THE LONG-TERM PAVEMENT PERFORMANCE PROGRAM ROADMAP

A STRATEGIC PLAN

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Executive Summary

The goal of the ongoing, 20-year long-term pavement performance (LTPP) studies is to give State and Provincial transportation departments—the owners and customers of the LTPP program—the information and tools they need to build and maintain longer-lasting pavements. The *Roadmap* charts a course to the program's near-term and longer term destinations, which are based on the products needed by State and Provincial highway agencies today.

The *Roadmap* was developed with input from all of the partners, which include State and Provincial highway agencies, the American Association of State Highway and Transportation Officials (AASHTO), the Transportation Research Board, industry, academia, and FHWA.

The LTPP program is a dynamic process; as needs and priorities shift, the *Roadmap* and data analysis plan will be adjusted accordingly.

PRODUCTS

The LTPP products are aimed at improving

- the selection and effectiveness of pavement maintenance strategies,
- the performance of various pavement rehabilitation techniques and materials, and
- the selection of design features for new construction or reconstruction of pavements.

Some products are already available, including those related to materials testing, pavement performance monitoring, and equipment standards and calibration procedures. Still under development are products directed at the selection and effectiveness of maintenance strategies, performance of various rehabilitation techniques and materials, and the selection of design features for new or total reconstruction.[1]

ANALYSIS PLAN

The LTPP data analysis plan contained in the *Roadmap* outlines how the data being collected can best be analyzed and applied to achieve the LTPP objectives.

The partners in the LTPP program will develop detailed plans for conducting the studies, analyzing the data, and reviewing the results.

The LTPP data analysis will augment the work being done by the AASHTO Joint Task Force on Pavements.

[1] A catalog describing the LTPP products will be available from FHWA by the end of December 1995. The products will be introduced at a mid-term national meeting, scheduled for March 26-28, 1996, in Irvine, California.

I. Introduction

BACKGROUND

The objective for the long-term pavement performance (LTPP) program was set forth in *America's Highways: Accelerating the Search for Innovation*:[1]

> Increase pavement life by the investigation of the long-term performance of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soils, and maintenance practices.

The report proposed a 20-year study of in-service pavements across the Nation. It also recognized the need for "major payoffs" from the proposed program in the short term (5 years) and in the intermediate term (10 years).

Through the cooperative efforts of the States, industry, academia, the American Association of State Highway and Transportation Officials (AASHTO), the Transportation Research Board (TRB), and the Federal Highway Administration (FHWA), research plans for the Strategic Highway Research Program (SHRP) were published in 1986.[2] The LTPP research plan established six specific objectives under the broad objective mentioned above:

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

To address these objectives, the plan set forth two types of studies (see Appendix A). The General Pavement Studies (GPS) would be a large experiment in terms of number of pavements, locations, and factors designed to produce a broad range of products and results. The Specific Pavement Studies (SPS) would be more targeted in terms of objectives, experimental approaches, and construction needs aimed at an intensive study of a few independent variables. As a larger sample of the pavement population, the GPS experiments would also serve as a validation reference for the SPS results. The GPS sections would

[1] *America's Highways: Accelerating the Search for Innovation.* Special Report 202. Washington, DC: Transportation Research Board, 1984.

[2] *Strategic Highway Research Program Research Plans.* Final Report. Washington, DC: Transportation Research Board, May 1986.

be selected from existing highways, and the SPS sections would be specially designed and constructed.

The GPS experimental design was tailored to produce short-term and intermediate-term results; the SPS experimental design could be considered to be directed towards the long-term results.

Funding for SHRP and LTPP was provided in the Surface Transportation and Uniform Relocation Assistance Act of 1987. SHRP funding ended in 1992, but funding for the continuation of the LTPP studies was provided in the Intermodal Surface Transportation Efficiency Act of 1992 (ISTEA). Operation of the LTPP program was transferred from SHRP to FHWA in June 1992.

PURPOSE OF THE ROADMAP

As the Cheshire cat said to Alice, "If you don't know where you want to go, any road will take you there." The purpose of the *LTPP Program Roadmap* is to:

- ➜ Propose the near- and long-term destinations—the products—for the Nation's LTPP program,
- ➜ Obtain input from, and the support of, the partners, and
- ➜ Communicate the plan to all the partners and stakeholders.

For the LTPP program, it is not only necessary to know where we want to go, but also to know the specific priorities and the necessary organizational and operational structures. The *Roadmap* strives to provide this complete picture.

CUSTOMERS

The principal stakeholders in the LTPP program are the State departments of transportation (DOTs) that operate the in-service pavement test sections and provide the voluminous amounts of historic information and operating information associated with these sections. As the pavement sites were being nominated and selected, the Canadian Provinces became another principal stakeholder by providing a number of critically needed test sections. In addition to being the principal stakeholders, these agencies are also the principal customers for the LTPP products. The LTPP program's objectives were established to respond to the needs of the States and Provinces.

Additional customers for the LTPP products include the following:

- ➜ Industry—the consultants, contractors, material suppliers, and equipment manufacturers and their associations that design, construct, and maintain the roadways and provide technical assistance to the public agencies
- ➜ Toll facilities
- ➜ Other government agencies that own and operate roads or pavements
- ➜ Local agencies
- ➜ Colleges and universities, both in education and research
- ➜ AASHTO, TRB and FHWA
- ➜ The international pavement engineering community

EXPECTATIONS

In preparing this document, an effort was made to determine which existing needs could be addressed through the analysis of the LTPP data base. The *Roadmap* development process included input from technical experts and top management of State DOTs, academia, AASHTO, industry associations, and FHWA. This input included ranking specific needs. The short-term and intermediate-term analysis activities described in this document reflect these needs and priorities.

PRODUCTS

The LTPP products are *things*—information, computer software, analysis procedures, testing procedures, design procedures, guidelines, etc.—derived from the LTPP data base or resulting from the research effort and delivered in a form that can be used by the States and Provinces to build better pavements. The LTPP products fall in four general categories:

1. Pavement design guides and maintenance strategies
2. Pavement monitoring procedures
3. Material testing
4. Equipment standards and calibration procedures

The products in Category 1 will primarily result from the analysis of the LTPP data base. The analysis products will be either qualitative or quantitative, depending on the level of effort expended in their development. Although some analysis is already under way, the major analysis effort will begin in 1996.

The products in Categories 2, 3, and 4 already exist and are being used by the LTPP program. Some of these products have been adopted by AASHTO and are being commercially manufactured and used, or are available for use. Information on these products is available from FHWA's Office of Technology Applications.[3] The majority of these products can be considered research grade and may need to be modified for general engineering applications. The LTPP Implementation Technical Working Group (TWG) will be reviewing these products for their state of readiness, applicability, packaging, and delivery methods.

IMPLEMENTATION

The implementation plan for the SHRP products is described in a June 1993 FHWA publication.[4] The *LTPP Program Roadmap* and the *Implementation Plan* are similar in nature in that the documents establish the goal, purpose, roles and responsibilities, and methodology for each program. In the *Implementation Plan,* a structure of four TWGs was established to provide technical recommendations for specific implementation activities. The LTPP Implementation TWG was charged with identifying and developing implementation activities for the LTPP products. A number of early products were considered by the LTPP Implementation TWG, and recommendations were offered regarding specific implementation activities.

Between 1993 and 1995, significant progress was made in expanding the list of available and planned LTPP products. This list is currently being compiled and will include the name of the product, a product description or purpose,

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[3] Office of Technology Applications, Federal Highway Administration, HTA-3, 400 Seventh St., SW., Washington, DC 20590. Fax: 202-366-7909.

[4] *Implementation Plan—Strategic Highway Research Program Products.* Washington DC: USDOT, Federal Highway Administration, June 1993.

and an estimate of the state of readiness (i.e., planned, under development, or currently available). This draft LTPP product catalog will be provided to the members of LTPP Implementation TWG so they can begin to develop implementation activities. The role of FHWA's Pavement Performance Division is to produce the products. FHWA's Office of Technology Applications, working with the program offices, will continue to be responsible for packaging and delivering these products to the customers.

The AASHTO Subcommittee on Materials has aggressively pursued the implementation of SHRP products. In cooperation with FHWA, AASHTO has designated a SHRP implementation coordinator to assist the Subcommittee in structuring a program for the rapid adoption of the SHRP and LTPP test methods, procedures, and specifications. AASHTO's *Provisional Materials Standards* contain 49 provisional standards related to SHRP-LTPP products.[5]

RESOURCES

The main resources of the LTPP program are the States' commitment and participation, the LTPP staff, and program funding. The *Roadmap* was developed under the assumption that all of these resources will remain constant. *To support the continued dedication of these resources, LTPP is focused on producing products that will improve pavements.*

If a reduction in any of the resources comes about, changes will have to be made in the *Roadmap.* However, the LTPP program's top priorities are analysis and product development. It is anticipated that any reductions in funding will be accommodated in other areas of the program. Establishing analysis as the top priority does not mean the operational efforts will be neglected. Establishing analysis as the top priority now means that it is time for the product of our operational efforts—namely, the data base—to be put to use.

In fiscal year 1995, the LTPP budget is approximately $14 million, of which $6 million is provided through Section 6001 of ISTEA and $8 million is provided through FHWA's general operating expenses. Approximately 70 percent of these funds are spent on operations (regional offices, technical assistance, data base, photographic distress surveys, equipment, and so forth); 15 percent are spent on data analysis; and 15 percent are spent on completing the SHRP asphalt, concrete and structures, and highway operations activities that require in-service evaluations. In addition, FHWA provides funding for the LTPP staff and travel expenses.

To reduce operations below the 70 percent level would require a significant change in the data collection activities for the approximately 2,800 pavement monitoring sections located across North America. Without doing the analysis, we are reluctant to make operational changes that may adversely affect future products. It is anticipated that the analysis will be funded at the 15 percent to 20 percent level for at least the next several years.

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[5] *Provisional Materials Standards.* Washington, DC: American Association of State Highway and Transportation Officials, 1985.

II. Partners and Their Roles and Responsibilities

PARTNERS

The LTPP program represents a cooperative effort of the highway community. The original partners in establishing SHRP and LTPP were the State departments of transportation, AASHTO, TRB, industry, academia, and FHWA. During the life of SHRP, this list of partners expanded to include the Canadian Provinces, the Canadian Strategic Highway Research Program (C-SHRP), and more than 30 other countries. This partnership extended beyond the development of the objectives and experimental plan to include the administrative and technical management of SHRP, in addition to sharing the workload in collecting and providing the data.

This partnership continues today as FHWA leads the implementation of the SHRP products and the operation of the LTPP studies. Through the TRB-SHRP Committee and the FHWA implementation TWGs, SHRP implementation and the LTPP studies continue to receive input from the partners (Figure 1).

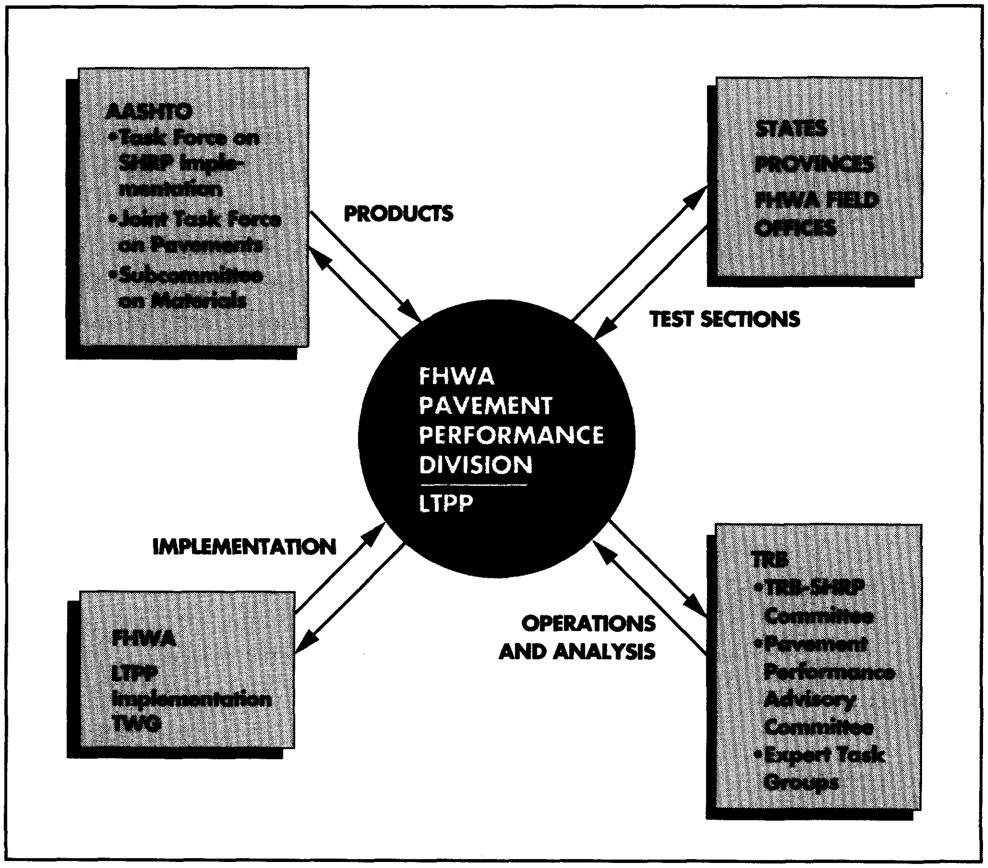

FIGURE 1 Coordination and Communication Among the Partners in the LTPP Program

ROLES AND RESPONSIBILITIES

The technical direction and operations of the LTPP program are shared by the partners. This section briefly describes their various responsibilities in running the program.

During the life of SHRP (1987-1992), the management of, and technical input to, the LTPP studies was provided by the SHRP Executive Committee, the LTPP Advisory Committee, and several expert task groups. The SHRP organization provided staff to conduct the operations; at its peak this included approximately 50 permanent and loaned staff for the 4 program areas (LTPP, asphalt, concrete and structures, and highway operations). With the transfer of the LTPP operations from SHRP to FHWA, the top management and technical input are now provided through a cooperative agreement between FHWA and TRB. The TRB-SHRP Committee is composed of top management from the States, AASHTO, industry, academia, Canada, and FHWA. The purpose of this committee is to provide top management input to the SHRP implementation program and the LTPP program. Supporting the TRB-SHRP Committee is the Pavement Performance Advisory Committee (PPAC) and several expert task groups (ETGs). The PPAC and its subcommittees provide technical input on LTPP research operations and analysis. PPAC is made up of technical managers and experts from the partners' organizations.

States and Provinces

The States and Provinces nominate, provide, and operate the in-service pavement monitoring sections. These sections are either existing pavements (GPS experiments) or have been specially constructed by the highway agencies to meet the LTPP experimental plan (SPS experiments). In addition to providing the monitoring sections, the States and Provinces provide various types of inventory and operations information, material testing, and traffic data collection. The States and Provinces also provide traffic control whenever LTPP equipment or contractors are on site gathering data. Construction of the SPS sections requires an extra level of effort in funds, staff, and coordination by the States, Provinces, highway contractors, and material suppliers.

The LTPP program has required, and will continue to require, a significant commitment on the part of the States and Provinces in order to reach the program's objectives. FHWA commends the States and Provinces for their commitment and efforts in support of the LTPP objectives.

An extremely valuable resource to SHRP and the LTPP program has been the loaned staff provided by the States, Provinces, and international participants. These experienced engineers have brought real-world input to the design and operation of the LTPP studies. As the LTPP program gears up for analysis, loaned staff members will be critical in formulating, managing, and conducting the data analysis. The loaned staff members are generally assigned to a 12- to 18-month term in FHWA's Turner-Fairbank Highway Research Center in McLean, Virginia. Financial assistance for travel and living expenses is provided by FHWA. The loaned staff members get involved with the daily LTPP activities, as well as specific areas of their research expertise.

The LTPP program is seeking experienced engineers and researchers in the areas of data analysis, data management, SPS studies, monitoring and evaluation, analysis of seasonal monitoring data, traffic engineering, and LTPP operation communications support. In 1994, the LTPP program accepted loaned staff from Texas DOT and Canada. It is hoped that in the future a larger contingent of State and international representatives will participate in the LTPP studies through the loaned staff program.

AASHTO

AASHTO has several committees involved with LTPP and SHRP implementation. These include the Joint Task Force on Pavements (JTFOP), the Subcommittee on Materials (SOM), and the Task Force on SHRP Implementation. Of immediate importance to the *LTPP Program Roadmap* is the framework currently being developed by the JTFOP regarding the advancement of pavement technology. It is expected that the LTPP products will directly meet some, but not all, of the JTFOP's objectives. The LTPP program's detailed analysis plans will be tailored to best fit the JTFOP's framework.

The LTPP program also coordinates with the SOM, since approximately two-thirds of State materials sections have responsibility for pavement design or management. All of the material sections provide input to their State's pavement design, construction, maintenance, and pavement management functions. In addition, a number of the potential LTPP products will be in the form of material specifications that fall under the jurisdiction of the SOM.

Finally, the LTPP program works with the AASHTO Task Force on SHRP Implementation, which is composed of eight top-level managers or chief engineers from member departments.

FHWA

Within FHWA, the Pavement Performance Division in the Office of Engineering R&D is responsible for the operation of the LTPP program. The LTPP portion of the Pavement Performance Division currently consists of seven permanent professional staff members, supplemented by an extensive system of support contracts. The contracts are for the operation of the four LTPP Regional Offices, photographic pavement distress surveys, overall technical assistance, and traffic data collection assistance. The Regional Offices are the main liaison with the States and Provinces and are responsible for both collecting data on the pavement monitoring sections and processing the data supplied by the highway agencies.

FHWA has several other offices or units that also support the LTPP program. At FHWA headquarters, these units consist of the Pavement Division in the Office of Engineering and the Engineering Applications Division in the Office of Technology Applications. The Pavement Division is the focal point for FHWA's pavement technology program. It is also responsible for the development of pavement-related regulations, policies, and guidelines for the

Federal-Aid Highway Program. The Pavement Division provides FHWA's formal representation to the TRB-SHRP PPAC and ETGs, and a division staff member chairs the LTPP Implementation TWG.

The Office of Technology Applications is FHWA's lead office for SHRP implementation. Information on all of the SHRP implementation activities is contained in the *SHRP Product Implementation Status Report* produced periodically by FHWA and available in hard copy or on-line through the SHRP Information Clearinghouse.

FHWA's Region and Division offices are currently deeply involved in the SHRP product implementation, but have had only limited involvement in the operation of the LTPP program. An increased involvement by these offices in the LTPP studies would be an asset to the program. The following are suggestions regarding specific activities for FHWA field offices:

- Coordination with the State and the LTPP program regarding data collection, test section status, technical concerns or issues, and product needs
- Coordination with the State to ensure that adequate resources are available to support the LTPP commitment
- Coordination, communication, and technical assistance in the identification, design, and construction of SPS projects
- Support for, and participation in, the technology transfer and implementation activities for the LTPP products

III. Data Management

DATA AVAILABILITY AND QUALITY

Any planning for the analysis of the LTPP data must consider what products are needed by the customers versus what information is available. The LTPP data base can be thought of as a very large and complex data warehouse. When asked the question, What data are available? there are several ways to respond. One way is to look at how many pavement sections are in each experimental design cell. Recruitment of GPS sections is complete, and the total population and geographical distribution of the experiments vary by type, from very good in the asphalt pavements on aggregate bases to fair and somewhat regionally distributed in a few of the other experiments. Overall, there are 780 GPS sections located in the United States and Canada. Recruitment for SPS-3 and SPS-4 (maintenance effectiveness for asphalt concrete and portland cement concrete pavements) is also complete. Recruitment of projects for SPS-1, -2, -5, -6, -7, and -8 is still under way. It is likely that the SPS-1, -2, -5, and -6 cells will be completely filled, while SPS-7 and -8 may not be. In addition, construction of SPS-9a test sections (Superpave binder) will begin in 1995 (the experimental cells are expected to be filled).

The next response to the question relates to the actual data. For example, in the Inventory module, more than 90 percent of the GPS sections have all of the "critical data elements." Critical data elements include such information as pavement material types and thickness. They do, however, only represent a portion of all the data that are collected. A meaningful determination of what is available can only be made after the specific information and data elements of interest are identified, a data request is made, and the supplied data are evaluated.

Finally, there is the quality of the data. For some of the data items, very rigorous procedures for data collection are used, and the resulting information can be considered research grade. For other data items, state-of-the-practice procedures are used, and the information can be considered engineering or applications grade. In other cases, the information represents what is available or what the current data collection procedures can provide. The quality of this latter category of data is yet to be determined.

To put the question of what data are available into overall perspective, the LTPP data base represents the largest and best pavement performance data base ever produced. It contains sufficient data to produce products today that will significantly improve pavement performance.

DATA BASE PHILOSOPHY

The LTPP data base can be considered a very large information warehouse (in fact, if you took all the information stored in the data base at this time and stored it on standard 1.44-megabyte disks, and then stacked the disks, the pile would reach 8.5 stories high). It is also a significantly different product than the other LTPP products. In some respects, the data base can be considered as more of a tool—or parts bin—for making products. The top priority in the operation of the data base is to acquire the information, ensure its quality, and input the information. The data base has been optimized for data storage and not access; as a result, it is not especially user-friendly. Although the customers for the LTPP products are the State and Provinces, the initial user of the data base in the majority of cases will be the pavement researcher who produces the products. With advancements in computer technology, and as the LTPP procedures become refined, the data base will become more of a product that can be readily used by the States.

IV. Data Analysis Plan

INTRODUCTION

The specific analysis areas described in this plan represent current thoughts on the most effective use of the data base and other resources to contribute to achievement of the LTPP objectives. Prioritization in light of resource (budgetary) constraints will be addressed in the development of the detailed analysis plans. As work proceeds, the analysis areas will be reexamined periodically and measured against progress in parallel investigations, the development of the data base, and the evolution of the needs of the LTPP constituency. Many of the early analysis products will be based primarily, if not exclusively, on data from the GPS experiments. The SPS experiments will become more important as a focal point for LTPP analytical efforts in the program's later years.

Although the analysis of the LTPP data will yield significant improvements in pavement design and management, it is important to realize that not all roads lead to LTPP. The LTPP program, and the resulting data base, were not designed to address all of the technical concerns of pavement engineers and managers. The 1986 LTPP research plan recommended that the data base be structured so that sufficient data would be available for both building empirical models and calibrating or improving mechanistic-empirical models.

LTPP can contribute to the advancement of pavement technology, but it is not the architect of the overall structure for a new pavement design system. The development of a coordinated plan for a new pavement design will be accomplished by the AASHTO Joint Task Force on Pavements. The LTPP program will coordinate its activities with the Joint Task Force on Pavements and contribute to the plan as data and resources allow.

FOCUS

The data analysis plan defines a set of study areas to be supported directly by the FHWA. Several key points needed to be understood in reading the analysis plan:

- ➜ The data analysis plan is "needs driven" and is not intended to be a coordinated set of activities that leads to a single goal or product. As noted previously, the AASHTO Joint Task Force on Pavements is establishing a framework for an improved pavement design procedure, to which LTPP will contribute.
- ➜ The data analysis plan is directed at producing products that can be used in providing better pavements.
- ➜ The data analysis plan is a strategic plan under which detailed analysis plans will be developed.
- ➜ The data analysis plan is a dynamic document that will be refined and changed as needs and the state of the program evolve.
- ➜ The data analysis plan represents the analysis activities that FHWA intends to support and is not intended to limit or preclude any other analysis efforts. To realize the full potential and benefits of the LTPP data base, it is essential that

other organizations and groups utilize the data base. These include, but are not limited to, the National Cooperative Highway Research Program (NCHRP), pooled-fund State Planning and Research projects, individual State research programs, industry-funded studies, and academic studies.

PREVIOUS ANALYSIS

In 1989, SHRP awarded two data analysis contracts as the first funded studies to be based on LTPP pavement performance data. The principal data analysis contract was awarded to a team from Brent Rauhut Engineering (BRE) and ERES Consultants. A smaller contract was awarded to Michigan State University. These contracts were intended as initial studies of the use of the data base, rather than as definitive investigations of pavement performance.

BRE and ERES extracted and processed LTPP data to create analytical data bases specifically tailored to the calculations they planned.[6] In the process, they identified and helped correct gaps, overlaps, and other inconsistencies in the data base. They developed preliminary distress-specific pavement performance models and conducted sensitivity analyses of their variables to identify those having the strongest influence on specific distresses.

Michigan State University performed a mechanistic evaluation of the AASHTO flexible design equations using 243 AASHTO-designed hypothetical pavement sections with various layer properties, roadbed soil moduli, and traffic volumes.[7] Through this effort, a number of aspects of the *AASHTO Guide for Design of Pavement Structures*[8] ("AASHTO Guide") procedures that are inconsistent with a mechanistic model for pavement structures were identified.

ANALYSIS IN PROGRESS

Several FHWA-sponsored efforts to analyze the LTPP data are currently under way. The anticipated products and delivery schedule for these contracts are summarized in Table 1.

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[6] J. Brent Rauhut, et al. *Early Analyses of Long-Term Pavement Performance General Pavement Studies Data: Lessons Learned and Recommendations for Future Analyses.* Washington, DC: National Research Council, Publ. No. SHRP-P-680, 1994.

Brian Killingsworth et al. *Early Analyses of LTPP General Pavement Studies Data: Data Processing and Evaluation.* Washington, DC: National Research Council, Publ. No. SHRP-P-684, 1994.

J. Brent Rauhut and Michael I. Darter. *Early Analyses of LTPP General Pavement Studies Data: Executive Summary.* Washington, DC: National Research Council, Publ. No. SHRP-P-392, 1994.

Amy L. Simpson et al. *Sensitivity Analyses for Selected Pavement Distresses.* Washington, DC: National Research Council, Publ. No. SHRP-P-393, 1994.

Jerome F. Daleiden et al. *Evaluation of the AASHTO Design Equations and Recommended Improvements.* Washington, DC: National Research Council, Publ. No. SHRP-P-394, 1994.

[7] Gilbert Y. Baladi and Frances X. McKelvey. *Mechanistic Evaluation and Calibration of the AASHTO Design Equations and Mechanistic Analysis of the SHRP Asphalt Surfaced Pavement Sections.* Washington, DC: National Research Council, Publ. No. SHRP-P-678, 1994.

[8] *AASHTO Guide for Design of Pavement Structures.* Washington, DC: American Association of State Highway and Transportation Officials, 1993.

TABLE 1: Long-Term Pavement Performance Data Analysis Currently In Progress

EMPHASIS	EXPECTED PRODUCTS	PRODUCTS READY	CONTRACTOR
Portland Cement Concrete (PCC) Pavement Design (1, 9, 15)	• Handbook(s) for the design and construction of long-lived PCC pavements, including: - Guidelines for the selection of *k* values on the basis of soil type and site conditions or back-calculation - Validation of the NCHRP 1-30 performance model for rigid pavements - Quantitative estimates of the effects of key design features and practices on PCC pavement performance - Improved performance prediction models for PCC pavements	12/97	ERES
Temperature Adjustment (6)	• Validated temperature prediction procedure for AC pavements • Temperature adjustment procedures for back-calculated moduli, deflections, and basin characteristics • Draft standard for temperature prediction and correction in the structural evaluation of AC pavements	11/95	Braun Intertec
Mechanistic Analysis (1, 9, 15)	• Calibrated mechanistic-empirical design procedures which include seasonal effects • Guidelines for improving the performance of continuously reinforced concrete (CRC) pavements • Guidelines for application of laboratory and back-calculated moduli in pavement design and evaluation	2/97	TTUSA
Performance Prediction for PCC Pavements (15)	• Statistical models to predict faulting, cracking, spalling, punchouts, and IRI in PCC pavements • Calibrated state-of-the-art mechanistic-empirical models for predicting cracking, faulting, spalling, and punchouts • New models to predict IRI as a function of the preceding distress models	8/96	Transtec
Maintenance Effectiveness (12)	• Quantification of the comparative effectiveness of different maintenance treatments (SPS-3 and SPS-4)	3/96	Nichols
	• Bayesian models to predict the effect of maintenance treatments on flexible pavements (SPS-3)	3/96	C-SHRP
Guidelines for Estimating Design Parameters (1)	• HMA pavement design handbook providing guidance on: - Use of back-calculated and laboratory moduli in pavement design - Estimation of moduli from other materials data - Consideration of drainage conditions in pavement design - Characterization of the subgrade, including seasonal variations - Estimation of AASHTO layer coefficients in light of seasonal variations in layer moduli	5/96	Brent Rauhut Engineering
Roughness Evaluation (11)	• Fully documented models for the prediction of pavement roughness in new and rehabilitated pavements.	12/96	SME

Note: Numbers in parentheses in Emphasis column refer to project areas identified in Appendix B—Analysis Objectives and Products.

ANALYSIS CATEGORIES

LTPP data analyses will cover a broad spectrum. For organizational purposes, these activities have been loosely grouped into three categories and three timeframes. The categories identified are intended to illustrate the anticipated range in the types of products produced. As such, they are neither all-inclusive nor uniquely bounded. The analysis categories are: knowledge and insight, performance models, and performance assessment and comparison.

Knowledge and Insight

The products in this category will take the form of factual, qualitative, and/or quantitative information concerning the performance of different pavements under the conditions represented by the LTPP test sections. These products would not involve performance or design models *per se*, but would be useful in decision making. The analyses will be introspective in nature—a comparison of one subset of the data from the LTPP data base with another subset to identify and quantify differences and similarities in performance and the factors that affect it.

Performance Models

These analyses will produce performance or design models, or components that will subsequently be used to build complete performance or design models. These models will describe relationships between particular measures of performance, such as a type of distress or roughness, and the key parameters believed to control the extent of this performance. The parameters considered in such models might include or represent the mechanical properties of the constituent materials, layer thicknesses, layer materials, traffic loadings, and environmental conditions. Project areas involving assessment or modeling of seasonal effects are included in this category.

It is anticipated that some of the models will be of a purely empirical (statistical) nature. Other models will be of a mechanistic-empirical type, combining statistics with the mechanics of how pavements respond to loads and thus relating pavement performance to predicted pavement responses—stress, strain, and deformation—induced as the pavement is trafficked. The models resulting from these efforts could range from empirical predictive equations for the development of individual distress types to complete design procedures.

The forms in which these models will be delivered will range from research reports to computer software. In many instances, the results of individual analysis projects will yield products that can be implemented in their own right. In some cases, individual analytical efforts may serve primarily as precursors to subsequent efforts—providing components of an "ultimate" design or performance prediction model, or preliminary information influencing the course of future analytical efforts.

Performance Assessment and Comparison

The products of analyses in this category will be specific, quantitative information on the effects of different design features on pavement performance. For the most part, these products will take the form of handbooks or guidelines for the selection of design features that will contribute to improved pavement performance. Analyses of this type are especially applicable to assessments of the relative effects of the different design features considered in the SPS experiments.

TIMEFRAMES FOR ANALYSIS

0 to 3 years

Objectives identified as having a timeframe of less than 3 years are immediately addressable with data currently available and have the potential to yield implementable products within 3 years. They are in no way dependent on the completion of other analysis activities.

3 to 5 years

Objectives identified as having a timeframe of 3 to 5 years require data or results (from analyses addressing other, related objectives) that are not immediately available, but that are expected to be available soon enough to allow completion of the analyses within 5 years.

5 to 10 years

Objectives identified as having a timeframe of 5 to 10 years require substantial time series data or depend on the results of analyses addressing other related objectives.

IDENTIFICATION AND SELECTION OF SPECIFIC STUDIES

The project selection for this plan was made by a task force composed of representatives of the Experimental Design and Analysis and Traffic Data Collection and Analysis ETGs; LTPP contractors; TRB; and FHWA.

Nominations for specific project areas to be considered for inclusion in this plan were solicited from a broad array of individuals and groups, including the State and Provincial coordinators, members of several of the ETGs, industry, and LTPP contractors. These nominations were then reviewed, sorted, refined, and combined, as appropriate, by the task force. The task force also identified a few additional project areas to fill "gaps" not covered by the nominations received prior to the meeting. In addition, the task force assigned a priority level (1 being a higher priority than 2) to each project area. Factors considered in this process included need, applicability of the LTPP data, and data availability (within a given timeframe or within the LTPP data base). Subsequent to the task force meeting, TRB and FHWA staff and contractors refined the project titles and prepared the project summaries present herein. As part of this staff work, a fourth analysis category—Seasonal Effects Models—was combined with the Performance Models category.

The result of this project identification and selection effort is summarized, by timeframe, in Tables 2A through 2C. Project areas that are at least partially addressed by work currently under way are denoted by shaded boxes. The numbers in parentheses refer to the project areas identified in Appendix B—Analysis Objectives and Products. Only two priority levels appear in the table

TABLE 2A: Summary of Near-Term (0-3 Years) Analysis Project Area By Product Category

PRIORITY	PRODUCT CATEGORY		
	KNOWLEDGE AND INSIGHT	PERFORMANCE MODELS	PERFORMANCE ASSESSMENT AND COMPARISON
1	*Guidelines for Estimating Design Parameters* (1)	Modeling of Load Transfer in PCC Pavements (5)	Effects of As-Constructed Variability on Performance (7)
	Evaluation of the Effects of Rehabilitation (2)	Temperature Adjustments for HMA Pavement Evaluation (6)	Relationship of Transverse Profile to Rutting, Rutting Measures, and Performance (8)
	Performance Comparisons of SPS Sections (3)		*Identification of Common Characteristics of Long-Lived GPS Sections* (9)
	Assessment of Traffic Sampling (4)		*Summary and Assessment of Early Performance of SPS Test Sections* (10)
			Roughness Evaluation (11)
			Evaluation of Pavement Maintenance Treatments (SPS-3 and SPS-4) (12)
			Investigation of Reductions in International Roughness Index With Time (13)
2	Investigation of PCC Strength Gain Rates (14)	Improved Performance Prediction Models for New Pavements (15)	

Note: Numbers in parentheses refer to project areas identified in Appendix B—Analysis Objectives and Products. Shaded boxes indicate project areas that are at least partially addressed by work currently under way. Project areas regarded as especially urgent are indicated by italic type.

TABLE 2B: Summary of Mid-Term (3-5 Years) Analysis Project Areas by Product Category

PRIORITY	PRODUCT CATEGORY		
	KNOWLEDGE AND INSIGHT	PERFORMANCE MODELS	PERFORMANCE ASSESSMENT AND COMPARISON
1	Comparison of Historical Traffic Estimates With Monitoring Data (16)	Improved Performance Prediction Models for New and Rehabilitated Pavements (18)	Effects of Specific Design Features on Performance (23)
	Assessment of Variability in HMA Pavement Layer Thickness and Stiffness (17)	Evaluation of Load-Response Models (19)	Relationships Between Material Quality and Performance (24)
		Adjustment of Deflection Data to Critical Design Conditions (20)	Inter-Relationships Between Distress Types (25)
		Variations in Layer Moduli, Stress Sensitivity, and Support (21)	
		Evaluation of *In Situ* Moisture and Temperature Prediction Models (22)	
		Relationship Between Roughness and Distress (27)	
2	Maintenance Requirements in Life-Cycle Cost Analyses (26)	Seasonal Effects on Roughness Measurements (28)	

Note: Numbers in parentheses refer to project areas identified in Appendix B— Analysis Objectives and Products.

TABLE 2C: Summary of Long-Term (5-10 Years) Analysis Project Areas by Product Category

PRIORITY	PRODUCT CATEGORY: KNOWLEDGE AND INSIGHT	PRODUCT CATEGORY: PERFORMANCE MODELS	PRODUCT CATEGORY: PERFORMANCE ASSESSMENT AND COMPARISON
1	Relationships Between Deflection and Distress (29)	Improved Performance Prediction Models for New and Rehabilitated Pavements (30)	Effects of Specific Design Features on Performance (37)
		Transfer Functions Relating Response to Distress (31)	
		Evaluation of Environmentally Induced Deterioration (32)	
		Procedure for Estimating Remaining Life (33)	
		Performance Models Incorporating Environmental and Drainage Parameters (34)	
		Modeling of Maintenance Effects on Pavement Performance (35)	
		Prediction of Seasonal Variations in Unbound Materials (36)	

Note: Numbers in parentheses refer to project areas identified in Appendix B— Analysis Objectives and Products.

because project areas deemed to be of low priority were not selected for inclusion in the plan. A few project areas regarded as being especially urgent are denoted by italic type. Several project areas are included in more than one timeframe, to provide for interim advances and take full advantage of the data that will accumulate in the long term.

It should be noted that the organization of these project areas does not necessarily reflect the manner in which they will be pursued. In some cases, a single project area may represent a single data analysis contract; in other cases, a single data analysis contract may encompass several project areas. Conversely, a single project area may be broken down into several smaller analysis projects.

NEXT STEPS

The plan for LTPP data analysis presented in the preceding pages represents a beginning—not an end. In the months and years to come, the plan will be adjusted and refined to reflect:

- ➔ Feedback from participants and partners in LTPP,
- ➔ Budgetary constraints,
- ➔ Evolution of AASHTO's process for development of new pavement design procedures, and
- ➔ Progress in FHWA-sponsored and parallel pavement research.

FHWA has begun the contracting process to select and put in place an analysis team. This team should be on board by early 1996 and will be charged with the development of detailed analysis plans and the conduct of the study. This team would also provide technical assistance in the development of strategies related to several of the critical issues facing LTPP. It is intended that this team would do the bulk of the analysis. Other teams will also be solicited and used in order to better fulfill LTPP's objectives.

TECHNICAL REVIEW

As the analysis plan is implemented, it is essential to involve the partners in the technical aspects of the individual studies. The LTPP program plans to use the TRB-SHRP Committee structure as a mechanism for gaining input from partners. Through this structure, partners can assist in:

- ➔ Developing the project-specific detailed analysis plans,
- ➔ Providing technical guidance during the conduct of the analysis, and
- ➔ Reviewing the final results.

In addition, communication between the analysis group and the LTPP Implementation TWG will be established.

V. Critical Issues

This document focuses on the LTPP program's top priority—the products—what is needed, how to produce them, and how to implement them. However, the LTPP program is facing a number of critical issues in the near and long terms. The critical issues are described below (in no particular order).

Resources

There is serious concern about long-term funding for the LTPP studies, particularly in the next surface transportation reauthorization bill.

Resource Allocation

For the next several years, analysis will be the top funding priority for LTPP. Following the initial round of analysis, it may be appropriate to redirect a significant portion of the analysis funds to address some of the operational issues.

Continued Commitment and Participation by States and Provinces

As noted previously, the States and Provinces incur a significant cost in staff and funding to support the LTPP studies. Without the pavement test sections and the information provided by the agencies, the LTPP program would be in jeopardy.

Ownership of the Program by the States and Provinces

How can FHWA strengthen and revitalize the sense of ownership of the LTPP program on the part of the States and Provinces? Is the current structure of management and technical committees working? Are the right people participating?

The GPS Studies

A review is needed to assess both the completeness and the quality of the data and what can be produced with the existing distribution of pavement test sections. If what we have is only enough to provide case study results, should these studies be closed and efforts redirected to those studies with a higher probability of producing the desired products?

The SPS Studies

The SPS studies are the ultimate source of information to develop improved pavement design and management products. As such, is additional emphasis and effort necessary from the LTPP program to realize this potential?

Traffic Data

Traffic is the most burdensome data element in terms of data collection requirements, operations, processing, and reliability. With the need to establish a strong relationship between traffic and pavement performance, it may be necessary for the LTPP program to reevaluate the who, how, and where of traffic data. FHWA is currently developing a plan to address the quality and quantity issues associated with traffic data collection. This plan will be reviewed through the TRB-SHRP Committee structure prior to dissemination.

Non-LTPP Program In-Service Monitoring

The LTPP program provides a unique opportunity to gather information and produce products on a number of very worthwhile pavement studies. There is a potential conflict between additional efforts that will enhance the quality of the desired LTPP products and those that respond to different program objectives. These other program commitments can detract from the LTPP program's ability to deliver its products.

In this iteration of the *Roadmap,* the intention is to identify the critical issues and present possible processes or methods for their resolution. The analysis activities will serve as a feedback loop regarding several of the critical issues. Also, as was done in the original LTPP planning, a review by statisticians will be useful. Input from AASHTO and the TRB-SHRP Committee will be obtained. These issues will be addressed in future editions of the *LTPP Program Roadmap* (tentatively targeted for mid-1996).

VI. Information and Communication

Communication is an essential item in the LTPP program. The LTPP program needs to provide information to a broad audience and establish a dialogue with a much smaller group of management and technical experts. The LTPP program is taking a number of steps to improve the information flow and communication. A few examples of this increased emphasis in communication follow.

Preparation of the *LTPP Program Roadmap* required communication with the principal partners. In addition, the *Roadmap* will be widely distributed so that the highway community can gain a better understanding of the LTPP program. An updated *Roadmap* is planned for 1996, which will address several of the critical issues. Again, the principal partners will be involved, and the highway community will be informed.

An LTPP product catalog will be available in fall 1995. The catalog will let the highway community know what is available and what is coming from the LTPP program.

The *Focus* newsletter, published by FHWA's Office of Technology Applications, is used extensively to provide LTPP information to its 8500+ readers.

An exhibit highlighting the LTPP products and partnerships is available.

A mid-term national LTPP meeting is planned for March 26-28, 1996, in Irvine, California. The focus of the meeting is products—what we have today, what is in production, and what can be produced. The target customers are the top management and technical staff of the States and Provinces, but the meeting is open to all. The meeting is being held in conjunction with the AASHTO Joint Task Force on Pavements workshop on developing the framework for the improved pavement design procedure.

The LTPP team is now preparing a biannual status report that covers the various operational aspects of the program. The report will be distributed to the States, Provinces, and FHWA field offices.

FHWA's LTPP team will continue to participate in the State SHRP coordinators meeting held in conjunction with the TRB annual meeting. In addition, LTPP regional meetings will also be held to facilitate communication between the States, FHWA field offices, and the LTPP team. The LTPP team is available for presentations at national and regional AASHTO meetings, association meetings, and State-level meetings.

Appendix A—Experimental Design

The LTPP program includes two fundamental classes of studies:

- ➜ General Pavement Studies (GPS)
- ➜ Specific Pavement Studies (SPS)

A matrix describes each experiment and consists of row and column factors that specify a pavement structure and conditions affecting the performance of the pavement. Using this factorial-type design, pavement sections are assigned to fill individual cells within an experiment based on the factors.

GPS EXPERIMENTS

GPS experiments generally represent the most commonly used pavement structural designs. GPS include nine types of existing, original, and rehabilitated in-service pavements. The GPS plan called for approximately 1,100 pavement test sections across the United States. One of the factors that heavily influenced the design of the GPS experiments was the need to produce short-term and intermediate-term results. To address these needs, the GPS experiments were designed to include pavements of varying age up to 15 years. Although this decision meant that the LTPP program would be monitoring older designs and materials, it was a necessary concession to produce the range in performance histories needed to support the stated objectives following 5 years and 10 years of data collection.

The nine original GPS experiments are:

GPS-1	Asphalt Concrete (AC) on Granular Base
GPS-2	AC on Bound Base
GPS-3	Jointed Plain Concrete
GPS-4	Jointed Reinforced Concrete
GPS-5	Continuously Reinforced Concrete
GPS-6	AC Overlay on AC
GPS-7	AC Overlay on Portland Cement Concrete (PCC) Pavements
GPS-8	Bonded PCC Overlays of PCC Pavements (Changed to SPS-7)
GPS-9	Unbonded PCC Overlays on PCC Pavements

SPS EXPERIMENTS

SPS test sections are specially constructed pavement structures designed to develop a better understanding of the effects on performance of selected maintenance, rehabilitation, and design factors not adequately covered in the GPS experiments. SPS sections are constructed under the LTPP program to allow for control of critical design factors and initiation of performance monitoring from the initial date of construction or accessibility to traffic.

SPS experiments consist of nine studies involving newly constructed or rehabilitated in-service pavements with multiple test sections. The original experimental design called for approximately 1,600 sections built at 200 locations. The nine SPS designs are:

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 Portland Cement Concrete Overlays of Concrete Pavements
SPS-8	Study of Environmental Effects in the Absence of Heavy Loads
SPS-9	Verification of SHRP Asphalt Specification and Mix Design

DATA TYPES

To accomplish the objectives of the LTPP study, an extensive data collection is required.[9] The information being collected in the LTPP studies is grouped into the following seven categories.

Inventory

Includes the location of the section, material properties, composition, construction improvements, layer thickness and types, and other background information about the section provided by the highway agencies.

Materials Testing

Field drilling and sampling are performed at each test section to provide documentation of the existing pavement structure. Field and laboratory tests are conducted to establish material properties and characteristics.

Climate

Includes site-specific estimates of various temperature, precipitation, humidity, and solar data statistics on a monthly basis for each test section, as well as actual values for these data from nearby weather stations.

Maintenance

Routine maintenance information, such as crack sealing and pothole patching, is provided by the participating highway agencies.

Rehabilitation

Includes information on the major improvements to a test section after its inclusion in the LTPP program.

Traffic

Includes the yearly estimates of volumes, axle load distribution by axle configurations, and equivalent single-axle loads (ESALs) for each site.

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[9] Data are collected on forms supplied in the *Data Collection Guide for Long-Term Pavement Performance Studies* (Washington, DC: Transportation Research Board) or in machine readable form from monitoring equipment.

Monitoring

Includes data on pavement condition, collected over time, including:

Deflection—Serves as the primary measure of the pavement's structural capacity. Most sections are expected to be tested approximately once every 5 years, while selected sections will be tested 12 to 14 times per year, every second year.

Profile—The longitudinal profile of each test section is measured approximately once a year. In addition to the profile data, the International Roughness Index (IRI), Mays Index, root mean square vertical acceleration, and slope variance are computed from the data and stored in the data base.

Surface Distress—The number of potholes and the severity, length, or area of surface cracking, spalling, and edge cracking are some of the data types collected annually or biannually via high-resolution 35-mm photographic methods. In general, manual distress surveys are conducted every other year.

Friction—Friction measurements are provided by the participating highway agencies.

Rutting—Photographic transverse-profile measurements are taken every 15 m (50 ft) along a test section with surface distress photography. Alternatively, a Dipstick (Face Technologies) is used to obtain manual cross-profile measurements.

DATA MANAGEMENT

The LTPP Information Management System (IMS) encompasses the processing of the data from the time of collection to the time that the data are released to the public. The IMS is currently composed of a two-tiered structure that encompasses the National Information Management System (NIMS) and four Regional Information Management Systems (RIMS).[10]

Four regional offices coordinate LTPP-related activities across the United States and Canada. Each region encompasses a group of States and Provinces, with test sections located throughout. Data are collected and entered in the LTPP regions and undergo quality control checks at the regional level.[11] Data are then transferred to NIMS, where additional quality control checks are made, before being released to the public.[12]

The Central Traffic Data Base (CTDB) houses the monitored traffic data. Summaries of the monitored traffic data are transferred from CTDB to NIMS. Traffic estimates for years prior to 1990 have been developed by the States and Provinces based on limited data. It is anticipated that the traffic estimates for most of the study sites for the year 1992 and beyond will be based on site-specific data. For the period between 1990 and 1992, estimates will be based on a mix of historical and monitored traffic data. Requests for either historic or monitoring traffic data are handled by TRB.

[10] The NIMS Administrator at TRB may be reached at 202-334-3259. The *LTPP Data Sampler and Data Request* demonstration diskette is an instructive tool to familiarize the users with actual data from the data base. Copies may be obtained from the Pavement Performance Division Office at FHWA (fax: 703-285-2767). Other documents, such as the *LTPP IMS Data User Guide* (Publication No. FHWA-RD-93-094), provide introductory information for users of the LTPP data base.

[11] As mandated by the Omnibus Trade and Competitiveness Act of 1988, the metric system is being adopted in all Federal Government programs. The metrication of the LTPP program will conform to AASHTO and American Society for Testing and Materials standards and will include conversion of data collection practices, testing and monitoring methods, the LTPP data base, and all new and existing documents and manuals. The process is currently in progress, but may take up to 4 years to complete.

[12] A detailed description of these checks is provided in the draft document *LTPP IMS Data Quality Checks,* published by FHWA in November 1994.

Appendix B—Analysis Objectives and Products

The specific objectives and anticipated products for each of the project areas identified in Tables 2A through 2C of the text are as follows.

NEAR-TERM, PRIORITY 1 ANALYSES

1. Guidelines for Estimating Design Parameters

Objective: To develop improved guidelines for the selection of design parameters to be used in existing design procedures, such as those provided in the *AASHTO Guide for Design of Pavement Structures* (the "AASHTO Guide").

Products:

Simplified procedures to estimate seasonal roadbed soil resilient modulus and *k* value
Improved guidelines for selection of load transfer coefficients
Improved guidelines for selection of drainage coefficients
Guidelines for estimating PCC modulus of rupture at 28 days
Guidelines for estimating PCC indirect tensile strength

Applications: In the near term, these products are directly applicable to pavement design using the current AASHTO Guide. In the longer term, application of some products in the development or use of new pavement design procedures is possible.

Principal Beneficiaries: State highway agencies and other users of the current AASHTO Guide pavement design procedures.

Additional Notes: All the LTPP experiments have the potential to contribute data that are applicable to these analyses. Analyses addressing this objective are currently in progress (see Table 1).

2. Evaluation of the Effects of Rehabilitation

Objective: To quantify the short-term effect of pavement rehabilitation on the structural and functional characteristics of the pavement.

Products:

Quantitative estimates of the degree to which the functional performance (e.g., roughness) of pavements is improved by different rehabilitation treatments
Quantitative estimates of the change in the structural capacity of pavements to be expected from different rehabilitation treatments

Applications: In the near term, the information obtained in these analyses can be used in cost/benefit analyses and to improve decision making with respect to the selection of rehabilitation measures and the timing of their application. Results may also have application in assessing the assumptions inherent in existing rehabilitation design methods and may contribute to the development of new design procedures for pavement rehabilitation.

Principal Beneficiaries: State highway agencies and others having responsibility for rehabilitating pavements.

Additional Notes: LTPP experiments that may contribute to these analyses include GPS-6B, GPS-7B, SPS-5, SPS-6, and SPS-7. Pre-overlay surface preparation treatments considered include patching, crack sealing, milling, PCC restoration, crack-and-seat, and minimal preparation.

3. Performance Comparison of SPS Sections

Objective: To identify performance trends, and differences therein, for the treatments and design features considered in the SPS experiments.

Product: Preliminary information on the relative performance of different rehabilitation treatments and design features under the conditions encountered in the SPS experiments.

Applications: These products will have immediate application in the selection of appropriate rehabilitation treatments and design features.

Principal Beneficiaries: State highway agencies and others responsible for design of new and rehabilitated pavements.

Additional Notes: The most comprehensive early results will be obtained from the rehabilitation experiments (SPS-5, SPS-6, and SPS-7), since they have the longest performance history. Similar objectives are also addressed in subsequent timeframes.

4. Assessment of Traffic Sampling

Objective: To assess the impact of different traffic sampling methodologies on the accuracy of the design traffic estimates and pavement designs.

Products:

Guidelines for the selection of cost-effective traffic monitoring programs as a function of the intended application of the data

Quantitative information on traffic variability

Applications: These products are directly applicable to the development of cost-effective traffic monitoring programs for pavement management and design purposes. Variability information is applicable in any current or future design procedure that considers variability of the input parameters (e.g., the current AASHTO Guide).

Principal Beneficiaries: State highway agencies and others responsible for providing reliable estimates of traffic for use in pavement design and management applications.

Additional Notes: These analyses will utilize data from those sites for which continuous weigh-in-motion data are available.

5. Modeling of Load Transfer in PCC Pavements

Objective: To quantify daily and seasonal variations in load transfer and relate those changes to observed joint/crack openings, dowel bar design and spacing, base type, time, and traffic loadings.

Products:

Improved guidelines for assessing the adequacy of load transfer in existing pavements

Models that can be used to predict, assess, and characterize load transfer conditions in the design and evaluation of new and rehabilitated PCC pavements

Applications: In the near term, these products are directly applicable in pavement management and rehabilitation design and in the evaluation and use of existing design procedures. In the longer term, they may contribute to the development of improved design procedures for PCC pavements.

Principal Beneficiaries: State highway agencies and others responsible for pavement evaluation and management.

Additional Notes: These analyses will rely heavily on the load transfer data obtained for rigid pavements included in the seasonal monitoring program.

6. Temperature Adjustments for Hot-Mix Asphalt Pavement Evaluation

Objective: To develop improved methodologies for temperature adjustments in the structural evaluation of hot-mix asphalt pavements.

Products:

Validated temperature prediction procedure for AC pavements,

Temperature adjustment procedures for back-calculated moduli, deflections, and deflection basin characteristics,

Draft standard for temperature prediction and correction in the structural evaluation of AC pavements.

Applications: These products will have immediate application in the interpretation and application of pavement deflection data in pavement management and design.

Principal Beneficiaries: State highway agencies and others responsible for interpretation and application of pavement deflection data for purposes of pavement management and/or design.

Additional Notes: This work is currently in progress (see Table 1).

7. Effects of As-Constructed Variability on Performance

Objective: To quantify the as-constructed variability of existing pavement sections and investigate the relationship between construction variability and performance.

Products:

Quantitative information on the as-constructed variability of LTPP test sections.
Preliminary information on the impact of variability on pavement performance.

Applications: In the near term, the information gleaned from these analyses will provide an improved basis for selection of pavement design parameters, development of sampling plans, and development of construction specifications.

Principal Beneficiaries: State highway agencies, consultants, and contractors involved in the design and construction of highway pavements.

Additional Notes: By using data from all of the available LTPP experiments, it should be possible to derive quantitative information on as-constructed variability in several key parameters, from conditions ranging from "typical" (based on GPS and preconstruction evaluation of SPS-3, SPS-4, SPS-5, SPS-6, and SPS-7) to "best case" (SPS-1 and SPS-2).

8. Relationships of Transverse Profile to Rutting, Rutting Measures, and Performance

Objective: To identify the relationships between transverse profile characteristics, damage mechanisms, and pavement performance.

Products:

Guidelines regarding the most appropriate measure(s) of pavement rutting (e.g., rut-depth definitions) for pavement evaluation and performance prediction applications.
Guidelines for interpreting transverse profile data to identify the damage mechanism leading to rutting.

Applications: In the near term, these products will lead to more accurate identification of the causes of pavement rutting, thereby facilitating decision making and selection of the most appropriate remedial measures. In the longer term, results could contribute to the development of improved predictive models for use in pavement design and management.

Principal Beneficiaries: State highway agencies and others responsible for pavement management and rehabilitation design.

9. Identification of Common Characteristics of Long-Lived GPS Sections

Objective: To identify the common features of pavement sections exhibiting superior performance.

Products:

Guidelines for the design and construction of long-lived pavements.
Quantitative information on the benefits of selected design features.

Applications: The conclusions drawn from this effort will have immediate application in the pavement design process and in cost/benefit analysis, yielding more informed decisions with respect to specific design features.

Principal Beneficiaries: State highway agencies and others responsible for the design and construction of pavements.

10. Summary and Assessment of Early Performance of SPS Test Sections

Objective: To identify trends in the performance of SPS test sections.
Product: Qualitative information on the effects of specific pavement design features on performance.

Applications: Information gleaned from this assessment will be immediately applicable in the selection of pavement design features.

Principal Beneficiaries: State highway agencies and others responsible for pavement design.

Additional Notes: Similar objectives are also planned for subsequent timeframes, when more performance information will have accrued.

11. Roughness Evaluation

Objective: To investigate the development of pavement roughness over time, as a function of pavement type and key pavement factors.

Products:

- Models for the prediction of pavement roughness, suitable for implementation in a pavement management system.
- Improved knowledge of the factors that influence the development of pavement roughness.

Applications: The models developed through this investigation will have immediate application in pavement management. In the longer term, the models and knowledge gained may have application in the development of improved pavement design procedures and guidelines.

Principal Beneficiaries: State highway agencies and others involved in pavement management.

Additional Notes: This work is currently in progress (see Table 1).

12. Evaluation of Pavement Maintenance Treatments (SPS-3 and SPS-4)

Objective: To evaluate the effectiveness of pavement maintenance treatments.

Products:

- Quantitative information on the effectiveness of different pavement maintenance treatments as a function of pretreatment pavement condition and environmental factors.
- Guidelines for the selection and timing of the application of maintenance treatments.

Applications: The results of these analyses will have immediate application in pavement maintenance and management decision making.

Principal Beneficiaries: State highway agencies and others responsible for maintenance.

Additional Notes: These objectives are currently being pursued (see Table 1).

13. Investigation of Reductions in IRI with Time

Objective: To investigate the observed phenomenon of decreases in the International Roughness Index (IRI) with time for some LTPP test sections.

Products:

- Improved understanding of the frequency of occurrence of decreases in roughness with time and knowledge of the factors that contribute to the observed phenomenon
- Guidelines for assessing the significance of year-to-year changes in IRI, and for scheduling profile surveys to facilitate interpretation

Application: The primary application of this information will be in the interpretation of IRI data obtained for research and pavement management purposes.

Principal Beneficiaries: State highway agencies and others involved in pavement management, pavement researchers, and other users of pavement roughness data.

NEAR TERM, PRIORITY 2 ANALYSES

14. Investigation of PCC Strength Gain Rates

Objective: To quantify the rate of strength gain for typical and high-strength concrete used in paving applications.

Products:

- Quantitative information on the rate of strength gain for portland cement concrete used in highway pavements
- Relationships between third-point flexural strength from laboratory cured beams, compressive strength of formed and laboratory-cured cylinders, and compressive strength and indirect tensile strength from cores

Applications: These strengths and strength gain rates have immediate application as inputs to existing and future rigid pavement design procedures. Longer term applications include use in future design procedures and in the development of improved quality control procedures.

Principal Beneficiaries: State highway agencies and others involved in the design, construction, and quality control evaluation of highway pavements.

Additional Notes: The data for this investigation will come primarily from the SPS-2 experiment.

15. Improved Performance Prediction Models for New Pavements

Objective: To develop improved distress-specific performance prediction models.
Product: Improved performance prediction models.

Application: Models will have immediate application in pavement management. In the longer term, they may contribute to the development of new pavement design procedures.

Principal Beneficiaries: State highway agencies and others involved in pavement management.

Additional Notes: Similar objectives are addressed in later timeframes, to take advantage of the additional data (and pavement distress) that will accumulate as the LTPP monitoring proceeds.

MID-TERM, PRIORITY 1 ANALYSES

16. Comparison of Historical Traffic Estimates with Monitoring Data

Objective: To compare the historical estimates of traffic on LTPP test sections prior to the start of traffic monitoring to site-specific monitoring data to evaluate the level of consistency.

Products:

- Quantitative information on the relationship between historical traffic estimates and current traffic.
- Quantitative information on current traffic volumes and load levels and the variability therein.

Applications: The knowledge gained from these analyses will have immediate application in improving the accuracy of the traffic predictions on which pavement design and management decisions are based.

Principal Beneficiaries: State highway agencies.

17. Assessment of Variability in Hot-Mix Asphalt Pavement Layer Thickness and Stiffness

Objective: To evaluate the variability in as-constructed pavement layer thicknesses and stiffness.

Products:

- Quantitative information on the degree of variability present in pavements, as constructed
- Qualitative information as to the design and construction factors that appear to be associated with higher or lower degrees of variability

Applications: This information has immediate applications in pavement design and construction management. In the longer term, it has applications in the development and application of improved pavement design procedures, performance prediction models, and construction specifications.

Principal Beneficiaries: State highway agencies and others involved in the design and construction of highway pavements.

Additional Notes: This analysis is dependent upon the acquisition of additional pavement thickness data (presumably via ground-penetrating radar [GPR] measurements), which has been planned, but not yet initiated.

18. Improved Performance Prediction Models for New and Rehabilitated Pavements

Objective: To develop improved distress-specific performance prediction models.

Product: Improved performance prediction models.

Applications: Models will have immediate application in pavement management and will contribute to the development of new pavement design procedures.

Principal Beneficiaries: State highway agencies and others involved in pavement management.

Additional Notes: These analyses will build upon the results of near-term work having similar objectives.

19. Evaluation of Load-Response Models

Objective: To evaluate analytical models used to estimate the response (in terms of stress, strain, or deflection) of pavement structures to load.

Product: Quantitative assessment of the adequacy of existing pavement response models that may be used in the development of mechanistically based pavement design procedures.

Applications: The results of this endeavor are applicable to the selection of an appropriate analytical model to be used as the basis for new design procedures for new and rehabilitated pavements.

Principal Beneficiaries: AASHTO and other organizations involved in the development of new design procedures.

Additional Notes: The primary source of data for this work will be the SPS-1 and SPS-2 test sites in which *in situ* pavement response instrumentation is (or will be) installed.

20. Adjustment of Deflection Data to Critical Design Conditions

Objective: To develop a methodology to adjust pavement deflection data to critical design conditions.

Product: Guidelines for seasonal adjustment (for both temperature and moisture effects) of deflection measurements used as input to design.

Applications: This product would facilitate application of deflection-based pavement design procedures.

Principal Beneficiaries: State highway agencies and others using deflection-based pavement design and evaluation procedures.

21. Variations in Layer Moduli, Stress Sensitivity, and Support

Objective: To evaluate and synthesize the magnitudes of daily and seasonal variations in pavement layer moduli and other measures of support.

Products:

- Practical and accurate material constitutive relationships to characterize unbound pavement materials as a function of variations in temperature and moisture conditions
- Quantitative information on the magnitude of modulus variation to be expected under a range of pavement temperature and moisture conditions encountered in North America
- Improved guidelines for selecting appropriate effective subgrade modulus (flexible pavements) and *k* values (rigid pavements) for design and rehabilitation analysis using the current AASHTO Guide procedures

Applications: These results will have immediate application in the current AASHTO Guide pavement design procedure and will make critical contributions to the development of new pavement design procedures by facilitating the direct consideration of different environmental conditions in the design process.

Principal Beneficiaries: State highway agencies using AASHTO Guide procedures; and developers of new pavement design procedures that explicitly consider varying environmental conditions.

22. *Evaluation of In Situ Moisture and Temperature Prediction Models*

Objective: To assess the accuracy of existing models (e.g., the FHWA environmental effects model) for prediction of *in situ* pavement moisture and temperature conditions.

Product: Enhanced model(s) for prediction of *in situ* pavement moisture and temperature conditions.

Applications: The principal application of these results will be in the development of new pavement design procedures that provide for explicit consideration of varying environmental conditions. In the near term, results may also have application in the use of the current AASHTO effective modulus concept for characterization of subgrade soils.

Principal Beneficiaries: AASHTO and others involved in the development of new pavement design procedures that explicitly consider varying environmental conditions.

23. *Effects of Specific Design Features on Pavement Performance*

Objective: To identify the effects of specific pavement design features on the performance of pavements.

Product: Quantitative information on the effects of specific pavement design features on performance.

Applications: Information gleaned from this assessment will be immediately applicable in the selection of pavement design features.

Principal Beneficiaries: State highway agencies and others responsible for pavement design.

Additional Notes: This is a continuation of the performance comparison investigation of SPS test sections from the early analysis. This activity will build on the earlier effort by providing more quantitative results, confirming (or refuting) early observations and providing for identification of secondary and longer-term effects.

24. *Relationships Between Material Quality and Performance*

Objective: To investigate the relationship between material quality and pavement performance.

Product: Performance-related specification limits for asphalt concrete (AC) and portland cement concrete (PCC) pavements.

Applications: These results have immediate applications in statistically based quality control and acceptance procedures.

Principal Beneficiaries: State highway agencies using, or considering use of, statistically based quality control procedures.

25. Interrelationships Between Distress Types

Objective: To investigate the degree of interrelationship in the occurrence of different distress types.

Product: Qualitative and/or quantitative information on the degree to which the presence of one distress type is an indicator of the probable development of other distress types, whether or not a cause-and-effect relationship exists.

Applications: The information gained in this analysis has immediate application in pavement management and may also be used in development of distress-based performance prediction models.

Principal Beneficiaries: State highway agencies and others responsible for pavement management.

MID-TERM, PRIORITY 2 ANALYSES

26. Maintenance Requirements in Life-Cycle Cost Analysis

Objective: Evaluation of the effect of maintenance type and frequency on pavement performance.

Product: Guidelines for typical maintenance requirements (type and frequency of application) as a function of pavement type and other conditions.

Applications: These guidelines will be applicable in the development of life-cycle cost estimates for competing design alternatives.

Principal Beneficiaries: State highway agencies and others involved in the development of life-cycle cost estimates for pavements.

Additional Notes: This is listed as a Priority 2 project because the degree to which the LTPP data will support this analysis is less than ideal.

27. Relationship Between Roughness and Distress

Objective: To investigate the relationship between roughness and the presence of other forms of pavement distress.

Products:

- Equations or algorithms that can be used to relate distress predictions to functional performance measures for use in design and pavement management.
- Qualitative information regarding the relative importance of the severity and extent of different distress types in relation to functional performance measures (i.e., roughness).

Applications: Knowledge gained through these analyses will have near-term applications in pavement management and longer term applications in the development of new pavement design procedures and performance models.

Principal Beneficiaries: State highway agencies and others involved in pavement management.

28. Seasonal Effects on Roughness Measurements

Objective: To document short-term seasonal variations in pavement roughness.

Products:

- Quantitative information on the magnitude of seasonal changes in pavement roughness as a function of environmental conditions.
- Guidelines for scheduling pavement roughness measurements to facilitate identification of long-term trends.

Applications: The principal application of this information will be in the scheduling and interpretation of pavement roughness data collected for pavement management purposes, to avoid having short-term variations confound identification of long-term trends.

Principal Beneficiaries: State highway agencies and others involved in pavement management.

LONG-TERM, PRIORITY 1 ANALYSES

29. Relationships Between Deflection and Distress

Objective: To investigate relationships between distress occurrence, progression of distresses, and deflection-based measures of structural capacity and/or condition.

Product: Simple relationships for the prediction of specific distress types using deflection measurements, deflection basin parameters, and/or back-calculated layer stiffness or structural indices.

Application: These results will be applicable in pavement management to predict or detect the development of certain types of distresses.

Principal Beneficiaries: State highway agencies and others involved in pavement management.

30. Improved Performance Prediction Models for New and Rehabilitated Pavements

Objective: To develop improved distress-specific performance prediction models.

Product: Improved performance prediction models.

Applications: Models will have immediate applications in pavement management and will contribute to the development of new pavement design procedures.

Principal Beneficiaries: State highway agencies and others involved in pavement management.

Additional Notes: These analyses will follow up on work having similar objectives in earlier timeframes. In the long-term analysis of LTPP data, improvements to the accuracy and precision of initial distress prediction models will be supported by the availability of longer performance histories and additional data for the test sections.

31. Transfer Functions Relating Response to Distress

Objective: To develop relationships for prediction of pavement damage as a function of computed material responses to traffic and climatic loads.

Product: Transfer functions or failure criteria for various damage mechanisms.

Applications: The primary application of these relationships will be in the development of mechanistically based design and analysis methods.

Principal Beneficiaries: AASHTO and others involved in the development of new pavement design procedures.

32. Evaluation of Environmentally Induced Deterioration

Objective: To determine the effects of environmentally induced deterioration on pavement performance.

Products:

- Quantitative information on the magnitude of environmentally induced pavement deterioration.
- Models that may be used to predict environmentally induced deterioration in the absence of heavy loads.

Applications: These results will have applications in pavement management for pavements not subjected to heavy loads, and in cost allocation efforts.

Additional Notes: The SPS-8 data will provide the primary basis for this work. SPS-1 and SPS-2 may also contribute.

33. Procedures for Estimating Remaining Life

Objective: To develop improved procedures for the prediction of remaining pavement life.

Product: Practical models and or procedures to predict the remaining service life of pavements.

Applications: The models and procedures developed have immediate application in design and economic analyses of alternative rehabilitation strategies, and in pavement management.

Principal Beneficiaries: State highway agencies and others involved in pavement management and rehabilitation design.

34. Performance Models Incorporating Environmental and Drainage Parameters

Objective: To develop a comprehensive approach for explicit consideration of environmental and drainage conditions in pavement performance modeling.

Product: A practical, reliable, and flexible approach to characterizing environmental conditions in pavement performance models.

Applications: Immediate applications of this product will be in the development of broadly applicable pavement design and performance models. When integrated into such models, the results are applicable in pavement design and management.

Principal Beneficiaries: AASHTO and others involved in the development of broadly applicable pavement design and performance models.

35. Modeling of Maintenance Effects on Pavement Performance

Objective: To develop mechanisms to explicitly address the effects of preventive and corrective maintenance treatments in pavement performance prediction.

Product: Performance prediction models that consider the effects of the timing and nature of maintenance activities.

Applications: These models have direct application in pavement management and life-cycle cost analyses.

Principal Beneficiaries: State highway agencies and others responsible for pavement management and life-cycle cost analysis.

36. Prediction of Seasonal Variations in Unbound Materials

Objective: To integrate, refine, and simplify previously developed constitutive relationships for unbound pavement materials with models for the prediction of *in situ* moisture and temperature conditions.

Product: Practical models to characterize temporal variations in pavement materials due to temperature and moisture effects.

Applications: The primary applications of these models will be in the development of mechanistically based pavement design procedures. Models may also be useful to adjust material parameters obtained under arbitrary laboratory or field conditions to some standard condition.

Principal Beneficiaries: State highway agencies using AASHTO Guide procedures and developers of new pavement design procedures that explicitly consider varying environmental conditions.

Additional Notes: This work follows up on project areas 23 and 24.

37. Effects of Specific Design Features on Performance

Objective: To identify the effects of specific pavement design features on the performance of pavements.

Products:

- Quantitative information on the effects of specific pavement design features on performance.
- Guidelines for the selection of pavement design features to achieve maximum pavement life at minimal cost.

Applications: Information gleaned from this assessment will be immediately applicable in the selection of pavement design features.

Principal Beneficiaries: State highway agencies and others responsible for pavement design.

Additional Notes: These analyses will follow up on work addressing similar objectives in earlier timeframes. They will build on the earlier efforts by confirming (or refuting) early observations and will provide for identification of secondary and longer term effects.