extend pavement life and serve a new generation of highway users.

The LTPP program was initiated as part of the Strategic Highway Research Program (SHRP) and is now administered by the Federal Highway Administration (FHWA) with the active participation of each of the state departments of transportation and the cooperation of the provincial transportation agencies of Canada. In June 2000, the FHWA LTPP Research Team sought guidance from the Transportation Research Board LTPP Committee regarding the appropriate content and focus of the LTPP studies from 2004 through 2009, the period likely to be covered by congressional legislation reauthorizing the Federal-Aid Highway Program.

It is the task of this committee to monitor the status and progress of the LTPP studies and to provide guidance to FHWA and the American Association of State Highway and Transportation Officials (AASHTO) on ongoing and prospective activities. In keeping with this task and the explicit request from FHWA, this report reviews the history of LTPP, assesses its status, identifies crucial needs of the program during the 2004 through 2009 period, and recommends actions to prepare for this period and fulfill the LTPP mission.

LTPP's MISSION

LTPP's mission is to foster increased pavement life through

- Collection and storage of performance data from a large number of in-service highways in the United States and Canada, over an extended period, to support analysis and product development;

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[1] No national records of annual expenditures on particular highway elements such as pavements are readily available. To determine the annual expenditure of all levels of government on pavement construction, maintenance, and repair it is necessary to draw inferences from more general statistics on highway expenditures. Data from *Highway Statistics 1999* (*2*) can be reasonably interpreted to show that $7.5 billion or about 50 percent of the total obligation of 1998 federal-aid funds was for pavement-related projects. If that ratio pertains to total highway capital outlays for all units of government, the capital outlay for pavement-related projects in 1998 was approximately $25 billion. If only 20 percent of the total of $28 billion spent for maintenance and service outlays for 1998 was pavement related, then total pavement-related expenditures for 1998 exceed $30 billion.

• Analysis of these data to describe how pavements perform and to explain why they perform as they do; and

• Translation of these insights into products for pavement design, rehabilitation, maintenance, and management.

LTPP's HISTORY

The need for a long-term pavement performance program was first raised in *America's Highways: Accelerating the Search for Innovation* (*3*). This report, prepared by a panel of senior leaders in the transportation community, noted that highway pavements were not always living up to design expectations and recommended a "long-term field test that systematically covered a wide range of climate, soil, construction, maintenance and loading conditions. . . ." In response to this recommendation, in 1986, AASHTO developed the design for such a program to be included in its plans for SHRP. Congress funded SHRP as part of federal-aid highway authorizing legislation in 1987. LTPP data collection began in 1989.

Physically, LTPP is the set of 17 studies and the database that stores the information gathered through the studies. The breadth and length of the program—what is being studied, over what period of time, and why—are probably best understood in terms of the expectations of the highway community for LTPP. These expectations have defined the mission of LTPP and guided its progress. Over time, evolution of these expectations has led to some updates of LTPP's mission, as well. Appendix 1 (p. 16) contains a more complete synopsis of LTPP's history.

LTPP provides the world's most broadly based compendium of information and data describing the long-term performance of in-service pavements. Because of the time span of these experiments—up to 20 years—assessments of progress must be made and funding of the program renewed periodically. Funding renewal for LTPP has been included in congressional legislation reauthorizing the Federal-Aid Highway Program. Current authorization legislation, the Transportation Equity Act for the 21st Century (TEA-21), expires in September 2003. Now is the time to undertake the periodic assessment of progress and planning for the program's needs in the next authorization period. This next period is critical to the success of LTPP as the studies near their projected 20-year life span and many of the anticipated products from the studies emerge.

The total projected funding required to support the work of the LTPP studies from FY 2004 through FY 2009 is $120 million to $125 million. This projection is an extrapolation of work effort based on historic expenditures for the LTPP studies. The annual level of effort projected here far exceeds that currently expended on the LTPP studies. This projection anticipates the closing and prevention of serious gaps in the data collection efforts and expanded efforts in data analysis and product development, the final phase in fulfilling the mission to extend pavement life through research. Details of LTPP program funding history and its projected needs are provided in Appendix 2 (p. 21).

Chapter 2

LTPP's Current Status

Each of the three LTPP activities—data collection, data analysis, and product development—is conducted in accordance with a well-defined plan. Current progress for each of these plans is discussed next and in greater detail in Appendixes 3 through 5.

DATA COLLECTION

The data collection plan was derived directly from the specific studies to be conducted within LTPP. To ensure collection of sufficient data of the types needed for analysis and product development, LTPP is organized as two sets of statistically designed experiments. The eight General Pavement Studies (GPS) experiments study in-service pavements in common use across the United States that incorporate materials and designs representing good engineering practice. The pavements under study in the GPS experiments were not constructed to meet specific LTPP criteria, and most were in service before LTPP monitoring began. The nine Specific Pavement Studies (SPS) experiments were designed to enable comparison and study of specific design features or treatments. The designs and treatments called for in the SPS experiments were constructed with multiple test sections (having different designs) at each test site. Data are collected before, during, and after construction to fully characterize test section conditions. Data collection at any test site is a function of the experiment in which that site lies. Data collection guides developed by SHRP and kept current by FHWA explicitly define the data elements to be collected at each test section, the sampling and testing protocols to be employed, and the processes for assessing the quality of the data and for storing them in the LTPP database.

There are currently about 2,100 GPS and SPS test sections with active data collection, a modest reduction from the peak number of about 2,300. GPS sections have 12 years of collected data with, on average, measurements every 30 to 36 months, beginning in 1989. SPS data collection began in 1990, but it was not until the mid-1990s that most SPS sections were under study. Construction of the last SPS test sections to join LTPP was completed in 2000. On average, SPS sections have approximately 5 years of collected data, with measurements every 24 to 30 months.

Data collection categories are climate, traffic volumes and loads, pavement layer type and thickness, material properties, and pavement condition (distress, longitudinal and transverse profile, and structural evaluation). Some of these data are collected centrally while others are the responsibility of the participating states or provinces. Regardless of the collecting agency, a high priority is placed on the accuracy and completeness of the measurements.

The schedules for collection of on-site performance data should extract maximum value from each test section before it leaves service. In 1996, a previous program assessment proposed adjustments to the frequency of performance testing to meet this objective. Because of a reduction in LTPP funding in the TEA-21 reauthorization legislation of 1998, this revised performance-monitoring schedule was never implemented. On the contrary, the frequency of some types of performance data collection was reduced.

The LTPP database is the central facility for assembly, storage, and maintenance of the data collected at the GPS and SPS test sections. It is LTPP's principal operational tool, its principal product, and its principal legacy to future generations of highway researchers and practitioners. The database currently contains approximately 13 gigabytes of data. Additional data, including more than 1.6 billion records of traffic classification and weight data, are stored off-line. A more detailed summary of the current status of LTPP data collection is provided in Appendix 3 (p. 30).

DATA ANALYSIS

Analysis of LTPP data began in earnest in 1992 with the evaluation of the then-current version of the *AASHTO Guide for the Design of Pavement Structures* (*4*). That analysis confirmed that the guide had outlived its usefulness and contributed to the decision to develop a new guide based on a more mechanistic understanding of pavement behavior. Since that initial analysis, a total of 46 data analysis reports have been published to date. Highlights of these reports can be found in *Key Findings from LTPP Analysis* (*5*).

Data analysis serves two functions. First, it provides the technical basis for identifying and developing tools and products that engineers and managers can use to design more cost-effective and better-performing pavements. Second, it ensures that the data being collected are of the quality and completeness needed to find answers to how and why pavements perform as they do. Currently, the National Cooperative Highway Research Program (NCHRP) is conducting LTPP data analysis using AASHTO-allocated funds in support of the first function, and FHWA is conducting analyses of the LTPP database using TEA-21 funds in support of the second.

Periodically, the TRB LTPP Committee, with the assistance of its subsidiary expert task groups (ETGs), makes recommendations for the pursuit of specific analytical objectives. These recommendations are based on the committee's Strategic Plan for Data Analysis. This plan lays out a long-term strategy for data analysis that recognizes both internal and external analytical needs, the current or anticipated data availability, and the building-block process through which the major products of LTPP will be developed. The LTPP data analysis plan defines the analytical efforts completed, currently under way, and yet to be undertaken that seek to explain why and under what circumstances pavements perform as they do. This plan is not a collection of stand-alone projects. It is a coordinated set of interrelated analyses, with the outcomes of some becoming input to others. Although each analysis has the potential of producing insights leading directly to products, equally important is the potential for results of one analysis to provide needed information for subsequent analyses. Generically, the types of data analyses to be conducted include studies of variability in traffic, materials, and performance data; validation of existing pavement design procedures; and comparisons of pavement performance.

As AASHTO decides annually, on a project-by-project basis, the level of its support of the LTPP studies, the NCHRP funding of LTPP data analysis fluctuates from year to year. This fluctuation, and the uncertainty about which projects will be funded in any given year, have constrained efforts to implement the data analysis plan in an order that maximizes the data's usefulness.

Data analysis projects already completed have addressed a broad array of topics, from field validation of pavement design procedures to studies of variability in traffic and materials data and the development of pavement roughness. Some analysis findings have already led to the development of products such as LTPPBind, software for predicting minimum pavement temperatures, which has been incorporated into the Superpave system of hot-mix asphalt materials design. As the Superpave system moves into general application, FHWA has estimated that the improved precision in the selection of asphalt binder will save the nation as much as $50 million per year.

Another product derived from analysis is the *1998 Supplement to the AASHTO Guide* (*6*) and the supporting FHWA Rigid Pavement Design software. Other findings provide valuable insights and direction to improve future LTPP data collection and analysis efforts. In Appendix 4 (p. 39), detailed information on the status of data analysis and the strategic plan that guides current analytical efforts is provided.

PRODUCTS

Products derived from LTPP have been flowing to the state departments of transportation (DOTs) and other segments of the highway community since the early years of the program. Initially these were methods, guidelines, and procedures for standardized testing and performance data collection. Although these procedures were developed as part of LTPP, their conversion into standard practices has been an AASHTO activity. Among products of this type are the LTPP *Distress Identification Manual* (*7*), new test methods to determine resilient modulus of cohesive and granular soils, and procedures for calibrating falling weight deflectometers. As the studies continue and newer technologies are adopted for use in LTPP, additional products like these will emerge. Currently, the FHWA LTPP Research Team, with the advice of the TRB LTPP Committee's ETG on Traffic Data Collection and Analysis, is developing calibration procedures for weigh-in-motion (WIM) devices—another step toward satisfying the expectation of the DOT chief engineers for improved WIM data collection [see Appendix 5 (p. 57)]. The practical application of products like these is that highway agencies will make better design and maintenance decisions and include better data in their asset management systems.

The LTPP database is, of course, LTPP's principal product. The database is a continually expanding and improving repository of data about in-service highway pavements in North America. It is already the most comprehensive source of pavement performance data ever assembled, and it will continue to be a primary source of data for analysts around the world. It will be used more extensively and will have more impact on highway pavement research than the data collected at the American Association of State Highway Officials (AASHO) Road Test, conducted from 1958 to 1960, which was the last major road test in the United States.

DataPave, an extract of commonly requested data on an easy-to-use compact disc (CD), is one of LTPP's most popular products. DataPave is software developed specifically to address the needs of occasional data users for whom access and manipulation of the entire database have proved difficult and confusing. The CDs produced by FHWA have enjoyed wide international distribution, and the feedback has been congratulatory and enthusiastic. An updated version is in development.

In any discussion of LTPP products, it is important to note that the expected products do not spring fully formed from the database. They are the outcome, first, of careful analysis and, then, the translation of the analytical findings into procedures and guidelines that can be used by highway engineers and managers.

Many of the most significant products developed from LTPP data will come not from the LTPP Research Team but from external researchers. For example, the new pavement design guide, being developed under NCHRP Project 1-37a, makes extensive use of LTPP data but is not a product of LTPP. Similarly, LTPP data are being used to verify the utility of various test methods being suggested as simple performance tests to be included in the Superpave system. As engineers know, reliable field data are invaluable to research like this, making it suitable for general use.

TEA-21, which reauthorized support for LTPP through 2003, charged FHWA with "the preparation of products to fulfill program objectives. . . ." FHWA's Office of Pavement Technology (OPT) is playing a key role in responding to this requirement for direct development of products within LTPP. Early in 1999, the FHWA LTPP Team and OPT began drafting a plan for the development and delivery of LTPP products. The TRB LTPP Committee formed the Subcommittee on LTPP Product Development and Delivery to maintain regular liaison with the FHWA team developing this plan. The role of the subcommittee is to provide comments and advice on this product plan as its development continues. The product development plan identifies the specific needs expressed by the states and provinces and tracks the development and delivery of products to meet these needs. The plan also defines a process for encouraging and supporting the development of LTPP products, and it outlines the roles and responsibilities within the LTPP community for that development.

POTENTIAL PRODUCTS

The product plan is more a continuing process than a definitive plan. As additional data are collected, and as more data analysis is completed, potential products are identified and added to the plan's tracking system. Therefore, progress is better measured by the number of products in the pipeline than by the percent of the plan completed. Six products are currently available, and approximately 20 potential products have been identified. In 2004, there are likely to be 10 products available and 40 potential products identified. FHWA has published the plan under the title *LTPP Product Plan* (*1*). A more detailed report on the status of the development of LTPP products is provided in Appendix 5 (p. 57).

Before passage of TEA-21, product development had been pursued using technology development resources outside of LTPP research funds. From 1993 to 1998, LTPP product development was managed within FHWA by a team from the Office of Technology Applications and OPT. It was this team that developed the DataPave software and translated findings of LTPP into standard practices in cooperation with AASHTO. This team also undertook the technology transfer activities necessary to deliver these products to the highway engineering community. The Office of Technology Applications, the special team, and the funds supporting product development disappeared with the passage of TEA-21 or soon thereafter. These changes have had the effect of turning the congressional instruction for LTPP to engage in "product preparation" into an "unfunded mandate." OPT has continued development of DataPave, the LTPP Profile Viewer, and LTPPBind, and AASHTO has allocated some funds for the development of LTPP products, but it is unlikely that much progress will be made in delivery of additional LTPP products in the current constrained circumstances.

Chapter 3
The Work Still to Be Done

Though LTPP is barely 12 years into the 20-year data collection effort, it is rapidly approaching a crucial moment. The federal-aid highway authorization legislation that currently supports LTPP expires at the end of September 2003. Presuming that the next reauthorization period will, like TEA-21, have a length of 6 years, it is critical to program success. Although it may be difficult to envision clearly all of the needs that must be met in the next 8 to 10 years if the LTPP studies are to satisfy the expectations held for them, sound plans must be laid now to meet those needs.

The work ahead for LTPP can be simply stated. It is to (*a*) complete data collection on all pavement test sections of prime value, (*b*) conduct data analysis according to the defined plan, and (*c*) develop products in a disciplined manner.

Accomplishing this work and meeting expectations will not be simple, however. Anything that jeopardizes the conduct of the work ahead is a matter of grave concern that must be addressed in planning for the reauthorization period. It is the task of FHWA to craft complete plans for the work that remains and to develop budgets that ensure that the work will be completed and the expectations held for LTPP will be met. If data gaps and shortfalls exist in 2009, there may be no further opportunity for remedy. In looking ahead to 2009, the following concerns must be addressed if LTPP is to succeed.

FUNDING CONCERNS

To execute its plans for data collection, data analysis, and product development, LTPP needs to receive sufficient funding from FY 2004 through FY 2009. TEA-21 provides, after the statutory limitation on the obligation of funds, $9 million per year for LTPP. This amount is insufficient to operate the program as planned. To address this shortfall, the member departments of AASHTO provided, through NCHRP, approximately $4.4 million per year in 1999, 2000, and 2001. On May 20, 2001, the AASHTO Board of Directors again authorized expenditure of NCHRP funds in support of LTPP. However, this support comes at the price of diminished NCHRP funding of other high-priority research needs. It seems unlikely that this continuing drain on NCHRP resources can be sustained for another 7 or 8 years.

Also, as AASHTO annually decides the level of its support for LTPP on a project-by-project basis, the total amount provided fluctuates from year to year. Consequently, opportunities to initiate planned data analysis projects when they would be most productive might be lost due to funding shortages. As the LTPP studies approach conclusion, it will be increasingly difficult to recover from losses associated with this fluctuation. Delayed analysis projects and the products they could generate may never be completed.

DATA CONCERNS

The database is the essence of LTPP. Collecting and entering the data into the database is the core activity. Providing data from the database to analysts, now and in the future, is the key objective. The database is LTPP's principal legacy to highway engineering, and the success of LTPP will be measured by its future use.

All data components in the data collection plan appear there because they can contribute to understanding the relationship among environment, pavement loading, and performance. Any portion of the performance data that is missing is a gap in the database that could prevent complete development of this understanding.

Three potential gaps of major significance must be closed. These gaps are (*a*) traffic volume and load data collection at the SPS sites, (*b*) selected materials testing on certain SPS projects, and (*c*) completion of the performance monitoring on a schedule that identifies the onset and development of distress at each test section.

Traffic data collection and SPS materials testing have been responsibilities of the individual state and provincial DOTs. Although every agency has made good-faith efforts to discharge these responsibilities, problems of data quality and timely monitoring and testing have arisen. Closing these gaps in the traffic loading and materials data is of the utmost importance to the success of LTPP.

An action plan has been developed for closing the gaps in the traffic data. This plan has been communicated to the states and provinces. A majority of states with SPS sites have agreed to participate in a centrally managed effort for collection of WIM data. Others, who did not agree with the central management concept, restated their commitment to provide the data they were originally asked to collect. Of the states that agreed to participate in the action plan, most also agreed to contribute to a pooled fund to pay for implementation of the plan; others agreed to participate but were unable or unwilling to contribute to the pooled fund. Some states with no obligation for SPS traffic data collection have also volunteered to participate in the pooled fund, essentially making their funds available for the good of all. It is imperative that this action plan be implemented aggressively and without delay and maintained throughout the 2004 through 2009 period.

A strategy for remedying the gap in materials data has been defined, but a detailed action plan remains to be developed. Because some of the concerns involve quality and variability in testing that has already been done, the only remedy might be renewed sampling at test sites and central testing to ensure quality and limit variation. If necessary, much of this work will also be done in the new authorization period simply because funds are not available to do it any sooner.

Collection of pavement performance data has always been the responsibility of the LTPP Research Team and subject to central control and budgeting. The TEA-21 reduction in funding, however, required lengthening the period between rounds of data collection for some types of pavement performance data. This is worrisome because reduced monitoring frequencies might make it impossible to distinguish the timing of the onset and progress of distress among different test sections at the same SPS test sites or between different test sites of the same experiment. Should this happen, it may confound future data analysis. Implementation of the previously planned but more expensive data collection schedules will limit the chance of this occurring. The ability of the database to support data analysis and product development should be assessed continuously. Any gaps in the performance data should be identified quickly and steps taken to close these gaps.

Among the many threats to the success of long-term projects is simple weariness. At any moment, it would be easy to conclude that the work has gone on long enough. If the LTPP studies are to meet generally held expectations, the data collection must be pursued to its logical conclusion.

Chapter 4
Beyond 2009

A key measure of the success of LTPP will be the legacy it leaves to future engineers and researchers. A comprehensive evaluation of this potential legacy must be made during the coming period, and plans must be drawn to secure the legacy beyond 2009.

Obviously, the database will be the major component of that legacy. If nothing else is done, plans to assure future access to the database must be formulated before the expiration of the current program. Materials recovered from the test sections and the test sections themselves might also constitute part of the LTPP legacy. As future researchers learn more about the behavior of pavements and their constituent materials, it may be profitable to retest certain materials or revisit LTPP test sites if they still exist. In this way, LTPP performance data can be used to verify theories of pavement performance developed in the future.

DATA COLLECTION, STORAGE, AND MANAGEMENT

Each LTPP test section has a unique timeline. For some sections, the timeline ends when 20 years of performance data have been collected. For others, it ends when an amount of data sufficient for LTPP analysis has been collected. And for yet others, it is when the condition of the test section renders collection of additional data unproductive. Ideally, LTPP data collection ends when all useful data from each test section have been collected. Since data collection on some sections only started in the mid- to late 1990s, useful data could be collected on those test sections beyond 2009.

Researchers and engineers in the federal government, state highway departments, industry associations, consulting firms, and universities will use the LTPP database in research, development, and design projects for decades to come. Some of the future applications of these data can only be conjectured. The responsible course is to leave to future generations the most complete assemblage of high-quality data possible and to develop a set of recommendations concerning long-term, post-LTPP maintenance and operation (i.e., receipt and response to requests for data).

Although the database is a resource that does not deteriorate with time and is not consumed by use, the materials samples presently stored in the Materials Reference Library are vulnerable to age and consumption. Decisions must be made soon regarding the collective responsibility to store these samples in ways that minimize deterioration, to provide portions of these samples on request, and to preserve a minimal amount of this material for only the most critical research.

Figures 3-1 and 3-2 in Appendix 3 (p. 30) show that some 600 test sections are expected to still be in service in 2009. The uncaptured value of the data that still could be collected from these test sections will be a function of their distribution both geographically and within the 17 experiments and cannot be estimated at this time. It is probably fruitless to continue data collection on the last surviving test site from any one experiment. On the other hand, if particular experiments still have healthy populations with adequate geographic distribution, it would be irresponsible to fail to investigate the uncaptured value of those test sections and to make considered decisions on how to proceed. A decision is also needed on the merits of permanently marking the location of all LTPP test sections so future researchers could revisit them.

DATA ANALYSIS

A product-driven (i.e., strategic) plan for the analysis of LTPP data has been developed and expanded and is being implemented. Although this plan has finite boundaries in scope and time, analysis of LTPP data beyond these boundaries will continue for decades. The status of data analysis will need to be assessed on an annual basis and the strategic plan updated whenever appropriate throughout the remaining time frame of LTPP as an operational programmatic activity. When the LTPP program shuts down, a final assessment of the database and update of the strategic plan will serve as a guide for analysts in the years immediately following.

PRODUCT DEVELOPMENT

A plan and a process for fostering the development of products from LTPP activities have been developed and are being implemented. Although it is impossible to predict the pathways that LTPP product development will follow or the ingenuity that will be applied in the development of innovative engineering tools, it is reasonable to expect these activities to continue for decades. Historically, it has been difficult to track the success of engineering innovations and ascribe their origin to particular research efforts. The LTPP database must be maintained as an easily accessible source of data and information for the development, validation, and calibration of highway engineering tools.

Chapter 5
What Will Be Lost If the Job Is Not Completed

The Interstate highways and other components of the National Highway System are approaching the end of their effective service lives. Since 1970, vehicle miles traveled have more than doubled and the average daily loads have increased almost sevenfold (*1*). Many segments of this network have already surpassed their design lives and require frequent repair. State and municipal networks are facing the same crisis. Highway and transportation agencies nationwide are under pressure to produce pavements that perform better and last longer. This demand cannot be met using the current suite of pavement engineering and management tools. The needed tools will only emerge from research.

This research has already begun. Considerable progress has been made through research in pavement materials because of the concentration on this topic in SHRP, NCHRP, and federal and state programs. Renewed interest in pavement quality has sparked research in performance-related specifications for paving materials and construction. NCHRP Project 1-37a, which is developing a new pavement design guide, marks a major step forward in the application of mechanistic principles to pavement design. The LTPP database will continue to be a principal source of pavement performance data used by those conducting this research and developing these new guides and by those seeking to apply these advances in real-world settings.

LTPP data are also being used to verify the utility of new tests proposed for inclusion in the Superpave system. As such research is completed, LTPP data will again be used to calibrate the new findings to regional conditions and to permit continuous quality improvement of engineering tools. Analyses of data will also reveal new concepts in design or indicators of performance, such as variation in concrete slab curvature, that can be adapted to pavement design and management systems. LTPP data will be used to verify that new materials or construction specifications proposed to improve pavement quality really do so.

That LTPP data are being used now does not indicate that the job is complete. Pavement distresses observed in the studies so far are primarily confined to the lighter-duty test sections. To learn the lessons required to design long-life, high-performance pavements, it is crucial to continue to track the performance of the more robust test sections. It is their performance that will yield the knowledge needed to develop, verify, and calibrate the designs demanded by 21st century highway networks. It is their performance that will demonstrate how to manage and maintain these new pavements. If LTPP stops now, what will have been learned is only how to build and maintain 20th century pavements better. Much more is needed.

Chapter 6
Recommendations

It is worth emphasizing at every opportunity the importance to the success of LTPP of the continuing collaboration of the states and Canadian provinces, AASHTO, FHWA, and TRB. Every entity has much to do if LTPP is to succeed, and the recommendations that follow will require the efforts of all in support of the one identified to take the lead.

The TRB LTPP Committee recommends that FHWA take the following actions to address the concerns identified here, to prepare for the interagency dialogs that are likely to ensue as the reauthorization legislation is drafted and debated, and to be operationally ready for the FY 2004 through FY 2009 period that is expected to be critical to the success of LTPP:

1. It is recommended that FHWA develop research plans and budgets for the Fiscal Years 2004 through 2009 that are consistent with the view of the future described in this report. Although the costs projected by the FHWA LTPP Research Team appear reasonable, sound and explicit budgets and work plans are essential if LTPP is to be fairly considered in the coming reauthorization discussions.

2. Three potential gaps of major significance must be closed before the termination of data collection. These gaps are (*a*) traffic volume and load data collection at the SPS sites, (*b*) selected materials testing on certain SPS projects, and (*c*) completion of the performance monitoring data collection on a schedule that identifies the onset of distress at each test section.

   The committee recommends that closing these gaps be given the highest priority by FHWA in the FY 2004 through FY 2009 time frame:
   - Implement the traffic data action plan aggressively and without delay;
   - Develop and implement an action plan for collecting SPS materials data; and
   - Implement enhanced data collection schedules as soon as possible.

3. In 2006, approximately halfway into the next period of federal-aid highway authorizing legislation, it will be possible to estimate more accurately what the program's accomplishments will be in 2009, and what more, if anything, should still be done. This will also be the appropriate time to lay plans to secure future access to the database and any other items of residual value.

   It is recommended that FHWA conduct a program assessment in FY 2006 for the following primary purposes:
   - To determine whether data collection activity may be concluded before or in FY 2009, or will have to continue beyond FY 2009, to capture performance data from SPS test sections that were built in the late 1990s; and
   - To determine whether remaining gaps in the database compromise mission completion and warrant further efforts to close these gaps.

4. There are lessons from the past that can be applied to LTPP. At present, data from the AASHO Road Test and the regional road tests conducted in the 1950s are no longer generally available. Materials from the AASHO Road Test were so freely distributed that they were consumed within several years. This made it impossible to link Road Test performance data to advances in materials testing and theory.

   It is recommended that FHWA develop plans to secure the legacy of LTPP. These plans for the post-LTPP time frame should cover the following activities:
   - Storage, maintenance, and user support of the LTPP database;
   - Storage and user support of LTPP's off-line Auxiliary Information Management System;

– Storage and user support of LTPP's Materials Reference Library;
– Continued implementation of LTPP data collection;
– Continued implementation of the Strategic Plan for LTPP Data Analysis; and
– Continued implementation of the *LTPP Product Plan* (*1*).

REFERENCES (CHAPTERS 1–6)

1. *LTPP Product Plan.* FHWA-RD-01-086. FHWA, U.S. Department of Transportation, 2001.
2. *Highway Statistics 1999.* FHWA, U.S. Department of Transportation, 2000.
3. *Special Report 202: America's Highways: Accelerating the Search for Innovation.* TRB, National Research Council, Washington, D.C., 1984.
4. *AASHTO Guide for the Design of Pavement Structures.* American Association of State Highway and Transportation Officials, Washington, D.C., 1993.
5. *Key Findings from LTPP Analysis, 1990-1999.* FHWA-RD-00-085. FHWA, U.S. Department of Transportation, 1985.
6. *1998 Supplement to the AASHTO Guide for the Design of Pavement Structures: Part II, Rigid Pavement Design and Rigid Pavement Joint Design.* American Association of State Highway and Transportation Officials, Washington D.C., 1998.
7. *Distress Identification Manual for the Long-Term Pavement Performance Project. SHRP-P-338.* National Research Council, Washington, D.C., 1993.

Appendix 1
LTPP Background

The need for a long-term pavement performance (LTPP) program was first raised in the Transportation Research Board's (TRB's) *Special Report 202,* prepared by a panel of senior leaders in the transportation community, who noted that highway pavements frequently did not live up to design expectations and who recommended a "long-term field test that systematically covered a wide range of climate, soil, construction, maintenance and loading conditions . . ." (*1*). In response to this recommendation, the American Association of State Highway and Transportation Officials (AASHTO) funded the development of the design for such a program (*2*).

THE "BLUE BOOK"

Special Report 202 (known as the "Blue Book") stated the purpose of LTPP as

> to develop a database for pavement performance over a wide range of conditions and service life factors. The database can then be used to answer the following important questions about pavement management and design:
>
> – What are the proper design and construction procedures for pavement rehabilitation and overlays to provide economical renewed pavement life?
> – What are the effects of various types and levels of pavement maintenance on pavement life and performance? What is the cost-benefit of pavement maintenance?
> – What is the cost of deferred maintenance and the ultimate effect on the life of the highway?
> – What are the effects of climatic and environmental variables on pavement life and pavement performance?
> – Are the long-term load effects (load magnitude, type, frequency, and summation of loads) now correctly evaluated for pavement design and construction methods?
> – Is it necessary to reevaluate the load equivalency factors developed from the AASHO Road Test in order to apply them over a wide variety of pavement strengths, material types, and environments?
> – What are the relative effects and interactions of load and environment (climatic) variables on pavement deterioration, performance, and service life?
> – What are the effects of varying subgrade materials types and strengths on pavement construction requirements and ultimate performance?
> – What is the load-carrying capacity of a pavement when the design life is reached?
> – What are the effects of alternative drainage designs on pavement performance and service life?

It is clear from these words that LTPP was intended to develop, over the 20-year period, a database that could be used to answer a number of high-priority questions being asked within the highway pavement community. It is not certain that the authors of the Blue Book expected LTPP to produce the answers within this period as no anticipated product delivery dates were noted nor did the cost estimates provided address data analysis.

THE "BROWN BOOK"

Subsequent to the publication of the TRB report, AASHTO led the development of more detailed plans to carry out the report's recommendations. These plans were published in *Strategic Highway Research Program: Research Plans* (*2*). The "Brown Book," as it came to be known, identified the activities planned for LTPP over a 20-year period—including site selection, data collection, data storage, analysis, and products—that would answer the questions posed in the Blue Book. The Brown Book laid out statistically sound experiments designed to lead to "better predictive models for use in design and pavement management, much better understanding of the effects of many variables on pavement performance, and new techniques for design and construction."

The Brown Book offered this goal:

> 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.

Specific objectives adopted to support this goal were to

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

The general results and products anticipated from LTPP were listed as

- Standardized data collection procedures, demonstrations of state-of-the-art data collection equipment, impetus for development of improved data collection equipment, a national pavement database, and a pavement data management system;
- Improved pavement performance models, original design methods, rehabilitation design methods, evaluation methods and procedures, design and rehabilitation strategy procedures, and life-cycle cost analysis;
- Quantification of effects on pavement performance of subsurface drainage, subgrade, load, materials, and pavement condition prior to rehabilitation; and
- Evaluations of new materials and innovative design and rehabilitation techniques.

When the Strategic Highway Research Program (SHRP) was initiated in 1987, these expectations guided the ultimate contract research program. The final experiment designs were based on the Brown Book experiment designs reconfigured for efficiency and to accommodate the realities of far-flung field experiments. SHRP began LTPP data collection in 1989. In 1992, the Federal Highway Administration (FHWA) assumed management of LTPP, and the Intermodal Surface Transportation Efficiency Act (ISTEA) authorized continuation of LTPP along the lines defined by SHRP.

Although the Brown Book remains one of the seminal documents of LTPP, it must be noted that the activities it defined and planned focused almost exclusively on data collection, as evidenced by the absence of budget estimates for analysis or product development. The budget for data collection was also based on the assumption that the states and provinces would conduct traffic data collection and Specific Pavement Studies (SPS) materials testing at their own expense. During the initial 5-year start-up phase of LTPP, the $10-million-per-year budget estimate proved remarkably accurate. This start-up budget, however, provided only modest funds for analysis and none for product development. As LTPP necessarily evolved to include data analysis and product development as major activities, and as the SPS sections were built, it is not surprising that the funds needed to conduct LTPP full bore would ultimately exceed the Brown Book's estimate of $10 million per year. As the administration of LTPP was turned over to FHWA, the SHRP Executive Committee estimated that the annual budget for LTPP would increase to around $14 million per year.

STATES' EXPECTATIONS

ISTEA was slated to expire in 1997, and LTPP would have to be reauthorized in new federal-aid highway legislation if the studies were to continue. In anticipation of this, in 1995, FHWA sought to determine the high-priority needs of the states for answers from LTPP and to redefine the program's promises and the states' expectations accordingly. Senior transportation officials in eight states were interviewed to elicit their expectations of LTPP.

States Convey Their Needs to LTPP: A Summary Report on Expectations (*3*) records the interviewees' expectations in the form of the following questions and statements:

- 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 weigh-in-motion (WIM) technology. We need to measure equivalent single axle loads more accurately.

These expectations echo strongly those cited in the Blue Book and Brown Book but have a more tangible feel. The chief highway engineers interviewed were more explicit in their desire for useful engineering tools and an enhanced knowledge base on which to base management and engineering decisions.

In response to these state officials, the TRB SHRP Committee, which at that time provided program review and advice to FHWA and AASHTO on the conduct of LTPP, recommended an enhanced program of data analysis (Letter Report from Charles L. Miller, TRB SHRP Committee Chairman, to Rodney E. Slater, FHWA Administrator, and Francis B. Francois, AASHTO Executive Director, August 9, 1995).

After some delay, new federal-aid highway authorization legislation was signed into law in June 1998. This Transportation Equity Act for the 21st Century continued funding for LTPP and added an explicit task for LTPP to "prepare products to fulfill program objectives and meet future pavement technology needs." Although it was generally expected that LTPP would yield such products, this was the first instance of legislative mandate for the program to manage product development.

THE MISSION OF LTPP

LTPP's mission, which has evolved with time to meet these promises and expectations, is to foster increased pavement life by conducting three interrelated activities:

- Collection and storage of performance data from a large number of in-service highways in the United States and Canada, over an extended period, to support analysis and product development;

• Analysis of these data to describe how pavements perform and to explain why they perform as they do; and

• Translation of these insights into products for pavement design, rehabilitation, maintenance, and management.

Although all three of these activities are important, populating the database with complete data of high quality is the principal activity. Without abundant high-quality data, neither the insights into pavement performance nor the delivery of the products usable by the states is possible.

LTPP's PARTICIPANTS

LTPP includes the departments of transportation (DOTs) for the 50 states, the District of Columbia, Puerto Rico, the 10 provincial transportation agencies of Canada, FHWA, AASHTO, the Canadian Strategic Highway Research Program, and the many engineers, researchers, and technicians in the employ of these organizations directly involved in the conduct of LTPP studies. By extension, LTPP also includes the paving industry, highway user groups, materials suppliers, equipment manufacturers, and those engineers and researchers who use LTPP research results.

FHWA provides the central team of researchers and analysts responsible for general management of the program and maintenance of the database. The FHWA team also collects performance data at each LTPP test section, conducts data analyses to ensure that the studies are yielding the quantity and quality of data needed for success, and manages the development of the products. The individual state and provincial DOTs are responsible for the construction and maintenance of the test sections and data collection related to the history, the construction materials and the traffic characteristics of each section, and the provision of traffic control required for other LTPP data col-

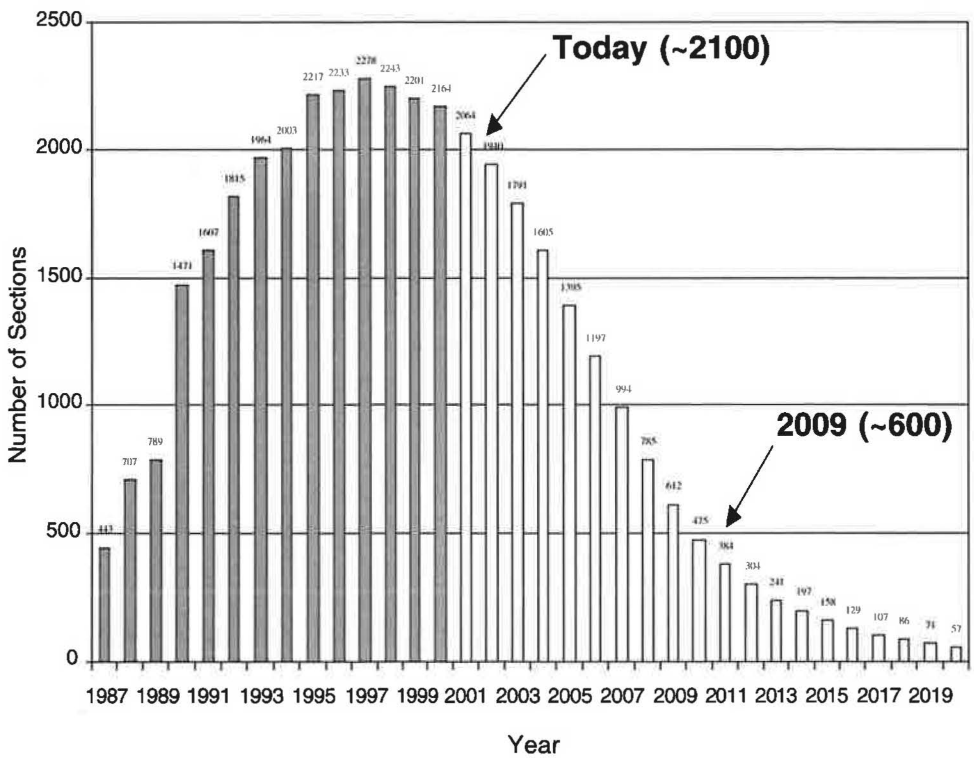

FIGURE 1-1 Variation in number of LTPP test sections over time.

lection activities. Each year since 1998, AASHTO, through its Standing Committee on Research has allocated a portion of NCHRP funds for LTPP data analysis projects and provided funds to FHWA to supplement the data collection budget. TRB, through the LTPP Committee, provides a continuing review of progress and advises FHWA and AASHTO on the conduct of the studies. By incorporating experts drawn from throughout the highway pavement community, the committee functions as the forum for the development of consensus advice about LTPP.

LTPP's TIME FRAME

Twenty years is generally understood to be the time frame for LTPP. This estimate was first offered in *Special Report 202* (*1*) and has been maintained subsequently as reasonable for accomplishing the fundamental mission of the program. For most LTPP test sections, the actual data collection time frame will be less than 20 years. Many of the test sections will go out of service before 20 years of monitoring. On the other hand, many of the SPS sections built in the 1990s will still be in service beyond the nominal 20-year data collection period that concludes in 2009, but they will not have 20 years of monitoring. Figure 1-1 shows the current prediction for the future decline in the number of test sections, indicating that 600 or more test sections will still be in service in 2009. It is too early to determine if monitoring these test sections beyond 2009 will be warranted. With this one possible and understandable exception, the original promise or expectation of 20 years of data collection for LTPP will be kept.

REFERENCES

1. *Special Report 202: America's Highways: Accelerating the Search for Innovation.* TRB, National Research Council, Washington, D.C., 1984.
2. *Strategic Highway Research Program: Research Plans.* TRB, National Research Council, Washington, D.C., 1986.
3. *States Convey Their Needs to LTPP: A Summary Report on Expectations.* AASHTO and FHWA, Oct. 1995.

Appendix 2
LTPP Funding

Probably no aspect of the LTPP studies has evolved more since the program's inception than its funding and administration. Initially, LTPP was one of four research programs known collectively as the Strategic Highway Research Program (SHRP), which was administered by the National Academy of Sciences, and received $50 million of the $150 million provided to SHRP by the Surface Transportation and Uniform Relocation Assistance Act of 1987. In 1992, the administration of LTPP was transferred to the Federal Highway Administration (FHWA). From 1992 through 1997, the Intermodal Surface Transportation Efficiency Act (ISTEA) provided $37.5 million for LTPP, and FHWA provided an additional $49.7 million from its research and technology funds. As shown in Figure 2-1, this averaged $14.5 million per year, approximately the amount that the SHRP Executive Committee estimated would be needed to sustain the LTPP studies when their administration was transferred from SHRP to FHWA. In 1998, the Transportation Equity Act for the 21st Century (TEA-21) provided $10 million per year for LTPP, subject to the legislatively mandated limitation on obligations. Through FY 2001, LTPP has received $36.35 million or approximately $9 million per year from TEA-21. This amount is significantly below the amount needed to conduct LTPP as planned and budgeted, particularly in view of the new legislative requirement in TEA-21 for LTPP to directly develop and prepare products.

In late 1998, when the dramatic reduction in the federal LTPP investment became evident, the American Association of State Highway and Transportation Officials Board of Directors unanimously voted to supplement the federal dollars with funding through the National Cooperative Highway Research Program (NCHRP). NCHRP has provided $13.27 million through 2001, or approximately $4.4 million per year, beginning effectively in 1999. Figure 2-1 illustrates the average annual national expenditure on LTPP through the SHRP, ISTEA, and TEA-21 time frames. At this time, the exact amount of the TEA-21 allocation for FY 2002 and FY 2003 is unknown, and there is no guarantee that NCHRP funds will be provided for FY 2003.

The total national investment to date in LTPP is $173.6 million dollars. Although a substantial amount, it is still less than the inflation-adjusted cost of the AASHO Road Test of 1958 to 1960, the last major study of pavement performance previous to LTPP. The American states and Canadian provinces have also provided financial support for LTPP for the construction of the test sections, materials testing, traffic data collection, and all of the management, staff, and equipment needed for a broad array of LTPP activities including traffic control during data collection. It is estimated that the states and provinces have contributed between $50 million and $75 million to LTPP in services and direct expenditures. Additionally, the past year has seen groups of state departments of transportation (DOTs) enter into pooled fund agreements in support of LTPP activities for which no other support is available.

PROJECTIONS OF FUTURE FUNDING NEEDS

As reported elsewhere in this document, substantial increases in effort will be needed to fill gaps in data collection that have opened in recent years and to prevent irremediable gaps from opening in the future. Increased effort will also be needed in data analysis and product development if the expectations for LTPP are to be met. Presumably, these increases will require additional funding.

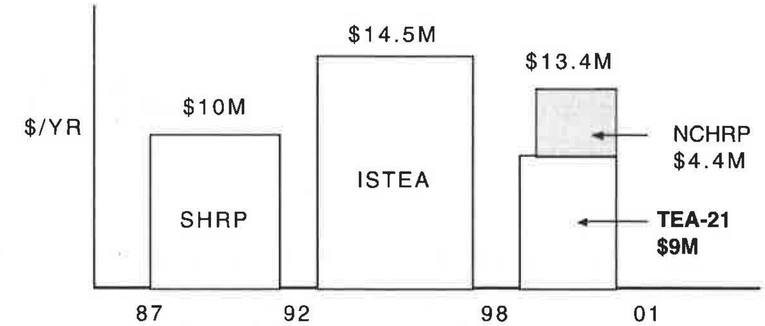

FIGURE 2-1 Previous LTPP funding.

The Transportation Research Board (TRB) LTPP Committee is not in a position to define or recommend budgets for the conduct of LTPP. On the other hand, if the committee is to recommend changes to the conduct of the studies during the period from FY 2004 through FY 2009, some scale of the economic impact of these recommendations must be presented. The most accurate information on the cost impact of changes in LTPP activities will, of course, come from the LTPP research team, at least when projected activities are similar to those currently in progress. As the committee developed its vision of the future, the research team was repeatedly asked to provide cost estimates for each contemplated activity. Table 2-1 provides a summary, by year, of the estimates developed for the FY 2004 through FY 2009 time period for all projected activities. The total of these estimates exceeds $124 million for the 6-year period.

TABLE 2-1 LTPP Annual Cost Projections, FY 2004–FY 2009: Preliminary Estimates Provided by FHWA LTPP Research Team

Cost Item	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Data Collection						
Pavement Performance & Seasonal Monitoring						
Deflection Testing	$1,618,403	$1,510,975	$1,166,529	$1,158,357	$881,862	$764,819
Profile Surveys	$1,731,652	$1,656,104	$1,473,878	$1,390,028	$1,148,644	$973,961
Manual Distress Surveys	$1,245,736	$1,247,843	$984,914	$995,755	$646,205	$580,102
Photographic Surveys	$1,164,695	$1,012,778	$872,855	$762,249	$643,647	$522,380
Subtotals:	$5,760,485	$5,427,699	$4,498,176	$4,306,388	$3,320,357	$2,841,262
Climatic Database Updates						
2004 Update	$112,551	$0	$0	$0	$0	$0
2008 Update	$0	$0	$0	$0	$126,677	$0
Subtotals:	$112,551	$0	$0	$0	$126,677	$0
Traffic Monitoring						
SPS Projects	$3,637,307	$1,985,257	$2,149,652	$2,246,611	$2,588,771	$1,506,230
GPS Sections	$1,770,707	$1,619,635	$1,424,151	$1,158,578	$918,288	$638,465
Subtotals:	$5,408,014	$3,604,892	$3,573,804	$3,405,189	$3,507,060	$2,144,695
Materials Testing						
P07 (AC) Resilient Modulus Testing	$1,232,432	$1,704,133	$447,770	$0	$0	$0
Missing SPS Materials Test Data	$838,504	$1,584,154	$746,283	$0	$0	$0
Subtotals:	$2,070,936	$3,288,287	$1,194,052	$0	$0	$0
Drainage Surveys						
Geomorphologic Characterization	$180,081	$185,484	$0	$0	$0	$0
Drainage Surveys	$110,581	$113,899	$117,316	$120,835	$124,460	$128,194
Subtotals:	$290,663	$299,383	$117,316	$120,835	$124,460	$128,194
Within Section Thickness Surveys						
AC Test Sections	$475,246	$489,503	$504,189	$0	$0	$0
PCC Test Sections	$179,462	$184,846	$190,392	$0	$0	$0
Subtotals:	$654,708	$674,350	$694,580	$0	$0	$0
Forensic Studies						
High-Level Studies	$450,204	$502,352	$573,145	$623,136	$655,933	$532,945
Mid-Level Studies	$315,142	$351,646	$401,202	$436,195	$459,153	$373,062
Low-Level Studies	$157,571	$175,823	$200,601	$218,098	$229,576	$186,531
Subtotals:	$922,917	$1,029,822	$1,174,947	$1,277,429	$1,344,662	$1,092,538

(continued)

TABLE 2-1 (*continued*) LTPP Annual Cost Projections, FY 2004–FY 2009: Preliminary Estimates Provided by FHWA LTPP Research Team

QA Review of Operations						
QA Review of Operations	$146,766	$151,169	$155,704	$160,376	$165,187	$42,536
Distress Accreditation Workshops	$99,270	$102,248	$105,315	$108,475	$111,729	$57,540
Profiler Rodeos	$35,454	$36,517	$37,613	$38,741	$55,865	$0
Subtotals:	$281,490	$289,934	$298,632	$307,591	$332,781	$100,076
Equipment: New and Maintenance						
FWDs & Maintenance	$956,682	$57,964	$59,703	$61,494	$63,339	$65,239
Profilers & Maintenance	$56,275	$637,601	$656,729	$61,494	$63,339	$65,239
Other Equipment & Maintenance	$168,826	$173,891	$179,108	$184,481	$190,016	$195,716
Subtotals:	$1,181,784	$869,456	$895,539	$307,468	$316,693	$326,193
Subtotal - Data Collection	$16,683,548	$15,483,822	$12,447,048	$9,724,901	$9,072,690	$6,632,958
Data Management						
Regional Activities						
Data Processing & QC	$648,293	$667,742	$1,146,290	$1,180,679	$243,220	$250,516
Problem/Feedback Report Resolution	$270,122	$278,226	$477,621	$491,950	$101,342	$104,382
AIMS Implementation Support	$162,073	$166,935	$286,573	$295,170	$60,805	$62,629
Subtotals:	$1,080,488	$1,112,903	$1,910,484	$1,967,798	$405,366	$417,527
Database Operations & Customer Support						
Data Processing & QA	$270,122	$278,226	$286,573	$787,119	$202,683	$208,764
Problem/Feedback Report Resolution	$54,024	$55,645	$57,315	$393,560	$40,537	$41,753
AIMS/Metrication Support	$81,037	$83,468	$85,972	$78,712	$60,805	$62,629
Customer Support	$108,049	$111,290	$114,629	$118,068	$81,073	$83,505
Database Backups & Security	$27,012	$27,823	$28,657	$157,424	$20,268	$20,876
Subtotals:	$540,244	$556,452	$573,145	$1,534,883	$405,366	$417,527
Data Management System						
Hardware & Software Upgrades	$112,551	$115,927	$119,405	$122,987	$126,677	$130,477
Coding of Computed Parameters	$288,130	$296,774	$305,677	$314,848	$324,293	$167,011
Database Metrication	$360,163	$370,968	$764,193	$0	$0	$0
AIMS Implementation	$432,195	$445,161	$458,516	$472,272	$486,440	$250,516
MRL Management	$112,551	$115,927	$119,405	$122,987	$126,677	$130,477
Subtotals:	$1,305,590	$1,344,758	$1,767,197	$1,033,094	$1,064,087	$678,482
Subtotal - Data Management	$2,926,323	$3,014,113	$4,250,826	$4,535,775	$1,874,820	$1,513,537
Other Data						
Planning	$0	$0	$0	$245,975	$253,354	$0
Transition of IMS/AIMS	$0	$0	$0	$0	$146,610	$150,258
Disposition of Equipment	$0	$0	$0	$0	$63,339	$65,239
Final LTPP Reports	$0	$0	$0	$0	$253,354	$260,955
Program Assessment	$0	$0	$238,810	$245,975	$253,354	$260,955
TRB Committees & ETGs	$685,000	$670,000	$644,000	$596,000	$528,000	$445,000
Subtotal - Other Data	$685,000	$670,000	$882,810	$1,087,950	$1,498,010	$1,182,406
Total - Data	$20,294,871	$19,167,935	$17,580,684	$15,348,626	$12,445,520	$9,328,901
Analysis						
Preliminary Analyses/Computed Parameters	$337,653	$463,710	$477,621	$860,912	$253,354	$521,909
Higher Order Analyses	$1,688,263	$1,738,911	$2,089,592	$2,189,175	$3,166,925	$3,261,933
TRB Committees & ETGs	$88,000	$88,000	$98,000	$123,000	$151,000	$189,000
Total - Analysis	$2,113,916	$2,290,621	$2,665,212	$3,173,087	$3,571,279	$3,972,842
Products						
Product Development	$450,204	$556,452	$764,193	$1,082,289	$1,621,466	$2,087,637
Product Delivery	$112,551	$139,113	$191,048	$270,572	$405,366	$521,909
TRB Committees & ETGs	$44,000	$51,000	$59,000	$81,000	$121,000	$166,000
Meetings & Workshops	$450,204	$231,855	$477,621	$285,152	$506,708	$502,536
Publications & Documents	$236,357	$472,714	$118,178	$354,535	$196,964	$196,964
Total - Products	$1,293,315	$1,451,133	$1,610,041	$2,073,549	$2,851,504	$3,475,047
Totals	**$23,702,101**	**$22,909,688**	**$21,855,938**	**$20,595,261**	**$18,868,303**	**$16,776,790**

Notes: QA = quality assurance; QC = quality control; IMS = Information Management System; AIMS = Auxiliary Information Management System; MRL = Materials Reference Library; AC = asphalt concrete; PCC = portland cement concrete; FWD = falling-weight deflectometer.

Because of the significant cost increases in the research team estimates, the committee sought some independent test of reasonableness that could be applied to those estimates. To do so, the committee has attempted to assign a dollar value to the historic levels of effort expended on the three principal functions of LTPP and to extrapolate to future work efforts expressed in monetary terms. This approach requires many assumptions about the equivalencies of past and future work. These extrapolations are the best collective judgment of the committee and are presented only as a test of the relative cost impacts of projected changes in levels of effort. They are not recommended budgets, nor does the committee recommend adoption of the preliminary estimates prepared by the research team. It will be left to the FHWA program managers to prepare actual budgets reflecting the program changes envisioned. These actual budgets should be expected to vary from the projections included here.

DATA COLLECTION AND MANAGEMENT

Data collection and management is, by far, the largest and most expensive of the three LTPP functions. As such, it is the set of activities requiring the most detailed test of the reasonableness of projected estimates.

Because these activities have evolved greatly since the onset of data collection, extrapolations to some future level of effort necessarily lack precision. Data collection activities today are not what they were 10 years ago, or what they will be even 3 or 4 years from today. It is possible, however, to create reasonable historical estimates of the average annual data collection cost per test section. From these historical estimates and knowledge of the effort entailed, it is possible to convey a sense of how the scale of activities recommended for FY 2004 through FY 2009 will compare to the present in monetary terms. Using this information, it is possible to test the reasonableness of the research team's preliminary estimates by comparing the projected costs per test section of the projected activities to historical estimates reflecting a similar level of effort.

Historical Estimates of Data Collection Costs per Section

When LTPP was managed as a part of SHRP, 1989 was the first year in which field data collection was fully under way. In that year, approximately $7 million were expended on data collection and management for 760 test sections or approximately $9,300 per section (*1*). Test section identification, demarcation, and materials sampling and testing were the dominant cost factors at that time. SHRP also invested heavily in communications and coordination with the participating states and provinces during this start-up phase. Nondestructive performance testing was also under way at a frequency somewhat greater than today. Conversely, data management cost was relatively low.

During the ISTEA period, FHWA reported spending an average of $13.5 million annually on a 6-year average of 2,085 test sections or approximately $6,500 per section. This drop in cost can be attributed to the cessation of general drilling and sampling and completion of most of the materials testing activities. Also, the growth in the number of test sections reduced the mean distance between test sections, so unproductive travel time was reduced. Data management costs, on the other hand, began to climb. The volume of data was growing geometrically, and several expensive computer hardware and software upgrades were necessary. This period also saw a major effort to monitor a subset of test sections on a seasonal basis and to collect local climatic data for this subset as well.

In 1998, the first year of TEA-21, total expenditures for data collection fell to $8.79 million for 2,243 test sections or roughly $3,900 per test section. This figure reflects the arbitrary constraint imposed by the TEA-21 budget reductions, and data collection in this year was below the necessary minimum for the health of the experiments. For example, no photographic distress records were obtained in 1998, and the frequencies of other monitoring activities were reduced to a minimum. Data management was at a low level, and other data-related activities were pared back.

In 2000, the budget was still constrained, but NCHRP support for data collection and management activities was now available. The FHWA was able to spend $10.96 million on data collection and management for 2,164 test sections or approximately $5,100 per test section. This expenditure still reflects a reduction in performance data collection frequency. Performance monitoring dominated the data collection activities. Data management costs were also above the 1998 level. For purposes of constructing future projections of work, FY 2000 is used as the base year.

Figure 2-2 summarizes the recent historical and projected future expenditures for LTPP. In preparing the projections, it has been assumed that funding will remain flat through FY 2003. This means that most efforts to fill data collection gaps or to accelerate data analysis and product development will be delayed until 2004. This delay has the effect of inflating the future estimates above what they might be if remedies could be put in place immediately. Given the evident reluctance of Congress to appropriate funds for highway research above the levels authorized in TEA-21, the assumption of flat funding seems reasonable.

The committee projection shows a rapid increase in the level of effort devoted to data collection and management in 2004. This increase is followed by a slow decline in expenditure to a level below the current by 2009. The increase primarily reflects a major jump in levels of effort for data collection.

Projected Estimates of Data Collection Cost per Section, FY 2004–2009

To fill existing gaps in data collection and forestall the development of others, increases in the level of effort devoted to data collection are necessary. The largest increase will result from increasing the frequency of nondestructive testing. Plans for this increase were laid some time ago and have been delayed because of the current financial shortfall. The projections used here are based on estimates developed by the LTPP Research Team in that earlier planning exercise and should be reasonably accurate. Other smaller increases in the level of effort will be occasioned by on-site subsurface drainage surveys of selected Specific Pavement Studies (SPS) test sections,

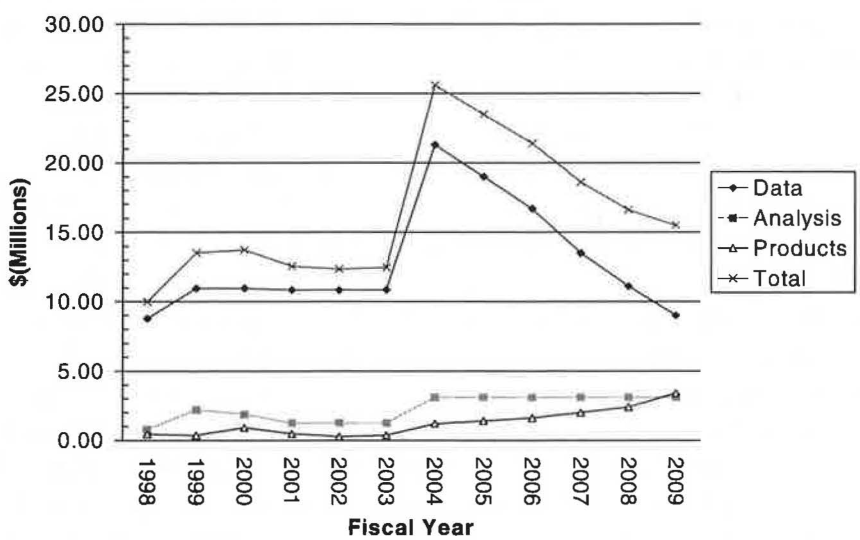

FIGURE 2-2 Projected LTPP work, FY 2004–FY 2009, expressed in dollars.

periodic updates of the climatic database, and one-time, ground-penetrating radar surveys to estimate within-section pavement thickness.

Another large increase will come from a renewed effort to complete the materials sampling and testing for the SPS studies. Depending on the ultimate assessment of the quantity and quality of SPS materials data obtained from the state DOTs, this effort might rival the scale of sampling and testing conducted for the General Pavement Studies (GPS). Based on the GPS experience, this increase may be as much as $3,000 per test section for approximately 900 test sections. Because the number of test sections leaving service each year will accelerate with time, this work must be started and completed as soon as possible. Three years seems a reasonable time period for this work based on the GPS experience. The estimate provided here is probably close to the maximum that might be necessary if assessment of SPS data quality and quantity is particularly bleak.

Forensic studies will be needed as the SPS test sections go out of service. Although no technical plans are yet in place for such studies, it is presumed they will require considerable effort. Because it will be difficult to predict when particular test sections will begin to fail, this effort will be largely responsive, with investigative teams required to react quickly when state transportation departments report the need to rehabilitate a failing test section for safety reasons. Although the research team provided year-by-year estimates, for purposes of this report, the committee has adopted a simple estimate of $1 million per year. Actual experience will probably vary markedly from year to year. Until more detailed plans for forensic investigations are developed, estimates of cost will remain very imprecise.

Although traffic data collection is currently a state function, the committee has included it in these projections. Whether traffic data collection is to become a centrally administered activity in the future or is to be left to the states is undecided. Regardless of who collects these data in the FY 2004 through FY 2009 time period, however, someone will incur substantial cost that is not currently budgeted, hence its inclusion here.

Table 2-2 assigns a dollar value for the anticipated increase in work effort per section for the FY 2004 through FY 2009 time period. In addition to data collection and management activities, the table also shows associated costs for communications and coordination, the recommended program assessment activity in 2006 and 2007, and presumed costs for final reports and disposition of the database and residual materials. The estimated levels of effort for these last two items are little more than placeholders. The projected level of effort for communications and coordination reflects the experience of the last several years. During the period of renewed sampling and testing, additional effort may be needed.

The figures shown in Table 2-1 can be tested for reasonableness against the historical estimates cited in Table 2-2. From FY 2004 through FY 2006, when data collection activities will be at their peak, the average cost per section will be slightly more than $9,000. This compares very well to the per section costs from 1989 ($9,300) when the array of activities and level of effort expended was most similar. In 2007 and beyond, the costs per section will decline to approximately $8,300. If the additional cost for forensic studies is excluded, the total falls to $7,100 per section, reasonably in line with the $6,500 cost per section of the ISTEA period.

These comparisons lead to the conclusion that the FHWA LTPP research team estimates for data collection costs in the FY 2004 through FY 2009 period are at least reasonable. When associated costs for communications, coordination, report publication, and the mid-period assessment are included, the estimated cost for data collection and management activities will be approximately $90 million to $95 million. This figure must be considered in light of all of the caveats cited above. This is only an aggregated projection of preliminary estimates tested for reasonableness against historical levels of effort. Many of the activities projected for the FY 2004 through FY 2009

TABLE 2-2 Projected Increases in Cost per Section, FY 2004–FY 2009

	FY 2004	*FY 2005*	*FY 2006*	*FY 2007*	*FY 2008*	*FY 2009*
Base Level (FY 2000) Cost/Section	$5,100	$5,100	$5,100	$5,100	$5,100	$5,100
Materials Sampling and Testing	$500	$1,000	$700	$0	$0	$0
Nondestructive Performance Testing	$1,900	$1,900	$1,900	$1,900	$1,900	$1,900
Subsurface Drainage Surveys	$200	$200	$100	$100	$100	$100
Climate Database Updates	$200	$0	$0	$100	$0	$0
Forensic Studies	$1,200	$1,200	$1,200	$1,200	$1,200	$1,200
Cost/Section	$9,100	$9,400	$9,000	$8,400	$8,300	$8,300
Traffic Data Collection	$3,800	$3,800	$3,800	$3,800	$3,800	$3,800
Total Cost/Section	$12,900	$13,200	$12,800	$12,200	$12,100	$12,100
Number of Active Sections	1605	1395	1197	994	785	612
Annual Cost	$20,704,500	$18,414,000	$15,321,600	$12,126,800	$9,498,500	$7,405,200
Other Associated Costs						
Communications and Coordination	$600,000	$600,000	$600,000	$600,000	$600,000	$600,000
Program Assessment and Planning	$0	$0	$750,000	$750,000		
20-Year Reports and Disposition	$0	$0	$0	$0	$1,000,000	$1,000,000
Subtotal	$600,000	$600,000	$1,350,000	$1,350,000	$1,600,000	$1,600,000
Total Annual Cost	$21,304,500	$19,014,000	$16,671,600	$13,476,800	$11,098,500	$9,005,200
					Total for Data Collection and Management	$90,570,600

time frame will be entirely new to LTPP, and the historical record may be an inaccurate predictor of future costs. When budgets built around well-defined plans are developed, significant variation from this estimate can be expected.

DATA ANALYSIS

Projection of the investment needed for data analysis is derived directly from the Strategic Plan for Data Analysis. This plan, described in Appendix 4 (p. 39), lays out the minimum program of analysis that must be followed if LTPP is to meet the expectations held by the state highway agencies and the highway industry. The Expert Task Group (ETG) on LTPP Data Analysis periodically reassesses this plan and updates the estimated cost of completion. Table 2-2 shows the likely funding requirement for each of the major objectives and subobjectives included in the plan. A contingency of 10 percent has been added to these estimates, as the true scope of projects pursued in later years is imprecisely known. Because some of the projects included in the plan build upon the successful completion of other projects, or require performance data not yet available, these estimates cannot be precisely tied to a calendar. Therefore an annual average for analysis by objective is projected, rather than estimates of actual year-to-year costs. Actual expenditures will vary from these averages. The projection for completion of the Strategic Plan for Data Analysis as currently formulated is $15.5 million or approximately $2.6 million per year.

In addition to analyses directed at satisfying the explicit expectations of LTPP program participants and stakeholders, more fundamental data studies must be undertaken on a continuing basis. These studies analyze the trends evident in specific types of data and the correlation among different classes of data known or supposed to be related. These analyses provide a quality-assurance check on the basic experiments and on data entering the database. A secondary outcome of these data studies is practical information about data trends and relationships that are useful in establishing the likelihood that more ambitious analyses will be successful. If, for example, data studies indicate limited development of distress in particular experiments, then analysts would know that more time is needed before a particular analysis dependent on variation in accumulation of these distresses is undertaken.

Because of the size and number of data types in the LTPP database, these types of analyses could consume significant funding. Judgment must be exercised in limiting these analyses to key variables that provide maximum quality assurance benefits. Over the past several years, FHWA has invested approximately $500,000 per year in data studies. For purposes of projecting future needs, this figure seems reasonable.

Thus the overall average annual funding needed to pursue the minimum required data analysis program is $3.1 million per year for a total of $18.6 million over the 6-year period. This figure is slightly larger than the estimate provided by the LTPP Research Team, but reasonable concurrence is evident.

PRODUCT DEVELOPMENT AND DELIVERY

As mentioned, TEA-21 imposed a mandate on the LTPP research effort to "prepare products to fulfill program objectives and meet future program needs," but it provided no funds explicitly for this purpose. The LTPP Research Team has developed a plan and process for product development, and mechanisms for delivery of such products are being developed in cooperation with the FHWA Office of Pavement Technology. Both FHWA and NCHRP have undertaken modest product development projects. If, however, product development and delivery is to ever be more than a token activity, specific funding must be allocated.

In developing projections for resource needs for product development and delivery, caution must take precedence. Even the most aggressive data collection and analysis efforts are naturally bounded by the experiment designs and data availability. Product development and delivery, however, have no such natural boundaries. Because of the sheer magnitude of pavement investments made by transportation agencies each year, a cost-effectiveness argument can be posed for almost any product that seems likely to reduce pavement cost or extend pavement life. Without exercise of due caution, all of the funds likely to be made available for product development and delivery might be consumed by the first few products to emerge from analysis, leaving no funds for future product delivery.

The FHWA *LTPP Product Plan* released in 2001 recognizes the need for caution (*2*). The planned approach includes a comprehensive product identification component so that all product development and delivery resources are not consumed by the first few products identified. Most of the LTPP products already identified are of a technical, rather than technological, nature [Appendix 5 (p. 57)]. That is, they are changes to procedures, guidelines, specifications, and the like. Such products generally are not as expensive to develop as new test devices or construction equipment. Presuming that products identified in the future will generally be similar, relatively modest resources should suffice for LTPP product development in the FY 2004 through FY 2009 period. Several million dollars a year will permit a significant, but manageable, increase in effort from current levels. As analysis will lead product identification, resources required at the beginning of the period will be smaller than those needed at the end. Figure 2-2 shows an initial estimate of $1.25 million for product development in 2004. As the findings of analysis increase in number, this will grow to about $3.5 million in 2009. Actual annual budgets for product development will, of course, be a function of the pace at which findings emerge and the nature of the resulting products.

This projection of resources needed for product development and delivery must be accompanied by major caveats. The projection is based on the presumption that the majority of products will be technical in nature and the scope of delivery efforts will be limited. It is very easy to conceive, however, of products requiring levels of effort well beyond those anticipated. If, for example, analytical findings reveal a new relationship between some materials property and extended performance, the resulting product may require a development and training effort of

TABLE 2-3 Projected Work Effort, 2004–2009, for All LTPP Components, Expressed in Dollars (Millions)

Function	Actual Expenditure			Presumed Expenditure			Projected Level of Effort by Fiscal Year (millions of dollars)						Total
	1998	1999		2001	2002	2003	2004	2005	2006	2007	2008	2009	2004 – 2009
Data	8.79	10.96	10.96	10.85	10.84	10.85	21.3	19.0	16.7	13.5	11.1	9.0	90.6
Analysis	0.77	2.21	1.88	1.24	1.24	1.24	3.1	3.1	3.1	3.1	3.1	3.1	18.6
Products	0.44	0.35	0.90	0.47	0.27	0.37	1.2	1.4	1.6	2.0	2.4	3.4	12.0
Total	10.00	13.52	13.74	12.56	12.35	12.46	25.6	23.5	21.4	18.6	16.6	15.5	121.2
Target Funding							26	24	21	19	17	16	123

unanticipated scope. An example from recent experience is the Superpave system of asphalt materials selection and paving design. In such cases, the scope of the development and delivery effort must be correlated to the anticipated benefits of the product, not to a projected budget for the LTPP studies. Funding for such efforts must also be found elsewhere. They cannot be accommodated within the projections given here.

Similarly, if analytical findings suggest new technologies for pavement management data collection, the development of such technology cannot be pursued within the LTPP program if funding is limited to projected levels.

The projected product development and delivery effort will provide a continuing capacity for identification of potential products and development and delivery of a number of relatively straightforward technical products. It is not intended to be a major technology development and transfer effort.

TOTAL PROJECTED FUNDING REQUIREMENT

As is evident from Table 2-3, the total projected funding required to carry the LTPP studies satisfactorily from FY 2004 through FY 2009 is between $120 million and $125 million. This figure represents the best collective judgment of the TRB LTPP Committee. The purpose of this estimate is only to provide economic scale to the recommendations of the committee for work that should be pursued during the FY 2004 through FY 2009 time period. It should not be construed as an estimated budget. Although the level of effort projected here might form the foundation of future funding requests, such requests should be supported by more detailed estimates based on accurate, up-to-date financial information. This is particularly true for activities such as ground-penetrating radar surveys that have not previously been employed in the LTPP studies. Additionally, the true dimensions of the perceived gaps in data collection should be more precisely determined.

The level of effort projected here far exceeds that currently expended on the LTPP studies. This projection anticipates the closing and prevention of serious gaps in the data collection efforts and expanded efforts in data analysis and product development so that the LTPP program fulfills its mission to extend pavement life through research.

REFERENCES

1. *Strategic Highway Research Program Annual Report, 1990.* National Research Council, Washington, D.C., 1991.
2. *LTPP Product Plan.* FHWA-RD-01-086. FHWA, U.S. Department of Transportation, Washington, D.C., 2001.

Appendix 3

LTPP Data Collection Status

The LTPP program is, by far, the largest effort ever undertaken to collect pavement performance data. Since the start of LTPP data collection more than a decade ago, more than 100 million records, occupying some 13 gigabytes of storage space, have been accumulated in the LTPP database, and the collection will continue to grow as original expectations of LTPP come to fruition.

Provided in this appendix is an overview of the status of LTPP data collection. As used herein, the term "data collection" encompasses all of the activities that culminate in the release of data from the LTPP database. Thus, it includes not only the actual collection and processing of data, but it also includes the development of the procedures used in collecting and processing the data and the development of the database in which the data are stored.

EXPERIMENTS

LTPP comprises two broad sets of experiments: the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS). The GPS experiments study in-service pavements in common use across the United States and Canada that incorporate materials and designs representing good engineering practice. The pavement types considered in the GPS experiments are identified in Table 3-1. The pavements studied in the GPS experiments were not constructed to meet specific LTPP criteria, and most were in service before LTPP monitoring began.

The SPS experiments were designed to enable comparison and study of specific design features or treatments. The specific pavement designs or treatments called for in the SPS experimental designs were constructed with multiple test sections (having different designs) at each test site. Data were collected before, during, and after construction to fully characterize test section conditions. The LTPP SPS experiments are identified in Table 3-2.

TEST SECTIONS

Currently, there are approximately 2,100 active LTPP in-service highway test sections throughout the United States and Canada. Figures 3-1 and 3-2 illustrate the evolution in the number and distribution of LTPP test sections among the GPS and SPS experiments over time. Obviously, the values shown for FY 2005 and FY 2009 are projections. In the early years, the number of test sections increased as the SPS projects were constructed, with the total number of sections reaching a peak value of almost 2,300 in 1997. Attrition and migration of test sections from one experiment to another (e.g., from GPS-1 or SPS-1 to GPS 6B) occur as test sections are rehabilitated or go out of service for other reasons. By FY 2009, it is estimated that the number of active LTPP test sections will be about 600.

DATA COLLECTION

The data collected for LTPP test sections are intended to fully characterize pavement performance, as well as the conditions (pavement structure, materials, climate, traffic, etc.) associated with that performance. To date, the data collected to characterize LTPP test sections include the following.

TABLE 3-1 LTPP GPS Experiments

Experiment	Title
GPS-1	Asphalt Concrete (AC) on Granular Base
GPS-2	AC on Bound Base
GPS-3	Jointed Plain Concrete Pavement
GPS-4	Jointed Reinforced Concrete Pavement
GPS-5	Continuously Reinforced Concrete Pavement
GPS-6A	Existing[1] AC Overlay of AC Pavement
GPS-6B	Planned[1] AC Overlay of AC Pavement
GPS-7A	Existing[1] AC Overlay of Portland Cement Concrete (PCC) Pavement
GPS-7B	Planned[1] AC Overlay of PCC Pavement
GPS-9	Unbonded PCC Overlay of PCC Pavement

[1] The distinction between "existing" and "planned" overlays is that planned overlays were placed after monitoring of pavement condition, such that pre-overlay condition data are available in the LTPP database. Existing overlays were in place before the start of LTPP monitoring, such that only anecdotal information on pre-overlay condition is available.

TABLE 3-2 LTPP SPS Experiments

Experiment	Title
SPS-1	Strategic Study of Structural Factors for Flexible Pavements
SPS-2	Strategic Study of Structural Factors for Rigid Pavements
SPS-3	Preventive Maintenance Effectiveness of Flexible Pavements
SPS-4	Preventive Maintenance Effectiveness of Rigid Pavements
SPS-5	Rehabilitation of Asphalt Concrete Pavements
SPS-6	Rehabilitation of Jointed Portland Cement Concrete Pavements
SPS-7	Bonded Concrete Overlays of Concrete Pavements
SPS-8	Study of Environmental Effects in the Absence of Heavy Loads
SPS-9	Validation of SHRP Asphalt Specifications and Mix Design and Innovations in Asphalt Pavements (Superpave Validation)

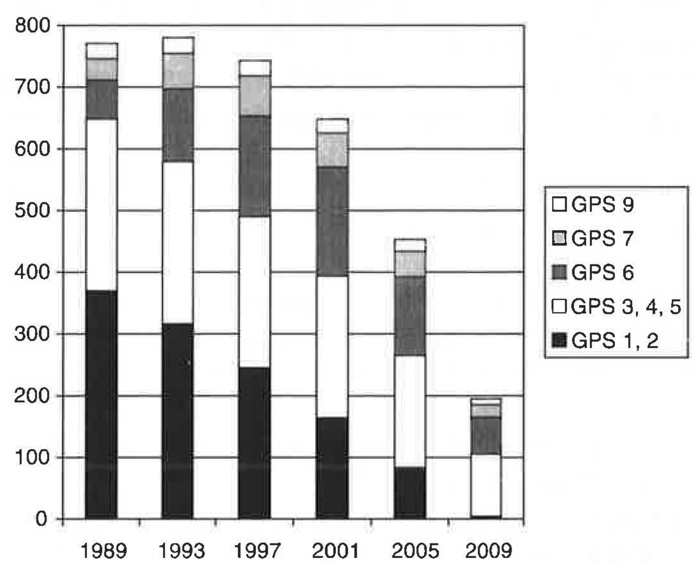

FIGURE 3-1 Number of active LTPP GPS test sections, 1989–2009.

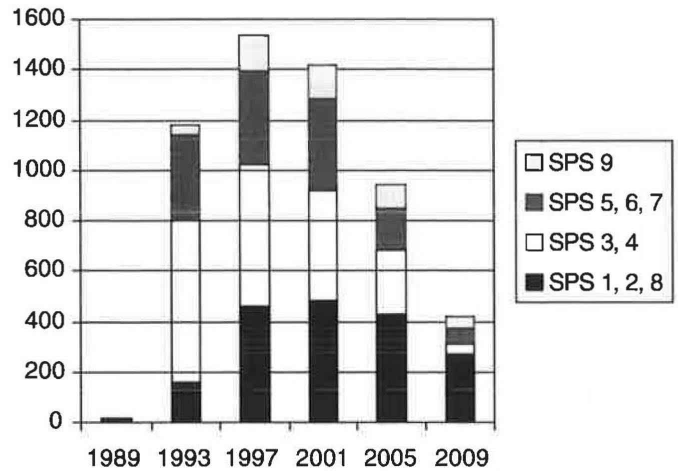

FIGURE 3-2 Number of active LTPP SPS test sections, 1989–2009.

Inventory and General Data

Basic information on test section location, construction dates, geometry, and data characterizing the pavement cross section and materials derived from agency records. These data are referred to as inventory data for the GPS and general data for the SPS. Collection of these data is essentially complete.

Test Data

Data characterizing the pavement cross section and materials obtained via sampling and laboratory testing of materials. These data are referred to as test data. Most of the materials testing for the GPS has been completed, with the primary exceptions being the resilient modulus testing of asphalt concrete (AC) cores and testing for the coefficient of thermal expansion of portland cement concrete (PCC). This testing was delayed by difficulties in developing repeatable test procedures. The AC resilient modulus testing has also been delayed by funding constraints.

Overall, the following testing for which the Federal Highway Administration (FHWA) is responsible remains to be completed:

- Resilient modulus for 244 unbound material samples,
- Resilient modulus for 1,500 bound material samples, and
- Coefficient of thermal expansion for 2,200 PCC cores.

The number of AC resilient modulus tests required is increasing at a rate of about 240 specimens per year, as LTPP test sections are overlaid.

Efforts are under way to complete SPS materials testing in all states. LTPP staff and contractors are working with the states to resample where necessary and to help complete the testing. Significant issues related to materials testing currently exist for SPS projects in nine states. Efforts to more fully characterize the gaps that may remain are in progress. Table 3-3 shows the status of materials test data as of January 2000. Additional data collection is needed in these areas:

TABLE 3-3 Completeness of Available LTPP Materials Test Data as of January 2000

Parameter	Percentage of Pavement Layers Represented in the LTPP Database with Required Test Data Complete														
	GPS Experiments										SPS Experiments[1]				
	1	2	3	4	5	6A	6B	7A	7B	9	1	2	5	6	8
AC Layer Thickness (TST-AC01-LAYER)	85.4	85.6	NA	NA	NA	87.7	77.5	NA	NA	NA	59.2	NA	66	2.3	100
Bulk Specific Gravity for Asphalt Bound Layers (TST-AC02)	98.3	97.9	NA	NA	NA	95.6	85.9	97.8	100	100	8.3	NA	22	43	50
Maximum Specific Gravity for Asphalt Bound Layers (TST-AC03)	93.1	95.7	NA	NA	NA	93.7	84.7	93.3	100	100	90	100	26	33	40
Asphalt Content (TST-AC04)	94.1	96.6	NA	NA	NA	97.7	88.1	1.1	95.5	50	74	86	31	33	40
Moisture Susceptibility of Asphaltic Concrete (TST-AC05)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	67	NA	0	NA	100
Gradation of Extracted Aggregate from Asphaltic Concrete	94.4	96.1	NA	NA	NA	96.1	90	90.9	95.1	50	78	66	24	100	75
Unconfined Compressive Strength of Treated Base, Subbase, and Subgrade Layers (TST-TB02)	NA	100	91	57	88	NA	75	100	NA	100	NA	NA	NA	50	NA
Atterberg Limits for Unbound Base, Subbase, and Subgrade Layers (TST-UG04-SS03)	92.5	93.1	92.4	95.5	96.7	90.7	78.1	96.7	91.7	97.5	74.2	85.7	30.6	33.3	40
Gradation of Coarse, Fine, and Combined Aggregate (TST-SS01-UG01-UG01)	91.6	92.6	89.3	95.4	95.8	90.8	77.1	95.2	83.3	94.9	69	57	61	59	75
Unconfined Compressive Strength of Subgrade Soil (TST-SS10)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	43	20	NA	NA	75

[1] Percentages reflect only those pavement layers for which some data are available in the LTPP database.

Maintenance and Rehabilitation Data

Data describing the maintenance and rehabilitation treatments applied to the test sections and the materials used. Collection of maintenance and rehabilitation data is an ongoing activity that cannot be completed until LTPP monitoring concludes. Keeping these data up-to-date is particularly challenging, as the required information often resides with highway agency personnel who are not actively involved in LTPP. Thus, periodic review of the data will be required to ensure that gaps in the maintenance and rehabilitation data do not develop.

Traffic Data

Traffic data collection is also an ongoing activity, which, unlike most LTPP data collection activities, is accomplished by the states. Traffic data collection has always been a challenge for LTPP, in part because traffic data collection technology has not lived up to the early expectation that it would be economically and technically feasible to install reliable weigh-in-motion (WIM) equipment at every LTPP test site. As a consequence, traffic data are incomplete relative to original expectations. Complete, high-quality traffic data are available for some sites, while little or no traffic data are available for others.

For the majority of LTPP test sites, traffic data availability falls somewhere in between. Twenty-three percent of the sections have complete vehicle classification data for 4 or more years between 1990 and 1999, and 11 percent have complete WIM data for the same time frame. Sixteen percent of the LTPP test sections lack monitored classification data for these years, and 23 percent lack monitored loading data for the same time period.

An effort to improve the traffic data situation for the SPS, referred to as the SPS Traffic Data Initiative, is currently under way. The centerpiece of this initiative is a pooled fund project to provide for central collection of traffic data for the SPS-1, SPS-2, SPS-5, and SPS-6 projects, as well as calibration of the WIM equipment used to collect the data. Data collection on a pilot-test basis was completed in the fall of 2001, and the full-scale data collection component of this initiative is expected to begin in the spring of 2002.

Deflection, Profile, and Distress Data

Pavement deflection, profile (both transverse and longitudinal), and distress data characterizing the structural and functional condition of the pavement over time. These monitoring data are the heart of the LTPP performance monitoring effort, and their collection is ongoing.

The monitoring requirements for LTPP have evolved over the years. One outcome of a program assessment undertaken in 1996 was a recommendation that the monitoring frequency of LTPP test sections be adjusted based on the potential of the test sections to contribute to achieving LTPP objectives. Each test section was assigned to one of four monitoring categories, depending on the experiment to which it was assigned and the completeness of the data collected to date. The monitoring requirements that were to have been implemented as a result are summarized in Table 3-4. This monitoring scheme was never implemented, however, because the current LTPP budget is insufficient to support the recommended monitoring frequencies. The current (less than optimal) LTPP monitoring requirements are summarized in Table 3-5.

TABLE 3-4 LTPP Monitoring Requirements: Desired

<table>
<tr><th>LTPP Experiment</th><th>Profile</th><th>Distress</th><th>FWD</th></tr>
<tr><td>SPS 1 & 2
SPS 5 & 6
SPS 8</td><td>Quarterly measurements with rotating months</td><td>Annual photographic survey and semi-annual manual surveys</td><td>Full coverage[2] every 3 years; partial coverage quarterly with rotation of month every year</td></tr>
<tr><td>SPS Supplemental</td><td>Same as core sections</td><td>Photographic surveys same as core sections and only responsive[3] manual surveys.</td><td rowspan="2">Full coverage every 5 years and responsive, full coverage testing</td></tr>
<tr><td>SPS 9 & GPS 1, 2, 3, 4, 5, 6B/C/D/S,7B/C/D/F/R/S[1], 9</td><td>Annual measurements</td><td>Photographic survey every 3 years and responsive manual surveys</td></tr>
<tr><td>GPS 6A & 7A, SPS 3, 4, 7</td><td>One last measurement</td><td>One last measurement</td><td>One last measurement</td></tr>
</table>

[1]Test sections having experiment designations of 6B, 6C, 6D, 6S, 7B, 7C, 7F, 7R, and 7S were monitored as LTPP test sections before rehabilitation. The rehabilitation treatments applied by the owner agencies were as follows:

B: Conventional hot-mix asphalt overlay and no structural milling or modifications
C: Overlay using a modified asphalt
D: Conventional hot-mix asphalt overlay of a previously overlaid pavement
F: PCC rehabilitated by crack or break-and-seat treatment with any hot-mix overlay
R: Rehabilitation using CPR treatments, without overlay
S: Asphalt concrete pavement rehabilitated with structural milling or application of fabric, in combination with any hot-mix overlay.
Treatment B is the preferred treatment for the LTPP experiments.

[2]Full coverage means that all test points are tested. Partial coverage means that a selected subset of test points is tested.
[3]Responsive surveys are triggered by an observation of changed condition or notification by the highway agency that some action is planned.

TABLE 3-5 LTPP Monitoring Requirements: Current

LTPP Experiment	Minimum Pavement Monitoring		
	Profile	Distress	FWD
SPS 1 & 2 SPS 5 & 6 SPS 8	Annual	Annual manual, photographic every 2 years	Every 2 years and responsive
SPS Supplemental	Same as core sections	Manual every 3 years, photographic every 2 years, and responsive	Every 5 years and responsive
SPS 9 & GPS 1,2,3,4,5,6B/C/D/S 7B/C/F/R/S, 9	Every 2 years		
GPS 6A & 7A, SPS 3,4,7	One last measurement	One last measurement	One last measurement

As of May 2001 the LTPP database includes, on average, five sets of deflection data per section, seven sets of longitudinal profile data per section, and four sets each of manual and photographic distress survey data per section, with each set of data representing data collection for one test date. Thus, on average, deflection testing has been conducted at 2- to 3-year intervals, while profile measurement and distress surveys have been conducted at intervals of 1 to 2 years.

Friction Data

In the early years of LTPP, the states were asked to collect and submit friction data for LTPP test sections. This requirement was dropped in 1999, as the data already collected were deemed sufficient. Friction data submitted by the states are accepted and entered into the LTPP database, but submission is no longer required. Thus, collection of friction data is essentially complete.

Climatic Data

Data characterizing weather conditions at the test site are typically derived from data collected and disseminated by the National Climatic Data Center for sites in the United States and by the Canadian Climatic Center for the Canadian sites. These data are obtained and added to the LTPP database on a periodic basis. Currently, data through mid-1997 are available. The next update is planned for FY 2004 or FY 2005.

For the SPS-1, SPS-2, and SPS-8 experiments, climatic data are obtained from automated weather stations installed at the test sites. These data are collected on an ongoing basis.

In addition, selected sections included in the LTPP Seasonal Monitoring Program were instrumented to obtain in situ temperature, moisture, and frost penetration data, as well as site-specific precipitation and temperature data. Data collection for the original Seasonal Monitoring Program was concluded in 1999. Currently, a follow-on data collection effort involving a smaller number of sites is ongoing.

Load Response Data

Lastly, the SPS-2 projects in North Carolina and Ohio and the SPS-1 project in Ohio were instrumented to obtain dynamic load response data; collection at the sites has been completed.

Two additional data collection efforts will be initiated later this year—inspection of the drainage systems installed in the SPS-1 and SPS-2 projects, and application of ground-penetrating radar (GPR) technology to obtain within-section pavement layer thickness data on the SPS-1 projects.

DATABASE

Most of the data collected through the LTPP studies are stored in a relational database developed by using ORACLE database software. By virtue of both the inherent nature of relational databases and the magnitude of LTPP, the LTPP database is complex and the logic of its organization is not obvious to the uninitiated. It is, nevertheless, the heart and soul of LTPP.

Although the structure for the majority of the modules and data tables that comprise the LTPP database is complete, development of the LTPP database will remain a work in progress for some time after the conclusion of LTPP performance monitoring. Database development activities that remain fall into four broad categories:

1. Addition of data tables to accommodate data not currently stored in the database. Included in this category are both new raw data, such as the within-section layer thickness data to be obtained through GPR testing, and computed parameter tables to store the results of intermediate computations based on data in the database. Computed parameters, such as backcalculated layer moduli, are expected to be of value to many analysts. Current work in this area includes the development of data tables for performance grade binder, the SPS-9 experiment data, and traffic data. Historically, detailed traffic data have been stored in a separate central traffic database. They are now being incorporated into the main LTPP database.
2. Modifications of the database to address feedback from users of the data. For example, the methodology used to document maintenance applied to LTPP test sections was recently revised, to make it easier for data users to know what was done when.
3. Technological evolution. Modification of the database to accommodate evolution of the computer hardware and ORACLE database software used for the database.
4. Analysis facilitation. Development of standard queries to facilitate delivery of data for common analytical purposes.

OFF-LINE DATA

Although many of the LTPP data are stored in and disseminated from the database, a substantial amount of information also resides off-line. Reasons for this include the nature of the information, the anticipated demand for the information, and limitations of the technology available at the time when initial decisions as to inclusion in the database were made. The most important off-line data are

- Traffic data (the central traffic database);
- Distress maps (hand drawn from manual surveys and digital from photographic surveys);
- SPS construction reports;
- Raw profile data;
- Deflection time-history data from falling weight deflectometer testing;
- Installation and deinstallation reports for the Seasonal Monitoring Program instrumentation;

- Material testing and sampling reports; and
- Equipment calibration and comparison data and reports.

The concept of an auxiliary information management system was devised to address the need to better manage the storage and dissemination of these off-line data. To date, resource limitations have constrained progress toward satisfactory resolution of the associated issues. Work that is in progress or completed includes incorporating traffic data from the central traffic database into the main LTPP database and digitizing manual distress maps so they can be disseminated electronically.

CHALLENGES, THREATS, AND OPPORTUNITIES

LTPP is faced with several challenges in the data collection arena. Foremost among these is simply staying the course. Maintaining a data collection program that requires the ongoing commitment and support of 62 highway agencies is a tremendous challenge. A strong and ongoing commitment to building and maintaining the human relationships that have made LTPP possible is essential if this challenge is to be met.

A second major challenge facing LTPP is the need to rectify several key deficiencies in the database. Although the LTPP database as it stands today is a tremendous asset, its full potential will not be realized if the existing deficiencies in traffic and materials data are not corrected. The ongoing SPS Traffic Data Initiative is beginning to address the traffic problem. Budget proposals for the FY 2004 through FY 2009 time frame include funding to continue this effort and to correct deficiencies in the materials data that may remain if the current efforts to obtain the required data from the states are not fully successful.

The need for forensic evaluation of LTPP test sites has been discussed, on and off, for more than a decade. There is widespread agreement that forensic investigation of LTPP test sections should be pursued. It has been said that premature failures, as well as the exceptional performers, must be examined closely if we are to understand fully why they have performed as they have. Despite all the discussion, there has been no definition of a cost-effective way to accomplish forensic investigation nor has there been success in defining the standard procedures to be employed. Thus, forensic investigation remains as an illusive challenge facing LTPP.

A final challenge facing LTPP in the area of data collection is the need to improve the accessibility of selected off-line or "shoe-box" data. Among the data to be addressed are construction reports for the LTPP SPS projects, the permanent photographic records of pavement distress and distress maps, deflection time-history data, materials sampling and testing reports, and equipment calibration and comparison data and reports.

Among the chief threats to LTPP is weariness. Given the costs, hard work, and challenges associated with conducting LTPP, it is too easy to conclude that this work has gone on long enough. If the initial objectives set out when LTPP was initiated are to be met, however, the majority of the LTPP test sections must be monitored until they fail. Failure to do so will produce a database with a great deal of information about the poorly performing test sections but not nearly enough information about those that perform best. If learning about long-term performance is the goal, the LTPP monitoring period cannot be cut short.

Another threat is the prevalence and perpetuation of misunderstandings and misinformation regarding the value and importance of different parts of the LTPP program. For example, one of the statements made too often is that the GPS experiments are of little value and should therefore be abandoned. A common justification cited for this position is that the materials and practices used in constructing the GPS test sections are no longer used. The GPS test sections are, however, basic hot-mix asphalt and PCC pavements that differ only modestly from more modern pavements. Even the degree to which they differ is firmly established, as are the physical and materials characteristics of each test site. GPS will become a significant database against which new pavement design models and procedures will be tested. The truth of the matter is that the GPS are of great value in their own right, and they are essential as a complement to the SPS. Without the GPS, there is no link to tie what is learned from the specially constructed SPS test sections and from other pavement research to more typical pavement construction practices.

The most important opportunity facing LTPP in the area of data collection is that time remains to remedy the data collection and management deficiencies that remain. It is, however, an opportunity that must be seized and addressed with adequate resources, both capital and human, at the earliest possible date. It seems unlikely that there will be another chance if this one is missed.

SUMMARY ASSESSMENT OF PROGRESS

Since the start of LTPP performance monitoring in 1989, substantial progress in LTPP data collection has been made, but much remains to be done. Excellent progress has been made in the collection and processing of pavement monitoring data and in the more routine materials testing activities for the GPS. Traffic data collection and materials testing for the SPS projects remain as areas of concern.

Appendix 4
LTPP Data Analysis Status

The earliest analyses of the data assembled through the LTPP program were undertaken almost a decade ago. That work, conducted under the auspices of the Strategic Highway Research Program (SHRP), served as the first test of the LTPP database and confirmed that the then-current *AASHTO Guide for Design of Pavement Structures* had outlived its usefulness (*1*). Analysis of the LTPP data, sponsored by the Federal Highway Administration (FHWA), was initiated in 1994 and has been ongoing since that time. Since 2000, as a result of the LTPP budget cut reflected in the Transportation Equity Act for the 21st Century, some analysis of the LTPP data has been conducted via the National Cooperative Highway Research Program (NCHRP). One project has been approved for pursuit as a pooled fund project managed by FHWA.

Described in this appendix is the current status of LTPP data analysis undertaken as a formal part of the LTPP studies. Analyses of LTPP data undertaken by others engaged in non-LTPP investigations are not included.

The November 9, 1999, Strategic Plan for LTPP Data Analysis (the Plan) and the November 3, 2000, LTPP Data Analysis Program (the Program), as updated in April 2001, serve as the frame of reference for assessing status. The work considered in evaluating status includes completed, ongoing, and planned analysis of the LTPP data sponsored by FHWA, NCHRP, and the states (via pooled fund initiatives). Although important, applications of the LTPP data by individual states or other entities are not considered in the assessment.

THE PLAN

The Plan provides a framework to guide analysis of data collected under the LTPP program. It was developed by the Transportation Research Board (TRB) Expert Task Group (ETG) on LTPP Data Analysis, approved by the TRB LTPP Committee (as the basis for evaluating progress and recommending analysis projects), and adopted by FHWA (as the basis for selecting projects to be undertaken).

The Plan's goal is "to develop knowledge, relationships, and models to facilitate improved pavement design and reliable performance predictions." The plan defines seven analysis objectives and identifies a number of analysis outcomes associated with each. These objectives and outcomes are derived from the original LTPP research plans and represent a more thorough definition of the expectations embodied in those plans. The analysis objectives are as follows:

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; and
7. Quantify the performance impact of specific design features (presence or absence of positive drainage, differing levels of pre-rehab surface preparation, etc.).

THE PROGRAM

In 2000, the ETG on LTPP Data Analysis expanded the Plan by developing the Program. The Program comprises a series of interdependent and interrelated current and near-term projects identified as necessary to achieve the objectives of the Plan. Although each project is associated with a particular strategic objective, it must be understood that the outcomes from individual projects may flow in several directions. Some outcomes will be the basis for products, in and of themselves, in addition to feeding into subsequent analysis projects. Subsequent analysis projects dependent on those outcomes may address the same strategic objective or other strategic objectives. Outcomes from projects identified with objectives 1, 2, and 3, in particular, support achievement of the performance prediction objectives (4, 5, 6, and 7).

The projects that comprise the LTPP Data Analysis Program serve two broad functions that must be conducted if LTPP is to fulfill expectations. The first is to provide the basis for identifying and developing products that engineers and managers can apply to design more cost-effective and better-performing pavements. The second is to determine if the data being collected are of the quality and completeness needed to find answers to how and why pavements perform as they do. Since 1997, FHWA's analytical resources have been primarily focused on the latter function, whereas the analysis projects recommended for pursuit via NCHRP or pooled fund mechanisms have focused on the former.

Tables 4-1 through 4-7 summarize the LTPP data analysis projects undertaken between 1994 and 2001. Although many of these projects predate the existence of the Plan, all of them contribute, in some way, to achievement of one or more of its objectives. For the purposes of this summary, each project has been assigned to one Plan objective. The reader should be aware that in many instances a single project would contribute to achievement of several objectives. This is especially true of projects associated with Objectives 1-4.

ANALYSIS STATUS

The status of LTPP data analysis relative to each of the seven Plan objectives is summarized in the next seven subsections of this appendix. An overall assessment of status is provided in the final section of this document. This assessment addresses only the analytical effort that is required. In most cases, additional work will be needed to develop implementable products based on the analytical outcomes defined in the Plan.

Strategic Objective 1: Improve Traffic Characterization and Prediction

The traffic data traditionally collected to support highway planning, pavement management, and design do not provide the information needed to support sound pavement design decisions for roads subjected to high volumes of heavy truckloads. The work to acquire these data, and to analyze the data collected, provide an opportunity to improve the characterization and prediction of the traffic loads to which pavements are subjected. Four analysis outcomes associated with this objective are identified in the Plan. The status of work toward each of these outcomes is described in the following sections.

A. Guidelines for Data Collection

The first outcome defined to achieve improved traffic characterization addresses the question "How do we collect data to meet current and future needs?" Efforts to improve the quality and quantity of traffic data collected for the LTPP Specific Pavement Studies (SPS) experiments have driven considerable progress toward improved guidelines for data collection. Although the traffic data-collection and processing guidelines developed for LTPP data collection are in no sense generic, they provide a starting point for development of more broadly applicable guidelines.

TABLE 4-1 Projects Related to Strategic Objective 1: Traffic Characterization and Prediction

Project	Description of Work	Outputs	Status	Sponsor
WIM Scale Calibration	Highlight the significance of scale-calibration error on LTPP data and describe the drawbacks of auto-calibration techniques currently used by some states to offset calibration errors.	TechBrief FHWA-RD-98-104 provides recommendations for implementing direct WIM scale calibration.	Completed. TechBrief published and distributed.	FHWA
Accuracy of LTPP Traffic-Loading Estimates	Analysis of the effects of varying truck-loading rates and data collection plans on equivalent single axle load estimates at sample sites in the LTPP database.	TechBrief FHWA-RD-98-124 provides basis for LTPP's revised traffic monitoring program and preliminary estimates of the accuracy and reliability of traffic loads used for LTPP research.	Completed. TechBrief published and distributed.	FHWA
Site-Specific Traffic-Loading Data	Quantify the effects of traffic-loading data error on LTPP's ability to develop accurate and reliable design equations.	TechBrief FHWA-RD-98-103 provides findings and recommendations concerning traffic-loading data errors.	Completed. TechBrief published and distributed.	FHWA
Vehicle Volume Distributions by Classification	Analysis of traffic volume and classification data to determine how short-duration truck volume counts can be used to accurately estimate the key variables needed for design, planning, and operational analyses.	TechBrief FHWA-RD-98-117 documents finding that truck volumes vary considerably by time of day, day of week, season, and from location to location.	Completed. TechBrief published and distributed.	FHWA
Traffic Backcasting	Develop and apply procedures to estimate cumulative traffic load spectra for each LTPP test site.	Methodology for estimating traffic load spectra documented in report FHWA-RD-00-054. Estimates of historical load spectra for LTPP test sites. Identification of anomalies in traffic data trends in the LTPP database.	Active. Stage 1 report documenting procedures published and distributed. Application of procedures to LTPP traffic data ongoing.	FHWA
Confidence of WIM Axle Load Data	Determine the confidence of WIM axle load data over time for different site conditions and calibration procedures.	Information to guide collection and evaluation of traffic-loading data.	Pending NCHRP 20-20(15)	NCHRP

TABLE 4-2 Projects Related to Strategic Objective 2: Materials Characterization

Project	Description of Work	Outputs	Status	Sponsor
Prediction of Asphalt Temperatures and Correction Factors	Analysis of LTPP seasonal monitoring data to (1) evaluate and further develop a methodology for predicting a representative pavement temperature in asphalt concrete (AC) pavements; and (2) develop temperature correction procedures for use in structural evaluation of AC pavements.	Report FHWA-RD-98-085 documents improved procedures for estimating AC pavement surface temperature, and temperature adjustment of backcalculated moduli, FWD deflection measurements, and deflection basin parameters.	Completed. Reports published and distributed.	FHWA
Guidelines for Estimating Design Parameters for Flexible Pavements	Analyze the LTPP materials and deflection data to develop guidelines for the use of backcalculated layer moduli, laboratory M_r data, and other materials data in the design of flexible pavements.	Reports FHWA-RD-97-076, FHWA-RD-97-083, and FHWA-RD-97-077 are design pamphlets providing guidance to aid users of the 1993 AASHTO Guide flexible pavement design procedures. Report FHWA-RD-97-085 documents the overall data analysis effort. Report FHWA-RD-97-086 documents the details of the backcalculation done as a part of the analysis. TechBrief FHWA-RD-97-093 highlights a trial application of dissipated work concepts to the analysis of pavement deflection data.	Completed. Reports and TechBriefs published and distributed.	FHWA
Backcalculation of Material Parameters from Deflection Data	Estimate pavement layer properties from deflection measurements for use in further data analyses and studies regarding pavement performance.	Backcalculation results for both rigid and flexible pavements (to be incorporated into the LTPP database). Reports FHWA-RD-00-086 and FHWA-RD-01-113) document procedures and results for backcalculation conducted on all available LTPP deflection data.	Active. Report FHWA-RD-00-086 published. Revisions to report FHWA-RD-01-113 in progress.	FHWA
Review of LTPP Materials Data	Identify and provide the basis for resolving any anomalous observations present in the LTPP laboratory materials data. Laboratory M_r data will be addressed in separate studies.	Basis for identifying typical or representative material parameters as a function of material type or classification. Information on the magnitude of differences between designed/planned material parameters and as-built conditions. Tables of representative material parameters for addition to the LTPP database.	Active Revisions to draft report in progress.	FHWA
Review of LTPP Resilient Modulus (M_r) Data for Unbound Materials	Identify and provide the basis for resolving any anomalous observations present in the LTPP laboratory M_r data for unbound materials.	Basis for identifying typical or representative material parameters as a function of material type or classification. Information to guide future application and use of LTPP M_r data in analysis. Recommendations with regard to the need for future improvements in the M_r data.	Active Revisions to draft report in progress.	FHWA
Significance of As-Constructed AC Air Voids to Pavement Performance	Develop new or modified air voids content guidelines for optimum pavement performance and examine the effect of the level of construction control in the LTPP GPS and SPS on the variability of as-constructed air voids and other volumetric properties.	Improved guidelines for selecting design AC air void contents.	Active NCHRP 20-50(14)	NCHRP

TABLE 4-3 Projects Related to Strategic Objective 3: Determination of Environmental Effects in Pavement Design and Performance Prediction

Project	Description of Work	Outputs	Status	Sponsor
Determining Soil Volumetric Moisture Content Using Time Domain Reflectometry (TDR)	Development of procedures and relationships for determining soil volumetric moisture content from TDR measurements collected at the LTPP Seasonal Monitoring Program (SMP) sites.	Report FHWA-RD-97-139 provides information on TDR, a technique that indirectly measures the in-situ volumetric moisture content of soil. Describes the technique and presents a model for predicting volumetric moisture using TDR data.	Completed. Report published and distributed.	FHWA
Analysis of Electrical Resistance Data	Estimate of the probable frost locations within the pavement structure, based upon interpretation of resistivity and temperature measurements at the SMP test sections.	Data delineating frozen zones within the pavement cross-section for the LTPP SMP sites. Report FHWA-RD-99-088 documenting analysis process and findings. Software source code and algorithms used to interpret data.	Completed.	FHWA
Analysis of TDR Measurements	Produce estimates of gravimetric moisture contents at LTPP SMP sites through interpretation of TDR measurements. Estimate the error associated with the TDR-based moisture content data.	Volumetric and gravimetric moisture content data for the LTPP SMP sites. Report FHWA-RD-99-115 documenting procedures, findings, and conclusions; software source code and algorithms used to interpret TDR traces.	Completed.	FHWA
Study of Pavement Temperatures	Evaluate and compare the pavement temperature data collected on the LTPP test sections using manual probes, in-pavement thermistor probes, and infrared temperature sensors. Characterize the variability in the measurements obtained with each type of device.	Report documenting the analysis approach and findings. Improved quality of LTPP pavement temperature data through identification and correction of errors.	Active. Revisions to draft final report in progress.	FHWA
Verification of LTPP Virtual Weather Stations	Evaluate accuracy of climatic data derived from NCDC climatic data for LTPP GPS test sections.	Information as to accuracy of climatic data estimates based on NCDC data; basis for software tool to estimate site-specific climatic data.	Active. Technical revisions to draft final report in progress.	FHWA
LTPP Seasonal Asphalt Concrete (AC) Pavement Temperature Models	Verify the existing SHRP low pavement temperature models and develop an LTPP model for Superpave binder selection.	Report FHWA-RD-97-103. TechBrief FHWA-RD-97-104. LTPP low pavement temperature model for Superpave binder selection. New seasonal AC database.	Completed. Report and TechBrief published and distributed.	FHWA
Daily and Seasonal Variations in In Situ Material Properties	Characterization of the patterns of daily and seasonal changes in in situ pavement material properties, determination of relationships between those changes and causal factors, and relationship between variations in properties and the seasonal structural capacity of flexible and rigid pavements.	Information on seasonal variations in pavement material properties and structural capacity. Models relating material parameters to the factors causing variations.	Active. NCHRP Project 20-50(7/12)	NCHRP

TABLE 4-4 Projects Related to Strategic Objective 4: Evaluation and Use of Pavement Condition Data in Pavement Management

Project	Description of Work	Outputs	Status	Sponsor
Analysis of LTPP Friction Data	Examine the availability, characteristics, quality, and the potential uses of the friction data being collected by highway agencies for the LTPP program.	Report FHWA-RD-99-037 documenting findings concerning friction data collected under the LTPP program	Completed.	FHWA
Study of Longitudinal Profile Variability	Characterize the variability associated with longitudinal profile measurements and diagnose the integrity of longitudinal profile data from both GPS and SPS sections.	Profile viewer software developed for review of time-series profile data recommended for development as LTPP product. Improved quality of existing LTPP longitudinal profile data and enhanced quality assurance measures for ongoing data collection. Report FHWA-RD 00-113 documents variability of LTPP profile data and methods used in evaluation thereof.	Completed. Final report published and distributed.	FHWA
Study of Transverse Profile	Evaluation of the LTPP transverse profile data to (1) quantify bias and precision and (2) develop and compute summary parameters (rut indices) to characterize pavement rutting.	Computed transverse profile indices (rut statistics) added to the database. Report FHWA-RD-01-1024 documenting analysis methods and findings, including estimates of bias and precision; recommendations for improvements and adjustments in transverse profile monitoring. Tech Brief FHWA-RD-01-027 documents limitations of 3- and 5-point rut depths.	Completed. Rut statistics are available in the LTPP database. TechBrief and final report published.	FHWA
Pavement Distress Variability	Characterize the variability associated with distress data collected through manual and photographic distress surveys.	Reports FHWA-RD-99-074 and 075 documenting analysis methodology and findings.	Completed. Final report published and distributed.	FHWA
Study of Pavement Deflections	Assess and characterize the variability in falling weight deflectometer (FWD) deflection data. Evaluate FWD test patterns and drop sequences. Identify data discrepancies that need to be resolved. Furnish information on timing of load-deflection testing for routine pavement evaluation and design.	Report documenting analysis approach and findings. Improved quality of LTPP deflection data through identification and correction of errors in recording of deflection sensor locations, etc. Procedures for reviewing FWD data for quality and accuracy, including an algorithm (SLIC) to check for correct sensor positions.	Active. Revisions to draft final report in progress.	FHWA
Joint Faulting Data Analysis	Examination of the LTPP joint faulting data to identify and explain anomalous data and develop representative faulting indices and statistics for each jointed concrete pavement test section.	Summary statistics to characterize joint faulting. Report FHWA-RD-00-076, documenting procedures and findings, including recommendations for improving future faulting data collection, specifically with respect to the necessity for improving the precision of faulting measurements.	Completed. Final report published and distributed.	FHWA
Production of Computational Data Set for Distress Analysis	Analysis of the LTPP distress data to reconcile differences between data collected using different (photographic and "manual") methods.	Consolidated distress data set, protocols and software for resolution of distress discrepancies. Report documenting methods and findings.	Active. Revisions to draft final report in progress.	FHWA
Factors Affecting Pavement Smoothness	Build upon previous analyses of the LTPP pavement roughness data to develop more complete information as to the factors that affect pavement roughness.	Information as to the factors that cause changes in pavement smoothness and quantification of the contributions of each.	Active. NCHRP Project 20-50 (8/13)	NCHRP
Feasibility of Using FWD Deflection to Characterize Pavement Construction Quality	Use the LTPP data to explore the feasibility of using FWD data as a tool for characterizing pavement construction quality.	Prototype procedures for using FWD data to assess construction quality.	Active NCHRP 20-50(09)	NCHRP

TABLE 4-5 Projects Related to Strategic Objective 5: Development of Pavement Response and Performance Models Applicable to Pavement Design and Performance Prediction

Project	Description of Work	Outputs	Status	Sponsor
Portland Cement Concrete Pavement Performance	Apply the LTPP data to test and verify the improved pavement support guidelines and AASHTO performance model proposed in NCHRP Project 1-30.	Report FHWA-RD-96-198. TechBrief FHWA-RD-97-035. Proposed supplement to the AASHTO Design Guide. Guidelines to improve the design of jointed plain concrete pavements.	Completed. Report and TechBrief published and distributed. Supplement adopted by AASHTO.	FHWA
Mechanistic Evaluation of Test Data from the LTPP Program	Apply the LTPP data to evaluate and calibrate existing mechanistic-empirical design procedures for rigid and flexible pavements, and develop guidelines for improving the performance of continuously reinforced concrete (CRC) pavements.	Report FHWA-RD-98-012 documents work with flexible pavement performance models. New forms of the fatigue cracking models proposed; new approach to predicting rutting developed. Report FHWA-RD-98-094 documents work with existing concrete pavement distress prediction procedures. Report FHWA-RD-99-086 documents the evaluation of LTPP CRC pavement test sections.	Completed. Report published and distributed.	FHWA
Variations in Pavement Design Inputs	Characterization of variations in traffic loadings, material properties, and layer thicknesses.	Information as to the magnitude of variation in key pavement design parameters.	Active. NCHRP Project 20-50 (05)	NCHRP

TABLE 4-6 Projects Related to Strategic Objective 6: Maintenance and Rehabilitation Strategy Selection and Performance Prediction

Project	Description of Work	Outputs	Status	Sponsor
Rehabilitation Performance Trends: Early Observations from LTPP SPS	Document early observations from the LTPP SPS experiments.	Report FHWA-RD-97-099 provides comparisons of performance trends to evaluate both the distinctions between the various rehabilitation treatments and the performance of individual treatments.	Completed. Report published and distributed.	FHWA
Evaluation of the Effects of Pavement Rehabilitation on Performance	Identify performance trends for the different treatments and design features included in SPS-5, SPS-6, SPS-7, GPS-6A, GPS-6B, GPS-7A, and GPS-7B. Quantify the short-term effects of rehabilitation on the structural and functional characteristics of pavements.	Report FHWA-RD-00-029 provides documentation of rehabilitation performance, as reflected in data collected through February 1997.	Completed. Final report submitted to National Technical Information Service (NTIS) (not published).	FHWA
Evaluation of the LTPP SPS-7 Experiment	Review the SPS-7 bonded concrete overlay projects and data to identify data deficiencies and construction deviations, and assess the analytical potential of the SPS-7 experiment and projects.	Report FHWA-RD-98-130 documents findings and recommendations from the study. Concluded that results of the SPS-7 experiment are of marginal value at best.	Completed. Final report submitted to NTIS (not published)	FHWA
Review of Maintenance and Rehabilitation (M&R) Data	Ensure that the maintenance and rehabilitation data available in the LTPP database are as complete and reliable as possible	Improved quality and completeness of the Report FHWA-RD-01-019 LTPP M&R data. Quantitative information as to the change in key performance measures that can be expected as a result of different M&R treatments.	Completed. Final report submitted to NTIS (not published).	FHWA
Pavement Maintenance Effectiveness	Evaluation of the SPS-3 and SPS-4 test sites data to determine the optimum timing for applying preventative maintenance treatments for flexible and rigid pavements.	Report FHWA-RD-97-102 considers three important characteristics of maintenance treatments – treatment performance, timing of application, and cost-effectiveness. Report FHWA-RD-96-208 and TechBrief FHWA-RD-97-029 document findings from field reviews and evaluations. Report FHWA-RD-97-155 considers three important characteristics of maintenance treatments for rigid pavements: treatment performance, timing of application, and cost effectiveness.	Completed. Report published and distributed.	FHWA
Effectiveness of Maintenance and Rehabilitation Options	Identification of the pre-maintenance and pre-rehabilitation conditions that influence the performance of different maintenance and rehabilitation treatments, and comparison of treatment performance.	Guidance for identification of appropriate maintenance and rehabilitation strategies for pavements.	Completed. NCHRP Project 20-50 (3/4) Agency final report published as NCHRP web document.	NCHRP

TABLE 4-7 Projects Related to Strategic Objective 7: Quantification of the Performance Impact of Specific Design Features

Project	Description of Work	Outputs	Status	Sponsor
Portland Cement Concrete (PCC) Pavement Performance	Evaluate and analyze PCC pavements in order to develop recommendations for the design and construction of long-lived concrete pavements.	Report FHWA-RD-98-052 provides practical recommendations that can be implemented by highway agencies to increase pavement life. Report FHWA-RD-98-113 documents performance models developed. Report FHWA-RD-98-127 documents the overall research effort.	Completed. Reports published and distributed.	FHWA
Development of Pavement Roughness	Investigate changes in pavement roughness over time and the relationship between roughness (and rate of change in roughness) and design factors, subgrade conditions, and climatic conditions.	Report FHWA-RD-97-147 and TechBriefs FHWA-RD-98-132, FHWA-RD-98-148, and FHWA-RD-98-149 provide information on roughness trends.	Completed. Report and TechBriefs published and distributed.	FHWA
Analysis of Well & Poorly Performing Pavements	Identify the common design features that lead to good performance of pavements and those that lead to poor (substandard) performance of pavements.	Reports FHWA-RD-97-131 and FHWA-RD-99-193 document the analysis and findings for PCC (JPCP, JRCP, CRCP) and asphalt concrete pavements, respectively.	Completed. Report FHWA-RD-97-131published and distributed. Report FHWA-RD-99-193 submitted to NTIS (not published).	FHWA
SPS Experiment Review	Comprehensive review of the SPS-1, -2, -5, and -6 experiments, as they were actually constructed. Will provide information to guide (1) planning for future analyses involving these experiments and (2) future monitoring of the test sites.	Recommended program of analysis for the SPS-1, 2, 5, and 6 experiments. Information and observations with regard to the performance of the design features and treatments considered. Recommendations as to the resolution and correction of data that are anomalous.	Active. Revised draft reports under review.	FHWA
Review of LTPP Layer Thickness Data	Assess LTPP layer thickness data to identify and explain anomalous observations, characterize the extent of variation in the layer thickness data between measurements at different locations, characterize the extent of variation in the layer thickness data between as-designed (inventory) and as-constructed (measured) thicknesses.	Information as to the magnitude of variation in layer thickness and the differences between as-designed and as-constructed layer thicknesses.	Active	FHWA
Review of SPS-8 Experiment	Comprehensive review of the SPS-8 experiment as actually constructed. Will provide information to guide (1) planning for future analyses involving this experiment and (2) future monitoring of the test sites.	Recommended program of analysis for the SPS-8 experiment. Information and observations with regard to the performance of the design features and treatments considered. Recommendations as to the resolution and correction of data that are anomalous.	Active	FHWA
Evaluation of Load Transfer	Comprehensive review of data related to joint/cracks LTE, development of representative LTE indices, and trend analysis of LTE data for the LTPP test sections.	Guidelines for assignment of input parameters for the AASHTO 2002 Design Guide. Basis for further improvement of mechanistic-empirical design procedures. Load transfer efficiency information for use in pavement structural evaluation.	Active	FHWA
Factors Affecting the Performance of Flexible and Rigid Pavements	Follow-up on a previous FHWA-sponsored study addressing the contributions of design and construction features to achieving different levels of performance.	Guidance on the impact of design and construction features on the level of performance.	Active NCHRP Project 20-50(10)	NCHRP
Relative Performance of Jointed Plain Concrete Pavements with Sealed and Unsealed Joints	Comparison of the performance of JPCP designed and constructed with unsealed joints to that of JPCP with sealed joints.	Factual information on the efficacy of unsealed joints.	Completed. NCHRP Project 20-50(2)	NCHRP

Notes: JPCP = jointed plain concrete pavement; JRCP = jointed reinforced concrete pavement; CRCP = continuously reinforced concrete pavement; LTE = load transfer efficiency.

Issues addressed in these guidelines include specifications for weigh-in-motion (WIM) equipment, installation, and calibration, and quality control and assurance measures for traffic data.

The keystone that remains to be developed through analysis of the LTPP data relates to the accuracy of WIM axle load data. This work is planned for pursuit via NCHRP 20-50(15), Confidence of WIM Axle Load Data, but has not yet been initiated. No further analytical work beyond that currently programmed is envisioned.

B. Guidelines for Applying Traffic-Loading and Classification Data in Pavement Design

The second outcome required to improve traffic characterization and prediction addresses the application of the data that are collected in the pavement design process. Early analysis of the variability and accuracy of traffic-loading data provided some of the information needed to support development of guidelines for application of traffic-loading and classification data in pavement design. Ongoing work under NCHRP 20-50(5), Variations in Pavement Design Inputs, is expected to provide additional information on the variability in traffic-loading data. The key issue that remains to be addressed is the relationship between the quantity and quality of traffic data used as input to the pavement design process and the precision and reliability of the resulting design. How do traffic data collection needs vary as the design reliability varies from 50 to 99 percent, with all other factors held constant, and how does that answer change as the other factors are varied? Project 1B1, Integration of Traffic Inputs for Specific Pavement Applications, is intended to address this issue, but has not yet been programmed.

It is likely that the outcomes of NCHRP 20-50(5) and Project 1B1, together with information already developed, will provide a basis for development of preliminary guidelines. These guidelines should then be evaluated and refined through analysis of the additional traffic data that will accumulate over the next several years.

C. Procedures for Forecasting and Backcasting Traffic-Loading Data

The third outcome defined to achieve improved traffic characterization and prediction addresses the need to estimate future and past traffic loads. Within LTPP, this is necessary to fill in the gaps in monitored traffic data. In the broader practice of pavement engineering, it is necessary to arrive at cumulative traffic estimates suitable for use in performance prediction and design.

Preliminary procedures to project (forecast or backcast) traffic-loading data for LTPP purposes were developed and reported in *Estimating Cumulative Traffic Loads* (*2*). Vetting of these procedures is ongoing, through their application in analysis targeted at filling in the gaps in the LTPP traffic data. This work will produce a prototype pavement-loading guide that may be used as the basis for developing generic tools to help agencies estimate traffic axle load spectra. This work is included in planned Project 1C1, Procedures for Forecasting and Backcasting Traffic Loading Data.

D. Impact of Pavement Roughness on the Dynamic Loads Applied to Pavements

Among the challenges associated with the use of WIM technology to monitor traffic loads is the fact that pavement loadings, as measured by WIM equipment, differ from the static loads by virtue of vehicle dynamics. Furthermore, the magnitude of the difference between the static load and dynamic load will vary as the roughness of the pavement leading into the WIM equipment varies. For this reason, longitudinal profile data were collected on the pavements leading into LTPP WIM sites for several years in the late 1980s and early 1990s. To date, these data have not been examined. Analysis of these data is needed to quantify the impact of pavement roughness on dynamic loads. Project 1D1, Tools for Analyzing Errors and Improving Accuracy of Existing WIM Systems, is intended to address this issue. No analytical work toward achievement of this outcome has been completed.

Strategic Objective 2: Improve Materials Characterization

Although the basic materials from which highway pavements are constructed have been in use for many years, many questions relating to their performance characteristics remain. This situation results from several factors: variability and complexity of these materials; changes in materials over time; changes in construction equipment and methods that affect the materials; environmental considerations; the interactions between materials and traffic conditions; the ongoing transition to pavement design procedures that are more mechanistically based; and the accompanying changes in how materials are characterized. The plan identifies six key outcomes supporting this objective.

A. Importance of Different Material Characteristics in Predicting Pavement Performance

Identification of the relative importance of different material characteristics in pavement performance prediction requires that materials characterization be examined from both a materials engineering perspective [what characteristics make an asphalt concrete (AC) mix resistant to permanent deformation?] and a pavement design perspective (what material characteristics are most critical to accurate prediction of pavement performance?). To date, several LTPP analysis projects have yielded findings regarding the material characteristics that affect performance. Ongoing work with LTPP materials, performance, and traffic data is laying the foundation needed to support more in-depth analysis. Future work will need to address this issue from both the materials and pavement design perspectives. Expected activities include review of the AC resilient modulus data and the data collected for the SPS-9 (Superpave Validation) experiment, review, evaluation, development and validation of performance prediction models, and sensitivity analyses. The required work with performance prediction models should be pursued in the context of broader investigations of the factors affecting pavement performance.

B. Relationships Between Laboratory and Field-Derived Material Parameters

The second outcome required to achieve improved materials characterization addresses the need to resolve differences between laboratory and field-derived material parameters, so that they may be used interchangeably in pavement design and performance prediction. The primary laboratory material parameters of interest are the dynamic and resilient modulus for AC materials, the elastic modulus of portland cement concrete (PCC) and cement-stabilized materials, and the resilient modulus of unbound materials. The corresponding field-derived parameters are the backcalculated moduli (or k-values) for these materials.

Past work in this area has provided guidance regarding the use of moduli and k-values backcalculated from falling weight deflectometer (FWD) data in the existing American Association of State Highway and Transportation Officials (AASHTO) pavement design procedures. Work completed more recently provides procedures for temperature adjustment of backcalculated AC layer moduli. Backcalculation of layer parameters has been completed for the majority of the LTPP deflection data. However, further review of the backcalculation results is required, and additional backcalculation will be required in the future to address recently collected data. Full achievement of this outcome will require review of existing information relative to the relationships between lab- and field-derived material parameters and analysis to develop the required relationships. This work is provided for in Project 2B1, Relationships Between Laboratory and Field-Derived Material Parameters.

C. Relationships Between As-Designed and As-Built Material Characteristics

The material parameters used to design pavements are often determined well in advance of actual construction, such that they may or may not accurately describe the materials that are ultimately used. Quite often, the magnitude of the differences that occur is unknown. Several completed or ongoing projects have or will yield information as to the extent of agreement or disagreement between as-designed (or as-planned) and as-built material characteristics (loosely interpreted to include layer thickness) for the LTPP test sections. It is believed that these projects, collectively, will yield the bulk of the pertinent information to be derived from the LTPP database. Thus, the primary work that remains is to synthesize and disseminate the analysis findings.

D. Effect on Pavement Performance of Different Levels of Material Variability and Quality
Preliminary, unpublished work with LTPP deflection and distress data suggests that variability in pavement deflection may be a good indicator of construction quality, with highly variable pavements performing less well than more uniform pavements. Recent work evaluating and characterizing the variability in LTPP performance and materials data provides a sound starting point for further work assessing the impact of variability on performance. Ongoing NCHRP Projects 20-50(05), Variations in Pavement Design Inputs, and 20-50(09), Feasibility of Using FWD Deflection Data to Characterize Pavement Construction Quality, are also expected to yield pertinent information.

In applying the LTPP data to address this issue, it is likely that variations in backcalculated layer moduli will be the primary indicator of material variability considered. Full achievement of this outcome is most appropriately pursued in the context of a broader investigation of the factors affecting pavement performance.

E. Estimation of Material Design Parameters from Other Materials Data
Ideally, the parameters used to characterize pavement materials for design purposes are determined by conducting the required tests on the materials to be used in construction. However, this is often infeasible, for a number of reasons. Thus, improving the ability to estimate key design parameters from other materials data is an important LTPP data analysis outcome. Two general approaches to achieving this outcome have been identified. One is the identification of typical values as a function of material type, classification, and so forth. The other is the development of predictive models. Predictive models for resilient modulus were pursued with minimal success in work reported in *Analysis Relating to Pavement Material Characterizations and Their Effects on Pavement Performance* (*3*). It is believed that alternative analytical approaches might yield greater success.

A series of three projects have been defined to address this issue that focus on (*a*) key base and subgrade engineering properties; (*b*) key hot-mix AC properties; and (*c*) key PCC properties. All three of these projects remain to be pursued. No further analytical effort beyond these three projects is currently envisioned.

Strategic Objective 3: Improve Consideration of Environmental Effects in Pavement Design and Performance Prediction
Full consideration of environmental effects in pavement design and performance prediction is a many-faceted problem. Among the aspects to be considered are

- Short-term temperature and moisture-induced variations in the stiffness and strength of the materials;
- Long-term changes in material stiffness and strength due to aging, temperature, and moisture-induced variations in the volume of the materials, and the stresses imposed by those changes; and
- Variations in the relative importance of different environmental effects and factors from one location to another.

A. Impact of Temperature and Moisture Variations on Pavement Performance
The impact of temperature and moisture variations is being addressed in several ongoing LTPP data analysis projects. Additional work in this area is ongoing as a part of NCHRP 1-37A and planned for pursuit under NCHRP 9-23. Full achievement of this outcome will require a series of analysis projects addressing various elements of the problem, and the ultimate answer is appropriately pursued as a part of a broad investigation of the factors affecting pavement performance.

Planned work toward achievement of this outcome includes an evaluation of the site-specific climatic data, assessment of the individual effects of loading and environment on pavement distress, and study of the effect of environmental factors on overload damage.

B. Impact of Freeze-Thaw Cycles on Pavement Performance
To date, analytical work addressing the impact of freeze-thaw cycles on pavement performance has yielded estimates of frost and thaw penetration depth that will support future work toward this outcome. No ongoing work addresses this outcome.

Future work toward this outcome includes Project 3B1, Effect on Pavement Performance of Multiple Freeze-Thaw Cycles vs. Deep Frost Penetration, which has been approved as a pooled fund project but not yet initiated. One additional project addressing this outcome has been defined to address the issue of pavement damage caused by swelling and frost-susceptible soils.

C. Long-Term Changes in Pavement Characteristics Due to Environmental Effects and Aging
Within the LTPP database, the primary source of information on long-term changes in LTPP pavement characteristics is the deflection data. To date, progress toward this objective is limited to the backcalculation of layer parameters from the deflection data. Ongoing work under NCHRP 20-50(5), Variations in Pavement Design Inputs, is expected to yield preliminary information addressing this issue. Work toward this outcome identified for pursuit in the near-term includes further evaluation of the Integrated Climatic Model. The issues to be addressed in this project may be adequately addressed by work ongoing through NCHRP Project 9-23, such that pursuit of the LTPP analysis project is unnecessary. Final answers regarding long-term changes in pavement characteristics due to environmental effects and aging can only be pursued at a later date (5 to 10 years from now), when the available LTPP data span a greater fraction of the life cycle of individual pavements.

D. Recommendations for Climatic Data Collection to Adequately Predict Pavement Performance
What climatic data does an agency need to collect to adequately predict pavement performance? The recently completed evaluation of the LTPP virtual weather station concept has shown that collection of site-specific precipitation and temperature data is probably not necessary. Future work addressing this outcome has not yet been defined and will depend heavily on the results from work addressing outcomes A, B, and C.

E. Region-Specific Guidelines for Considering Environmental and Load Effects
Much of the work completed, ongoing, or planned, to achieve outcomes A–D, will also contribute to achieving region-specific guidelines for considering environmental and load effects. Two additional projects have been identified to support achievement of this outcome—one addresses guidelines for pavement modeling and design, and a second addresses the effects of load and environment on highway cost allocation.

Strategic Objective 4: Improve Evaluation and Use of Pavement Condition Data in Pavement Management

By far, the most voluminous subset of the LTPP data is that comprising the distress, profile, and deflection data collected to monitor the condition of the test sections over time. The potential of these data as a source of information to support improvements in the evaluation and use of pavement condition data in all aspects of pavement management is tremendous.

A. Comprehensive Guidelines for Assessing the Relative Performance of Different Pavements

What information do we need to obtain to draw meaningful conclusions as to the relative performance of different pavements? To date, progress toward the answer to this question is embodied in findings regarding the variability in LTPP distress (both manual and photographic), profile, and deflection data. Further information regarding load transfer at joints and cracks in rigid pavements will be derived through an ongoing analysis project.

Work planned for pursuit in the future addresses the need to consider variability in pavement condition data, the need for default values or models for use in life-cycle cost analysis, development of comprehensive guidelines addressing both the type and quantity of data required to draw meaningful conclusions for different applications, and development of improved numerical indices to characterize pavement condition.

B. Improved Measures of Pavement Structural Condition for Use in Network-Level Pavement Management

The LTPP deflection data and supporting information provide an unprecedented basis for development and evaluation of deflection-based measures of pavement structural condition. To date, improved procedures for temperature estimation and temperature adjustment of FWD data collected on flexible pavements have been developed, and a product development project to promote their use is being pursued. Review of the LTPP deflection data has yielded a promising method to check FWD data for errors in the location of the deflection sensors relative to the applied load, as well as information on the variability in deflection data. Planned work toward this outcome includes characterization of the curvature of PCC slabs and development of simplified techniques for evaluation and interpretation of pavement deflections.

C. Models Relating Functional and Structural Performance

Mechanistically based models may be used to predict the structural performance of pavements, but they do not provide a direct indication of functional performance. Several completed analysis projects contribute toward the development of models relating functional and structural performance, and some work using LTPP data to explore the relationship between pavement distress and pavement roughness has been pursued as part of NCHRP 1-37A. However, no LTPP analysis specifically directed toward development of models relating structural and functional performance has been undertaken thus far. To date, one project has been planned to look at the relationship between ride quality and structural support.

D. Criteria for Applying Performance Measures to Construction Quality Evaluation

The LTPP data will support development of a broad range of criteria applicable to construction quality evaluation. Work that has already been completed provides information that could support criteria related to pavement smoothness. NCHRP Project 20-50(09), Feasibility of Using FWD Deflection Data to Characterize Pavement Construction Quality, is looking at the feasibility of using FWD data to characterize construction quality. Deflection data collected during construction of the SPS projects should be evaluated to assess the value and feasibility of using similar testing for routine construction quality control. To date, one project has been identified to pursue the development of early performance criteria for use in pavement construction warranties.

E. Relationship Between Variation in Pavement Performance Measures and Environmental Factors

Profile and distress monitoring of the LTPP Seasonal Monitoring Program sections was conducted on a quarterly basis to allow consideration of possible seasonal variations in pavement condition measures. Analysis of how these data vary with environmental factors (e.g., temperature) will provide key information needed to enable correct interpretation of performance data collected at different times of year. LTPP data analysis conducted to date has provided information that will support pursuit of this outcome, but it does not address it directly. One analysis project is planned to apply the available data to quantify the effect of environmental variables on pavement performance measures.

Strategic Objective 5: Development of Pavement Response and Performance Models Applicable to Pavement Design and Performance Prediction

Among the expectations of LTPP is that it will yield improvements in pavement design and performance prediction. Indeed, it has already done so. The earliest analyses of the LTPP data—those conducted under SHRP sponsorship in the early 1990s—applied the LTPP data to evaluate the 1986 AASHTO Guide design equations (*1*). This work confirmed that those equations were obsolete and helped to provide the impetus for development of new pavement design procedures. Subsequently, one of the first FHWA-sponsored LTPP analysis projects provided field verification of design procedures for improved, jointed, PCC pavement developed via NCHRP, and subsequently adopted as the *1998 Supplement to the AASHTO Guide* (*4*). Currently, the NCHRP 1-37A research team is using LTPP data to verify, validate, and calibrate the performance models that will form the basis for the 2002 Guide for Design of New and Rehabilitated Pavement Structures.

A. Guidelines for Selecting Load-Response Models for Use in Pavement Design as a Function of the Acceptable Level of Risk and Model Complexity

Over the years, a number of models for prediction of pavement responses to load have been developed. The first outcome defined to support improvements in performance prediction models addresses the issue of model selection. To date, work toward this outcome has been limited to an initial evaluation of the load-response data collected at instrumented test sites in Ohio and North Carolina. One additional project addressing the evaluation of load-response models has been defined.

B. Mechanistic-Empirical Procedures for Using Commonly Collected Pavement Data to Predict Specific Distresses

Mechanistic-empirical performance prediction procedures are a key to achievement of expected improvements in pavement design. To date, the primary application of LTPP data in the development of mechanistic-empirical procedures for distress prediction is in the development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures, under NCHRP 1-37A. In addition, one LTPP data analysis project contributing to this outcome is in progress. That project, NCHRP 20-50(5), provides for evaluation of variability in pavement design inputs. One additional project to provide for evaluation of the 2002 Guide performance prediction models has been defined. The need for further work addressing this outcome cannot be fully assessed until the 2002 Guide becomes available.

C. Calibrated Relationships Between Pavement Response and Individual Distress Types
Although several completed or ongoing LTPP analysis projects have or will yield findings that will support the future pursuit of relationships between pavement response and distress (i.e., transfer functions), no work specifically directed toward it has been undertaken to date. One project addressing the verification of reflective cracking models has been defined. As with outcome B, full definition of future work addressing this outcome is appropriately deferred until the 2002 Guide is available for in-depth review by all.

Strategic Objective 6: Provide Guidance for Maintenance and Rehabilitation Strategy Selection and Performance Prediction
Another expectation of LTPP is that it will provide information to guide the selection of maintenance and rehabilitation strategies. The first outcome defined to address this expectation is the development of information. The second outcome addresses the need to deliver the information obtained in the form of comprehensive guidelines.

A. Quantitative Information on the Performance of Maintenance and Rehabilitation Treatments, Including the Effect of Pretreatment Condition
Several past analysis projects have addressed the performance of the maintenance and rehabilitation treatments considered in the LTPP experiments, and one project, NCHRP Project 20-50(3/4), is ongoing. It is currently envisioned that future work addressing the performance of maintenance and rehabilitation treatments will be pursued in conjunction with the development of guidelines, as provided for in outcome 6B.

B. Guidance on the Timing and Selection of Pavement Maintenance and Rehabilitation Options and Expected Performance Life of Each
Several completed and ongoing projects lay the groundwork necessary to develop guidance on the timing and selection of pavement maintenance and rehabilitation options, but no work specifically directed at this outcome has been undertaken thus far. Project 6B1 has been planned to develop guidelines for selecting pavement rehabilitation strategies. This project is intended to build upon the outcome of NCHRP 20-50(3/4), Effectiveness of Maintenance and Rehabilitation Options. The need for additional follow-on projects (to take advantage of the additional performance data that will accumulate in the future) can be assessed more accurately once the planned project is under way.

Strategic Objective 7: Quantify the Performance Impact of Specific Design Features
How do different design features affect pavement performance? The LTPP SPS experiments were designed to provide some answers to this question. Final answers cannot be derived from the data collected to date, as the accumulated performance history for many of the SPS test sections is still relatively short. However, some answers can and have been drawn from the General Pavement Studies test sections, and near-term analysis of the SPS projects is needed to lay the groundwork that will enable achievement of the ultimate objectives of these experiments. For example, review of the SPS-1, -2, -5, and -6 experiments has resulted in the identification and correction of several significant gaps in the data released for use in analysis.

A. Quantitative Information on the Impact of Design Features on Measured Pavement Responses
While final conclusions as to the impact of design features on performance cannot be drawn until

the pavements under study have been in service long enough to exhibit measurable distress, it is believed that preliminary conclusions can be drawn from differences in pavement response to load. Past analysis of the SPS-5 and -6 data provided information on the impact of design features on pavement response early in the life of the rehabilitation treatment. Similar analyses have not, as yet, been pursued for the SPS-1 and -2 experiments. NCHRP 20/50(2), Relative Performance of Jointed Plain Concrete Pavements with Sealed and Unsealed Joints, ongoing FHWA-sponsored reviews of the LTPP layer thickness and load transfer data, and the SPS-8 experiment will contribute to achievement of this outcome, as will the planned FY 2002 NCHRP Project 20-50(16), The Impact of Design Features on Pavement Response for New Flexible and Rigid Pavements. To date, one additional project addressing this outcome has been defined. That project is to look at the impact of design features on the response of rehabilitated pavements.

B. Quantitative Information on the Impact of Design Features on Pavement Distress
Several past and ongoing analysis projects have and will provide information as to the impact of design features on pavement distress. More definitive answers for the design features considered in the SPS experiments are expected to come from analysis of those data in the long term. NCHRP Project 20-50(2), Relative Performance of Jointed Plain Concrete Pavements with Sealed and Unsealed Joints, provided limited information on the impact of sealed versus unsealed joints. Ongoing analysis through NCHRP LTPP analysis projects 20-50(8/13), Factors Affecting Pavement Smoothness, and 20-50(1), Factors Affecting the Performance of Rigid and Flexible Pavements, will also contribute to this outcome. Future work identified to date includes two projects, 7B1a and 7B1b, are intended to focus primarily on the SPS-1 and -2 projects to look at the impact of design features on pavement distress for new flexible and rigid pavements, respectively.

C. Guidelines for the Selection of Pavement Design Features
Several efforts are under way to provide guidance as to the selection of pavement design features based on information derived through analysis of the LTPP data, including a national workshop on pavement smoothness [NCHRP 20-51(1)] and a PCC pavement practice manual and workshop [NCHRP 20-51(2)]. Currently, no LTPP data analysis projects have been defined to address this outcome. It is likely that the work required will involve review and synthesis of the other outcomes supporting this objective.

OPPORTUNITIES AND CHALLENGES

The LTPP database is ripe with opportunities to advance our knowledge and understanding of how and why pavements perform as they do. These opportunities are reflected in the Strategic Plan and the supporting program of analysis. It must be understood that a number of these opportunities involve critical issues that can only be addressed by using LTPP data. The required information cannot be obtained by individual states or by isolated accelerated pavement testing studies. For example:

- Strategic Objective 3 addresses the effect of the environment on pavement performance. The importance of this work is recognized not only in the technical community but also by Congress. The data required to begin addressing this issue are now available.
- Among the issues addressed under Strategic Objective 7 is the relative performance of drained versus undrained pavement sections. This is a current, critical national issue, and LTPP is the only source of data that will support definitive conclusions as to the cost-effectiveness of using positive drainage systems.

• Strategic Objective 6 addresses the optimal timing and cost-effectiveness of various rehabilitation treatments and strategies—another current and very critical issue of national importance.

Sufficient staffing and funding are needed to address these and other critical national issues that can only be addressed through analysis of the LTPP data. With limited staff resources, and insufficient funding, the greatest challenge is to pursue the work that can be supported in a programmatic (as opposed to ad hoc) fashion, so that maximum overall effectiveness can be achieved.

SUMMARY ASSESSMENT OF PROGRESS

Overall, reasonable progress has been made in the analysis of the LTPP data in relation to the limited financial and human resources applied to date. However, the progress made to date, and that which may be anticipated over the next several years, is not as great as it should be, by virtue of the limited funding available to support LTPP data analysis activities. An adequate and steady stream of funding is needed to achieve both efficiency in the overall analysis effort and timely delivery of the outcomes that are desired, expected, and desperately needed.

The work required to fully achieve the objectives set forth in the Plan has not, and indeed cannot, be fully defined, because each subsequent step in the analytical process depends upon the outcomes of the preceding steps. Likely next steps are a matter of speculation, but until the initial steps have been completed, projections of what should come next are best thought of as educated guesses, rather than firm plans. If the answers were known a priori, analysis would be unnecessary.

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Appendix 5
LTPP Product Development Status

From the time LTPP was first conceived, there has been an expectation that the studies would not only collect data but also yield products of use to state departments of transportation (DOTs) and other transportation agencies. The earliest products to come from LTPP are improved pavement data collection and testing tools that came about because they were needed to support LTPP data collection. Foremost among these early products are procedures for calibration of falling weight deflectometers (FWDs), the LTPP *Distress Identification Manual* (*1*), and improved procedures for resilient modulus testing of soils and aggregates. These and other early LTPP products were introduced in the Strategic Highway Research Program (SHRP) product identification effort that culminated in the 1992 publication of the *SHRP Product Catalog* (*2*). Additional LTPP products, derived through analysis of the LTPP data, were brought to the fore in the *1996 Product Preview* published by the Federal Highway Administration (FHWA) (*3*). These products included guidelines for selecting material parameters for use with the 1993 AASHTO Guide design procedures, the basis of the LTPPBind software for Superpave binder selection (*4*). More recent efforts have sought to put into place a systematic process for identification, tracking, and development of products based on LTPP data analysis findings—the *LTPP Product Plan* (*5*).

The current status of LTPP product development is described in this appendix, which begins with an overview of the LTPP products (or potential products) already in existence, or under development, and their status. This information is followed by a brief overview of the *LTPP Product Plan,* which has been established to guide future LTPP product development efforts, and a discussion of the challenges and opportunities associated with LTPP product development efforts.

LTPP PRODUCTS

What is an LTPP product? Over the history of LTPP, this seemingly simple question has been the subject of considerable debate, and the prevailing answer has evolved over time. LTPP products are ready-to-use guidelines, procedures, protocols, best practices, software, equipment, and so forth, that are developed as part of the LTPP studies, and packaged for and delivered to the management and technical staff of state and provincial highway agencies in North America.

This is a relatively narrow definition in that it ignores as a product the increase in knowledge that improves engineering and managerial judgment and decision making. For example, early analyses of LTPP data demonstrated that current pavement design methods were underpredicting the deterioration of asphalt pavements in almost half the cases. Although it does not conform to the narrow definition of an LTPP product, this finding is of value and benefit to the states and provinces in that it contributed to subsequent decisions to develop a new national pavement design guide.

Brief discussions of the more tangible products delivered thus far, or currently under development, are provided in the remainder of this section. Potential products that have been identified, but for which no development funds are available, are also noted. Products that are expected to come about as a result of ongoing or planned analysis, but which are currently more in the realm of expectation than reality, are not discussed in this document.

PRODUCTS ADDRESSING NEW OR RECONSTRUCTED PAVEMENTS

Rigid Pavement Design Software

LTPP data analysis findings reported in 1996 (*6*) demonstrated the validity of the guidelines for *k*-value selection and concrete pavement performance prediction reported in *NCHRP Report 372: Support Under Portland Cement Concrete Pavement* (*7*). As a result, the American Association of State Highway and Transportation Officials (AASHTO) adopted the proposed guidelines as the *1998 Supplement to the AASHTO Guide for Design of Pavement Structures* (*8*). These procedures represent a substantial improvement over those provided in the 1993 Guide, because they enable the engineer to tailor design details such as slab length to the specific conditions present at a particular site, resulting in reduced life-cycle costs. The magnitude of the cost savings will vary with site conditions, with a 30 percent reduction being a reasonable average.

The LTPP Rigid Pavement Design (RPD) software was developed to facilitate application of the improved procedures. The RPD software is a Microsoft Excel spreadsheet template that automates the computations required to use the *1998 Supplement.* It includes separate tables for determining accumulated traffic loading, seasonally adjusted *k*-values, depth to rigid layer, and performing corner break and faulting checks. This product is complete and available for use. It may be downloaded from the FHWA LTPP web page (http://www.tfhrc.gov/pavement/ltpp/ltpp.htm). It has also been incorporated into a National Highway Institute training course, PCC Design Details, which is currently being updated to include recent LTPP research findings.

LTPPBind

Estimates of low and high pavement temperature are key to selection of the appropriate Superpave performance grade (PG) binder. Absent the data to show otherwise, the original Superpave binder selection algorithm assumed that pavement temperature is equal to air temperature. One of the first applications of data collected at the LTPP Seasonal Monitoring Program test sections showed that this assumption is unduly conservative. This research also produced a set of models that yield more accurate predictions of the true pavement temperature. These results are important because undue conservatism in selection of the PG binder grade can translate into increased use of more costly modified binders, particularly for states with both extremely high and extremely low temperatures. Nationwide, it is estimated that this product is saving $50 million per year in agency construction costs.

The LTPPBind software is the LTPP product developed to put these research findings into the hands of Superpave users. This product is complete and available for use. It may be downloaded from the LTPP web page. LTPPBind has been incorporated into the AASHTO Standard Specifications for the Superpave System.

Improved Procedures for Resilient Modulus Testing of Unbound Materials

Resilient modulus is the key parameter used to characterize pavement materials in the 1993 *AASHTO Guide for Design of Pavement Structures* (*4*). Resilient modulus testing of unbound materials will become even more important as agencies move toward implementation of more mechanistically based design procedures now under development. However, the standard test methods for determination of resilient modulus in place when LTPP was started did not yield consistent and repeatable results. For this reason, improved procedures for resilient modulus testing of unbound materials were among the earliest products to come from LTPP. The LTPP procedures are available for use as an AASHTO provisional standard, "Standard Test Method for Determining the Resilient Modulus of Soils and Aggregate Materials." The report *LTPP Materials Characterization: Resilient Modulus of Unbound Materials (LTPP Protocol P-46) Laboratory*

Startup and Quality Control Procedures (FHWA-RD-96-176) provides guidance with regard to laboratory test equipment verification and quality control procedures. A set of three videotapes was produced to address key questions about the test procedures. An update of the resilient modulus start-up procedures is in progress.

Portland Cement Concrete Pavement Practice Manual

A number of LTPP analysis projects have yielded important information about the performance of portland cement concrete (PCC) pavements. Although none of these findings will, by themselves, revolutionize pavement engineering, knowledge and application of these findings can improve pavement design decisions and thus the long-term performance of PCC pavements. A PCC pavement practice manual based on LTPP findings is currently under development. The manual was presented at a pilot workshop in July 2001 and was expected to be available for distribution by the end of 2001.

Improving Pavement Smoothness

Common sense, user surveys, and vehicle operating cost research all tell us that smooth pavements are important. High customer satisfaction and low vehicle operating costs go hand in hand with smooth pavements. LTPP data analysis findings reported in 1998 (*9*) provided important information about the factors affecting pavement smoothness. Further information regarding the factors that cause changes in pavement smoothness will be forthcoming from ongoing LTPP data analysis conducted via NCHRP Project 20-50(8/13). These findings provide the basis for information on best practices—practices that will help agencies achieve and maintain smooth pavements—to be presented at an August 2002 workshop on pavement smoothness, to be conducted via NCHRP Project 20-51(1).

Design Pamphlets in Support of the 1993 *AASHTO Guide for the Design of Pavement Structures*

One of the challenges faced by agencies implementing the 1993 *AASHTO Guide for Design of Pavement Structures* was the absence of reliable test procedures and comprehensive guidance for determining the pavement layer moduli and subgrade support parameters to be used as input to the design process (*4*). An LTPP data analysis project completed in 1997 addressed this challenge by providing the basis for the guidance that was needed and delivering that guidance in the form of three design pamphlets, as follows.

- *Design Pamphlet for the Backcalculation of Pavement Layer Moduli in Support of the 1993 AASHTO Guide for the Design of Pavement Structures,* September 1997 (FHWA-RD-97-076). (Available in hard copy.)
- *Design Pamphlet for the Determination of Design Subgrade in Support of the 1993 AASHTO Guide for the Design of Pavement Structures,* September 1997 (FHWA-RD-97-083). (Available through the National Technical Information Service or in PDF from the LTPP web page.)
- *Design Pamphlet for the Determination of Layered Elastic Moduli for Flexible Pavement Design in Support of the 1993 AASHTO Guide for the Design of Pavement Structures,* September 1997 (FHWA-RD-97-077). (Available in hard copy.)

Although intended for use with the 1993 Guide, much of the information provided in these pamphlets may also be applicable to new procedures now under development.

Guidelines for Design Resilient Modulus for Soils

As noted previously, use of the resilient modulus to characterize unbound materials will become increasingly important as agencies move toward more-mechanistic design procedures. Thus, it is important that agencies have complete and comprehensive guidance to help them select appropriate design values. Several existing LTPP products address this need, and more recent efforts have yielded additional pertinent information. This product, which is currently under development by FHWA, with funding from the National Cooperative Highway Research Program (NCHRP), will synthesize all of the pertinent information and products developed through or in support of LTPP testing and data analysis to develop comprehensive guidelines for determining the design resilient modulus for soils. This product is expected to be available in April 2002.

Guidelines for Determining As-Built Material Properties (Proposed, But Development Unfunded)

If pavement management is to be truly effective, agencies must collect data characterizing the as-built characteristics of their pavement structures. Without such data, they are forced to make decisions on the basis of design or assumed values that may or may not accurately reflect the as-placed materials. The product envisioned is a comprehensive guide, based on LTPP-developed procedures, for characterization of as-built (as opposed to as-designed) material properties. The guide would facilitate the process of identifying the most appropriate procedures for use in a particular application. Topics to be addressed include sampling (destructive or nondestructive), testing, and data analysis, reduction, and interpretation. The information obtained through application of these guidelines would be applicable in pavement management activities at both the project and network levels such as performance prediction, remaining life estimation, performance-related specifications, and construction contract administration.

The planned development of this product has been delayed because of funding shortfalls.

PRODUCTS ADDRESSING MAINTENANCE AND REHABILITATION OF PAVEMENTS

LTPP's long-term monitoring of pavement maintenance under SHRP H-106 test sites has shown that long-lasting, cost-effective pavement repairs can be achieved through the use of high-quality materials and appropriate construction practices. Four manuals of practice developed under the SHRP H-106 project provided guidance as to material selection and repair procedures for some of the most common pavement repairs. The following manuals, which have been updated and revised to include pertinent long-term performance and cost-effectiveness information, are available for use in both hardcopy form and as PDF files on the FHWA LTPP web page. Use of these manuals will help agencies achieve the maximum benefits from their investment in pavement maintenance. The manuals are

- *Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements—Manual of Practice,* December 1999 (FHWA-RD-99-152);
- *Materials and Procedures for Repair of Potholes in Asphalt-Surfaced Pavements—Manual of Practice,* December 1999 (FHWA-RD-99-168);
- *Materials and Procedures for Repair of Joint Seals in Portland Cement Concrete Pavement Joints—Manual of Practice,* December 1999 (FHWA-RD-99-146); and
- *Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements—Manual of Practice,* December 1999 (FHWA-RD-99-147).

PRODUCTS ADDRESSING PAVEMENT MANAGEMENT SYSTEM TOOLS AND TECHNIQUES

FWD Calibration Procedures

Deflection testing with FWDs has become an important part of highway agency efforts to characterize the structural condition of their pavements. If the decisions made on the basis of these data are to be sound, the data themselves must be accurate. For more than a decade, LTPP procedures for FWD calibration have helped to ensure that FWD data are as accurate as they can be. Working in partnership with state DOT hosts in Pennsylvania, Texas, Minnesota, and Nevada, SHRP established four FWD calibration centers. These centers have been used to calibrate the FWDs used in LTPP data collection, as well as those used by highway agencies for their own purposes. The LTPP procedures were adopted by AASHTO as a provisional standard and are used by at least one FWD manufacturer. Last year, the four FWD calibration centers were used to calibrate a total of 79 FWDs, including 57 owned by state highway agencies.

Both documentation and a set of videotapes are available to help calibration center users understand calibration benefits and procedures, and the preparation that is necessary to ensure that their calibration goes smoothly (*10*).

Software for Sensor Spacing

Correct interpretation of FWD data requires that the engineer have accurate information on the placement of the FWD deflection sensors. Although most agencies have established specific sensor locations to be used in their testing, sensors are occasionally mislocated for a variety of reasons. Recently completed LTPP analyses have yielded an analytical procedure and software that can be used to evaluate FWD data for potential sensor spacing errors. Timely application of this software can alert FWD operators to the possibility of errant sensor spacing, so that the actual spacing can be measured or corrected as appropriate. Currently, this software exists in a form suitable only for LTPP internal use. It has been recommended that FHWA work with FWD manufacturers to encourage incorporation of the LTPP methodology in their data collection software, so that maximum effectiveness can be achieved.

Guidelines for Temperature Adjustment of FWD Results

Because the stiffness of asphalt concrete varies with temperature, FWD test results obtained on flexible pavements must be adjusted for temperature if data obtained at different times are to be used interchangeably. An LTPP data analysis report documents the development of procedures for temperature prediction and adjustment factors for asphalt pavements (*11*). These procedures are intended for use in the analysis and interpretation of FWD test results. Draft standards are included in the research report and are usable in their present form. Both the AASHTO Subcommittee on Materials and ASTM Committee D4.39 are currently considering adoption of these procedures. A product development project to develop software that will facilitate application of these procedures has just been initiated by FHWA, with funding provided via NCHRP. It is scheduled for completion in April 2002.

Coefficient of Thermal Expansion of Concrete

The potential for thermal expansion of the concrete is an important consideration in concrete pavement design. However, prior to LTPP, no standard test method for determining the coefficient of thermal expansion of concrete existed. In response to LTPP's need to characterize concrete materials, FHWA's Portland Cement Concrete Pavement Team developed a test method to determine the coefficient of thermal expansion of the concrete used in LTPP test sections. The test method has been adopted by AASHTO as TP60-00, "Standard Test Method for Coefficient of Thermal Expansion of Hydraulic Cement Concrete," and is being used for determining this property at LTPP test sections.

Profile Viewer Software

Collection of longitudinal profile data has become the predominant means of evaluating and monitoring pavement roughness. Effective quality control and correct interpretation of these data often require that the analyst review not only summary indices [such as the International Roughness Index (IRI)] derived from the data, but also the profiles themselves. Prototype profile viewer software was developed to conduct the work reported in *LTPP Profile Variability* (*12*). This software allows the user to easily compare longitudinal profile data obtained from multiple profile data collection runs on the same or different dates. Development of a distribution-quality version of the profile viewer software is in progress to provide software having similar functionality for use by highway agencies. The final product will provide the analysis capabilities to compute summary indices such as IRI and power spectral density, in addition to the profile display functions available in the prototype version. The intent is to provide pavement engineers with a tool that will help them understand what is really going on in the pavement, to support sound decisions regarding rehabilitation and repair, and to provide effective quality control for pavement profile data. This work is funded as a part of FHWA's Pavement Smoothness Initiative and is scheduled for completion in July 2002.

LTPP Distress Identification Manual

Identification of the most appropriate strategy for pavement repair or rehabilitation requires an accurate assessment of pavement condition. The LTPP *Distress Identification Manual* provides criteria for assessing pavement distress in terms of type, severity, and extent. The most recent version of the manual was published as SHRP Report SHRP-P-338 (*1*). Refinements of the manual based on LTPP experience and distress data analysis findings are ongoing for LTPP purposes. A product development project to produce a distribution quality version of the updated manual is under way.

Guidelines for Conducting Distress Surveys (Proposed, But Development Unfunded)

Accurate and repeatable data characterizing pavement condition are essential to sound pavement design and management decisions. Achieving accurate and repeatable pavement distress data is particularly challenging, by virtue of the subjective nature of the data collection process. Work conducted in support of LTPP distress data collection activities, and analysis of the LTPP distress data has yielded information that provides a sound basis for improved distress data collection guidelines.

This proposed product would expand upon the ongoing development of an updated version of the LTPP *Distress Identification Manual* and LTPP analysis findings regarding the variability in pavement distress data, to provide guidelines on quality control, and recommendations on collecting quality manual and automated pavement distress data. The outcome may also suggest revision to the AASHTO Provisional Standard for Pavement Condition Data Collection.

The development of this product has also been delayed as a result of funding cutbacks.

Products Addressing Traffic Loading and Environment

Accurate information on actual or likely weather conditions at a particular location is needed for a wide variety of pavement applications—ranging from construction or maintenance scheduling to pavement design. Analysis of LTPP climatic data has shown that the virtual weather station concept used to estimate climatic conditions at the General Pavement Studies test sections is sound. That is, estimates of site-specific weather conditions derived by using data from several nearby National Climatic Data Center (NCDC) weather stations are very accurate. The implications of this finding for highway agencies is that the climatic data required to address a number of pavement-related needs can be obtained from existing data sources. Agencies need not go to the trouble or expense of collecting site-specific climatic data in most instances. A software tool to estimate site-specific weather conditions at any location in the United States by using the data compiled by NCDC is under development. A prototype has been developed and demonstrated. FHWA is cooperating with the California Department of Transportation in developing a distribution-quality product, which is expected to be available early in 2002.

PRODUCTS ADDRESSING DATA SERVICES

The LTPP Database and DataPave

Foremost among the products of LTPP is the LTPP database, the most comprehensive source of data documenting the structure and performance of in-service pavements ever assembled. The LTPP database is unique among LTPP products in that it is simultaneously available to all for use and is a work in progress. Similarly, it is both a product in its own right and the foundation for the majority of the LTPP products that will accrue in the long term.

The first public release of the LTPP data occurred in 1991. In 1998, a vast improvement in the accessibility of the LTPP data was achieved through the release of DataPave, a software package that includes most (but not all) of the currently available LTPP data. The DataPave user interface makes it easy for users to select the subset of the LTPP data they wish to work with. The selected data may then be saved in any of several formats for further manipulation and analysis using Microsoft Excel, Access, or statistical software. Currently, DataPave 2.0 is available. DataPave 3.0, which will include most of the LTPP data collected through March of 2001, was released in the fall of 2001.

LTPP Seasonal Monitoring CD-ROM

The LTPP Seasonal Monitoring Program was an intensive monitoring effort undertaken on a subset of the LTPP test sections to obtain data that will further understanding of seasonal variations in pavement structures and the factors that cause those variations. Data collection for the initial LTPP Seasonal Monitoring Program was concluded in 1999. Although the data collected in the monitoring of the test sections is available in the LTPP database, a substantial amount of supporting information is not readily accessible, as it was compiled in the form of reports documenting the installation of the instrumentation. Work is currently under way to package all of the data and supporting documentation from the Seasonal Monitoring Program on an easy-to-use CD-ROM, to facilitate future application of the data.

PRODUCT DEVELOPMENT, PACKAGING, AND DELIVERY EFFORTS

The earliest delivery of LTPP products was initiated with the 1992 release of the *SHRP Product Catalog* (*2*) and a series of product brochures supporting the catalog. Follow-up efforts included the broad dissemination of the LTPP *Distress Identification Manual* (*1*), the inclusion of a distress rater training course based on that used for LTPP in the National Highway Institute course offerings, and consideration and adoption by AASHTO (typically as provisional standards) of a number of LTPP test protocols.

In 1996, FHWA formed the LTPP Product Implementation Team. The mandate of this group was to

1. Evaluate all available LTPP outputs for product implementation potential;
2. Determine which LTPP outputs are "directly usable by our partners" and assign them top implementation priority;
3. Adapt, refine, or complete development on outputs not directly usable in their existing form; and
4. Develop marketing and packaging plans for LTPP products offering the greatest potential benefit to the highway community.

The efforts of the LTPP Product Implementation Team yielded

- The first widespread dissemination of the LTPP database in the form of the original DataPave software. In addition to the development of DataPave, the team spearheaded the development and conduct of a series of workshops to introduce potential users to DataPave and the LTPP data. More than 2,500 copies of the DataPave 2.0 software were distributed to potential users.
- A set of videotapes to support and promote use of the FWD calibration centers.
- Plans for software improvements and training to support FWD calibration.
- A set of videotapes to explain and promote the improved resilient modulus test procedures developed for LTPP.
- Trial application of the LTPP resilient modulus test procedures in state highway agency laboratories in Kansas and North Carolina.
- The RPD software.

Although the LTPP Product Implementation Team made significant advances, their efforts were cut short by the effects of the Transportation Equity Act for the 21st Century, which did not provide the funding required for the completion of planned work. During subsequent FHWA reorganization, the team was disbanded. The planned FWD software improvements and training did not come to fruition, and the trial application of the LTPP resilient modulus test procedures was terminated before reaching all of the interested states.

Currently, the responsibility for LTPP product development and implementation resides with the FHWA Infrastructure Core Business Unit, Office of Pavement Technology.

PRODUCT PLAN

The *LTPP Product Plan* was released in April 2001 (*5*). This plan establishes key definitions and criteria to be used in evaluating potential LTPP products, and it defines the roles and responsibilities of the different groups involved in LTPP product identification, monitoring, development, and delivery. It also identifies the needs to be addressed and outlines the product development and delivery processes, including the stakeholders who must be kept involved and informed of the product development process. Lastly, it outlines a process for monitoring the identification, development, and delivery of LTPP products.

OPPORTUNITIES AND CHALLENGES

The opportunities to derive products from the LTPP database, and the tools (testing and data collection procedures, data processing and evaluation tools, and so forth) developed to obtain and process the LTPP data are tremendous. Some of those opportunities are evident a priori. Others become evident after the required analytical work is under way. Some of those opportunities will pan out; others may not. The one thing that is certain is that the potential inherent in LTPP will not be realized if the opportunities that present themselves are not seized.

However, developing LTPP products is not enough to ensure the accrual of all the benefits that LTPP was intended to deliver. Packaging and delivering the LTPP products in a fashion that ensures their adoption by the agencies responsible for building and maintaining the nation's highway pavement is equally important.

Currently, the greatest challenge facing LTPP in seizing the opportunity to develop and deliver LTPP products is one of resource availability. Several aspects of the resource allocation issue are of critical importance. Obviously, it is important that adequate staff resources be allocated to product development and delivery activities and that this work be adequately funded. Less obvious is the fact that these activities must be viewed as a long-term commitment. The work that is undertaken must be carried to fruition. Doing so requires a predictable stream of funding, in addition to some constancy in the allocation of human resources.

SUMMARY ASSESSMENT OF PROGRESS

To date LTPP has produced a variety of valuable products. Some of these products, like DataPave, the FWD calibration procedures, and the LTPPBind temperature prediction algorithms, are quite heavily used. Others, such as the RPD software, have not yet seen widespread use. A greater investment in product delivery and marketing effort will be required if the full potential of the LTPP products already on the shelf is to be realized.

Overall, the progress made to date is reasonable in relation to the very limited resources that have been allocated to LTPP product development and delivery. However, the largest portion of the work in this area remains to be accomplished. Much of the work that will be needed cannot as yet be fully defined, pending completion of the analysis that will provide the basis for product development.

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