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MANAGEMENT & FINANCES OF LONG-TERM PAVEMENT RESEARCH STUDIES: THE U.S. LONG-TERM PAVEMENT PERFORMANCE EXPERIENCE

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ABSTRACT: Ambitious goals and objectives were set for the U.S. Long-Term Pavement Performance (LTPP) program – the most comprehensive research study ever undertaken to provide the data necessary to understand how and why pavements perform as they do – from the start, but working towards them and remaining faithful has not been easy. This is especially true when considering the program has gone through two management agencies and four highway legislations. Its success is directly attributable to the management staff that guided and executed the program with the support of its contractors and advisory structure. Throughout LTPP's life, these parties periodically re-evaluated the program, making changes to priorities and plans as needed and adjusting to fluctuating budget realities, but never changing its goal and objectives. This paper looks at the key management and financial issues faced, and lessons learned over the life of the program. Issues and lessons include those associated with the short- and long-term program planning (priorities in the face of budget realities), the project team as well as the stakeholders and data users, execution of the work with particular emphasis on the creation of a database containing high-quality and complete data sets, coordination and marketing activities, and products and benefits that have been and will continue to evolve from the program.

KEY WORDS: long-term pavement performance, project management, project finance, pavement research, pavement database, pavement condition monitoring

INTRODUCTION

LTPP was the most comprehensive research program ever undertaken to provide the data necessary to understand how and why pavements perform as they do. Ambitious goals and objectives were set for the program from the start, but working towards them and remaining faithful was not easy. This is especially true when considering the program went through two management agencies and four highway legislations. Its success is directly attributable to the management staff that guided and executed the program with the support of its contractors and advisory structure. Throughout LTPP's life, these parties periodically re-evaluated the program, making changes to priorities and plans as needed and adjusting to fluctuating budget realities, but never changing its goal and objectives.

The LTPP program was established in part to provide for new pavement design, management and maintenance tools that could be used to extend pavement life from long term time series observations. More specifically, the stated objective of the LTPP studies was "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." The specific objectives adopted to support that goal were to:

- Evaluate existing design methods;
- Develop improved design methods including rehabilitation strategies;
- Improve design equations;
- Determine the effects of loads, environment, material properties and variability, construction quality, and maintenance levels;
- Determine effects of specific design features; and
- Establish a national long-term pavement database to support future needs.

These objectives were purposely designed to address a wide range of pavement information issues. To accomplish the stated goal and objectives, 17 scientifically designed field experiments were implemented in two broad studies: General Pavement Studies (GPS) and Specific Pavement Studies (SPS). The experiments developed under the LTPP program are shown in Tables 1 and 2. Figure 1 shows the geographic distribution of the test sections studied as part of the program.

Table 1: List of GPS Experiments.

Experiment	Experiment Title
GPS-1	Asphalt Concrete (AC) Pavement on Granular Base
GPS-2	AC Pavement on Bound Base
GPS-3	Jointed Plain Concrete Pavement (JPCP)
GPS-4	Jointed Reinforced Concrete Pavement (JRCP)
GPS-5	Continuously Reinforced Concrete Pavement (CRCP)
GPS-6	AC Overlay of AC Pavement
GPS-7	AC Overlay on PCC Pavement
GPS-9	Unbonded PCC Overlay on PCC Pavement

Table 2: List of SPS Experiments by Category.

Category	Experiment	Title
Pavement Structural Factors	SPS-1	Strategic Study of Structural Factors for Flexible Pavements
	SPS-2	Strategic Study of Structural Factors for Rigid Pavements
Pavement Maintenance	SPS-3	Preventive Maintenance Effectiveness of Flexible Pavements
	SPS-4	Preventive Maintenance Effectiveness of Rigid Pavements
Pavement Rehabilitation	SPS-5	Rehabilitation of AC Pavements
	SPS-6	Rehabilitation of Jointed Portland Cement Concrete (JPCC) Pavements
	SPS-7	Bonded PCC Overlays of Concrete Pavements
Environmental Effects	SPS-8	Study of Environmental Effects in the Absence of Heavy Loads
Asphalt Aggregate Mixture Specifications	SPS-9P/ SPS-9A	Validation and Refinements of Superpave® Asphalt Specifications and Mix Design Process/SuperPave Asphalt Binder Study

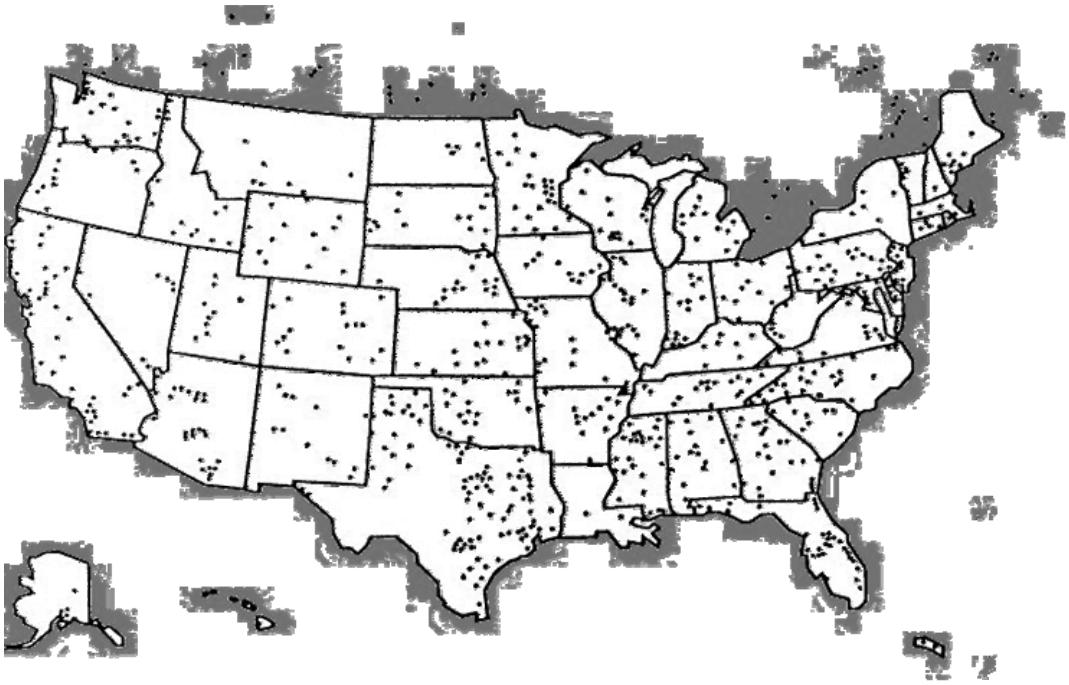

Figure 1: Geographical Distribution of LTPP Test Sections.

This paper looks at the key management and financial issues faced, and lessons learned during the process of implementation of these carefully design experiments. Issues and lessons include those associated with the short- and long-term program planning, the project team as well as the stakeholders and data users, execution of the work with particular emphasis on the creation of a database containing high-quality and complete data sets, coordination and marketing activities, and products and benefits that have been and will continue to evolve from the program.

ORGANIZATIONAL MANAGEMENT

The LTPP program began operations in 1987 under the five-year Strategic Highway Research Program (SHRP) administered by the National Research Council (NRC) of the National Academy of Sciences (NAS). In 1991, the Federal Highway Administration (FHWA) made a commitment to assume management and administrative responsibilities in 1992 to continue LTPP and to complete the period of pavement performance monitoring. It was always understood that realizing the full benefit of this research investment required the program to be continued over the long term, originally envisioned as a period of 20 years.

It was also understood that for LTPP to meet its objectives, the individual studies that comprised the program had to be carefully designed to yield verifiable conclusions and the massive data collection effort had to be uniform and consistent from study-to-study and from place-to-place. The data had to be stored in such a way that it was readily accessible to all participants and future researchers as well. These conditions required a nationwide level of cooperation among highway agencies, consultant researchers and contractors, and national organizations seldom seen in pavement research. To manage and coordinate this multi-organizational effort, initially SHRP professional staff and then FHWA professional staff served as the focal point for this cooperative network.

SHRP Management Structure (1987-1992)

The Surface Transportation and Uniform Relocation Assistance Act of 1987 (STURAA) was signed into public law on April 2, 1987 and it formally authorized and provided funding to SHRP. The SHRP program office was established in Washington, D.C., that same year and operations began in the program's four main focus areas. They were: asphalt, concrete and structures, highway operations (maintenance and work-zone safety) and long-term pavement performance

Central Management

Overall program management fell under the responsibility of the SHRP Executive Director, while a SHRP Program Manager was responsible for the day-to-day operations in each of the focus areas with the support of a small staff of engineers. Collectively, the SHRP Executive Director, SHRP Program Manager and support staff represented the central management staff for each program area. In the case of the LTPP program area, the remaining members of the central management staff included: a senior engineer responsible for and over-viewing all program technical activities; an engineer responsible for pavement monitoring activities; an engineer responsible for field sampling and materials testing activities; an engineer responsible for database operations; and an engineer responsible for traffic monitoring activities

Four Regional Engineers (REs) served as an extension to the central LTPP management staff, each based at one of the four LTPP Regional Coordination Office Contractor's (RCOC's) offices – North Atlantic Region, North Central Region, Southern Region and Western Region. These Regional Engineers were responsible for over-viewing and reporting on the activities of the regional contractors to the central management staff in Washington, D.C., as well as for providing overall support in a variety of activities including marketing of the program and test section recruitment.

Loaned Staff from state and provincial highway agencies as well as International Participants also aided the central management staff in the conduct of the LTPP program during the SHRP years. Typically, these people rotated on a one to two year basis and they tended to focus their efforts on specific technical activities such as traffic monitoring and seasonal monitoring.

Contractors

In November of 1987, the central LTPP management staff retained the services of a technical assistance contractor to provide technical and management services in support of SHRP in the development and conduct of the LTPP studies. The LTPP Technical Assistance Contract (TAC) was the first contract awarded under the LTPP program. The activities provided by this contract were numerous and varied, consisting primarily of serving as an arm of the management staff in the accomplishment of technical activities required for program implementation.

Beginning in 1988, several additional contracts were awarded in order to fully move forward with implementation of the LTPP program. Many of these, were directly associated with the four regions into which North America was divided into for purposes of implementing and managing the LTPP activities more efficiently. Those four regions – North Atlantic, North Central, Southern and Western – remained unchanged throughout the life of the program. Together with the TAC, the four Regional Coordination Office Contractors (RCOC's) represented the primary and largest (dollar-wise) LTPP contracts. The objective of the RCOC contracts was to provide regional office technical and management services in support of SHRP in the development and conduct of the LTPP studies. Other major LTPP contracts awarded during the 1987 to 1992 SHRP-era included:

- Automated (continuous 35-mm black & white photograph) Pavement Distress Record Contract.
- Road Profiling System Contract.
- Portland Cement Concrete (PCC) Laboratory Materials Testing Contract.
- Regional Soil and Asphalt Testing Contracts.
- Information Management System (IMS) Development Contract.
- Information Management System (IMS) Operations Contract.
- Data Analysis Contracts.
- Falling Weight Deflectometers Contract.
- Regional Drilling and Materials Sampling Contracts.

Peer Review

During the 1987 to 1992 period, when part of SHRP, the Pavement Performance Advisory Committee (PPAC) provided oversight and guidance for the LTPP program. This was the first of

two committees of the National Academies that provided advice pertaining to the LTPP program throughout its life and it performed its function until 1995 when it was retired. PPAC provided programmatic review and technical commentary on the program objectives, long-range plans, near-term operational activities and progress of the LTPP research program. It also conducted external, non-governmental reviews of, and comments on, the technical progress of ongoing pavement performance research, and identified needs for further research projects.

Various subcommittees to the PPAC, known as the Expert Task Groups (ETG's) addressed specific program technical issues. These ETG's covered such topics as Experiment Design and Analysis, Traffic, Data Collection and Analysis, Deflection Testing and Backcalculation, and Environmental data, among other technical topics. The primary function of the ETG's was to answer specific technical questions that arose during the development and implementation of the studies.

FHWA Management Structure (1992 - 2009)

The Intermodal Surface Transportation Efficiency Act (ISTEA) was enacted December 18, 1991 and it formally authorized continuation of the LTPP program and implementation of SHRP products under FHWA management. The ISTEA also provided FHWA funding to support the aforementioned activities. The LTPP program office was set up at the FHWA Turner-Fairbanks Highway Research Center (TFHRC) in McLean, Virginia.

Central Staff

The LTPP Team falls under the FHWA Office of Infrastructure Research & Development. While the FHWA organizational structure changed a number of times over the life of the LTPP program, a discussion of each re-organization is beyond the scope of this report. The focus of this discussion is on the FHWA LTPP Team and its activities, not exactly where it fit within the FHWA each year.

Overall program management fell under the responsibility of the FHWA LTPP Team Leader, who was responsible for the day-to-day operations and also oversaw the LTPP Technical Assistance Contract, the TRB LTPP contract and the LTPP general administration contract. In addition to the team leader, other members comprising the central FHWA LTPP management staff included: an engineer responsible for overseeing the LTPP regional contractors, and who also managed the LTPP materials sampling and testing activities including the various contractors and the Materials Reference Library; an engineer responsible for the LTPP database operation activities; an engineer responsible for the traffic data collection activities; and an engineer responsible for the data analysis and product development activities.

Through 2002, the FHWA LTPP central management staff also counted on the services of four LTPP Regional Engineers, each based at one of the four LTPP Regional Coordination Office Contractor's offices. These Regional Engineers continued to perform the same functions as under SHRP. In addition, like SHRP, the FHWA LTPP team counted on the support of loaned staff from state and provincial highway agencies, especially in the decade of the 1990s. These individuals typically rotated on a one to two year basis and tended to focus their efforts on specific technical activities such as deflection testing, the seasonal monitoring program, and the program assessment and improvement campaign.

As was the case during SHRP years, the FHWA LTPP team continued to receive significant contributions from highway agencies throughout North America. The highway agencies were responsible for test section construction, materials testing, traffic and data collection, and all management, staff, and equipment required for the broad array of LTPP activities including traffic control during data collection. In addition, groups of state departments of transportation (DOTs) entered into pooled fund agreements in support of important LTPP activities for which no other support was available.

Contractors

By far, the largest (dollar-wise) LTPP contracts under management by FHWA were the Technical Assistance Contract (TAC) and the four Regional Coordination Office Contracts (RCOC's). The regional contracts covered the same four regions and boundaries as defined under SHRP.

The LTPP TAC was awarded by FHWA in July 1992 and its objective was to provide all necessary facilities, equipment, services, supplies, materials, and personnel to perform the necessary pavement engineering and traffic engineering technical activities in support of the FHWA LTPP Program. The 1992 LTPP Technical Assistance Contract or TAC was in place for five years, until 1997, and was re-advertised and awarded by FHWA in 1997 for another five years and in 2002 for a little more than seven years. The name of the contract changed to LTPP Technical Support Services Contract or TSSC in 1997 and remained as such for the remainder of the program.

For the North Atlantic, North Central, Southern and Western Regional Coordination Office Contracts (RCOC's), their objective was to provide technical non-personnel services in support of the development and conduct of LTPP studies, including all data collection, data processing and data quality activities for LTPP project sections within each LTPP Region's geographical boundaries. The first RCOC contracts under the FHWA LTPP management were issued in May 1992, during the SHRP-to-FHWA management transition period. Those contracts were for four-years in length, and they were subsequently re-advertised and awarded for additional five-year periods in 1996, 2001and 2006. With one exception, the incumbent regional contractors and most of the associated key staff remained in place throughout the life of the LTPP program. The lone exception was the North Central RCOC, where the contractor changed twice (i.e., three different contractors) over the life of the program, with the second transition occurring out-of-cycle with the rest of the RCOC award process.

In addition to the five major contracts detailed so far, other major LTPP contracts included:

- Materials Sampling and Testing Contracts
- Equipment Purchase Contracts
- Photographic Distress Contract
- Data Analysis Contracts
- General Administration Support Contract
- Materials Reference Library Contract
- LTPP Products Contracts
- Determining Layer Thicknesses by Using Ground Penetrating Radar Contract

- Video Edge Drainage Inspections Contract
- LTPP Specific Pavement Study (SPS) Traffic Pooled-Fund Study TPF-5(004) Contracts
- Falling Weight Deflectometer (FWD) Calibration Center and Operational Improvements Pooled-Fund Study TPF-5(039) Contract
- Automated Distress Analysis for Pavement(s) (ADAPT) Contract

Formal Peer Review

FHWA entered into a contract with SHRP to continue to provide the peer-review functions of the LTPP Pavement Performance Advisory Committee (PPAC) and its supporting Expert Task Groups (ETG's) for a period of fifteen months, from July 1, 1992 to September 20, 1993. At the end of that period, the FHWA entered into a direct contract with the Transportation Research Board for provision of formal peer review regarding LTPP program matters. That contract with the Academy was periodically renewed through the life of LTPP.

Once SHRP ended in 1992, the PPAC readdressed its counsel to FHWA and AASHTO until 1995, when the committee was retired. The TRB LTPP Committee was then established to provide advice on LTPP's programmatic planning, operations, and progress and to coordinate work on specific technical issues conducted by various subcommittees (Expert Task Groups). Thus, the TRB LTPP Committee was the second of two committees of the National Academies to provide advice pertaining to the LTPP studies.

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

As was the case with PPAC, various Expert Task Groups or ETG's addressed specific program technical issues in support of the TRB LTPP Committee. Through 2006, the ETG's providing support to the TRB LTPP committee included: Automated Distress (later expanded to include profiler operation); Materials Data Collection and Analysis (later expanded to include FWD operations); Data Analysis; Product Development and Delivery; Database Development and Operations; Traffic Data Collection and Analysis; and Program Improvement.

In 2006, as a direct result of the budget constraints imposed on the LTPP program from the SAFETEA-LU highway legislation, the number of ETG's providing support to the TRB LTPP Committee was reduced to just two. The TRB ETG on LTPP Traffic Data Collection and Analysis continued to provide the same functions as before, and a "super" ETG was created by combining many of the functions of those ETG's that existed prior to 2006. The TRB ETG on LTPP Special Activities advised the FHWA on matters related to collection, processing, uploading into the LTPP database, and analysis of all data other than traffic data recorded at or determined from samples collected at LTPP test sites. The work of the ETG facilitated the accumulation in the LTPP database of high-quality data in quantities sufficient to support LTPP analysis projects. These projects were

designed to produce outcomes addressing the high-priority pavement-related needs of state highway departments.

Thus, since 2006, the TRB LTPP Committee with the support of the Traffic and Special Activities ETG's provided the formal peer-review functions for all LTPP-related activities.

HIGHWAY BILL AUTHORIZATIONS AND IMPACTS ON OPERATIONS

Since its start in 1987, the LTPP program has gone through the following four highway legislations:

- Surface Transportation and Uniform Relocation Assistance Act (STURAA)
- Inter-modal Surface Transportation Efficiency Act (ISTEA)
- Transportation Efficiency Act for the 21st Century (TEA-21)
- Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)

More so than management, LTPP funding evolved and changed over the life of the program. Table 3 shows the LTPP program funding by highway legislation.

Table 3. Total LTPP Program Funding, FY 1987 through 2009

Years	Source	Million $	Comment
1987 - 1991	1987 STURAA	**$50.00**	Under SHRP
1992 - 1997	ISTEA 6001 and FHWA GOE	**$87.30**	Under FHWA
1998 - 2003	TEA-21, AASHTO (NCHRP) and RABA	**$75.51**	Under FHWA
2004 - 2009	TEA-21 Extensions, SAFETEA-LU, FHWA and SAFETEA-LU Technical	**$50.07**	Under FHWA
	Total:	**$262.88**	

Initially, LTPP received $50 million of the $150 million provided to SHRP by the STURAA of 1987. While significant, the budget realities had an impact on a number of program issues, such as the reduction in the types and numbers of pavement layer materials tests to be performed, but perhaps none as significant and long lasting as the following two:

- SPS pavement layer materials testing program was decentralized, with materials sampling and testing guidelines developed by LTPP and site specific sampling plans adapted by regional contractors working closely with each highway agency. The individual highway agencies graciously took on the responsibility for all sampling and lab testing of materials from each SPS project within the state or province, except for the resilient modulus testing of unbound and hot-mix asphalt (HMA) materials, which were to be performed by LTPP. This is in contrast to the

testing on the General Pavement Studies (GPS) test sections, where LTPP performed material sampling and testing activities with support from the highway agencies. As a consequence, the SPS materials test results were inconsistent relative to LTPP's high-standards.

- Responsibility for traffic data collection was assigned to the individual participating highway agencies, and they made a good faith effort to discharge of that responsibility at both LTPP GPS and SPS test sections. However, traffic-monitoring technology never lived up to the early expectation that it would be economically and technically feasible to install reliable Weight-in-Motion (WIM) equipment at every LTPP test site. This, coupled with data quality and timely monitoring problem issues that arose, led to large traffic data gaps in the LTPP database.

The impact of the above two issues on LTPP operations became quite evident in the mid-1990s, at the mid-point of the program, and eventually led to the development and implementation of important materials testing and traffic monitoring action plans to address data deficiencies, which required a significant level of additional funding.

In 1992, the administration of LTPP was transferred to the FHWA. From 1992 through 1997, the ISTEA provided $37.52 million for LTPP, and FHWA provided an additional $49.77 million from its research and technology funds. This averaged $14.55 million per year; approximately the amount that was estimated would be needed to sustain the LTPP studies when their administration was transferred from SHRP to FHWA. This budget represented a 45% increase over that under the STURAA legislation that covered LTPP during the 1987 to 1992 SHRP years. More importantly, this budget increase permitted the LTPP program to make important adjustments as well as to implement new initiatives that would prove to have a positive impact on the program including:

- Increased monitoring frequencies on LTPP test sections, particularly for FWD deflection testing and longitudinal profile surveys.
- Formal introduction of pavement surface manual distress surveys (in addition to the photographic distress surveys), which were carried out by the LTPP regional contractors.
- Implementation of the Seasonal Monitoring Program (SMP), which was established to obtain a fundamental understanding of the magnitude and impact of temporal variations in pavement response and material properties due to the separate and combined effects of temperature and moisture variations. It was envisioned that the products from the SMP study would provide the means to link pavement response data obtained at random points in time to critical design conditions, the means to validate models for relationships between environmental conditions and in situ structural properties of pavement materials, and expanded knowledge of the magnitude and impact of the changes involved. When this program was terminated in 2004, it represented the end to perhaps one of the most successful undertakings within the LTPP program.
- Planning and initial implementation of the dynamic load response (DLR) program at select LTPP SPS-1 and –2 projects, which were intended to capture real-time pavement responses (stresses, strains, deflections and pressures) resulting from actual traffic loadings.

From 1998 through 2003, funding from the TEA-21 and the Revenue Aligned Budget Authority (RABA) of the TEA-21 plus contributions to the program from AASHTO provided $12.59 million per year for LTPP. The reduction in budget impacted on the LTPP program's ability to effectively plan and execute key activities required to complete the program's mission. The decreased level of

funding required that LTPP make some significant program adjustments, taking into consideration contractual obligations and programmatic issues. Some of those adjustments included:

- Basic data collection and processing activities were cut back to levels below those during the ISTEA legislation and well below those required to complete the LTPP mission.
- Important data collection activities were either postponed or delayed, including drainage surveys, forensic investigations, within test section thickness surveys and some quality assurance review activities. In addition, purchase of much needed equipment was postponed.
- The seasonal monitoring program was terminated.
- Development and population of key computed parameters for storage in the database were postponed. The most salient of these parameters was the dynamic modulus of hot-mix asphalt concrete mixtures, which was considered essential in the calibration of AASHTO's mechanistic-empirical pavement design guide at the regional and local level. Other affected computed parameters included the moisture content of unbound layer from TDR readings and elastic layer moduli backcalculation from deflection data.
- Planning for needed future procurements stopped due to budget uncertainties.
- Bare minimum work assignments were made to the data analysis contracts awarded during the original TEA-21 legislation.
- No new product development activities were started.
- Key Ancillary Information Management System (AIMS) activities had to be either cut back or postponed, including work on the LTPP library.
- Vital communication and coordination activities were hampered due to limited funds, especially those involving the TRB LTPP Committee and ETGs, as well as those requiring travel funds. It was not possible to hold a number of important meetings and coordination activities had to rely more on teleconferences.

Were it not for the contributions made to the program by AASHTO and funding derived from the Revenue Aligned Budget Authority (RABA), the negative impact of TEA-21 on LTPP operations would have been much greater.

The TEA-21 adjustments were clearly painful cuts for a twenty-year program to endure and still deliver the impact products LTPP was designed to produce. Perhaps the most critical impact of the TEA-21 extensions to achievement of the program's goals was on the program's inability to monitor aging pavement test sections at needed intervals. Cutbacks in monitoring frequency resulted in sections going out of study without the final round of condition measurements being completed.

Finally, from 2004 through 2009, funding resulting from extensions of the TEA-21, SAFETEA-LU and associated technical corrections bill, and FHWA provided approximately $8.35 million per year for the LTPP program. To put things into perspective, the funding required to fulfill the LTPP mission from FY 2004 through 2009 was $120 million dollars, or approximately $20 million dollars per year. This figure included activities designed to address program weaknesses and emerging needs. With the budget provided by the SAFETEA-LU legislation, however, it was not possible to perform many of the desired corrective actions. Furthermore, the legislation was not clear if LTPP operations would be extended past 2009. Like the previous legislation, it extended authority for

operation of the program to the termination date of the current bill. Since the future of LTPP was not clear, the FHWA decided that the most responsible course of action for use of program funds was to prepare for both a transition of LTPP activities past 2009 and possible program termination in 2009.

These considerations led to the establishment of a "quality pavement performance database and supporting ancillary information and document warehouse that enables researchers to better fulfill the goals of understanding pavement performance on which the program was founded" as the primary priority deliverable for LTPP at the end of the legislation. The decision to make use of available LTPP resources for the above referenced priority required significant adjustments to other program activities. They included:

- Data collection activities -- Reduction in pavement condition data collection frequencies; placing more than 300 active test sections in the out-of-study category; monitoring was to be performed only on a subset of priority test sections; quantitative pavement surface images for distress interpretation would not be obtained; structural response measurements with the FWD were suspended; funds would not be used to support the regional FWD calibration centers; materials tests for aging previously planned in the SPS materials action plan were eliminated; planned test section drainage features characterization activities were eliminated; additional ground penetrating radar measurements were eliminated; plans to address deficiencies in traffic volume and load data on GPS project sites were eliminated; and no expenditure of program funds for replacement or updates to field data collection equipment.
- Database activities – Development of an analysis database would not be performed; overhaul of database automated quality checks was suspended; development of a complete metadata database for all off-line ancillary information was suspended; reduction of data releases to an annual cycle; conversion of data element units to a common standard was suspended; and LTPP funding would not be provided to support DataPave Online and database user training.
- Data analysis activities – No further investment of LTPP program funds would be dedicated to formal data analysis projects through 2009.
- Product development activities – No LTPP program funds would be allocated to product development from 2006-2009.
- Coordination activities – Elimination of LTPP sponsored national and regional meetings and reduction in frequency of national coordination meetings with LTPP data collection contractor staff and meetings between the data analysis contractors and operation staff.

While there is a chance that the LTPP program will end as such at the conclusion of the current legislation, much work is clearly required to complete the LTPP mission as a result of the budget reductions in the TEA-21 and SAFETEA-LU legislations.

In summary, the total national investment through 2009 in the LTPP program was $262.88 million dollars. However, this figure does not include FHWA engineering and clerical staff salaries, travel, equipment, supplies and routine overhead costs. In addition, it does not include the financial support provided by the American states and Canadian provinces for the construction of the test sections, materials testing, traffic data collection, and all of the management, staff, and equipment supporting the broad array of LTPP activities—particularly traffic control during data collection. It is estimated

that the states and provinces have contributed in excess of $500 million to LTPP in services and direct expenditures. Additionally, under the TEA-21 and SAFETEA-LU legislations, groups of state departments of transportation (DOTs) entered into pooled fund agreements in support of LTPP activities for which no other support was available.

PRODUCTS AND BENEFITS

The most important product of the LTPP program to date is its publicly available database: the largest and most comprehensive pavement performance database ever created for research purposes. The LTPP database is a relational database, meaning that it is composed of separate, but related, tables of data. The production database is currently implemented in Oracle, and its overall structure is based on the LTPP data collection and processing flow.

It has always been expected that the LTPP program would not only provide data necessary to determine how and why pavement perform as they do, but that it would also yield products and tools to extend pavement life. After nearly two decades of data collection, many valuable insights, innovations and products have indeed emerged, and not just those originally envisioned by those who formulated the program.

Perhaps one of the biggest contributions that the LTPP program made in its early days was the advancement of pavement and traffic data collection techniques, data quality control tools, and materials testing protocols needed to support data collection. Quality, uniform and consistent data collection is of paramount importance to the program. When LTPP started, refined “off-the-shelf” “ready-to-use” tools, procedures, and equipment needed to accomplish the program objectives were not available. Significant time and resources were spent on the development of those tools following quality management principles. A few examples of those tools include:

- Data collection techniques including: manuals and/or procedures; equipment specifications and acceptance; and equipment and software package to measure pavement subsurface temperature, moisture, and frost.
- Data quality and quality assurance tools including: distress raters accreditation workshops and distress time history review procedure and software (DiVA); laboratory startup procedure for resilient modulus testing of HMA and unbound materials; calibration and validation of WIM traffic sites and traffic analysis and QC software; profiler comparison rodeos; LTPP FWD calibration centers; QC/QA software; and automated multi-tiered data checks to check data completeness, range, and valid relationships between data elements after the data has been entered into the database.
- Materials testing protocols including: PCC thermal coefficient of expansion test; resilient modulus, creep compliance, and indirect tensile strength of HMA materials; resilient modulus of unbound materials; and interface bond strength test for PCC overlays on PCC.

As more and more data were collected over the years, the LTPP program began to analyze those data, and that resulted in numerous insights, innovations and products to improve existing pavement design and construction procedures and maintenance practices. In addition, tools to make the LTPP data more accessible and user-friendly to the public were developed. A few examples of both are provided below:

- LTPPBind – Software program developed to help highway agencies select the most suitable and cost-effective Superpave asphalt binder Performance Grade (PG) for a particular site.
- Pavement Maintenance and Repair Manuals
- Asphalt Pavement Layer Temperature Measurements – A more efficient method to take asphalt pavement layer temperatures measurements was developed.
- Rigid Pavement Design Software – This software automates the design and analysis procedures in the 1998 AASHTO supplement.
- Implementation of wider PCC slabs – Based on the early results of the SPS-2 experiment and a supplemental study conducted by the Colorado Department of Transportation (DOT), the 14-ft slab is now the preferred option for designers in that state, primarily in a rural setting.
- Implementation of narrower joints – The results of the Colorado SPS-4 study on narrower joints revealed that the single cut 1/8" concrete joints to be as effective as the standard double cut 3/8-inch joints.
- Analysis findings regarding skewed joints – LTPP analysis findings showed that skewed joints offer no performance advantage over perpendicular joints, and as a consequence, the Pennsylvania DOT has discontinued use of skewed joints on their concrete pavements.
- LTPP data has been used by Oregon DOT to examine issues related to rutting in PCC pavements.
- The mechanistic-empirical design guide that resulted from the NCHRP 1-37A project, for example, would not have been possible without the LTPP data.
- DataPave Online – Beginning in March of 2003, a significant portion of the data contained in the LTPP database was made available via the web at http://www.datapave.com.
- SMP CD-ROM Set – A single source for data collected under the Seasonal Monitoring Program (SMP) along with relevant documents.
- Resilient Modulus CD-ROM – A comprehensive set of guidelines on the resilient modulus test for soil and aggregate materials using LTPP data and findings.

Another very significant unanticipated benefit of the LTPP program was the introduction and use of LTPP data in university engineering curriculum. Many engineering schools with significant pavement engineering courses developed course curriculum around the LTPP data and database. In addition to challenging students with computational problems based on real field data, it also resulted in the side benefit of introducing professors and students to database manipulation tools; an emerging need for future engineers not presently contained in most engineering curriculums. From the authors' personal experience, hundreds of undergraduate and graduate students have used the LTPP database as part of their pavement engineering curriculum, and more than 75 engineering students with advanced degrees based on analysis of LTPP data have graduated and are now working in the profession.

The above is just a small sampling of the benefits that have resulted from the analysis of the LTPP data to date. There are more than 300 reports, brochures, technical briefs and other documents from the Strategic Highway Research Program, National Cooperative Highway Research Program, FHWA, Canadian Strategic Highway Research Program, Transportation Research Board, and publications from pavement engineering related technical conferences that present results, conclusions, and recommendations based on the analysis of LTPP data. Many LTPP sponsored

reports can be downloaded free of charge from the more than 150 reports posted on the LTPP web page http://www.fhwa.dot.gov/pavement/ltpp/. These reports and other documentation are also distributed with the standard data release available from LTPP customer service at ltppinfo@fhwa.dot.gov. Even more insights, innovations and products are expected to emerge from the LTPP program in the coming years as the focus shifts from data collection to data analysis and product development.

SUMMARY

Performance of a truly long-term study requires a solid commitment to clearly defined goals, and flexibility to react to changing economic climates. Staying true to the ultimate objective can be daunting when faced with strong political objections. Consideration must be given to delivery of short-term successes, to remind partners that there is value to the efforts under way. In the case of the LTPP program, prioritization of activities was a pervasive reality. In most cases data collection took precedence over others, since analysis and data cleansing could occur later, but time series data collection needed to occur on schedule.

The Long-Term Pavement Performance program started under the Strategic Highway Research Program, and carried forward by the Federal Highway Administration is still under way, over 20 years after its inception. It has survived changes in leadership and funding, while keeping a vigilant eye on the goals and objectives of the program, and delivering products and benefits along the way. The primary product of the activity, the LTPP Database, is available for use to anyone interested, while it also continues to be expanded and improved.

Recognizing the benefits of the program, there has been discussion about development of a follow on program, with studies of broader implication. A Long-Term Infrastructure Research Program could incorporate the lessons learned and structure of the LTPP program, expanded to consider other infrastructure items such as bridges, signage, etc. LTPP has proven the concept is sound, and there is value to the study. While it is extremely difficult to quantify expenditures versus monetary benefits, all indications are that LTPP has delivered on its promise of savings, and will continue to do so for many years to come.

REFERENCES

Several dozens of reference documents were used in the preparation of this paper. Listing them all here would require the addition of pages beyond those allowed by the congress' guidelines, while reducing the length of the paper text in order to fit the references was not considered a viable option. Instead, the reader is referred to the library section of the Federal Highway Administration's LTPP web site for a comprehensive list of LTPP documents. The referenced web site library section may be accessed via the following link: **http://www.fhwa.dot.gov/pavement/ltpp/library.cfm**