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EVALUATION OF THE MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE FOR IMPLEMENTATION IN IOWA

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Abstract. With the release of the new Mechanistic-Empirical Pavement Design Guide (MEPDG) in the USA, there is a big shift in pavement analysis and design and many state highway agencies are undertaking initiatives to implement the MEPDG. The Iowa Department of Transportation (DOT) is one such highway agency in the USA interested in implementing the MEPDG. In order to effectively and efficiently transition to the MEPDG from the current empirical approach and accelerate its adoption, the Iowa DOT needs a detailed implementation and training strategy. In support of the MEPDG implementation initiatives, sensitivity studies were conducted using the MEPDG software to identify design inputs pertaining to flexible pavements that are of particular sensitivity in Iowa. Based on a study of the MEPDG design components, the results of sensitivity analyses and past experience, this paper, which is the second of the two companion papers, presents key initiatives for implementing the MEPDG in Iowa. The need for implementing the MEPDG at Iowa DOT and the results of rigid pavement input parameter sensitivity analysis are discussed in detail in the first paper.

Keywords: M-E Pavement Design Guide (MEPDG), asphalt concrete, flexible pavement, calibration, rutting, cracking, sensitivity analysis.

1. Introduction

With the release of the new Mechanistic-Empirical (M-E) Pavement Design Guide (MEPDG) by 2004 National Cooperative Highway Research Program (NCHRP) "*Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*" Project 1-37A in the USA, pavement design has taken a leap forward. The MEPDG provides the user with an integrated set of models (climate + traffic + materials), which through a set of empirical models projects future performance (cracking, rutting, faulting, etc.).

The edition currently available for evaluation (as of Dec 2007) will change and a provisional design guide is yet to be released. Some areas of change are known even now, while others have yet to be identified and may only come to light as they are identified during the general implementation.

In order to effectively and efficiently transit to the MEPDG, state Dept of Transportations (DOTs) need a detailed implementation and training strategy. In addition, pavement design input parameters must be determined locally based on their effects on pavement performance.

It is suspected that it will take most states in the USA approx 3 years just to prepare to implement the MEPDG in its current form. Initiatives and strategies for implementing the MEPDG in Indiana (Nantung *et al.* 2005) and Texas (Uzan *et al.* 2005) were published recently. This paper discusses the development of a strategic plan for implementing the MEPDG in Iowa.

2. Objectives

The following are the objectives of this paper:

- to conduct sensitivity analyses to determine pavement design input parameters which have a significant effect on pavement distresses for flexible pavements in Iowa;
- to examine MEPDG design components related to traffic, climate, structural and non-structural elements and provide suitable implementation recommendations for each component;
- to discuss the need for validating and re-calibrating the MEPDG distress models, if necessary, using available Long-Term Pavement Performance (LTPP) and Iowa DOT Pavement Management Information System (PMIS) data.

3. Sensitivity analysis – flexible pavement design inputs

A sensitivity study was undertaken to evaluate and identify those input parameters related to material properties, traffic and climate that have significant or no influence on the MEPDG performance models for flexible pavement systems in Iowa. The full details of this study are report-

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ed elsewhere (Ceylan *et al.* 2006; Kim *et al.* 2005, 2006). The sensitivities of MEPDG performance measures (longitudinal cracking, alligator cracking, transverse cracking, rutting, and smoothness) to inputs were studied by either varying one input parameter or by varying input parameters per trial in a representative Iowa highway pavement structure using the MEPDG software.

3.1. Design input parameters

Two existing and typical flexible pavement structures in Iowa, one on US-20 in Buchanan County and one on I-80 in Cedar County, were considered in this study. The US-20 (Buchanan County) pavement section had 76 mm (3 in) of asphalt concrete (AC) surface over 406 mm (16 in) of AC base. A 254 mm (10 in) crushed gravel subbase course separated the AC layers and the subgrade. The pavement rested on an A-7-6 (clayey soil) classified subgrade soil. The I-80 (Cedar County) pavement structure comprised of 76 mm (3 in) of AC surface, 406 mm (16 in) of AC base resting on an A-7-6 classified subgrade soil.

The design input parameters were divided into 2 groups – "fixed" input parameters and "varied" input parameters. The fixed input parameters were assigned constant values and were not changed at any time during the analyses. Each of the varied input parameters was varied over a typical range of values (varied values) to study its particular effect on performance, while "standard" values were assigned for other input parameters.

A total of 20 key inputs related to material properties, traffic and climate were evaluated. A design life of 20 years was selected and a deterministic analysis (a nominal 50% design reliability) was used. Table 1 summarizes the design inputs and their values for the base or reference case.

To reflect Iowa traffic conditions, the monthly adjustment factors and the vehicle class distributions were obtained from the Iowa DOT traffic database. Five cases of vehicle class distributions were investigated to study the effect of vehicle class distribution on the flexible pavement performance models. Two new climate data files, one for Buchanan County and one for Cedar County, were generated to determine the standard input values for conducting the analysis. To investigate the effect of climate on performance, Burlington in Southern Iowa (relatively warm) and Estherville in Northern Iowa (relatively cold) were chosen as varied input values.

The pavement materials considered in this study could be divided into 3 major groups – AC, unbound granular aggregates, and subgrade. Most properties of AC required in the MEPDG software were investigated in this study. However, for the unbound and subgrade materials, strength-based properties were investigated using the Enhanced Integrated Climate Model (EICM) input analysis. The standard values used for the material properties matched the actual field pavement properties in Buchanan and Cedar counties as closely as possible.

3.2. Analysis

The sensitivities of five MEPDG performance measures were investigated by varying each of the varied input parameter per trial run. A limited study was also conducted to investigate the 2-way interaction among input variables in terms of their combined effect on performance. This was done by varying 2 of the varied inputs per trial run. The following input variables, with respect to their effect on performance, were studied at 2 levels of AC layer thickness (low and high): traffic distribution, tire pressure, Nominal Maximum Aggregate Size (NMAS), performance grade (PG) binder, AC thermal conductivity, and AC heat capacity. The AC layer thicknesses ranged from a "low" value of 76 mm (3 in) (standard value) to a "high" value of 203 mm (8 in).

3.3. Results

The MEPDG software runs for this study provided numerous charts and tables as outputs. Due to space constraints, it is difficult to present a full discussion of all the investigated input parameters in this paper. A summary of the results of MEPDG software runs is presented.

Similar to the approach used in the sensitivity analysis for rigid pavement design inputs, each evaluated input parameter in this study was categorized into 1 of the 5 groups based on the visual inspection of the sensitivity plots: extremely sensitive (ES), very sensitive (VS), sensitive (S), moderately sensitive (MS), or not sensitive (NS). An overall summary of the flexible pavement sensitivity analysis results is presented in Table 2.

Selected sensitivity plots are displayed in Fig. 1, with examples of inputs at different degrees of sensitivity for each performance measure. Examples of sensitivity plots illustrating the effect of input variables on flexible pavement performance at different AC thicknesses are presented in Fig. 2. The plotted data in both the Figs correspond to predicted performance measures accumulated over a 20 year design period. In general, the sensitivity of design input listed in each cell of Table 2 applies to both the pavement structures considered in this study.

Interestingly, there was no input parameter that was sensitive to all the MEPDG performance measures in this study. Most of the investigated input parameters were found to be sensitive to longitudinal cracking while most were listed as NS for alligator cracking. Alligator cracking does not seem to be a critical distress in flexible pavement structures with relatively thick AC layers as considered in this study. The inputs related to material properties and climate were especially sensitive to predicted transverse cracking. In general, the binder PG, AC mix volumetric properties, climate, average annual daily truck traffic (AADTT), type of base (moduli), base layer thickness, etc. had significant impact on most of the predicted performance measures (Table 3).

4. Sensitivity analyses – summary

In support of the MEPDG implementation initiatives in Iowa, sensitivity studies were conducted using the MEPDG software to identify those input factors pertaining to flexible pavements that are of particular sensitivity in Iowa. Table 3 lists the input factors which have been identified to be of significant sensitivity for Iowa. Of these, the ES inputs merit early consideration and resolution. In addition to the factors

Table 1. Flexible pavement design inputs (base case values)

Input parameter	Value
Design life in years	20
Pavement construction month	Sep/2004
Traffic open month	Oct/2004
Initial IRI in m/km	0.6
Terminal IRI in m /km	2.71 (limit)
AC longitudinal cracking in m/km	400 (limit)
AC alligator cracking in %	25 (limit)
AC transverse cracking in m/km	190 (limit)
Permanent deformation – total in mm	19 (limit)
Permanent deformation – AC only in mm	6 (limit)
2-way average annual daily truck traffic (AADTT) in vpd	1168 for Buchanan County 10 928 for Cedar County
Number of lanes in design direction	2
% of trucks in design direction	50
% of trucks in design lane	90
Operational speed in km/h	97
Mean wheel location in cm	46
Traffic wander standard deviation in mm	254
Design lane width in m	3.65
Average axle width in m	2.6
Dual tire spacing in mm	305
Tire pressure – single and dual tire in kPa	827/827
Axle spacing – tandem, tridem, quad axle in cm	131, 125, 125
Average axle spacing in m	3.6, 4.6, 5.5
% of trucks	33, 33, 34
Climate data file	Buchanan County file/Cedar County file
Asphalt binder grade	PG 58-28
Asphalt surface thickness in mm	76
Asphalt base thickness in mm	330 (Buchanan)/406 (Cedar)
Surface AC aggregate gradation	NMAS 19 mm gradation – cuml % retained 19 mm: 0 – cuml % retained 9.5 mm: 22 – cuml % retained 4.75 mm: 48 – % passing 75 μm: 3
Base AC aggregate gradation	NMAS 19 mm gradation – cuml % retained 19 mm: 0 – cuml % retained 9.5 mm: 25 – cuml % retained 4.75 mm: 56 – % passing 75 μm: 3
Initial volumetric properties: Vbe/ Va/ VMA in %	11/7/18
Poisson's ratio	0.25
Thermal conductivity in calories/s×cm×°C)	0.00277
Heat capacity in calorie/gram×°C)	0.23
Subbase thickness in mm	254
Type of subbase material	crushed gravel (CG)
Type of subgrade material	A-7-6
Aggregate coefficient of thermal extraction (per °C)	0.162×10^{-6}

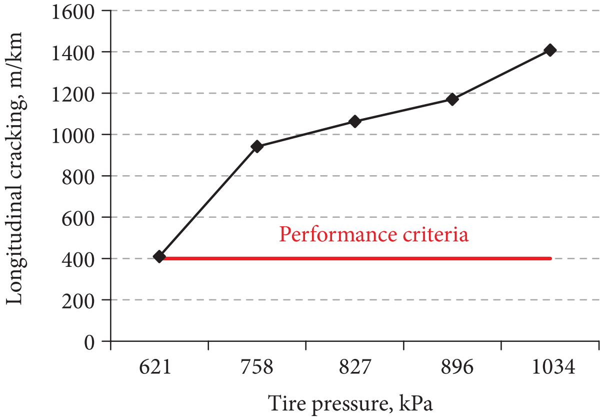
Table 2. Summary of results of sensitivity analyses for flexible pavements

Flexible pavement design inputs	Performance models								
	Cracking			Rutting					Roughness
	Long.	Alli.	Trans.	AC surface	AC base	Sub-base	Sub-grade	Total	
AC layer thickness	S	NS	NS	NS	NS	NS	NS	NS/MS	NS
Nominal max size	S	NS	NS	NS/MS	NS	NS	NS	NS/MS	NS
PG grade	ES	NS	ES	MS/S	NS	NS	NS	MS/S	MS/S
AC volumetric	VS	NS	VS/ES	MS	NS	NS	NS	MS	MS/S
AC unit weight	MS/S	NS	NS	NS/MS	NS	NS	NS	NS/MS	NS
AC Poisson's ratio	MS/S	NS	NS	S	NS	NS	NS	S	NS
AC thermal cond.	S	NS	MS	NS/MS	NS	NS	NS	NS	NS
AC heat capacity	VS	NS	VS	MS/S	NS	NS	NS	MS/S	MS
Tire pressure	VS	NS	NS	MS	NS	NS	NS	MS	NS
AADTT	VS	MS/S	NS	ES	S	NS	S	ES	NS
Traffic distribution	VS	NS	NS	MS	NS	NS	NS	MS	NS
Traffic speed	VS	NS	NS	S/VS	NS/MS	NS	NS	S/VS	NS
Traffic wander	MS/S	NS	NS	NS	NS	NS	NS	NS	NS
Climate	VS	NS	ES	S	NS/MS	NS	NS/MS	S	S
Base thickness	S/VS	S/VS	NS	VS	NS/MS	NS	NS/MS	VS	MS
Base type (M_r)	MS/S	ES	NS/MS	VS	MS/S	NS	NS/MS	VS	VS/S
Subbase thickness	MS/S	NS	NS	NS	NS	NS	NS/MS	NS	NS
Subbase type (M_r)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Subgrade type (M_r)	ES	MS	NS	NS	NS	NS	NS/MS	NS/MS	NS/MS
Agg. therm. coeff.	NS	NS	NS	NS	NS	NS	NS	NS	NS

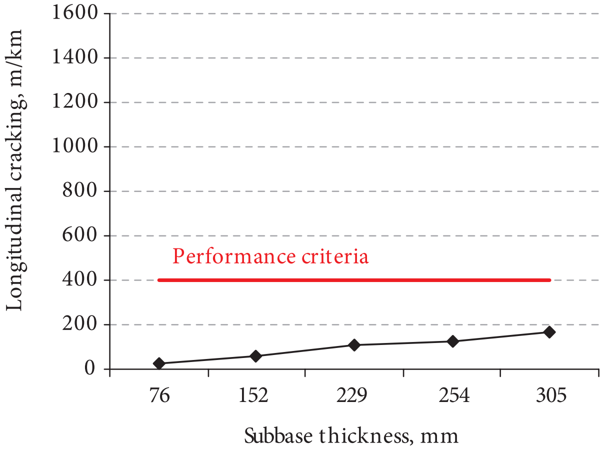
Note: ES – extremely sensitive; VS – very sensitive; S – sensitive; MS – moderately sensitive; NS – not sensitive; **designer can control directly**; designer may not change, but must know

Table 3. Input factors of significant sensitivity (flexible pavements)

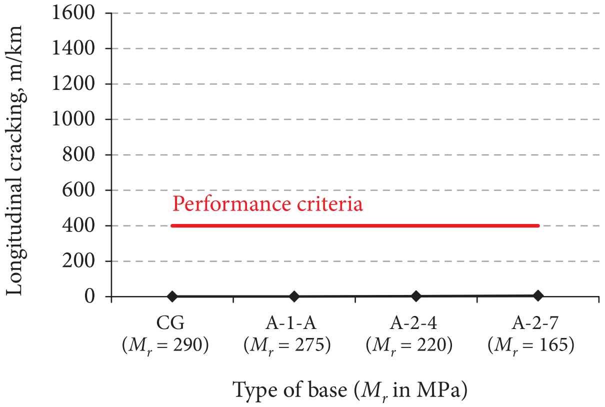
Flexible pavements	Extremely sensitive (ES)	Sensitive to very sensitive (S/VS)
Longitudinal cracking	performance grade (PG) binder; type of subgrade (M_r – moduli).	AC layer thickness; nominal max size; AC volumetric properties; thermal conductivity; heat capacity; tire pressure; AADTT; traffic distribution; traffic velocity; climate data; base layer thickness.
Alligator cracking	type of base (M_r – moduli)	base thickness; AADTT.
Transverse cracking	PG binder; climate data from different stations	AC volumetric properties; thermal conductivity; heat capacity.
Rutting	AADTT	Poisson's ratio; traffic velocity; climate data from different stations; base layer thickness; type of base (M_r – moduli).
Roughness		climate data from different stations; type of base (M_r – moduli).



Example of very sensitive input (location – Cedar, design life – 20 years, AC(PG 58–28) – 76 mm, AC base (PG 58–28) – 406 mm, subgrade (A-7-6, M_r = 55.2 MPa), AADTT – 10 928);

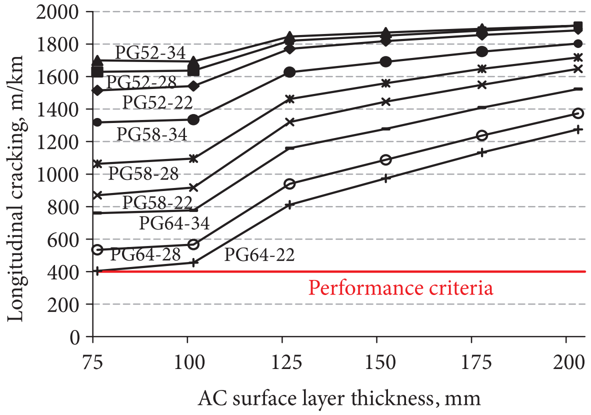


Example of sensitive input (location – Buchanan, design life – 20years, AC (PG 58-28) – 76 mm, AC base (PG58-28) – 330 mm, subbase (CG) – 76–305 mm, subgrade (A-7-6, M_r = 55.2 MPa), AADTT – 1168);

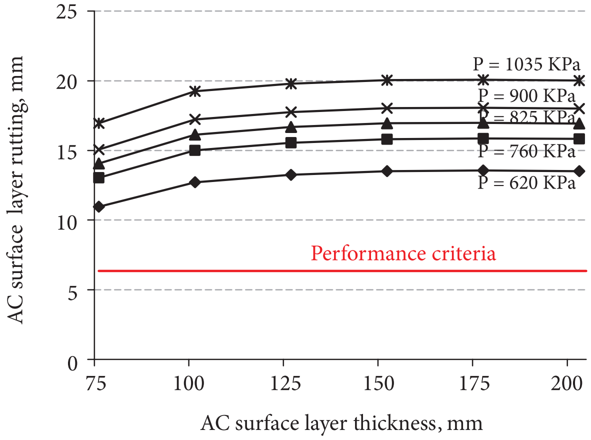


Example of insensitive input (location – Buchanan, design life – 20 years, AC (PG 58-28) – 76 mm, base – 330 mm, subbase (CG) – 254 mm, subgrade (A-7-6, M_r = 55.2 MPa)

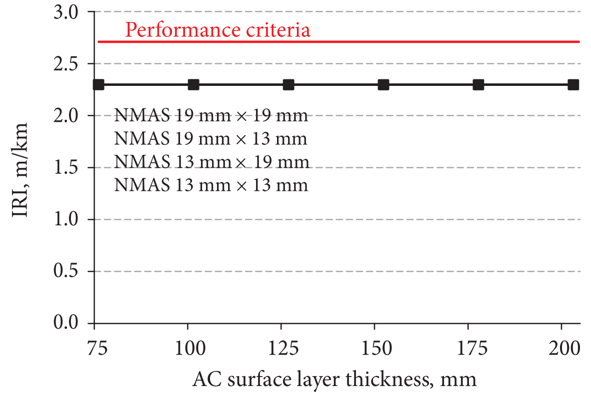
Fig. 1. Effect of input parameters on AC longitudinal cracking – examples for different levels of sensitivity



Effect of AC surface layer thickness and PG binder grading on longitudinal cracking (location – Cedar, design life – 20 years, AC(PG 58–28) – 76–203 mm, AC base (PG 58–28) – 406 mm, subgrade (A-7-6, M_r = 55.2 MPa), AADTT – 10 928);



Effect of AC surface layer thickness and tire pressure on AC surface layer rutting (location – Cedar, design life – 20 years, AC(PG 58–28) – 76–203 mm, AC base (PG 58–28) – 406 mm, subgrade (A-7-6, M_r = 55.2 MPa), AADTT – 10 928);



Effect of AC surface layer thickness and NMAS on IRI (location – Cedar, design life – 20 years, AC(PG 58–28) – 76–203 mm, AC base (PG 58–28) – 406 mm, subgrade (A-7-6, M_r = 55.2 MPa), AADTT – 1168)

Fig. 2. Interactive effect of two design inputs on flexible pavement performance – some examples (location – Cedar, design life – 20 years, AC(PG 58–28) – 76–203 mm, AC base (PG 58–28) – 406 mm, subgrade (A-7-6, M_r = 55.2 MPa), AADTT – 10 928)

listed in Table 3, there are some other factors that exhibit some degree of sensitivity under certain conditions.

5. Implementation recommendations

The MEPDG components were closely examined to provide recommendations for implementing the MEPDG in Iowa (Coree *et al.* 2005). Based on the results of sensitivity analyses and past experience, implementation recommendations were made for relevant modules in the MEPDG.

5.1. Implementation recommendations for traffic

In developing the MEPDG, it was recognized that the traditionally used traffic parameters such as AADT or ESAL do not sufficiently recognize the differing effects of different axle loads and configurations on the pavement. Consequently, the use of "traffic spectra" is now recommended. In this approach, the anticipated traffic must be classified by axle type (single, tandem, tridem, etc.), and within each type, the distribution of axle weights is prescribed. Further, daily, weekly, and seasonal volume distributions are possible. In other words, the traffic spectrum approach requires a more realistic knowledge of the actual distribution of axle types, weights and occurrence in time than has been traditional.

Iowa DOT is currently well-placed to use the MEPDG traffic input format. However, a number of specific recommendations are made to increase the success of implementation:

- a joint committee of the Iowa DOT Design Section and Traffic Section should examine the various traffic input screens in the MEPDG software and come to an agreement on the best process to identify and transmit the data to the Design Section;
- project-specific traffic data transfer to the Design Section should be made by electronic means in the required formats, allowing the MEPDG software to read and complete the traffic data input automatically;
- since many highways in Iowa are low-volume traffic platforms that carry generic traffic patterns, default traffic input files should be created for different functional highway classes, leaving the detailed site-specific traffic analyses to the higher classes of highway and those with significant seasonal imbalances.

5.2. Implementation recommendations for environment

In order to incorporate environmental effects within the MEPDG software, 3 elements are required:

1) a site-specific environmental data set (external),
2) a material-specific set of thermal-related properties (heat capacity, thermal conductivity, etc) (internal), and
3) the Enhanced Integrated Climatic Model (EICM) algorithm to compute the transmission of heat (and moisture) within the pavement structure.

The MEPDG software incorporates a set of environmental data sets for specific locations within the USA, with 15 locations in Iowa. The 15 Iowa data sets may be insufficient to derive full benefit from the site-specificity that the software can provide. Further, these data sets provide historical records for between 17 months and somewhat less than 5 years. Ideally, each data set should provide, at least, 11 years of historical data.

It is recommended that the Iowa DOT seek to fill the Iowa site-specific data sets with a min of 11 years (preferably 20–30 years) of continuous data in order to make the data sets more statistically representative. This may have to be done under research contract with the Iowa State University (ISU) Dept of Agronomy, which may have the best access to the necessary data.

5.3. Implementation recommendations for structural elements

The materials considered in the MEPDG include: Hot-Mix Asphalt (HMA), Portland Cement Concrete (PCC), stabilized materials, and subgrade and unbound materials. Each material must have its structural properties defined as input. These properties are typically the elastic (or resilient) modulus E (or E^*) and the Poisson's ratio, μ.

- Since in most cases it is unlikely that project-specific material information (eg. job-mix formulae) will be available at the time of the structural design, it is recommended that the Iowa DOT determine representative input values for each specification or bid-item in the current specification.

5.4. Implementation recommendations for non-structural elements

In conjunction with the structurally-related input, the MEPDG software requires a number of non-structural input values. These variously relate to the transmission of thermal energy through the material (heat capacity and thermal conductivity), the rheological properties of the asphalt binder, the specific gravity, hydraulic conductivity and degree of saturation of unbound materials, cross-sectional geometry, dowel bar diameter and spacing, pavement cross slope, etc.

Sensitivity studies (discussed previously) indicate that pavement performance may be significantly sensitive to the thermal properties of the materials. Therefore, it is recommended that the Iowa DOT establish realistic thermal input values for Iowa materials (aggregates, HMA and PCC), i.e. HMA heat capacity and PCC coefficient of thermal expansion.

6. Validation and calibration of distress models

The performance models in the MEPDG have been calibrated against information in the national LTPP database. Not only is that database somewhat imperfect (as it contains considerable amount of level 3 input), but the coverage of appropriate pavement types is somewhat incomplete and Iowa may not be adequately represented. It will be necessary, therefore, to validate the default calibration against Iowa data and recalibrate the default calibrations as necessary.

Many of the MEPDG calibrations were carried out in the mid-to-late 1990s. Since that time, more of the state-submitted LTPP program data has passed quality screening and is now available. While it is clear that when the calibrations were undertaken, Iowa was under-represented in the LTPP database, that situation either has, or shortly will be, corrected. This will allow Iowa to undertake local validation and calibration activity.

The project team recommends that the Iowa DOT validate performance predictions using available LTPP and PMIS data. This activity will require a number of steps:

- identify and rank the predominant distress types in Iowa for each pavement type through an examination of the PMIS database;
- select a statistically significant number of highway sections for each distress type; use of LTPP sites with these distresses is particularly encouraged;
- input data appropriate to the last major construction activity on these sections, and use it to predict the development of the relevant distress to the current time;
- compare the MEPDG predictions against the LTPP or PMIS measured distresses;
- determine if the MEPDG accurately predicts the distress level;
    - if YES, the MEPDG algorithm for this distress is valid;
    - if NO, the MEPDG algorithm for this distress is not valid, compare the PMIS data to the MEPDG data to determine adjustment factors for re-calibrating the MEPDG models.

7. MEPDG implementation initiatives by other highway agencies

Iowa DOT is one of the few highway agencies that is pursuing the implementation of the MEPDG. Saeed and Hall (2003) presented Mississippi DOT's pro-active approach to implement the MEPDG even before the MEPDG was released. The Mississippi DOT is implementing the MEPDG in two phases. An implementation plan was developed in Phase I, and actual implementation of the MEPDG occurs in Phase II. Implementation activities at Mississippi DOT include becoming familiar with the MEPDG procedure and training of staff, developing an implementation plan, conducting initial material tests on HMA, developing a traffic estimation procedure, and selection of field sections for use in local calibration of the procedure.

Nantung *et al.* (2005) proposed implementation initiatives of the MEPDG in Indiana. A matrix of trial runs conducted using the MEPDG software suggested that a higher design level input does not necessarily guarantee a higher accuracy in predicting pavement performance. The software runs also confirmed the need for using input values obtained from local rather than national calibration. Nantung *et al.* (2005) indicated that the hierarchical approach to design inputs is an important feature in the MEPDG. A decision to choose a higher input level from the start of the design process in many cases may not result in a more efficient design. It was proposed that the hierarchical design inputs should be selected in a case by case basis after a thorough evaluation of all the design modules and sensitivity analysis.

Uzan *et al.* (2005) proposed a strategic plan for implementing the MEPDG for the Texas DOT operations which included training, laboratory testing and equipment acquisition, field forensic studies for calibration, calibration and validation of the MEPDG and additional studies. Their paper focused on implementation issues for design of new flexible pavements. A few focused studies were presented, including:

1) preliminary local calibration of the guide using 11 test sections in Texas,
2) traffic composition effect compared to that of the traditional 80 kN ESALs and of the design load, and
3) effect of the choice of the weather station and of changing the water table depth on performance of the pavement.

The findings indicated that the MEPDG predicts rutting and fatigue cracking fairly closely to the data for Texas, but the model for longitudinal cracking is not as precise. Uzan *et al.* (2005) noted that care must be exercised when using an existing empirical design procedure, in parallel with the MEPDG. It may lead to a different design, without any mechanistic justification, and the engineer may not be able to determine which is the better design.

8. Summary of observations

The Iowa Department of Transportation (DOT) currently utilizes the empirically-based AASHTO pavement design procedures originally derived from the 1960 Road Test data. It is clear that these empirical procedures are no longer applicable to current conditions in Iowa. With the release of the new MEPDG in the US, pavement design has taken a big leap forward.

In support of the MEPDG implementation initiatives at Iowa DOT, sensitivity studies were conducted using the MEPDG to identify design inputs pertaining to both rigid pavements and flexible pavements that are of particular sensitivity in Iowa as well as those factors that are of no particular sensitivity.

Based on a thorough examination of the MEPDG design components, the results of sensitivity analyses and past experience, implementation recommendations were made for traffic, climate, structural and non-structural elements. Since the new design approach includes the use of mechanistic-empirical procedures and performance prediction models, in-depth knowledge about the use of design inputs for pavement designs is required. An expert system should be established to help pavement design engineers determine which design inputs to modify.

The performance models in the MEPDG have been calibrated against information in the national LTPP database, which did not adequately represent Iowa. It will be necessary, therefore, to validate the MEPDG performance predictions using the available LTPP and Iowa DOT PMIS data and further calibrate the models locally.

A training program for pavement engineers with an emphasis on obtaining the relevant level of design inputs should be implemented. In order to adequately implement the use of the MEPDG, it will be necessary to train all Iowa DOT staff involved with the MEPDG design process. Training should also be provided for representatives from the areas of traffic, materials, PMIS and special investigations from central and district offices.

In summary, it is recommended that the Iowa DOT seek to implement the MEPDG as the preferred approach to pavement design and evaluation. However, immediate implementation is neither feasible nor possible. Therefore, the Iowa DOT should seek to position itself such that general implementation is possible in approx 3 years, and allow further 2 years for full implementation.

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