Contributions of the Long-Term Pavement Performance Program to Pavement Management System Improvements: Better Data and Performance Models

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ABSTRACT

The United States interstate highways and other components of the national highway system are approaching the end of their effective service lives. Many segments of this network have already surpassed their design lives and require frequent repair. State and municipal networks are facing the same crisis. Highway agencies nationwide are under pressure to produce pavements that perform better and last longer. This demand cannot be met using the current suite of pavement engineering and management tools. The new tools needed to meet the challenge can only emerge from research. The Long-Term Pavement Performance (LTPP) program goes a long way towards meeting the challenge. Its mission is to promote increased pavement life through research, and after 20-years, LTPP has produced many products that have benefited pavement engineering and management practices. In addition to building a national pavement database, products derived from LTPP have been flowing to the highway community since its early years ranging from standardized data collection methods, new engineering tools, and new pavement design methods. This paper details LTPP's contributions towards the advancement of pavement

management, with particular emphasis in better Pavement Management System data and improved pavement performance models.

INTRODUCTION

The United States reaps a substantial return from investment in our pavement, an investment of approximately $40 billion a year. As large as that figure sounds, a recent article in Roads and Bridges puts the annual savings from the interstate system at $737 billion, providing "safety benefits, saved time, reduced fuel and lower consumer costs."(1) However, the interstate highways and other components of the national highway system are approaching the end of their effective service lives. Since 1970, traveled vehicle miles have doubled and the average daily loads have increased almost sevenfold. Many segments of this network already have surpassed their design lives and require frequent repair. State and municipal networks are facing the same crisis. Highway and transportation agencies nationwide are under pressure to produce pavements that perform better and last longer. This demand cannot be met using the current suite of pavement engineering and management tools. The new tools to meet these challenges can only emerge from research.

The Long-Term Pavement Performance (LTPP) research program goes a very long way towards meeting these challenges. The need for LTPP was first identified in the 1984 report, America's Highways: Accelerating the Search for Innovation.(2) This report noted that highway pavements were not living up to design expectations and recommended that the development of a pavement performance database could answer important questions about pavement management and design. In 1986, based on this recommendation, the American Association of State Highway and Transportation Officials (AASHTO) developed the plan to be included in the Strategic Highway Research Program (SHRP). The mission defined for LTPP was to promote increased pavement life through the collection and storage of performance data from a large number of in-service highways over an extended period, analysis of these data to describe how pavements perform and to explain why they perform as they do, and translate these insights into knowledge and usable engineering products.

Implementation of LTPP began in 1987, and to accomplish its mission, the program established a set of 17 field experiments, a database to store the collected experimental data, and supporting technical documentation. From this information, it was envisioned that new pavement design, management, and maintenance systems would be developed to extend pavement life and serve a new generation of highway administrators and users. And indeed, after twenty years, LTPP has produced many products that have benefited pavement engineering and pavement management practices. In addition to building a national pavement database (the most strategic product as it enables new insights to be developed from the collected data by a vast audience of interested data users - e.g., developers of the new Mechanistic Empirical Pavement Design Guide under the NCHRP 1-37A project have stated that it would have been impossible to develop the guide without LTPP data), products derived from LTPP have been flowing to the highway agencies and other segments of the highway community since the early years of the program ranging from standardized data collection methods, new engineering tools, and new pavement design methods. These advances are just the beginning, as many significant activities, real benefits and innovative products remain to be performed and developed in the coming years.

This paper details LTPP's contributions towards the advancement of pavement management systems. The first section of the paper provides an overview of the program. The next section discusses contributions made by the program that have resulted in better PMS data, including advances in data collection techniques and quality control/quality assurance tools. The following section addresses LTPP contributions towards improved pavement performance models, with special emphasis on distress and roughness models. Other contributions from the LTPP program are discussed next, followed by the summary and conclusions section.

OVERVIEW OF THE PROGRAM

LTPP was established as a twenty-year program whose stated goal is “to increase pavement life by investigation of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrades, 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 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.

To accomplish these stated goal and objectives, 17 scientifically designed field experiments were implemented within two broad study areas: General Pavement Studies (GPS) and Specific Pavement Studies (SPS). The GPS study area represents a series of experiments on selected pavement sections that were in service at the beginning of the program. These experiments were restricted to pavements that incorporate materials and designs representing good engineering practices and that had strategic future importance. These experiments were also limited to pavement structures in common use throughout the United States due to the nation-wide thrust of the program. As these experiments incorporated in-service pavements of a wide variety of ages and condition, they were expected to yield results more quickly than the SPS study.

The SPS program is a long-term study of specially constructed, maintained or rehabilitated pavement sections incorporating a controlled set of experiment design and construction features. The objective of this study was to evaluate a broader range of factors than that available from pavements designed to meet local conditions. For example, some of the SPS pavement structures included thin pavements under heavy traffic and thick pavements under light traffic. Table 1 provides a listing of the experiments included in the GPS and SPS study areas.

TABLE 1 List of LTPP 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 of Portland Cement Concrete (PCC) Pavement
GPS-9	Unbonded PCC Overlay of PCC Pavement
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 AC Pavements
SPS-6	Rehabilitation of Jointed PCC Pavements
SPS-7	Bonded PCC Overlays of PCC Pavements
SPS-8	Study of Environmental Effects in the Absence of Heavy Loads
SPS-9P/ SPS-9A	Validation and Refinements of Superpave® Asphalt Specifications and Mix Design Process/Superpave® Asphalt Binder Study

Ultimately, the LTPP program incorporated nearly 2,500 test sections on in-service pavements located throughout North America. Figure 1 provides the geographical distribution of these sections. The figure identifies the approximate 900 locations of the test sections. Some of the sections are co-located such that these 900 locations represent nearly 2,500 test sections. On each of these sections, data were collected regarding the environment, inventory, maintenance, materials testing, monitoring, rehabilitation, and traffic. The majority of these data are stored in the LTPP Pavement Performance Database. Data not included in the database include such information as raw traffic and profile data, falling weight deflectometer time history data, distress maps, distress images, and photographs. Additionally, the documentation defining how each data element is to be collected is not stored in the database.

Monitoring on these test sections began in 1989, and has led to a number of valuable insights and innovations in data collection and quality control as well as improvements in understanding of how and why pavements work as they do.

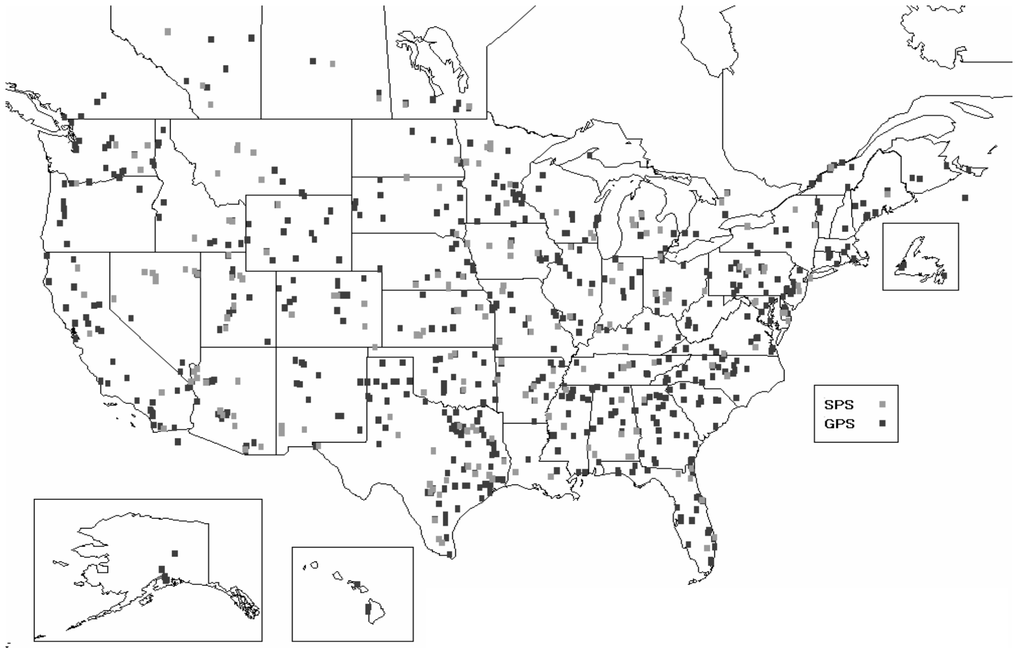

FIGURE 1 Geographical distribution of LTPP test sections

BETTER PMS DATA
Data Collection
When the LTPP program began in 1987, standards for production-level data collection of research quality data were virtually non-existent. Any existing methodologies used for production-level evaluation were primarily used for pavement management by State agencies and required quick visual surveys and not the detailed surveys required for use with research. The LTPP program began by developing a series of manuals to be used for these research quality data collection efforts.

The Distress Identification Manual (DIM), illustrated in Figure 2, provides a set of definitions to identify each type of distress that can be observed on asphalt concrete, jointed concrete, or continuously-reinforced concrete pavements.(*3*) Definitions are provided for severity levels associated with each type of distress along with the key characteristics associated with the observation and measurement of each distress. These definitions have become the starting point of distress definitions used for pavement management and discussions of distress across the nation. Not every agency performing pavement management will require collection of each individual type of distress listed in the DIM. However, the LTPP DIM has become the standard list from which an agency will select the distresses to be used with their system. Further the DIM has been made available in a pocket-sized guide providing a simple handbook that can be used by distress raters in the field.(*4,5,6*)

Similarly, a manual was created for collection of longitudinal profile data or ride quality data.(*7*) When LTPP initially began, inertial profilers were being commercially manufactured by one or two companies. These devices used optical or ultrasonic sensors for data collection and very few were being used even for pavement management purposes. With the advent of the LTPP program and standardized data collection procedures, most of the states are using inertial profilers for collection of ride quality for pavement management purposes and many are using these devices for evaluation of smoothness as part of their construction acceptance programs.

Further, the LTPP program has provided the opportunity for a variety of agencies to become familiar with the inertial profiling equipment before adopting it for standard use.

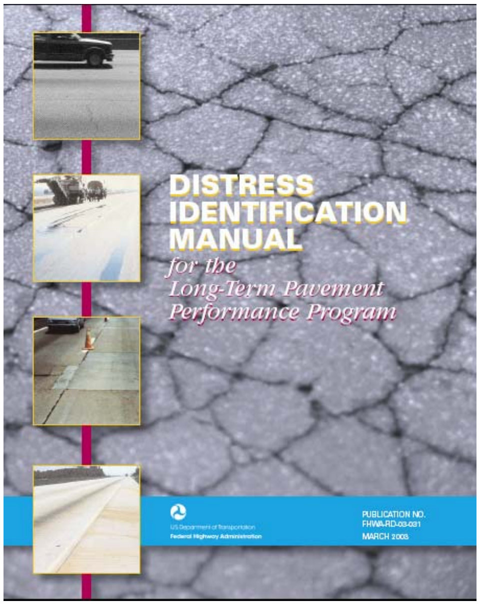

FIGURE 2 Distress Identification Manual used for LTPP

The LTPP program developed an operations manual for falling weight deflectometer (FWD) testing. The manual established minimum testing operations to ascertain variability along the length of a section and at a given point.(*8*) When the LTPP program was initiated only a few state agencies owned and operated FWDs for either project or network level testing. The LTPP program has assisted in making this equipment more commonplace and less mysterious. Now, most state agencies use FWD testing on their project level testing and a few, such as Virginia, are beginning to use this testing for network level evaluation.(*9*) Even local agencies are beginning to use these equipment to evaluate rehabilitation requirements on their streets.

Both inertial profilers and FWDs require routine maintenance to ensure that the equipment stays in good operating order. The LTPP program developed a guide to provide for the necessary maintenance operations and intervals for maintenance for both of these equipment.(*10*) These manuals are readily available to the general public allowing for every agency owning this type of equipment to take advantage of the many years of experience of the LTPP program.

Quality Control/Quality Assurance

The LTPP program has initiated a number of Quality Control/Quality Assurance (QC/QA) programs that have been emulated by agencies throughout the US and lead to improved data for use in pavement management. The following items include some of the studies in this area performed by the LTPP program:

- Developed a training and accreditation program to ensure that the distress surveyors are ready for production level data collection. The training program was developed into a National Highway Institute course. This accreditation program provides for a minimum standard of performance for receiving and maintaining accreditation. This program can and has been provided to local and state agencies for improving the quality of distress data collected under their jurisdiction.

- Evaluation of variability associated with distress data collection.(*11*) This study identified the expected variation between raters for a given type of distress. From this study and other evaluations of the LTPP distress data, pavement managers across the nation have gained an understanding of various complexities associated with distress data collection. For instance, many researchers assumed that fatigue cracking first appeared as longitudinal cracking in the wheelpath. The LTPP program has been able to prove this assumption and provided a means for evaluating longitudinal cracking in the wheelpath as fatigue.
- The LTPP program has standardized the various sets of tests that should be performed on a daily basis for use in collection of ride quality data. Based on these checks, the data collection crew is enabled to identify that the equipment is operating as expected. These checks evaluate the operation of each individual component of the inertial profiler.
- The ProVal software developed by the Federal Highway Administration was based on the ProQual software used for review and processing of the longitudinal profile data.(*12*) ProVal is quickly becoming the software of choice by highway agencies around the nation for use in reviewing and evaluating longitudinal profile data. The software provides a very simple interface and allows for users to evaluate multiple indices from a given profile. Additionally, the software has a module that allows users to evaluate the improvements in ride quality made by milling portions of a roadway.
- The process of performing an annual calibration of the Falling Weight Deflectometers was established by the LTPP program. Under this program, four regional calibration centers were established to perform a reference calibration. These centers perform a calibration on the load cell and individual geophones used in performing the FWD testing. Additionally, the LTPP program developed a relative calibration that can be used between visits to the calibration center.(*13*) The relative calibration is so termed because it checks the equipment against itself. There is currently a project underway which will provide a more reliable and simple to use method for performing the reference calibration. This improved procedure is likely to result in more calibration centers located across the nation making it easier for agencies to maintain the calibration of their equipment on a routine basis and resulting in improved quality of the data collected.
- Analysis of LTPP data led to the development of the SLIC procedure.(*14*) The SLIC procedure allows the analyst to evaluate the positioning of the geophones on the FWD in comparison with their stated location.

Each of these items has led to improvement in controlling the quality of the data used for managing pavements around the nation.

There are also a number of activities that have been performed for the LTPP program, which improves the overall quality of the data collected besides those listed above. First, under the LTPP program, a set of specifications for purchase of equipment have been developed. These specifications provide a means for ensuring that the equipment obtained meet a minimum level of performance. Any agency specification for purchase of equipment should dictate a minimum level of repeatability and accuracy within the data collected. Additionally, the equipment should meet the agency needs for data storage providing ease in input and identifying the metadata associated with the data being collected. These metadata include such items as location, personnel performing the collection, and date of data collection.

In addition to these specifications, the LTPP program has lead the way in comparing various pieces of equipment. The LTPP held the first ever FWD Thump-off to compare reproducibility of data between various equipment types. The first was held in 1988 and followed by a second in 1989. The thump-offs were not able to prove conclusively that each FWD produces exactly the same results at a given test location. However, these thump-offs led to the creation of the reference and relative calibration protocols. The theory is that with continued testing, the stiffness at a given location will change. The reference and relative calibrations implemented using the procedures previously identified should ensure that these equipment are collecting accurate, repeatable, reproducible data.

The LTPP program also established the protocol for comparing inertial profilers. The LTPP profiler rodeos have been used to ensure that the devices for each regional operation were operating within the same parameters. The rodeos were performed every one to two years and evaluated the reproducibility of the equipment. These rodeos laid the groundwork for providing a standard for profiler verification.

IMPROVED PAVEMENT PERFORMANCE MODEL

In addition to the improvements in data collection, the LTPP program has led to numerous improvements in pavement performance models and analysis of pavement data. The LTPP program has led to improvements in performing temperature adjustments of backcalculated asphalt concrete moduli.(*15*) This methodology improves the reliability of the data used for evaluating structural performance of pavements by adjusting moduli to a common temperature. This study evaluated prior methods for temperature adjustment of backcalculated moduli using LTPP data. The study identified improvements in these methods. Additionally, a procedure was developed for performing temperature adjustments for network level data collection which is much simpler to implement but still improves the accuracy of the asphalt moduli determined using the deflection data.

The LTPP program has developed a series of relationships between the various indices used for evaluating ride quality.(*16*) These indices allow agencies that have historically used one index for pavement management and/or construction acceptance to relate that data to the International Roughness Index (IRI). The IRI is the most commonly used index for evaluating ride quality in the U.S. The study investigated the relationship between the IRI and the California profilograph profile index (PI). The PI was examined using several different blanking bands including the 2 mm (0.08 in), 1 mm (0.04 in.) and a zero blanking band. The PI was not closely related to the IRI; however, the relationship was significantly improved with the smaller blanking binds.

In addition to the investigation of indices that can be used for the evaluation of ride quality, one LTPP study evaluated the progression of roughness on pavements.(*17*) This study evaluated how roughness progression differed on different types of pavements. The most important finding from this study was that the primary factor in the development of roughness in pavement is the amount of roughness that is present in the pavement at the time of construction. In short, pavements that are built smooth stay smoother longer and have a longer service life. Pavements that are built rough have a more rapid progression of roughness and will result in a shorter service life. This study in combination with the one identified above provide evidence of the need to monitor pavements from “birth” using the same statistics throughout their life. Further, these studies provide a means for assisting pavement managers for estimating statistics they are more comfortable with using from data evaluated in a different way.

Under the LTPP program, improvements were made in the evaluation of rutting on pavements.(*18*) Data from the LTPP program were used to illustrate deficiencies in methods used by many highway agencies for evaluating rut depth using three or five lasers. The study compared the amount of rutting determined using the full transverse profile to the rutting determined based on what would have theoretically been collected by a three-laser system and a five-laser system. The study illustrated that there was no relationship between the rut depth calculated using the full transverse profile and the rutting calculated based on three lasers, as illustrated in Figure 3. The relationship between the rut depth calculated from the full transverse profile and the five-laser rut depth was somewhat improved over the relationship with the three-laser rut depth; however, it was still poor. This study indicates that the traditional methods used for collecting rut depth for pavement management purposes are not of the quality that are required for making good decisions.

This same study provided a series of indices that can be used for evaluating rutting on asphalt surfaces.(*18*) These methods can all be used for evaluation of rutting in terms of pavement management. These indices include several area methods identifying the area between the pavement surface and an imaginary line connecting the end points of the profile. The rut depths are calculated based on a six-foot straightedge and based on an imaginary wireline stretched across the profile. Additionally, for each rut depth, the width of the rut and the location of the maximum depth in each half of the lane are identified within the LTPP database. This study allows pavement managers to evaluate different techniques for measuring rutting and how these techniques can improve the decisions made for repairs.

The Mechanistic-Empirical Pavement Design Guide (MEPDG) models were calibrated using data from the LTPP program.(*19*) These models provide a method for evaluating pavement performance over the expected life of the pavement and to evaluate various repair techniques. Improved techniques in evaluating pavement performance can lead to tremendous cost savings by keeping highway agencies from over-designing pavements to meet a minimum life or from having to perform costly repairs soon after construction due to insufficient structure.

Besides all of the work leading to improvements in each the components of a pavement management system, namely the data collection, quality control, and modeling, the LTPP program has led to improvement in understanding of various maintenance and rehabilitation strategies. The program provided a means for various agencies to perform side-by-side comparisons of different strategies to see how these techniques performed under a given traffic, subgrade, and environment.

The final product that allows for continued improvements in pavement management is the Long-Term Pavement Performance database. The LTPP database contains nearly 20 years of data documenting the construction, climate, maintenance, rehabilitation, traffic, materials, and monitoring data. Data analysts have just begun to probe into the LTPP database and all of the lessons that these data can teach.

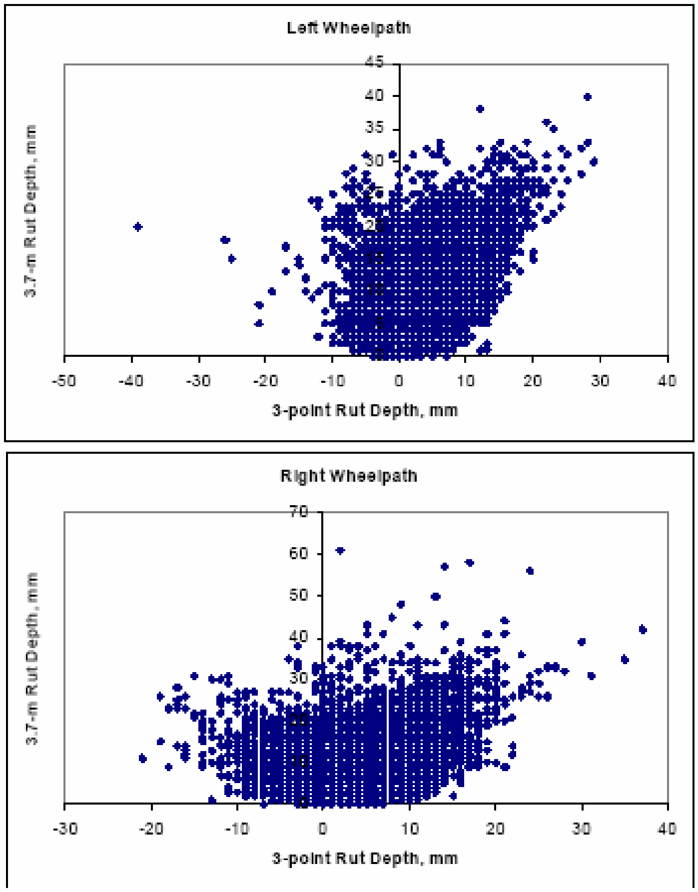

FIGURE 3 Comparison of 3-laser rut depth and wireline rut depth (*18)*

CONCLUSION

The LTPP program has led to improvements in each aspect of pavement management. The program has provided improvements in data collection and quality control of data collection by standardizing test methods and improving existing methods. This paper has attempted to illustrate the improvements in monitoring data collection. The LTPP program has also provided improvements in many other data collections areas which are important to pavement managers such as materials testing and traffic.

The program has also provided improvements in modeling for analysis of individual aspects of the data collection. These model improvements include the evaluation used for specific elements such as temperature adjustment of backcalculated moduli of asphalt layers. Models such as the MEPDG provide for improved prediction of the pavement performance. Additionally, the data collected for the LTPP program has provided improved understanding in various maintenance and rehabilitation treatment. Further, the LTPP database can and will lead to improvements in pavement management for years to come as analysts continue to mine the data for all it has to teach us on how and why pavements perform as they do.

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