Year	Title	Author(s)
2009	Performance and Economic Benefits of Thick Granular Base for Flexible Pavement Design in Ohio	Yu, Xiong; Beck, Randall
2009	Development of Permanent Deformation Model of Asphalt Mixtures for Korean Pavement Design Guide	Le, Anh Thang; Lee, Hyun Jong; Park, Hee Mun; Lee, Sang Yum
2009	Development of Robust Approach for Evaluation of Airport Pavement Bearing Capacity	Lee, Ying-Haur; Liu, Yao-Bin; Lin, Jyh-Dong; Ker, Hsiang-Wei
2009	Sensitivity Analysis of the MEPDG Using Measured Probability Distributions of Pavement Layer Thickness	Aguiar-Moya, Jose Pablo; Banerjee, Ambarish; Prozzi, Jorge A.
2009	Calibration of “Mechanistic–Empirical Pavement Design Guide” Permanent Deformation Models: Texas Experience with Long-Term Pavement Performance	Banerjee, Ambarish; Aguiar-Moya, Jose Pablo; Prozzi, Jorge A.
2008	Development of a Pavement Rutting Model from Long-Term Pavement Performance Data	Luo, Rong; Prozzi, Jorge A.
2008	International Roughness Index Model Enhancement for Flexible Pavement Design Using LTPP Data	Zhou, Guoqing; Wang, Linbing; Lu, Yang
2008	Lessons Learned During Implementation of Mechanistic-Empirical Pavement Design Guide	Mehta, Yusuf A; Sauber, Robert W; Owad, Jeffrey; Krause, Jared
2008	Prediction Models for Transverse Cracking of Jointed Concrete Pavements: Development with Long-Term Pavement Performance Database	Ker, Hsiang-Wei; Lee, Ying-Haur; Lin, Chia-Huei
2008	Use of Texas LTPP Database to Support Validation and Calibration of MEPDG	Aguiar-Moya, Jose Pablo; Hong, Feng; Prozzi, Jorge A.
2008	Development of Fatigue Cracking Prediction Models Using Long-Term Pavement Performance Database	Ker, Hsiang-Wei; Lee, Ying-Haur; Wu, Pei-Hwa
2008	Local Calibration of Mechanistic–Empirical Pavement Design Guide for Flexible Pavement Design	Muthadi, Naresh R; Kim, Youngsoo Richard
2008	Models for Predicting Top-Down Cracking of Hot-Mix Asphalt Layers (NCHRP 1-42A)	Roque, Reynaldo
2008	User Manual and Local Calibration Guide for the Mechanistic-Empirical Pavement Design Guide and Software (NCHRP 1-40B)	Von Quintus, Harold L.
2007	Development of Fatigue Cracking Performance	Ker, Hsiang-Wei; Lee,

	Prediction Models for Flexible Pavements Using LTPP Database	Ying-Haur; Wu, Pei-Hwa
2007	Reliability-Based Approach for Using LTPP and APT Test Results for Estimating Fatigue Performance	Prozzi, Jorgé A; Guo, Runhua
2007	Use of Genetic Algorithm and Finite Element Method for Backcalculating Layer Moduli in Asphalt Pavements	Park, Hee Mun; Park, Seong-Wan; Hwang, Jung-Joon
2007	Evaluation of New Mechanistic–Empirical Pavement Design Guide Rutting Models for Multiple-Axle Loads	Salama, Hassan Kamal; Haider, Syed Waqar; Chatti, Karim
2007	Consideration of Finite Slab Size in Back-calculation Analysis of Jointed Concrete Pavements	Setiadji, Bagus Hario; Fwa, T.F.
2007	Development of a Probabilistic Joint Opening Model Using LTPP Data	Lee, Seung Woo; Jeong, Jin-Hoon; Chon, Beom-Jun
2007	Expected Service Life of Hot-Mix Asphalt Pavements in Long-Term Pavement Performance Program	Von Quintus, Harold L; Mallela, Jagannath; Jiang, Jane; Buncher, Mark
2006	Backcalculation of Permanent Deformation Parameters Using Time Series Rut Data from In-Service Pavements	Salama, Hassan K; Chatti, Karim; Haider, Syed Waqar
2006	Calibration of Mechanistic-Empirical Rutting Model Using In-Service Pavement Data from SPS-1 Experiment	Chatti, Karim
2006	Development of Roughness Deterioration Models for National Park Service Network	Helali, Khaled, et al
2006	Effect of Design and Site Factors on Long-Term Performance of Flexible Pavements in SPS-1 Experiment	Chatti, Karim
2006	Effects of Multiple Freeze Cycles and Deep Frost Penetration on Pavement Performance and Cost	Jackson, N; Puccinelli, J.
2006	Evaluation of Backcalculation Methods for Nondestructive Determination of Concrete Pavement Properties	Fwa, T. F; Setiadji, Bagus Hario
2006	Evaluation of Pavement Slab Rocking and Pumping with Elevation Profile Data	Byrum, Christopher Ronald
2006	Evaluation of Resilient Modulus Model Parameters for Mechanistic–Empirical Pavement Design	Elias, Mohammed B; Titi, Hani H.
2006	Feasibility Study for Gray Theory Based Pavement Smoothness Prediction Models	Li, Qiang, et al
2006	Forwardcalculation Spreadsheets	
2006	Guidelines for Review and Evaluation of	Stubstad, R. N; Jiang,

	Backcalculation Results	Y. J; Lukanen, E. O.
2006	Investigations of Environmental and Traffic Impacts on “Mechanistic-Empirical Pavement Design Guide” Predictions	Zaghloul, Sameh, et al
2006	LTPP Data Analysis: Optimization of Traffic Data Collection for Specific Pavement Design Applications	
2006	Network-Level Evaluation of Specific Pavement Study-2 Experiment: Using a Long-Term Pavement Performance Database	Buch, Neeraj, et al
2006	Review of the Long-Term Pavement Performance Backcalculation Results Final Report	Stubstad, R. N; Jiang, Y. J; Clevenson, M. L; Lukanen, E. O.
2006	Seasonal Variations in the Moduli of Unbound Pavement Layers	Richter, Cheryl A.
2006	Sensitivity of NCHRP 1-37A Pavement Design to Traffic Input	Papagiannakis, A., et al
2006	Sensitivity Study of Iowa Flexible Pavements Using Mechanistic-Empirical Pavement Design Guide	Ceylan, Halil, et al
2006	Technical Assistance to NCHRP and NCHRP Project 1-40A: Versions 0.9 and 1.0 of the M-E Pavement Design Software (NCHRP 1-40D)	Harrigan, Edward
2006	Use of Deflection and Distresses in Pavement Performance: Does Mechanistic-Empirical Pavement Design Guide Miss Something?	Vitillo, Nicholas P; Zaghloul, Sameh; Ayed, Amr; Jumikis
2005	Concrete Pavement Design in Kansas Following the Mechanistic-Empirical Pavement Design Guide	Khanum, Taslima, et al
2005	Effect of Seasonal Moisture Variation on Subgrade Resilient Modulus	Salem, Hassan M.
2005	Implementing the Mechanistic-Empirical Pavement Design Guide: Implementation Plan	Coree, Brian; Ceylan, Halil; Harrington, Dale
2005	Sensitivity Analysis of Rigid Pavement Systems Using Mechanistic- Empirical Pavement Design Guide	Guclu, Alper; Ceylan, Halil
2005	Sensitivity Study of Design Input Parameters for Two Flexible Pavement Systems Using the Mechanistic-Empirical Pavement Design Guide	Kim, Sunghwan; Ceylan, Halil; Heitzman, Michael
2005	Survival Analysis of Fatigue Cracking for Flexible Pavements Based on Long-Term Pavement Performance Data	Wang, Yuhong; Mahboub, Kamyar C; Hancher, Donn E.
2005	Verification for the Calibrated Permanent Deformation Models for the 2002 Design Guide (With Discussion)	El-Basyouny, Mohamed M; Witczak, Matthew W;

		El-Badawy, Sherif
2005	Verification of the Calibrated Fatigue Cracking Models for the 2002 Design Guide (With Discussion)	El-Basyouny, Mohamed M; Witczak, Matthew W.
2004	Analysis of Temperature Data for the National Center for Asphalt Technology Test Track	Watson, D. E; Zhang, J; Powell, R. B.
2004	Assessment of Overlay Roughness in Long-Term Pavement Performance Test Sites: Canadian Case Study	Smith, J. T; Tighe, S. L.
2004	Pavement Roughness Modeling Using Back-Propagation Neural Networks	Choi, J-H; Adams, T M; Bahia, H. U.
2004	Use of Artificial Neural Networks for Predicting Rigid Pavement Roughness	Teomete, Egemen, et al
2004	Using Long-Term Pavement Performance Data to Predict Seasonal Variation in Asphalt Concrete Modulas	Salem, H. M; Bayomy, F M; Al-Taher, M. G; Genc, I. H.
2003	Analysis of Influences on As-Built Pavement Roughness in Asphalt Overlays	Raymond, C. M., et al
2003	Demonstration and Evaluation of SUPERPAVE Technologies: Final Evaluation Report for CT Route 2	Larsen, D. A.
2003	Effects of Excessive Pavement Joint Opening and Freezing on Sealants	Lee, S. W; Stoffels, S. M.
2003	Prediction of Longitudinal Roughness Using Neural Network	Farias, M. M; Neto, S.A.D; Souza, R. O.
2002	Benefiting from LTPP - A State’s Perspective	Hoffman, G
2002	Calibration of a Pavement Roughness Model Based on Finite Element Simulation	Saleh, M. F; Mamlouk, M. S.
2002	Development of Asphalt Overlay Performance Models from the C-LTPP Experiment	Tighe, S; Haas, R; Ningyuan, L.
2002	Development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures (NCHRP 1-37A)	
2002	LTPP Data Analysis: Variations in Pavement Design Inputs	Stubstad, R. N; Tayabji, S. D; Lukanen, E. O.
2002	Temperature Correction of Multiload-Level Falling Weight Deflectometer Deflections	Park, H. M; Kim, Y. R; Park, S.
2002	Utilizing the Long-Term Pavement Performance Database in Evaluating the Effectiveness of Pavement Smoothness	Ksaibati, K; Mahmood, S. A.
2001	Performance of Continuously Reinforced Concrete Pavements in the LTPP Program	Tayabji, S. D; Wu, C. L; Plei, M.
2001	Smoothness Models for Hot-Mix Asphalt Surfaced Pavements: Developed from Long-Term Pavement	Von Quintus, H. L; Eltahan, A; Yau, A.

	Performance Program Data	
2000	LTPP and the 2002 Pavement Design Guide	
2000	LTPP and the 2002 Pavement Design Guide (Brochure)	
1999	Design and Construction of PCC Pavements, Volume III: Improved PCC Performance Models	Titus-Glover, L; Owusu-Antwi, E B; Darter, M. I.
1999	Determination of Resilient Modulus for Maine Roadway Soils	Smart, A. L; Humphrey, D. N.
1999	Evaluation of Rigid Pavement Joint Seal Movement	Morian, D; Suthahar, N; Stoffels, S.
1999	Evaluation of the 1993 AASHTO Flexible Pavement Design Model Using the LTPP Database	Sheehan, M. J; Tarr, S M; Okamoto, P. A.
1999	New Software Tool Paves the Way for More Cost-Effective, Durable Roads in Kansas: Kansas Relies on LTPPBind Software to Select SuperPave Binder PGS	
1999	Rigid Pavement Design Software: A New Tool for Improved Rigid Pavement Design	
1999	Roughness Trends at C-SHRP LTPP Sites	Haas, R; Li, N; Tighe, S.
1998	Calibration of Mechanistic-Empirical Rutting Model for In-Service Pavements	Ali, H. A; Tayabji, S. D; La Torre, F.
1998	Calibration of Performance Models for Jointed Plain Concrete Pavements Using Long-Term Pavement Performance Database	Bustos, M., et al
1998	Computer Parameters: Freeze/Thaw Monograph for Long Term Pavement Performance (LTPP)	
1998	Design and Construction of PCC Pavements, Volume I: Summary of Design Features and Construction Practices that Influence Performance of Pavements	Owusu-Antwi, E. B; Titus-Glover, L; Darter, M. I
1998	Evaluation of Mechanistic-Empirical Performance Prediction Models for Flexible Pavements	Ali, H. A; Tayabji, S. D.
1998	Mechanistic Evaluation of Test Data from LTPP Flexible Pavement Test Sections, Volume I: Final Report	Ali, H. A; Tayabji, S. D.
1998	Mechanistic Evaluation of Test Data From LTPP Jointed Concrete Pavement Test Sections	Jiang, Y. J; Tayabji, S. D; Wu, C. L.
1998	Mechanistic Evaluation of Test Data from Long-Term Pavement Performance Jointed Plain Concrete Pavement Test Sections	Jiang, Y. J; Tayabji, S. D.
1998	Mechanistic Evaluation of Test Data from LTPP Flexible Pavement Test Sections, Volume II: Final	Ali, H. A; Tayabji, S. D.

	Report – Appendices	
1998	Roughness Prediction Model Based on the Artificial Neural Network Approach	La Torre, F; Domenichini, L; Darter, M.
1998	Roughness Trends of Flexible Pavements	
1998	Supplement to the AASHTO Guide for Design of Pavement Structures, Part II - Rigid Pavement Design & Rigid Pavement Joint Design	
1998	Transverse Cracking Distress in Long-Term Pavement Performance Jointed Concrete Pavement Sections	Moody, E. D.
1997	Advanced Methods for Using FWD Deflection-Time Data to Predict Pavement Performance	
1997	Design Pamphlet for the Backcalculation of Pavement Layer Moduli in Support of the 1993 AASHTO Guide for the Design of Pavement Structures	Von Quintus, H; Killingsworth, B.
1997	Development of Performance Prediction Models for Dry-No-Freeze and Dry-Freeze Zones using LTPP Data	Senn, K; Frith, D; Yapp, M. T; Scofield, L.
1997	Evaluation of Long-Term Pavement Performance Data Using HDM-III Probabilistic Failure-Time Models for Crack Initiation in Bituminous Pavements	Van Dam, T. J; Chesher, A. D; Peshkin, D. G.
1996	Data Analysis Procedures for Long-Term Pavement Performance Prediction	Kerali, H. R; Lawrence, A. J; Awad, K. R.
1996	Prediction of Pavement Remaining Life	Vepa, T. S; George, K. P; Shekharan, A. R.
1994	Mechanistic Predictions of the Performance of Pavements in the SHRP LTPP Program	Lytton, R. L.
1994	Prediction of AC Mat Temperatures for Routine Load/Deflection Measurements	Stubstad, R. N., et al
1994	Using Pavement Performance Data to Develop Mechanistic-Empirical Concepts for Deteriorated and Rehabilitated Pavements. Final Report.	Rao, J. S., et al
1993	SHRP Procedure for Temperature Correction for Maximum Deflections	
1991	Improving Concrete Pavements through SHRP Research	Hanna, A. N; Jawed, I.
1991	Laboratory and Field Evaluations and Correlations of Properties of Pavement Components	Allen, D. L; Graves, R. C; Fleckenstein, L. J.
1990	Impact of Digital Filtering on FWD Load Cell and Deflection Sensor Responses	Rada, G. R., et al

1989	SHRP Plans for Nondestructive Deflection Testing in the Development of Pavement Performance Prediction Models	Ritcher, C. A; Rauhut, J. B.

Title: Expected Service Life of Hot-Mix Asphalt Pavements in Long-Term Pavement Performance Program

Author(s): Von Quintus, Harold L; Mallela, Jagannath; Jiang, Jane; Buncher, Mark

Date: 2007

Publisher: Transportation Research Record: Journal of the Transportation Research Board No. 1990; Transportation Research Board

Abstract/Synopsis:
One of the objectives for the Long-Term Pavement Performance (LTPP) program is to develop improved design methodologies for pavements. To achieve that objective, hundreds of hot-mix asphalt (HMA) test sections have been established and are being monitored to determine the performance characteristics of HMA pavements. The data from this program can be used to validate improved design methodologies and to establish the service life of HMA pavements. Specific findings are summarized from a study sponsored by the Asphalt Pavement Alliance to determine the expected service life of HMA or flexible pavements included in LTPP by using survivability analyses.

Application/Use: The results from this program are applicable to pavement researchers and engineers developing improved design methodologies for HMA pavements.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: As the LTPP program monitors a wide array of pavement sections, a better understanding of the expected service life of HMA pavements can be achieved, giving pavement managers a valuable resource in predicting the service life of HMA pavements in their network with similar conditions. The LTPP program is the foundation for these discoveries.

Future Benefit: As pavement managers are better equipped to evaluate and predict the conditions of the pavements in their network, they can be more strategic in allocating funds to meet those needs and for designing newly constructed pavements with better service lives. The monitored pavement sections in the LTPP program will continue to be an invaluable resource in this regard.

Title: Development of a Probabilistic Joint Opening Model Using LTPP Data

Author(s): Lee, Seung Woo; Jeong, Jin-Hoon; Chon, Beom-Jun

Date: 2007

Publisher: Transportation Research Board 86th Annual Meeting, Transportation Research Board

Abstract/Synopsis:
Joint opening of concrete pavement is caused by changes in the temperature and humidity of concrete slabs. The joint opening influences load transfer efficiency (LTE) between two adjacent slabs and performance of sealants of the joint. The joint opening has been commonly predicted by the AASHTO joint opening model in the design of concrete pavement. The magnitude of joint openings is variously distributed in a given pavement section and the AASHTO model theoretically predicts the average joint opening of a section. As the result, the AASHTO model inevitably underestimates a considerable portion of the joint opening. Joint sealants are designed based on the predicted joint openings. Thus, joints that show larger openings than the predicted size may experience faulting at an early age of the concrete pavement owing to loss of the LTE due to pumping of base materials through the failed joint sealants. In addition, unexpected spalling may develop because of intrusion of incompressible materials into the joints through the torn sealants. Intruded incompressible materials induce compressive stress at the joints when the concrete slabs expand and the joints are closed because of temperature rise. In this study, factors influencing the variations in the joint openings of concrete pavements were investigated using data of the LTPP SMP sections. A probabilistic joint opening model using the upper bound of the 90% confidence interval of the joint opening was developed in order to mitigate underestimation of the joint opening. The newly developed joint opening model was validated using a series of data pertaining to joint movement measured at the Korea Highway Corporation (KHC) test road.

Application/Use: The results from this study are applicable to pavement managers and researchers interested in joint opening on PCCP.

Contribution: Cost Savings; Improvement in Knowledge; Implementation/Usage

Present Benefit: The ability to accurately predict joint openings in pavements is a valuable tool for pavement managers and rehabilitators. Improving existing prediction methods is important in order to more accurately plan for the ultimate pavement performance. Data from the LTPP program was instrumental in developing this prediction model.

Future Benefit: As pavement design continues to shift toward a mechanistic-empirical method, the development of more accurate prediction models based on field data will become more important. A significant cost savings can be obtained by agencies implementing the more more-accurate prediction models in their pavement designs and maintenance programs. The LTPP program will continue to be an essential resource for developing more accurate prediction models, equipping pavement engineers with the necessary tools to cost-effectively designing higher performing pavements.

Title: Consideration of Finite Slab Size in Backcalculation Analysis of Jointed Concrete Pavements

Author(s): Setiadji, Bagus Hario; Fwa, T.F.

Date: 2007

Publisher: Transportation Research Record: Journal of the Transportation Research Board No. 2005, Transportation Research Board

Abstract/Synopsis:
The effects of finite slab size and load transfer across joints usually are ignored in the backcalculation analysis of jointed concrete pavements when the test load is applied on an interior point of the slab concerned. Although correction factors have been proposed to take these effects into consideration, the benefits of doing so have yet to be established, and their use has not been accepted in routine backcalculation tests. A study was conducted to assess whether significant improvements in the accuracy of backcalculation analysis could be achieved by considering finite slab size and load transfer at joints in the backcalculation analysis of jointed concrete pavement systems. Five backcalculation methods were evaluated with measured deflection data extracted from the Long-Term Pavement Performance database, and comparisons were made with the measured pavement properties. The analysis based on the measured field data offered affirmative evidence of the theoretical lower- and upper-bound estimates provided by backcalculation solutions based on the infinite slab model and one-slab model, respectively. An error analysis was presented to show that the infinite slab model gave superior solutions as compared with the one-slab model. A nine-slab model that considered finite slab size and joint load transfer effects resulted in only marginal improvements in the backcalculation results. Two finite slab size models that applied correction factors to infinite-slab solutions were found to produce the largest errors among the five backcalculation models studied.

Application/Use: The results from this paper are applicable to pavement engineers interested in the effectiveness of existing backcalculation analysis methods for jointed concrete pavements.

Contribution: Improvement in Knowledge; Lessons Learned

Present Benefit: The ability to accurately analyze jointed pavement concretes using backcalculation methods is an important tool for pavement engineers to better evaluate their pavement conditions. This study evaluated a number of existing backcalculation analysis methods and exposed their effectiveness using data collected from the LTPP program.

Future Benefit: As existing backcalculation analysis methods are evaluated and refined, pavement engineers will be better equipped in making strategic decisions to maintain and improve their pavement network. The LTPP database will continue to be a valuable source to evaluate the effectiveness of existing backcalculation methods and to validate alternative methods.

Title: Evaluation of New Mechanistic–Empirical Pavement Design Guide Rutting Models for Multiple-Axle Loads

Author(s): Salama, Hassan Kamal; Haider, Syed Waqar; Chatti, Karim

Date: 2007

Publisher: Transportation Research Record: Journal of the Transportation Research Board No. 2005, Transportation Research Board

Abstract/Synopsis:
The new FHWA Mechanistic–Empirical Pavement Design Guide (M-E PDG) does away with the AASHO-derived concept of the equivalent single-axle load and calculates damage caused by various axle configurations directly. Because multiple axles represent about half the axle configurations that the pavement will experience, there is a need to evaluate the M-E PDG procedure for predicting rutting due to multiple-axle configurations. Axle factors (AFs) based on rutting were calculated for different axle configurations by using three procedures: the M-E PDG, accounting for the effect of each individual axle within a group, and integrating the entire strain pulse. The AFs from these procedures were compared with laboratory-derived values for asphalt concrete. Also, layer rutting contributions were predicted for six in-service SPS-1 experiment sections from the Long-Term Pavement Performance Program with the M-E PDG software and were compared with the analysis of their transverse surface profiles. The results show that the M-E PDG procedure underestimates rutting prediction due to multiple axles. Calibration of the M-E PDG rut models with field data seems to improve their prediction, although it is still lower than expected for multiple axles. The best method for calculating rut depths under multiple axles appears to be integration of the entire strain pulse. This method shows that rutting damage is proportional to the number of axles within an axle group. This theory was confirmed in the laboratory for asphalt concrete. Also, although the M-E PDG rut models are superior to previous rut models, in that they are able to dissect the total surface rutting between all pavement layers, their prediction of the individual layer rutting contributions does not always agree with results from the analysis of measured transverse profiles.

Application/Use: The results from this paper are applicable to pavement managers and maintenance/rehabilitation engineers considering rutting in pavements.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The ability to accurately predict pavement rutting in pavements is an valuable tool for pavement managers and maintenance engineers. This project evaluated the effectiveness of existing methods and investigated ways to improve those methods. The LTPP database was used to test the effectiveness of the existing methods as well as to validate improved rutting prediction methods.

Future Benefit: As pavement engineers are able to better predict rutting and other distresses in their pavements, a considerable cost savings can be achieved improving the overall health of their pavement network. As these prediction methods are discovered and refined, pavement engineers will be more effective in planning for their pavement needs and in allocating limited funds strategically in order to achieve the maximum impact on their pavement networks. The LTPP database will continue to be a significant tool in evaluating existing prediction methods and validating new methods.

Title: Use of Genetic Algorithm and Finite Element Method for Backcalculating Layer Moduli in Asphalt Pavements

Author(s): Park, Hee Mun; Park, Seong-Wan; Hwang, Jung-Joon

Date: 2007

Publisher: Transportation Research Board 86th Annual Meeting

Abstract/Synopsis:
The backcalculation program (GAPAVE) using genetic algorithm (GA) and finite element method (FEM) is developed to predict the layer moduli from the falling weight deflectometer (FWD) deflections. A number of backcalculation programs are available for estimating pavement layer moduli from surface deflections. However, they are mostly based on the layered elastic theory in calculating the surface deflections and pavement responses. The use of FEM in the forward calculation incorporating with GA enables to improve the accuracy in backcalculating the pavement layer moduli. The optimum GA parameters were selected from the sensitivity analysis for six different pavement structures. A comparison study with the MODULUS program and other GA parameters was conducted to check the prediction accuracy of GAPAVE program. It is found that the use of optimum GA parameters suggested by author can improve the prediction quality in backcalculating the pavement layer moduli. FWD deflection data and resilient modulus test data for 24 pavement sections obtained from Long-Term Pavement Performance database were used to evaluate the performance of the developed backcalculation program. Backcalculated layer moduli for AC layer and subgrade were compared with the resilient moduli obtained from the laboratory testing. The validation results indicate that the GAPAVE can accurately estimate the actual stiffness characteristics of the pavement materials.

Application/Use: The results from this study are applicable to pavement managers and maintenance/rehabilitation engineers.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The FWD test is highly advantageous for pavement engineers because of its non-destructive nature and the ability to back-calculate pavement properties. Therefore, the ability to refine the backcalculation methods and obtain a more accurate result is a valuable tool for pavement engineers. The LTPP database was used to evaluate the effectiveness of the backcalculation method presented in this report.

Future Benefit: As pavement engineers are able to more accurately assess the conditions of their pavements, they will be able to better focus their resources toward the most effective strategies to address those needs. The LTPP program will continue to be a valuable resource to assist pavement engineers in obtaining a better understanding of pavement performance and to make further advancements in the pavement industry.

Title: Reliability-Based Approach for Using LTPP and APT Test Results for Estimating Fatigue Performance

Author(s): Prozzi, Jorgé A; Guo, Runhua

Date: 2007

Publisher: Transportation Research Board 86th Annual Meeting

Abstract/Synopsis:
Pavement performance prediction in terms of fatigue cracking and surface rutting are at the core of any mechanistically-based pavement design method. In particular, the estimation of the expected fatigue field performance of a flexible pavement section is based on the estimation of the maximum tensile strain at the bottom of the asphalt layers and its correlation to the performance of the same mix in the laboratory under bending beam test. This laboratory-based estimation is calibrated to better predict actual field performance by means of "shift factors". Although several studies have been conducted to address the main variables affecting shift factors, none of them have been comprehensive and often are limited to assessing the effect of one variable at a time. The objective of this paper is to propose a reliability-based approach to develop a comprehensive methodology that can address the effects of the most significant variables on shift factors to calibrate accelerated pavement test (APT) performance to better match field performance as captured by the Long-Term Pavement Performance. The proposed methodology addresses what are currently considered the most important factors but recognizes that other important factors could have been neglected. The method, however, can be readily modified to incorporate any new variables as they are identified and quantified.

Application/Use: The results from this paper are applicable to material testing engineers interested in improving the accuracy of the accelerated pavement tests.

Contribution: Improvement in Knowledge

Present Benefit: The ability to accurately relate laboratory tests to field performance is important in being able to understand and predict pavement performance under various conditions. This paper is beneficial to pavement material testing engineers in being able to improve the accuracy of the laboratory tests and relate those results to observations in the field by using the LTPP database.

Present Benefit: As laboratory test methods are refined, pavement engineers will be able to recreate field conditions in controlled environments and improve the accuracy of the test results. The LTPP database will continue to be a significant resource to calibrate laboratory tests with field observations in order to be able to further understand pavement behavior through tests in controlled environments.

Title: Development of Fatigue Cracking Performance Prediction Models for Flexible Pavements Using LTPP Database

Author(s): Ker, Hsiang-Wei; Lee, Ying-Haur; Wu, Pei-Hwa

Date: 2007

Publisher: Transportation Research Board 86th Annual Meeting

Abstract/Synopsis:
The main objective of this study is to develop improved fatigue cracking models for flexible pavements using the Long-Term Pavement Performance (LTPP) database. The retrieval, preparation, and cleaning of the database were carefully handled in a more systematic and automatic approach. The prediction accuracy of the existing prediction models implemented in the improved 2002 AASHTO guide was found to be inadequate. Exploratory data analysis indicated that the normality assumption with random errors and constant variance using conventional regression techniques might not be appropriate for this study. Therefore, several modern regression techniques including generalized linear model (GLM) and generalized additive model (GAM) along with the assumption of Poisson distribution and quasi-likelihood estimation method were adopted for the modeling process. The resulting mechanistic-empirical model included several variables such as yearly KESALs, pavement age, annual precipitation, annual temperature, critical tensile strain under the AC surface layer, and freeze-thaw cycle for the prediction of fatigue cracking. The goodness of the model fit was further examined through the significant testing and various sensitivity analyses of pertinent explanatory parameters. The tentatively proposed predictive models appeared to reasonably agree with the pavement performance data although their further enhancements are possible and recommended.

Application/Use: The results from this paper are applicable to pavement engineers and rehabilitation specialists.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The ability to accurately predict fatigue cracking of pavements is of great benefit, enabling pavement managers to be more strategic in planning for maintenance and rehabilitation projects throughout their pavement network. The end result is achieving higher performing pavements in more cost-effective ways. The LTPP database was a critical instrument in the development of these models to predict fatigue cracking in pavements.

Future Benefit: As these models are used more widely, there is a significant cost savings to be gained. The LTPP program has been instrumental in bringing advancements to the pavement industry, and will continue to be an invaluable resource to gaining a better understanding of pavement behavior and for developing cost-effective strategies to improve pavement performance.

Title: Performance and Economic Benefits of Thick Granular Base for Flexible Pavement Design in Ohio

Author(s): Yu, Xiong; Beck, Randall

Date: June 2009

Publisher: Case Western Reserve University; Ohio Department of Transportation; Federal Highway Administration

Abstract/Synopsis:
This project investigates the feasibility of using thick granular base for flexible pavement design in Ohio. The criteria considered include the performance criteria and life cycle economic analyses. The performance of different types of base layer design are compared using the Long Term Pavement Performance (LTPP) database. The focus is on the ability of achieving uniform dynamic deflections using Falling Weight Deflectometer (FWD) data. Based on FWD records from the LTPP database, the relative merits of different base type design are compared. The pavement performance is predicted using the "Mechanistic-Empirical Pavement Design Guide" (MEPDG) design software. A sensitivity study is conducted on the effects of granular base layer parameters on pavement performance. From the relative improvement in terms of pavement distress reduction, an optimal base layer thickness of 12 in. to 15 in. is identified. The use of thicker granular base (from the current 4 in. to 6 in. granular base currently used in Ohio to 12 in. thick granular base) is predicted to increase the pavement service life for around 30% using the criteria for common types of distresses. Life cycle analyses are conducted using a simplified model. The model indicates that for the typical Ohio flexible pavement sections, doubling the thickness of base layer, while causing higher initial construction cost, will result in life cycle cost savings. Thus performance predictions using the MEPDG and life cycle economic analyses support positively the use of granular base in flexible pavement design in Ohio. It is also found in this study that the climate model of the existing MEPDG design software does not adequately account for the regional climate conditions (such as freeze-thaw effects) effect on pavement performance. It is recommended to conduct further analyses of field performance data to validate the MEPDG model predictions. Finally, recommendations are provided on the specifications for screening the supply sources of granular materials for granular base construction.

Information Documentation page has the title as “Investigation of the Performance and Economic Benefits of Thick Granular Base for Flexible Pavement Design in Ohio.”

Application/Use: This study is directly applicable to pavement management, design, and rehabilitation.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The LTPP database has provided a means to determine the effect of different base materials on the performance and life-cycle of pavements. This information can better serve pavement designers and pavement managers on pavements in a cost-effective manner.

Future Benefit: The LTPP database will continue to provide the foundation for further studies on pavement performance and lead to greater improvements in the way pavements are designed, constructed, and maintained.

Title: Development of Permanent Deformation Model of Asphalt Mixtures for Korean Pavement Design Guide

Author(s): Le, Anh Thang; Lee, Hyun Jong; Park, Hee Mun; Lee, Sang Yum

Date: 2009

Publisher: Transportation Research Board 88th Annual Meeting

Abstract/Synopsis:
The Korean Pavement Design Guide (KPDG) has been developed based on the mechanistic-empirical principle. This paper presents the permanent deformation model of asphalt mixtures in the KPDG. The permanent deformation model has been developed for various types of asphalt mixtures using the triaxial repeated loading test. This model has been calibrated with Accelerated Pavement Test (APT) and Long Term Pavement Performance (LTPP) database. Through triaxial repeated loading tests, the permanent deformation model of asphalt mixtures has been developed to address the effect of temperature and initial air voids. The model coefficients for the temperature and air void obtained from the triaxial tests do not need to be calibrated. However, the model coefficients for the shift factor and number of load repetition should be calibrated with APT data. It is found from this study that the model requires a correction factor to consider the effects of total asphalt concrete (AC) layer thicknesses. The correction factor is useful to simulate the distribution of real vertical plastic strain for different AC layer thicknesses. A shift factor has been found by comparing the measured rut depth from the LTPP sections and predicted values from the KPDG program. It is observed from a verification study that the final permanent deformation model developed in this study can predict the field rut depth of various AC pavements quite accurately.

Application/Use: The results of this paper are directly applicable to pavement designers using the KPDG. However, these results are also applicable to pavement designers, in general, with the desire to know more about the factors affecting permanent deformations in pavements.

Contribution: Improvement in Knowledge; Implementation/Usage

Present Benefit: A better understanding of the factors affecting permanent deformation in pavements and the ability to predict this deformation are valuable assets for pavement designers and rehabilitation specialists. The LTPP database provided a means of calibrating the prediction model developed in this research project and a way to test the accuracy of these results based on LTPP field data.

Future Benefit: The LTPP database will continue to provide the foundation for further studies on pavement performance and the critical factors affecting pavements. The LTPP database is an invaluable resource that will continue to lead toward greater improvements in the way pavements are designed, constructed, and maintained.

Title: Development of Robust Approach for Evaluation of Airport Pavement Bearing Capacity

Author(s): Lee, Ying-Haur; Liu, Yao-Bin; Lin, Jyh-Dong; Ker, Hsiang-Wei

Date: 2009

Publisher: Transportation Research Board 88th Annual Meeting

Abstract/Synopsis:
The Aircraft Classification Number/Pavement Classification Number (ACN/PCN) method has been adopted by the International Civil Aviation Organization (ICAO) as the standard for reporting airfield pavement bearing strength. Although it has been clearly recommended that the engineer should simultaneously consider the mean and standard deviation in the selection of an evaluation or design input value, many evaluation and design procedures currently only use the mean value in the analysis (AC 150/5370-11A). This study will first illustrate its definitions, possible applications, and potential problems in arriving at a consistent and repeatable value based on the results of nondestructive testing. A goodness study of the existing backcalculation results using the Long-Term Pavement Performance (LTPP) database was conducted. For a more conservative evaluation and design approach, the mean value minus one standard deviation (or the so-called 85% confidence level) may be used for obtaining evaluation or design inputs in general (AC 150/5320-6D). Nevertheless, it was found that this proposed procedure is not based on sound statistical principles especially when its probability distribution function of the population is almost always unknown. In engineering practice, a subset of the population or a random sample is often collected to represent the population characteristics of interest. Consequently, the concepts of random sampling, central limit theorem, and confidence intervals for hypothesis testing were adopted. It was proposed that a single representative design input for the entire runway pavement be determined by the lower limit of 95% confidence level (1-tail) to derive a more consistent and repeatable PCN value. A case study was conducted to illustrate the potential problems of the existing ACN/PCN procedures and the benefits of the proposed revisions.

Application/Use: This study is directly applicable to pavement engineers specializing in airport runways.

Contribution: Improvement in Knowledge

Present Benefit: The ability to evaluate the bearing capacity of airport pavements is an important aspect of the pavement design and overall performance. Thus, the ability to improve upon existing ACN/PCN procedures is of great benefit to airport pavement designers. The LTPP database was an invaluable asset in this study, as it provided a large amount of data that could be analyzed with existing methods to determine the quality of the backcalculation data and expose the issues with the current ACN/PCN procedures and the benefits of potential revisions.

Future Benefit: The LTPP database will continue to be a source of information for researchers and engineers in pavement design and maintenance. As the LTPP program continues, it will further the advancement of the way pavements are designed, built, and maintained.

Title: Sensitivity Analysis of the MEPDG Using Measured Probability Distributions of Pavement Layer Thickness

Author(s): Aguiar-Moya, Jose Pablo; Banerjee, Ambarish; Prozzi, Jorge A.

Date: 2009

Publisher: Transportation Research Board 88th Annual Meeting

Abstract/Synopsis:
It is widely accepted that a change in thickness on one of the pavement layers, primarily the surface layer, has a considerable impact on the performance that the pavement will exhibit. It is therefore important to characterize the variability of pavement layer thickness so that the performance of a pavement structure not only considers the mean/target design thickness, but also accounts for the effect of spatial thickness variation. This study focuses on Long Term Pavement Performance (LTPP) SPS-1 sections located in the State of Texas for the purpose of determining the thickness distribution associated with the HMA surface layer, the HMA binder course, and the granular base layer, by means of GPR data. Results from previous research and visual analysis indicate that pavement layers are normally distributed. Therefore, tests for determining normal goodness-of-fit were used in assessing the hypothesis that the thickness data for each individual analyzed layer can come from a normal distribution. The results indicate that 86.1% of the analyzed pavement layers have normally distributed thicknesses. An analysis of the thickness changes that occur within a given section as measured along the lane centerline and under the right wheel-path was also performed. Finally, based on the coefficient of variation identified for the HMA surface and granular base layers, a sensitivity analysis was performed using the Mechanistic-Empirical Pavement Design Guide (M-E PDG). The results show a considerable change in distress, mainly fatigue cracking, as the layer thicknesses change within a range of +/- 3 standard deviations from the mean thickness.

Application/Use: The ability to quantify the effect of pavement layer thicknesses on the overall pavement performance is directly applicable for pavement design engineers.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: A better understanding of the relationship between pavement layer thicknesses and pavement performance is of great benefit to pavement designers. The results from this study can be used to assist pavement designers perform cost-effective designs to achieve the optimal pavement performance. This study was heavily dependent upon the LTPP database, which was used to generate the probability distributions for this study.

Future Benefit: The LTPP database is an invaluable resource that will continue to be the foundation of many pavement studies, leading to advancements in the pavement industry and enabling pavement specialists to design cost-effective solutions and higher performance pavements.

Title: Local Calibration of Mechanistic–Empirical Pavement Design Guide for Flexible Pavement Design

Author(s): Muthadi, Naresh R; Kim, Youngsoo Richard

Date: 2008

Publisher: Transportation Research Board

Abstract/Synopsis:
This paper presents the calibration of the Mechanistic–Empirical Pavement Design Guide (MEPDG) for flexible pavements located in North Carolina. Two distress models, permanent deformation and bottom-up fatigue cracking, were used for this effort. A total of 53 pavement sections were selected from the Long-Term Pavement Performance (LTPP) program and the North Carolina Department of Transportation databases for the calibration and validation process. The verification runs for the LTPP sections performed with the parameters developed during the national calibration effort under NCHRP Project 1-37A showed promising results. The Microsoft Excel Solver program was used to fit the predicted rut depth values to the measured values by changing the coefficients in the permanent deformation models for hot-mix asphalt (HMA) and unbound materials. In this process, the sum of the squared errors was minimized for each of the permanent deformation models separately. For the alligator cracking model, the only possibility of reducing the standard error and bias was through the transfer function. Again, the Microsoft Excel Solver program was used to minimize the sum of the squared errors of the measured and the predicted cracking by varying the C1 and C2 parameters of the transfer function. The standard error for the HMA permanent deformation model, as well as that for the alligator cracking model, was found to be significantly less than the global standard error after the calibration. It was decided that both models would be kept for a more robust calibration in the future that would increase the number of sections and include more detailed inputs (mostly Level 1 inputs).

Application/Use: The results in this paper are directly applicable to pavement managers in North Carolina. However, these results can also be useful to other state agencies interested in calibrating the MEPDG to their site conditions.

Contribution: Cost Savings; Improvement in Knowledge; Implementation/Usage

Present Benefit: The ability to more accurately predict the permanent pavement deformation and bottom-up fatigue cracking is a valuable tool for pavement managers and pavement engineers. With this information, pavement engineers will be able to better assess the pavement needs and be more effective in allocating the available funds to meet those needs. The data collected through the LTPP program was used to calibrate these models.

Future Benefit: The LTPP database is an invaluable resource for pavement researchers and pavement engineers. This data collected through the LTPP program will continue to aid in furthering the understanding of pavement behavior and developing more accurate models to predict this behavior. As more accurate pavement prediction models are developed and utilized, a significant cost savings can be achieved and higher performing pavements can be designed.

Title: Calibration of “Mechanistic–Empirical Pavement Design Guide” Permanent Deformation Models: Texas Experience with Long-Term Pavement Performance

Author(s): Banerjee, Ambarish; Aguiar-Moya, Jose Pablo; Prozzi, Jorge A.

Date: 2009

Publisher: Transportation Research Record: Journal of the Transportation Research Board No. 2094

Abstract/Synopsis:
The performance models in the “Mechanistic–Empirical Pavement Design Guide” (MEPDG), developed under NCHRP 1-37A and 1-40D, are calibrated with sections throughout the United States. Hence, it is necessary to calibrate these models for specific states and regional conditions because of the differences in materials, environmental conditions, and construction practices. In general, a pavement design based on the nationally calibrated MEPDG will result in either an overestimate or underestimate of the pavement layer thicknesses because of systematic errors arising from local differences. This deficiency calls for local calibration of the performance models in the MEPDG so that they can be used to design pavements at a regional level. The calibration procedure described in this paper concentrates on finding two bias correction factors for the asphalt concrete (AC) permanent deformation performance model after values derived from expert knowledge have been assumed for the subgrade permanent deformation calibration factors. Pavement data from the Texas Specific Pavement Study (SPS)-1 and SPS-3 experiments of the Long-Term Pavement Performance database were used to run the MEPDG and calibrate the guide to Texas conditions. The regional calibration factors were obtained by minimizing the sum of squared errors between the observed and predicted surface permanent deformation. In this case, a simultaneous joint optimization routine was applied because it was theoretically sound. Finally, an average of the regional calibration coefficients for AC and subgrade permanent deformation was computed to obtain the set of state-default calibration coefficients for Texas.

Application/Use: The ability to more accurately predict pavement deformation based on regional conditions is directly applicable for state agency and highway pavement designers and rehabilitation specialists.

Contribution: Cost Savings; Improvement in Knowledge; Implementation/Usage

Present Benefit: The consideration of regional factors affecting the MEPDG pavement deformation model and the ability to calibrate that model to achieve more accurate results is of great benefit and can result in significant cost savings on local, state and federal levels. The LTPP database was not only used to help generate the MEPDG probability models, but also, in this study, to better calibrate those models based on regional conditions.

Future Benefit: The long term performance data collected at SPS projects will allow life-cycle cost analyses to be conducted on the various designs and can be used to optimize resources. Additionally, the local

Title: Development of Fatigue Cracking Prediction Models Using Long-Term Pavement Performance Database

Author(s): Ker, Hsiang-Wei; Lee, Ying-Haur; Wu, Pei-Hwa

Date: November 2008

Publisher: Journal of Transportation Engineering Vol. 134 No. 11

Abstract/Synopsis:
This study strives to develop improved fatigue cracking models using the long-term pavement performance database. The prediction accuracy of the existing models was found to be inadequate. Several modern regression techniques including generalized linear model and generalized additive model along with the assumption of Poisson distribution and quasi-likelihood estimation method were adopted for the modeling process. After many trials in eliminating insignificant and inappropriate parameters, the resulting model included several variables such as yearly KESALs, pavement age, annual precipitation, annual temperature, critical tensile strain under the asphalt-concrete surface layer, and freeze-thaw cycle for the prediction of fatigue cracking. The proposed model appeared to have substantial improvements over the existing models although their further enhancements are possible and recommended.

Application/Use: The results from this paper are applicable to agency pavement engineers and rehabilitation specialists.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: The ability to accurately predict fatigue cracking of pavements is of great benefit, enabling pavement managers to be more strategic in planning for maintenance and rehabilitation projects throughout their pavement network. The end result is achieving higher performing pavements in more cost-effective ways. The LTPP database was a critical instrument in the development of these models to predict fatigue cracking in pavements.

Future Benefit: As these models are used more widely by agencies, there is a significant cost savings to be gained. The LTPP program has been instrumental in bringing advancements to the pavement industry, and will continue to be an invaluable resource to gaining a better understanding of pavement behavior and for developing cost-effective strategies to improve pavement performance.

Title: Use of Texas LTPP Database to Support Validation and Calibration of MEPDG

Author(s): Aguiar-Moya, Jose Pablo; Hong, Feng; Prozzi, Jorge A.

Date: 2008

Publisher: Transportation Research Board 87th Annual Meeting

Abstract/Synopsis:
Currently, newer pavement design methodologies are being developed and implemented. They are based on mechanistic-empirical (M-E) principles where pavement responses are determined mechanistically from material, traffic, and environmental properties that are later correlated through statistical models to in place performance of the pavement structures. However, this process is complex and data intensive and generally requires a vast amount of information, not only to be used, but more importantly to be calibrated to specific conditions or regions so that the designs or performance estimations are accurate. After reviewing existing pavement management databases currently in use by the Texas Department of Transportation (TxDOT), it is clear that most of the current databases serve well for network level applications, but do not contain required information and cannot be directly applied to data-intensive project-specific applications such as mechanistic pavement design. Consequently, this paper focuses on the development of the Texas Flexible Pavement Database, the main purpose of which is to aid in pavement design through the development of new and calibration of existing M-E design models. The paper presents a brief introduction to the different modules included in the database: structure and materials, traffic, environment, and performance. It shows how the users can interact with the database and the different modules through a simple, yet objective user interface, and it provides a general idea of what is included in each of the different modules and how they meet current M-E design requirements.

Application/Use: The findings from this study can be used in pavement applications.

Contribution: Cost Savings; Improvement in Knowledge; Implementation/Usage

Present Benefit: As pavement design continues to move toward a mechanistic-empirical approach, the need to calibrate and refine these methods for more accurate results is critical. With more accurate models, pavement designers and rehabilitation specialists will be able to more effectively assess the needs of the pavements and determine the most cost-effective solution to meet those needs. The LTPP database was a vital tool in developing this calibration method.

Future Benefit: A significant cost benefit can be achieved as numerous state agencies begin integrating MEPDG calibration into their pavement approaches. This method assists pavement designers in considering the effect of the site conditions on the overall pavement performance. The LTPP database has been an invaluable resource for pavement researchers and engineers and will continue to further the pavement industry and lead to cost-effective solutions for higher performance pavements.

Title: Prediction Models for Transverse Cracking of Jointed Concrete Pavements: Development with Long-Term Pavement Performance Database

Author(s): Ker, Hsiang-Wei; Lee, Ying-Haur; Lin, Chia-Huei

Date: 2008

Publisher: Transportation Research Board

Abstract/Synopsis:
The main objective of this study was to develop improved prediction models for transverse cracking of jointed concrete pavements with the Long-Term Pavement Performance database. The retrieval, preparation, and cleaning of the database were carefully handled with a systematic and automatic approach. The prediction accuracy of the existing prediction models implemented in the recommended Mechanistic–Empirical Pavement Design Guide (NCHRP Project 1-37A) was found to be inadequate. Exploratory data analysis indicated that the normality assumption with random errors and constant variance by using conventional regression techniques might not be appropriate for this study. Therefore, several modern regression techniques, including the generalized linear model and the generalized additive model, along with the assumption of Poisson distribution, were adopted for the modeling process. The resulting mechanistic–empirical model included several variables—such as pavement age, yearly equivalent single-axle loads (ESALs), accumulated ESALs, annual precipitation, freeze–thaw cycle, annual temperature range, stress ratio, and percent steel—for the prediction of transverse cracking. The goodness of fit was further examined through significant testing and various sensitivity analyses of pertinent explanatory parameters. The tentatively proposed predictive models appeared to agree reasonably with the pavement performance data, although their further enhancements are possible and recommended.

Application/Use: This paper is applicable to performance prediction and pavement design.

Contribution: Improvement in Knowledge

Present Benefit: The LTPP database has provided sufficient data to support an evaluation on cracking mechanisms in rigid pavements. This information is useful in performance modeling. The relationship between cracking performance and various pavement features will also be useful in selecting between design alternatives.

Future Benefit: This study will continue to add benefit as pavement design moves from an empirical to a mechanistic-empirical design method. The LTPP database will continue to be an invaluable tool for researchers and pavement engineers and will lead to further advancements in the pavement industry.

Title: Lessons Learned During Implementation of Mechanistic-Empirical Pavement Design Guide

Author(s): Mehta, Yusuf A; Sauber, Robert W; Owad, Jeffrey; Krause, Jared

Date: 2008

Publisher: Transportation Research Board

Abstract/Synopsis:
The purpose of this paper is to present the lessons learned during implementation of the Mechanistic-Empirical Pavement Design Guide (MEPDG) and to provide a detailed framework on how to validate the design guide using level 3 inputs. The performance models in the MEPDG were calibrated using Long Term Pavement Performance (LTPP) data from highway sections all over the United States. Therefore, the design guide with level 3 inputs must be validated for soil, environmental and traffic conditions typically observed in a specific region. In this study, accurate input and performance data from seven LTPP sections in the state of New Jersey were obtained. To ensure accurate data were used in the design guide, the data were collected from multiple sources, such as the as-built plans and NJDOT databases. A case-by-case comparison was conducted between predicted and measured performance data for every section and each distress, such as rutting, fatigue cracking, longitudinal cracking, transverse, cracking and roughness. The analysis determined the conditions where the level 3 inputs may not be appropriate. This step is critical before any state agency starts implementing the design guide. This paper provides the state agency with the tools and the knowledge needed to successfully implement the design guide. The framework will also serve as practical guide to state agencies and research institutions as the pavement community begins to adopt the new design guide.

Application/Use: The results from this paper are useful for pavement managers and rehabilitation engineers who want a better understanding of the applications and limitations of the MEPDG.

Contribution: Cost Savings; Lessons Learned

Present Benefit: As pavement design moves toward a mechanistic-empirical design method, it is important to understand the applications and limitations of the MEPDG so that pavement managers can achieve the most strategically effective design with limited resources. The LTPP database was a significant resource that was used to develop the MEPDG and in the analysis performed in this paper.

Future Benefit: The LTPP database is an invaluable resource that has been used to develop the statistical models used in the MEPDG and will continue to bring lasting benefits to the pavement industry. The data collected through the LTPP program will continue to be used, in conjunction with other sources, to validate existing and proposed pavement design methods and to reveal their applications and limitations so that pavement managers will be better equipped to achieve higher performing pavements in cost-effectively.

Title: International Roughness Index Model Enhancement for Flexible Pavement Design Using LTPP Data

Author(s): Zhou, Guoqing; Wang, Linbing; Lu, Yang

Date: 2008

Publisher: Transportation Research Board

Abstract/Synopsis:
Many researchers have developed different forms of the IRI model to measure the smoothness. Regardless of which forms, the major factors to contribute the IRI model can be roughly divided into two categories: variables related to distress, and variables related to non-distress. This paper investigates how the variables impact the pavement smoothness by using Long-Term Pavement Performance (LTPP) program data. The main contributions of this paper are (1) comprehensively analyzes the smoothness models in order to identify the independent factors of IRI model, (2) present the application of data snooping method to detect and remove the outlier involved in the LTPP database, (3) evaluate the three models that describe the relationship between the pavement age and the IRI values using the 10 test sections of the LTPP program database, and then recommend best one, (4) evaluate the effect of the different elements of site factors and climate condition to IRI model, and suggest the choice of appropriate site factor and climate variables, (5) suggest the data combination and data interpolation on the basis of the LTPP data set, and (6) establish the prediction of IRI model using linear regression model. The results of the regression analyses have demonstrated that those distresses identified in this paper have directly related to incremental changes in the IRI and a significant effect on incremental changes in IRI with time. The results from this study have also shown that the regressed model has a slight enhancement relative to the JPCP model. Hopefully, these investigation and studies can be used for the management, design, and/or evaluation for flexible pavement.

Application/Use: This study is valuable to those involved in selecting and designing rehabilitation alternatives.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The findings from this report are beneficial because they quantify the distress related and non-distress related effects on roughness accumulation. This is an important tool for pavement managers in more accurately predicting IRI over time and considering site conditions and their effect on pavement roughness. Ten LTPP project sites were used to evaluate IRI models and to describe the relationship between pavement age and the corresponding IRI value.

Future Benefit: The evaluation conducted as part of this project will continue to be useful. Quantifying the relationship between pavement age and roughness accumulation will be quite valuable in making rehabilitation and design decisions. The LTPP database will continue to bring lasting benefits to the pavement industry and assist researchers and pavement engineers in obtaining a better understanding of pavement behavior.

Title: Development of a Pavement Rutting Model from Long-Term Pavement Performance Data

Author(s): Luo, Rong; Prozzi, Jorge A.

Date: 2008

Publisher: Transportation Research Board 87th Annual Meeting

Abstract/Synopsis:
Rutting is one of the most important types of load-associated distresses that develop on flexible pavements. Extensive research has been conducted on the development of empirical models to predict pavement rutting progression using different data sources. However, the rutting data in the Long-Term Pavement Performance (LTPP) database has rarely been used to develop empirical rutting models. This paper uses the rutting data collected on LTPP sections in the State of Texas to statistically estimate the relationship of rut depth and explanatory variables representing pavement structure, materials, traffic loading and climate. All data used in this paper are extracted from different modules of the LTPP database. The proposed model demonstrates a concave trend of the rut depth with respect to the load repetition that is a common finding in most empirical rutting models. All climate parameters in this model show significant effects on the rutting progression. The structural number is statistically significant and has a negative estimated parameter, which indicates that a stronger pavement has smaller rutting depth.

Application/Use: This study will be used by pavement designers and engineers.

Contribution: Cost Savings; Improvement in Knowledge

Present Benefit: This study has provided insight into factors contributing to rutting and used the LTPP database to generate a rutting prediction model. Pavement managers and engineers can benefit from this study by incorporating this model in their pavement strategies to predict and schedule pavement maintenance in their network.

Future Benefit: As pavement design progresses towards a mechanistic-empirical design method, these prediction models will be more widely used by state agency pavement engineers and they will be better equipped in making strategic decisions for identifying and meeting the needs in their pavement network.

Title: Models for Predicting Top-Down Cracking of Hot-Mix Asphalt Layers (NCHRP 1-42A)

Author(s): Roque, Reynaldo

Date: 2008

Publisher: Transportation Research Board

Abstract/Synopsis: Until recently, load-associated fatigue cracking of hot-mix asphalt (HMA) concrete-surfaced pavements that occurs in the wheelpath has been thought to always initiate at the bottom of the HMA layer and propagate to the surface. However, recent studies have determined that load-related HMA fatigue cracks can also be initiated at the surface of the pavement and propagate downward through the HMA layer. The penetration of water and other foreign debris into these cracks can further accelerate the propagation of the crack through the HMA surface layer. These studies indicate that environmental conditions, tire-pavement interaction, mixture characteristics, pavement structure, and construction practices are among the factors that influence the occurrence of this cracking. Hypotheses regarding top-down cracking mechanisms have been suggested; test methods for evaluating HMA-mixture susceptibility to cracking have been proposed; and preliminary models for predicting crack initiation and propagation have been developed.

Recent work completed under NCHRP 1-42 provided further review of some of the issues related to top-down cracking. However, additional research is needed to address these and other issues associated with top-down cracking and to develop mechanistic-based models for use in mechanistic-empirical procedures for design and analysis of new and rehabilitated flexible pavements.

The objective of this project is to develop mechanistic-based models for predicting top-down cracking in HMA layers.

Application/Use: The prediction models developed will be incorporated into the M-E PDG, which will be used in pavement design, evaluation, and analysis across the country.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: The development of cracking models will be useful in refining the M-E PDG for adoption and implementation and will improve the prediction capabilities of the software. The study will also provide insights into the mechanisms involved in top-down and bottom-up cracking. Knowledge in this arena will provide benefit in pavement design, mixture design, rehabilitation selection, and maintenance programming.

Future Benefit: The results from this study will shed much needed light on top-down cracking and will help engineers understand pavement deterioration more thoroughly. LTPP SPS-1 test sections provide an excellent source of performance data that could be used to study top-down cracking. Forensic analysis of these sites would supplement the performance data already collected and would provide verification of the origin of cracking on the SPS-1 pavements.

Title: User Manual and Local Calibration Guide for the Mechanistic-Empirical Pavement Design Guide and Software (NCHRP 1-40B)

Author(s): Von Quintus, Harold L.

Date: March 2008

Publisher: Transportation Research Board

Abstract/Synopsis: The distress prediction models in the recommended M-E Pavement Design Guide have been calibrated to national averages based on data gathered by the Long-Term Pavement Performance (LTPP). It is widely recognized—and specifically pointed out by the NCHRP 1-37A team—that, for the distress models to be fully applicable for the particular materials, construction practices, and environmental conditions in a given state or geographic region, they should be calibrated with data obtained locally. The objects of this study were to: (1) develop a User Manual for the M-E PDG and software and (2) develop a detailed, practical guide for highway agencies for local or regional calibration of the distress models in the Guide.

Application/Use: The M-E pavement design guide will be used in pavement design, evaluation, and analysis across the country.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: The M-E PDG is a shift in the paradigm of pavement design/evaluation. The Guide incorporates mechanistic principles with empirical performance relationships. The 1993 AASHTO guide was developed using empirical correlations from data collected at the AASHO Road Test. Additionally, the output from the M-E PDG is a set of performance predictions based on an input set of site conditions and pavement structure. This allows the software to be used both to develop pavement designs and to evaluate existing pavements. The Guide's prediction models were developed using LTPP sites. In fact, developers of the Guide have stated that the project would not have been possible without LTPP. Because the data is from in-services pavements all across the U.S. and Canada and exposed to a wide range of traffic, climate, and subgrade conditions, the M-E PDG is calibrated on a national level. To refine the Guide to local conditions, many agencies will rely on local LTPP sites in the implementation process.

Future Benefit: The M-E PDG will likely be used by numerous agencies to perform pavement design and evaluation. Properly calibrated and implemented models will result in cost-effective pavement designs and overall improvement in the condition of the pavement network.

Title: Backcalculation of Permanent Deformation Parameters Using Time Series Rut Data from In-Service Pavements

Author(s): Salama, Hassan K; Chatti, Karim; Haider, Syed Waqar

Date: 2006

Publisher: Transportation Research Board

Abstract/Synopsis: Time series of rut data from 109 in-service pavement sections in the Long-Term Pavement Performance (LTPP) Special Pavement Study-1 (SPS-1) experiment were used to predict the permanent deformation parameters for the VESYS mechanistic–empirical rut model. This was accomplished by matching the rut performance curves versus time being matched for each section with a commercially available iterative solver. To ensure uniqueness of each section's permanent deformation parameters (PDPs), the transverse surface profiles were used to match the most likely contributions by layer according to the criteria proposed in the NCHRP Report 468. On average, the contribution to the total surface rutting from the various pavement layers was as follows: 57 percent from the asphalt concrete layer, 27 percent from the base layer, and 16 percent from the subgrade. These results confirmed that the contribution to the total rutting from asphalt concrete and base layers is important and needs to be included in any mechanistic–empirical design procedure.

Application/Use: The study will be valuable to those interested in predicting surface rutting using M-E approaches.

Contribution: Improvement in Knowledge

Present Benefit: The ability to accurately predict rutting accumulation along with the originating layer can be useful for material and pavement engineers. The value of the LTPP database is in the availability of time series rut data used in the analysis.

Future Benefit: LTPP will continue to benefit research activities similar to this project as long as the data remains accessible.

Title: Calibration of Mechanistic-Empirical Rutting Model Using In-Service Pavement Data from SPS-1 Experiment

Author(s): Chatti, Karim

Date: 2006

Publisher: Transportation Research Board

Abstract/Synopsis: This paper presents the results from multivariate regression analyses on rut data from the SPS-1 experiment in the Long Term Pavement Performance (LTPP) program to develop models for predicting permanent deformation parameters "a" and 8 for a three-layer pavement system (asphalt concrete, base and subgrade). All available material, structural, and climatic data used to explain rutting were extracted from the LTPP database. Using simple linear regression, "a" and 8-were regressed against these independent variables. The variables that have reasonable relationships (relatively higher R2) were introduced into the multiple linear regression models. The backward regression analysis was used to select the statistically significant variables for the final models. The variables selected for AC rutting included the strain at the middle of the AC layer, % passing sieve number 10 and % voids filled with asphalt of the most upper AC layer, the average of daily maximum air temperatures for the year, and the freezing index. The variables selected for base rutting included the backcalculated base modulus, thickness of the base layer, % passing sieve number 200, a newly developed weighted average gradation index, and the strain at the middle of the base layer. The variables selected for subgrade rutting included the strain at the middle of the first 40 inches of subgrade, a weighted gradation index and the plasticity index of the subgrade, the number of days above 32.2 ^{o}C, the number of days with more than 0.25 mm precipitation, and the backcalculated subgrade modulus. In general, the "a" prediction models for all layers are more precise than those for 8. This could be due to the fact that the "a" and 8-values were backcalculated from time-series data, which show the rate of growth in rut depth over time. It should also be noted that 8-values for the AC and base layers were significantly affected (positively) by their corresponding a-values. This implies that pavements with lower 8-values (lower initial rutting) will show lower a-values (higher rut growth with time) and vice-versa.

Application/Use: This study will be used by those implementing and calibrating the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: This study has provided insight into factors contributing to rutting. Additionally, the paper can assist in implementing and calibrating the M-E PDG to local conditions.

Future Benefit: The evaluation conducted in this paper will be beneficial as the M-E PDG continues to be investigated, calibrated, and implemented.

Title: Development of Roughness Deterioration Models for National Park Service Network

Author(s): Helali, Khaled; Voth, Michael D; Bekheet, Wael; Amenta, James A; VanDerHurst, Perry

Date: 2006

Publisher: Transportation Research Board

Conference Title: Transportation Research Board 85th Annual Meeting

Abstract/Synopsis: The National Parks Services (NPS) road system of Park Roads and Parkways (PRP) includes over 8,000 miles of paved and unpaved roads jointly administered by NPS and the Federal Highway Administration (FHWA). Recently, NPS and the Federal Lands Highway Program (FLHP) took an initiative to develop a Pavement Management System (FLH-PMS) to manage the PRP network. As part of the development of FLH-PMS, it was necessary to generate a complete set of performance prediction models for the various pavement performance indices used by NPS. Developing these models represented a unique challenge since the PRP road network primarily consists of low volume roads spread across the nation with different climatic conditions, subgrade soil conditions, and traffic levels. Also, the amount of historic performance and construction history data available was very limited. Utilizing the performance class approach, Long Term Pavement Performance (LTPP) data was used to supplement the limited amount of data available for the PRP network, by developing general performance trends or base models. These models were then adjusted using the data available for the PRP road network, as well as NPS-specific experience. In this paper the analyses performed to develop roughness deterioration models using the performance classes approach and the LTPP database is presented. The development of various environmental zone boundaries, which presented a particular challenge in project, is also detailed. The development of the models through PRP specific data and the FLHP and NPS expert opinion is then discussed, followed by the validation of the models through ground truth visits.

Application/Use: The outcome from this study is used by the National Park Services to manage the system of roads under their jurisdiction.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Developing performance curves for the National Park Services provides a means of properly and efficiently maintaining the pavement network. The curves can also be used as a tool for planning future improvements and for budgeting purposes. Because of the limited amount of available data on the network, LTPP data was instrumental in the development of base curves for the project.

Future Benefit: The performance curves will be used in the future and will continue to add benefit. As additional information is collected, the curves can be fine-tuned for improved prediction.

Title: Effect of Design and Site Factors on Long-Term Performance of Flexible Pavements in SPS-1 Experiment

Author(s): Chatti, Karim

Date: 2006

Publisher: Transportation Research Board

Conference Title: Transportation Research Board 85th Annual Meeting

Abstract/Synopsis: Results are presented from a study to evaluate the relative influence of design and site factors on the performance of in-service flexible pavements. The data are from the SPS-1 experiment of the Long-Term Performance Pavement (LTPP) program. This experiment was designed to investigate the effects of HMA surface layer thickness, base type, base thickness, and drainage on the performance of new flexible pavements constructed in different site conditions (subgrade type and climate). Base type was found to be the most critical design factor affecting fatigue cracking, roughness (IRI), and longitudinal cracking (wheel path). The best performance was shown by pavement sections with asphalt treated bases (ATB). This effect should be interpreted in light of the fact that an ATB effectively means a thicker HMA layer. Drainage and base type, when combined, also play an important role in improving performance, especially in terms of fatigue and longitudinal cracking. Base thickness has only secondary effects on performance, mainly in the case of roughness and rutting. In addition, climatic conditions were found to have a significant effect on flexible pavement performance. Longitudinal cracking (wheel path) and transverse cracking seem to be associated with a wet-freeze environment, while longitudinal cracking (non-wheel path) seems to be dominant in a freeze climate. In general, pavements built on fine-grained soils have shown the worst performance, especially in terms of roughness. Although most of the findings from this study support the existing understanding of pavement performance, they also provide an overview of the interactions between design and site factors and new insights for achieving better long-term pavement performance.

Application/Use: This study is used by those interested in the contribution of design factors on flexible pavement performance.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The present benefit for this study is an understanding in the interaction between design parameters and climate and the resultant changes in pavement performance. The LTPP database provides a means of conducting this type of study on a national scale.

Future Benefit: The findings from this study will be useful in transferring mechanistic evaluations to field performance for various design parameters.

Title: Effects of Multiple Freeze Cycles and Deep Frost Penetration on Pavement Performance and Cost

Authors: Jackson, N; Puccinelli, J.

Date: November 2006

Publisher: Federal Highway Administration

Abstract/Synopsis: The objectives of this study are to: (1) quantify the effects of frost penetration on pavement performance in climates with deep sustained frost as compared to environments with multiple freeze-thaw cycles, (2) investigate the effect that local adaptations have on mitigating frost penetration damage, and (3) estimate the associated cost of constructing and maintaining pavements in freezing climates. The approach consisted of modeling various pavement performance measures using both climatic and nonclimatic input variables and performance data collected as part of the Long Term Pavement Performance program. Five climatic scenarios are defined in terms of climatic input variables for the models. Predicted performance measures are presented for each of the climatic scenarios and compared at a 95 percent confidence interval to determine statistically significant performance differences. Participating Pooled Fund States were queried as to standard specifications, standard designs, average life expectancies, and construction costs specific to each State Highway Agency (SHA). This data along with information acquired through literature review of SHA standard practices is summarized with consideration given to the mitigation of frost-related damage. Life cycle cost analysis for each climatic scenario using predicted performance to determine average life and average agency construction costs for standard pavement sections is also discussed and compared. The use of the performance models for local calibration as required in the National Cooperative Highway Research Program Mechanistic-Empirical design guide is explored along with the possible application of the performance models in pavement management systems.

Application/Use: This document can be used to make pavement design decisions to mitigate climatic effects. It is also useful in pavement management as the performance trends developed in the study can be used at a local level to predict service life and pavement condition.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: This document provides insight into the performance of pavements exposed to various climates and investigates possible mitigation techniques. The costs associated with differential performance are also discussed. The models developed were based on national data—only available for the LTPP database—and have a large inference range. The models are applicable to pavement management as well as to the implementation of the M-E PDG.

Future Benefit: The performance curves will be used in the future by agencies to supplement their pavement management data as well as to evaluate the prediction capabilities of the M-E PDG on regional basis.

Title: Evaluation of Backcalculation Methods for Nondestructive Determination of Concrete Pavement Properties

Author(s): Fwa, T. F; Setiadji, Bagus Hario

Date: 2006

Publisher: Transportation Research Board

Journal: Transportation Research Record: Journal of the Transportation Research Board No. 1949

Abstract/Synopsis: Different backcalculation algorithms often give different answers in backcalculated pavement properties. This is because of the differences in the type of pavement models, solution search procedure, and deflection matching criteria used in the backcalculation analysis. Regardless of the theory applied and the backcalculation algorithm adopted, a logical basis of selection of the backcalculation procedure for practical applications would be to assess whether the backcalculated pavement properties could provide good estimates of the actual pavement properties. Today, the ease and the convenience of access to the Long-Term Pavement Performance (LTPP) database of actual measured data enable a highway agency to adopt this approach to select a backcalculation algorithm that meets its needs. With the LTPP-measured data, this approach was applied to evaluate the relative merits of four backcalculation algorithms (two versions of ILLIBACK, NUSBACK, and LTPP best-fit method) by a comparison of the computed elastic modulus of concrete pavement slab and the modulus of subgrade reaction of concrete pavements against the LTPP measured values. The performance of the four algorithms was greatly affected by the constraints imposed by the deflection theory adopted and was significantly dependent on their respective criteria used to match the computed and measured deflections. The number of sensors used in the backcalculation, as well as the choice of sensor configuration, can significantly affect the performance of the backcalculation algorithms.

Application/Use: This study can be used by those interested in backcalculation of concrete pavements.

Contribution: Improvement in Knowledge

Present Benefit: Understanding the accuracy of backcalculation results and the influences on various factors on backcalculation processes is very important in pavement design and evaluation. The LTPP database offers FWD data as well as information on pavement structure and materials along with monitored performance, which provides a means of conducting backcalculation studies.

Future Benefit: The results from this paper will add value in future FWD analyses. Additionally, the LTPP data will continue to provide a source of data not available outside of LTPP.

Title: Evaluation of Pavement Slab Rocking and Pumping with Elevation Profile Data

Author(s): Byrum, Christopher Ronald

Date: 2006

Publisher: Transportation Research Board

Journal Title: Transportation Research Record: Journal of the Transportation Research Board No. 1947

Abstract/Synopsis: A method is presented for estimating the amount of slab rocking and the amount of earth moved beneath a jointed concrete pavement as a result of slab rocking. The estimates are obtained with data from noncontact rapidly traveling profilers that collect surface elevation profiles along roadways at normal driving speeds without lane closure or traffic control costs. With profile data from FHWA Long-Term Pavement Performance (LTPP) General Pavement Study 3 (GPS-3) test sites, examples are provided to show how the apparent slab rocking and pumping volumes develop over time for most GPS-3 test sections that have shown significant faulting. The calculated pumping volume rate per equivalent single-axle load (ESAL) is shown to be relatively constant over time at these LTPP test sites. A preliminary linear regression predictive model for pumping rate per ESAL as a function of pavement design parameters is provided based on the test group of faulting GPS-3 pavements. This study indicates that pumping rate can be reduced with thicker and longer slabs and thicker layers of erosion-resistant base and subbase overlying erosion-susceptible subgrades. Slab lengths less than 15 ft (4.57 m) long appear noticeably more susceptible to rocking and pumping. Sites with high pumping rates typically have a combination of unusually large slabs locked in upward curvature and erosion-susceptible cross-section designs.

Application/Use: This paper can be used by pavement engineers interested in mitigating pumping and faulting in JPCC pavements.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Understanding the effect of joint spacing and slab thickness on pumping and faulting can be extremely beneficial. Pumping and subsequent faulting can increase the roughness of the road significantly and will trigger maintenance activities. Mitigating or slowing this process can lead to significant cost savings. One of the largest contributions the LTPP program has made to the pavement community is a national database which supports countless research projects similar to this study that would not have been possible without LTPP.

Future Benefit: The LTPP database will continue to support studies similar to this as long as the database remains accessible.

Title: Evaluation of Resilient Modulus Model Parameters for Mechanistic–Empirical Pavement Design

Author(s): Elias, Mohammed B; Titi, Hani H.

Date: 2006

Publisher: American Society of Civil Engineers

Journal Title: Transportation Research Record: Journal of the Transportation Research Board No. 1967

Abstract/Synopsis: Correlations were developed to estimate the resilient modulus of various Wisconsin subgrade soils from basic soil properties. A laboratory testing program was conducted on common subgrade soils to evaluate their physical and compaction properties. The resilient modulus of the investigated soils was determined from repeated load triaxial testing according to the AASHTO T 307 procedure. The laboratory testing program produced consistent results and a high-quality database. The resilient modulus constitutive equation adopted by NCHRP Project 1-37A was selected for this study. Comprehensive statistical analysis was performed to develop correlations between basic soil properties and the resilient modulus model parameters k sub i. The analysis did not yield good results when the whole test database was used. However, good results were obtained when fine-grained and coarse-grained soils were analyzed separately. The correlations developed were able to estimate the resilient modulus of the compacted subgrade soils with reasonable accuracy. To inspect the performance of the models developed in this study, comparison with the models developed on the basis of the Long-Term Pavement Performance (LTPP) database was made. The LTPP models did not yield good results compared with the models proposed by this study because of differences in the test procedures, test equipment, sample preparation, and other conditions involved with development of both LTPP and the models of this study.

Application/Use: This study is applicable to materials and pavement engineers interested in the resilient modulus of subgrade.

Contribution: Improvement in Knowledge

Present Benefit: This study provides information that will be beneficial to using the M-E PDG. The ability to relate soil properties to resilient modulus model parameters will result in better estimates of resilient modulus and better pavement performance predictions. The LTPP database provides a reference data set that was used to evaluate the dataset developed in the study.

Future Benefit: The future benefit provided by this study will be realized as the M-E PDG is implemented and subgrade parameter estimations are needed.

Title: Feasibility Study for Gray Theory Based Pavement Smoothness Prediction Models

Author(s): Li, Qiang; Wang, Kelvin C. P; Elliott, Robert P; Hall, Kevin D.

Date: 2006

Publisher: American Society of Civil Engineers

Conference Title: Applications of Advanced Technology in Transportation. Proceedings of the Ninth International Conference

Abstract/Synopsis: In the proposed Mechanistic-Empirical Design Guide (MEPDG) (NCHRP 1-37A, 2001), the functional performance indicator is pavement smoothness as measured by the International Roughness Index (IRI). The MEPDG IRI prediction models were developed based on the general hypothesis that changes in smoothness result from various distress types that can be predicted by the MEPDG program. Using pavement distress data from the Long Term Pavement Performance (LTPP) database, traditional regression analysis was used to statistically establish the MEPDG prediction equations. This paper attempts to use a new technique for pavement smoothness prediction. The gray system theory was derived in the 1980s for modeling uncertain systems with the characteristics of partially known information. A pavement performance prediction system can fit the domain of the gray system. The gray theory based prediction method is used in this paper to develop IRI prediction equations. With the data exported from the LTPP database, it is found that certain specific types of distresses significantly affect the accuracy of the predictions. After trial and error calculations, Gray Model based smoothness predictions are established using influencing factors similar to the ones used in MEPDG. Based on the comparisons of results from the two prediction methods with LTPP field data, it is shown that the Gray Model based method provides promising results and be useful for modeling pavement performance.

Application/Use: The paper can be used by those interested in pavement roughness predictions.

Contribution: Improvement in Knowledge

Present Benefit: The study provides comparisons between two roughness prediction models: the M-E PDG, and the Gray Model. This comparison is beneficial because it introduces an additional prediction tool (the Gray Model) and studies the output of this model relative to the M-E PDG model.

Future Benefit: The LTPP database will provide additional benefit by providing data that will allow evaluations of new and existing prediction models. The study at hand may be used further in new modeling techniques.

Title: Forwardcalculation Spreadsheets

Date: 2006

Publisher: FHWA

Abstract/Synopsis: These spreadsheets contain formulas that can be used to review and evaluate backcalculation data, thereby making all forwardcalculation input quantities transparent to those who want to use the methodology. In total, four spreadsheets are available—two for asphalt-bound surfaces and two for cement-bound surfaces. All four spreadsheets include metric and U.S. standard units. These spreadsheets are based on the approaches and methodologies described in the following reports:

- Review of Long-Term Pavement Performance Backcalculation Results
- Guidelines for Review and Evaluation of Backcalculation Results

Application/Use: These spreadsheets can be used by those who are interested in reviewing FWD results.

Contribution: Cost Savings; Implementation/Usage; Advancement in Technology.

Present Benefit: FWD data has been used extensively in determining layer moduli and developing appropriate rehabilitation strategies. These spreadsheets provide a tool in reviewing backcalculated information as well as in comparing results from different backcalculation techniques. This offers a better understanding of the results obtained from FWD testing, which can lead to better rehabilitation strategy selection.

Future Benefit: FWD data will continue to be an essential component in pavement design and evaluation, especially with the movement to more mechanistically-based approaches. Better evaluation and review techniques will result in improved pavement designs and rehabilitation strategy selections, resulting in cost savings.

Title: Guidelines for Review and Evaluation of Backcalculation Results

Author(s): Stubstad, R. N; Jiang, Y. J; Lukanen, E. O.

Date: 2006

Publisher: Applied Research Associates, Incorporated; Federal Highway Administration

Abstract/Synopsis: This document presents a new approach to determining layered elastic moduli from in situ load-deflection data, which was developed under the Federal Highway Administration's project for reviewing Long-Term Pavement Performance (LTPP) backcalculation data. This approach is called forwardcalculation, and it differs from backcalculation in that modulus estimates are calculated directly from the load and deflection data using closed-form formulae rather than through iteration. The closed-form forwardcalculation equations are used for the subgrade and the bound surface course, respectively, for both flexible and rigid pavement falling weight deflectometer (FWD) data. Intermediate layer moduli are estimated through commonly used modular ratios between adjacent layers. The audience for this document includes highway agency engineers, researchers, and consultants who are involved in pavement analysis, design, construction, and deflection data analysis.

Application/Use: The approach proposed in this paper can be utilized by pavement analysts and designers using FWD data in their evaluations.

Contribution: Improvement in Knowledge

Present Benefit: The methodology developed in this study is an additional tool for those in the pavement community. FWD data is useful in determining the structural adequacy of existing pavements, estimating subgrade properties, void detection, and load transfer efficiency.

Future Benefit: The data available from LTPP will benefit future studies looking at new procedures to analyze FWD data. This information will also support validation of existing procedures.

Title: Investigations of Environmental and Traffic Impacts on "Mechanistic-Empirical Pavement Design Guide" Predictions

Author(s): Zaghloul, Sameh; Ayed, Amr; Abd El Halim, Amir; Vitillo, Nicholas P; Sauber, Robert W.

Date: 2006

Publisher: Transportation Research Board

Journal Title: Transportation Research Record: Journal of the Transportation Research Board No. 1967

Abstract/Synopsis: The "Mechanistic–Empirical Pavement Design Guide" (MEPDG) represents a major improvement on its predecessors, particularly in its comprehensive coverage of environmental impact on pavement performance. Another improvement is the approach introduced to assess and accumulate damage created by traffic. A major strength of the MEPDG is the consideration given to the interaction between environmental, material, and traffic parameters, rather than consideration of only the parameters themselves. The process through which these interactions are considered sounds very comprehensive; however, is it practical? The Enhanced Integrated Climatic Model (EICM) is a core component of the MEPDG; it controls the material properties used in the analysis to a great extent. As a result, EICM predictions have a significant impact on MEPDG-accumulated damage and therefore on predicted service life. In a previous study, an effort was made to validate EICM predictions with field-measured temperature and moisture profiles outside the MEPDG. However, this effort was not successful. Therefore, the potential impacts of the accuracy of EICM predictions on MEPDG-predicted damage and hence on expected pavement service life were investigated. Eight weather stations closest to New Jersey's Long-Term Pavement Performance Specific Pavement Study 5 site were analyzed. In addition, to address the interaction between environment and traffic in the MEPDG, analyses were run with two traffic input levels: first with Level 3 traffic data and then with Level 1 traffic data.

Application/Use: This paper can be used to evaluate the adequacy of the EICM and the impacts of environment and traffic on M-E PDG predictions.

Contribution: Improvement in Knowledge

Present Benefit: The findings from this study are beneficial to the implementation and use of the M-E PDG. Understanding sensitivity and interactions between inputs into the performance models is very useful to designers. Additionally, an evaluation of the accuracy of the EICM will ultimately improve the pavement designs produced through the M-E PDG.

Future Benefit: This study will be used to understand the variability inherent in the EICM and its effect on pavement design in the M-E PDG. Findings from this study may be used to modify the M-E PDG.

Title: LTPP Data Analysis: Optimization of Traffic Data Collection for Specific Pavement Design Applications

Date: 2006

Publisher: Federal Highway Administration

Journal Title: TechBrief No. FHWA-HRT-06-111

Abstract/Synopsis: The Long-Term Pavement Performance (LTPP) program conducted a study to establish the relationship between the traffic data collection effort, including the combination of traffic data acquisition technologies and length of time coverage, and the variability in predicted pavement life using the "Mechanistic-Empirical Pavement Design Guide" (M-E PDG). For the study, researchers used extended-coverage weigh-in-motion (WIM) data from the LTPP Standard Data Release (SDR) 16.0 to simulate a wide range of traffic data collection scenarios. This resulted in the development of two specific products: (1) Guidelines for the type, amount, and quality of traffic data input required for particular design situations considering the sensitivity of the pavement design process to the variability in traffic load input; and (2) Directions for future traffic data collection efforts to address both LTPP and State agency collection needs for pavement design applications. This TechBrief contains further discussion of the study findings and conclusions.

Application/Use: The finding from this paper can be used by pavement design engineers looking to implement and use the M-E PDG.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Understanding the relationship between traffic data collection requirements and pavement design error is extremely beneficial. Significant cost savings can be realized when the error in pavement design is minimized. The findings from this study also provide an understanding for the amount of traffic data that will be required in the implementation of the M-E PDG. With this knowledge, agencies can develop a plan for network-level traffic monitoring.

Future Benefit: The future benefit of this study will be realized as agencies begin implementing the M-E PDG. The findings from this study are not only useful in determining the effect of traffic on pavement design results, but can also be used in planning future traffic monitoring based on an established acceptable error. The error associated with traffic data collection requirements will also be included in the local calibration/validation process of the M-E PDG.

Title: Network-Level Evaluation of Specific Pavement Study-2 Experiment: Using a Long-Term Pavement Performance Database

Author(s): Buch, Neeraj; Chatti, Karim; Haider, Syed Waqar; Pulipaka, Aswani S; Lyles, Richard W; Gilliland, Dennis

Date: 2006

Publisher: Transportation Research Board

Journal Title: Transportation Research Record: Journal of the Transportation Research Board No. 1947

Abstract/Synopsis: The research described here was conducted as a part of NCHRP Project 20-50 (10&16), Long-Term Pavement Performance (LTPP) Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements. The relative effects of various design and site factors on the performance of jointed plain concrete (JPC) pavements are presented. The data used in this study were primarily drawn from Release 17 of DataPave. The Specific Pavement Study (SPS) 2 experiment was designed to investigate the effects of portland cement concrete (PCC) slab thickness, base type, drainage, PCC flexural strength, and slab width on the performance of JPC pavements. On the basis of the statistical analysis of 167 test sections, ranging in age from 5 to 12 years, it was concluded that base type was the most critical design factor affecting performance in terms of cracking and roughness as measured by the international roughness index. Pavement sections with a permeable asphalt-treated base and in-pavement drainage performed better than those with a dense-graded aggregate base or a lean concrete base.

Application/Use: The results from this study can be used by pavement engineers in evaluating the contribution of design features on pavement performance.

Contribution: Cost Savings, Improvement in Knowledge.

Present Benefit: The SPS-2 projects constructed and monitored as part of the LTPP program are extremely beneficial. At each site, at least twelve test sections, consisting of various base types, drainage, slab thicknesses, flexural strengths, and slab widths are located consecutively. This provides an opportunity to make direct comparisons between design features because other factors such as traffic, subgrade conditions, and climate are constant. These in-service pavements offer a wealth of knowledge that is not readily available elsewhere. Findings from this evaluation can be used to determine the cost-effectiveness of design features for specific applications. Efficient and proper pavement design can lead to significant cost savings.

Future Benefit: As the pavement community moves towards M-E PDG, the SPS-2 projects will play a vital role in the local calibration of the guide.

Title: Review of the Long-Term Pavement Performance Backcalculation Results Final Report

Author(s): Stubstad, R. N; Jiang, Y. J; Clevenson, M. L; Lukanen, E. O.

Date: 2006

Publisher: Applied Research Associates, Incorporated; Federal Highway Administration

Abstract/Synopsis: A new approach to determine layered elastic moduli from in situ load-deflection data was developed. This “forwardcalculation” approach differs from backcalculation in that modulus estimates come directly from the load and deflection data using closed-form formulae rather than iteration. The forwardcalculation equations are used for the subgrade and the bound surface course for both flexible and rigid pavement falling weight deflectometer (FWD) data. Intermediate layer moduli are estimated through commonly used modular ratios between adjacent layers. The entire Long-Term Pavement Performance (LTPP) set of backcalculated parameters was screened using forwardcalculated moduli. Any assumed or fixed modulus value was left as is and not further screened (e.g., hard bottom). Further, any back- or forwardcalculated values outside a broad range of reasonable values were not further screened, but flagged as unreasonable. Finally, a set of broad range convergence flags (0=acceptable, 1=marginal, 2=questionable, and 3=unacceptable) were applied to the backcalculated dataset, depending on how closely the pairs of back- and forwardcalculated moduli matched. Since both techniques used identical FWD load-deflection data as input, the moduli derived from each approach should be reasonably close to each other (within a factor of 1.5 to qualify as acceptable, for example). Although backcalculated values cannot be rejected merely because they are outside a reasonable or acceptable range, the complementary forwardcalculated values were usually more stable on a section-by-section basis. The exception was the portion of the database based on slab-on-dense-liquid or slab-on-elastic-solid theory, where the correspondence between the two approaches was excellent and very stable. Therefore, it is recommended that the backcalculated database be retained as is, with the addition of checks and flags so the database user can choose the best method, depending on the application.

Application/Use: This evaluation can be used by those looking at FWD data in the LTPP database.

Contribution: Improvement in Knowledge

Present Benefit: Independent reviews conducted on the LTPP database are essential to ensure quality. Quality data benefits users of the data. The development and investigation of a fowardcalculation process also adds benefit by providing an additional tool for those evaluating FWD data.

Future Benefit: The data available from LTPP will benefit future studies looking at new procedures to analyze FWD data. This information will also support validation of existing procedures.

Title: Seasonal Variations in the Moduli of Unbound Pavement Layers

Author(s): Richter, Cheryl A.

Date: 2006

Publisher: Federal Highway Administration

Abstract/Synopsis: The in situ moduli of unbound pavement materials vary on a seasonal basis as a function of temperature and moisture conditions. Knowledge of these variations is required for accurate prediction of pavement life for pavement design and other pavement management activities. The primary objective of this study is to advance the rational estimation of seasonal variations in backcalculated pavement layer moduli using data collected via the Seasonal Monitoring Program of the Long-Term Pavement Performance Program. Principal components of this endeavor included: evaluation of the moisture predictive capabilities of the Enhanced Integrated Climatic Model (EICM); development of empirical models to predict backcalculated pavement layer moduli as a function of moisture content, stress state, and other explanatory variables; and trial application of the models developed to predict backcalculated moduli for unbound pavement layers. This investigation yielded two key findings. First, it provided the impetus for developing EICM Version 2.6 by demonstrating the practical inadequacies of EICM Versions 2.0 and 2.1 when applied to the prediction of in situ moisture content, and then demonstrated that substantial improvement in the moisture predictive capability of the EICM had been achieved in Version 2.6. Second, the research identified fundamental discrepancies between layer moduli backcalculated using linear-layered elastic theory and the laboratory resilient modulus test conditions. Other important findings included (1) variation in moisture content is not always the most important factor associated with seasonal variations in pavement layer moduli, and (2) a model form that fits linear elastic backcalculated moduli reasonably well. The overall accuracy of the modulus predictions achieved in the trial application of the predictive models was not fully acceptable. Several avenues for further research to improve upon these results are identified.

Application/Use: The findings from this study were used to update the EICM, which is used directly in the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: Improvement to the EICM provides benefit by improving the prediction capability of the M-E PDG. Additional understanding of the relationship between backcaluclated layer moduli and linear-layered elastic theory is also a direct benefit from this study.

Future Benefit: The use of the updated EICM will increase in value as the M-E PDG is implemented and used. Along those lines, understanding changes in moduli with season and the correlation between backcaclulated and laboratory values will prove to be beneficial to designers in the future.

Title: Sensitivity of NCHRP 1-37A Pavement Design to Traffic Input

Author(s): Papagiannakis, A. Thomas; Bracher, Michael; Li, J; Jackson, Newton C.

Date: 2006

Publisher: Transportation Research Board

Journal Title: Transportation Research Record: Journal of the Transportation Research Board No. 1945

Abstract/Synopsis: This study deals with the sensitivity of the NCHRP 1-37A Pavement Design Guide predictions to traffic data input. A number of traffic data collection scenarios are simulated with the use of extended coverage (more than 299 days per year) weigh-in-motion (WIM) data from the Long-Term Pavement Performance (LTPP) database. These scenarios consist of combinations of site-specific, regional, and national data, including total truck counts, truck counts by class, and axle-load distributions by axle type. For each simulated scenario, traffic input to the NCHRP 1-37 Pavement Design Guide is estimated with the methodologies prescribed in the "Traffic Monitoring Guide." For discontinuous time coverage scenarios, all possible time coverage combinations are considered, and the range in the estimated traffic input parameters is computed. Pavement life predictions are obtained under mean traffic input for all traffic data collection scenarios and under low percentile input for the discontinuous traffic data collection scenarios.

Application/Use: The findings from this paper can be used by pavement design engineers looking to implement and use the M-E PDG.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Understanding the sensitivity of the M-E PDG relative to traffic input is extremely beneficial to pavement design engineers. This sensitivity can be used to establish the level of data collection that is required for use in pavement design. The information can also be used to develop a plan for network-level traffic monitoring.

Future Benefit: The future benefit of this study will be realized as agencies begin implementing the M-E PDG. The findings from this study are not only useful in determining the effect of traffic on pavement design results, but can also be used in planning future traffic monitoring based on an established acceptable error. The error associated with traffic data collection requirements will also be included in the local calibration/validation process of the M-E PDG.

Title: Sensitivity Study of Iowa Flexible Pavements Using Mechanistic-Empirical Pavement Design Guide

Author(s): Ceylan, Halil; Kim, Sunghwan; Heitzman, Michael; Gopalakrishnan, Kasthurirangan

Date: 2006

Publisher: Transportation Research Board

Conference Title: Transportation Research Board 85th Annual Meeting

Abstract/Synopsis: In the newly released Mechanistic-Empirical Pavement Design Guide (MEPDG), the coefficients of the distress prediction models were determined through national calibration efforts of the Long-Term Pavement Performance (LTPP) program. But the LTPP database used to develop the calibrated distress models did not include test sections from Iowa. Thus, there is a need to recalibrate the models, if required, to use them for pavement design and rehabilitation in Iowa. As a first step in this direction, a preliminary sensitivity study was undertaken to assess the comparative effect of design input parameters pertaining to material properties, traffic and climate on performance of two existing flexible pavements in Iowa with relatively thick Asphalt Concrete (AC) layers. A total of 20 individual inputs were evaluated by studying the effect of each input on five different performance measures (longitudinal cracking, alligator cracking, transverse cracking, rutting, and roughness) for each pavement structure resulting in about 200 simulations using the MEPDG. A limited set of runs were also conducted to study the two-way interaction among the input variables (e.g., effect of traffic distribution on performance for varying AC surface thicknesses). The results showed that the predicted longitudinal cracking was influenced by most input parameters. Alligator cracking, roughness, and rutting in unbound layers remained insensitive to most input parameters. There is no input parameter that is sensitive to all the performance measures. Future research will focus on comparing the predicted measures against the recorded pavement distresses in the Iowa DOT's Pavement Management Information System (PMIS) database.

Application/Use: This study applies directly to pavement design in Iowa and the findings will be used as part of local validation/calibration of the M-E PDG in Iowa.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: It has been documented that the development of the M-E PDG would not have been possible without the LTPP database and many agencies will rely heavily on the database in the calibration/validation process. This study offers insight into the sensitivity of the M-E PDG performance predictions with changes to material properties, traffic, and climate.

Future Benefit: The study will be useful to Iowa as they continue implementing the M-E PDG. The LTPP database will offer value as agencies use it to evaluate the M-E PDG prediction capability at a regional or local level.

Title: Technical Assistance to NCHRP and NCHRP Project 1-40A: Versions 0.9 and 1.0 of the M-E Pavement Design Software (NCHRP 1-40D)

Author(s): Harrigan, Edward

Date: 2006

Publisher: Transportation Research Board

Abstract/Synopsis: In conjunction with the other projects related to the development of the M-E PDG, there was a need for a coordinated effort to produce improved, corrected versions 0.9 and 1.0 of the M-E Pavement Design Guide software and to provide ongoing technical troubleshooting support to NCHRP and FHWA. This will aide in the adoption of the Guide and implementation by local agencies.

Application/Use: The M-E pavement design guide will be used in pavement design, evaluation, and analysis across the country.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: The M-E PDG is a shift in the paradigm of pavement design/evaluation. The Guide incorporates mechanistic principles with empirical performance relationships. The 1993 AASHTO guide was developed using empirical correlations from data collected at the AASHO Road Test. Additionally, the output from the M-E PDG is a set of performance predictions based on an input set of site conditions and pavement structure. This allows the software to be used both to develop pavement designs and to evaluate existing pavements. The Guide's prediction models were developed using LTPP sites. In fact, developers of the Guide have stated that the project would not have been possible without LTPP. Because the data is from in-services pavements all across the U.S. and Canada and exposed to a wide range of traffic, climate, and subgrade conditions, the M-E PDG is calibrated on a national level. To refine the Guide to local conditions, many agencies will rely on local LTPP sites in the implementation process.

Future Benefit: The M-E PDG will likely be used by numerous agencies to perform pavement design and evaluation. Properly calibrated and implemented models will result in cost-effective pavement designs and overall improvement in the condition of the pavement network.

Title: Use of Deflection and Distresses in Pavement Performance: Does Mechanistic-Empirical Pavement Design Guide Miss Something?

Author(s): Vitillo, Nicholas P; Zaghloul, Sameh; Ayed, Amr; Jumikis

Date: 2006

Publisher: Transportation Research

Conference Title: Transportation Research Board 85th Annual Meeting

Abstract/Synopsis: Although the new Mechanistic-Empirical Pavement Design Guide (MEPDG) is still in the review stage, it represents a major improvement on its predecessors. One of its advantages is the comprehensive coverage of the environmental, material, and traffic parameters, as well as their interactions. However, several issues need to be investigated as a part of the review process. This paper will address two that are related to the pavement performance component of MEPDG: the coverage of the performance indicators and the interaction among the distresses used in MEPDG to estimate pavement service life. Important questions should be asked, such as: do the MEPDG performance indicators provide enough coverage of pavement performance? Are all the main aspects of pavement performance covered in MEPDG? Is a pavement section with only one distress expected to have the same life/performance as another section with the same level of this distress, plus other distresses? Does the existence of more than one distress accelerate deterioration? If MEPDG was used to evaluate two designs and predicted that one design would develop a certain set of distresses, while the other section would develop another set of distresses, which of these two designs would provide better performance and be most cost-effective? Through a discussion of relevant previous studies and the results of more specific analyses performed on the Long Term Pavement Performance (LTPP) historic performance data of two Specific Pavement Study (SPS) sites in New Jersey, this paper tries to address these questions and evaluate the potential impacts of the results.

Application/Use: This study can be used to understand the pavement performance predictions produced from the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: Findings from this study are beneficial in that they provide insight into the performance predictions of the M-E PDG. This is another example of the value of the LTPP database in pavement research. This and similar studies would not have been possible if the LTPP database were not available.

Future Benefit: Findings from the study will continue to add value as agencies beginning implementing the M-E PDG. The LTPP database will continue to support studies similar to this as long as the database remains accessible.

Title: Concrete Pavement Design in Kansas Following the Mechanistic-Empirical Pavement Design Guide

Author(s): Khanum, Taslima; Hossain, Mustaque; Romanoschi, Stefan A.; Barezinsky, Richard

Date: 2005

Publisher: Iowa State University, Ames

Conference Title: Proceedings of the 2005 Mid-Continent Transportation Research Symposium

Abstract/Synopsis: The AASHTO Guide for Design of Pavement Structures uses empirical performance equations for concrete pavement design. The new Mechanistic-Empirical Pavement Design Guide (MEPDG) provides methodologies for mechanistic-empirical pavement design. Five roadway sections, designed by the Kansas Department of Transportation (KDOT) using 1986 and 1993 AASHTO pavement design guides, and three Long-Term Pavement Performance (LTPP) sections in Kansas were analyzed using MEPDG. Project-specific construction and materials data and MEPDG default traffic data were used in the analysis. The predicted output variables, IRI and faulting, were compared with those obtained during KDOT annual pavement condition surveys or from the LTPP database. The results show that the predicted IRI values are similar to the measured values. MEPDG analysis showed minimal or no faulting, although both predicted and measured faulting values were insignificant for all practical purposes. The sensitivity analysis results show that IRI is the most sensitive output with respect to the traffic inputs. Percentage of slabs cracked increases significantly with increasing truck traffic and decreases with increasing slab thickness. Faulting is the least sensitive parameter.

Application/Use: This paper is applicable to those in the M-E PDG implementation process and will be directly used by KDOT.

Contribution: Improvement in Knowledge

Present Benefit: This paper is beneficial to local calibration/validation of the M-E PDG for Kansas conditions. This paper provides insight into PCC pavement sensitivity and will aide in establishing the level of effort necessary to quantify material properties used in the M-E PDG.

Future Benefit: As additional agencies begin implementing the M-E PDG, findings from this study will continue to be used as a reference. The LTPP database will also be utilized by many agencies in the implementation process.

Title: Effect of Seasonal Moisture Variation on Subgrade Resilient Modulus

Author(s): Salem, Hassan M.

Date: 2005

Publisher: Federal Highway Administration; American Society of Civil Engineers

Abstract/Synopsis: It is well known that environmental changes have severe effects on pavement performance. While an asphalt layer may be more sensitive to temperature, a soil or untreated pavement layer might be more affected by the change in moisture. This research aims at quantifying the effect of subgrade moisture variation, caused by environmental changes, on a subgrade's resilient modulus and including its effects in the design process for new and rehabilitated pavements. To achieve this objective, data representing different soil types in non-freeze zones at various Long-Term Pavement Performance Seasonal Monitoring Program (LTPP-SMP) sites were downloaded from the DataPave 3.0 software. The downloaded data were analyzed to establish the effect of subgrade moisture variation on a subgrade's resilient strength represented by the backcalculated elastic modulus. The analysis indicated that moisture in the subgrade layer is related to the precipitation intensity. The study also revealed that a Seasonal Adjustment Factor (SAF) could be used to shift the subgrade modulus from a normal season to another. The SAF is considered a key input in the mechanistic-based pavement design system. It allows the inclusion of the seasonal effects on the layer moduli for different seasons. In this paper, a method is presented for calculating the SAF for the subgrade soils. Using the collected data, regression analysis was performed and correlation equations were developed. These equations relate the backcalculated subgrade modulus to the subgrade moisture content and to other soil properties. The SAF relates the change in the moisture content to the change in the modulus value.

Application/Use: The findings from this study are directly applicable to M-E pavement design.

Contribution: Improvement in Knowledge

Present Benefit: Understanding changes in subgrade modulus as a function of changes in moisture content is beneficial in pavement design. It allows designers to select pavement sections that efficiently account for these seasonal variations.

Future Benefit: As pavement design moves towards M-E PDG practices, understanding modulus changes will be an essential part of the process. The results from this study will be useful in estimating subgrade modulus values in different seasons.

Title: Implementing the Mechanistic-Empirical Pavement Design Guide: Implementation Plan

Author(s): Coree, Brian; Ceylan, Halil; Harrington, Dale

Date: May 2005

Publisher: Iowa Highway Research Board

Abstract/Synopsis: The current 1993 American Association of State Highway and Transportation Officials (AASHTO) Pavement Design Guide is based on the empirical interpretation of the results of the 1960 AASHTO Road Test. With the release of the new Mechanistic-Empirical (M-E) Pavement Design Guide, pavement design has taken a "quantum" leap forward. In order to effectively and efficiently transition to the M-E Pavement Design Guide, state DOTs need a detailed implementation and training strategy. This document is a plan for the M-E Pavement Design Guide to be implemented in Iowa.

Application/Use: This implementation plan is directly applicable to pavement design at the Iowa Department of Transportation.

Contribution: Cost Savings, Improvement in Knowledge, Advancement in Technology.

Present Benefit: The development of the M-E PDG relied heavily on the LTPP database. The validation and calibration at a local level will also depend on the LTPP data available in the area. In fact, this implementation strategy suggests that LTPP data be used in conjunction with PMS information to validate and calibrate the models.

Future Benefit: Validation and calibration of the M-E PDG is just on of the many future benefits that the LTPP database will provide.

Title: Sensitivity Analysis of Rigid Pavement Systems Using Mechanistic- Empirical Pavement Design Guide

Author(s): Guclu, Alper; Ceylan, Halil

Date: 2005

Publisher: Iowa State University, Ames

Conference Title: Proceedings of the 2005 Mid-Continent Transportation Research Symposium

Abstract/Synopsis: Pavement design procedures available in the literature do not fully take advantage of mechanistic design concepts, and as a result, heavily rely on empirical approaches. Because of their heavy dependence on empirical procedures, the existing rigid pavement design methodologies do not capture the actual behavior of Portland Cement Concrete (PCC) pavements. However, reliance on empirical solutions can be reduced by introducing mechanistic-empirical methods, now adopted in the newly released Mechanistic-Empirical Pavement Design Guide (MEPDG). This new design procedure incorporates a wide range of input parameters associated with the mechanics of rigid pavements. A study was undertaken to compare the sensitivity of these various input parameters on the performance of concrete pavements. Two Jointed Plain Concrete Pavement (JPCP) sites were selected in Iowa. These two sections are also part of the Long Term Pavement Performance (LTPP) program, where a long history of pavement performance data exists. Data obtained from the Iowa Department of Transportation (Iowa DOT) Pavement Management Information System (PMIS) and LTPP database were used to form two standard pavement sections for the comprehensive sensitivity analyses. The sensitivity analyses were conducted using the MEPDG software to study the effects of design input parameters on pavement performance, specifically faulting, transverse cracking, and smoothness. Based on the sensitivity results, the rigid pavement input parameters were ranked and categorized from most sensitive to insensitive to help pavement design engineers to identify the level of importance for each input parameter. The curl/warp effective temperature difference (built-in curling and warping of the slabs) and PCC thermal properties are found to be the most sensitive input parameters. Based on the comprehensive sensitivity analyses, the idea of developing an expert system is introduced to help the designer identify the input parameters that can be modified to satisfy the predetermined pavement performance criteria.

Application/Use: This paper is useful in implementing the M-E PDG for PCC pavements and of particular interest for pavement designers in Iowa.

Contribution: Improvement in Knowledge

Present Benefit: The M-E PDG implementation process consists of evaluating the sensitivity of the predictions. This paper provides insight into sensitivity for PCC pavements and will aide in establishing the level of effort necessary to quantify material properties used in the M-E PDG.

<u>Future Benefit:</u> As additional agencies begin implementing the M-E PDG, findings from this study will continue to be used as a reference. The LTPP database will also be utilized by many agencies in the implementation process.

Title: Sensitivity Study of Design Input Parameters for Two Flexible Pavement Systems Using the Mechanistic-Empirical Pavement Design Guide

Author(s): Kim, Sunghwan; Ceylan, Halil; Heitzman, Michael

Date: 2005

Publisher: Iowa State University, Ames

Conference Title: Proceedings of the 2005 Mid-Continent Transportation Research Symposium

Abstract/Synopsis: Many agencies use the AASHTO Guide for Design of Pavement Structures to design their pavement systems. The limitation inherent in this method is the empirical nature of the decision process, which was derived from a road test conducted almost 45 years ago in Ottawa, Illinois. The newly released Mechanistic-Empirical Pavement Design Guide (MEPDG), based on NCHRP Study 1-37A, has adopted a mechanistic-empirical pavement design procedure, in which pavement distresses are calculated through calibrated distress prediction models based on material properties laboratory test results and local climatic conditions. The calibrated distress prediction models are based on the critical pavement responses mechanistically calculated by a structural model and coefficients determined through national calibration efforts using the Long-Term Pavement Performance (LTPP) database. The MEPDG requires many parameters to map the calibrated distress prediction models with traffic, environment, and material properties. The present study was conducted to evaluate the relative sensitivity of MEPDG input parameters to asphalt cement concrete (ACC) properties, traffic, and climatic conditions based on field data from two existing Iowa flexible pavement systems. The sensitivities of five MEPDG performance measures (longitudinal cracking, alligator cracking, thermal cracking, rutting, fatigue cracking, and smoothness) were studied by either varying a single input parameter or by varying two input parameters at a time. The findings of this study, presented in this paper, will provide pavement designers a better understanding of those design parameters that affect certain pavement distresses the most and need careful consideration during the design process.

Application/Use: This study applies directly to pavement design in Iowa and the findings will be used as part of local validation/calibration of the M-E PDG in Iowa.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: It has been documented that the development of the M-E PDG would not have been possible without the LTPP database, and many agencies will rely heavily on the database in the calibration/validation process. This study offers insight into the sensitivity of the M-E PDG performance predictions with changes to material properties, traffic, and climate.

Future Benefit: This study will be beneficial in the future as the M-E PDG continues to be evaluated and implemented.

Title: Survival Analysis of Fatigue Cracking for Flexible Pavements Based on Long-Term Pavement Performance Data

Author(s): Wang, Yuhong; Mahboub, Kamyar C; Hancher, Donn E.

Date: 2005

Publisher: American Society of Civil Engineers

Journal Title: Journal of Transportation Engineering Vol. 131 No. 8

Abstract/Synopsis: The study presented in this paper analyzed the development patterns of fatigue cracking shown in flexible pavement test sections of the Long-Term Pavement Performance (LTPP) Program. A large number of LTPP test sections exhibited a sudden burst of fatigue cracking after a few years of service. In order to characterize this type of LTPP cracking data, a survival analysis was conducted to investigate the relationship between fatigue failure time and various influencing factors. After dropping insignificant influencing factors, accelerated failure time models were developed to show the quantitative relationship between fatigue failure time and asphalt concrete layer thickness, Portland cement concrete base layer thickness, average traffic level, intensity of precipitation, and freeze-thaw cycles. The error distribution of the accelerated failure time model was found to be best represented by the generalized gamma distribution. The model can also be used to predict the average behavior of fatigue failures of flexible pavements.

Application/Use: The evaluation of fatigue cracking can be used to predict average fatigue performance, which is applicable in pavement management.

Contribution: Improvement in Knowledge

Present Benefit: This analysis investigates the contribution of key factors on fatigue accumulation and provides a pavement performance prediction tool. This is beneficial to those interested in predicting average fatigue performance for a given set of conditions.

Future Benefit: LTPP will continue to benefit the pavement community by providing quality data for research.

Title: Verification for the Calibrated Permanent Deformation Models for the 2002 Design Guide (With Discussion)

Author(s): El-Basyouny, Mohamed M; Witczak, Matthew W; El-Badawy, Sherif

Date: 2005

Publisher: Association of Asphalt Paving Technologists

Conference Title: 2005 Journal of the Association of Asphalt Paving Technologists: From the Proceedings of the Technical Sessions

Journal Title: Journal of the Association of Asphalt Paving Technologists Vol. 74

Abstract/Synopsis: The new design approach adopted in the 2002 Design Guide utilized a mechanistic-empirical pavement design procedure. The 2002 Design Guide provides time series predictions of several major distress types. One such distress mechanism is the permanent deformation (rutting). The Design guide solution predicts the total pavement rut depth, as a function of time, by predicting and summing the individual rutting contributed by all rut susceptible layers (asphalt, granular base, subbase and subgrade). This necessitated that a set of rutting models be implemented in the new design method to reflect the new design procedure. The pavement rutting prediction models included in the Design Guide nationally were calibrated by using actual sections from the Long-Term Pavement Performance (LTPP) database, to reflect the field performance of the flexible pavements. To ensure that the calibrated model is as accurate as possible and that the predicted model trends are as close as possible to what experience, practical knowledge and reasonable engineering judgment of the performance of the asphalt concrete pavements allows; an extensive sensitivity analysis was conducted using a wide variety of salient variables that were felt to have an impact on pavement rutting considered in the Design Guide. This paper contains an in-depth detailed analysis for the entire sensitivity study. In this study, a typical section was run using the 2002 Design Guide software. Different levels for each variable considered were used while keeping the other variables constant. The results of the sensitivity runs and the performance of the section with respect to the variables were found to be very logical and rational. In fact, the Mechanistic-Empirical design approach appears to provide the user with a much more powerful tool to assess the complex interaction of design parameters to performance than is currently available in any other design methodology in the world.

Application/Use: The findings from this study can be used to understand the rutting prediction model of the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: Quantifying the sensitivity of the M-E PDG models to inputs in the model will assist agencies during the implementation process of the M-E PDG. This provides information that can be used to prioritize material characterization efforts. The results can also be used to familiarize designers with the predictions and how changes in design effect those predictions.

Future Benefit: Understanding the sensitivity of the M-E PDG will be critical to developing cost effective pavement designs. The LTPP database is beneficial to the M-E PDG efforts because it provides data that are needed in the local calibration/validation process as well as sensitivity analysis.

Title: Verification of the Calibrated Fatigue Cracking Models for the 2002 Design Guide (With Discussion)

Author(s): El-Basyouny, Mohamed M; Witczak, Matthew W.

Date: 2005

Publisher: Association of Asphalt Paving Technologists

Conference Title: 2005 Journal of the Association of Asphalt Paving Technologists: From the Proceedings of the Technical Sessions

Journal Title: Journal of the Association of Asphalt Paving Technologists Vol. 74

Abstract/Synopsis: The new design approach adopted in the 2002 Design Guide utilized a mechanistic-empirical pavement design procedure. This necessitated that a new set of fatigue cracking models to be used in the new design method to reflect the new design procedure. The pavement fatigue cracking prediction models included in the Design Guide were calibrated by using actual sections from the Long-Term Pavement Performance (LTPP) database, to reflect the field performance of the flexible pavements. To ensure that the calibrated model is as accurate as possible and that the predicted model trends are as close as possible to what experience, practical knowledge and reasonable engineering judgment of the performance of the asphalt concrete pavements allows; an extensive sensitivity analysis was conducted using a wide variety of salient variables that were felt to have an impact on both types of fatigue cracking (top-down and bottom-up) considered in the Design Guide. This paper contains an in-depth detailed analysis for the entire sensitivity study. A typical section was run using the 2002 Design Guide software. Different levels for each variable considered were used while keeping the other variables constant. The results of the sensitivity runs and the performance of the section with respect to the variables was very logic and relevant to the performance expected.

Application/Use: The findings from this study can be used to understand the fatigue cracking prediction model of the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: Quantifying the sensitivity of the M-E PDG models to inputs in the model will assist agencies during the implementation process of the M-E PDG. This provides information that can be used to prioritize material characterization efforts. The results can also be used to familiarize designers with the predictions and how changes in design effect those predictions.

Future Benefit: Sensitivity of the M-E PDG can be used to develop cost effective pavement designs. The LTPP database is beneficial to the M-E PDG efforts because it provides data that are needed in the local calibration/validation process as well as a sensitivity analysis.

Title: Analysis of Temperature Data for the National Center for Asphalt Technology Test Track

Author(s): Watson, D. E; Zhang, J; Powell, R. B.

Date: 2004

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1891

Abstract/Synopsis: Several combinations of mix type, aggregate type, asphalt binder type, and layer thickness are in place at the National Center for Asphalt Technology (NCAT) test track. It was desirable to examine the effects these various combinations may have on temperatures within the pavement. The purpose of this study was to evaluate measured versus predicted temperatures, evaluate the effect of mix type on pavement temperature, and compare the effect of surface layer thickness on pavement temperatures. On the basis of temperature data from the NCAT test track, some of the general conclusions are that (1) both the Strategic Highway Research Program (SHRP) and Long-Term Pavement Performance (LTPP) temperature models slightly underpredicted high pavement temperatures at 50 percent reliability and slightly overpredicted temperatures at 98 percent reliability and (2) the low-temperature models for SHRP overpredicted low pavement temperatures for both 50 percent and 98 percent reliability. The LTPP models were also overly conservative at 98 percent reliability. These results indicate that asphalt binders may not need to be as soft as specified in the SUPERPAVE performance grading system for low-temperature performance.

Application/Use: The findings from this study are applicable to the selection of binder grade in pavements.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The LTPP database was used to develop temperature prediction models for use in PG binder grade selection. This has been beneficial in improved materials selection and pavement performance.

Future Benefit: The temperature prediction models will continue to be beneficial. Proper binder selection leads to more cost-effective and better-performing pavements.

Title: Assessment of Overlay Roughness in Long-Term Pavement Performance Test Sites: Canadian Case Study

Author(s): Smith, J. T; Tighe, S. L.

Date: 2004

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1869

Abstract/Synopsis: A study was conducted on asphalt pavement overlay performance in the Canadian environment. It investigated the impact of asphalt overlay thickness, climatic zone, and subgrade type on the progression of roughness as described by the international roughness index (IRI). Data from the Canadian Long-Term Pavement Performance (LTPP) test sites were analyzed. As a result of the investigation, pavement factors that significantly impact overlay performance in the Canadian environment were identified. Data collected over the first 13 years of study were used to show national and provincial roughness trends from 53 test sites. The IRI data were statistically summarized (mean, standard deviation) for each category by the age of the overlay section. With the summarized data, regression analysis was used to determine an equation that best describes the progression of roughness. Two-factor analysis of variance was used to determine if there were any significant differences within specific categories. The results of the regression analysis were compared with the Canadian Strategic Highway Research Project LTPP to confirm the validity of the roughness progression equations. Results show that overlay thickness and climatic zones significantly impact the roughness, while subgrade type has little influence on the IRI values. The roughness progression equations achieved squared correlation coefficients (R-squared) between 0.93 and 0.39, demonstrating the accuracy of the model equations.

Application/Use: The results from this paper can be used to understand roughness accumulation and the effects of overlay thickness and climatic zone on this accumulation.

Contribution: Improvement in Knowledge

Present Benefit: Roughness significantly affects the end user's perception on the quality of the pavement. The ability to predict the accumulation of roughness, as well understanding the factors that contribute to improved ride quality performance are extremely useful to the transportation industry. Roughness predictions can be used as a tool in programming funds for future rehabilitation.

Future Benefit: The LTPP program offers approximately 20 years of performance data for in-service pavements. The data can be used to predict performance in areas with limited monitored data. Understanding the contribution of overlay thickness and other factors on roughness will also be beneficial to agencies as they consider rehabilitation alternatives.

Title: Pavement Roughness Modeling Using Back-Propagation Neural Networks

Author(s): Choi, J-H; Adams, T M; Bahia, H. U.

Date: 2004

Publisher: Blackwell Publishing

Journal Title: Computer-Aided Civil and Infrastructure Engineering Vol. 19 No. 4

Abstract/Synopsis: Quantifying the relationship between material and construction (M&C) variables and pavement performance is a key ongoing area of research. However, it is understood that deriving such relationships is too complex and too poorly understood to develop using traditional statistical methods. Therefore, this work focuses on the analysis of a data set from the Long-Term Pavement Performance (LTPP) database to quantify the contribution of M&C variables of asphalt concrete on pavement performance (i.e., international roughness indicator) using a back-propagation neural network (BPNN) algorithm. It was found that by using sensitivity analysis neural network trained with optimal number of epochs could be used effectively for better understanding of the factors controlling overall performance indicators, establishing quantitative functions to weigh the role of such factors, and for use in performance-related specifications.

Application/Use: The findings from this study are useful for those interested in studying factors influencing pavement roughness. It is also applicable in evaluating neural network algorithms for prediction purposes.

Contribution: Improvement in Knowledge

Present Benefit: The study offers insight into the contribution of materials and construction related factors on pavement roughness. Understanding these interactions improves materials selection and can be used in establishing construction specifications. Additionally, the neural network algorithms used in this study may be applied to other pavement predictions.

Future Benefit: The LTPP database will contribute to future research by providing data necessary to evaluate new prediction techniques. As part of this process, bias, error, and sensitivity studies can also be conducted using the LTPP database. These improved prediction techniques, along with quantified variability, will benefit the pavement community in a multitude of areas.

Title: Use of Artificial Neural Networks for Predicting Rigid Pavement Roughness

Author(s): Teomete, Egemen; Bayrak, Mustafa Birkan; Agarwal, Manish

Date: 2004

Publisher: Iowa State University, Ames

Conference Title: 2004 Transportation Scholars Conference

Abstract/Synopsis: This paper focuses on analyzing the Long Term Pavement Performance (LTPP) database to predict the international roughness index (IRI) in rigid pavements using artificial neural networks (ANNs). Large number of input parameters such as pavement layer data including the initial IRI value, age, faulting, traffic data, and transverse cracking data for 3 different severity levels (low, medium, and high) were used to predict the IRI values for jointed Portland cement concrete (JPCC) pavements. Substantial amounts of pavement performance data queried from 83 pavement sections that belong to 9 states were used in developing the ANN pavement roughness prediction models. The developed ANN models were able to successfully predict the measured IRI values with coefficient of multiple determination values of 0.84 for the training data set and 0.81 for the testing data set. Results showed that the selection criteria for the testing sets are very important when evaluating the performance of the ANN models. It was demonstrated that ANNs are capable of mapping the complex, nonlinear relationship between the large number of pavement input parameters and the pavement roughness index of IRI value. Such models can be used to predict and forecast the pavement roughness index for pavement management system applications.

Application/Use: This paper can be used by those interested in pavement roughness predictions.

Contribution: Improvement in Knowledge

Present Benefit: Pavement roughness predictions are useful in pavement management as well as pavement design. Accurate predictions can be used to make cost-effective decisions on improvements in timing and budgeting. This paper is also useful in evaluating artificial neural network algorithms.

Future Benefit: The LTPP database will contribute to future research by providing data necessary to evaluate new prediction techniques. As part of this process, bias, error, and sensitivity studies can also be conducted using the LTPP database. Improved prediction techniques, along with quantified variability, will benefit the pavement community in a multitude of areas.

Title: Using Long-Term Pavement Performance Data to Predict Seasonal Variation in Asphalt Concrete Modulas

Author(s): Salem, H. M; Bayomy, F M; Al-Taher, M. G; Genc, I. H.

Date: 2004

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1896

Abstract/Synopsis: The seasonal variation of the asphalt concrete (AC) modulus with changes in pavement temperature is discussed. The main goal of the research was to develop (a) regression models that enable design engineers to assess seasonal changes in AC modulus and (b) an algorithm for calculating a seasonal adjustment factor (SAF) that allows estimating AC modulus in any season from a known reference value. The study is based on analyzing data collected at Long-Term Pavement Performance (LTPP) program sites in both freezing and nonfreezing zones. The data were obtained from the LTPP database in the DataPave 3.0 software. The approach adopted in this study was to select LTPP-seasonal monitoring program sites that represent various climatic regions and use the backcalculated modulus and pavement temperature data to develop regression models for the modulus-temperature relationships for various sites in both freezing and nonfreezing zones. Two regression models were developed to relate the variation in modulus with the variation in pavement temperatures in various seasons for both freezing and nonfreezing zones. These models incorporate AC layer properties such as thickness, bulk specific gravity, air voids, and asphalt binder grade. A model for determining the SAF was also developed.

Application/Use: The findings from this study are directly applicable to pavement design.

Contribution: Improvement in Knowledge

Present Benefit: Understanding changes in AC modulus as a function of changes in temperature is beneficial in pavement design. It allows designers to select pavement sections and materials that efficiently account for these seasonal variations.

Future Benefit: As pavement design moves towards M-E PDG practices, understanding modulus changes will be an essential part of the process. The results from this study will be useful in estimating AC modulus values in different seasons.

Title: Analysis of Influences on As-Built Pavement Roughness in Asphalt Overlays

Author(s): Raymond, C. M; Tighe, S. L; Haas, R; Rothenburg, Leo

Date: 2003

Publisher: International Journal of Pavement Engineering Vol. 4 No. 4

Journal Title: Application Notes

Abstract/Synopsis: Pavement designers, construction engineers and contractors must understand the effects that influence the as-built roughness of a pavement so that they can maximize their designs, smoothness specifications, and bidding of contracts with smoothness specifications. This paper uses data from the Long-Term Pavement Performance (LTPP) program to examine four factors in order to determine their effects on the as-built roughness of a pavement. These factors include the extent of surface preparation prior to resurfacing, pavement roughness prior to resurfacing, overlay thickness and type of overlay material. To investigate the effects of these factors and any interactive effects, statistical procedures including paired data analyses, regression analyses and a repeated measures analysis were performed. Results showed that the extent of surface preparation, overlay thickness, and pavement roughness prior to resurfacing had a statistically significant effect on the as-built roughness of a pavement either directly or interactively with another variable. The overlay mix type did not have an influence on as-built pavement roughness. Data from the Canadian Long-Term Pavement Performance program is used to validate the results for overlay thickness and pavement roughness prior to resurfacing. Prediction equations are also developed to estimate the as-built roughness of a pavement under various conditions. Based on these findings, it is recommended that the lower as-built roughness that is achieved by incorporating a thicker pavement overlay and/or intensive surface preparation should be considered in pavement design.

Application/Use: This paper can be used by those designing overlay rehabilitation alternatives.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: This paper provides information on the effect of overlay design features on as-built pavement roughness. This information can be used to select overlay design features that reduce as-built roughness. Roughness after construction has a significant impact on the accumulation of roughness over time. Minimizing construction-related roughness can lead to improved roughness over time. This results in improved pavement performance and reduced user costs.

Future Benefit: Overlay rehabilitations are a common practice. Information on the factors that contribute to roughness will continue to be beneficial as overlay construction continues.

Title: Demonstration and Evaluation of SUPERPAVE Technologies: Final Evaluation Report for CT Route 2

Author(s): Larsen, D. A.

Date: 2003

Publisher: Connecticut Department of Transportation; Federal Highway Administration

Abstract/Synopsis: Connecticut's first full-scale SUPERPAVE project was constructed in 1997 on CT State Route 2 in Colchester, Lebanon, and Bozrah. Six 2-mile sections, four SUPERPAVE and two Connecticut Department of Transportation (ConnDOT) Class 1 overlays were placed between May and September 1997. Two of the SUPERPAVE mixes and one Class 1 mix utilized 20 percent RAP obtained by milling the existing surface layer from Route 2. This was also Connecticut's first hot mix asphalt (HMA) project where Quality Control was the responsibility of the contractor. This final report covers the period following construction where field evaluations were performed from September 1997 through March 2003. During this time frame, pavement cores were removed, friction tests obtained, and condition surveys were performed. ConnDOT research staff collected information on the full 2-mile sections using manual surveys and automated equipment; and, since this project is also part of the Federal Highway Administration's (FHWA's) LTPP SPS 9A study for "Verification of SHRP Asphalt Specification and Mix Design," 1000 ft sections within each of the six pavements were monitored, sampled and tested by the North Atlantic FHWA LTPP regional contractor using SHRP-LTPP protocols. The pavements are performing as would be expected for 5-year-old overlays on a 27-year-old base. Thus far, there are only minor differences between the conventional ConnDOT Class 1 overlays and the SUPERPAVE mixes. The mixes containing 20 percent RAP appear to be performing slightly worse than the virgin mixes, possibly due to excessive air voids, higher permeability, lower asphalt content, and a high groundwater table.

Application/Use: This report can provide information on performance of SUPERPAVE mixes compared to standard Connecticut mixes.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The study is beneficial to Connecticut in determining the differences in performance between their existing mix design procedures and the SUPERPAVE procedures.

Future Benefit: The data collected at the site will serve as a basis for future monitoring. Additional monitoring will provide an opportunity to quantify differences in performance and develop life cycle cost comparisons.

Title: Effects of Excessive Pavement Joint Opening and Freezing on Sealants

Author(s): Lee, S. W; Stoffels, S. M.

Date: 2003

Publisher: American Society of Civil Engineers

Journal Title: Journal of Transportation Engineering Vol. 129 No. 4

Abstract/Synopsis: The primary purposes of joint sealing in jointed concrete pavements are to minimize moisture infiltration through the joints, to reduce moisture-related distress (such as pumping), and to prevent the intrusion of incompressible material into joints to minimize pressure-related distress (such as spalling). However, the dilemma of whether to or not to seal frequently has arisen since the benefit of improvement in pavement performance with joint sealing could not be clearly demonstrated in a number of prior studies. Premature failure of sealant has been considered as a major cause of the ineffectiveness of joint seal. Poor construction quality and material properties of sealant have been considered as problems that induce the premature failure of joint seal. In this study, other causes, which are related to the shortcomings of the AASHTO joint seal design method, which may induce premature failure of joint seal, are addressed. The first cause is in situ joint openings larger than AASHTO predictions. Variability of joint openings in a given pavement section, including erratic large openings at a considerable portion of joints, has been discussed. High chances of adhesion-type failure are plausibly related with such erratic large openings. The relationship between sealant damage and the ratio of in situ maximum joint opening to permissible sealant elongation was demonstrated in this study based on the observations from 90 joints in 16 jointed concrete long term performance pavement special pavement studies (LTPP SMP) sites. The second cause is joint freezing (defined as joints showing no movement). At frozen joints, joint seals are likely to be redundant, and a waste of money. A method for joint seal design with survival criteria is suggested in this study. In this model, joint openings are estimated based on the Lee-Stoffels model, a probabilistic model that can predict the magnitudes of joint opening with its probabilities. Joint seal designs for 16 LTPP SMP sites, based on this survival model, indicated that some sections should have sealant-type changed, to permit more elongation with the given joint reservoir, whereas other sections do not need joint seal.

Application/Use: The findings presented are useful in joint design and sealant material selection.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Proper design and material selection of joints is essential in mitigating pumping, spalling, faulting, and other damage in PCC pavement. This paper provides information on joint opening variation that is useful in determining the joint reservoir and sealant type.

Future Benefit: The SMP experiment conducted as part of the LTPP program provides data on joint opening linked with performance and climatic information. This is extremely valuable in understanding pavement response variation with changes in season and will continue to benefit the pavement community.

Title: Prediction of Longitudinal Roughness Using Neural Network

Author(s): Farias, M. M; Neto, S.A.D; Souza, R. O.

Date: 2003

Publisher: Universidade do Minho, Portugal

Conference Title: Maintenance and Rehabilitation of Pavements and Technological Control

Abstract/Synopsis: Longitudinal roughness is the major cause of discomfort for passengers and the main variable when computing rideability and serviceability indices of pavements in several countries. Therefore it is important to predict when the road will achieve a critical level of roughness in order to allocate funds fir necessary maintenance and rehabilitation. In this paper, International Roughness Index (IRI) values were obtained for a profile database of the Long-Term Pavement Performance (LTPP) program, including 42 states of the USA. Later neural networks were used to predict this index having input parameters related to the type of sub-grade soil pavements structure (layer thickness), climate and traffic. A neural network was able to forecast IRI with an extremely high correlation factor (R2=0.99). Besides, neural network provided a sensitivity analysis indicating relative contribution factors related to the structural number (49%), climate (31%), and traffic (20%). Multivariate linear and nonlinear statistic regressions were also performed and could not find any correlation at all.

Application/Use: This paper can be used by those interested in pavement roughness predictions.

Contribution: Improvement in Knowledge

Present Benefit: This paper provides insight on pavement roughness prediction using neural network algorithms. Predictions are useful in pavement management as well as pavement design.

Future Benefit: The LTPP database provides the means of evaluating new prediction models and techniques. This will be beneficial as new techniques are introduced as it allows error and variability estimates to be established.

Title: Benefiting from LTPP - A State's Perspective

Author(s): Hoffman, G.

Date: 2002

Publisher: Federal Highway Administration

Journal Title: Public Roads Vol. 65 No. 6

Abstract/Synopsis: For more than a decade, the U.S. Federal Government, the States, and Canadian provinces have invested in the Long-Term Pavement Performance Program (LTPP), a 20-year pavement research project. During its first ten years, LTPP gathered, processed, and analyzed data describing the structure, service conditions, and performance of more than 2,500 pavement test sections in North America. This article provides a discussion of the values and benefits of LTPP to date from the perspective of the author's experience with the Program in the state of Pennsylvania.

Application/Use: This article is useful in providing state highway agencies examples of how the LTPP program can be used in many aspects of their operation.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The LTPP program has a wide variety of products that can be used by state highway agencies. This includes data collection/equipment protocol, performance data from across the country, as well as many research results. This information can supplement ongoing research at the state-level or can be implemented directly. In either case, cost savings can be realized by tapping the LTPP resource.

Future Benefit: The LTPP program will continue to add benefit as new research needs arise. In particular, local calibration and validation of the M-E PDG will rely heavily on LTPP data.

Title: Calibration of a Pavement Roughness Model Based on Finite Element Simulation

Author(s): Saleh, M. F; Mamlouk, M. S.

Date: 2002

Publisher: Taylor & Francis Limited

Journal Title: International Journal of Pavement Engineering Vol. 3 No. 4

Abstract/Synopsis: In this paper calibration and verification of a roughness performance model of flexible pavements, which was previously developed, is conducted. 110 in-service pavement sections were extracted from the Long Term Pavement Performance (LTPP) database 2000, 86 of which were used for calibration and the remainders were used for verification. These pavement sections were taken from four different climatic zones: dry freeze, dry no-freeze, wet freeze and wet no-freeze, Calibrating factors were determined for each climatic zone by minimizing the differences between observed and predicted roughness data at all ages. Calibration factors were determined and incorporated in the roughness performance model so that a minimum total prediction error was obtained. The calibration factors for the four climatic zones and the global zone ranged from 0.689 to 0.757. For all the climatic zones the observed and predicted roughness data after calibration were very well correlated coefficients ranging from 0.879 to 0.913, which proves the applicability of the model.

Application/Use: The paper is useful for those interested in the prediction of pavement roughness.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: The LTPP database provides a large source of data for calibrating and validating prediction models. This is beneficial in evaluating new prediction techniques and improving existing applications.

Future Benefit: Accurate performance predictions are beneficial in pavement management applications as they allow for optimum treatment timing and can be used for budgeting purposes.

Title: Development of Asphalt Overlay Performance Models from the C-LTPP Experiment

Author(s): Tighe, S; Haas, R; Ningyuan, L.

Date: 2002

Publisher: International Society for Asphalt Pavements

Conference Title: Ninth International Conference on Asphalt Pavements

Abstract/Synopsis: The Canadian Long Term Pavement Performance (C-LTPP) study was initiated in 1989. The study involves 65 sections in the 24 provincial sites that received rehabilitation comprising various thicknesses of asphalt overlays. This paper describes the impacts of the various alternative rehabilitation treatments on pavement performance in terms of roughness progression under comparative traffic loading, climate, and subgrade soil conditions. Factor effects, including climatic zone, subgrade type and traffic level were also evaluated. The methodology developed in this study on pavement roughness evaluation can be applied to performance trends analysis of other LTPP data.

Application/Use: The results from this paper can be used to understand roughness accumulation and the effects of overlay thickness and climatic zone on this accumulation.

Contribution: Improvement in Knowledge

Present Benefit: Roughness significantly affects the end user's perception on the quality of the pavement. The ability to predict the accumulation of roughness as well as the factors that contribute to improved ride quality performance are extremely beneficial to the transportation industry. Roughness predictions can be used as a tool in programming funds for future rehabilitation.

Future Benefit: The LTPP program offers approximately 20 years of performance data for in-service pavements. The data can be used to predict performance in areas with limited monitored data. Understanding the contribution of overlay thickness and other factors on roughness will also benefit agencies as they investigate rehabilitation alternatives.

Title: Development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures (NCHRP 1-37A)

Date: 2002

Publisher: FHWA

Abstract/Synopsis: This project produced a mechanistic-empirical (M-E) pavement design guide that includes (1) a Guide for M-E design and analysis, (2) companion software with documentation and a user manual, and (3) implementation and training materials. The guide includes procedures for the analysis and design of new and rehabilitated, flexible, rigid, and semi-rigid pavements. It uses M-E numerical models to analyze input data for traffic, climate, materials, and structure to estimate damage accumulation and predict performance, in terms of distress and smoothness, over user-specified service life for comparison with threshold values (i.e., it does not provide structural thickness as an output).

This research reviewed relevant domestic and foreign literature, research findings, current practices, and databases relative to pavement analysis and design; developed a design guide based on sound mechanistic principles; presented the Guide as a computational software; and provided related documentation and training materials. The Guide provides a uniform basis for the design of flexible, rigid, and composite pavements and employs common design parameters for traffic, subgrade, and environment. It uses M-E performance models that were calibrated using field data from the Long Term Pavement Performance (LTPP) studies and other sources.

Application/Use: The M-E pavement design guide will be used in pavement design, evaluation, and analysis across the country.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: The M-E PDG is a shift in the paradigm of pavement design/ evaluation. The Guide incorporates mechanistic principles with empirical performance relationships. The 1993 AASHTO guide was developed using empirical correlations from data collected at the AASHO Road Test. Additionally, the output from the M-E PDG is a set of performance predictions based on an input set of site conditions and pavement structure. This allows the software to be used both to develop pavement designs and to evaluate existing pavements. The Guide's prediction models were developed using LTPP sites. In fact, developers of the Guide have stated that the project would not have been possible without LTPP. Because the data is from in-services pavements all across the U.S. and Canada and exposed to a wide range of traffic, climate, and subgrade conditions, the M-E PDG is calibrated on a national level. To refine the Guide to local conditions, many agencies will rely on local LTPP sites in the implementation process.

Future Benefit: The M-E PDG will likely be used by numerous agencies to perform pavement design and evaluation. Properly calibrated and implemented models will result in cost-effective pavement designs and overall improvement in the condition of the pavement network.

Title: LTPP Data Analysis: Variations in Pavement Design Inputs

Author(s): Stubstad, R. N; Tayabji, S. D; Lukanen, E. O.

Date: 2002

Publisher: National Cooperative Highway Research Program

Journal Title: NCHRP Web Document 48

Abstract/Synopsis: This report presents the results of research on variations in pavement design inputs and quantifies the variability of these key pavement design parameters. It is often the case that precisely this variability is the ultimate cause of observed pavement distress. The major findings are as follows: (1) A review of the literature did not reveal the variability of all of the important pavement design input parameters. Even where variability was discussed and reported in the literature, the databases used to arrive at the reported variability were generally limited. (2) For the five categories of design inputs addressed in this study, the Long Term Pavement Performance (LTPP) database yielded very useful information on variability. All important pavement design input parameters are well represented in the data with the possible exception of sufficiently accurate backcalculated moduli and the long-term variability of load transfer efficiency of jointed concrete pavements. (3) Variability in design inputs is generally measured in terms of standard deviation or coefficient of variation. More importantly, the use of various "certainty" or confidence levels for pavement design inputs is also reported. Typical values for each major pavement design input category have been developed and are reported in various summary tables.

Application/Use: This study is directly applicable to pavement design.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: Quantifying the variability for design input parameters can be extremely beneficial in optimizing pavement design. Coupling this information with sensitivity analyses would provide information needed to determine the appropriate level of effort to be dedicated to obtaining design parameters.

Future Benefit: The LTPP database provides an excellent source for variability studies. The database will provide future benefit for additional research in variability as well as many other topics.

Title: Temperature Correction of Multiload-Level Falling Weight Deflectometer Deflections

Author(s): Park, H. M; Kim, Y. R; Park, S.

Date: 2002

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1806

Abstract/Synopsis: A new temperature correction procedure was developed for multiload-level falling weight deflectometer (FWD) deflections for flexible pavements in North Carolina. In this procedure, temperature correction factors were dependent on the radial offset distance from the FWD load plate. Temperature and FWD multiload-level deflection data used in developing this procedure were collected from 11 pavements in three different climatic regions of North Carolina. The effect of the FWD load level on this temperature correction procedure was investigated. Research efforts focused on improving the accuracy of the current temperature correction procedure of the North Carolina Department of Transportation. The measured deflection and temperature data were also used to validate the long-term pavement performance (LTPP) temperature correction procedure. It was found that the effective pavement temperature prediction algorithm in the LTPP procedure is relatively accurate and that the temperature-deflection correction procedure undercorrects the deflections at higher temperatures in pavements with an asphalt concrete layer thicker than 242 mm. The main reason for this deficiency is that the LTPP procedure was developed from the national database and cannot fully consider the local variation in mixture characteristics.

Application/Use: The paper is directly applicable to FWD data collection in North Carolina.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: This study involves evaluating the LTPP temperature correction model. This model has been used as a national standard and was developed from data collected as part of the LTPP program. This model provides an avenue of adjusting deflections based on temperature during data collection. Without the LTPP database, a national model would not have been feasible.

Future Benefit: The LTPP database offers the resources to develop new relationships or evaluate and modify existing procedures on a national scale. This is beneficial as new procedures are continuously created. Without the LTPP database, it would be difficult to evaluate these on a national level.

Title: Utilizing the Long-Term Pavement Performance Database in Evaluating the Effectiveness of Pavement Smoothness

Author(s): Ksaibati, K; Mahmood, S. A.

Date: 2002

Publisher: Mountain-Plains Consortium

Abstract/Synopsis: State Highway Agencies (SHAs) in the United States use smoothness specifications to insure that they are providing the public with quality roads. Monetary incentives/disincentive policies based on the initial roughness values are used by SHAs to encourage contractors to build smoother roads. To justify the extra costs associated with smoothness specifications, it is important to demonstrate that smoother roadways do stay smooth over time. This research study was conducted at the University of Wyoming to examine if the initial roughness of a pavement section has any effects on its long-term performance. A large number of test sections from the Long-Term Pavement Performance (LTPP) database was included in the study. The statistical tests performed indicate that asphalt and concrete pavements with low initial smoothness stay smooth over time. This study also emphasized the importance of utilization of the LTPP database.

Application/Use: This paper can be used by those interested in post-construction smoothness and its effect on long term roughness accumulation.

Contribution: Improvement in Knowledge

Present Benefit: Quantifying the relationship between initial smoothness and progression of roughness over time allows highway agencies to adjust specifications and optimize long term performance. The amount of data available in the LTPP database allows this type of study to be conducted on a large dataset, over a variety of in situ conditions, creating robust results.

Future Benefit: The inventory and performance data in the LTPP database will be valuable to researchers as similar future studies and evaluations are conducted.

Title: Performance of Continuously Reinforced Concrete Pavements in the LTPP Program

Author(s): Tayabji, S. D; Wu, C. L; Plei, M.

Date: 2001

Publisher: International Society for Concrete Pavements

Conference Title: Seventh International Conference on Concrete Pavements. The Use of Concrete in Developing Long-Lasting Pavement Solutions for the 21st Century

Abstract/Synopsis: Since the 1960's, thousands of miles of continuously reinforced concrete pavements (CRCP) have been constructed in the United States. These pavements have typically provided a service life of more than 20 years without requiring major rehabilitation. Design procedures of CRCP have evolved over time. The thickness design is typically based on the design procedures for jointed concrete pavements, with many agencies using slightly lower thickness than those determined for comparable jointed concrete pavements. The design for the continuous longitudinal steel is actually based on meeting the requirements of three criteria related to crack spacing, cracks width, and concrete strength. Over the last 10 years the performance of eighty-five CRCP sections throughout the United States has been monitored as part of the GPS-5 experiment of the Long-Term Pavement Performance (LTPP) program. The age of these sections range from 5 to 34 years and the thickness of the sections are primarily 203 to 254 millimeters. Most of the sections incorporate about 0.60 percent of steel. The objective of this paper is to provide the results of a study conducted to evaluate the performance of these sections. Key features of the sections are detailed and the performance trends, in terms of observed distresses, ride, and structural testing are discussed. Finally, the results of the analysis of well performing CRCP sections are presented.

Application/Use: This study is directly applicable to pavement engineers involved with design, construction, and maintenance of CRCP.

Contribution: Cost Savings, Improvement in Knowledge.

Present Benefit: The LTPP database contains inventory and performance data for CRCP test sections. This information is beneficial in evaluating current CRCP design practices as well as understanding key design factors in performance. This type of research can lead to refinements in design practices, thereby creating more cost-effective designs.

Future Benefit: The data available through LTPP will continue to provide a means of evaluating pavement performance to enhance design, construction, and maintenance activities. This will lead to improved performance at reduced overall cost.

Title: Smoothness Models for Hot-Mix Asphalt Surfaced Pavements: Developed from Long-Term Pavement Performance Program Data

Author(s): Von Quintus, H. L; Eltahan, A; Yau, A.

Date: 2001

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1764

Abstract/Synopsis: The results of a study conducted to determine the relationship between changes in the surface distress of flexible pavements and incremental changes in the international roughness index (IRI) or ride quality by using Long-Term Pavement Performance (LTPP) program data are presented. The results of the regression analyses completed to identify those distresses found to be important and related to incremental changes in the IRI were obtained under the sponsorship of National Cooperative Highway Research Program (NCHRP) Project 1-37A (Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures). The results from the study have shown that selected distresses do have a significant effect on incremental changes in IRI with time and traffic.

Application/Use: The results summarized can be used for the management, design, or evaluation of pavement structures.

Contribution: Improvement in Knowledge

Present Benefit: The relationship between roughness and surface distress is beneficial in pavement management and design. By understanding the contribution of distress to smoothness, pavement managers can select maintenance treatments to mitigate the largest contributors or develop rehabilitation alternatives that correct distress deficiencies and improve smoothness.

Future Benefit: The LTPP database has both distress and roughness performance data for pavement test sections. The national nature of the dataset allows robust analyses to be conducted to study the interaction between various performance measures.

Title: LTPP and the 2002 Pavement Design Guide

Date: 2000

Publisher: Federal Highway Administration

Abstract/Synopsis: The American Association of State Highway and Transportation Official's (AASHTO) Guide for the Design of Pavement Structures is widely used in the design of new and rehabilitated highway pavements. However, the current Design Guide, published in 1993, is widely recognized as being inadequate for the design challenges currently faced by highway agencies because it relies on empirically based procedures founded on test data that are not representative of current pavement design conditions. The 1993 Design Guide does not offer the best available design procedures. For this reason, the National Cooperative Highway Research Program (NCHRP) has undertaken Project 1-37A, “Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures.” This pamphlet discusses the reasons that a new Design Guide is possible, and lists its benefits. It describes the Long Term Pavement Performance (LTPP) program and discusses how the LTPP data address the current Design Guide's limitations. Included are discussions of traffic loadings, LTPP test sections, and data on rehabilitation, climate, subgrade materials, base materials, vehicle fleet, drainage and distress. The pamphlet explores the LTPP and procedures that will be used as inputs for evaluation. It discusses the LTPP data which will be used for calibration and validation. Finally, it describes the role of LTPP data in the future enhancement of the 2002 Design Guide. Special Pavement Sections (SPS), and the useful data they will generate, are described.

Application/Use: The M-E PDG will be the national standard for pavement design.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology; Implementation/Usage.

Present Benefit: It is well documented that the M-E PDG used LTPP data extensively as a critical element in the guide’s development. The M-E PDG is just one example of the numerous studies that would not have been possible if LTPP data was unavailable. There is currently no source of pavement information that approaches the LTPP database. The LTPP database contains comprehensive inventory, materials, traffic, climatic, and performance data for pavements across North America.

Future Benefit: When considering the future benefit of the LTPP database, comparisons must be made to the AASHO road test. Data collected at the road test has been used for over 40 years. Considering that the LTPP database is much larger and more comprehensive than the road test dataset, it is highly likely that LTPP will be referenced and utilized for at least the next 40 years. Without the LTPP database, SHAs and local agencies would be hard pressed to find the condition data required to properly implement the M-E PDG.

Title: LTPP and the 2002 Pavement Design Guide (Brochure)

Date: 2000

Publisher: Federal Highway Administration

Abstract/Synopsis: This brochure briefly discusses why a new pavement design guide is necessary, what makes it possible today, and the benefits of a 2002 Design Guide. The Long Term Pavement Performance (LTPP) program is then discussed and information is presented on: how LTPP data address the current design guide's limitations; the use of LTPP data for calibration and validation; the use of LTPP data and procedures as inputs and for evaluation; and the role of LTPP data in the future enhancement of the 2002 Design Guide.

Application/Use: The M-E PDG will be the national standard for pavement design.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology; Implementation/Usage.

Application/Use: It is well documented that the M-E PDG used LTPP data extensively as a critical resource in the guide's development. The M-E PDG is just one example of the numerous studies that would not have been possible if LTPP data was unavailable. There is currently no comprehensive source of pavement information that approaches the LTPP database. The LTPP database contains detailed inventory, materials, traffic, climatic, and performance data for pavements across North America.

Future Benefit: When considering the future benefit of the LTPP database, comparisons must be made to the AASHO road test. Data collected at the road test has been used for over 40 years. Considering that the LTPP database is much larger and more comprehensive than the road test dataset, it is highly likely that LTPP will be referenced and utilized for at least the next 40 years. In the short term, the LTPP database will be an essential component of calibrating and validating the M-E PDG to local conditions. Without the LTPP database, SHA and local agencies would be hard pressed to find the condition data required to properly implement the M-E PDG.

Title: Design and Construction of PCC Pavements, Volume III: Improved PCC Performance Models

Authors: Titus-Glover, L; Owusu-Antwi, E B; Darter, M. I.

Date: 1999

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Abstract/Synopsis: This study was conducted to evaluate and analyze portland cement concrete (PCC) pavements in order to develop recommendations for the design and construction of long-lived concrete pavements. It involved a detailed evaluation and analysis of the PCC pavement data in the Long-Term Pavement Performance (LTPP) database using a variety of methods to determine the design features and practices that have beneficial effects on long-term performance. Emphasis was placed on identifying those specific design features that can be included during design to improve the performance of PCC pavements under various combinations of environmental and traffic loading conditions, and for different subgrade support conditions. The study focused on the development of practical recommendations that can be implemented by highway agencies to increase pavement life. This volume describes and provides information on improved pavement distress and roughness prediction models that were developed as part of the study. A key focus was to develop distress and roughness prediction models that incorporate mechanistic principles but are still practical for use by State highway agencies.

Application/Use: The models developed in this study are directly applicable to rigid pavement design.

Contribution: Cost Savings; Improvement in Knowledge; Implementation/Usage.

Present Benefit: The distress and roughness prediction models are beneficial in understanding the contribution of design features to pavement performance. Additionally, the interaction between these design feature and in situ conditions, such as climate, subgrade, and traffic can also be evaluated. This information can be used by pavement designers in selecting cost-effective pavement design alternatives. Additionally, design policy can be modified to accommodate relevant findings from this analysis.

Future Benefit: The findings from this study can be useful in the implementation of the M-E PDG. The prediction curves will aid in the local calibration and validation process. Additionally, the results from this study can be used as part of sensitivity analyses.

Title: Determination of Resilient Modulus for Maine Roadway Soils

Authors: Smart, A. L; Humphrey, D. N.

Date: 1999

Publisher: University of Maine, Orono; Maine Department of Transportation

Abstract/Synopsis: The Maine Department of Transportation commissioned this study to examine methods of obtaining resilient modulus for use in pavement design. Resilient modulus is a measure of soil layer stiffness and is highly subjective to density, moisture content, soil fabric structure, compaction method, laboratory equipment compliance, and technician skill. As a result, several alternative test methods have been proposed. These alternative test methods include resilient modulus correlation to results from torsional shear and resonant column tests, a modified gyratory test machine normally used for testing asphalt concrete specimens, and a small-scale falling weight deflectometer (FWD) device. The study used resilient modulus test data of 14 Maine soils published by Law Engineering (1992). Soil index property data and FWD data were obtained from the Strategic Highway Research Program's Long Term Pavement Performance (LTPP) database. Three methods for determining resilient modulus were examined: (1) backcalculation of resilient modulus using computer software, (2) determination of the K sub n constants for various constitutive resilient modulus equations by linear regression analysis, and (3) correlations between resilient modulus and soil property data and stress state. Computer backcalculation was done using MODCOMP 4 and MODULUS 5.1. The backcalculated resilient moduli did not compare well with the laboratory moduli when the programs automatically estimated the depth to hard layer and outliers were neglected. The K sub n constants for 7 common constitutive relationships were developed for 14 Maine soils using linear regression. Two equations correlating resilient modulus to dry density, water content, grain size distribution and stress state were also generated from linear regression techniques. California bearing ratio (CBR) does not correlate well with resilient modulus, therefore, no correlations involving CBR were examined.

Application/Use: This study will be used by materials and pavement engineers looking for resilient modulus estimates ob subgrade materials in the Maine area.

Contribution: Cost Savings, Improvement in Knowledge.

Present Benefit: Accurate estimates for subgrade resilient modulus are necessary for proper pavement design. The models developed will be a useful pavement design tool, particularly in projects where resilient modulus data was not obtained. Information on the relationship between FWD backcalculated results and measured resilient modulus can be useful in design as well.

Future Benefit: Pavement designs in Maine may be based on correlation derived from this study. Additional benefit will be realized as the M-E PDG is implemented and used for pavement evaluation and design.

Title: Evaluation of Rigid Pavement Joint Seal Movement

Authors: Morian, D. A; Suthahar, N; Stoffels, S.

Date: 1999

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1684

Abstract/Synopsis: The subject of sealing concrete pavement joints has been studied for many years, and a wealth of technology exists for successfully installing pavement joint seals. However, in practice, a great deal of inadequate performance has been observed by highway agencies in the United States in recent years. A primary reason for the observed problems is inadequate control of construction processes. Another very significant factor affecting the performance of joint seals is climatic conditions. Examined are the effects of climate on the movement of rigid pavement joints. Temperature, joint movement, and other data collected as a part of the Long-Term Pavement Performance (LTPP) program data collection for seasonal sites have been used to assess actual joint movements in various climatic conditions throughout the United States and Canada. These measured data are compared with theoretically calculated joint movements. In most cases the actual movements appear to be greater than those theoretically predicted. On the basis of measured joint openings from LTPP seasonal sections, the conclusion is made that the measured joint opening values are greater than joint opening values calculated using the AASHTO equation. The data also provide evidence that irregular joint openings are present at all the sites evaluated.

Application/Use: This study is directly applicable to rigid pavement design including both joint and sealant design.

Contribution: Improvement in Knowledge

Present Benefit: The LTPP SMP experiment has provided value in terms of sufficient data availability to support this analysis. The findings from the report can be used to understand the accuracy of the AASHTO joint opening equation and can be used to evaluate joint designs and sealant materials.

Future Benefit: Data from the SMP experiment will continue to provide an avenue to study specific responses resulting from variations of in situ conditions. There is currently no other source of data that matches the quantity and detail of the LTPP database.

Title: Evaluation of the 1993 AASHTO Flexible Pavement Design Model Using the LTPP Database

Authors: Sheehan, M. J; Tarr, S M; Okamoto, P. A.

Date: 1999

Publisher: Portland Cement Association

Abstract/Synopsis: The purpose of this analysis was to evaluate the predictive capability of the 1993 AASHTO flexible design model with data obtained from the Long Term Pavement Performance (LTPP) database. Specifically, the data used in this analysis comes from the following two General Pavement Study (GPS) experiments: GPS-1 Asphalt Concrete on Granular Base, and GPS-2 Asphalt Concrete on Bound Base. The current LTPP database consists of 211 GPS-1 and 126 GPS-2 sections located throughout the United States and Canada. A variety of information and data has been collected for each section, including climatic, material properties, traffic loadings, profile, distress, and numerous other types of data. The 1993 AASHTO flexible design model was evaluated by comparing the "predicted" cumulative 80 kN (18,000 lb.) equivalent single axle loads (ESALs) for each test section using the design model to the "actual" ESALs (estimated from LTPP traffic data) carried by the section. The scope of this analysis involved looking at a number of subsets of this predicted versus actual data. For both pavement types (GPS-1 and GPS-2), the effects of the following variables were investigated: climatic region, asphalt concrete thickness, structural number, traffic level, subgrade type, and subgrade resilient modulus. In addition, the analyses were run at three different reliability levels (50 percent, 75 percent and 90 percent) to demonstrate the need to design at a level above 50 percent. The statistical analysis indicates that the AASHTO flexible pavement model provides biased predictions for ESALs for a significant portion of the LTPP data, especially for GPS-1 test sections.

Application/Use: This study is directly applicable to flexible pavement design.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: This study is beneficial in understanding how the 1993 AASHTO design procedure relates to actual performance. The LTPP database provides the data required to complete the evaluation. Findings can be used to improve the design process and make better informed decisions on the selection of design input factors. This improves performance and leads to more cost-effective pavement designs.

Future Benefit: The LTPP database will be used in a similar fashion to calibrate and validate the M-E PDG. The comprehensive nature of the LTPP data will be invaluable in this regard as there is currently no other source of quality data that would support such an endeavor.

Title: New Software Tool Paves the Way for More Cost-Effective, Durable Roads in Kansas: Kansas Relies on LTPPBind Software to Select SuperPave Binder PGS

Date: 1999

Publisher: Federal Highway Administration

Journal Title: Application Notes

Abstract/Synopsis: The Long Term Pavement Performance (LTPP) program recently used data from its Seasonal Monitoring Program to quantify the relationship between air and pavement temperatures. This evaluation resulted in the development of improved low and high pavement temperature models for selecting Superpave performance grade (PG) asphalt binders. These improved models were then incorporated into a software program called LTPPBind. Today, the Kansas Department of Transportation (KDOT) relies on LTPPBind to select its Superpave binder PGs. LTPPBind provides users with the ability to select PGs based on actual site temperature conditions and adjust the selection based on site traffic loading and speed conditions. Benefits include reduced thermal cracking and rutting, less frequent road repairs, fewer highway maintenance zones to snarl traffic, and reduced costs.

Application/Use: LTPPBind software can be used to select the appropriate PG binder grading for a given climate and design reliability. It is also useful in selecting crack sealant with material properties that match climatic demands of the project.

Contribution: Cost Savings; Implementation/Usage.

Present Benefit: Improper binder selection in pavement design can lead to premature pavement failures and costly repairs. LTPPBind provides the means to select PG binder grading that matches a project's climatic demands and reliability requirements. This improves pavement performance and reduces the probability of premature failure. Similarily, LTPPBind can be beneficial in selecting the appropriate crack sealant. Crack sealant with the appropriate material properties will not fail prematurely. This improves pavement performance and slows future deterioration.

Future Benefit: Proper selection of binder and crack sealant will lead to an overall improvement in pavement condition. As agencies implement pavement management programs with optimal maintenance timing, it is critical to select crack sealants that will perform well for many years. This reduces costs and improves performance.

Title: Rigid Pavement Design Software: A New Tool for Improved Rigid Pavement Design

Date: 1999

Publisher: Federal Highway Administration

Journal Title: Product Brief

Abstract/Synopsis: Improved guidelines for designing Portland Cement Concrete pavements were developed under National Cooperative Highway Research Program (NCHRP) research and were validated by Long Term Pavement Performance (LTPP) data. To help highway managers and engineers implement this improved design procedure, the LTPP program developed a software program called Rigid Pavement Design Software. The software allows the engineer to tailor the rigid pavement design to site-specific conditions, materials, traffic, and design details. The resulting design is more cost effective and reliable. The new software is intended to be used in concert with DARwin (the computerized version of the AASHTO '93 Guide) as an interim tool. This Product Brief describes the Rigid Pavement Design Software, discusses who can benefit from it, and presents its new or modified design features that are not available in DARwin.

Application/Use: This software is directly applicable to rigid pavement design.

Contribution: Cost Savings; Advancement in Technology; Implementation/Usage.

Present Benefit: This software is beneficial to all involved in rigid pavement design. Pavement engineers can use the software to efficiently design pavements using improved procedures to achieve optimized sections given in situ conditions.

Future Benefit: LTPP has provided data to support modifying existing design procedures. Additional benefit has been realized in the development of the M-E PDG and the data available through LTPP will be essential to successful implementation of the new M-E PDG.

Title: Roughness Trends at C-SHRP LTPP Sites

Authors: Haas, R; Li, N; Tighe, S.

Date: 1999

Publisher: Transportation Association of Canada

Abstract/Synopsis: The Canadian Long Term Pavement Performance (C-LTPP) study began in 1989. Most of the 65 sections in the 24 provincial sites received overlay rehabilitation treatments of various thicknesses in 1989. Measurements of roughness in both wheel paths have been taken annually or biannually at most of the sites, using a "Dipstick" profiler, and converted to International Roughness Index (IRI) in m/km. This study reviews the first seven years of the roughness measurements on all of the 65 sections prior to and after overlay rehabilitation. The purpose is to investigate the impacts of the various alternative rehabilitation strategies on pavement roughness progression under comparative traffic loading, climate, and subgrade soil conditions. Roughness trends are the main subject of this report. But it should be emphasized that these trends only cover the initial part of a long term pavement performance experiment. Individual provincial trends of roughness range from a linear to near linear progression to essentially no change to year to year variations which do not yet indicate a clear trend. Progression of average roughness for thin overlays (30-60 mm) is significantly higher on a national basis than for medium (60-100 mm) and thick (100-185 mm) overlays. In addition, the rate of roughness progression is increasing. Factor effects, including climatic zone, subgrade type and traffic level were also evaluated.

Application/Use: The results from this paper can be used to understand roughness accumulation and the effects of overlay thickness and climatic zone on this accumulation.

Contribution: Improvement in Knowledge

Present Benefit: Roughness significantly affects the end user's perception on the quality of the pavement. The ability to predict the accumulation of roughness, as well as the factors that contribute to improved ride quality, are extremely useful to the transportation industry. Roughness predictions can be used as a tool in programming funds for future rehabilitation.

Future Benefit: The LTPP offers approximately 20 years of performance data for in-service pavements. The data can be used to predict performance in areas with limited.

Title: Calibration of Mechanistic-Empirical Rutting Model for In-Service Pavements

Authors: Ali, H. A; Tayabji, S. D; La Torre, F.

Date: 1998

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1629

Abstract/Synopsis: Rutting is a major failure mode for flexible pavements. Pavement engineers have been trying to control and arrest the development of rutting for years. Many models are available to relate pavement rutting to design features, traffic loading, and climatic conditions. These models range from purely empirical to mechanistic models. Mechanistic-empirical models (the Asphalt Institute and Shell) were used to predict the development of rutting for 61 Long-Term Pavement Performance (LTPP) test sections. The rutting damage, calculated using these models, did not appear to be a good predictor of the observed rutting depth. A new rutting model was developed and calibrated using the data from the 61 LTPP sections. The model accounts for the plastic deformation in all pavement layers and allows the use of actual axle load and type, rather than the equivalent single axle load, in characterizing traffic.

Application/Use: This study will be used by those implementing and calibrating the M-E PDG.

Contribution: Improvement in Knowledge

Present Benefit: This study has provided insight into factors contributing to rutting. Additionally, the paper can assist in implementing and calibrating the M-E PDG to local conditions

Future Benefit: The evaluation conducted in this paper will be beneficial as the M-E PDG continues to be investigated, calibrated, and implemented.

Title: Calibration of Performance Models for Jointed Plain Concrete Pavements Using Long-Term Pavement Performance Database

Authors: Bustos, M; de Solminihac, H. E; Darter, M. I; Caroca, A; Covarrubias, J. P.

Date: 1998

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1629

Abstract/Synopsis: A methodology for calibrating performance models for jointed plain concrete pavements (JPCP) is presented; it is based on statistical analysis of data from the Long-Term Pavement Performance (LTPP) database. The methodology provides calibration factors to pavements in four climatic regions (dry-freeze, dry-nonfreeze, wet-freeze, and wet-nonfreeze) for the JPCP performance models in HDM-4: joint faulting, transverse cracking, joint spalling, and roughness. The procedure allows calculation of global calibration factors, which does not affect significantly the quality of the prediction compared with the quality achieved through the use of regional factors.

Application/Use: This is directly applicable to pavement design and performance modeling using M-E procedures.

Contribution: Improvement in Knowledge

Present Benefit: The procedure described in the paper will be beneficial to agencies in implementing the M-E PDG on a local level. The calibration and validation process will require the use of site specific data. If this is not available through agency records, the LTPP database will provide the data needed

Future Benefit: The LTPP database provides a source of site-specific data that can be used in the M-E PDG implementation process. This will be particularly valuable for agencies that do not have sufficient data available from pavement management systems or other sources of in situ condition/performance.

Title: Computer Parameters: Freeze/Thaw Monograph for Long Term Pavement Performance (LTPP)

Date: 1998

Publisher: Federal Highway Administration

Abstract/Synopsis: To study the effect of freezing/thawing conditions on pavement performance, data from three electrical resistivity (ER) measurements (resistivity, resistance, and voltage) are collected approximately every month, every other year at selected Seasonal Monitoring Program (SMP) sections. In addition, soil temperature data are collected daily. An interactive procedure was developed and used to interpret ER and temperature data and to derive the freeze state and frost penetration parameters. The data are contained in two tables: SMP_FREEZE_STATE and SMP_FROST_PENETRATION. The SMP_FREEZE_STATE table characterizes the freeze state as frozen or non-frozen at each measurement depth. SMP_FROST_PENETRATION translates the freeze state at each measurement depth into starting and ending depths of frozen layer(s).

Application/Use: The study can be used by those interested in the influence of frost penetration on pavement response and performance.

Contribution: Improvement in Knowledge; Advancement in Technology; Implementation/Usage.

Present Benefit: The results from this study provide frost penetration estimates for LTPP-SMP sites. The frost information, together with the large quantity of performance monitoring collected at these sites, provides an excellent research data source. Additionally, the techniques for interpreting frost conditions based on electrical resistivity and temperature may be implemented by agencies who wish to monitor in-situ frost accumulation.

Future Benefit: The analysis conducted for this project provides an avenue for future research in understanding changes in pavement layer properties. This will be beneficial in quantifying mechanistic material properties, which are essential for the new M-E PDG.

Title: Design and Construction of PCC Pavements, Volume I: Summary of Design Features and Construction Practices that Influence Performance of Pavements

Authors: Owusu-Antwi, E. B; Titus-Glover, L; Darter, M. I.

Date: 1998

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Abstract/Synopsis: A study has been conducted to evaluate and analyze portland cement concrete (PCC) pavements in order to develop recommendations for the design and construction of long-lived concrete pavements. It involved a detailed evaluation and analysis of the PCC pavement data in the Long Term Pavement Performance (LTPP) database using a variety of means to determine the beneficial effects of design features and construction practices on long-term performance. Emphasis was placed on identifying those specific design features that can be included during design to improve the performance of PCC pavements under various combinations of environmental and traffic loading conditions, and for different subgrade support conditions. The study focused on the development of practical recommendations that can be easily implemented by highway agencies to increase pavement life. This volume provides a concise summary of the results that were obtained from the study. It includes an overview of the engineering and statistical analyses that were conducted and presents results that can be used by State highway agencies to obtain high-performance PCC pavements. Implementation of the recommendations will increase the reliability of PCC pavements.

Application/Use: This study has been used to modify rigid pavement design practices.

Contribution: Cost Savings; Improvement in Knowledge.

Present Benefit: The LTPP database supported the evaluation of existing design procedures based on actual field performance. In doing this, revised procedures were developed to better reflect observed performance. With these revisions, improvements were made to rigid pavement design that lead to better performance and more cost-efficient design. Additionally, agencies can use the findings from this evaluation to revise design policies.

Future Benefit: The comprehensive nature of the LTPP database is unmatched. As such, the LTPP database will continue to add benefit in validating and calibrating the M-E PDG as part of the implementation process. Calibration will provide improved prediction capabilities of the M-E PDG given local conditions and will optimize performance.

Title: Evaluation of Mechanistic-Empirical Performance Prediction Models for Flexible Pavements

Authors: Ali, H. A; Tayabji, S. D.

Date: 1998

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1629

Abstract/Synopsis: In recognition of the potential of mechanistic-empirical (M-E) methods in analyzing pavements and predicting their performance, pavement engineers around the country have been advocating the movement toward M-E design methods. In fact, the next AASHTO "Guide for Design of Pavement Structures" is planned to be mechanistically based. Since many of the performance models used in the M-E methods are laboratory-derived, it is important to validate these models using data from in-service pavements. The Long-Term Pavement Performance (LTPP) program data provide the means to evaluate and improve these models. The fatigue and rutting performances of LTPP flexible pavements were predicted using some well-known M-E models, given the loading and environmental conditions of these pavements. The predicted performances were then compared with actual fatigue cracking and rutting observed in these pavements. Although more data are required to arrive at a more conclusive evaluation, fatigue cracking models appeared to be consistent with observations, whereas rutting models showed poor agreement with the observed rutting. Continuous functions that relate fatigue cracking to fatigue damage were developed.

Application/Use: This study is directly applicable to pavement design and performance modeling.

Contribution: Improvement in Knowledge

Present Benefit: This study provides an understanding of the prediction capabilities included in the M-E PDG for performance of flexible pavements. With this information, engineers using the M-E PDG will be able to make useful designs based on the capabilities of the prediction models.

Future Benefit: This study will be useful in validating and calibrating the M-E PDG as part of local implementation. The LTPP database will play a vital role in this process as well. Agencies without comprehensive, site-specific data will rely heavily on the LTPP test sections.

Title: Mechanistic Evaluation of Test Data from LTPP Flexible Pavement Test Sections, Volume I: Final Report

Authors: Ali, H. A; Tayabji, S. D.

Date: 1998

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Abstract/Synopsis: The study reported here was conducted to assess how well some of the existing asphalt pavement mechanistic-empirical distress prediction models performed when used in conjunction with the data being collected as part of the national Long Term Pavement Performance (LTPP) program. As part of the study, appropriate data were obtained from the National Information Management System (NIMS) for the GPS-1 and GPS-2 experiments. The first phase of the data analysis involved using the deflection test data to backcalculate pavement layer moduli values. Using representative values of the layer moduli, structural analyses were performed for up to 140 axle-load configurations for the selected test sections. Then, the Asphalt Institute and the Shell procedures were used to predict fatigue cracking and rutting damage. The computed results were compared with observed values. Based on the results, new forms of the fatigue cracking models have been proposed. Also, a new approach to predicting rutting has been developed. This new procedure would account for rutting in each pavement layer and would consider rate-hardening typically observed in the development of rutting. This study has shown that, even given the many current limitations in the LTPP database, the LTPP data can be used successfully to develop a better insight into pavement behavior and to improve pavement performance.

Application/Use: This is directly applicable to performance prediction and M-E pavement design.

Contribution: Improvement in Knowledge

Present Benefit: This study provides insight into the various mechanistic prediction equations for flexible pavements. The LTPP database provides a comprehensive source for such evaluations. The results of this study were used to revise existing models as well as to develop new models in the prediction of rutting and fatigue. These are additional tools that can be used in pavement design.

Future Benefit: The results of this study will be beneficial in moving from a purely empirical design procedure to the M-E PDG. The LTPP database will continue to add value in improving pavement performance modeling.

Title: Mechanistic Evaluation of Test Data From LTPP Jointed Concrete Pavement Test Sections

Authors: Jiang, Y. J; Tayabji, S. D; Wu, C. L.

Date: 1998

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Abstract/Synopsis: This study was conducted to assess how well some of the existing concrete pavement mechanistic-empirical based distress prediction procedures performed when used in conjunction with the data being collected as part of the national Long-Term Pavement Performance (LTPP) program. As part of the study, appropriate data were obtained from the National Information Management System (NIMS) for the GPS-3 and GPS-4 experiments. Structural analysis was performed for up to 140 axle load configurations for the selected test sections. Then, ILLICON and the Portland Cement Association (PCA) procedures were used to predict fatigue cracking and joint faulting damage, respectively. The computed results were compared with observed values. This study has shown that, even given the many current limitations in the LTPP database, the LTPP data can be used successfully to develop better insight into pavement behavior and to improve pavement performance.

Application/Use: This study is directly applicable to rigid pavement design.

Contribution: Improvement in Knowledge

Present Benefit: The LTPP database provides in-service performance data with layer and material properties. This provides a means of comparing existing predictive models to actual performance and modifying the models based on observations or developing completely new methods. In any case, the data can be used to understand pavement performance.

Future Benefit: The LTPP database will continue to provide value to the pavement community. The data will serve6 Tc5 TDb7o th001urce fobrthting the M-E PDG to local conditions. Additionally, the database will be used to develop and evaluate new modeling techniques.

Title: Mechanistic Evaluation of Test Data from Long-Term Pavement Performance Jointed Plain Concrete Pavement Test Sections

Authors: Jiang, Y. J; Tayabji, S. D.

Date: 1998

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1629

Abstract/Synopsis: Over the years, pavement engineers have attempted to develop rational mechanistic-empirical (M-E) methods for predicting pavement performance. In fact, the next version of AASHTO's "Guide for Design of Pavements" is planned to be mechanistically based. Many M-E procedures have been developed on the basis of a combination of laboratory test data, theory, and limited field verification. Therefore, it is important to validate and calibrate these procedures using additional data from in-service pavements. The Long-Term Pavement Performance (LTPP) program data provide the means to evaluate and improve these models. A study was conducted to assess the performance of some of the existing concrete pavement M-E-based distress prediction procedures when used in conjunction with the data being collected as part of the LTPP program. Fatigue cracking damage was estimated using the NCHRP 1-26 approach and compared with observed fatigue damage at 52 GPS-3 test sections. It was shown that the LTPP data can be used successfully to develop better insight into pavement behavior and to improve pavement performance.

Application/Use: This study is directly applicable to pavement design and performance modeling.

Contribution: Improvement in Knowledge

Present Benefit: This study provides an understanding of the prediction capabilities included in the M-E PDG for performance of rigid pavements. With this information, engineers using the M-E PDG will be able to make improved designs based on the capabilities of the prediction models.

Future Benefit: This study will be beneficial in validating and calibrating the M-E PDG as part of local implementation. The LTPP database will play a vital role in this process as well. Agencies without comprehensive, site-specific data will rely heavily on the LTPP test sections.

Title: Mechanistic Evaluation of Test Data from LTPP Flexible Pavement Test Sections, Volume II: Final Report – Appendices

Authors: Ali, H. A; Tayabji, S. D.

Date: 1998

Publisher: ERES Consultants, Incorporated; Federal Highway Administration

Abstract/Synopsis: The study reported here was conducted to assess how well some of the existing asphalt pavement mechanistic-empirical distress prediction models performed when used in conjunction with the data being collected as part of the national Long Term Pavement Performance (LTPP) program. As part of the study, appropriate data were obtained from the National Information Management System (NIMS) for the GPS-1 and GPS-2 experiments. The first phase of the data analysis involved using the deflection test data to backcalculate pavement layer moduli values. Using representative values of the layer moduli, structural analyses were performed for up to 140 axle-load configurations for the selected test sections. Then, the Asphalt Institute and the Shell procedures were used to predict fatigue cracking and rutting damage. The computed results were compared with observed values. Based on the results, new forms of the fatigue cracking models have been proposed. Also, a new approach to predicting rutting has been developed. This new procedure would account for rutting in each pavement layer and would consider rate-hardening typically observed in the development of rutting. This study has shown that, even given the many current limitations in the LTPP database, the LTPP data can be used successfully to develop a better insight into pavement behavior and to improve pavement performance.

Application/Use: This is directly applicable to performance prediction and M-E pavement design.

Contribution: Improvement in Knowledge

Present Benefit: This study provides insight into the various mechanistic prediction equations for flexible pavements. The LTPP database provides a comprehensive source for such evaluation. The results of this study were used to revise existing models as well as to develop new models in the prediction of rutting and fatigue. These are additional tools that can be used in pavement design.

Future Benefit: The results of this study will be beneficial in moving from a purely empirical design procedure to the M-E PDG. The LTPP database will continue to add value in improving pavement performance modeling.

Title: Roughness Prediction Model Based on the Artificial Neural Network Approach

Authors: La Torre, F; Domenichini, L; Darter, M. I.

Date: 1998

Publisher: University of Pretoria

Conference Title: Fourth International Conference on Managing Pavements

Abstract/Synopsis: Prediction of the future roughness of a flexible pavement section is important in programming rehabilitation needs. This study utilizes the Artificial Neural Network (ANN) approach to predict the future International Roughness Index (IRI) year by year up to a maximum pavement age of 20 years. The ANN program requires key information about a pavement section including the current IRI, pavement design, climate, traffic and other variables to predict yearly IRI values into the future. The program was developed initially using synthetic data to reproduce a well defined function and then utilized data from the Long-Term Pavement Performance (LTPP) program database to calibrate the ANN. Accuracy of the predictions was tested using LTPP sections not used in the development and was found to be reasonable for programming purposes. The ANN was developed as a Microsoft Windows95 based software tool and can be used in routine pavement management programming.

Application/Use: This paper can be used by those interested in pavement roughness predictions.

Contribution: Improvement in Knowledge

Present Benefit: Pavement roughness predictions are useful in pavement management as well as pavement design. Accurate predictions can be used to make cost-effective decisions on improvement timing and budget. This paper is also useful in evaluating artificial neural network algorithms.

Future Benefit: The LTPP database will contribute to future research by providing data necessary to evaluate new prediction techniques. As part of this process, bias, error, and sensitivity studies can also be conducted using the LTPP database. Improved prediction techniques, along with quantified variability will benefit the pavement community in a multitude of areas.

Title: Roughness Trends of Flexible Pavements

Date: 1998

Publisher: Federal Highway Administration

Journal Title: TechBrief

Abstract/Synopsis: Roughness is widely regarded as the most important measure of pavement performance because it is the measure most evident to the traveling public. It greatly affects ride quality, safety, and vehicle operating costs. Therefore, understanding how and why roughness occurs in pavements is of major concern to highway agencies. To this end, the Long Term Pavement Performance (LTPP) program recently completed a study to investigate the changes in roughness of flexible pavements over time and their relationship to design factors, subgrade conditions, and climatic conditions. The results of this study were published in Report No. FHWA-RD-97-147, "Investigation of Development of Pavement Roughness." This document reviews that report.

Application/Use: The results from this paper can be used to understand roughness accumulation and the effects of certain factors on this accumulation.

Contribution: Improvement in Knowledge

Present Benefit: Roughness significantly affects the end user's perception on pavement quality. The ability to predict roughness accumulation, as well as the factors that contribute to improved ride quality, are extremely beneficial to the transportation industry. Roughness predictions can be used as a tool in programming funds for future rehabilitation.

Future Benefit: The LTPP offers approximately 20 years of performance data for in-service pavements. The data can be used to predict performance in areas with limited monitored data. Understanding the contribution of various factors on roughness will also be helpful to agencies as they investigate rehabilitation alternatives.

Title: Supplement to the AASHTO Guide for Design of Pavement Structures, Part II - Rigid Pavement Design & Rigid Pavement Joint Design

Date: 1998

Publisher: American Association of State Highway and Transportation Officials

Abstract/Synopsis: This Supplement includes alternative design procedures that can be used in place of or in conjunction with the American Association of State Highway and Transportation Officials (AASHTO) "Guide for the Design of Pavement Structures", Part II, Section 3.2, Rigid Pavement Design, and Section 3.3, Rigid Pavement Joint Design. The Supplement contains the recommendations from National Cooperative Highway Research Program (NCHRP) Project 1-30, modified based on the results of the verification study conducted using the Long Term Pavement Performance (LTPP) database.

Application/Use: This study has been used to modify rigid pavement design practices.

Contribution: Cost savings; Improvement in Knowledge; Implementation/Usage.

Present Benefit: The LTPP database supported the evaluation of existing design procedures based on actual field performance. In doing this, revised procedures were developed to better reflect observed performance. With these revisions, improvements were made to rigid pavement design that lead to better performance and more cost-efficient design.

Future Benefit: The comprehensive nature of the LTPP database is unmatched. As such, the LTPP database will continue to add benefit in validating and calibrating the M-E PDG as part of the implementation process. Calibration will provide improved prediction capabilities of the M-E PDG given local conditions and will optimize performance.

Title: Transverse Cracking Distress in Long-Term Pavement Performance Jointed Concrete Pavement Sections

Authors: Moody, E. D.

Date: 1998

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1629

Abstract/Synopsis: Transverse cracking is one of the more common distress manifestations in jointed concrete pavements. While the extent of transverse cracking is largely related to the specified joint spacing, there are several other primary design variables and distress mechanisms that can cause varying degrees of transverse cracking. These primary mechanisms and their associated variables are well-documented in the literature. However, all of these mechanisms often work on the pavement simultaneously over many years and as a result, it has historically been difficult to calibrate prediction models with field data. The Strategic Highway Research Program's Long-Term Pavement Performance (LTPP) program has collected a significant amount of condition survey data on more than 110 jointed plain concrete pavements (JPCP) and 65 jointed reinforced concrete pavements (JRCP) throughout North America over the last 7 years. The occurrence of transverse cracking in these sections is one of the principal distresses documented in the condition surveys and therefore provides an excellent data source for examining the relationships between the various primary distress mechanisms and the actual occurrence of distress in the field. Although it is premature to develop or calibrate purely "mechanistic" models based on the LTPP data, enough data have been collected to begin analyzing this distress and its association with the numerous prediction variables in the LTPP database. A complete analysis of the transverse cracking that has occurred in these LTPP test sections, along with their respective relationships with the primary prediction variables found in the primary distress mechanisms, is provided.

Application/Use: This paper is applicable to performance prediction and pavement design.

Contribution: Improvement in Knowledge

Present Benefit: The LTPP database has provided sufficient data to support an evaluation on cracking mechanisms in rigid pavements. This information is useful in performance modeling. The relationship between cracking performance and various pavement features will also be useful in selecting between design alternatives.

Future Benefit: This study will continue to add benefit as pavement design moves from an empirical to an M-E basis.

Title: Advanced Methods for Using FWD Deflection-Time Data to Predict Pavement Performance

Date: 1997

Publisher: Federal Highway Administration

Journal Title: TechBrief

Abstract/Synopsis: An important property of materials that defines the viscoelastic and inelastic characteristics of materials is the dissipated work or dissipated energy of the material. Dissipated energy has been used in the asphalt concrete fatigue area for many years by some agencies. The falling-weight deflectometer (FWD) load deflection-time data can be used to measure the dissipated work during the loading and unloading of the pavement structure from the FWD impact load. This dissipated work should be related to the occurrence of selected surface distresses, especially for asphalt concrete-surfaced pavements. The deflection-time history data collected within the Long-Term Pavement Performance (LTPP) program represent an invaluable data source and critical data element that has yet to be thoroughly investigated and used to its full potential in pavement diagnostic studies. A limited study was undertaken to determine if there is any relationship between the dissipated work as measured with the FWD and levels of pavement distress. The study also shows some of the different parameters that can be used from the deflection-time data and the benefit of using these data for pavement diagnostic studies and pavement classifications.

Application/Use: The findings from this study are applicable to those interested in using FWD data to analyze pavements.

Contribution: Improvement in Knowledge

Present Benefit: This study provides an addition tool in pavement design and evaluation. LTPP has added value by providing FWD data and materials property data used to conduct the analysis.

Future Benefit: The results from this study could be used directly in pavement evaluations or could be used as a stepping stone for additional work on ANN-based backcalculation.

Title: Design Pamphlet for the Backcalculation of Pavement Layer Moduli in Support of the 1993 AASHTO Guide for the Design of Pavement Structures

Authors: Von Quintus, H; Killingsworth, B.

Date: 1997

Publisher: Brent Rauhut Engineering, Incorporated; Federal Highway Administration

Abstract/Synopsis: This design pamphlet details the procedures to backcal

Title: Development of Performance Prediction Models for Dry-No-Freeze and Dry-Freeze Zones using LTPP Data

Authors: Senn, K; Frith, D; Yapp, M. T; Scofield, L.

Date: 1997

Publisher: University of Washington, Seattle

Conference Title: Eighth International Conference on Asphalt Pavements

Abstract/Synopsis: The Long Term Pavement Performance (LTPP) program is currently in the eighth year of a twenty year project to monitor and collect pavement data on approximately 800 general pavement studies (GPS) sections across the United States and Canada. This paper focuses on GPS-1 sections (asphalt surfacing on a granular base) located in the Dry-Freeze and Dry-No Freeze zones of the Western United States. Approximately 50 sites were selected from these two zones. Using data collected from the LTPP sites, this paper presents the analyses used to develop pavement performance prediction models. Performance is measured in terms of individual distress types, such as roughness and fatigue cracking. A discussion of the problems inherent in such a process is also included. It is recommended that future analysis along similar lines focus on specific pavement study (SPS) sections.

Application/Use: This paper is directly applicable to performance modeling of flexible pavements.

Contribution: Improvement in Knowledge

Present Benefit: Test sections monitored as part of the LTPP program can be used to develop prediction models for pavement performance in terms of surface distress, rutting, roughness, and deflections. Accurate predictions are beneficial in pavement management to determine proper treatment/rehabilitation timing and selection as well as for programming funding.

Future Benefit: The LTPP database will continue to be used to not only develop new prediction models but also to calibrate existing prediction models as part of the M-E PDG.

Title: Evaluation of Long-Term Pavement Performance Data Using HDM-III Probabilistic Failure-Time Models for Crack Initiation in Bituminous Pavements

Authors: Van Dam, T. J; Chesher, A. D; Peshkin, D. G.

Date: 1997

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1592

Abstract/Synopsis: Cracking is perhaps the most important distress in bituminous pavements. It plays a key role in modeling bituminous pavement performance in the World Bank's Highway Design and Maintenance Standards Model Version III (HDM-III) with the belief that a cracked pavement is susceptible to moisture ingress, which accelerates pavement deterioration. Strategic Highway Research Program Long-Term Pavement Performance (LTPP) data were analyzed by using the probabilistic failure-time crack initiation models previously developed for use in HDM-III. On the basis of that analysis, it is concluded that the HDM-III models do not accurately capture the climatic factors that play a role in linear cracking initiation typically observed in North America. When considering only fatigue-related cracking, HDM-III models could be successfully fit to the data, but concerns related to the shape parameter call into question their general applicability. It is concluded that although some aspects of this analysis suggest that HDM-III models adequately model fatigue-related crack initiation in LTPP pavement sections, overall the results are inconclusive and a more in-depth analysis needs to be conducted.

Application/Use: The report can be used by those interested in performance modeling.

Contribution: Improvement in Knowledge

Present Benefit: This study provides information on performance prediction modeling techniques. The LTPP database provides a comprehensive data set that can be used to evaluate the prediction capabilities of models and make comparisons between different techniques. The models developed as part of the study are beneficial to pavement management as they can be used to estimate performance life to determine proper treatment scheduling.

Future Benefit: The LTPP database will continue to support the development of pavement performance models. This type of work will be valuable in improving modeling techniques. Performance modeling is helpful in quantifying the effect of various factors on deterioration over the life of pavements.

Title: Data Analysis Procedures for Long-Term Pavement Performance Prediction

Authors: Kerali, H. R; Lawrence, A. J; Awad, K. R.

Date: 1996

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1524

Abstract/Synopsis: The results of 3 years of research aimed at investigating data analysis methods used in the development of pavement performance relationships are reported. The research was part of the U.K. collaborative program linked to the U.S. Strategic Highway Research Program (SHRP), in particular the Long-Term Pavement Performance (LTPP) experiment. The development of pavement performance models usually concludes with the application of regression techniques to determine coefficients for model parameters. It is important to identify the model forms and the engineering or mechanistic principles to be used in the data analyses in the initial stages and then to censor any obvious anomalies in the data. This was applied to data on pavement rutting measured by the Transport Research Laboratory over a 20-year period in the United Kingdom. Engineering knowledge of rutting progression suggests a cubic model form, with the quadratic component representing typical performance in early pavement life. An attempt was made to derive a rutting model that took into account material properties, layer thickness, and aggregate types. The pavement structural number concept was applied as a proxy for pavement strength for the different pavement structures used in the test sites. The results of the analyses confirmed that material properties, layer thickness, and their combined effects influence rutting, but in ways that vary greatly. No simple model form was found to adequately predict rutting for a variety of pavement types, even with general categorical model forms.

Application/Use: This paper can be used by those interested in developing rutting prediction models for flexible pavements.

Contribution: Improvement in Knowledge

Present Benefit: The development of rutting models based on in-situ conditions can be beneficial to pavement management, design, and construction. Quantifying the influence of certain factors on rutting is useful in mitigating rutting through materials selection, pavement design, and quality control. The LTPP database provides a source of rutting data linked to in-situ conditions that can be used to develop robust prediction models.

Future Benefit: The LTPP database will continue to be used to evaluate existing models as well as to develop new prediction tools. The large number of in-service pavements that comprise the LTPP database makes it well-suited for the development of robust and comprehensive predictive models.

Title: Prediction of Pavement Remaining Life

Authors: Vepa, T. S; George, K. P; Shekharan, A. R.

Date: 1996

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1524

Abstract/Synopsis: The evaluation of remaining life is necessary to make optimal use of the structural capacity of in-service pavements. It simply represents the useful life left in the pavement until a failure condition is reached. Knowledge of remaining life facilitates decision making in regard to strategies for reconstruction-rehabilitation of roads, thereby leading to the efficient use of existing resources. Several methods proposed or used by various agencies to estimate the remaining lives of pavements are reviewed. They are classified under two categories: functional and structural. Making use of the Mississippi Department of Transportation pavement management system data base, survivor curves are developed for seven classes of flexible pavements with from thin to thick structures. By using these survivor curves a novel method for estimating remaining life is proposed. The reasonableness of the selected methods is examined by putting them to use in calculating the remaining lives of each of eight rigid and flexible pavement sections, all of them from the Mississippi global positioning system sections of the Strategic Highway Research Program - Long-Term Pavement Performance (LTPP) project. With the structural details, falling weight deflectometer deflection data, and the distress information compiled from the LTPP information management system data base, the authors use two and four methods for rigid and flexible pavements, respectively, to determine the remaining lives. The remaining lives calculated by two methods for rigid pavements are comparable. Three of four methods for flexible pavements also generated comparable remaining lives. The authors were encouraged by the results and recommend that the survivor curve approach be explored further for network-level remaining life calculations. The reliabilities of various techniques currently available for the remaining life calculation are discussed.

Application/Use: This study is applicable to pavement management as well as pavement design.

Contribution: Improvement in Knowledge

Present Benefit: The LTPP database has provided a source of in-service performance data that was used to evaluated six remaining life models. By doing this, pavement managers and designers using remaining life analysis techniques can select the best method for a given application and can also benefit from the reliability analysis reported in this study.

Future Benefit: The LTPP database will continue to be used to evaluate existing models as well as to develop new prediction tools. The large number of in-service pavements that comprise the LTPP database makes it well-suited for the development of robust and comprehensive predictive models.

Title: Mechanistic Predictions of the Performance of Pavements in the SHRP LTPP Program

Authors: Lytton, R. L.

Date: 1994

Publisher: Swedish Road and Transport Research Institute

Conference Title: Strategic Highway Research Program (SHRP) and Traffic Safety on Two Continents, Proceedings of the Conference

Abstract/Synopsis: The calibrated mechanistic pavement performance prediction method developed in the SHRP A005 contract is an advance from the phenomenological prediction methods that have been used for the last two decades. The new methods make possible the use of material properties for specifications; simpler, more straightforward tests to determine these material properties; and permit the calibration of the models and specifications to local or regional conditions and materials; and are the basis of the new SHRP mix design procedure, SUPERPAVE tm. The new concepts that have been employed in the prediction models could not have been done without the capabilities of the latest generation of microcomputers. The new concepts used in the predictions of pavement distress include the following: (1) microcracking in fatigue crack initiation; (2) shearing stress propagation of fatigue cracks; (3) rutting due to both volumetric and shearing plastic strains; (4) use of fracture mechanics and fracture properties to predict crack initiation ;and propagation; (5) use of plasticity theory and plastic properties including cohesion and friction angles to predict rutting; (6) use of system identification methods to calibrate the prediction models; (7) both "forward" and "backward" calibration can be done.

Application/Use: This is directly applicable to pavement analysis and design.

Contribution: Improvement in Knowledge, Advancement in Technology.

Present Benefit: This research explores some fundamental mechanistic prediction models. This fundamental study can serve as the basis for further mechanistic-empirical relationships and analysis.

Future Benefit: Performance data available in the LTPP database will continue to be a useful tool in evaluating predicting models as well as establishing transfer function for mechanistic-empirical analysis and design. Additional benefit will be realized in calibrating and validating the M-E PDG to local conditions.

Title: Prediction of AC Mat Temperatures for Routine Load/Deflection Measurements

Authors: Stubstad, R. N; Baltzer, S; Lukanen, E. O; Ertman-Larsen, H. J.

Date: 1994

Publisher: Minnesota Department of Transportation

Conference Title: 4th International Conference, Bearing Capacity of Roads and Airfields

Abstract/Synopsis: An asphalt layer is highly viscoelastic, with a changing modulus, or stiffness, as a function of mat temperature. When conducting routine load/deflection measurements, for example with a Falling Weight Deflectometer (FWD), it is very important that the representative or "weighted average" mat temperature is known, so the modulus derived for the AC layer is correctly related to the temperature of the layer when the FWD tests were conducted. This paper summarizes the results of the most recent research on the subject, and also uses the conclusions from a companion paper entitled "Temperature Correction of Asphalt Moduli for FWD Measurements." Based on this work, together with Southgate's data and results from SHRP's LTPP studies, a new relationship is developed which uses a series of readily available time, air temperature, and AC thickness data, plus the AC surface temperature only as measured by an automatic infrared sensing device mounted on the FWD. This new method is called "BELLS", whereby a very close approximation of the weighted average AC mat temperature at the time of testing is easily obtainable using a relatively simple, computerized relationship. The BELLS mat temperature calculation method thus allows the engineer to adjust the derived (backcalculated) AC modulus to, e.g., seasonal or standard values at any other appropriate mat temperature(s).

Application/Use: This is directly applicable to pavement analysis and design using FWD data.

Contribution: Improvement in Knowledge

Present Benefit: Temperature plays a significant role in FWD backcalculation results and subsequent design decisions. The ability to accurately estimate pavement temperatures improves the utility of the FWD as a pavement analysis tool.

Future Benefit: FWD data is now an integral part of pavement analysis/design and is getting more use in pavement management. Because of this, temperature prediction models will continue to be developed and refined. Data collected at LTPP SMP sites will be extremely valuable in this regard.

Title: Using Pavement Performance Data to Develop Mechanistic-Empirical Concepts for Deteriorated and Rehabilitated Pavements. Final Report.

Authors: Rao, J. S; Shah, N. S; Mueller, G. L; Shahin, M. Y; George, K. P; Carpenter, S. M.

Date: 1994

Publisher: Globetrotters Engineering Corporation; Federal Highway Administration

Abstract/Synopsis: This report summarizes existing pavement condition indices, and available prediction models for each condition index. This report also identifies existing data bases, where the required variables for the prediction models have been collected. Successive chapters detail: the condition indices and their prediction models; the selected data bases (HPMS, SHRP-LTPP, Copes, FHWA Design, FHWA Rehabilitation, Texas CRCP, and FMIS) with analysis and evaluation of each; significant data elements in the SHRP-LTPP data base; data elements for future development models; current types of prediction models and modeling techniques; and a computer flow chart illustrating data requirements and the conceptual operation of models to select and design maintenance and rehabilitation alternatives. The conclusions emphasize the development of modeling tools, rather than specific models. The proposed MODEL TOOL BOX allows each user to develop models unique to their environment, soil types, and maintenance and rehabilitation most frequently used.

Application/Use: This can be used by those interested in M-E pavement evaluation and provides a summary of the various performance data sources.

Contribution: Improvement in Knowledge

Present Benefit: The LTPP database is the most comprehensive source of performance data available for pavement research and analysis. This report provides information on M-E evaluation of pavements, which is a significant progression from purely empirical processes.

Future Benefit: The LTPP database will continue to be the go-to source for pavement related research. In fact, LTPP was relied upon heavily for the development of the M-E PDG and will be a necessary component in local calibration/validation.

Title: SHRP Procedure for Temperature Correction for Maximum Deflections

Date: 1993

Publisher: Strategic Highway Research Program

Abstract/Synopsis: Because accurate data are the key to the success of the Strategic Highway Research Program's (SHRP) Long Tem Pavement Performance (LTPP) study, a number of measures have been implemented to ensure quality of the pavement deflection data. This includes, among others, quality assurance software. The latter includes a program called FWDCHECK which has been developed to analyze deflection data. In the case of asphaltic concrete pavements, this structural capacity analysis follows the AASHTO direct structural number procedure. Since asphaltic concrete materials are temperature dependent in nature, measured deflections and correct measured maximum deflections to a standard temperature is required so that the comparison of predicted versus expected structural capacities is a valid one. This report documents the temperature correction procedure developed for and used in the FWDCHECK program.

Application/Use: This is directly applicable to pavement analysis and design using FWD data.

Contribution: Improvement in Knowledge; Implementation/Usage

Present Benefit: Temperature plays a significant role in FWD backcalculation results and subsequent design decisions. The ability to accurately estimate pavement temperatures improves the utility of the FWD as a pavement analysis tool.

Future Benefit: FWD data an integral part of pavement analysis/design and is getting more use in pavement management. Because of this, temperature prediction models will continue to be developed and refined. Data collected at LTPP SMP sites will be extremely valuable in this regard.

Title: Improving Concrete Pavements through SHRP Research

Authors: Hanna, A. N; Jawed, I.

Date: 1991

Publisher: National Swedish Road & Traffic Research Institute; Transportation Research Board; Statens VAEG- OCH

Journal Title: VTI Rapport

Abstract/Synopsis: Substantial improvements in concrete pavements will be achieved through studies performed in three of SHRP research areas: the Long-Term Pavement Performance (LTPP), the Highway Operations and the Concrete and Structures. The LTPP studies aim at better understanding the effects on performance of traffic, environment, material properties, and other factors. The Highway Operations studies encompass those that are concerned with the effectiveness and cost of alternative methods, materials, and equipment for preventive pavement maintenance. The Concrete and Structures studies encompass studies that are concerned with the different aspects of the concrete used in highway pavements and structures. This paper identifies the concrete pavement-related products resulting from SHRP research and highlights their contribution to improving concrete pavements.

Application/Use: Early papers regarding LTPP can be used by those interested in the objectives of the program in its infant stages. These reports were also used as internal planning tools.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: Early program documentation can provide significant insight into the early intention/objectives of the program. This information can be used to understand how the program evolved and provides background in the decision process. This documents the LTPP program's early vision for rigid concrete pavements.

Future Benefit: Establishing a national, long-term research program requires significant planning and coordination. Program documentation since the inception of the LTPP program will be extremely beneficial to future data users.

Title: Laboratory and Field Evaluations and Correlations of Properties of Pavement Components

Authors: Allen, D. L; Graves, R. C; Fleckenstein, L. J.

Date: 1991

Publisher: University of Kentucky, Lexington; Kentucky Transportation Cabinet; Federal Highway Administration

Abstract/Synopsis: This report documents the selection and sampling of 21 long-term pavement performance testing sites. Seven of those sites were also chosen to be a part of the Long Term Pavement Performance (LTPP) portion of the Strategic Highway Research Program (SHRP). All sites were sampled in accordance with SHRP protocol and procedures. The report includes three years of visual distress data and pavement deflection data obtained by a road rater. There were wide variabilities in backcalculated subgrade moduli and asphaltic concrete moduli within each 500-ft (152.4-m) test section. Laboratory resilient modulus tests were performed on undisturbed samples of the subgrade and asphaltic concrete cores. Again, there was wide variability between laboratory resilient moduli and backcalculated moduli from field deflection. A number of models were developed to permit estimation of pavement distresses with time, annual average daily traffic (AADT), or equivalent single axle loads (ESALs). In addition, relationships were developed between laboratory and field data. It is recommended that longer-term data be obtained, to refine the models and to make their estimations more accurate. The models developed in this study can estimate the service history of a pavement.

Application/Use: This study is directly applicable to pavement analysis using FWD data.

Contribution: Improvement in Knowledge

Present Benefit: FWD data can be a powerful tool in estimating the in-situ layer properties of a pavement structure. The study provides insight into the variability of FWD data as well as the differences between the backcalculation results and actual laboratory measurements.

Future Benefit: The LTPP database provides a significant amount of laboratory testing results and FWD deflection data that can be used to evaluate new and existing backcalculation techniques.

Title: Impact of Digital Filtering on FWD Load Cell and Deflection Sensor Responses

Authors: Rada, G. R; Rabinow, S. D; Richter, C. A; Witczak, M. W.

Date: 1990

Publisher: Transportation Research Board

Journal Title: Transportation Research Record No. 1260

Abstract/Synopsis: The deflection response of pavements under an applied load will be studied in the Strategic Highway Research Program's (SHRP's) Long-Term Pavement Performance (LTPP) study using a falling weight deflectometer (FWD). The SHRP computer software system for the collection of data also possesses the capability to filter the data by means of a digital low-pass filter. SHRP decided to assess the effects of digital filtering of FWD data before implementation of the software in the field. Comparative analyses of noise were performed using the results of an FWD pilot study conducted in Greensboro, North Carolina, as well as other test sections throughout the United States. The results show that filtering of FWD data introduces significant random errors, particularly for rigid pavements tested under heavy loads. These errors tend to compound each other when the filtered deflections are normalized by the filtered load data. Also, the use of filtered load and deflection data may yield normalized deflection responses that exceed current normalized deflection tolerance limits, particularly for heavy loads on rigid pavements. Accordingly, it has been recommended that all FWD data be collected by SHRP with the filter off. However, because some unknown level of noise is contained within FWD data, it is also recommended that additional load- and deflection-time histories be collected and stored. Thus, if advances occur in the filtering process, the data can be reanalyzed to obtain more accurate peak load and deflection values for use in the backcalculation of layer moduli.

Application/Use: This paper is directly applicable to FWD data collection and analysis.

Contribution: Improvement in Knowledge; Advancement in Technology.

Present Benefit: This study provides information on the influence of low-pass filters on FWD analysis results. The results were used to make decisions on the collection of FWD data for use in LTPP, and can be applied to other FWD data collection procedures as well. The results can also be used by pavement engineers to account for low-pass filter effects in pavement evaluations and designs.

Future Benefit: FWD data will continue to be used as a valuable tool in evaluating existing pavement systems.

Title: SHRP Plans for Nondestructive Deflection Testing in the Development of Pavement Performance Prediction Models

Authors: Ritcher, C. A; Rauhut, J. B.

Date: 1989

Publisher: American Society for Testing and Materials

Conference Title: First International Symposium on Nondestructive Testing of Pavements and Backcalculation of Moduli

Abstract/Synopsis: Nondestructive deflection testing using falling weight deflectometers is one element of the monitoring effort planned by the Strategy Highway Research Program (SHRP) for the Long-Term Pavement Performance Studies (LTPP). Nondestructive deflection testing provides data for the backcalculation of moduli for the various pavement structural layers, as well as critically important data on material variability that is expected to be an important independent variable in future pavement performance prediction models. The backcalculated layer moduli are critical to the development of calibrated mechanistic-empirical models for a variety of uses. These moduli must be calculated using standard procedures representing the state of the art. Current studies are aimed at identifying specific problems leading to unacceptable variations in backcalculated moduli when using different computer codes and closure tolerances. It is expected that these studies will provide a wealth of information which will be useful as SHRP planning for the use of deflection testing proceeds. Backcalculated moduli from measurements at a number of locations within a test section are to be used to establish the mean, minimum, maximum, and standard deviation of moduli for each layer. In addition, it is planned that four drop heights will be used to apply four different load levels at a single location. Four load levels should provide the variations in layer moduli with stress sensitivity. Presently it is planned to use nondestructive testing to study variations in deflections and moduli on a seasonal basis, especially variations through the spring thaw in northern climates. These studies should provide critically important information that has been a severe limiting factor in past attempts to predict the performance of pavements subjected to spring thaw conditions. While major damage occurs to pavements during the spring thaw, these conditions have never been adequately accounted for on a mechanistic basis. This paper summarizes current (as of Spring 1988) SHRP planning for the utilization of nondestructive deflection testing in their Long-Term Pavement Performance Studies. The plans presented herein are preliminary. It is hoped that this presentation will generate comments as well as constructive criticism, which might be incorporated into SHRP plans before work has progressed to a point where changes are difficult to make.

Application/Use: This paper documents early plans for non-destructive pavement testing of LTPP test sections.

Contribution: Cost Savings; Improvement in Knowledge; Advancement in Technology.

Present Benefit: This document illustrates the resources devoted by the LTPP program in developing plans and protocol that ensure sufficient data is collected and that it is quality information. These procedures are available—through user's manuals, processing software, and quality control algorithms—for use on an agency level. Using the established methodologies, agencies realize reduced start up costs. Quality data collection has significant value in both the short and long term.

Future Benefit: The methodologies will continue to be useful to agencies collecting non-destructive testing data. Additional benefits will be realized in using the data collected at LTPP sites for research.