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16. Abstract

This five-year project was initiated to collect materials and pavement performance data on a minimum of 100 highway test sections around the State of Texas, incorporating flexible pavements and overlays. Besides being used to calibrate and validate mechanistic-empirical (M-E) design models, the data collected will also serve as an ongoing reference data source and/or diagnostic tool for TxDOT engineers and other transportation professionals.

Towards this goal, this interim report provides a documentation of the comprehensive work plans and strategies that were developed to calibrate and validate the M-E models and the associated software. As a minimum, the calibration and validation plans covers the following M-E models and associated software:

- The FPS.
- The TxACOL.
- The TxM-E.
- The M-E PDG.

As discussed in this interim report, these strategic work plans were devised on the premise that data for calibrating and validating these M-E models/software will predominantly come from the Project 0-6658 MS Access Data Storage System (DSS). Accordingly, the DSS is also discussed in this interim report. Demonstration examples of the software (FPS, TxACOL, and M-E PDG) runs are also included in the report.

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TEXAS FLEXIBLE PAVEMENTS AND OVERLAYS: CALIBRATION PLANS FOR M-E MODELS AND RELATED SOFTWARE

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The researcher in charge was Lubinda F. Walubita.

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Data CD located in back of the product

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LIST OF NOTATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of variance
AC	Asphalt concrete (HMA)
ACP	Asphalt concrete pavement
ADT	Average daily traffic
ADTT	Average daily truck traffic
AV	Air voids
Avg	Average
CV	Coefficient of variation
CTB	Cement-treated base
CTIS	Center for Transportation Infrastructure Systems
DCP	Dynamic cone penetrometer
DSS	Data storage system
EB	Eastbound direction
EICM	Enhanced integrated climatic model
ESAL	Equivalent axle single load
FHWA	Federal Highway Administration
FPS	Flexible Pavement System
FWD	Falling weight deflectometer
IRI	International roughness index
GIS	Geographical Information System
GPR	Ground penetrating radar
GPS	Geographical positioning system
FWD	Falling weight deflectometer
HMA	Hot-mix asphalt
HSD	Honestly significant difference
HWTT	Hamburg wheel tracking test
Hwy	Highway
LFA	Lime fly ash

LTB	Lime-treated base
LTPP	Long-Term Pavement Performance
M-E	Mechanistic Empirical
M-E PDG	Mechanistic Empirical Pavement Design Guide
MESALs	Million equivalent single axle loads
MS	Microsoft©
M_R	Resilient modulus
NB	Northbound direction
NDT	Non-destructive test (or testing)
OT	Overlay Tester
PCC	Portland concrete cement
PD	Permanent deformation
PI	Principal Investigator
PMIS	Pavement Management Information System
PP	Perpetual Pavement
PSI	Pavement serviceability index
PSPA	Portable seismic property analyzer
PVMNT	Pavement
QA	Quality assurance
QC	Quality control
RBL	Rich-bottom layer (fatigue crack-resistant layer)
RRL	Rut-resistant layer
SB	Southbound direction
SPS	Specific pavement studies
TFPDB	Texas Flexible Pavement Database
TSFP	Texas Successful Flexible Pavement
TTI	Texas Transportation Institute
TxACOL	Texas Asphalt Concrete Overlay Design and Analysis System
TxDOT	Texas Department of Transportation
TxM-E	Texas Mechanistic-Empirical Flexible Pavement Design System
UT	University of Texas at Austin

UTEP	University of Texas at El Paso
WB	Westbound direction
WC	Wet-cold climatic region
WIM	Weigh-in-motion
WP	Wheel path

CHAPTER 1: INTRODUCTION

Proper calibration of pavement design and rehabilitation performance models to conditions in Texas is essential for cost-effective flexible pavement and overlay designs. The degree of excellence with which TxDOT's pavement design models are calibrated will determine how billions of dollars of future roadway investment capital are spent. The magnitude of the benefits and consequences involved makes this research project one of the more important research efforts that the department has undertaken in recent memory.

Collection of quality and reliable pavement performance data on a sustained basis will be the main goal of this project. This presents a perfect opportunity to calibrate and validate the current design methods and models for both flexible pavements and overlays. The calibration of these models to Texas local conditions will result in pavement and overlay designs that maintain superior performance expectations and are more economical in the long term.

OBJECTIVES AND SCOPE OF WORK

The primary goal of this five-year project is to collect and develop a data storage system of materials and pavement performance data on a minimum of 100 highway test sections around Texas. For easy management and access, the user-friendly MS Access® is being used as the data storage medium for the collected data. As a minimum, the data collected and the associated MS Access Data Storage System (DSS) will serve two purposes, namely (Walubita et al., 2012):

- To calibrate and validate the mechanistic-empirical (M-E) design models.
- Serve as an ongoing reference source and/or diagnostic tool for TxDOT engineers and other transportation professionals.

Toward these objectives and as documented in this interim report, the specific objective of this task was to develop strategic work plans for calibrating and validating the M-E models and the associated software, namely (Walubita et al., 2012):

- The FPS.
- The TxACOL.
- The TxM-E.
- The M-E PDG.

For each of the above M-E models/software, the scope of work includes relating the material's model to response (i.e., stress, strain), relating response to field distresses, and relating the distresses to some overall performance indicators or indices such as PSI, IRI, etc. Where applicable, M-E transfer functions were also developed and are discussed in this interim report.

This interim report also includes a description of how the data that was collected and stored in the DSS will be used for the calibration and validation processes of the M-E models/software. Specifically, the report will focus on how to access the data for input into the M-E software.

DESCRIPTION OF THE REPORT CONTENTS

This report, denoted here as Product 0-6658-P4, documents the calibration and validation plans for the M-E models and the associated software, including the DSS data access. The scope and contents of the report covers the following aspects:

- Chapter 2: Calibration and validation plans.
- Chapter 3: The Project 0-6658 data storage system.
- Chapter 4: The FPS model and associated software.
- Chapter 5: The TxACOL model and associated software.
- Chapter 6: The TxM-E model and associated software.
- Chapter 7: The M-E PDG software.
- Chapter 8: Summary and recommendations.

Some appendices of important data are included at the end of the report along with a CD of some M-E models, analysis demonstrations, and example results. Additionally, reference should also be made to the following reports that are an integral part of the work documented in this interim report:

1) Report 0-6658-1 (Walubita et al., 2012).
2) Report 0-6658-P1 (Walubita et al., 2011).
3) Report 0-6658-P3 (Walubita et al., 2012).
4) Report 0-6658-P6 (Walubita et al., 2011c).
5) Report 0-6622-1 (Hu et al., 2012a).
6) Report 0-6622-2 (Hu et al., 2012b).
7) Report 0-5798-2 (Zhou et al., 2010).

8) Report 0-5798-1 (Zhou et al., 2008).
9) Tech Memo Task 0-6622-4a (Navarro et al., 2012).
10) Tech Memo Task 0-6622-4b (Tirado et al., 2012).

SUMMARY

This introductory chapter discussed the background and research objectives along with the scope and content of the report. Specifically, this report, denoted as Product 0-6658-P4, documents the strategic work plans that were developed for calibrating and validating the M-E models and the associated software.

However, it should be emphasized that the input data, analysis, and results presented in this interim report are preliminary and should not be used to judge the capability, accuracy, and/or applicability of the M-E models and related software. The intent is merely to outline the proposed calibration work plans and demonstrate how the data from the DSS will be utilized to run the software. Comprehensive M-E analyses and software runs will be conducted in due course as more data is collected during the course of the study.

CHAPTER 2: CALIBRATION AND VALIDATION PLANS

This chapter presents and discusses the generalized plans and framework for calibrating the M-E models and related software. The purpose of calibration is essentially to determine the calibration factors that relate some predicted to actual measured parameters or values such as pavement response, distresses, performance, etc. Ideally, these calibration factors serve as the interface relating the M-E models to actual field conditions.

CALIBRATION PROCESS

The overall framework and process for calibrating the M-E models will be to compare predicted to actual measured values as depicted in the flow chart in Figure 2-1. The approach shown in Figure 2-1, which also includes a validation phase, allows for a sensitivity analysis and determination of the systematic differences within the experimental factorial as well as the possibility to evaluate the residual differences between the predictions and measured values. As shown in Figure 2-1, the calibration process will consist of the following steps:

Step 1: Assemble the M-E input data and the actual measured field response, performance, and distresses. For this study, these data will be extracted from the Project 0-6658 Data Storage System (DSS); which is discussed in the subsequent Chapter 3.

Step 2: Use the data from the Project 0-6658 DSS to run the M-E models and/or related software to predict response and/or performance.

Step 3: Compare and analyze the M-E model predictions relative to the actual measured responses and/or predictions. At minimum, the comparative analysis will incorporate visual graphs (i.e., scatter plots) and statistical analysis such as t-tests, correlations, regressions, optimizations, ANOVA, Tukey's HSD test, etc. Ninety percent confidence level will be used as the measure of statistical similarity between the predicted and the actual measured field values.

Step 4: Adjust and/or modify the M-E model if the predictions are statistically significantly different from the measure and iteratively re-run the calibration process to modify and/or develop new transfer functions and calibration factors.

Step 5: M-E model calibration is complete if the predicted and the actual measured field values are statistically similar – and then, proceed to model validation.

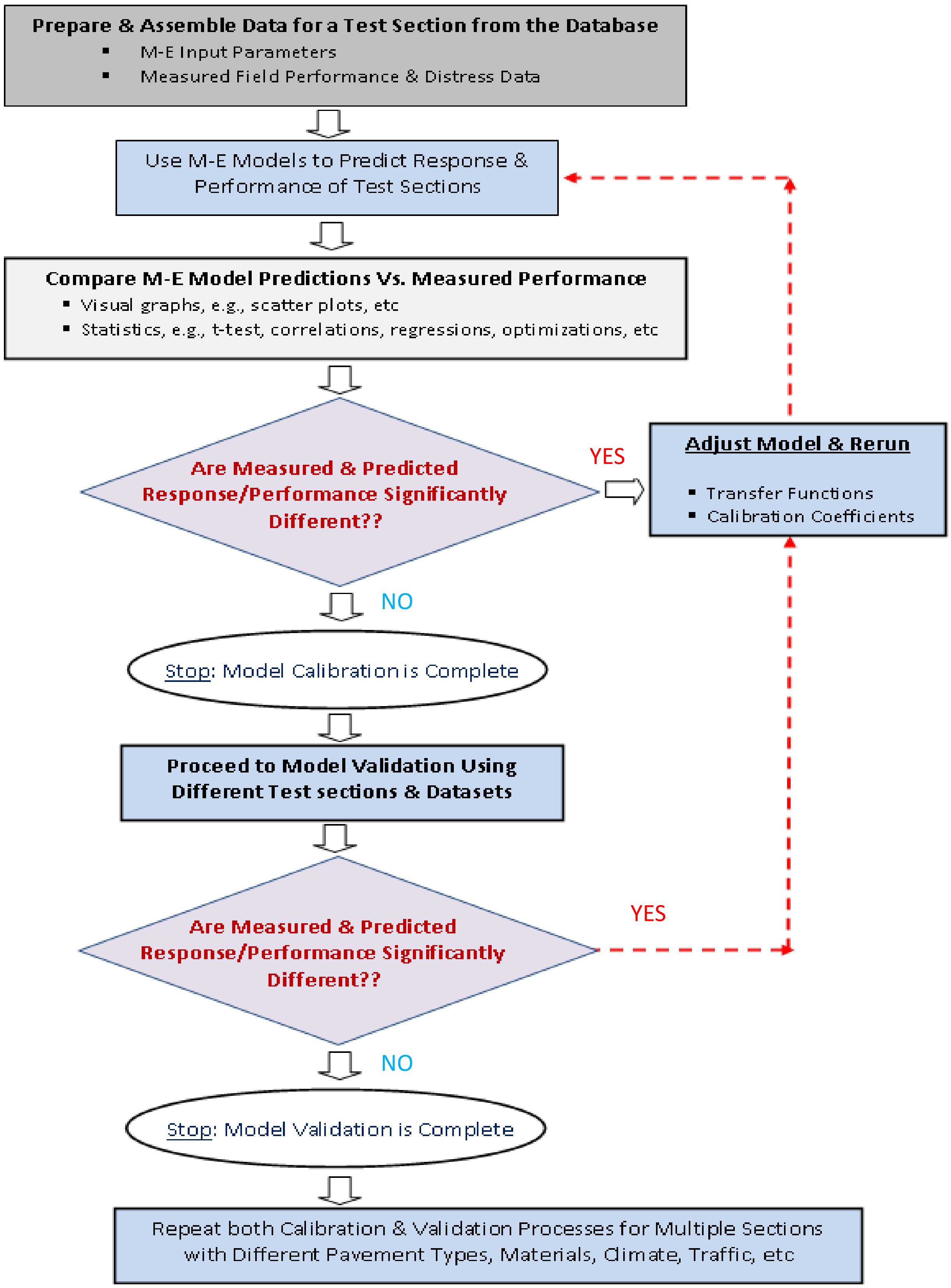


Figure 2-1. Calibration-Validation Flow Chart.

Based on Figure 2-1 and as shown in Figure 2-2, the framework for the M-E calibration process will focus on the following key aspects:

- Relating material models to response.
- Relating response to distress.
- Relating distresses to performance.

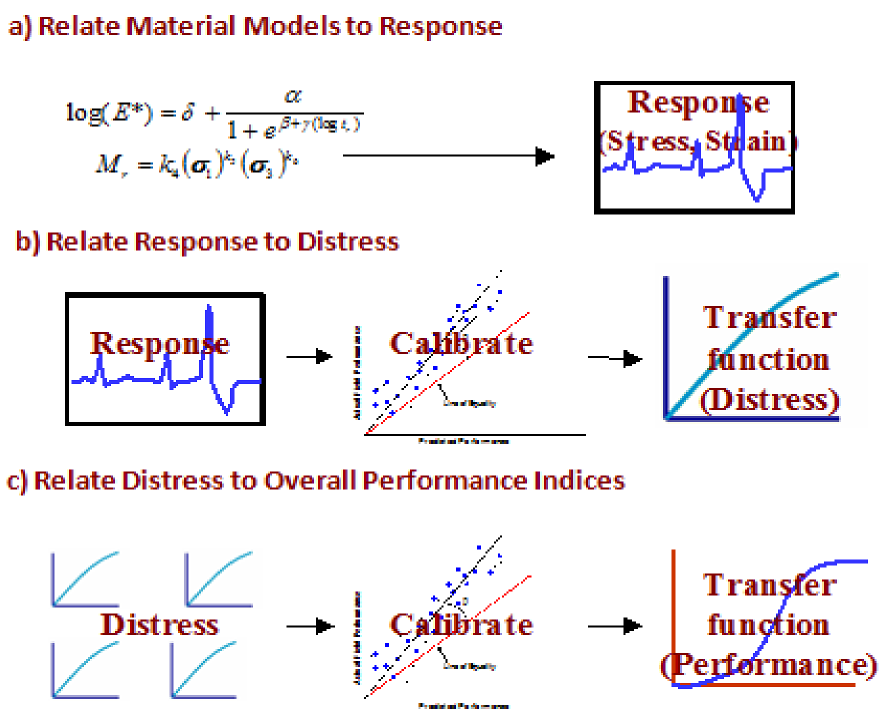


Figure 2-2. Framework for the Calibration Process (Krugler et al., 2007).

Relate Material Models to Response

This aspect includes computing critical stresses and strains based on site conditions. For each test section in the DSS, researchers will use available values for the inputs (e.g., material properties) to estimate responses (i.e., stresses, strains, deflections, etc.). The predicted responses will then be compared and related to those measured in the field, where available. At minimum, the calibration data for this aspect (which will be accessed from the Project 0-6658 DSS) should consist of the following:

- Pavement structure (i.e., layer information).
- Material properties (e.g., lab moduli and field FWD).

- Number and magnitude of loads applied.
- Environmental condition (temperature and moisture) at time of test.

Relate Response to Distress

This aspect includes computing distresses using the M-E models and calibrating the models by comparing computed distresses to actual measured pavement distresses. As contained in the Project 0-6658 DSS, this will require condition survey data of such distresses as cracking, rutting, deflections, etc. At minimum, the following key distresses will be investigated as applicable to the specific M-E model in question (FPS, TxACOL, TxM-E, or M-E PDG):

- Bottom-up cracking models of hot-mix asphalt.
- Rutting (i.e., total rutting, HMA, base, and/or subgrade where applicable).
- Cracking (fatigue, reflective, top-down, etc.).
- Deflections.

Relate Distresses to Overall Performance Indices

The first step of this process is to evaluate and select the relevant performance indicators. Secondly, transfer functions will be proposed where applicable (in conjunction with Study 0-6622) to relate pavement distresses to pavement performance indices such as the PSI and IRI used in TxDOT's PMIS. Both of these performance indicators are currently being measured and stored in the Project 0-6658 DSS. So, it is be feasible to propose or make recommendations for modifications to the transfer functions and M-E models.

Statistical and Sensitivity Analyses – Errors and Variances

Ideally, the results of calibration runs should yield data similar to that shown in Figure 2-3. If there is bias in the predictions and/or if the errors are significantly large, then modifications or adjustments to the calibration factors may be warranted through an iterative and sensitivity analysis. Consequently, a comprehensive sensitivity analysis of the error terms will be performed to determine what adjustments need to be applied to the calibration factors to eliminate any bias and/or reduce the error term.

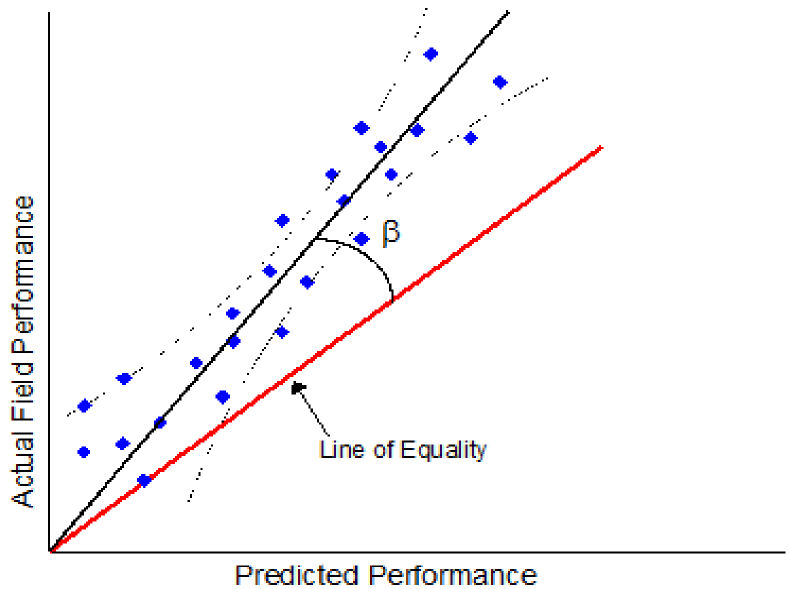


Figure 2-3. Ideal Result from the Calibration Process (Krugler et al., 2007).

Various statistical analysis tools as discussed in the preceding text will be incorporated for comparing the model predictions and measured values at two other reliability levels (namely 80 and 95 percent) in addition to 90 percent. These statistical tools will, among others, assist in selecting suitable data sets and data validation for the test sections so as to make the appropriate recommendations for modifications to the transfer functions and calibration coefficients. Thus, each calibration factor developed will be associated with some degree of accuracy in terms of the reliability level and error tolerance or variance.

Additionally, the researchers will also consider the following approaches in the calibration/validation procedure:

- If sufficient test sections and performance observations are available for a specific distress, a split sampling technique can be used in the calibration-validation process. A portion of the test sections will be selected randomly for making adjustments to the calibration factors. The remainder of the test section will be used to validate these calibration coefficients.
- If a sufficient number of sites or number of performance observations is unavailable for a specific distress, a "jackknife" technique as used in NCHRP 9-30 to develop an experimental plan to further calibrate the performance prediction models, will be used in the calibration process.

VALIDATION PROCESS

As discussed in the preceding text, the primary objective of calibration and validation is to ensure that the M-E model predictions relate to and match field conditions within a specified statistical error tolerance. So, once the calibration process has been successfully completed, i.e., calibration factors determined and the M-E model predictions are consistent with measured field values, the next step would be to perform a validation process.

As shown in Figure 2-1, a different set of test sections and datasets should be used for the validation process. So, different test sections from those used in the calibration process from the Project 0-6658 DSS will be used. If the predicted values statistically differ from the measured values during the validation process, then the calibration process should be repeated iteratively to modify the transfer factors and develop new calibration factors. Thereafter, a validation process should be conducted again. M-E model validation is considered to be successfully complete if the predicted and measured values are statistically similar within the prescribed error tolerance.

The last aspect would be to repeat the calibration and validation processes for multiple test sections with different data sets such as PVMNT structure, material properties, climate, traffic data, etc. If needed and if the predicted significantly differs from the measured values, iteratively repeat the processes illustrated in Figure 2-1.

During both processes of calibration and validation, a minimum of three variables should be considered for each characteristic factor as shown in Table 2-1.

Table 2-1. Calibration Matrix Plan – Key Factors and Variables.

#	Factor	Number of Variables to Consider	Comment
1	PVMNT type	≥ 3	
2	PVMNT structure	≥ 3	
3	Material type	≥ 3	
4	Climatic & environmental type	≥ 3	
5	Traffic level	≥ 3	
6	Distress type	≥ 3	
7	Etc.	≥ 3	

Based on Table 2-1, this means that a minimum of 729 variables will be utilized in the calibration and validation processes.

STUDY 0-6622 AND THE PROJECT 0-6658 DSS

Study 0-6622 is involved with M-E model development (Zhou, 2011). As such, the M-E model calibration and validation processes will be conducted jointly with this study. Data from the Project 0-6658 DSS and Study 0-6622 will be used for the M-E model calibration and validation processes.

ONGOING CALIBRATION AND VALIDATION PROCESSES

An additional element of this task will be to recommend ongoing calibration and validation activities to assure continued close alignment of these M-E models with the types of flexible pavement materials and structure types of the future. Figure 2-4 illustrates an example of an ongoing recalibration process.

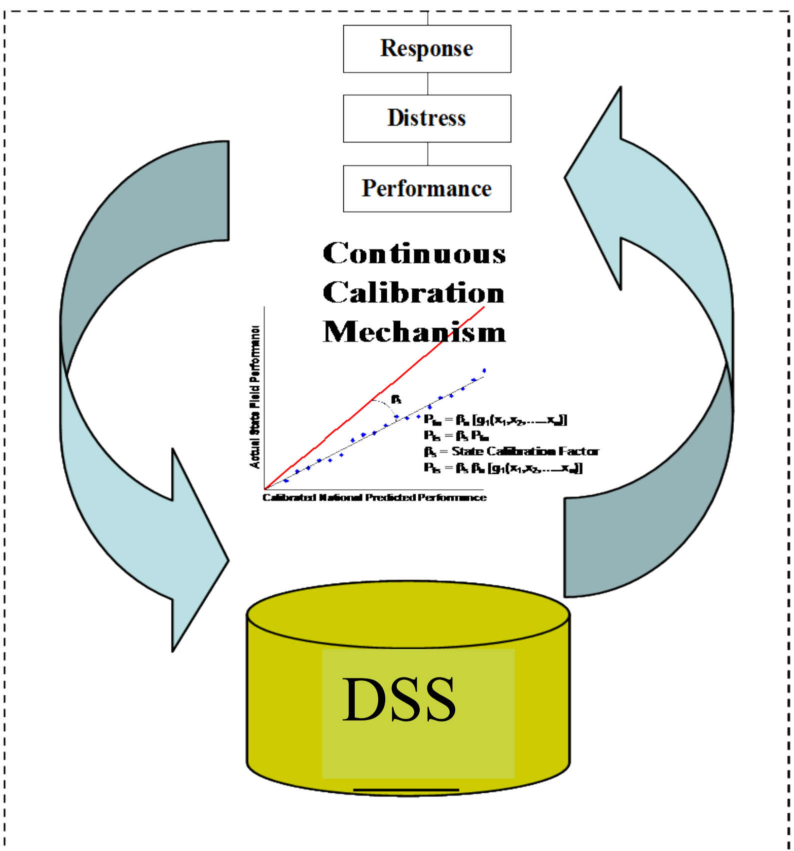


Figure 2-4. Process of a Continuous Calibration Mechanism (Krugler et al., 2007).

The research team will also consider approaches for potentially automating or semi-automating calibration activities to facilitate future recalibrations long after completion of this project. Wherever possible, automated methods developed to assist our research team in performing calibrations will be made available for later TxDOT use.

MODIFICATION OF M-E MODELS AND SOFTWARE CODES

It should be stated and emphasized here that modification of the M-E models and/or software codes is outside the scope of this study. Therefore, the main outcome from the calibration and validation processes will be the following two primary items:

- Tabulation/listing of the proposed/recommended local calibration factors (coefficients) for each respective M-E model and the associated software.
- Recommendations for modifying the M-E models, transfer functions, and/or the associated software codes, where applicable.

SUMMARY

This chapter provided and discussed the framework and plans for calibrating the M-E models along with an illustration of the validation process. The primary objective of calibration and validation processes is to ensure that the M-E model predictions relate to and match field conditions. Therefore, a comprehensive iterative and sensitivity analysis will be undertaken to develop calibration factors (coefficients) meeting the Texas local conditions for the M-E models and the associated software. However, while recommendations for changes may be made, actual M-E model and/or software code modification is outside the scope of this study.

To be executed in close liaison with Study 0-6622, the Project 0-6658 DSS will be utilized as the data source (both lab and field generated) for calibrating the M-E models and developing the calibrating factors. The Project 0-6658 DSS is discussed in the subsequent chapter.

CHAPTER 3: THE PROJECT 0-6658 DATA STORAGE SYSTEM

As discussed in the preceding chapters, one of the primary objectives of developing the Project 0-6658 DSS is to use it for calibrating and validating the Texas M-E models developed in Study 0-6622 (Walubita et al., 2012; Zhou, 2011). That is, the researchers will use the data from the Project 0-6658 DSS to calibrate and validate the M-E models and associated software, in close liaison with Study 0-6622 (Zhou, 2011).

As per TxDOT's instructions, MS Access® was selected and utilized as the data storage medium for the Project 0-6658 DSS. Figure 3-1 shows the main user interface screen for the MS Access Project 0-6658 DSS. Refer also to the CD accompanying this interim report.

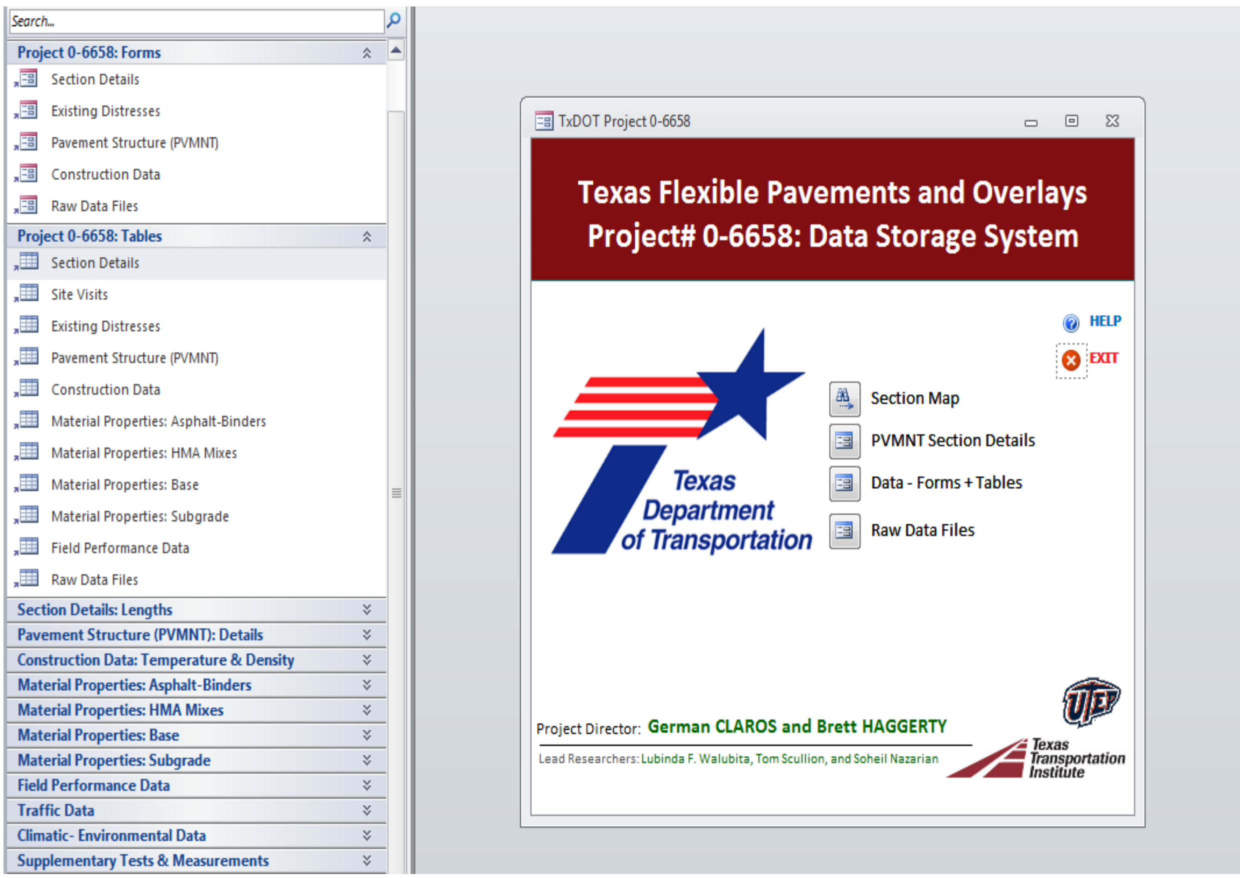


Figure 3-1. Main Screen User-Interface for the Project 0-6658 DSS.

With the preceding background, this chapter describes and discusses the Project 0-6658 DSS in terms of the following key aspects:

- DSS structure (forms, tables, etc.).
- Data content (construction, lab, and field data).
- Attachments and external links.
- Data access and general navigation.
- Exporting and emailing data.
- Interactive data analysis (computation, graphical plots, etc.).
- Raw data files.
- Help function.

While this chapter will limit itself to the above basic aspects of the Project 0-6658 DSS and data content, a detailed user's manual will be made available in future publications. A summary of key points concludes the chapter. A prototype demo Project 0-6658 DSS is included on a CD in a sleeve on the back cover of this interim report.

DSS STRUCTURE AND ORGANIZATIONAL LAYOUT

Figure 3-2 shows the structure and organizational layout for the Project 0-6658 DSS. The system consists of the following main fields (Walubita et al., 2012):

- The main screen or switchboard (Figure 3-1).
- TxDOT and Contractor contact details.
- Forms and Tables.

The Forms and Tables consist of the data shown in Figures 3-3 and 3-4. In these two figures, the plus sign (+) next to the data field indicates there is an additional set of data linked to that particular data field. Some examples are shown in the subsequent Figures 3-5 and 3-6 for "Section Details" and "Pavement Structure Data," respectively.

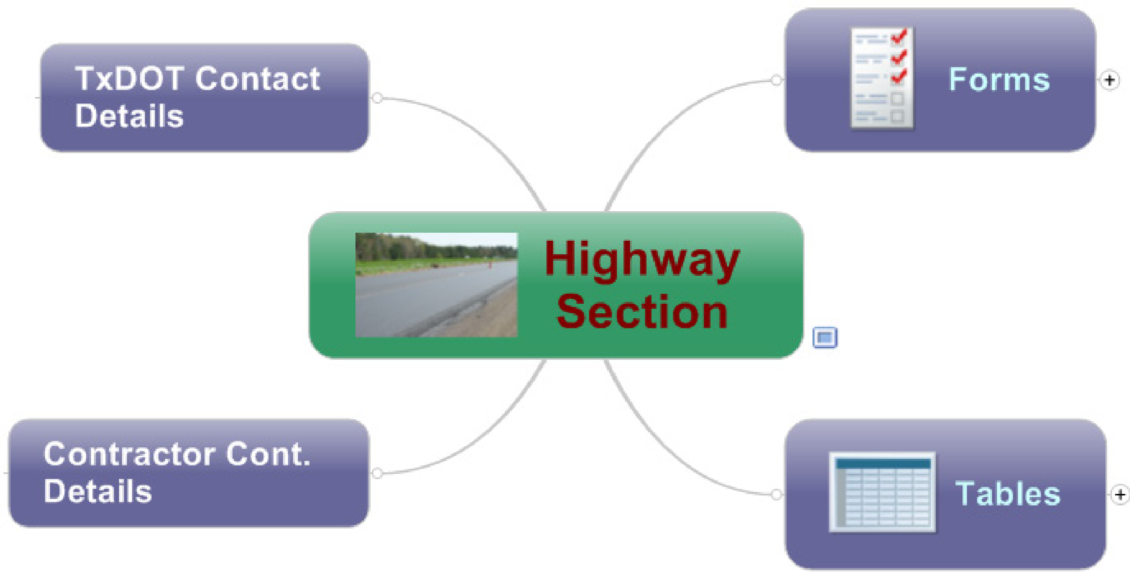


Figure 3-2. Structural Layout for the Project 0-6658 SS.

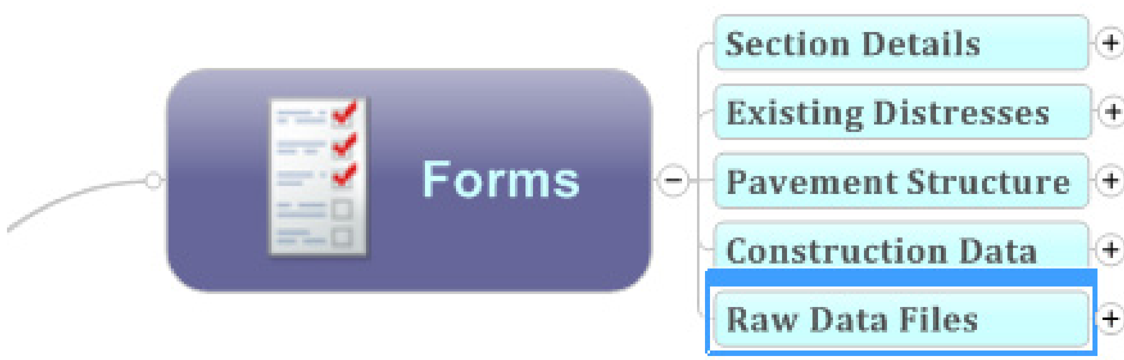


Figure 3-3. List of Data Stored as Forms.

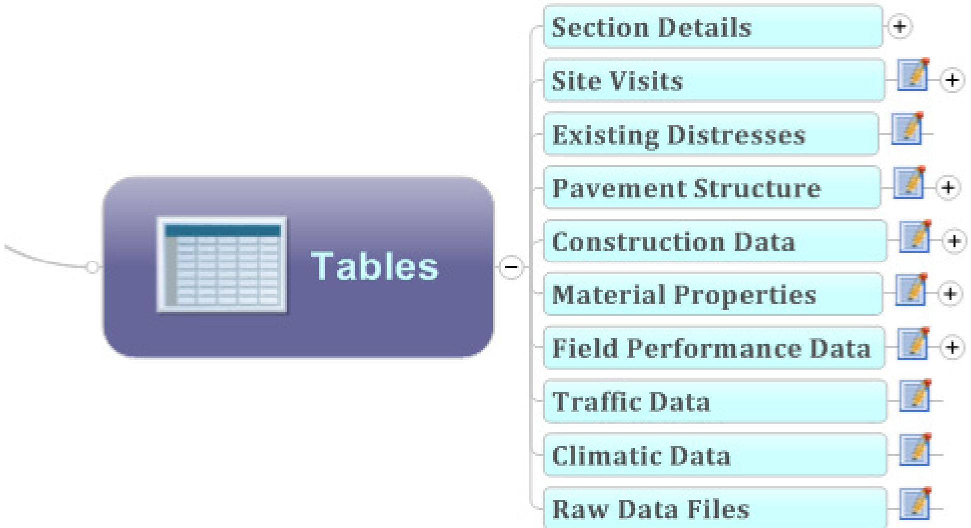


Figure 3-4. List of Data Stored as Tables.

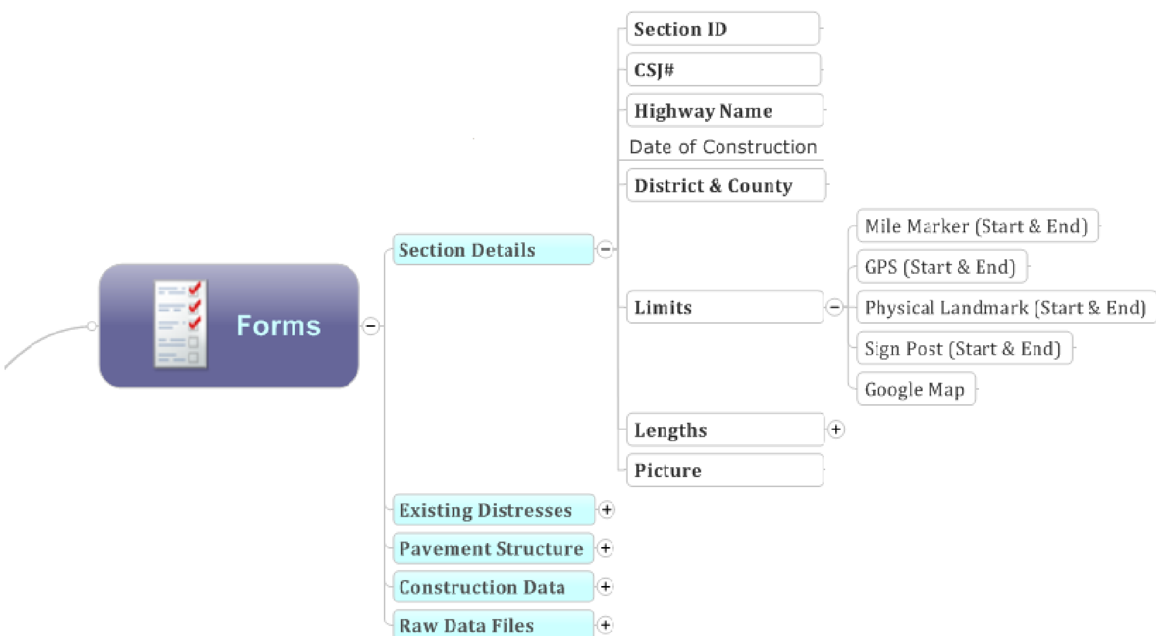


Figure 3-5. Example Data Links and Content for Section Details.

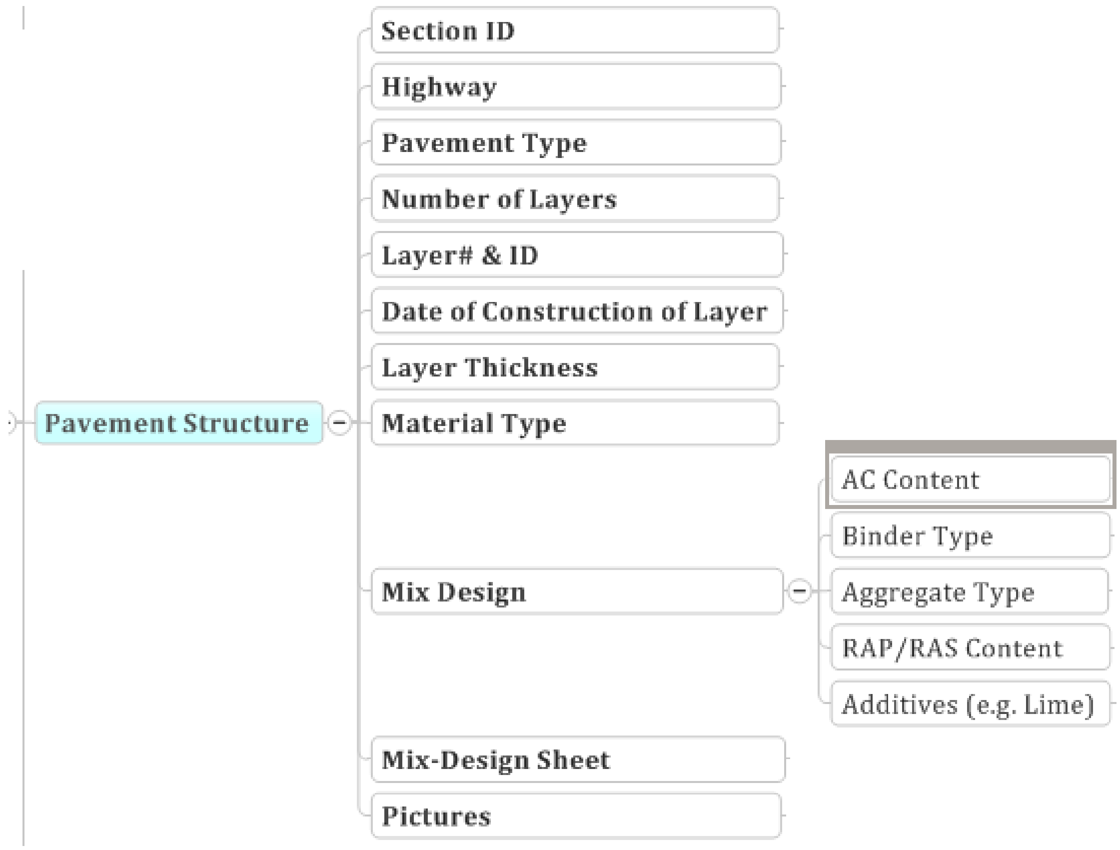


Figure 3-6. Example Data Links and Content for Pavement Structure.

Detailed descriptions of the data fields shown in Figures 3-2 through 3-6 along with the entire structure for the Project 0-6658 DSS will be documented in the user's manual (Walubita et al., 2012). In general, however, Figures 3-1 through 3-6 provide the fundamental idea and insights into how Project 0-6658 DSS is organized and accessed. Refinement and/or modification of the DSS structural layout will be an ongoing process:

- As more and more data are continuously gathered.
- Based on the M-E model and software needs.
- Based on review comments from TxDOT.

The primary intent is to make the DSS as simple and accessible as possible but without compromising data quantity, quality, and usefulness. So, the data structure and/or content of the DSS may be modified as the studies progresses.

THE DSS DATA CONTENT

As shown on the "Main Screen" or "Switchboard" in Figure 3-1, the DSS data content is primarily comprised of the following main items:

- Section Map.
- PVMNT Section Details.
- Forms and Tables.
- Raw Data Files.

These data items, along with some demonstrative examples, are discussed in the subsequent text. Appendix A shows more details of the DSS layout and data content.

Section Map

Clicking on the "Section Map" button leads to an interactive Google map that shows the geographical location of the Hwy test sections and WIM stations around Texas (see Figure 3-7). A legend for the PVMNT types and WIM stations is also included.

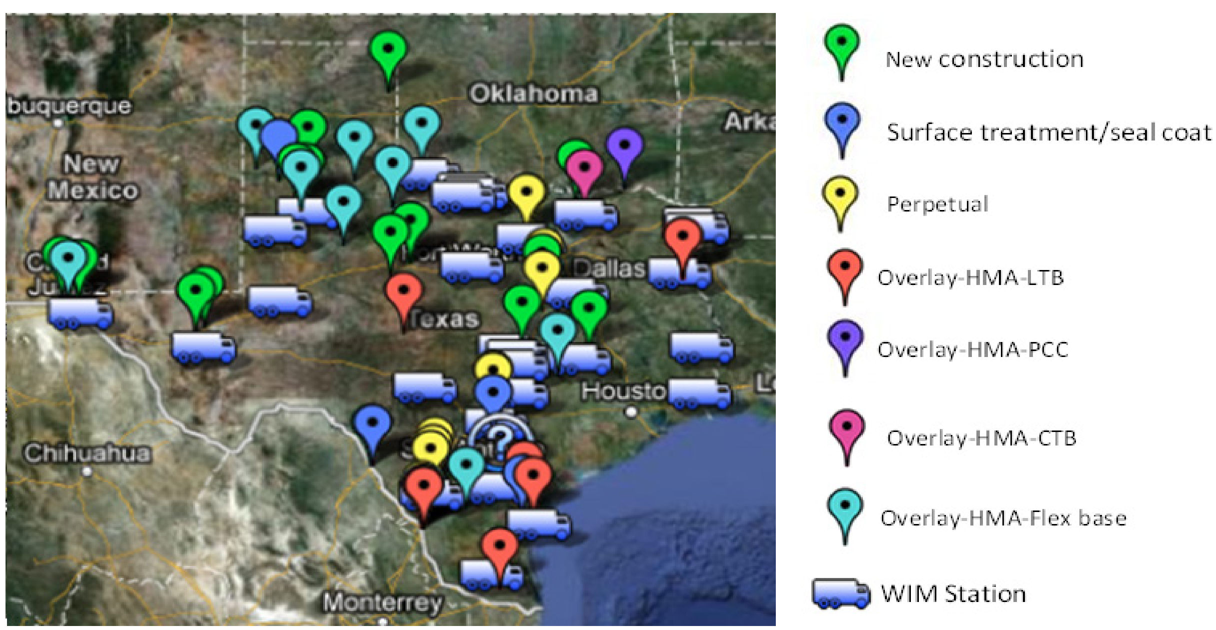


Figure 3-7. Interactive Google for the Hwy Test Sections and WIM Stations.

As shown in Figure 3-8, clicking on any Hwy test section on the Google map displays a pictorial view of the test section and the PVMNT structure data such as layer thickness, material type, and date of construction. These PVMNT structure data are necessary as manual inputs into the M-E models and associated software.

Figure 3-8. Section Map and PVMNT Structure Data.

PVMNT Section Details

As shown in Figure 3-9, clicking on the "PVMNT Section Details" button pulls out the Hwy section details that include information such as section ID#, CSJ#, Hwy name, PVMNT type, climatic region, district, county, lane direction, etc. All these data are necessary inputs into the M-E models and related software. For easy visual display, the information is also arranged in a "Form" layout, which is discussed in the subsequent text.

Section Details

Section_ID	CSJ#	HWY	PVMNT_Type	ClimaticRegion	Direction	District	Count
TxDOT_TTI-00001	006303057	US 59	Overlay-HMA-LTB	Wet-Cold	SB (both lanes)	ATLANTA	PANOLA
TxDOT_TTI-00002	035301026	SH 114	Perpetual	Wet-Cold	EB (oustide Lane)	FORT WORTH	WISE
TxDOT_TTI-00003	035301026	SH 114	Perpetual	Wet-Cold	EB Outside lane	FORT WORTH	WISE
TxDOT_TTI-00004	001407083	IH 35	New Construction	Moderate	NB Outside lane	WACO	HILL
TxDOT_TTI-00005	029914013	LOOP 480	New Construction	Dry-Warm	NB Outside lane	LAREDO	MAVERIC
TxDOT_TTI-00006	054902025	SH 121	Overlay-HMA-CTB	Wet-Cold	NB (outside lane)	PARIS	FANNIN
TxDOT_TTI-00007	013608039	US 271	Overlay-HMA-PCC	Wet-Cold	SB (outside)	PARIS	LAMAR
TxDOT_TTI-00008	004519047	US 82	New Construction	Wet-Cold	WB Outside lane	PARIS	GRAYSOI
TxDOT_TTI-00009	001506071	IH 35	New Construction	Moderate	SB Outside lane	WACO	BELL
TxDOT_TTI-00010	001802049	IH 35	Perpetual	Dry-Warm	SB (outside)	LAREDO	LA SALLE
TxDOT_TTI-00011	001801063	IH 35	Perpetual	Dry-Warm	NB (outside)	LAREDO	LA SALLE
TxDOT_TTI-00012	001708067	IH 35	Perpetual	Dry-Warm	NB (outside)	LAREDO	LA SALLE
TxDOT_TTI-00013	006303057	US 59	Overlay-HMA-LTB	Wet-Cold	SB (both lanes)	ATLANTA	PANOLA
TxDOT_TTI-00014	006303057	US 59	Overlay-HMA-LTB	Wet-Cold	SB (both lanes)	ATLANTA	PANOLA
TxDOT_TTI-00015	011702028	SH 21	New Construction	Wet-Warm	EB Outside lane	BRYAN	BRAZOS
TxDOT_TTI-00016	007004030	US 87	Overlay-HMA-LTB	Dry-Warm		SAN ANGELO	CONCHC
TxDOT_TTI-00017	034202051	SH 107	Overlay-HMA-LTB	Dry-Warm		PHARR	HIDALGC
TxDOT_TTI-00018	001805062	IH 35	Perpetual	Dry-Warm	SB Outside lane	LAREDO	WEBB
TxDOT_TTI-00019	001604091	IH 35	Perpetual	Dry-Warm	SB Outside lane	SAN ANTONIO	COMAL
TxDOT_TTI-00020	001604094	IH 35	Perpetual	Dry-Warm	SB Outside lane	SAN ANTONIO	COMAL
TxDOT_TTI-00021	001501164	IH 35	Perpetual	Moderate	NB Outside lane	WACO	MCLENN

Figure 3-9. PVMNT Section Details.

Forms and Tables

For easy management and access, all the data in the DSS are stored in a tabular format and summarized in Table 3-1. As shown in Figure 3-1 (top left corner), some data such as "Pavement Structure" have also been stored and displayed in a "Form" layout for easy visual display; refer also to the example shown subsequently in Figure 3-10. All these data are necessary as input parameters for both calibrating and running the M-E models/software. In the current setup, however, these data have to be accessed manually for entry into the M-E models/software.

Table 3-1. List of Data Contained in the Project 0-6658 DSS.

#	Category	Data Type	Table Format	Form
1	Section details	– Section ID# & Hwy name – District & county – Climatic region – Lane direction – Etc.	Yes	Yes
2	Site visits	– Date – Activities – Etc.	Yes	No
3	Existing distresses (Overlays only)	– Crack survey date – Crack mapping & survey sheets – Rut measurements – Etc.	Yes	Yes
4	PVMNT structure	– Number of layers – Layer thickness & material type – Date of layer construction – Etc.	Yes	Yes
5	Construction data	– Construction date – Contractor details – Material type & layer thickness – Construction method – Compaction data (i.e., rollers) – Temperatures & densities – Etc.	Yes	Yes
6	Material properties	– Asphalt-binders – HMA, seal coats, etc. – Base (treated & untreated) – Subgrade (raw & treated) – Etc.	Yes	No
7	Field performance	– Date – Rutting & cracking data – Bleeding & aggregate loss – Profiles (IRI & PSI) – PVMNT temperatures – FWD deflections & modulus data – DCP & PSPA modulus data – GPR & coring – Etc.	Yes	No
8	Climatic data	– Temperature – Precipitation – Etc.	Yes	No
9	Traffic	– ADT – ADTT & % trucks – Vehicle classification – Vehicle speed – Hourly distributions – 18 kips ESALs (estimates) – Etc.	Yes	No
10	Supplementary tests	– OT monotonic – HMA flow number – Etc.	Yes	No

Layer#	LayerID	DateOfConstruction	Thickness (in)	MaterialType	MixDesign
3	HMA (Type C)	2012	4	Type C	PG 64-22 + 20% RAP
2	Base	2011	10	Flex	Grade 4
1	Treated subgrade	2011	6	4% cement	4% cement treated subgrade
0	Subgrade	2011		Compacted natural soi	
0			0		

Figure 3-10. DSS Form for Pavement Structure Data.

Raw Data Files

Raw data files also constitute an integral component of the Project 0-6658 DSS. Consisting of design, field, lab, construction, traffic, and climate data, these raw data files are provided so that users can have the opportunity to reanalyze the raw data depending on their needs/objectives and/or verify the data contained in the DSS. It also allows users to directly and manually obtain the M-E model and software input data directly from the raw data files if needed.

As shown in Figure 3-11, clicking on the "Raw Data Files" function will lead to a "Raw Data Prompt" screen for subsequent accessing of the TTI and UTEP SharePoint files of their raw data, respectively. A user ID and password are required to access and view the SharePoint raw data files; users should contact the lead researcher (PI) or project director if they need access.

Attachments and External Links

MS Access® allows for inclusion of some attachments and external links. In some limited cases and where needed, these attachments and links have been included in the Project 0-6658 DSS, namely:

- Attachments: surveys sheets (pdf), mix-design sheets (pdf and/or Excel® format), etc.
- External links: GPS coordinates (test sections, WIM stations, etc.), weather stations, etc.

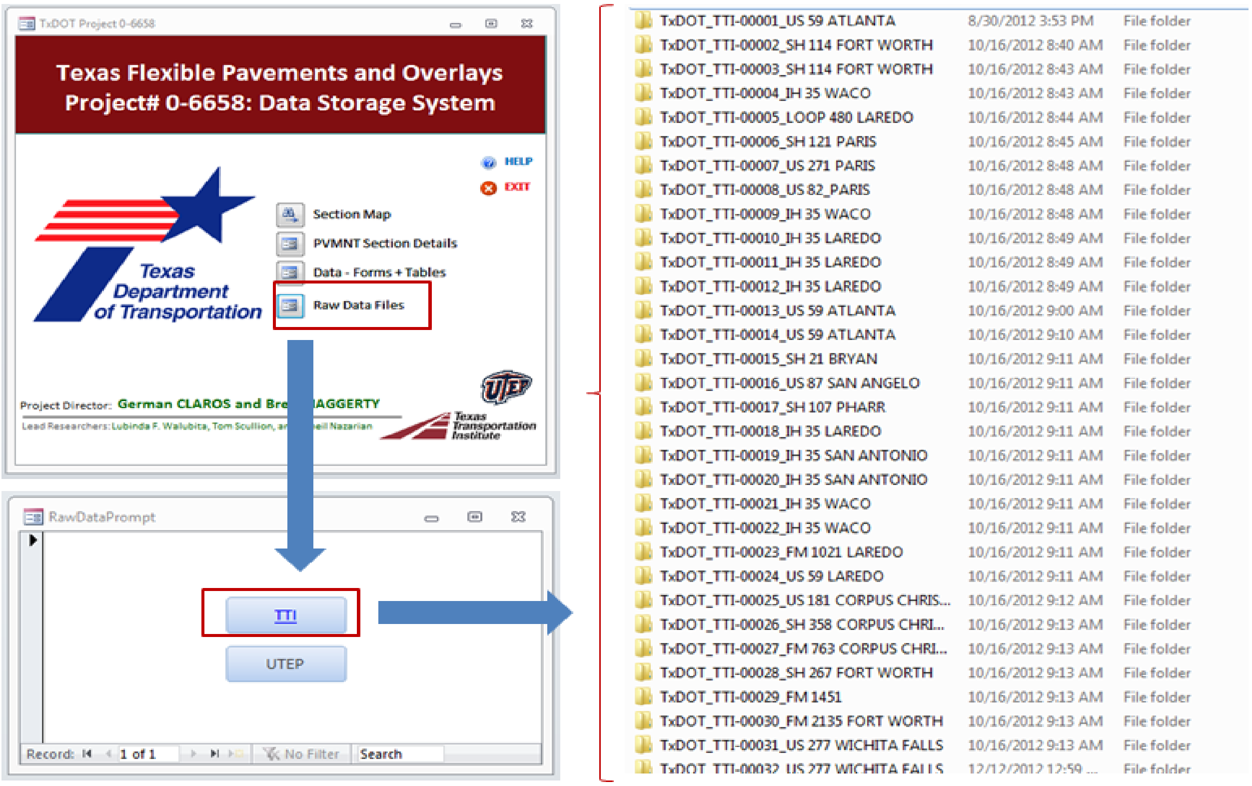


Figure 3-11. The DSS and Raw Data Access.

DATA ACCESS AND GENERAL NAVIGATION

The user must readily access the data content if he/she is to satisfactorily utilize the DSS. It should also be fairly easy to navigate through the DSS. As stated previously, the DSS is being maintained in the MS Access® environment and therefore, it is relatively user-friendly. Nonetheless, a user's manual will be provided to accompany the DSS in future publications.

As discussed in the subsequent test, the current DSS setup is such that these data are accessed manually and entered manually into the M-E models/software.

Interactive Data Analysis

Within the DSS, the data can be interactively accessed, viewed, and displayed as tables, forms, graphs, or bar charts. Multiple tables can also be accessed to display different data for a given test section; see example in Figure 3-12 for Section TxDOT_TTI-00001.

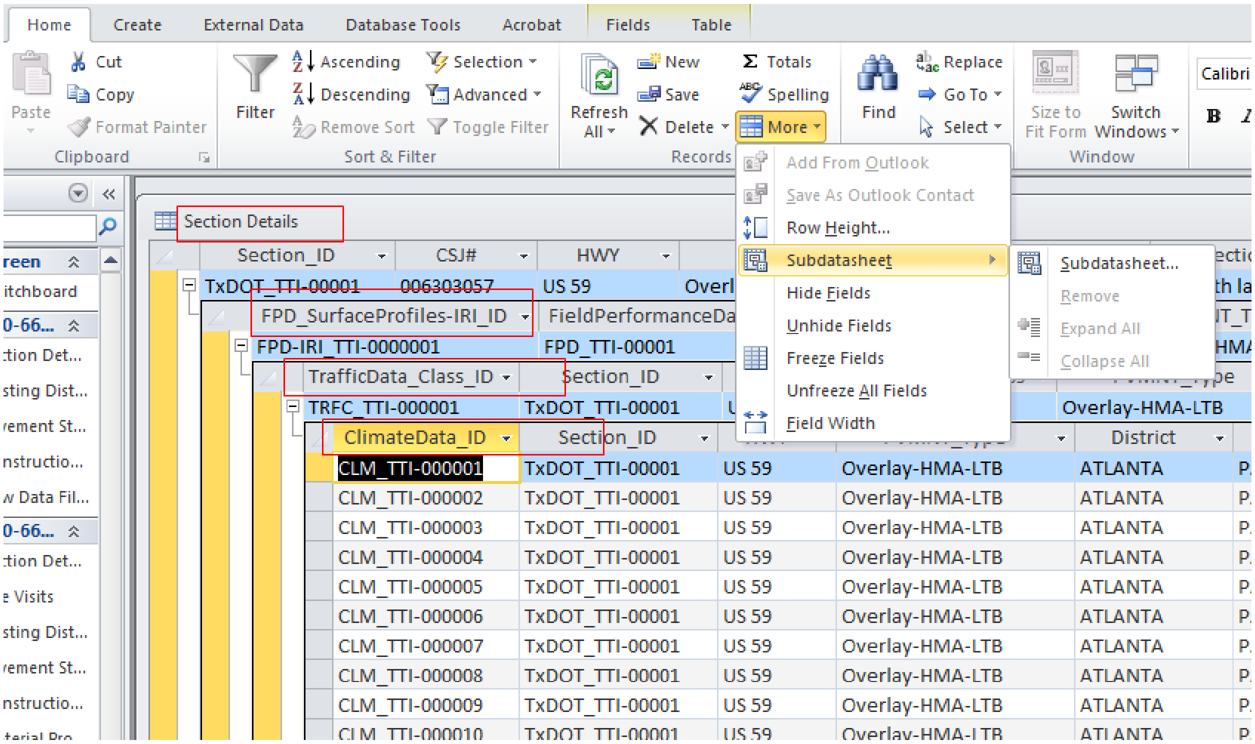


Figure 3-12. MS Access and DSS Multiple Table Display (TxDOT_TTI-00001).

As an example, Figure 3-12 shows multiple tables for Section TxDOT_TTI-00001, namely: "Section Details," "Surface Profiles," "Traffic Data," and "Climate Data". Graphs or bar charts can also be used to interactively access and compare different test sections, materials, etc.; see example in Figure 3-13.

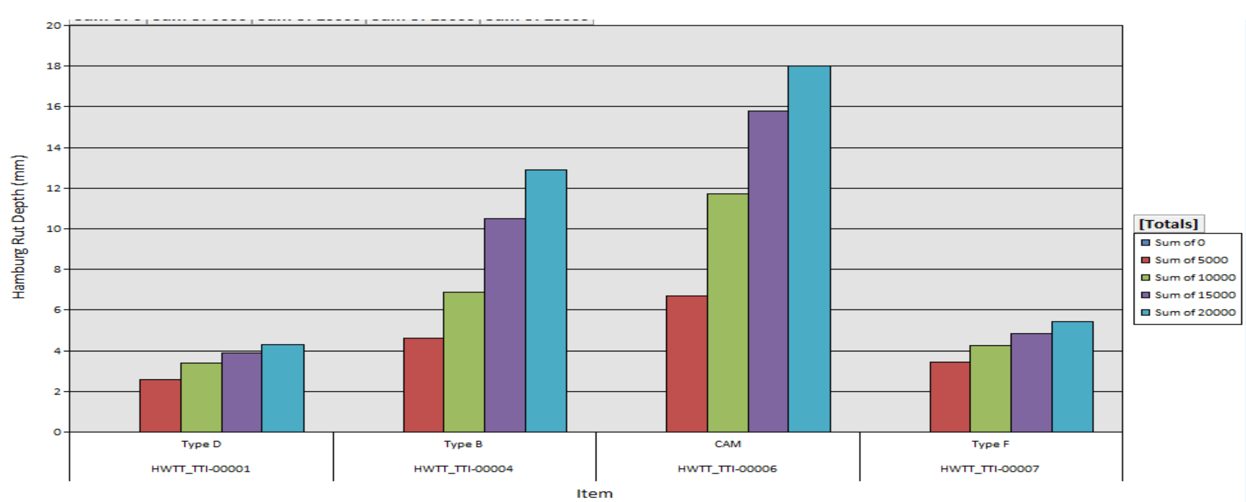


Figure 3-13. MS Access and DSS Graphical Plots–Bar Charts.

As shown in Figure 3-14, the MS Access® also allows for direct analysis of the data within the DSS. This includes features such as computing averages, standard deviation, minimum, maximum, etc.

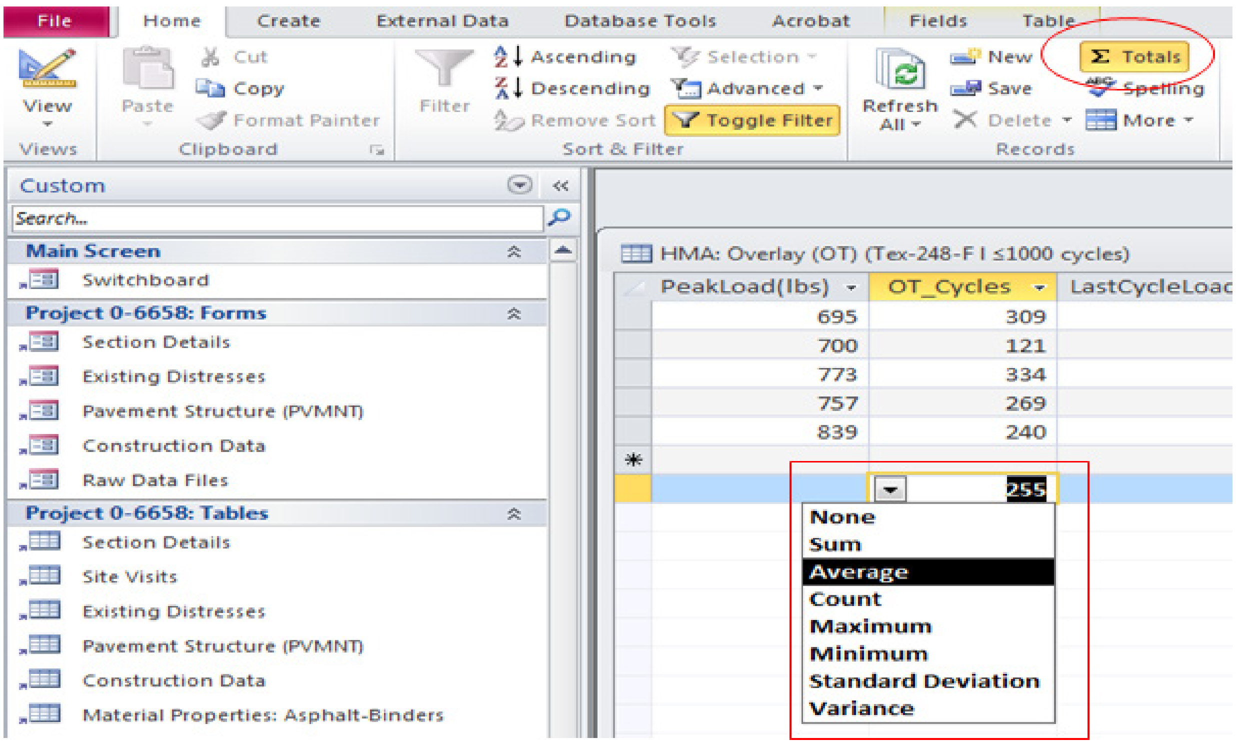


Figure 3-14. Example MS Access and DSS Interactive Computations.

Exporting and Emailing Data

MS Access allows for direct importing, exporting, and emailing of the data from the DSS (see Figure 3-15). So, data can easily be exported and/or emailed in any desired format for subsequent analyses or manual entry into the M-E models and related software. In the future, there are plans to develop a bridging platform that will directly export data from the DSS into the M-E models and related software.

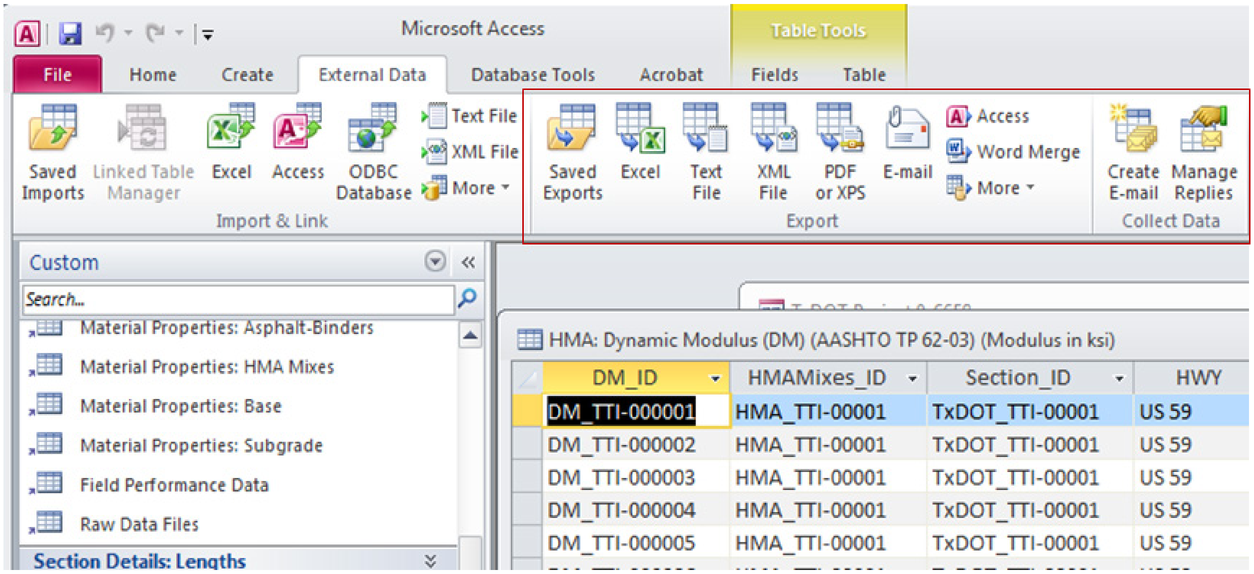


Figure 3-15. MS Access and DSS Exporting/Emailing Menu.

HELP FUNCTION

To assist with instructions for navigating through the DSS as well as troubleshooting, a "Help" function as shown in Figures 3-1 and 3-16 have been provided within the DSS. Figure 3-16 shows that the "Help" function consists of the following items:

- User's manual for the DSS.
- Technical reports associated with Project 0-6658.
- Test procedures and specifications related to Project 0-6658.
- Data collection forms for Project 0-6658.
- M-E PVMNT software that are related to Project 0-6658.
- Credits directory.

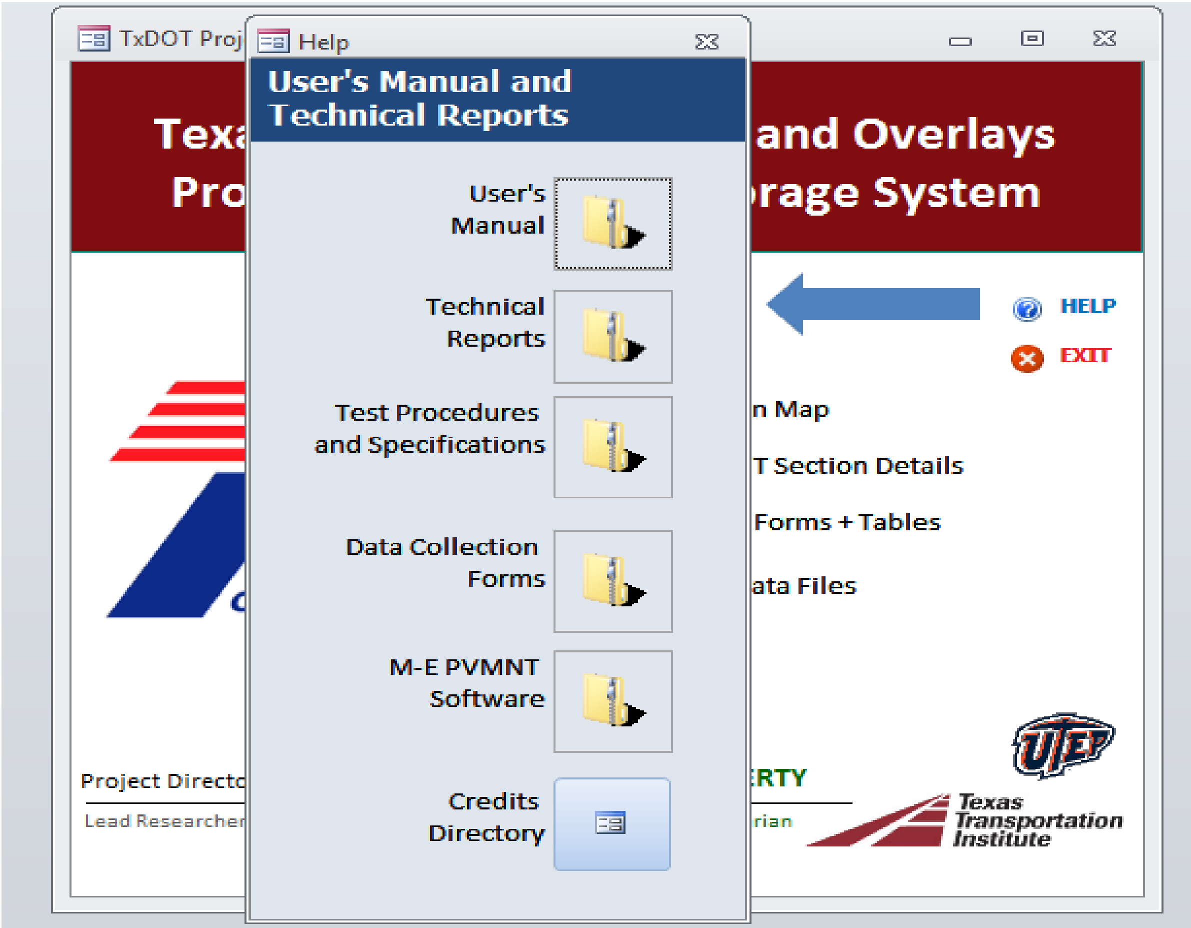


Figure 3-16. The DSS Help Function.

SUMMARY

This chapter provided a basic description of the Project 0-6658 MS Access® Data Storage System with a focus on the data content and accessibility (exporting and emailing). Appendix A has a detailed listing of the DSS data content. A CD with a prototype DSS is also provided in the back sleeve of this interim report.

As discussed in the chapter, the data is accessed manually and entered manually into the M-E models/software; this is quite laborious and time-consuming. In the next phase of the project, the key challenge would therefore be to explore the feasibility of developing a bridging platform that would automatically and directly export the data from the DSS into the respective M-E models and associated software without requiring manual intervention.

CHAPTER 4: THE FPS AND ASSOCIATED SOFTWARE

This chapter presents an overview of the FPS including the basic input data, output data, and the key M-E models to be calibrated and validated. The generalized calibration framework and data source for performing these calibrations were previously discussed in Chapters 2 and 3. A summary is then presented at the end of the chapter to highlight the key points.

OVERVIEW

The Flexible Pavement System (FPS) is a mechanistic-empirical (M-E) based software that TxDOT routinely uses for:

- Pavement structural (thickness) design.
- Overlay design.
- Stress-strain response analysis.
- Pavement life prediction (rutting and cracking).

The FPS design approach is based on a linear-elastic analysis system and the key material input is the back-calculated FWD modulus values of the pavement layers. The FPS design system itself is comprised of two fundamental processes:

- Trial pavement structure development and thickness design.
- Design checks, including performance prediction.

The FPS system has an embedded performance function relating the computed surface curvature index of the pavement to the loss in ride quality. The design check is principally based on either the mechanistic design concepts or the Texas Triaxial criteria. The mechanistic design check basically computes and checks the sufficiency of the mechanistic responses in terms of maximum horizontal tensile strains at the bottom of the lowest HMA layer and the maximum vertical compressive strains on top of the subgrade not exceeding prescribed limits. The mechanistic design check is recommended for all pavements with HMA surfaces.

However, the fatigue analysis is restricted to pavements where the HMA thickness is greater than 1.5 inches, but should be run for informational purposes on all thin-surfaced HMA designs. The Texas Triaxial criterion checks the likelihood of shear failure in the subgrade soil under the heaviest wheel load anticipated for the pavement section.

TxDOT traditionally uses the FPS for conventional flexible HMA pavement design. Figure 4-1 shows that FPS 21 (V1.3, Release 06-01-2012) is the latest version currently in use at the time of this report. It is multi-layered and allows for up to seven layers to be considered. Characteristic features of the FPS 21 including the input and output data are discussed in the subsequent text. Appendix B lists the full FPS input and output data along with the DSS location details.

Figure 4-1. FPS 21 Main Screen.

BASIC FPS INPUT DATA

The FPS software interface provides an easy navigation system through which the engineer/designer can input various necessary data ranging from pavement structure details to traffic and climatic data prior to design and/or analysis of a given highway. The software provides two options for inputting data: 1) through an existing input file, or 2) by manually filling up each required data input field. In this section, the second option will be discussed. Figure 4-2 shows a detailed step-by-step organizational map of the FPS data input system.

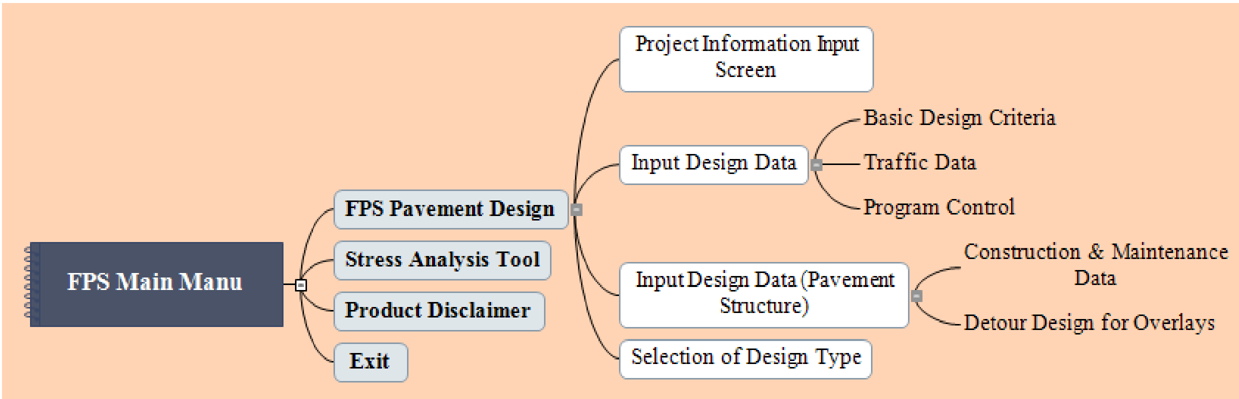


Figure 4-2. Organizational Map for the FPS Software.

Table 4-1 lists the basic FPS input data, which are categorized as general, traffic, PVMNT structure, material properties, climatic, and miscellaneous data (or other inputs). The data input steps for the FPS are discussed in further details in the subsequent texts.

Table 4-1. List of Basic FPS Input Data.

#	Category	Data Type	Location in the DSS	Comment
1	General	– Problem ID, Analysis date	N/A	User input
		– Location (Highway, District, County)	PVMNT Section Details	
		– CSJ (Control#, Section#, Job#)	PVMNT Section Details	
2	Traffic	– ADT (Beginning & End) – 18 Kip ESALs – % trucks	Traffic Data\Volume & Classification	An Excel macro is available to approximate the 18 kip ESALs
		– Approach speed to overlay zone – Avg speed (overlay & non-overlay direction) – % ADT/hr of construction	N/A	User input based on help file guidelines
3	PVMNT structure	– Layer description & thicknesses	PVMNT Structure Details	
4	Material properties	– FWD modulus	Field Performance Data\FWD Back-calculated Modulus	
		– Poisson's ratio	N/A	User/default
5	Other inputs	Basic Design Criteria – Analysis periods – Design confidence level – Serviceability Indices (initial, final)	N/A	User input based on help file guideline
		Construction & Maintenance Data – Overlay construction time – ACP compaction density & production rate – Maintenance cost – Detour Design for Overlays	N/A	User inputs

Project Information Input Screen

This is the first step of the FPS data input. The screen includes general information regarding the highway, e.g., user assigned problem number, name of highway, location information, date of analysis, etc. An interface, including an interactive map of Texas, is provided in this screen where the location details (district and county name) can be easily selected from a dropdown list (see Figure 4-3).

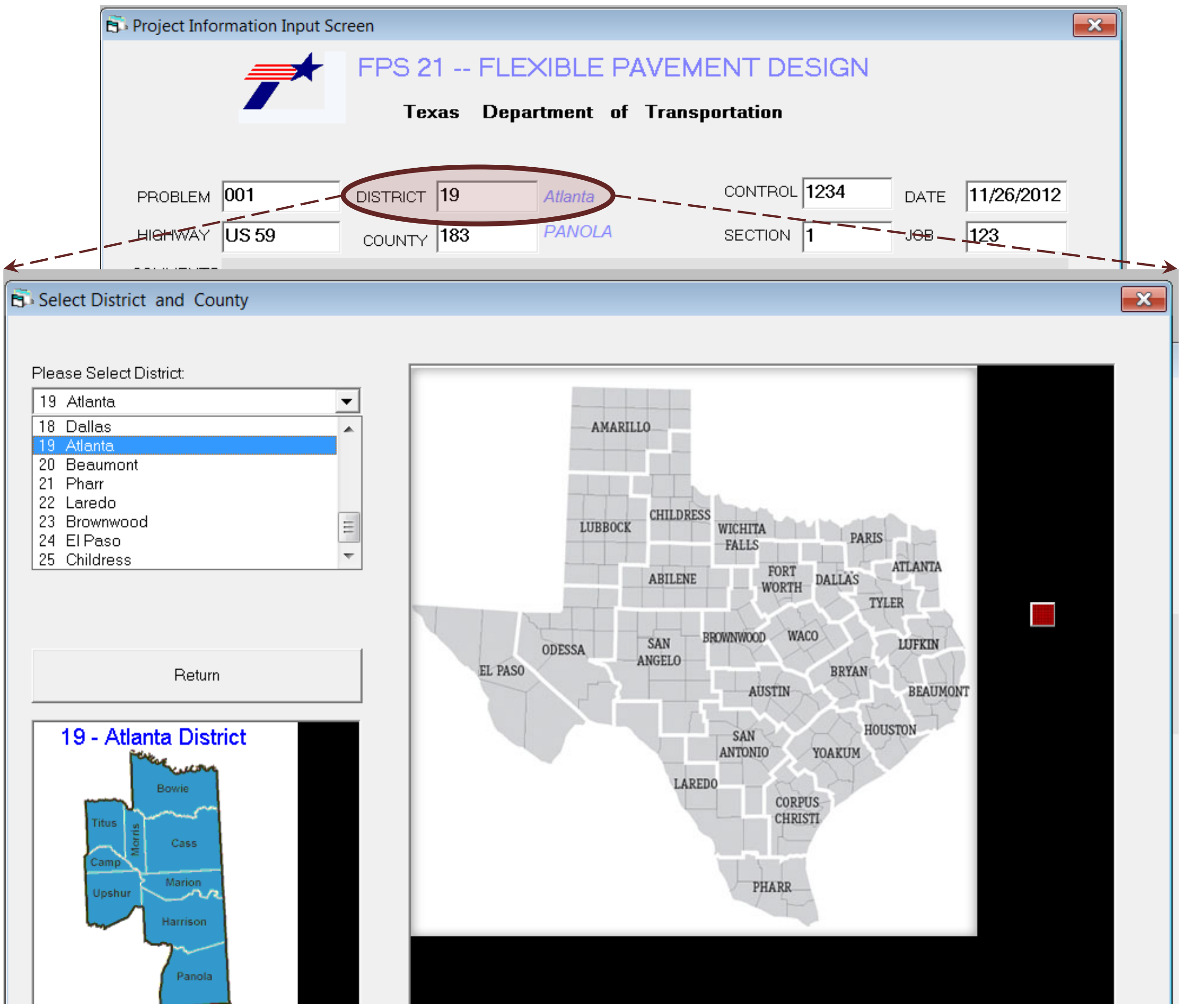


Figure 4-3. Project Information Input Screen and Interface for Selecting District and County.

As outlined in Table 4-1, all the information required in this screen are available in the DSS in the 'PVMNT Section Details' table. As an example, the pertinent information for US 59 (DSS section ID: TxDOT_TTI-00001) were used in Figure 4-3.

Input Design Data

In the input design data screen (Figure 4-4), there are three major categories of data to be provided. In the *Basic Design Criteria* category, most of the information to be provided is user inputs based on cost-budget considerations and expected performances of the highway. The guidelines for selecting this information are outlined in the 'Help File' provided with the software. The *Program Control* category includes three parameters that are designed to act as analysis constraints or design controls. These can be adjusted to limit the number of available solutions to a given set of data sets.

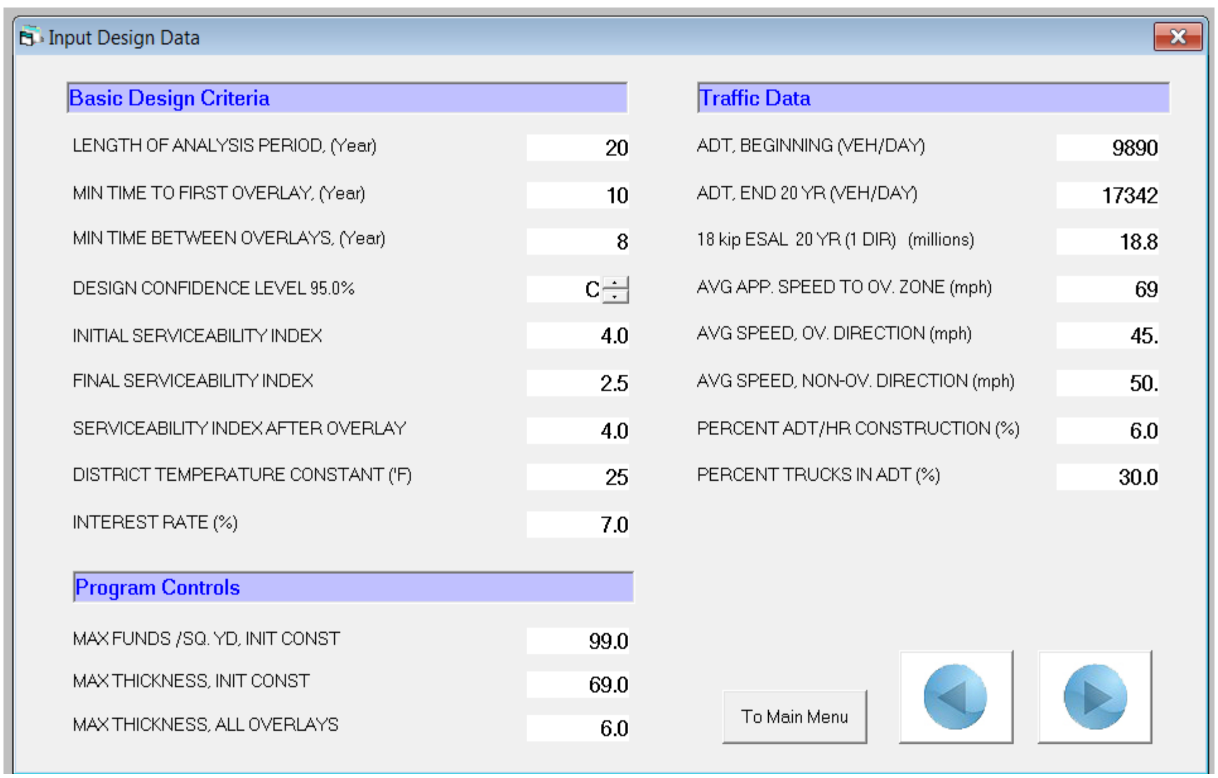


Figure 4-4. FPS Input Design Data Screen.

The most important category in the 'Input Design Data' screen is the *Traffic Data*. As listed in Table 4-1, the required data in this category are available in the DSS data group 'Traffic

Data' under the 'Volume & Classification' table. Figure 4-5 shows a screenshot of the 'Traffic Data: Volume & Classification' table from the DSS filtered for the US 59 traffic data only.

Traffic Data: Volume & Classification (Report 0-6658-R1)

Section_ID	HWY	Date	LaneDirection	LaneDesignation	ADT	%Trucks	ADTT	AVG_VehicleSpeed (mph)
TxDOT_TTI-00042	SH 21	10/18/2012	EB	Outside	3120	11.00%	343	69.80
TxDOT_TTI-00042	SH 21	10/18/2012	EB	Inside	1033	5.00%	52	69.80
TxDOT_TTI-00057	FM 469	9/5/2012		Outside	213	48.00%	102	60.30
TxDOT_TTI-00057	FM 469	9/5/2012		Inside	19	57.00%	11	60.30
TxDOT_TTI-00001	US 59	10/31/2012	SB	Outside	3888	34.00%	1322	69.00
TxDOT_TTI-00001	US 59	10/31/2012	SB	Inside	1057	17.00%	180	69.00

Record: 49 of 49 Unfiltered Search

Figure 4-5. DSS Table – Traffic Data Volume and Classification.

The traffic data presented in the DSS are derived from periodic traffic counts (volume and speed classifications) at each highway test section using traffic tube counters. Using an assumed traffic growth factor (ranging between 2.5 and 5.0 percent, depending on the highway class/type), these data are subsequently analyzed to estimate the 18kip ESALs at the end of the design period. To further aid the users with traffic data input, an Excel macro has been developed and is included in the CD accompanying this interim report.

The assumed traffic growth factors and estimated ESAL values will eventually be replaced by more accurate ESAL values calculated through 'Cluster Analysis' of actual WIM station data. In year four of the study, the traffic tube data (after a minimum of three consecutive yearly measurements) will also be used to generate and compute actual traffic growth factors for each highway test section.

Input Design Data (Pavement Structure)

As shown in Figure 4-6, details of pavement structure (design type, layer details, and material properties) are provided in the final step of FPS data input system along with two other categories, namely the *Construction & Maintenance Data* and *Detour Design for Overlay.*

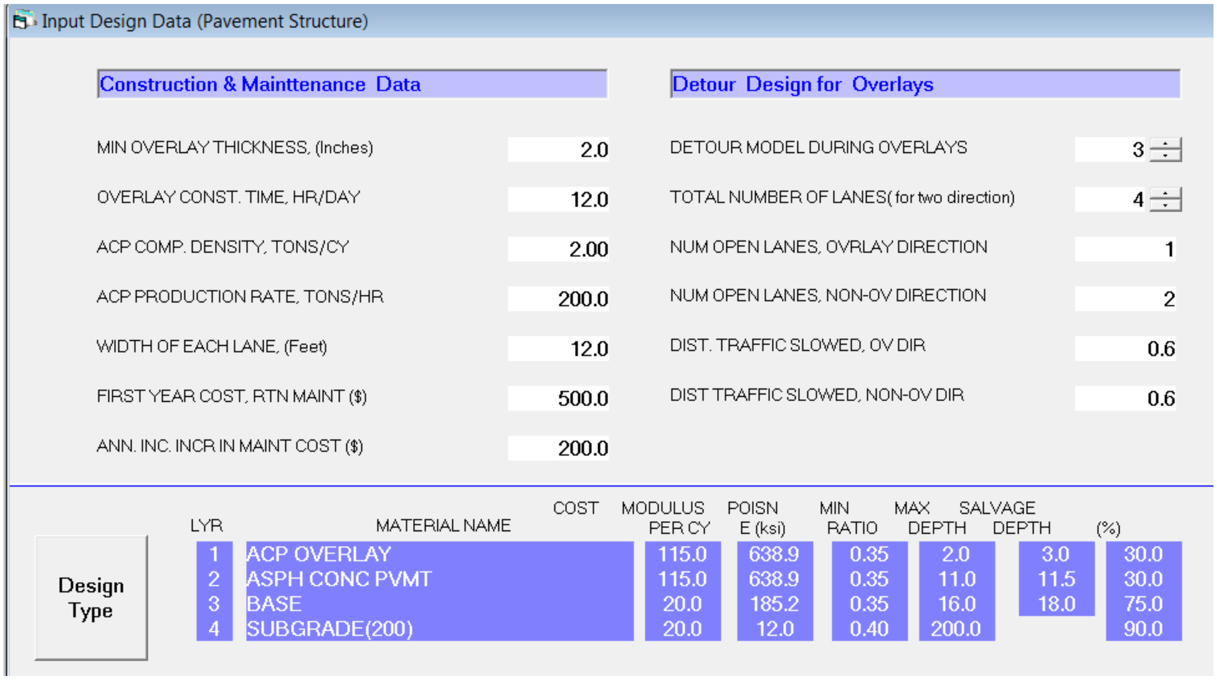


Figure 4-6. FPS Input Design Data – Pavement Structure.

In both these categories (*Construction & Maintenance Data* and *Detour Design for Overlay.*), the input parameters are designed with the focus on determining the maintenance costs of the highway over its lifetime. In particular, determining the cost of future overlay construction is a given priority. As listed in Table 4-1, most of these input parameters are user determined and are thus not included in the DSS. However, in some instances, the DSS can come to aid the designer with support data for determining these input data values. For example, the primary parameter for the detour design for overlays is the number of lanes in the highways, which can be found from the DSS's "PVMNT Section Details" table.

The *Pavement Structure Details* is one of the most important input categories for the FPS software. The FPS data input interface provides an option for selecting the type of pavement to be designed from a list of six predefined and one user-defined structure types (layer details) (see Figure 4-7). The DSS table 'PVMNT Structure Details' (Figure 4-8) lists the layer details in a pavement structure for a given highway test section that will aid the designer in selecting the appropriate design type.

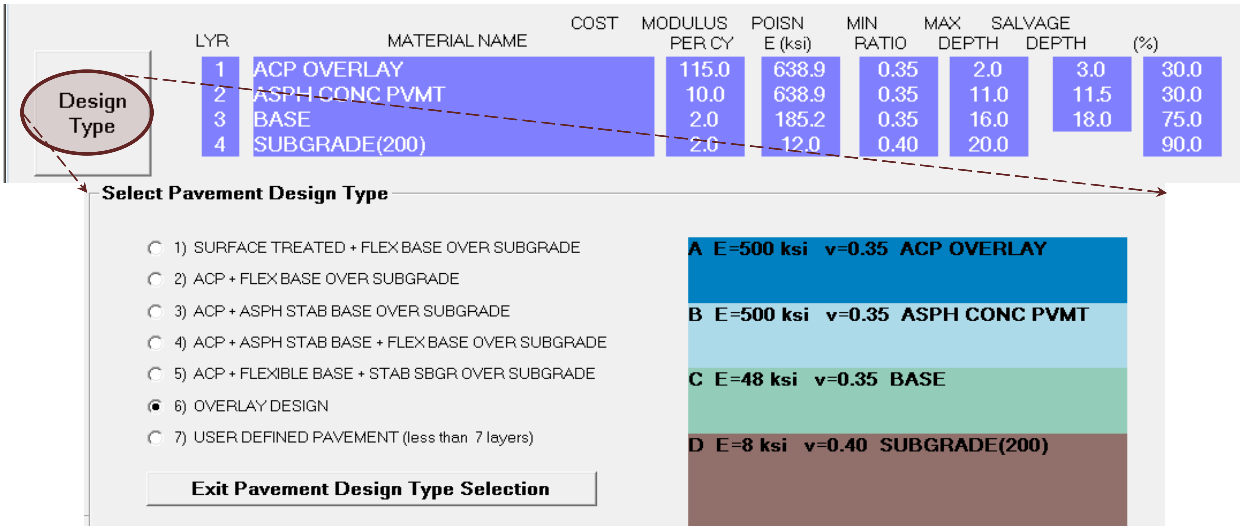
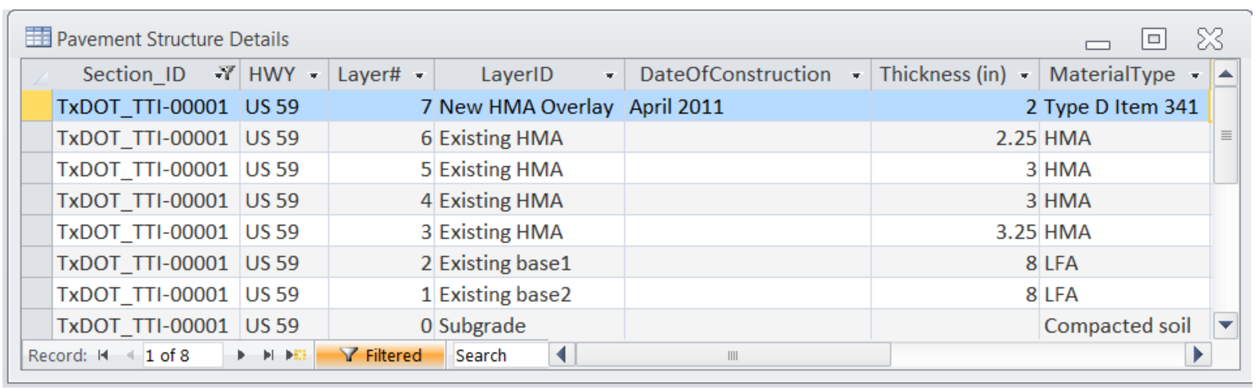


Figure 4-7. Selecting Pavement Design Type (Layer Details).



Pavement Structure Details

Section_ID	HWY	Layer#	LayerID	DateOfConstruction	Thickness (in)	MaterialType
TxDOT_TTI-00001	US 59	7	New HMA Overlay	April 2011	2	Type D Item 341
TxDOT_TTI-00001	US 59	6	Existing HMA		2.25	HMA
TxDOT_TTI-00001	US 59	5	Existing HMA		3	HMA
TxDOT_TTI-00001	US 59	4	Existing HMA		3	HMA
TxDOT_TTI-00001	US 59	3	Existing HMA		3.25	HMA
TxDOT_TTI-00001	US 59	2	Existing base1		8	LFA
TxDOT_TTI-00001	US 59	1	Existing base2		8	LFA
TxDOT_TTI-00001	US 59	0	Subgrade			Compacted soil

Record: 1 of 8 Filtered Search

Figure 4-8. DSS Table – PVMNT Structure Details (Filtered for US 59).

Upon selecting the appropriate design type, the designer can edit the required material properties for each layer. Among the required layer properties, the layer thicknesses (maximum and minimum) are obtained from the DSS 'Pavement Structure Details' table (see Figure 4-8). The modulus can be obtained from DSS tables 'FPD: FWD Back Calculated Modulus' while the Poisson's ratio can simply be assumed or a default value utilized. Information on the "layer material cost" and the "% of salvageable materials" are not included in the DSS; the designer will need to assume these parameters or follow established guidelines to input these values.

RUNNING THE FPS SOFTWARE

Once all the required input parameters are properly entered, the FPS analysis is run to obtain the output results. The average FPS run time (analysis time) is very short (less than 5 minutes) after all the input parameters are properly entered; however, this varies as a function of the computer processing speed/capability. A detailed step-by-step demonstration for running the FPS software (using the DSS) is included in the accompanying CD in the form of PPT slides. The analysis and interpretation of the FPS output data are discussed in the subsequent sections of this chapter.

BASIC FPS OUTPUT DATA

The FPS design program checks for all the viable solutions/designs within the design criteria and program controls, based on the material properties defined and the structural boundaries outlined to meet the applied loading parameters. In some cases, the number of viable solutions to a design problem can be more than one, i.e., the FPS has the potential to yield multiple design options. Figure 4-9 shows an example of an FPS design output summary page for Loop 480 (new construction section) in the Laredo District.

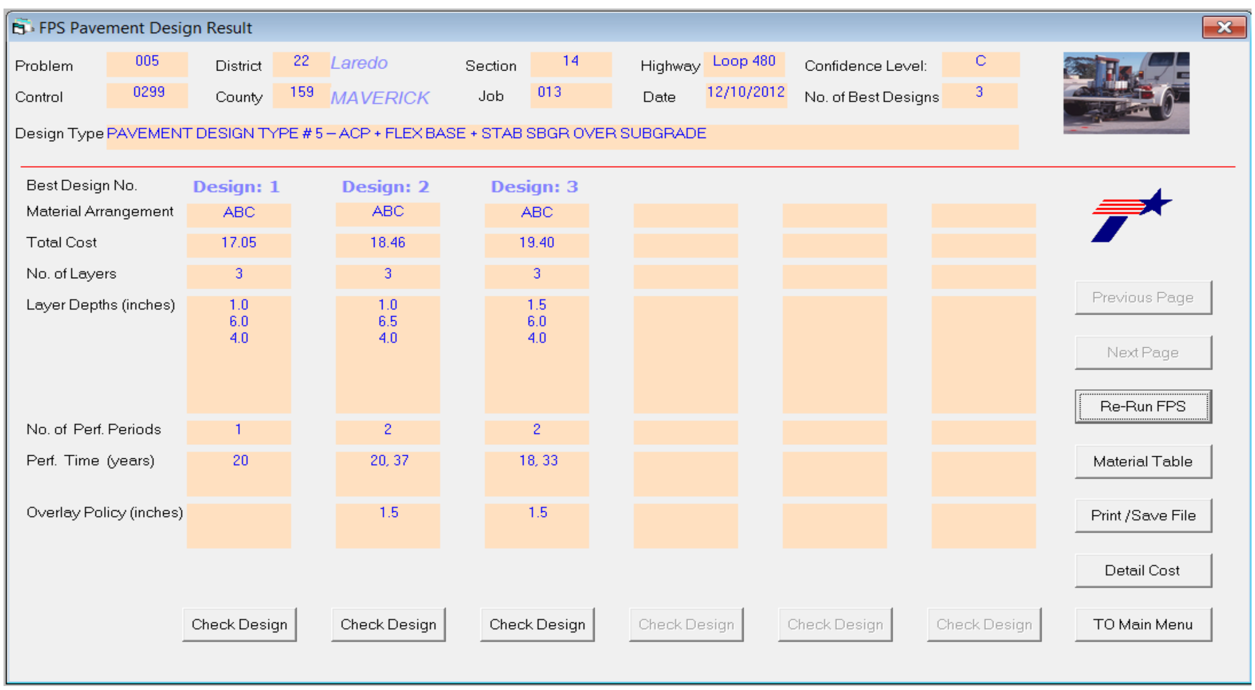


Figure 4-9. FPS Design Output Results Summary for TxDOT_TTI-00005 (Loop 480).

For this example, there are three viable solutions based on the given input parameters. The key design output parameters to be noted are 'Layer Depths,' 'Number of Performance Periods,' and 'Performance Time.' The design also indicates the necessity of overlays to be constructed on the highway for continued serviceability. It also forecasts on the total lifetime cost of the highway section.

From Figure 4-10, there are several post-processing options available to the designer for detailed M-E evaluation and analysis of the output results.

The 'Check Design' shows a detailed graphical presentation of the layer thicknesses and provides options for mechanistic and Triaxial design checks as well as stress analysis. The 'Mechanistic Check' option helps the designer to fine-tune the layer thicknesses based on the projected long-term cracking and rutting performances of the highway (see Figure 4-10).

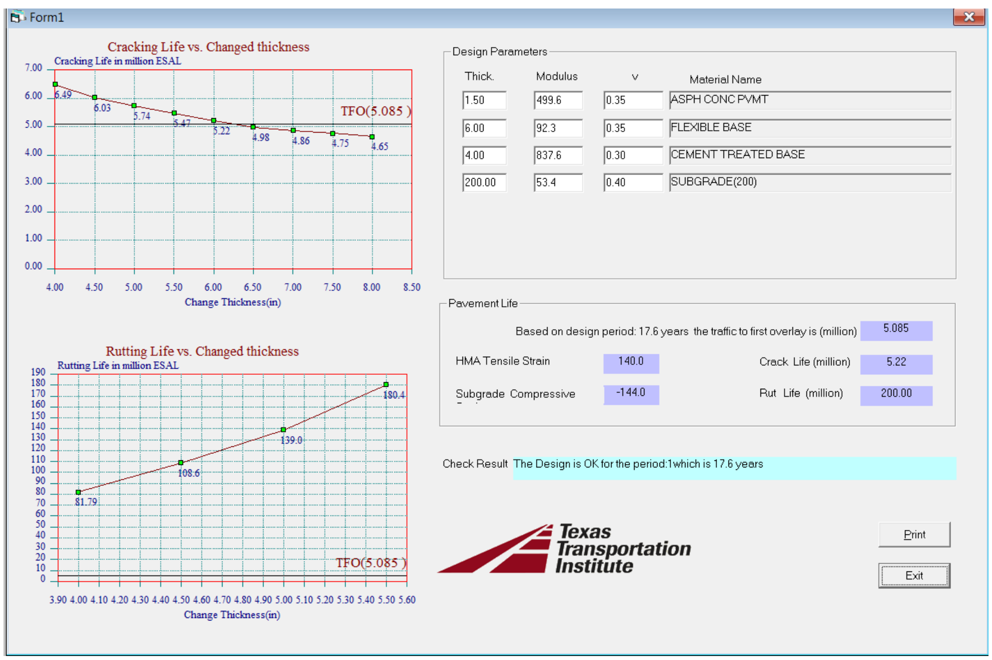


Figure 4-10. FPS Design Output – Mechanistic Check.

There is also an option for selecting the cracking and rutting analyses models and customizing the model parameters to better suit the specific highway section. Under the 'Check Design' category, there is also an option for a detailed stress-strain analysis showing the stress and strain distributions across the thickness of the layers.

Once the designs are analyzed and checked through mechanistic, Triaxial, and stress analysis, the FPS aids the designer to choose the most suitable design through a detailed cost analysis. Figure 4-11 compares the three designs for the example section based on overall project cost considerations.

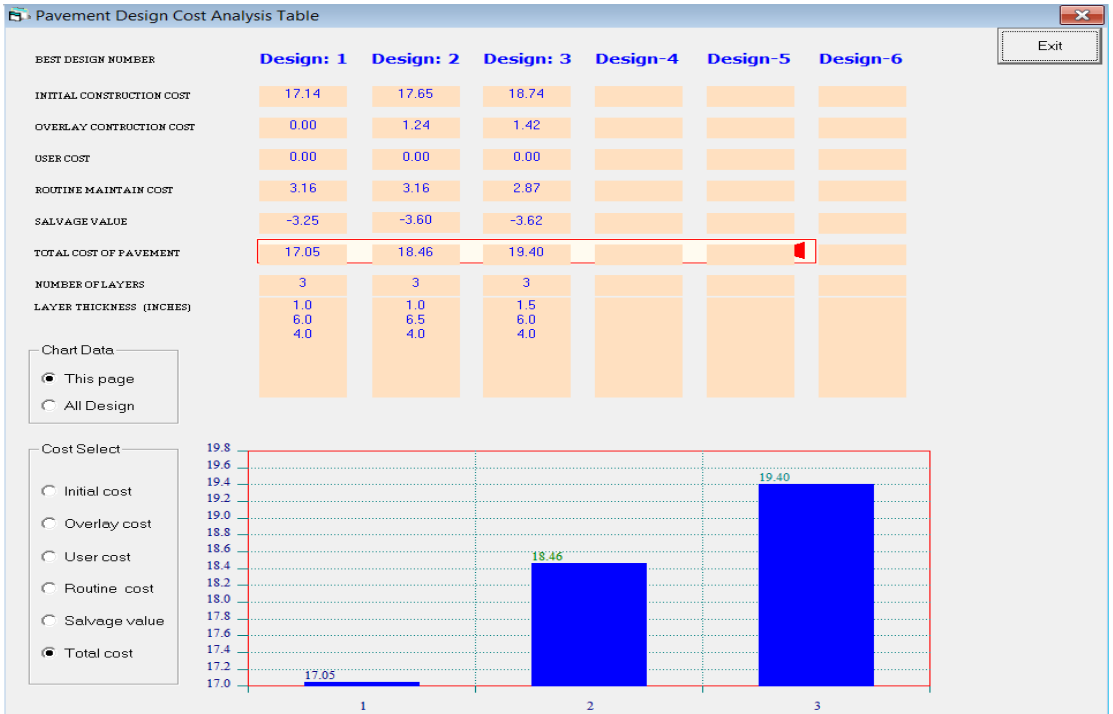


Figure 4-11. FPS Design Output – Cost Analysis.

KEY FPS MODELS TO BE CALIBRATED AND VALIDATED

The FPS mechanistic design check involves two key M-E models, cracking and rutting (see Figure 4-12). These models will be the primary focus of the FPS calibration and validation to ensure that the model predictions match the field performance. Model calibration will be achieved through iterative and sensitivity variations of the calibration factors (f_i) until the FPS predictions and actual field performance measurements/observations match each other within the given error tolerance, namely (Huang et al., 1996):

- Cracking (fatigue) – calibration factors f_1, f_2, and f_3.
- Rutting – calibration factors f_4 and f_5.

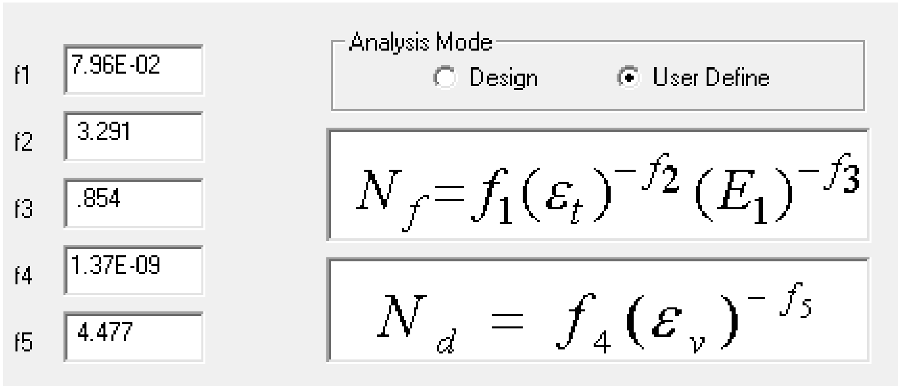


Figure 4-12. FPS Cracking (Fatigue) and Rutting M-E Models.

The f_i factors (coefficients) shown in Figure 4-11 are design or default values that are inherently built-in the FPS software. In the FPS calibration and validation processes of this study, new calibration factors that match measured field performance with the DSS field test sections will be developed through iterative/sensitivity analysis and recommended as surrogates, supplements, or utilized as “user-defined” values. Where applicable, recommendations for modifying the M-E models shown in Figure 4-12 along with the software code will also be made.

Triaxial design checks and stress-strain analyses will also be performed to authenticate the validity of the FPS performance predictions including the validation process. If needed, calibration factors will be readjusted accordingly.

CANDIDATE TEST SECTIONS FOR CALIBRATING AND VALIDATING THE FPS

As outlined in Chapters 2 and 3, the researchers plan to use actual field data from several Texas highways to calibrate and validate the FPS. The data required for this extensive calibration and validation process will be acquired from the Project 0-6658 DSS. The DSS includes a substantial number of highway test sections from all climatic regions of Texas, with a wide range of traffic loadings and a variety of pavement structures, thus providing the perfect data pool for such a study. In addition to construction and field performance data, the DSS also contains comprehensive and useful laboratory test data including material properties.

Table 4-2 lists some of the DSS candidate test sections earmarked for the calibration and validation of the FPS models and associated software.

Table 4-2. Candidate DSS Test Sections for Calibrating and Validating the FPS.

#	DSS Section ID	Hwy	PVMNT Type	Climatic Region	District	County
1	TxDOT_TTI-00001	US 59	Overlay-HMA-LTB	Wet-Cold	Atlanta	Panola
2	TxDOT_TTI-00005	Loop 480	New Construction	Dry-Warm	Laredo	Maverick
3	TxDOT_TTI-00006	SH 121	Overlay-HMA-CTB	Wet-Cold	Paris	Fannin
4	TxDOT_TTI-00002	SH 114	Perpetual	Wet-Cold	Fort Worth	Wise
5	TxDOT_TTI-00003	SH 114	Perpetual	Wet-Cold	Fort Worth	Wise
6	TxDOT_TTI-00032	US 277	New Construction	Wet-Cold	Wichita Falls	Baylor
7	TxDOT_TTI-00015	SH 21	New Construction	Wet-warm	Bryan	Brazos
8	TxDOT_TTI-00009	IH 35	New Construction	Moderate	Waco	Bell
9	TxDOT_TTI-00010	IH 35	Perpetual	Dry-Warm	Laredo	La Salle
10	TxDOT_TTI-00012	IH 35	Perpetual	Dry-Warm	Laredo	La Salle

EXAMPLE FPS RUNS USING THE PROJECT 0-6658 DSS DATA

To demonstrate the use of the Project 0-6658 DSS for running the FPS software, four test sections were evaluated, namely:

- TxDOT_TTI-00001 (US 59, Atlanta District).
- TxDOT_TTI-00005 (Loop 480, Laredo District).
- TxDOT_TTI-00002 and TxDOT_TTI-00003 (SH 114, Fort Worth).

The required input data were acquired from the DSS and, where unavailable, default values were used following the FPS guidelines. Table 4-3 through 4-5 shows the results of these FPS analyses. Detailed input and output data for these example FPS runs are listed in Appendix B and the CD (i.e., FPS input files) accompanying this interim report. A discussion of these examples is provided in the subsequent text.

However, several additional input parameters are required while running the FPS software other than the ones listed in Tables 4-3 and 4-4. Most of these data are either used defined design controls or related to budget-cost considerations and are not in the DSS. As of now, all these parameters were kept unchanged for all the example test sections discussed in this chapter. Appendix B lists the default values that were used.

Table 4-3. FPS Run for Section# TxDOT_TTI-00005 (Loop 480, LRD).

Input Data		Output Data	
Category	**Value**	**Category**	**Value**
General		Layer Depths	
– Analysis Period	20 years	– Asphalt Concrete Pavement	4 inch
– Design Confidence Level	C (95%)	– Flex Base	10 inch
– Initial Serviceability Index	4.5	– Cement Treated Base	6 inch
– Final Serviceability Index	2.5		
– Number of Lanes (each direction)	2	Performance Periods	
– Lane Width	12 ft	– Initial	15.3 years
		– After First Overlay	29.3 years
Traffic			
– ADT Beginning	6292		
– ADT End (20 years)	11033	Crack Life (number of traffic)	6.66 millions
– 18 kip ESAL (20 years)	6.1 M	Rutting Life (number of traffic)	200 millions
– % Trucks in ADT	14%		
Pavement Structure		HMA Tensile Strain (layer bottom)	130.00
– Design Type	ACP+FlexBase+ CTB+Subgrade	HMA Tensile Stress (layer bottom)	73.5 psi
Modulus, E (ksi)			
– Asphalt Concrete Pavement	499.6	Total Cost of Pavement	25.97
– Flex Base	92.3		
– Cement Treated Base	837.6		
– Subgrade	53.4		
Poison's Ratio			
– Asphalt Concrete Pavement	0.35		
– Flex Base	0.35		
– Cement Treated Base	0.30		
– Subgrade	0.40		

As shown in Table 4-3, the FPS run for this section indicates that cracking (6.66 million ESALs) will be the governing failure criteria, while the likelihood occurrence of rutting failure within the design life is very minimal. Although long-term field performance is still warranted (currently ongoing) to substantiate these performance predictions, these FPS analytical results are thus far consistent with the laboratory test results contained in the DSS. For example, the laboratory OT cracking and HWTT rutting performance of the Type C plant-mix from Loop 480 is as follows:

- OT cracking cycles = 77 (which is less than the minimum 100 OT cycles proposed for Type C mixes; suggesting potential for cracking; Walubita et al., 2012b).

- HWTT rutting = 4.76 mm after 20,000 load passes (which is significantly less than the 12.5 mm threshold; suggesting a very rut-resistant mix).

Table 4-4. FPS Run for Section# TxDOT_TTI-000001 (US 59, ATL).

Input		Output	
Category	Value	Category	Value
General		Layer Depths	
– Analysis Period	20 years	– ACP Overlay	2 inch
– Design Confidence Level	C (95%)	– Asphalt Concrete Pavement	11.5 inch
– Initial Serviceability Index	4.8	– Base	16 inch
– Final Serviceability Index	3.5		
– Number of Lanes (each direction)	2	Performance Periods	
– Lane Width	12 ft	– Initial	35.4 years
Traffic		Crack Life (number of traffic)	200 millions
– ADT Beginning	9890	Rutting Life (number of traffic)	200 millions
– ADT End (20 years)	17342		
– 18 kip ESAL (20 years)	18.8 M		
– % Trucks in ADT	30%		
Pavement Structure		HMA Tensile Strain (layer bottom)	12.8
– Design Type	Overlay Design	HMA Tensile Stress (layer bottom)	36.1 psi
Modulus, E (ksi)			
– ACP Overlay	638.9	Total Cost of Pavement	51.58
– Asphalt Concrete Pavement	638.9		
– Base	185.2		
– Subgrade	26.1		
Poisson's Ratio			
– ACP Overlay	0.35		
– Asphalt Concrete Pavement	0.35		
– Base	0.35		
– Subgrade	0.40		

The FPS predictions in Table 4-4 suggest satisfactory performance with no major rutting or cracking failure problems for this test section. These FPS results are thus far consistent with the DSS data both in terms of all the laboratory test data and field performance measurements as of fall 2012 (after 21 months of service); namely:

- Field performance (fall 2012 after 21 months of service) = 2.5 mm (less than the 12.52 mm threshold) average surface rutting with zero cracking.
- Lab test data (HWTT and OT) = 4.3 mm (less the 12.5 mm threshold) and 255 OT cycles (greater than the minimum 150 proposed for Type D mixes [Walubita et al., 2012b]).

Table 4-5. FPS Runs for TxDOT_TTI-00002 and TxDOT_TTI-00003 (SH 114, FTW).

Item	TxDOT_TTI-00002	TxDOT_TTI-00003
Hwy	SH 114 (Superpave)	SH 114 (Conventional)
Mix-design	SFHMA mixes	Type B and C mixes
PP structure	SMA + ¾-inch SFHMA + 1-inch SFHMA (RRL) + RBL + base + subgrade	SMA + Type C + Type B (RRL) + RBL + base + subgrade
PP structure thickness	30 inches = 22-inches HMA + 8-inches base	30 inches = 22-inches HMA + 8-inches base
Lab Hamburg rutting for surfacing SMA (field core) (≤ 12.5 mm)	5.18 mm @ 20 k	5.18 mm @ 20 k
Lab permanent micro-strain after 5 000 load repetitions (RLPD) for the RRL	7,500 με	14,000 με
Lab OT cracking for RBL (field core) (≥ 300)	652	550
Lab modulus at 77°F for RRL (field core)	1346 ksi	1063 ksi
Field surface rutting (summer12) (≤ 0.5-inches)	0.125 inches	0.10 inches
Field cracking (summer12)	None	None
Field IRI (summer12) (≤ 172 in/mi)	56.45 in/mi	60.70 in/mi
Field FWD surface deflections (summer12 at 115°F) (≤ 20 mils)	4.3 mils	4.9 mils
Years in service at time of this report	6	6
FPS strain analyses (≤ 70 & 200 με, respectively)	35 με (tensile) & 99 με (compressive)	29 με (tensile) & 79 με (compressive)
FPS service life prediction	27 yrs	23 yrs

Like the preceding examples, Table 4-5 shows consistency among the FPS analytical predictions, actual field measurements, and laboratory test predictions as of summer 2012. The ongoing long-term field performance monitoring is still warranted to further substantiate these findings. As shown in Figure 4-13 and consistent with laboratory test and FPS performance predictions shown in Table 4-5, both test sections show satisfactory performance after over 6 years of service.

Overall, all the examples demonstrated in this chapter would theoretically suggest that the current FPS design calibration factors (f_i) shown in Figure 4-11 are sufficient since the FPS analytical predictions do not differ significantly from the actual field performance of the test sections in question. However, these are just a limited number of DSS test sections with limited long-term performance data. More test sections with additional long-term field performance data will be evaluated in the upcoming calibration and validation works.

Figure 4-13. TxDOT_TTI-00002 and TxDOT_TTI-00003 after 8 Years of Service (No Visual Distresses).

CHALLENGES AND LIMITATIONS – THE DSS AND FPS SOFTWARE

As noted in the preceding discussion, the Project 0-6658 DSS has exhibited potential to be used to run and calibrate the FPS. However, these data from the DSS currently has to be entered manually into the FPS, which is rather a tedious and cumbersome process. Due to the differences in the platform media, there is no provision for automated exporting of the data from the DSS to the FPS software.

Therefore, a key challenge is for these researchers to develop a bridging platform for directly exporting the data from the DSS into the FPS. In addition to maximizing efficiency, this will also ensure that accurate data as it is from the DSS is automatically exported into the FPS without the likelihood of human error during manual entry.

Like any other database, the DSS data content does not meet the FPS data requirements 100 percent; so some input values will have to be assumed or default values used. However, efforts have been made to ensure that all the critical FPS input data are available and can be accessed from the DSS. Some of the data not presently available in the latest DSS version that can just be assumed or defaulted based on the FPS guidelines include the following:

- Program controls: max fund and pavement thickness during initial construction, total max overlay thickness.
- Traffic data: max speed overlay and non-overlay direction.
- Construction and maintenance data: Overlay construction time, HMA production rate, Routine maintenance cost, Annual incremental maintenance cost, etc.
- Detour design: Distance of traffic slowed overlay direction, Distance of traffic slowed non-overlay direction.
- Design type (material properties): Poisson's ratio.

SUMMARY

This chapter presented and discussed an overview of the FPS software along with the proposed calibrations plans and usage of the Project 0-6658 DSS, specifically addressing the following key aspects.

- Target M-E models to be checked for calibration were also discussed, namely the rutting and cracking models.
- The calibration factors (coefficients) to be checked, modified, and/or developed through a comprehensive iterative and sensitivity analyses.
- Running the FPS software using the DSS, including DSS data sources and location.
- FPS demonstration examples using the DSS data and test sections.
- Correlation between the FPS analysis predictions and the DSS data (both lab and field).

Overall, this chapter has demonstrated and proved that the DSS can satisfactorily be used to run the FPS software, albeit that more data and test sections are still needed. That is, the current DSS format and structure has sufficient data to successfully run and calibrate the FPS models and associated software. However, there is still a challenge to populate it with more data and also, if possible, to automate the data exporting process from the DSS, so as to maximize efficiency and data accuracy when inputting into the FPS software.

Some PPT slides (including input and output FPS files) demonstrating how to run the FPS using the DSS and its data content are included in the accompanying CD.

CHAPTER 5: THE TxACOL AND ASSOCIATED SOFTWARE

This chapter presents an overview of the TxACOL including the basic input data, output data, and the key M-E models to be calibrated and validated. The generalized calibration framework and data source for performing these calibrations were previously discussed in Chapters 2 and 3. A summary is then presented at the end of the chapter to highlight the key points and recommendations.

OVERVIEW

The TxACOL is an M-E based software that is primarily developed for HMA overlay thickness design and analysis, with the two calibrated distress types integrated as follows:

- Reflective cracking.
- Permanent deformation (rutting).

Figure 5-1, as a framework, presents the basic input/output parameters as well as the reflective cracking and rutting models used in the TxACOL software.

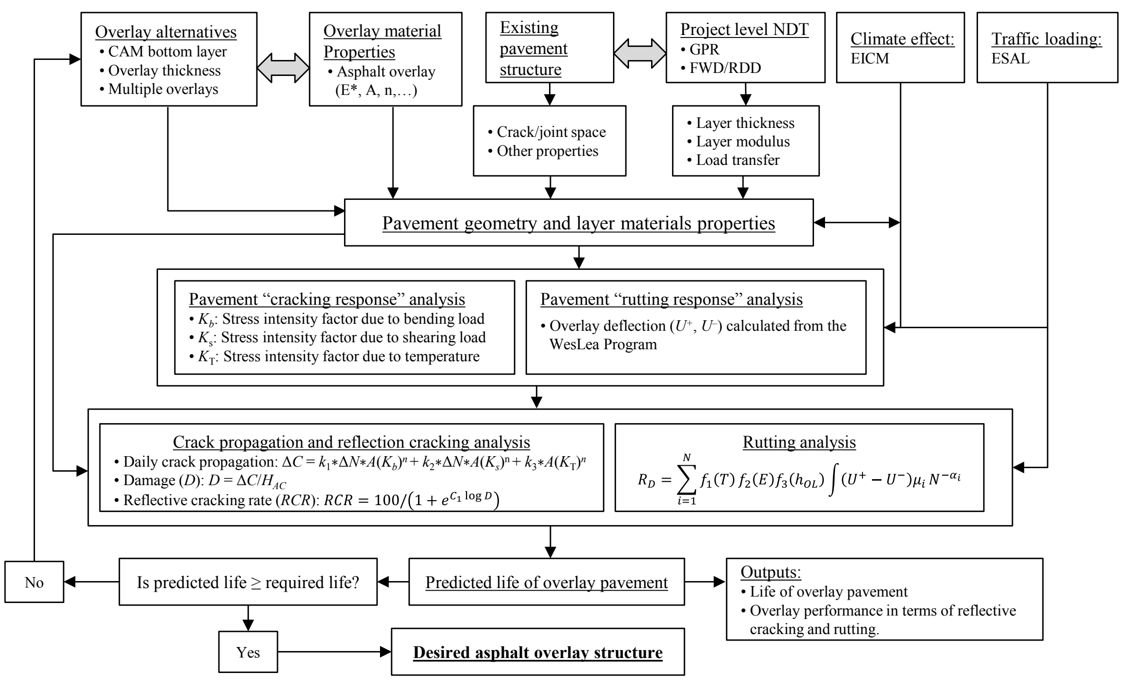


Figure 5-1. Framework of TxACOL Software (Zhou et al., 2009).

As shown in Figure 5-1, the TxACOL system consists of four main input components for HMA overlay design and analysis, namely the following:

1) HMA overlay material properties.
2) Existing pavement structures.
3) Climatic conditions.
4) Traffic loading.

The TxACOL allows users to choose different overlay structures (single- or double-layer overlay) and different types of mixes and binder types, such as Type C, Type D, SMA, CAM, etc., and the Superpave PG binder grading. The required input properties for overlay mix are dynamic modulus, fracture properties (A and n), and rutting properties (α and μ) of which default values are provided in the TxACOL software as well. The required input parameters indicating existing pavement conditions are layer thickness, layer modulus, joints/crack spacing, load transfer efficient (LTE) at joints, and severity level of existing cracks. These parameters are obtained by both in-situ field surveys and NDT such as GPR and FWD.

The TxACOL employs the enhanced integrated climatic model (EICM), which is also used in the M-E PDG to predict the pavement layer temperature based on weather station data in Texas. To input climatic data, users can either load up an existing EICM file of a design project or create a new file by selecting the closest weather stations. The standard traffic inputs in the TxACOL software are the number of 18 kip ESALs in the 20-year design period and ADT at the beginning and end of the 20-year service, which are also used in the FPS software. Appendix C1 lists full TxACOL input data along with the DSS location details. A detailed TxACOL input data is discussed in the subsequent text.

BASIC TXACOL INPUT DATA

To support entering all required input parameters easily, the TxACOL software interface provides an easy navigation system. The users can enter the project general information consisting of General Information, Project Identification, Analysis Parameters & Criteria and the input in three main categories: traffic, climate, and structure & material properties (see Figure 5-2).

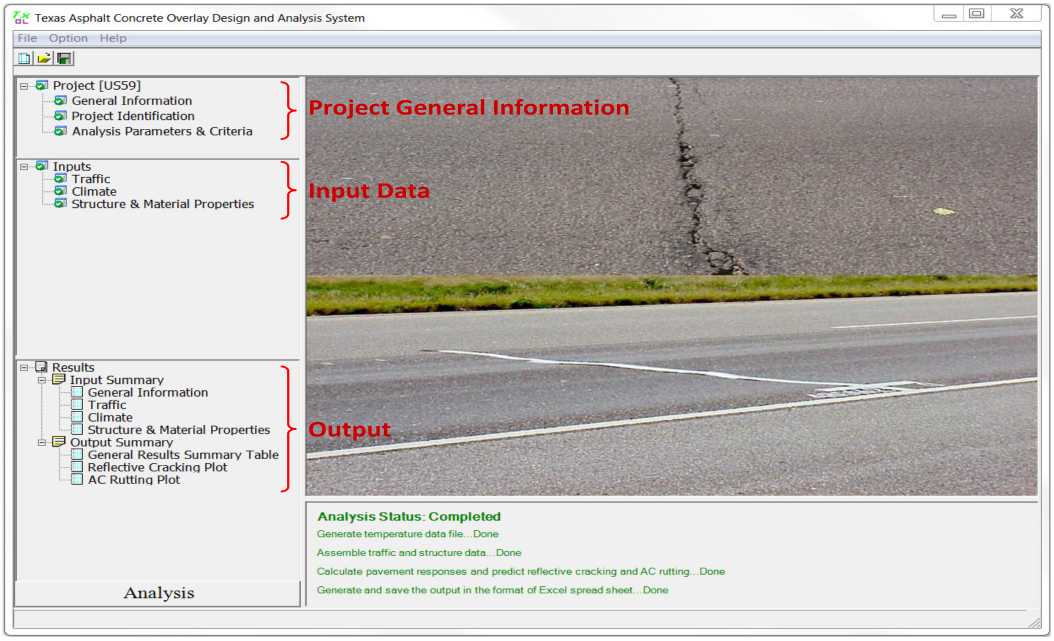


Figure 5-2. Main Screen of the TxACOL Software.

Table 5-1 presents the list of general, traffic, and climatic input parameters required for the TxACOL software and the location of each parameter in the DSS. As well, Table 5-2 lists the input parameters related to the structure and material properties of the pavement layers.

Table 5-1. List of Basic TxACOL Input for General, Traffic, and Climatic Information.

#	Category	Data Type	Location in the DSS	Comment
1	General Information	– Type of AC overlay design	Pavement Structure Details	
		– Analysis/Design Life (yr.)	N/A	User input
		– Pavement OL construction month – Traffic open month	Pavement Structure Details	
2	Project Identification	– District, County, CSJ – Reference mark (Begin/End)	Section Details	
		– Functional class	Traffic: Classification	
3	Analysis Parameter & Criteria	– Reflective cracking rate (%) – AC rutting (in)	N/A	User input
4	Traffic	– ADT (Beginning & End) – 18 kip ESALs – Operation speed	Traffic: Volume & Classification	
5	Climate	– Option 1: Load existing data file	Raw data files	
		– Option 2: Create new data file ○ Latitude, longitude, elevation	Section Details	

Table 5-2. List of Basic TxACOL Input for Structure and Material Properties.

#	Category	Data Type	Location in the DSS	Comment
1	Structural Input	– No. of layer (overlay & base) – Thickness – Material type	Pavement Structure Details	
2	AC Overlay	– Thermal coefficient of expansion	HMA: Thermal coefficient	
		– Poisson's ratio	N/A	User input
		– Superpave PG binder grading	Pavement Structure Details	
		– Dynamic modulus	HMA: Dynamic Modulus	Temp./Frequency
		– Fracture properties: temp., A, and n	HMA: OT Fracture Properties	
		– Rutting properties: temp., α, and μ	HMA: Repeated Loading (RLPD)	
3	Existing AC	– Thermal coefficient of expansion	N/A	Default value
		– Poisson's ratio	N/A	Default value
		– Main crack pattern – Cracking type – Severity level	- FPD: Alligator cracking - FPD: Longitudinal cracking - FPD: Transverse cracking - FPD: Block cracking	
		– FWD back-calculated modulus	FPD: FWD back-calculated modulus	
3	Existing JPCP (JRCP)/CRCP	– Thermal coefficient of expansion	N/A	Default value
		– Poisson's ratio	N/A	Default value
		– Joint/crack spacing	Existing Distress	
		– Modulus	FPD: FWD back-calculated modulus	
		– Load transfer efficiency	FPD: FWD Load Transfer Efficiency	
4	Existing Base (Granular)	– Poisson's ratio	N/A	Default value
		– Modulus input	FPD: FWD back-calculated modulus	
4	Existing Base (Stabilized)	– Poisson's ratio	N/A	Default value
		– Thermal coefficient of expansion	N/A	Default value
		– Mechanical strength properties: Modulus	FPD: FWD back-calculated modulus	
5	Existing Subgrade	– Poisson's ratio	N/A	Default value
		– Modulus Input	FPD: FWD back-calculated modulus	

Project General Information Inputs

Project General Information Inputs consists of General Information, Project Identification, and Analysis Parameters & Criteria. Each input is discussed in further detail in the subsequent text.

General Information

Figure 5-3 shows that the General Information includes two major inputs: 1) Type of AC overlay design and 2) Analysis/Design life (years). The users should select one of three AC overlay design types: 1) AC/AC, 2) AC/JPC (JRCP), and 3) AC/CRCP. Based on the selection, the TxACOL provides an input screen for structure and material properties described subsequently. When the construction information is specified, the software calculates pavement response and predicts reflective cracking and AC rutting from the traffic open month.

Project Identification

The Project Identification input mainly requires the location data of overlay projects: District, County, Control-Section-Job (CSJ), or Reference Mark Begin/End. A district and county can be selected from the dropdown boxes (see Figure 5-4).

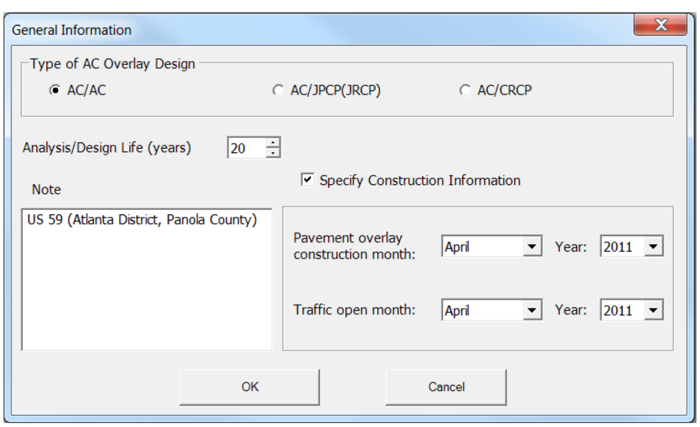


Figure 5-3. General Information Input Screen.

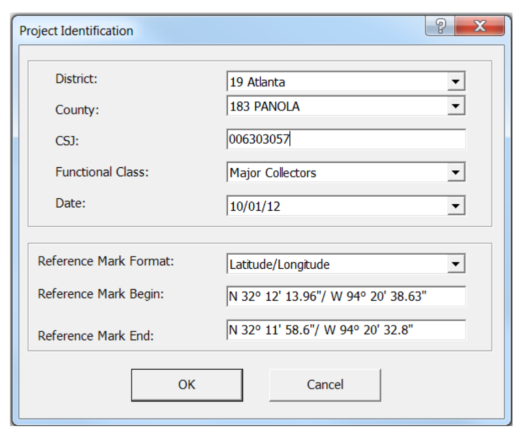


Figure 5-4. Project Identification Screen.

Analysis Parameters and Performance Criteria

Since the reflective cracking and rutting models are integrated in the TxACOL software, criteria for both HMA overlay failures should be specified as the analysis stop threshold. Figure 5-5 depicts the input screen of the analysis parameter and performance criteria.

Traffic Load (ESALs) Input

The TxACOL software requires 18 kips ESALs for 20 years, ADT at beginning and end at 20 years, and operational speed, which are the same information required in the FPS software (see Figure 5-6). This information is available in the table of “Traffic Data: Volume & Classification” in the Project 0-6658 DSS.

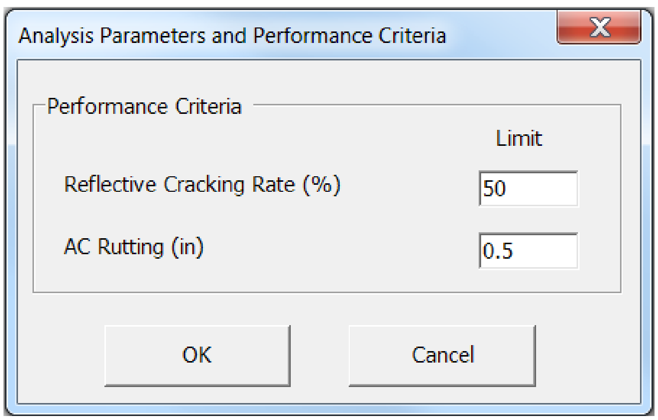


Figure 5-5. Performance Criteria Input Screen.

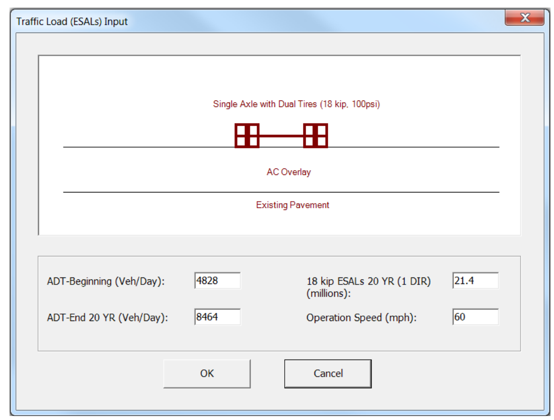
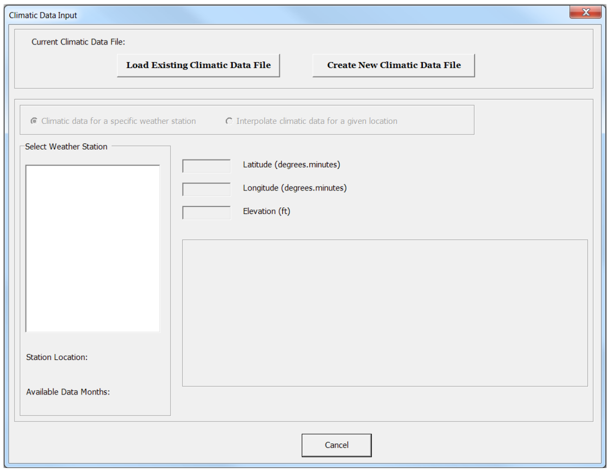
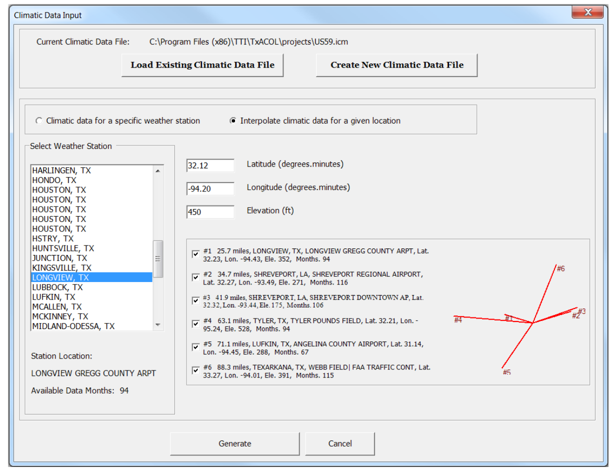


Figure 5-6. Traffic Load Input Screen.

Climate

There are two options with respect to climate data input in the TxACOL software: 1) Load Existing Climate Data File, or 2) Create New Climate Data File as shown in Figure 5-7 (a). In the option of Load Existing Climate Data File, the user can select an existing climatic data file (*.icm), which is available in the climatic data file folder of each test section in the DSS. If users do not have an existing file, Option 2 should be selected to create a climatic data file for a specific project. Users can select a specific weather station close to the project under “Climatic data for a specific weather station” function. In case there is not a close weather station to the overlay project, a climate data should be created by “Interpolating climate data for a given location” function. As Figure 5-7 (b) shows, the TxACOL automatically generates the climate data after the user enters latitude, longitude, and elevation data available in the DSS, then runs the EICM program.





(a) Climatic Input General Screen. **(b) Interpolating Climatic Data.**

Figure 5-7. TxACOL Climatic Input Screens.

Structure and Material Properties

In the main screen for the "Structure and Material Properties" input as shown in Figure 5-8, the user should input the thickness and material type as well as the numbers of AC overlay, existing AC, and existing base. Also, the user can select different types of material for each layer, such as Type C and D, SMA, SMAR, or CAM for AC overlay layer and granular or stabilized material for the base layer. The material properties of each layer are entered in the input screen for each specific pavement structure layer described subsequently.

AC Overlay

The material properties of AC overlay layer is one of the most important input categories in the TxACOL software since the program analyzes the overlay pavement performance in terms of reflective cracking and rutting distresses of the layer. The Project 0-6658 DSS provides the thermal coefficient of expansion, binder type, and dynamic modulus as well as the material performance properties for fracture and rutting properties data. Figure 5-9 demonstrates the input screen of the AC Overlay, including the input parameters of the test section TxDOT_TTI-00001 (US59) in Atlanta District.

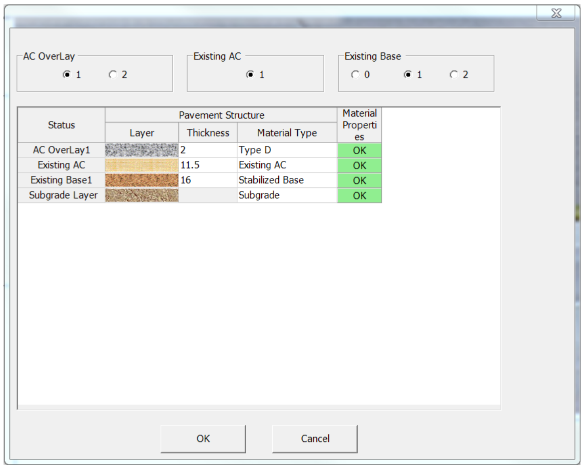


Figure 5-8. Main Screen of PVMNT Structure.

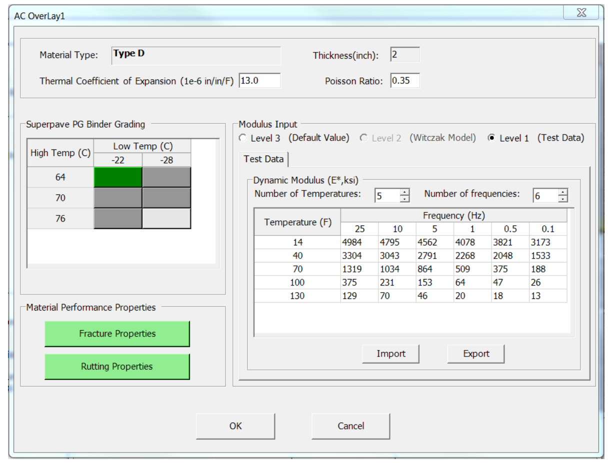
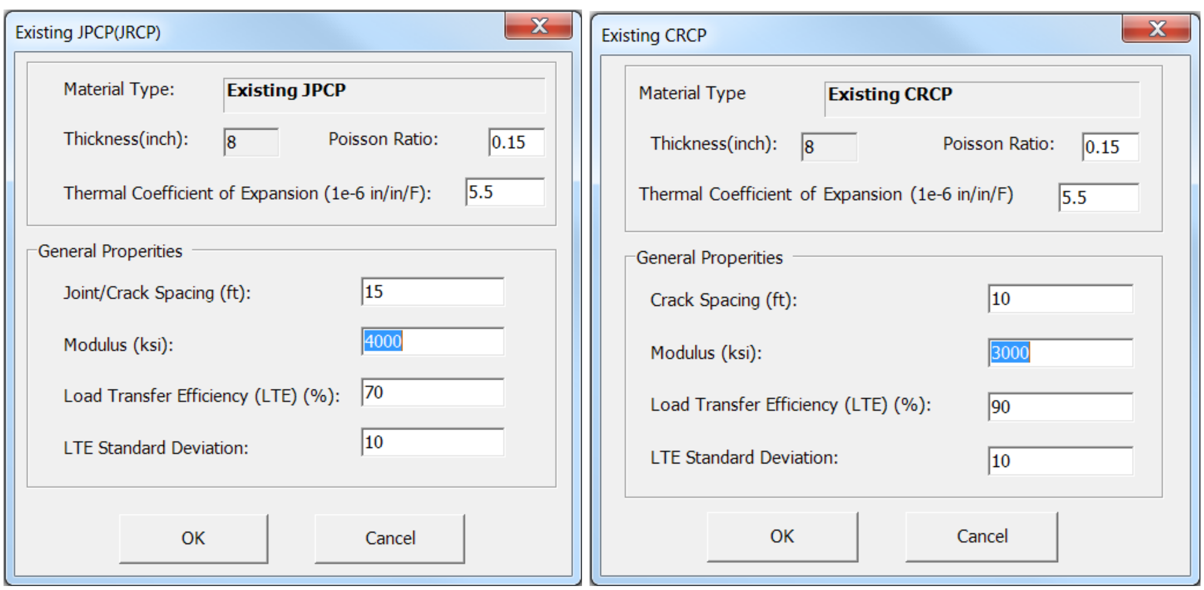


Figure 5-9. AC Overlay Input Screen.

Existing Surface

There are two types of existing surface, which should be selected in General Information step, in the TxACOL software: rigid surface and AC surface. Figure 5-10 shows that the rigid surface consists of JPCP (JRCP) and CRCP, which are very similar input parameters.



(a) Existing JPCP (JRCP). **(b) Existing CRCP.**

Figure 5-10. TxACOL Existing Rigid Surface Input Screens.

Existing AC

Four types of input parameter are required for the existing AC layer as shown in Figure 5-11:

- Thermal coefficient of expansion.
- Cracking pattern/type (alligator, longitudinal, transverse, or block cracking).
- Crack severity level.
- FWD back-calculated modulus.

The DSS provided all input parameters, except for the thermal expansion coefficient.

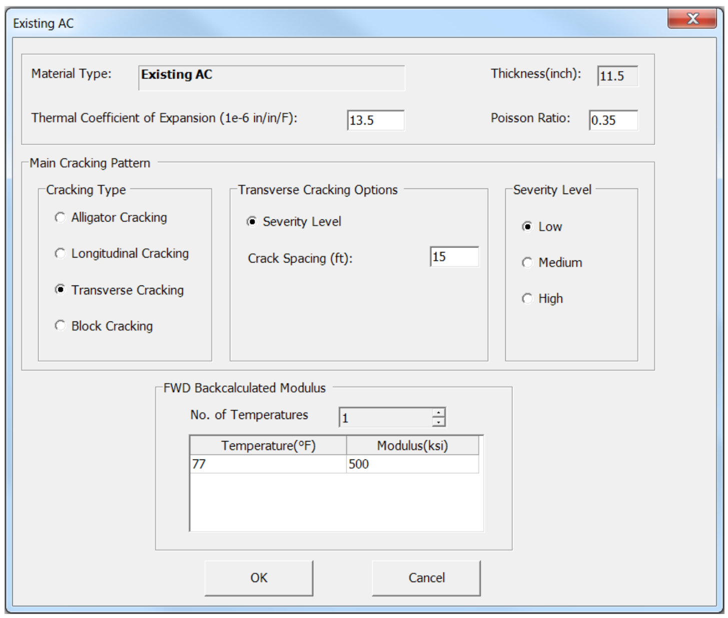
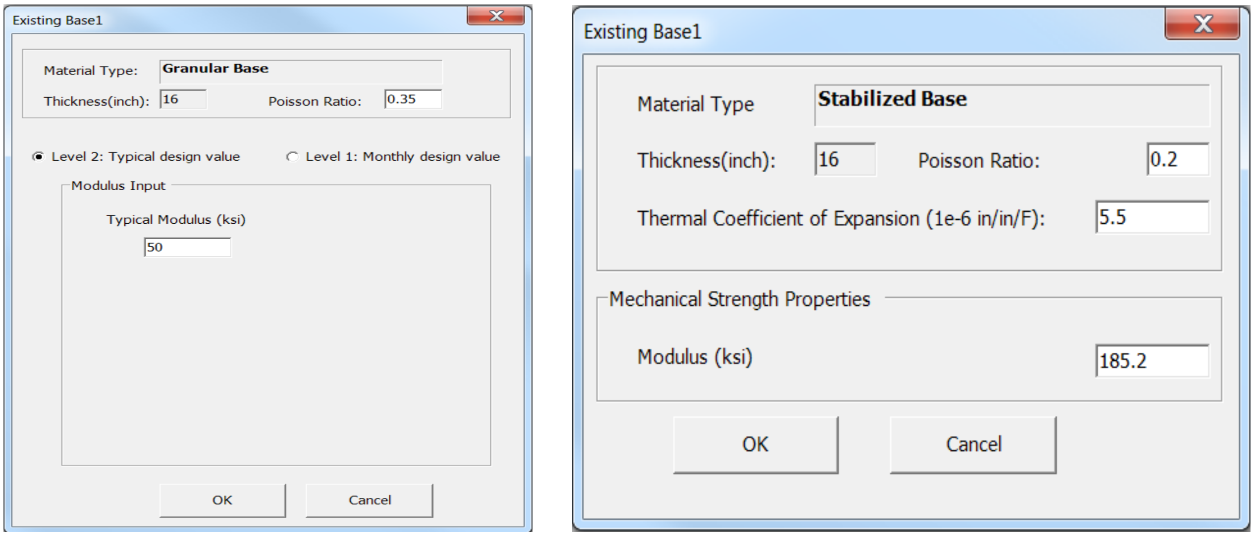


Figure 5-11. TxACOL Existing AC Input Screen.

Existing Base and Subgrade

While the user should select one type of existing base materials among granular base, stabilized base, or stabilized subgrade, the properties input required for the layers are very similar. All types of base and subgrade need the Poisson's ratio and modulus, but only the stabilized layer requires the thermal coefficient of expansion value as well (see Figure 5-12).



(a) Granular Base. **(b) Stabilized Base.**

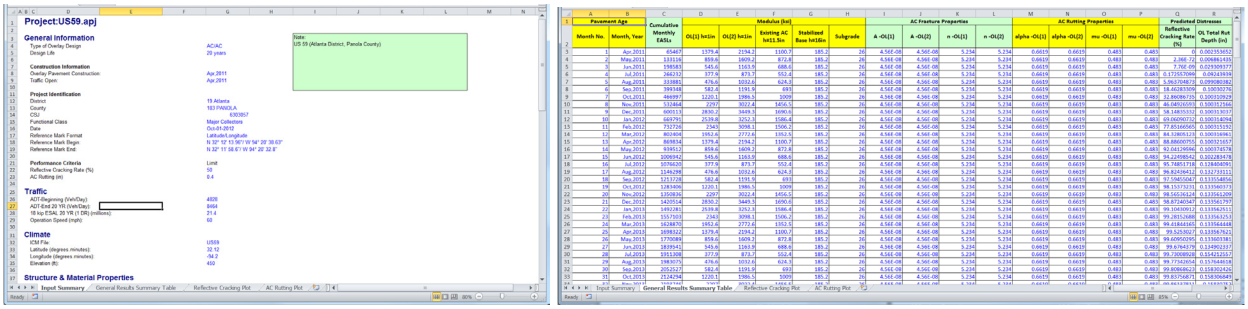
Figure 5-12. TxACOL Existing Base Input Screens.

RUNNING THE TXACOL SOFTWARE

After entering the required input into the TxACOL software, the user can click the "Analysis" button to analyze and predict the performance of the AC overlay project. Although the running time varies depending on the computer processing speed/capability and project/pavement type, the typical time is generally less than 5 minutes. A detailed step-by-step demonstration for running the TxACOL software (using the DSS) is included as PPT slides in the accompanying CD. The analysis and interpretation of the TxACOL output data are discussed in the subsequent sections of this chapter.

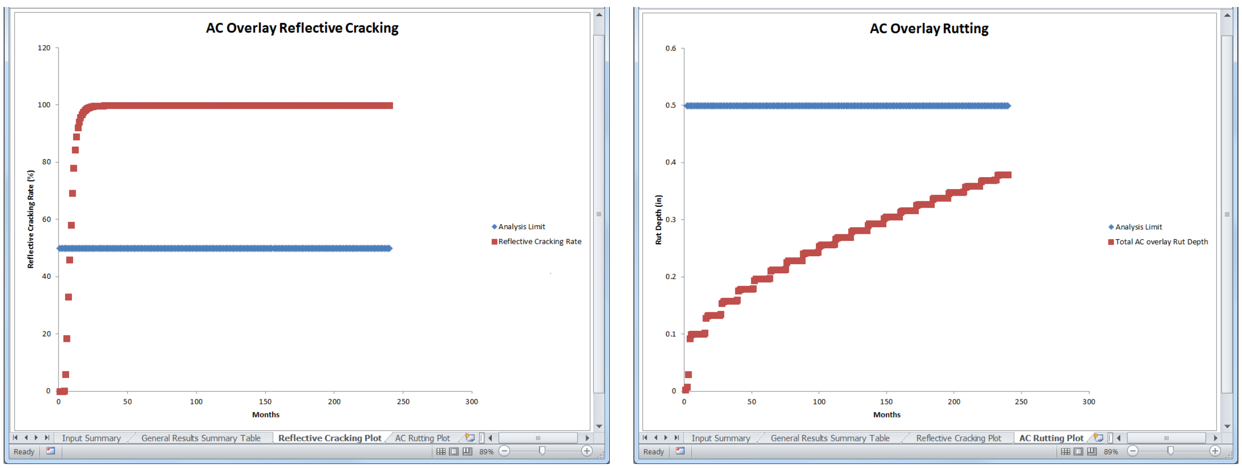
BASIC TXACOL OUTPUT DATA

The software automatically creates the input and output summaries, in MS Excel format, of the analyzed overlay design project. The input summary provides the general information, traffic climate, structure, and material properties. Also, a summary of the predictions for reflective cracking and rutting distresses are provided both in tabular and graphical (as a function of time in months) formats. Figure 5-13 presents the tables of input summary and general output results summary, and Figure 5-14 shows the reflective cracking and rutting development plots.



(a) Input Summary. (b) General Results Summary Table.

Figure 5-13. Example TxACOL Input and Result Summary Tables.



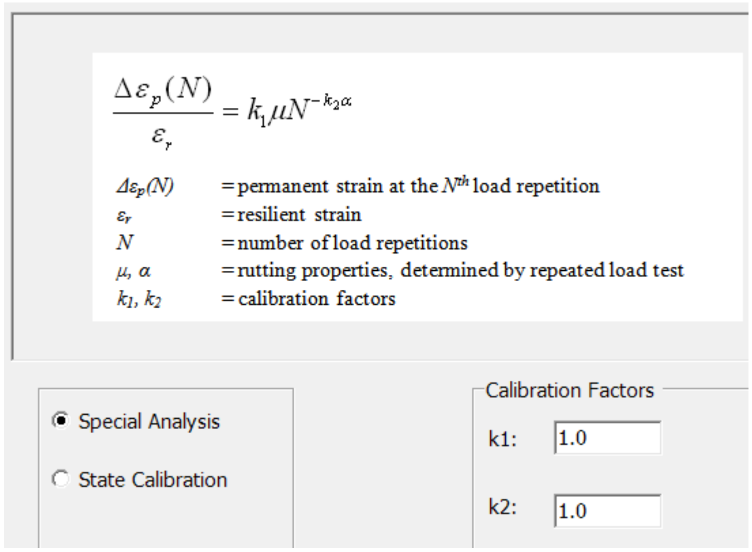
(a) Reflective Cracking (b) Rutting

Figure 5-14. AC Overlay Reflective Cracking and Rutting Development Plots.

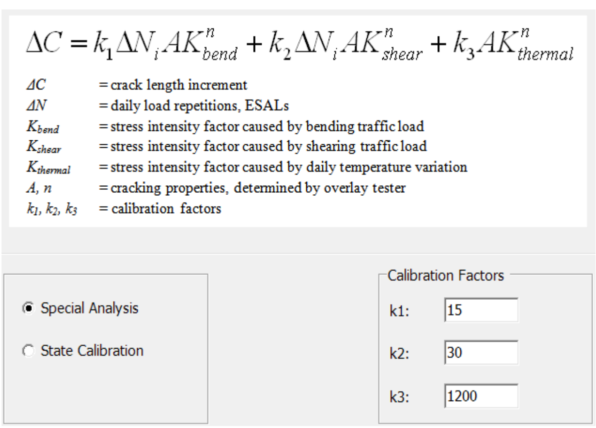
KEY TXACOL MODELS TO BE CALIBRATED AND VALIDATED

As shown in Figure 5-15, the TxACOL software provides the following calibration factors for each model:

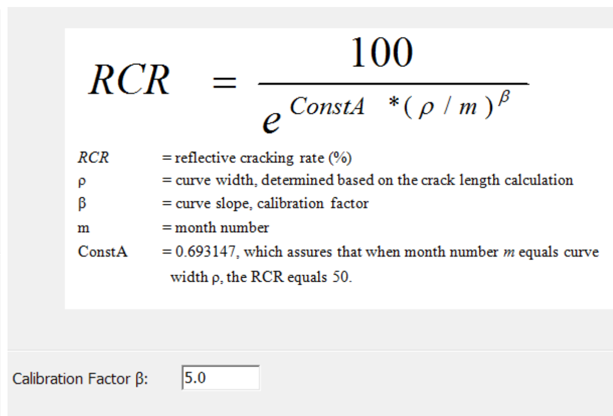
- AC rutting model: k_1 and k_2.
- Reflection crack propagation model: k_1, k_2, and k_3.
- Reflection cracking rate model: β.



(a) AC Rutting.



(b) AC Crack Propagation.



(c) Reflective Cracking.

Figure 5-15. TxACOL M-E Performance Models and Calibrations.

The research team will focus primarily on these models for the TxACOL calibration and validation to ensure that the model predictions match the measured field performance. Figure 2-1 shows that the calibration will be performed by iterative and sensitivity analysis of the calibration factors until the prediction from the TxACOL software and the field performance measurements/observations from the DSS match each other within the given error tolerance.

CANDIDATE TEST SECTIONS FOR CALIBRATING AND VALIDATING THE TxACOL

For the calibration and validation of the TxACOL, which is one of the key tasks in this study, the research team plans to analyze various test sections including different overlaid pavement structures and climatic regions. As noted in the Chapter 3, all of the data required for running the TxACOL software are included in the Project 0-6658 DSS. Some candidate test sections for preliminary calibration and validation of the TxACOL models are listed in Table 5-3 based on the pavement type and climate region.

Table 5-3. Candidate DSS Test Sections for Calibrating and Validating the TxACOL.

#	DSS Section ID	Hwy	PVMNT Type	Climatic Region	District	County
1	TxDOT_TTI-00001	US 59	Overlay-HMA-LTB	Wet-Cold	Atlanta	Panola
2	TxDOT_TTI-00007	US 271	Overlay-HMA-PCC	Wet-Cold	Paris	Lamar
3	TxDOT_TTI-00006	SH 121	Overlay-HMA-CTB	Wet Cold	Paris	Fannin
4	TxDOT_TTI-00024	US 59	Overlay-HMA-Flexbase	Dry-Warm	Laredo	Duval
5	TxDOT_TTI-00025	US 181	Overlay-HMA-LTB	Moderate	Corpus Christi	San Patricio
6	TxDOT_TTI-00040	LOOP 20	Overlay-HMA-LTB	Dry-Warm	Laredo	Webb
7	TxDOT_TTI-00042	SH 21	Overlay-HMA-Flexbase	Wet-Warm	Bryan	Burleson
8	TxDOT_TTI-00048	SH 123	Overlay	Dry-Warm	San Antonio	Wilson
9	TxDOT_TTI-00026	SH 358	Overlay-HMA-LTB	Moderate	Corpus Christi	Nueces
10	TxDOT_TTI-00038	IH 10	Overlay	Wet-Warm	Beaumont	Chambers

EXAMPLE TxACOL RUNS USING THE PROJECT 0-6658 DSS DATA

To demonstrate the use of the Project 0-6658 DSS for running the TxACOL software, the following three test sections were evaluated, namely:

- TxDOT_TTI-00001 (US 59, Atlanta District).
- TxDOT_TTI-00007 (US 271, Paris District).
- TxDOT_TTI-00006 (SH 121, Paris District).

As noted in the previous sections, certain required input parameters were obtained from the DSS while default values were used for data unavailable in the DSS such as the Poisson's ratio. The running process for each section is discussed in the following sections along with the input data from the DSS and the results from the TxACOL software.

The first section for the demonstration is test section TxDOT_TTI-00001 (US 59) in the Atlanta District, Panola County in a WC climatic region. The pavement structure consists of a 2-inch HMA overlay layer placed on April 2011, an 11.5-inch existing HMA surface, and a

16-inch lime-fly ash (LFA) treated base. All input parameters used to analyze and predict the performance in the TxACOL software are presented in Table 5-4 in accordance with each category.

Table 5-4. TxACOL Input Data of Section# TxDOT_TTI-00001 (US 59, ATL).

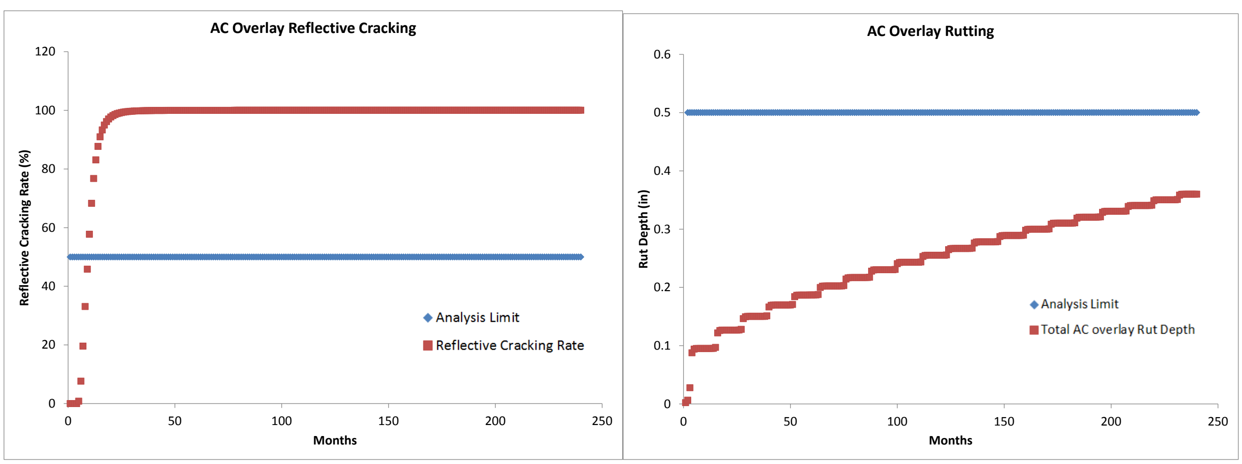
Category	Value	Category	Value
General Information		Material Properties: AC OverLay1	
– Type of AC overlay design	AC/AC	– Thermal coefficient of expansion	13.0**
– Analysis/Design Life (yr.)	20	– Poisson's ratio	0.35*
– PVMNT OL construction month	April 2011	– PG binder grading	64-22
– Traffic open month	April 2011	– Dynamic Modulus	See DSS**
Analysis Parameter & Criteria		– Fracture properties: Temp./A/n	77F/4.56E-8/5.234
– Reflective cracking rate (%)	50	– Rutting properties: Temp./α /μ	104/0.6266/0.530 102/0.6619/0.483
– AC rutting	0.5		
Traffic		Material Properties: Existing AC	
– ADT-Beginning (veh/day)	9,890	– Thermal coefficient of expansion	13.5*
– ADT-End 20 yr (veh/day)	17,342	– Poisson's ratio	0.35*
– 18 kip ESALs 20 yr (1 dir)	18.8M	– Cracking type/spacing (ft.)	Trans. Crack/15
– Operation speed (mph)	69	– Severity level	Medium
Climate (Create new climatic file)		– FWD back-calculated modulus	77°F/822.6ksi
– Latitude (degree.minutes)	32.12	Material Properties: Existing Base	
– Longitude (degrees.minutes)	−94.20	– Poisson's ratio	0.2*
– Elevation (ft)	450	– Thermal coefficient of expansion	5.5*
Structural Input: thick./material type		– Modulus (ksi)	185.2
– AC overlay 1	2 in./Type D	Material Properties: Subgrade	
– Existing AC	11.5 in./AC	– Poisson's ratio	0.4*
– Existing base 1	16 in./Stab. Base	– Modulus (ksi)	26.1
– Subgrade layer	−/Subgrade		

* Default values in TxACOL software
** Material Properties: HMA Mixes (Thermal Coefficient, Dynamic Modulus [DM], etc) in DSS

It should be noted that the traffic data (specifically the 18 kips ESALs) in Table 5-4 and the subsequent Tables 5-5 and 5-6 were estimated from the traffic counts (volume and speed classifications) using traffic tube counters and assumed traffic growth rates (i.e., 3% for US 59). Therefore, these traffic input data (18 kips ESALs and ADT-end 20 yr) could have impacted the performance prediction of the TxACOL analyses. However, these assumed traffic growth factors and the estimated 18 kips ESAL values will eventually be replaced with more accurate data in the future after a minimum of three consecutive yearly traffic measurements on each test section and subsequent analyses. Therefore, the TxACOL analysis will be rerun once more accurate 18 kips

ESAL data is generated. The ADT (beginning) on the other hand is based on actual measured traffic counts using the traffic tubes.

Figure 5-16 presents the reflective cracking and rutting plots generated from TxACOL software based on the US 59 input parameters. The results show that while the rutting prediction suggests satisfactory performance without significant rutting failure within 20 years of the analysis period, the reflective cracking failure is very critical since its development reaches 50 percent in less than 20 months. However, the surface condition of the US 59 section surveyed visually in October 2012 indicates that the section did not have any cracking on the surface even though it has been in service for 21 months since the overlay placement. This difference between predicted and actual field performances may indicate the need for calibrating the reflective cracking models in the related TxACOL software or rechecking the input data, particularly considering that the 18 kips ESALs were estimated based on assumed traffic growth factors.



(a) Reflective Cracking **(b) Rutting**

Figure 5-16. Overlay Performance Plots of Section# TxDOT_TTI-00001 (US 59, ATL).

Consistent with the actual measured field performance as at the time of this interim report, laboratory test results also predicted satisfactory performance for this test section with no major cracking or rutting distresses during the pavement's design life. The laboratory test results and actual measured field performance are summarized as follows:

- Lab test data (HWTT and OT) = 4.3 mm (less the 12.5 mm threshold) and 255 OT cycles (greater than the minimum 150 proposed for Type D mixes [Walubita et al., 2012b]).

- Field performance (Fall 2012 after 21 months of service) = 2.5 mm (less than the 12.52 mm threshold) average surface rutting with zero cracking (see Figure 5-17).

Figure 5-17. TxDOT_TTI-00001 (US 59, ATL) after 21 Months of Service (No Visual Distresses).

In contrast to the TxACOL performance predictions in Figure 5-16, Figure 5-17 clearly shows no reflective cracking after 21 months of service. Although this is just one test section with the need to evaluate more test sections along with more long-term performance data, the discrepancy between the analytical predictions (TxACOL) and the field (supplemented with lab test data) may suggest the need to calibrate the reflective cracking model or otherwise, a review of the input data particularly that that the 18 kips ESALs were estimated based on assumed traffic growth factors. . Nonetheless, the TxACOL analysis will be rerun once more accurate 18 kips ESALs traffic data is generated.

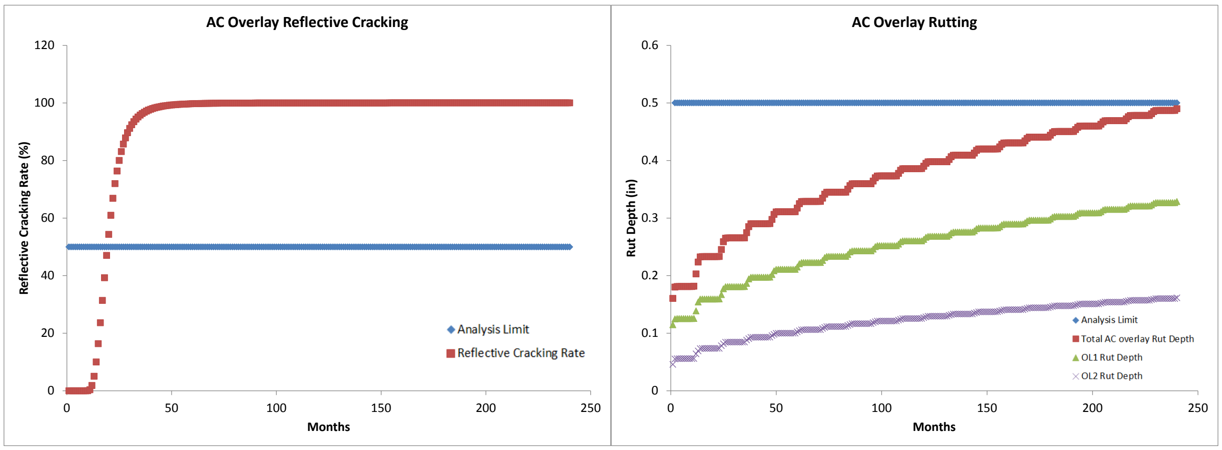
Next example section is TxDOT_TTI-00007 (US 271) located in Paris District, Lamar County. The section has two HMA overlay layers consisting of 1.5-inch PFC and 2.0-inch Type F mixes on existing HMA and PCC layer resting on the subgrade. Therefore, the pavement structure for running the TxACOL software was set as "AC over AC" design with the existing PCC layer considered as the "stabilized base layer" (see Table 5-5). Also, since the HMA fracture parameters (*A* and *n*) of both overlay materials (PFC and Type F) had not yet been measured at the time of this report and that the TxACOL software does not provide default values for PFC and Type F mixes, these researchers assumed the *A* and *n* values using the default values of the Type D mix. However, the assumed values will eventually be replaced by actual values measured in the laboratory in the future, and the TxACOL analysis will be rerun to get more accurate results.

Table 5-5. TxACOL Input Data for Section# TxDOT_TTI-00007 (US 271, PAR).

Category	Value	Category	Value
<u>General Information</u>		<u>Material Properties: AC Overlay1</u>	
– Type of AC overlay design	AC/AC	– Thermal coefficient of expansion	13.5*
– Analysis/Design Life (yr.)	20	– Poisson's ratio	0.35*
– PVMNT OL construction month	Nov. 2011	– PG binder grading	76-22
– Traffic open month	Nov. 2011	– Dynamic Modulus	See DSS**
<u>Analysis Parameter & Criteria</u>		– Fracture properties: Temp./A/n	77/4.67E-6/3.925*
– Reflective cracking rate (%)	50	– Rutting properties: Temp./α /μ	104/0.82/0.39 122/0.87/0.66
– AC rutting	0.5	<u>Material Properties: AC OverLay2</u>	
<u>Traffic</u>		– Thermal coefficient of expansion	13.5*
– ADT-Beginning (veh/day)	4,491	– Poisson's ratio	0.35*
– ADT-End 20 yr (veh/day)	7,875	– PG binder grading	76-22
– 18 kip ESALs 20 yr (1 dir)	12.3M	– Dynamic Modulus	See DSS**
– Operation speed (mph)	67	– Fracture properties: Temp./A/n	77/4.67E-6/3.925*
<u>Climate (Create new climatic file)</u>		– Rutting properties: Temp./α /μ	104/0.80/0.36 122/0.62/0.12
– Latitude (degrees.minutes)	33.51	<u>Material Properties: Existing AC</u>	
– Longitude (degrees.minutes)	−95.30	– Thermal coefficient of expansion	13.5*
– Elevation (ft)	450	– Poisson's ratio	0.35*
<u>Structural Input: thick./material type</u>		– Cracking type/spacing (ft.)	Trans. Crack/15
– AC overlay 1	1.5 in./ PFC	– Severity level	High
– AC overlay 2	2 in./ Type F	– FWD back-calculated modulus	77°F/433.1ksi
– Existing AC	6.5 in./AC	<u>Material Properties: Existing Base 1</u>	
– Existing Base 1	9 in./Stab. base	– Poisson's ratio	0.2*
– Subgrade layer	−/Subgrade	– Thermal coefficient of expansion	5.5*
		– Modulus (ksi)	4527.4
		<u>Material Properties: Subgrade</u>	
		– Poisson's ratio	0.4*
		– Modulus (ksi)	25.4

* Default values in TxACOL software (assumed/used Type D *A* and *n* default values for PFC and Type F mixes)
** Table of "HMA: Dynamic Modulus (DM)" in DSS

The TxACOL predictions in Figure 5-18 shows that the reflective cracking rate development reaches the 50 percent cracking rate at around 20 months. By contrast, the resistance on the AC overlay rutting looks promising because the prediction of total overlay rutting depth is less than 0.5-inch within the 20-year design life.



(a) Reflective Cracking **(b) Rutting**

Figure 5-18. Overlay Performance Plots of Section# TxDOT_TTI-00007 (US 271, PAR).

As at the time of this report, TxDOT_TTI-00007 has been in service for 13 months with no visual distresses, which is also consistent with the laboratory test predictions as contained in the DSS (see Figure 5-19). Therefore, long-term performance monitoring is still needed to verify this, in particular, the 20-months 50 percent reflective cracking prediction shown in Figure 5-18b Furthermore, the fracture parameters *A* and *n* were assumed based on the Type D default values and could therefore have impacted the results. The TxACOL analysis for this section will therefore be rerun once the PFC and Type F fracture parameters *A* and *n* have been measured in the laboratory.

Figure 5-19. TxDOT_TTI-00007 (US 271, PAR) after 13 Months of Service (No Visual Distresses).

Table 5-6 lists the required input data for running test section# TxDOT_TTI-00006 (SH 121) consisting of two overlay layers: 1.5-inch PFC and 2-inch CAM over existing HMA. The existing base layer is CTB material. Similar to US 271 in Table 5-5, *A* and *n* values of the PFC material were assumed based on the Type D default values. The values will be replaced with actual values measured in the laboratory in the future and the TxACOL analysis will be rerun to generate more accurate results

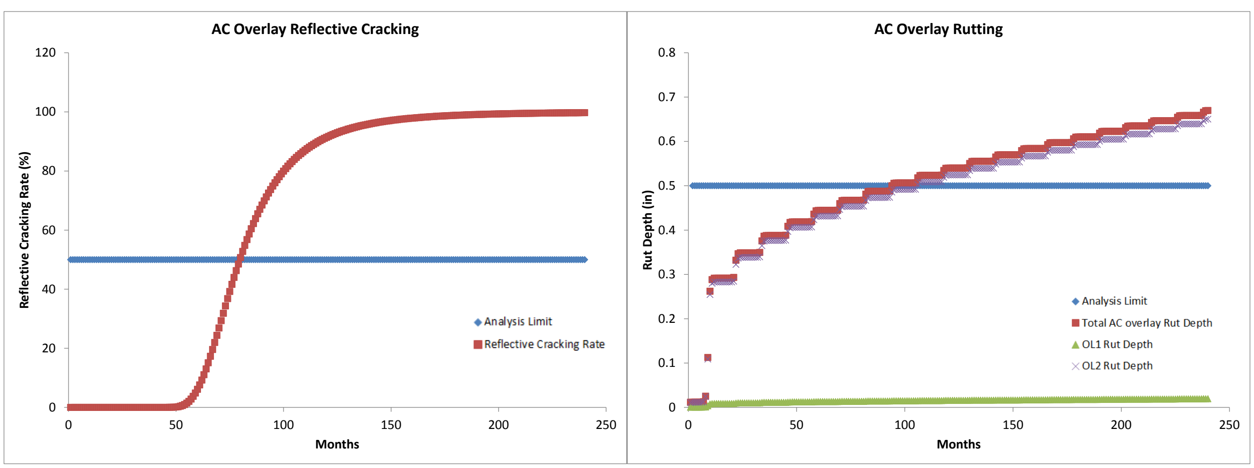
Table 5-6. TxACOL Input Data for Section# TxDOT_TTI-00006 (SH 121, PAR).

Category	Value	Category	Value
General Information		Material Properties: AC Overlay1	
– Type of AC overlay design	AC/AC	– Thermal coefficient of expansion	13.5*
– Analysis/Design Life (yr.)	20	– Poisson's ratio	0.35*
– PVMNT OL construction month	Oct. 2011	– PG binder grading	76-22
– Traffic open month	Oct. 2011	– Dynamic Modulus	See DSS**
Analysis Parameter & Criteria		– Fracture properties: Temp./A/n	77/4.67E-6/3.925*
– Reflective cracking rate (%)	50	– Rutting properties: Temp./α /μ	104/0.83/0.78
– AC rutting	0.5		122/0.78/0.58
Traffic		Material Properties: AC OverLay2	
– ADT-Beginning (veh/day)	3,146	– Thermal coefficient of expansion	13.5*
– ADT-End 20 yrs (veh/day)	5,517	– Poisson's ratio	0.35*
– 18 kip ESALs 20 yrs (1 dir)	6.1M	– PG binder grading	76-22
– Operation speed (mph)	69.6	– Dynamic Modulus	See DSS**
Climate (Create new climatic file)		– Fracture properties: Temp./A/n	77/1.41E-8/5.516*

– Latitude (degree.minutes)	33.28	– Rutting properties: Temp./α /μ	104/0.59/0.34 122/0.46/0.58
– Longitude (degrees.minutes)	−96.16		
– Elevation (ft)	450	<u>Material Properties: Existing AC</u>	
<u>Structural Input: thick./material type</u>		– Thermal coefficient of expansion	13.5*
– AC overlay 1	1.5 in./PFC	– Poisson's ratio	0.35*
– AC overlay 2	2 in./CAM	– Cracking type	Alligator crack
– Existing AC	4.5 in./AC	– Severity level	Medium
– Existing base 1	9.5 in./Stab Base	– FWD back-calculated modulus	77°F/683ksi
– Subgrade layer	−/Subgrade	<u>Material Properties: Existing Base</u>	
		– Poisson's ratio	0.2*
		– Thermal coefficient of expansion	5.5*
		– Modulus (ksi)	1995.0
		<u>Material Properties: Subgrade</u>	
		– Poisson's ratio	0.4*
		– Modulus (ksi)	28.0

* Default values in TxACOL software (assumed/used Type D A and n default values for PFC)
** Table of "HMA: Dynamic Modulus (DM)" in DSS

Figure 5-20 indicates satisfactory performance up to 5–6 years of service with reflective cracking as the governing distress criterion. As at the time of this report, the overlay has been in service for 14 months without any problems (see Figure 5-21), which is consistent with the TxACOL predictions shown in Figure 5-20.



(a) Reflective Cracking **(b) Rutting**

Figure 5-20. Overlay Performance Plots of Section# TxDOT_TTI-00006 (SH 121, PAR).

Figure 5-21. TxDOT_TTI-00006 (SH 121, PAR) after 14 Months of Service (No Visual Distresses).

As shown in Figure 5-21, TxDOT_TTI-00006 shows satisfactory field performance with no distresses after 14 months of service. Therefore, a minimum 5 years performance monitoring period is strongly recommended to verify the TxACOL predictions shown in Figure 5-20.

CHALLENGES AND LIMITATIONS – THE DSS AND TXACOL SOFTWARE

As shown in the above demonstration examples, the Project 0-6658 DSS is capable of being used to run the TxACOL by providing the input parameters required in the software. Nevertheless, entering the data manually from the DSS into the TxACOL is rather a tedious and cumbersome process. Due to the differences in the platform media, there is no provision for automated exporting of the data from the DSS to the TxACOL software. Therefore, a key challenge is to develop a bridging platform to export the DSS data directly into the TxACOL. In addition to maximizing efficiency, this will also ensure that accurate data is automatically exported into the TxACOL without the likelihood of human error during manual entry.

Like any other database, the DSS data content does not provide all TxACOL data requirements; therefore, some input values such as the Poisson's ratio or the thermal coefficient of expansion of stabilized base material should be assumed or default values used. However, efforts have been made to ensure that all the critical TxACOL input data are available and can be accessed from the DSS. Presently, the researchers are working to generate and include the following critical data that are unavailable in the current DSS version:

- Traffic data.
    - Growth factors (currently assumed).
    - ADT-End 20 years.
- Climate
    - EICM file for each test section.
- Existing AC properties.
    - Thermal coefficient of expansion (measured using field cores, if applicable).

Also another challenge is that the DSS is currently still being updated and as such some data may still be missing and/or unavailable. As noted in the aforementioned discussions, these data include the HMA fracture parameters A and n; and will be updated in the DSS as soon as laboratory testing for each respective test section is complete. Likewise, the traffic data (ADT, growth factors, 18 kips ESALs, etc.) will also be continuously updated as actual data is periodically measured from the field.

The current version of the TxACOL software does not have an option for an "AC overlay (s) over existing HMA over PCC". Recommendations are that this type of PVMNT structure should be analyzed as an "AC overlay (s) over existing HMA over CTB." Another issue is that the TxACOL analyzes the development of reflective cracking based on the assumption that the existing AC layer has cracked through the whole AC thickness. So, for accurate crack prediction at this point (for AC overlays over AC), the following aspects should be considered:

- The "cracked depth" of the existing AC layer should be considered as the "existing AC layer"; see Figures 5-22 and 5-23.
- The rest of the "un-cracked thickness of the existing AC layer" should be treated as a "granular base layer"; see Figures 5-22 and 5-23.
- The corresponding modulus of the granular base layer should be the same as that of the existing AC layer at a reference temperature of 77°F.

As noted in Appendix C2 and Figure 5-24, a re-analysis of test section TxDOT_TTI-00001 (US 59) with the above PVMNT modification considerations has yielded a reasonable reflective crack life of over 60 months. This is significantly different from the less than 20 months reflective crack life prediction in Figure 5-16.

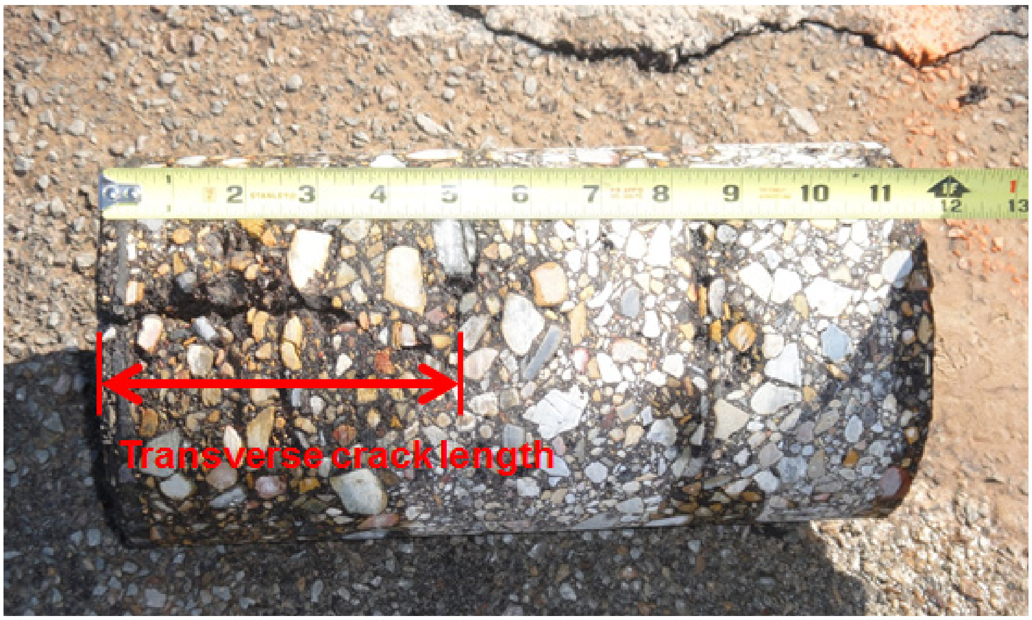


Figure 5-22. TxDOT_TTI-00006: Field Core of US59 Existing AC Layer.

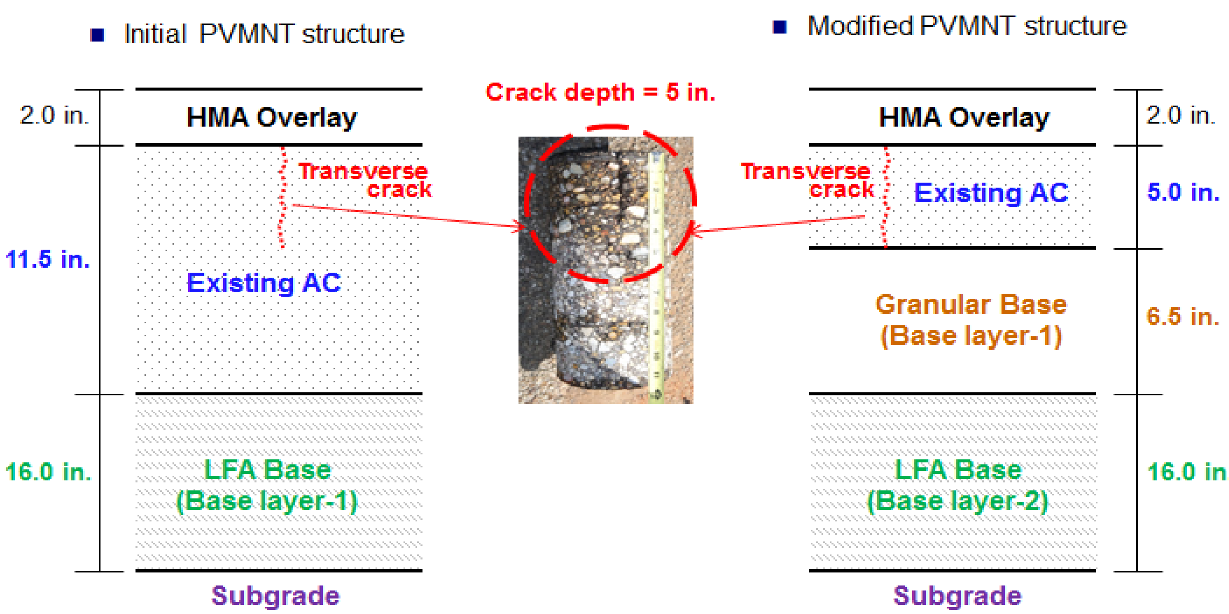


Figure 5-23. TxDOT_TTI-00006: US 59 PVMNT Structure.

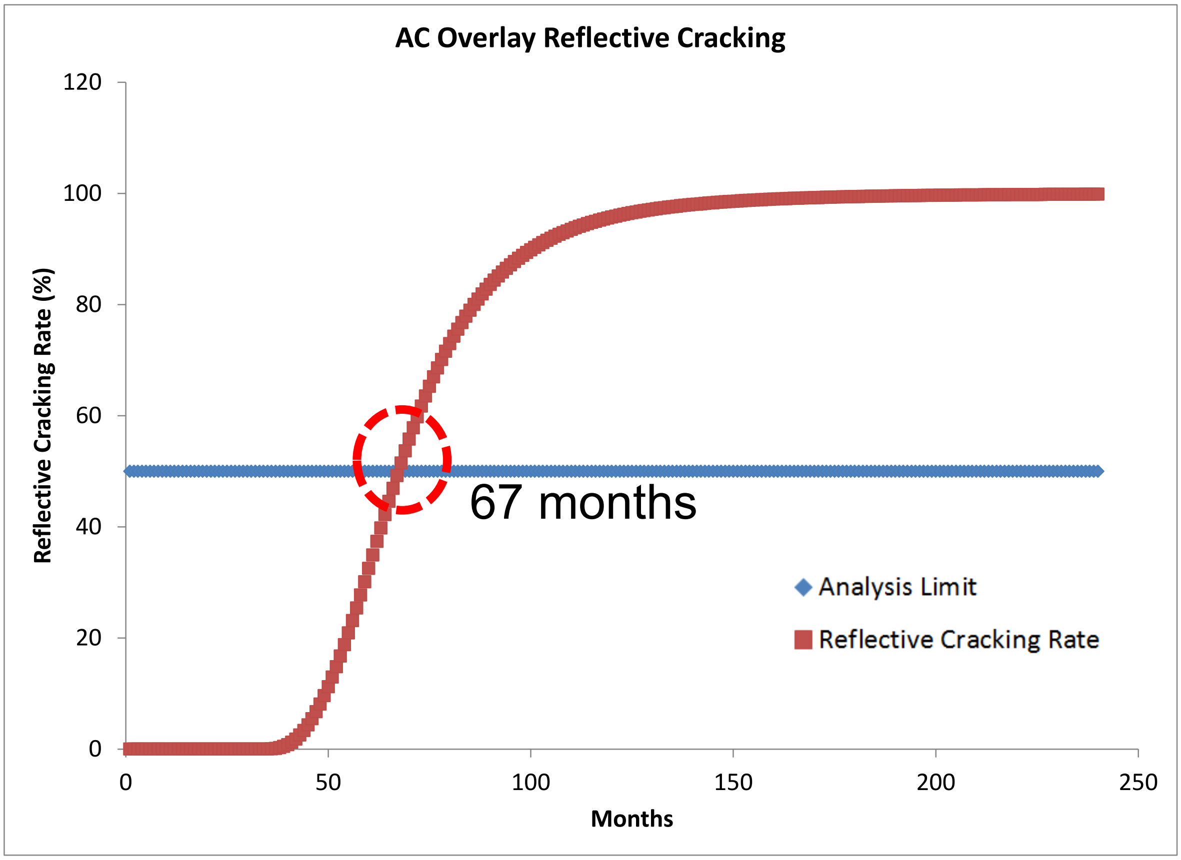


Figure 5-24. TxDOT_TTI-00001 (US 59) – Reflective Crack Life Prediction with the Modified Existing PVMNT Structure.

Compared with Figure 5-16, the modification of the PVMNT structure due to the transverse crack depth of the existing AC layer has a significant effect on the reflective cracking prediction. It has yielded a reflective crack life prediction of over 5 years, which is considered reasonable. The crack depth of existing AC layer should thus be always measured to get highly accurate crack prediction with the TxACOL analysis.

SUMMARY

This chapter presented and discussed an overview of the TxACOL software along with the proposed calibrations plans and usage of the Project 0-6658 DSS, specifically addressing the following key aspects:

- Target M-E models to be checked for calibration were discussed, namely the reflective cracking and rutting models.

- The calibration factors (coefficients) to be checked, modified, and/or developed through a comprehensive iterative and sensitivity analyses.
- Running the TxACOL software using the DSS, including DSS data sources and location.
- TxACOL demonstration examples using the DSS data and test sections.

Overall, this chapter has demonstrated and proved that the Project 0-6658 DSS is capable of being used to run the TxACOL software, albeit that more data and test sections are still needed. The current DSS format and structure has sufficient data to successfully run and calibrate the TxACOL models and associated software. However, there is still a challenge to populate it with more data and also, if possible, to automate the data exporting process from the DSS, so as to maximize efficiency and data accuracy when entering into the TxACOL software.

Some PPT slides (including input and output FPS files) demonstrating how to run the TxACOL using the DSS and its data content are included in the accompanying CD. However, caution should also be exercised to consider the following aspects when running the TxACOL software:

- "AC overlay (s) over existing HMA over PCC" should be analyzed as "AC overlay (s) over existing HMA over CTB."
- For AC overlays over AC, only the "cracked depth" of the existing AC layer should be considered as the "existing AC layer". The rest of the "un-cracked thickness of the existing AC layer" should be treated as a "granular base layer" and the corresponding modulus of the granular base layer should be the same as that of the existing AC layer at a reference temperature of 77°F.

CHAPTER 6: THE TxM-E AND ASSOCIATED SOFTWARE

The TxM-E is currently under development in Study 0-6622 (Zhou, 2011), and as such, there are no detailed discussions of the TxM-E models and associated software in this interim report. Reference should be made to the following publications for full details of the TxM-E models, associated software, calibration plans, etc.:

- Report 0-6622-1 (Hu et al., 2012a).
- Report 0-6622-2 (Hu et al., 2012b).
- Tech Memo Task 0-6622-4a (Navarro et al., 2012).
- Tech Memo Task 0-6622-4b (Tirado et al., 2012).

However, a similar approach as discussed in the preceding chapters will be executed on the TxM-E models and its associated software during the calibration and validation processes. The Project 0-6658 DSS in liaison with Study 0-6622 will be utilized as the data source. As discussed in the previous chapters, this study will predominantly focus on assessing and validating the accuracy of the calibration factors (or coefficients) in correlating to actual field performance data through a comprehensive iterative and sensitivity analysis. Therefore, this study's calibration/validation process will be limited to the following two key outcomes:

- Tabulation/listing of the proposed/recommended local calibration factors (coefficients) for each respective TxM-E model and the associated software.
- Recommendations for modifying the TxM-E models and the associated software codes, where applicable.

Actual modification of the TxM-E models and/or software code is outside the scope of this study. However, these researchers will work closely with Study 0-622 when executing these tasks (calibration and validation) including running of the TxM-E software (Zhou, 2011). Note that in addition to field data, the DSS laboratory test data will also be used to supplement the calibration process. The basic TxM-E input and output data along with the DSS location details are listed in Appendix D.

CHAPTER 7: THE M-E PDG AND ASSOCIATED SOFTWARE

This chapter presents an overview of the M-E PDG including the basic input data, output data, and the key M-E models to be calibrated and validated. The generalized calibration framework and data source for performing these calibrations were previously discussed in Chapters 2 and 3. A summary is then presented at the end of the chapter to highlight the key points and findings.

OVERVIEW

The M-E PDG is an M-E based analytical software for pavement structural design analysis and performance prediction, within a given service period (AASHTO, 2008). The M-E PDG design procedure is primarily based on pavement performance predictions of increased levels of distress over time. Figure 7-1 shows a pictorial illustration of the M-E PDG Version 1.1 main screen.

Figure 7-1. The M-E PDG Software Main Screen.

However, unlike the FPS, the M-E PDG does not directly generate pavement layer thickness designs. Instead, trial pavement layer thicknesses/combinations are iteratively input into the software and the thicknesses/combinations that meet the prescribed performance criteria are selected as the final designs. The performance predictions include permanent deformation, rutting, cracking (bottom-up and top-down), thermal fracture, and surface roughness (IRI).

The M-E PDG adapts the following two major aspects of M-E based material characterization, pavement response properties and major distress/transfer functions:

- Pavement response properties are required to predict states of stress, strain, and deformation within the pavement structure when subjected to external wheel loads and thermal stresses. The properties for assumed elastic material behavior are the elastic modulus and Poisson's ratio.
- The major M-E PDG distress/transfer functions for asphalt pavements are load-related fatigue fracture, permanent deformation, rutting, and thermal cracking.

As discussed in the subsequent text, Figure 7-2 shows a detailed step-by-step organizational map of the M-E PDG system including the input and output data.

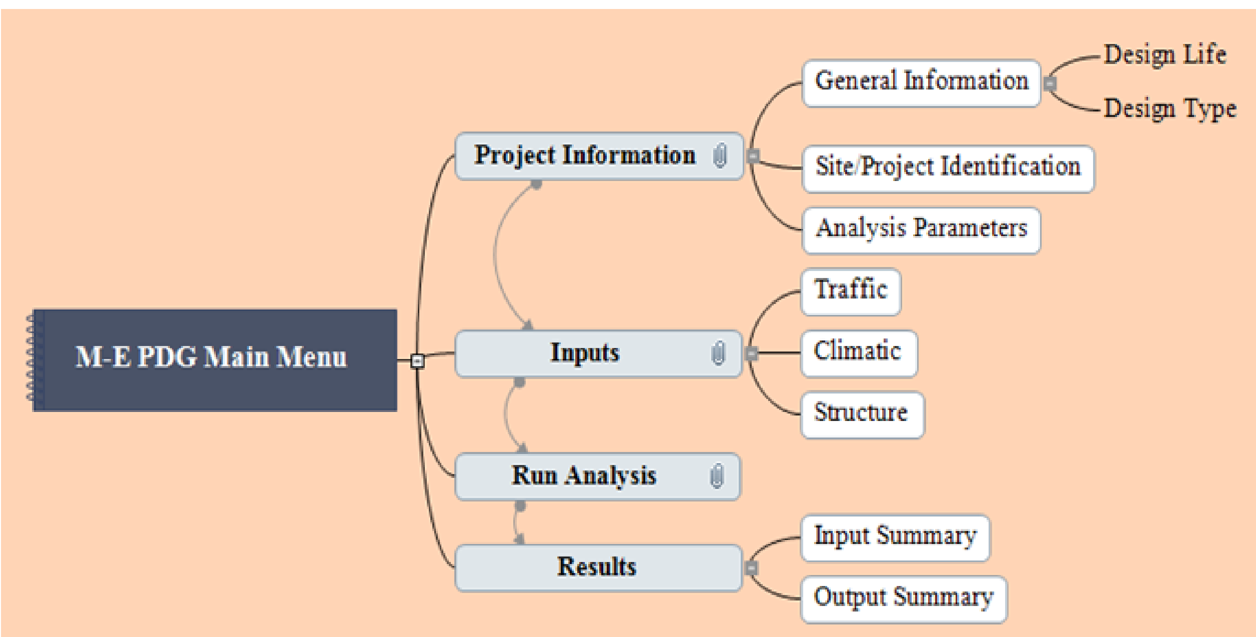


Figure 7-2. Organizational Map for the M-E PDG Software.

BASIC M-E PDG INPUT DATA

In terms of the input data, the M-E PDG utilizes a hierarchical system for both material characterization and analysis (AASHTO, 2008). This system has three material property input levels. Level 1 represents a design philosophy of the highest achievable reliability, and Levels 2 and 3 have successively lower reliability, respectively. In addition to the typical volumetrics, Level 1 input requires laboratory-measured binder and asphalt mixture properties such as the shear and dynamic modulus, respectively, whereas Level 3 input requires only the PG binder grade and aggregate gradation characteristics. Level 2 utilizes measured binder shear modulus properties and aggregate gradation characteristics.

The full M-E PDG input data along with the DSS location details are listed in Appendix F (Walubita et al., 2011; 2012). As shown in both Figure 7-2 and Appendix E, the basic M-E PDG input data include the general project information, traffic, climate (environment), pavement structure and material properties, distress failure limits, pavement design life, and a design reliability level (AASHTO, 2008).

RUNNING THE M-E PDG SOFTWARE

The M-E PDG software has the capability to handle multiple layers over a 50-year analysis period, which makes it appropriate for designing and analyzing perpetual pavements. Depending on the pavement design type and input data, the M-E PDG run time can range from 25 minutes to over 1 hour; however, the M-E PDG run time for a given project also depends on the computer processing speed/capability. A detailed step-by-step demonstration for running the M-E PDG software (using the DSS) is included as PPT slides in the accompanying CD.

BASIC M-E PDG OUTPUT DATA

During execution, the M-E PDG software predicts performance at any age of the pavement for a given pavement structure and traffic level under a particular environmental location (AASHTO, 2008). The M-E PDG predicted performance is then matched against predefined performance criteria at a given reliability level and design life.

The basic M-E PDG output data (typically plotted as a function of time) include pavement rutting, cracking, roughness (IRI), etc.; see example in Figure 7-3 for test section

TxDOT_TTI-00001 (US 59, ATL). Full details of the M-E PDG input data along with some graphical example results are listed in Appendix E (Walubita et al., 2011; 2012).

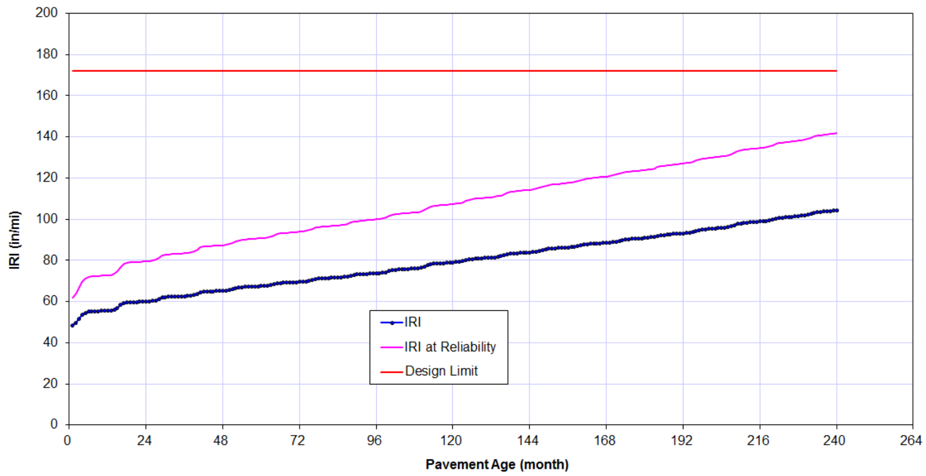


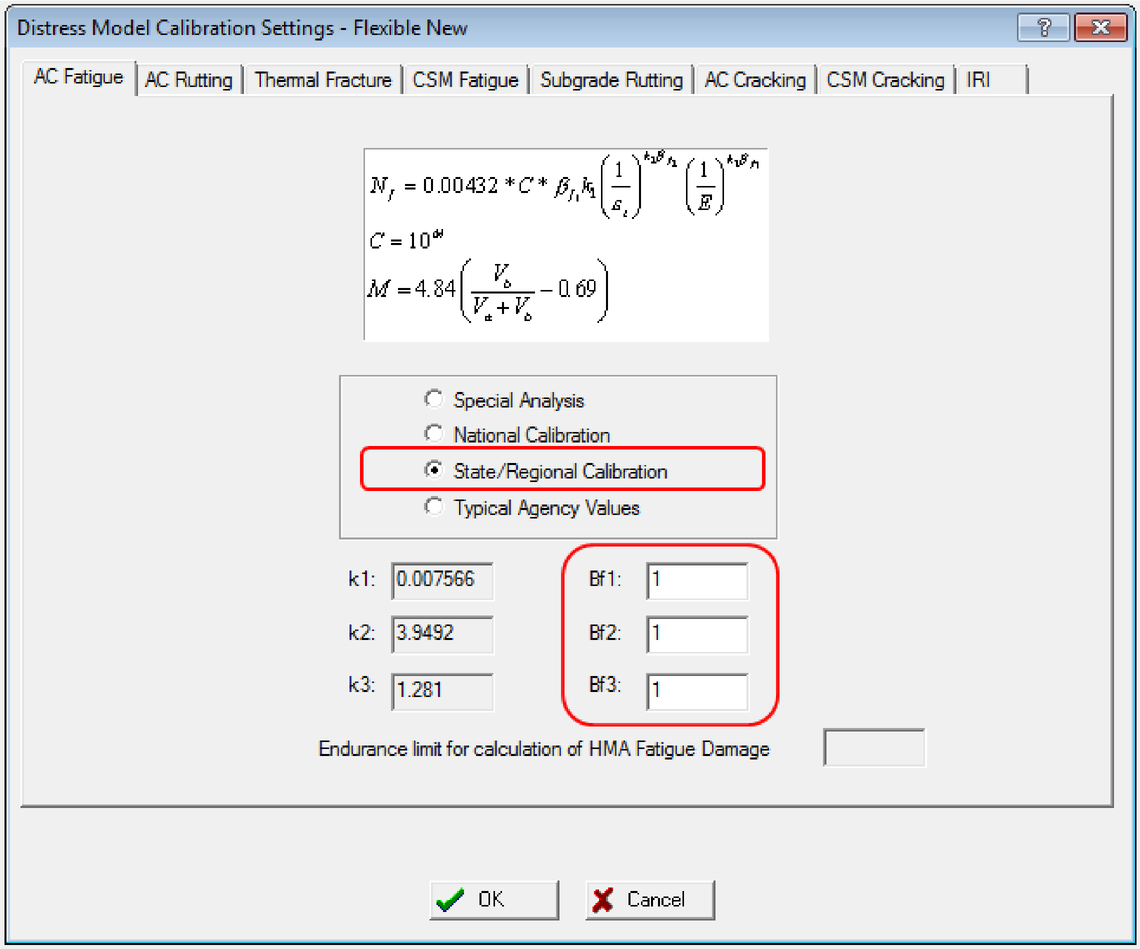
Figure 7-3. M-E PDG Roughness (IRI) Analysis for TxDOT_TTI-00001 (US 59, ATL).

KEY M-E PDG MODELS TO BE CALIBRATED AND VALIDATED

A comprehensive iterative and sensitivity analysis will be required to successfully calibrate and validate the M-E PDG models; essentially to develop "Local State or Regional" calibration factors as opposed to the default built-in "National" calibration factors. Similar to the TxM-E, the M-E PDG has numerous M-E models that need to be calibrated to Texas location conditions. Accessed through the "Tools" and "Calibration Settings" functions in the M-E PDG software, M-E distress models whose calibration factors need to be verified and/or modified include the following:

- Rutting (AC [HMA], base, subgrade, etc.).
- Cracking (fatigue, thermal, bottom-up, top-down, reflective, CSM, etc.).
- Thermal fracture.
- Fatigue (CSM).
- IRI, etc.

As an example, Figure 7-4 shows the M-E distress models to be calibrated with respect to a "New Flexible Pavement." Similar distress models exist for flexible rehab and rigid pavements.



$$N_f = 0.00432 * C * \beta_{f1} k_1 \left(\frac{1}{\varepsilon_t}\right)^{k_2 \beta_{f2}} \left(\frac{1}{E}\right)^{k_3 \beta_{f3}}$$

$$C = 10^M$$

$$M = 4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right)$$

Figure 7-4. Example of the M-E PDG AC Fatigue Distress Model to be Calibrated.

Using the DSS data, the calibration of the M-E PDG AC distress fatigue model (for instance) in Figure 7-4 will entail developing local "State/Regional Calibration" factors, namely Bf1, Bf2, and Bf3. A similar iterative and sensitivity analysis approach will be conducted for all the other M-E PDG distress models to develop local "State/Regional Calibration" factors by way of correlating the M-E PDG distress predictions to actual measured field performance data in the DSS. However, note that this study is only limited to flexible pavements and/or AC overlays over concrete pavements; see distress models for flexible rehab pavement in Figure 7-5.

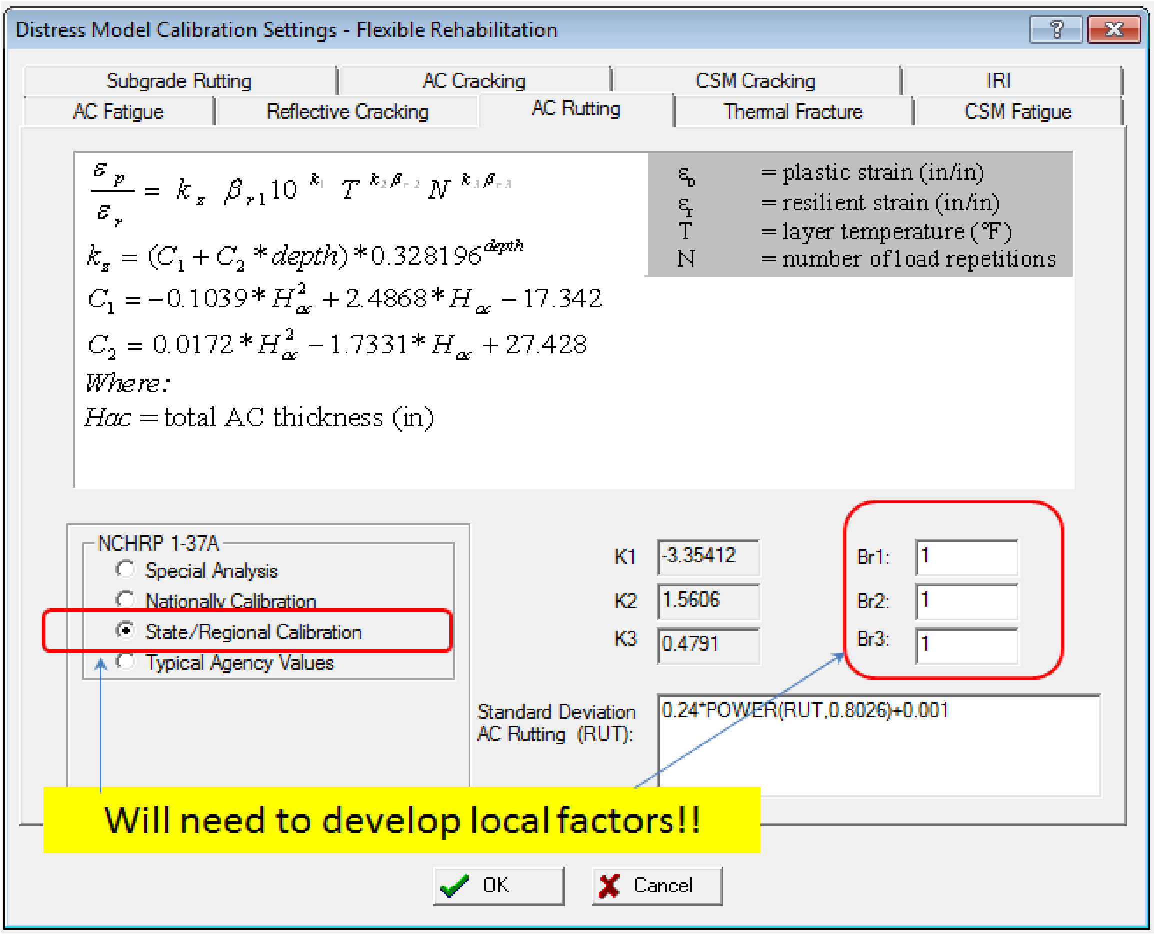


Figure 7-5. Example M-E PDG Distress Models to be Calibrated for Flexible Rehab Pavements.

CANDIDATE TEST SECTIONS FOR CALIBRATING AND VALIDATING THE M-E PDG

As outlined in Chapters 2 and 3, actual field data from the Project 0-6658 DSS will be used to calibrate and validate the M-E PDG models. The DSS contains a substantial number of Hwy test sections from all climatic regions of Texas, with a wide range of field performance, traffic, and laboratory test data; thus providing a very perfect data pool for this kind of a study. In addition, the test sections in the DSS consist of a variety of PVMNT structures as well as construction data that are ideal for calibrating the M-E models.

Table 7-1 lists some of the DSS candidate test sections earmarked for the calibration and validation of the M-E PDG models and associated software.

Table 7-1. Candidate DSS Test Sections for Calibrating and Validating the M-E PDG.

#	DSS Section ID	Hwy	PVMNT Type	Climatic Region	District	County
1	TxDOT_TTI-00001	US 59	Overlay-HMA-LTB	Wet-Cold	Atlanta	Panola
2	TxDOT_TTI-00005	Loop 480	New Construction	Dry-Warm	Laredo	Maverick
3	TxDOT_TTI-00006	SH 121	Overlay-HMA-CTB	Wet-Cold	Paris	Fannin
4	TxDOT_TTI-00002	SH 114	Perpetual	Wet-Cold	Fort Worth	Wise
5	TxDOT_TTI-00003	SH 114	Perpetual	Wet-Cold	Fort Worth	Wise
6	TxDOT_TTI-00032	US 277	New Construction	Wet-Cold	Wichita Falls	Baylor
7	TxDOT_TTI-00015	SH 21	New Construction	Wet-warm	Bryan	Brazos
8	TxDOT_TTI-00009	IH 35	New Construction	Moderate	Waco	Bell
9	TxDOT_TTI-00006	US 271	Overlay-HMA-PCC	Wet-Cold	Paris	Lamar
10	TxDOT_TTI-00025	US 181	Overlay-HMA-LTB	Moderate	Corpus Christi	Nueces

EXAMPLE M-E PDG RUNS USING THE PROJECT 0-6658 DSS DATA

To demonstrate the use of the Project 0-6658 DSS for running the M-E PDG software, the researchers evaluated test section TxDOT_TTI-00001 (US 59, ATL) from the DSS. The input data file and DSS data source location are listed in Appendix E. Where these data were unavailable in the DSS, the researchers used default values or otherwise simply assumed. The results and performance predictions of the M-E PDG analysis of TxDOT_TTI-00001 are shown in Figure 7-6 through 7-10.

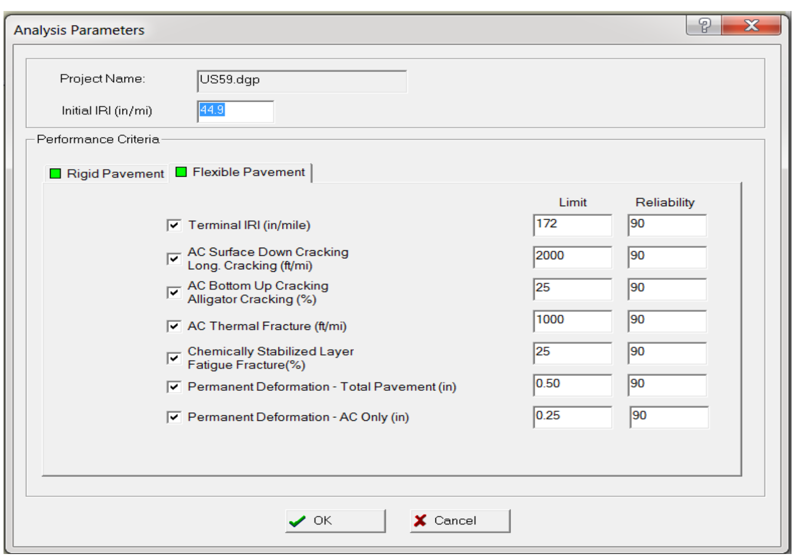


Figure 7-6. M-E PDG Analysis Parameters for TxDOT_TTI-00001 (US 59, ATL).

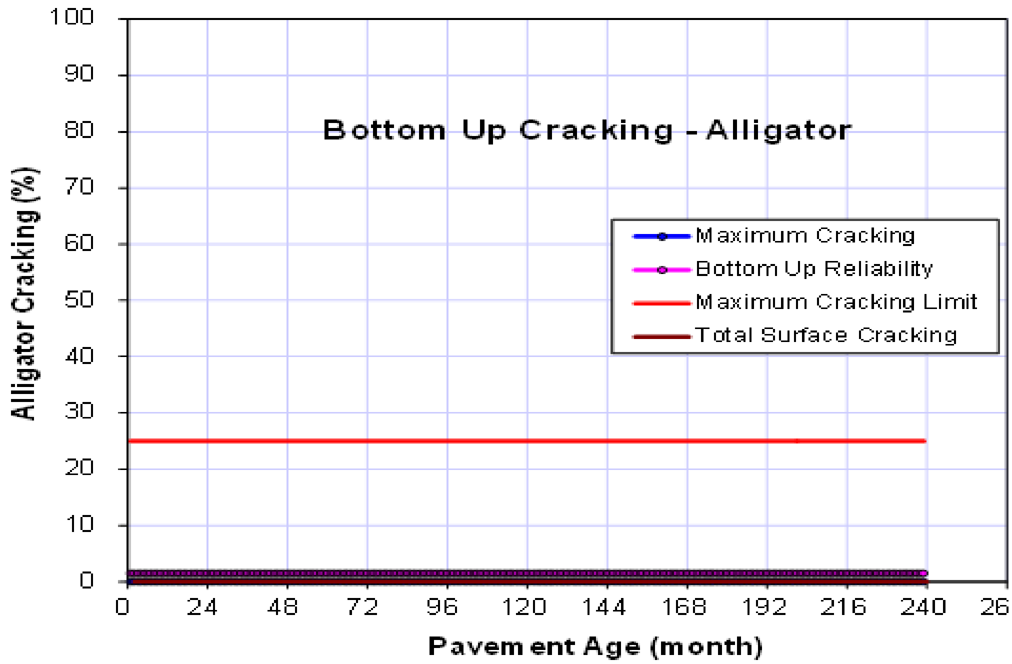


Figure 7-7. M-E PDG Alligator Cracking for TxDOT_TTI-00001 (US 59, ATL).

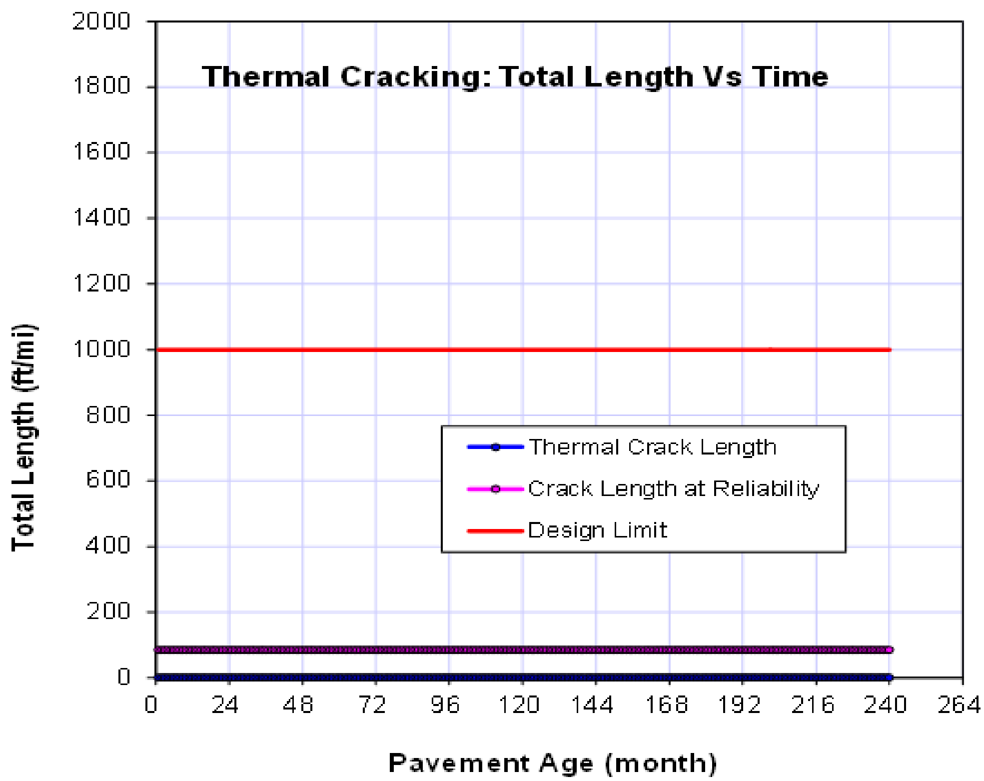


Figure 7-8. M-E PDG Thermal Cracking for TxDOT_TTI-00001 (US 59, ATL).

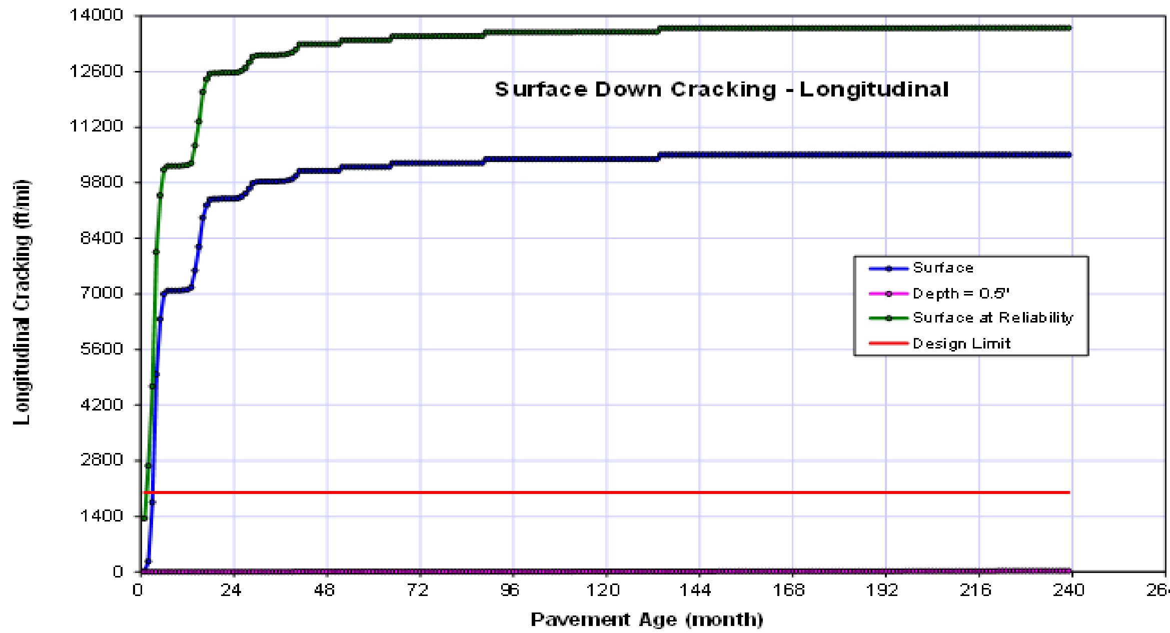


Figure 7-9. M-E PDG Longitudinal Cracking for TxDOT_TTI-00001 (US 59, ATL).

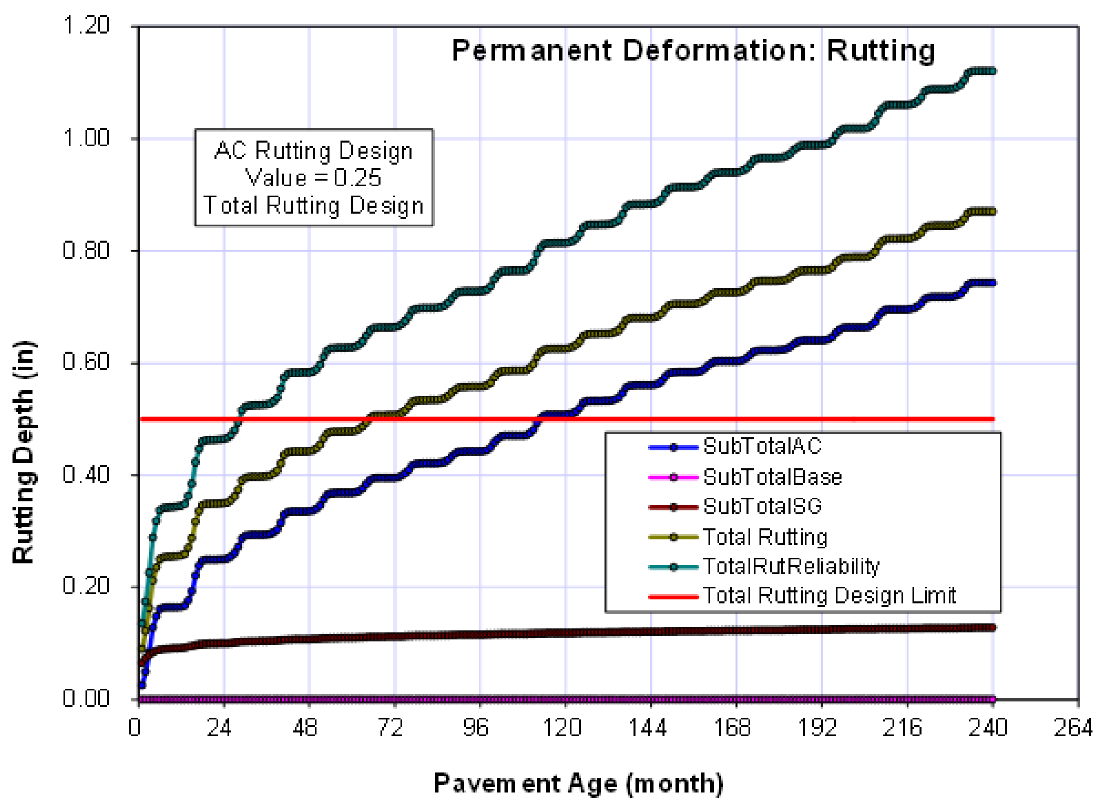


Figure 7-10. M-E PDG Rutting for TxDOT_TTI-00001 (US 59, ATL).

As noted in Figure 7-6 through 7-10, the M-E PDG analytically predicts performance and graphs the respective distresses as a function of pavement age in terms of time (months). These graphs allows for easy visual analysis of the results. From the M-E PDG plots (Figure 7-6 through 7-10), the following can be inferred about TxDOT_TTI-00001 (US 59, ATL):

- The initial IRI (44.90 inches/mi) indicated in Figure 7-6 is the actual IRI obtained from the DSS that these researchers had physically measured just after construction. This test section (US 59) has now been in service for 21 months at the time of this report. The M-E PDG predicted IRI at 24 months in Figure 7-3 is 55 inches/mi while it is 48 inches/mi in the field as indicated in the DSS. Although there is a need to analyze more test sections, this may indicate the need to calibrate the IRI model or recheck the input data, particularly the traffic load spectra data.
- Figures 7-7 and 7-8 show no evidence of alligator or thermal cracking, which is consistent with the field observations as of the time of this report; see the subsequent Figure 7-11 (no cracking). This also correlates with the laboratory test data in the DSS.
- However, Figures 7-9 and 7-10 are a cause for concern as the M-E PDG predictions do not match the actual field performance measurements. Figure 7-9 indicates longitudinal (surface-down) cracking just after 2 months of service. The test section has been in service for 21 months and as shown in the subsequent Figure 7-11, there is no visible cracking on this test section. Furthermore, the lab test data as contained in the DSS shows the surfacing HMA mix with a crack life of 255 OT cycles used on this test section has sufficient cracking resistance and satisfactorily met the minimum 150 OT cycles proposed for Type D mixes (Walubita et al., 2012b). While more test sections need to be evaluated, this discrepancy may suggest either of the following:
  - Review and check the input data, particularly the traffic load spectra data.
  - Calibrate the surface-down cracking models (i.e., develop local state/regional calibration factors).
  - Review and modify the analysis parameter (see Figure 7-6).
- Similarly, Figure 7-10 shows a predicted total rutting of about 0.35 inches in the second year of service (22 months). However, the measured surface rutting in the field was only 0.101 inches after 21 months of service. Laboratory HWTT rutting data in the DSS also indicates that the Type D surfacing mix used on this test

section has sufficient rutting resistance, i.e., 4.3 mm HWTT rut depth versus the 12.5 mm threshold. Therefore, while analyzing more test sections and rechecking the input data (e.g., traffic load spectra data) is imperative, there may be a need to review some of the calibration factors.

Figure 7-11. TxDOT_TTI-0001 (US 59, ATL) after 21 Months of Service (No Visual Distresses).

Overall, the above demonstration example provides evidence that the Project 0-6658 DSS has the potential to be used to run and calibrate the M-E PDG models. However, while the need for evaluating more test sections with long-term performance data is inevitable, the discrepancies noted between the M-E PDG predictions versus actual field and lab test data for some distresses suggest the following:

- Caution with the input data entry into the M-E PDG. It is imperative that accurate input data is used.
- Development of local state/regional calibration factors for the distress models in question. As such, a comprehensive iterative and sensitivity analysis will be imperative.
- Review and modification of the analysis parameters and design limits where applicable.

- Rechecking the input data, particularly the traffic load spectra data. Nonetheless, the M-E PDG analysis will need to be rerun once more accurate traffic load spectra data is generated from the ongoing cluster analysis.

CHALLENGES AND LIMITATIONS – THE DSS AND THE M-E PDG SOFTWARE

As noted in the preceding discussion, the Project 0-6658 DSS has exhibited potential to be used to run and calibrate the M-E PDG models. However, these data from the DSS currently have to be entered manually into the M-E PDG; which is rather a tedious and cumbersome process. Due to the differences in the platform media, there is no provision for automated exporting of the data from the DSS to the M-E PDG software. Therefore, a key challenge is for these researchers to develop a bridging platform for directly exporting the data from the DSS into the M-E PDG. In addition to maximizing efficiency, this will also ensure that accurate data from the DSS are automatically exported into the M-E PDG without the likelihood of human error during manual entry.

Like any other data storage system, the DSS data content does not totally meet the M-E PDG data requirements; so some input values will have to be assumed or default values used. However, efforts have been made to ensure that all the critical M-E PDG input data are available and can be accessed from the DSS.

Additionally, one of the major challenges to be addressed with respect to the TxM-E and M-E PDG software is the traffic load spectra data, which is currently unavailable in the DSS. Presently, these researchers are working on means to generate and include these critical data that are unavailable in the current DSS version, namely:

- Traffic data – from both traffic tube counters and the ongoing cluster analysis.
    - Monthly adjustment factor.
    - Hourly distribution (to be computed from the traffic tube data).
    - Axle factors by axle type (load spectra analysis).
    - Mean wheel location, traffic wander standard deviation, number of axles/truck (load spectra analysis).
    - Average axle width, dual tire spacing, tire pressure, axle spacing.
- Asphalt-binder and HMA properties of existing pavement structures (in case of overlay or rehab sections).

SUMMARY

This chapter presented and discussed an overview of the M-E PDG software along with the proposed calibration plans and usage of the Project 0-6658 DSS, specifically addressing the following key aspects.

- M-E models to be checked for calibration including rutting, cracking, fracture, and IRI models.
- The calibration factors (coefficients) to be checked, modified, and/or developed through comprehensive iterative and sensitivity analyses; specifically to develop local state/regional calibration factors.
- Running the M-E PDG software using the DSS, including DSS data sources and location.
- M-E PDG demonstration example using one of the DSS data and test sections.
- Correlation between the M-E PDG analysis predictions and the DSS data (both lab and field).

Overall, this chapter has demonstrated and proved that the DSS can satisfactorily be used to run the M-E PDG software, albeit there is still a challenge to populate it with more data and also, if possible, to automate the data exporting process from the DSS. Although there is some data limitation with the current DSS versions, the format and structure has sufficient useful data to successfully run and calibrate the M-E PDG models and associated software. Presently, these researchers are involved in extensive cluster analysis to generate traffic load spectra data for each test section, for subsequent input into the DSS.

Some PPT slides (including input and output M-E PDG files) demonstrating how to run the M-E PDG using the DSS and its data content are included in the accompanying CD.

CHAPTER 8: M-E MODEL COMPARISONS RELATIVE TO FIELD AND LABORATORY DATA

Four M-E models and related software—namely FPS, TxACOL, TxM-E, and M-E PDG—were discussed in the preceding chapters of this report. To summarize: this chapter compares these M-E models and associated software relative to field and laboratory data, primarily addressing the following aspects:

- M-E model performance predictions and correlation with field and laboratory data.
- M-E model accuracy in relating to field performance data.
- Software comparisons in terms of user-friendliness, capabilities, and applications.

Using the Project 0-6658 DSS as the data source, these researchers will routinely conduct these comparative evaluations of the M-E models and related software as an integral part of the ongoing calibration and validation processes. To illustrate: some examples are demonstrated in this chapter, namely for the following three test sections: 1) TxDOT_TTI-00001, 2) TxDOT_TTI-00002, and 3) TxDOT_TTI-00003.

As discussed in the subsequent sections of this chapter, the M-E model and software performance predictions for the above test sections have been compared with and correlated to the actual measured field performance data in the DSS; which is also supplemented with laboratory test data. A side-by-side comparison of the software is also presented to highlight their merits and demerits. A summary of key findings and recommendations then wraps up the chapter.

TEST SECTION TXDOT_TTI-00001 (US 59, ATL)

As a demonstration example, Figure 8-1 through 8-3 show a comparative plot of the rutting, cracking, and IRI results for test section TxDOT_TTI-00001 (US 59, ATL) from the preceding Chapters 4, 5, and 7. Additional input data for these analyses can be found in the DSS that is included in the accompanying CD in the sleeve at the back of this interim report. The figures are analyzed and discussed in the subsequent text.

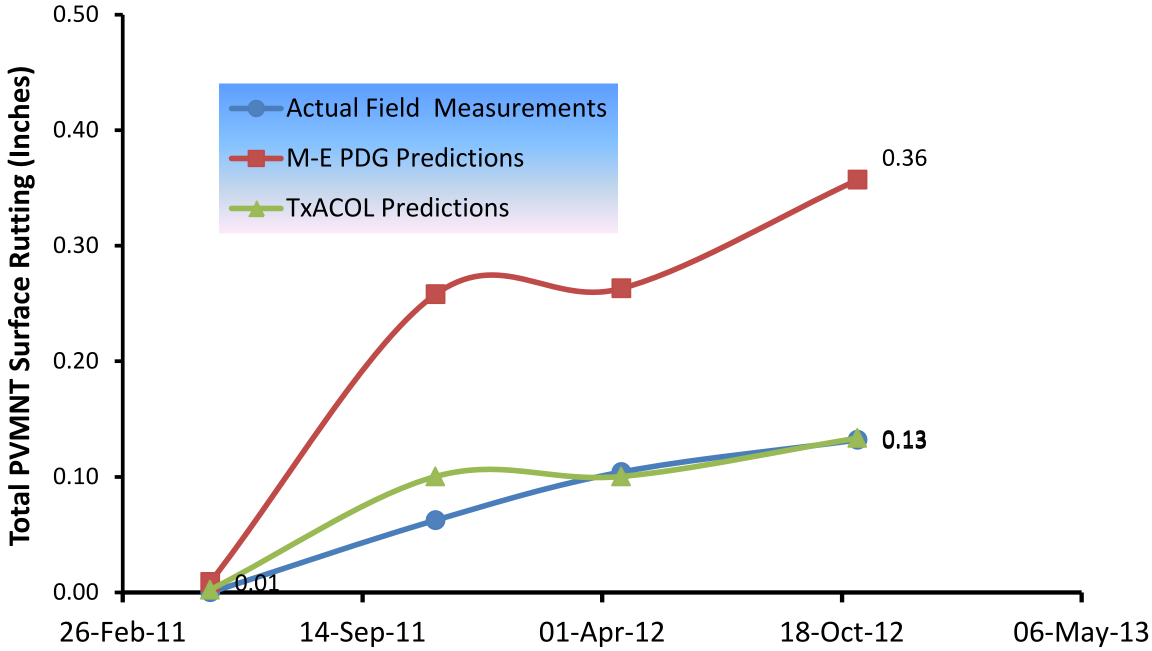


Figure 8-1. Comparison of Surface Rutting Results (TxDOT_TTI-00001).

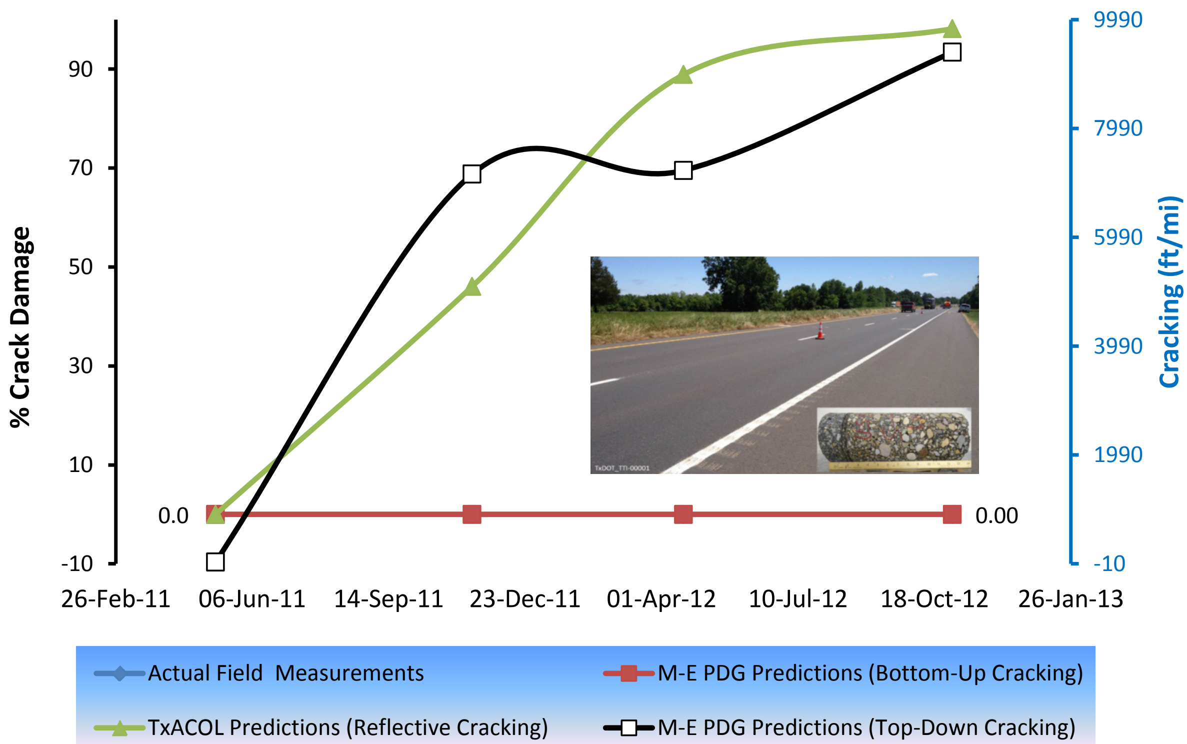


Figure 8-2. Comparison of Cracking Results (TxDOT_TTI-00001).

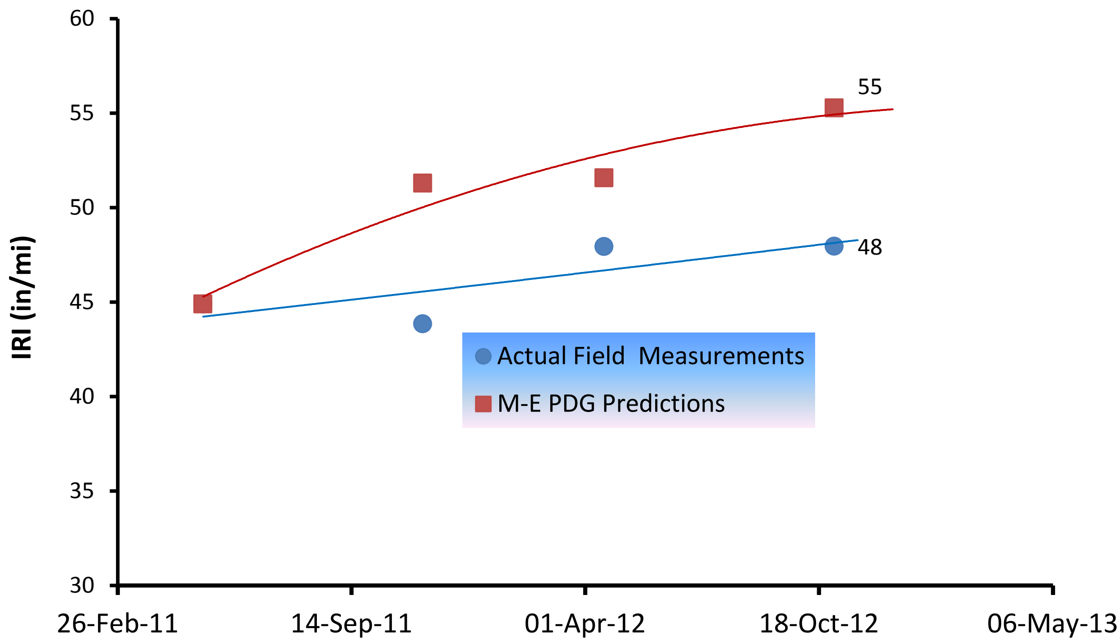


Figure 8-3. Comparison of IRI Results (TxDOT_TTI-00001).

At the time of this report, TxDOT_TTI-00001 had been in service for almost 2 years (i.e., 21 months). By looking at Figure 8-1 through 8-3 compared with Figure 7-11, one can infer the following:

- The M-E PDG total surface rutting predictions in Figure 8-1 does not correlate with the actual field measured surface rutting. While the TxACOL prediction acceptably matches and correlates to the actual field measured values, the M-E PDG is significantly way off. This is not surprising because the M-E PDG has not yet been calibrated to local Texas conditions, whereas TxACOL is locally developed software. These results emphasize the need to calibrate the M-E PDG rutting models using the DSS data or otherwise recheck the input data, particularly with respect to traffic load spectra data. The analysis will need to be rerun in the future once site specific traffic load spectra data is generated from the ongoing cluster analysis.
- In Figure 8-2, the M-E PDG predicted no evidence of bottom-up cracking, which is consistent with actual field observations at the time of this report. By contrast, however, the M-E PDG and TxACOL shows evidence for the likely occurrence of top down and reflective cracking, respectively, within the test section's first 21 months of service. Although more long-term performance data are still needed, Figure 7-11 may suggest

the need to review the calibrations factors for the TxACOL reflective and M-E PDG top-down cracking models, respectively, or otherwise recheck the input data (particularly traffic data) and where necessary, rerun the software once more accurate data has been gathered from the ongoing measurements and data analyses.

- On the other hand, Figure 8-3 suggests that a slight modification in the IRI calibration factors may be needed to match the M-E PDG predictions to the actual measured IRI values. However, analyzing more test sections and using more accurate traffic load spectra data is imperative before such a modification can be implemented.

As demonstrated in Chapter 4, the FPS predicted satisfactory performance with no indication of potential rutting or cracking problems. Laboratory test results as contained in the DSS also did not capture any potential rutting or cracking problems in the Type D surfacing mix used for test section TxDOT_TTI-00001 (US 59):

- HWTT rutting = 4.3 mm (less the 12.5 mm threshold).
- OT cracking = 255 cycles (greater than the minimum 150 proposed for Type D mixes) (Walubita et al., 2012b).

In practice, however, one or two maintenance activities would be required within the 20-year design life of the pavement. Therefore, sufficient long-term field performance data along with more test sections are strongly needed to aid in the satisfactory calibration of the M-E models. To ensure confidence and reliability in the calibration process, it is recommended to have at minimum 5 years' worth of field performance data for each test section. Also, more accurate traffic data (18 kips ESALs, load spectra, etc.) need be generated to ensure accurate predictions by the software.

TEST SECTION TXDOT_TTI-00002 (SH 114, FTW)

Although more long-term field performance data is warranted, the M-E PDG results in the subsequent Figure 8-3 through 8-6 may suggest the need to review and develop local calibration factors for the M-E PDG rutting and IRI models. Input data for these analyses were sourced from the DSS, which is included in the accompanying CD of this interim report. As shown in Figure 8-3 and 8-6, both the M-E PDG rutting and IRI performance predictions do not match the actual field measurements. However, input data, particularly traffic load spectra data, could be a contributing factor. Therefore, the analysis will have to be rerun once more accurate load spectra data is generated.

Consistent with field observations as of December 2012, the M-E PDG predicted no cracking on this test section (Figure 8-5), which is also in agreement with the FPS analyses and laboratory test predictions discussed in Chapter 4. Test section TxDOT_TTI-00002 had been in service for at least 7 years at the time of this report and, to date, still exhibits satisfactory performance with no visible distresses (see Figures 4-12 and 8-5).

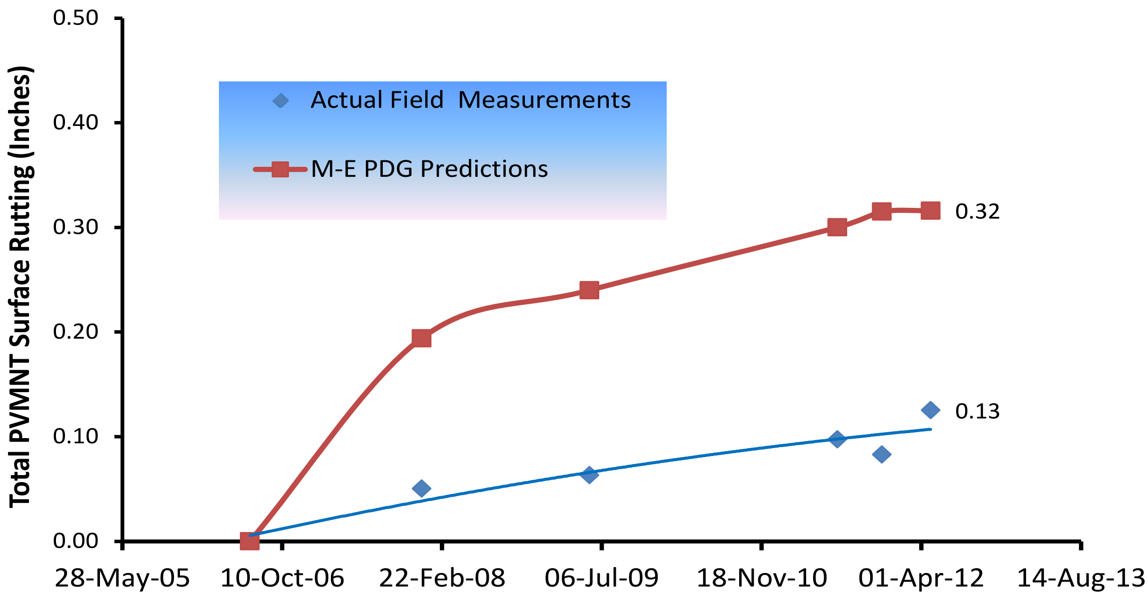


Figure 8-4. Comparison of Rutting Results (TxDOT_TTI-00002).

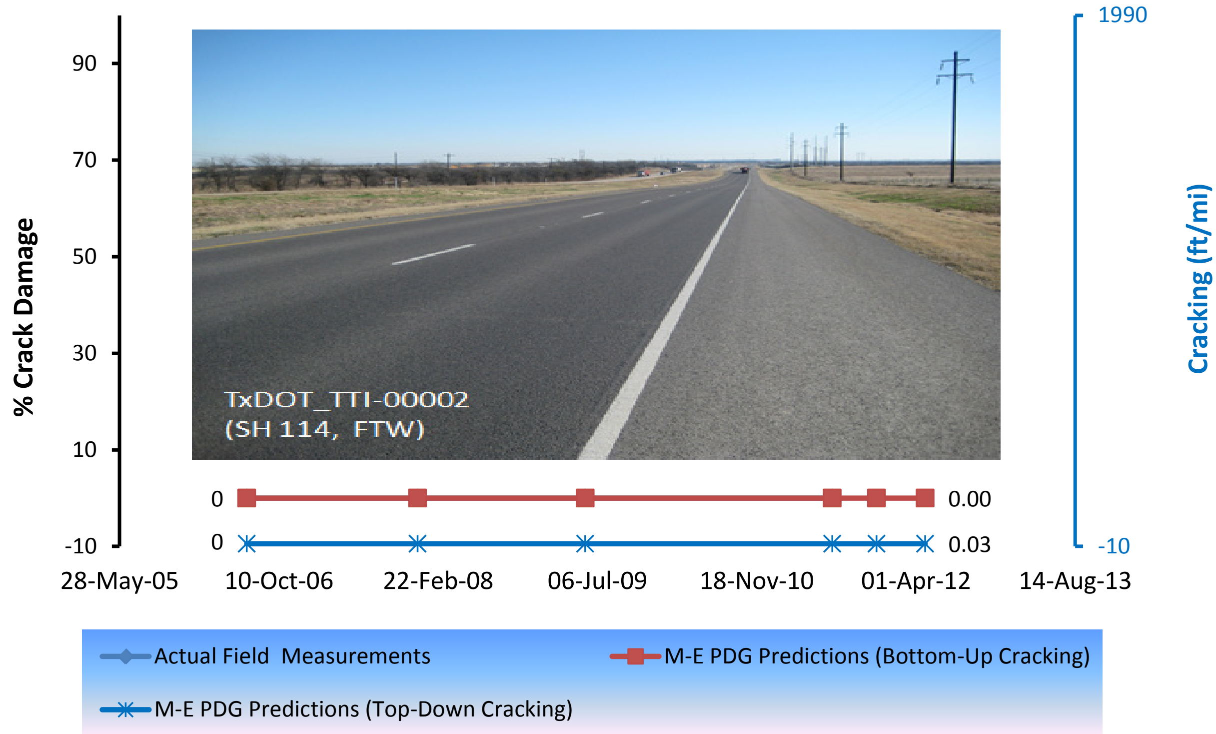


Figure 8-5. Comparison of Cracking Results (TxDOT_TTI-00002).

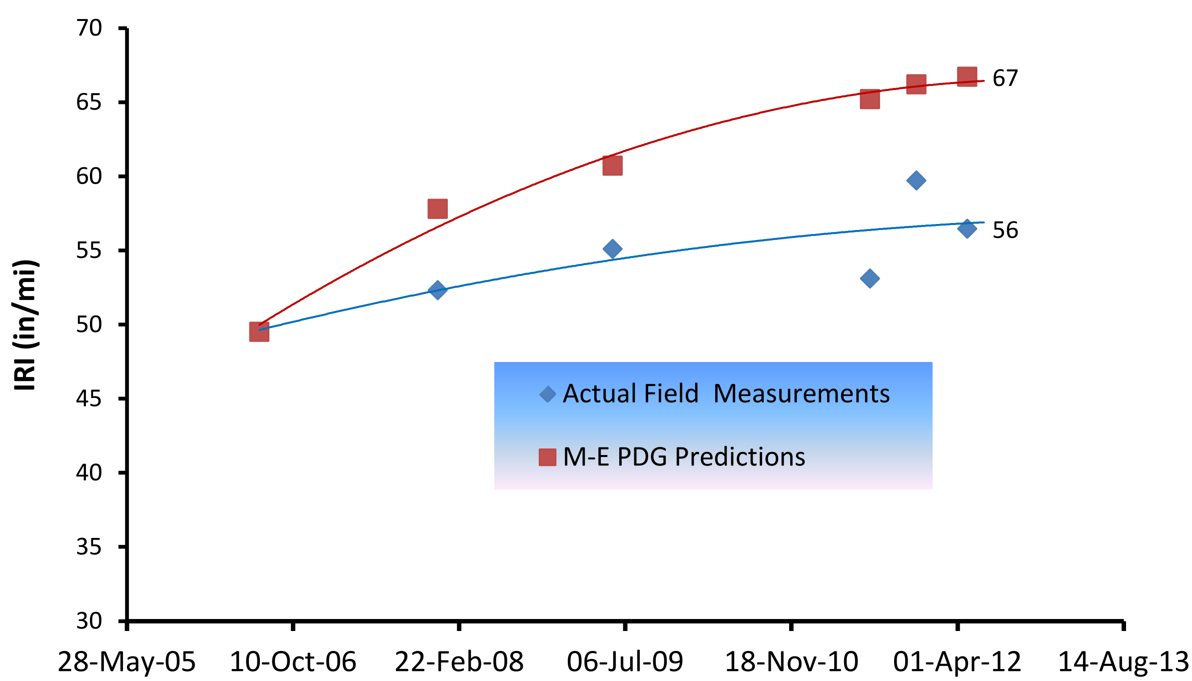


Figure 8-6. Comparison of IRI Results (TxDOT_TTI-00002).

TEST SECTION TXDOT_TTI-00003 (SH 114, FTW)

Consistent with field performance measurements as at the time of this report, both the FPS analyses and the laboratory test data shown in Chapter 4 predicted satisfactory performance for this test section (see Figures 4-12 and 8-8). That is, both the FPS and the lab test data contained in the DSS did not detect any propensity for performance issues on this test section.

Like the preceding examples, Figures 8-7 and 8-9 suggest the need to review and develop local calibration factors for the M-E PDG rutting and IRI models. The M-E PDG analytical predictions do not match the actual field measurements for rutting and roughness (IRI). Input data, particularly traffic load spectra data, could be a contributing factor. Therefore, the analysis will have to be rerun once more accurate load spectra data is generated.

However, Figure 8-8 shows zero likelihood for serious cracking problems on this test section, which is also consistent with the observed field performance. Input data for these analyses were sourced from the DSS, which is included in the accompanying CD of this interim report.

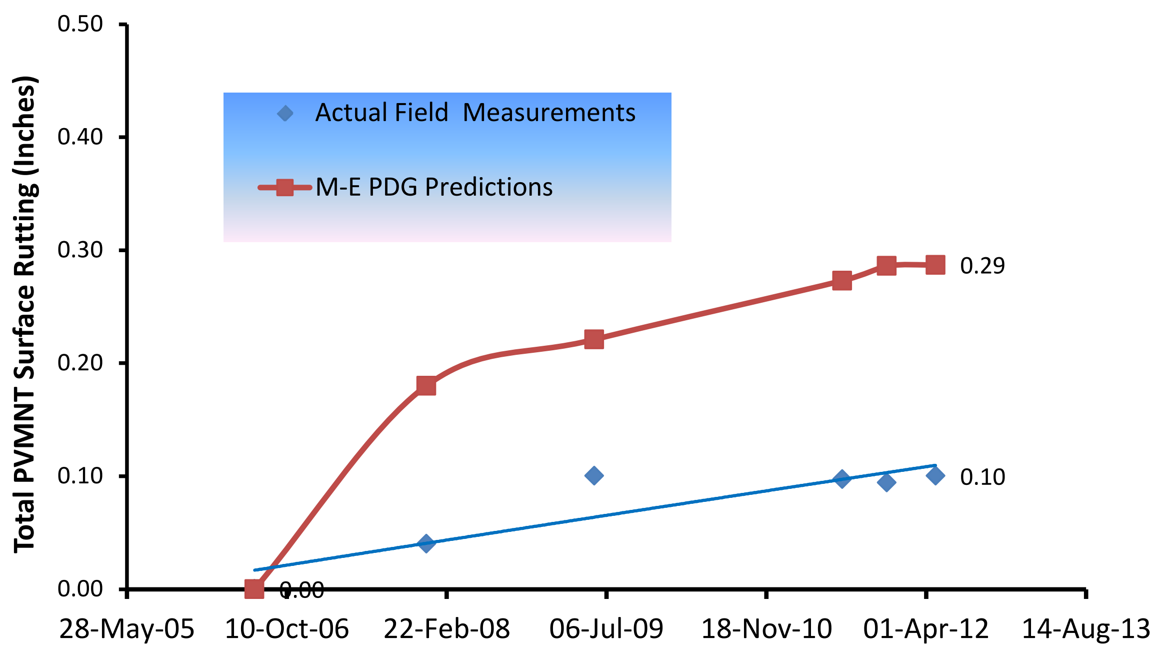


Figure 8-7. Comparison of Rutting Results (TxDOT_TTI-00003).

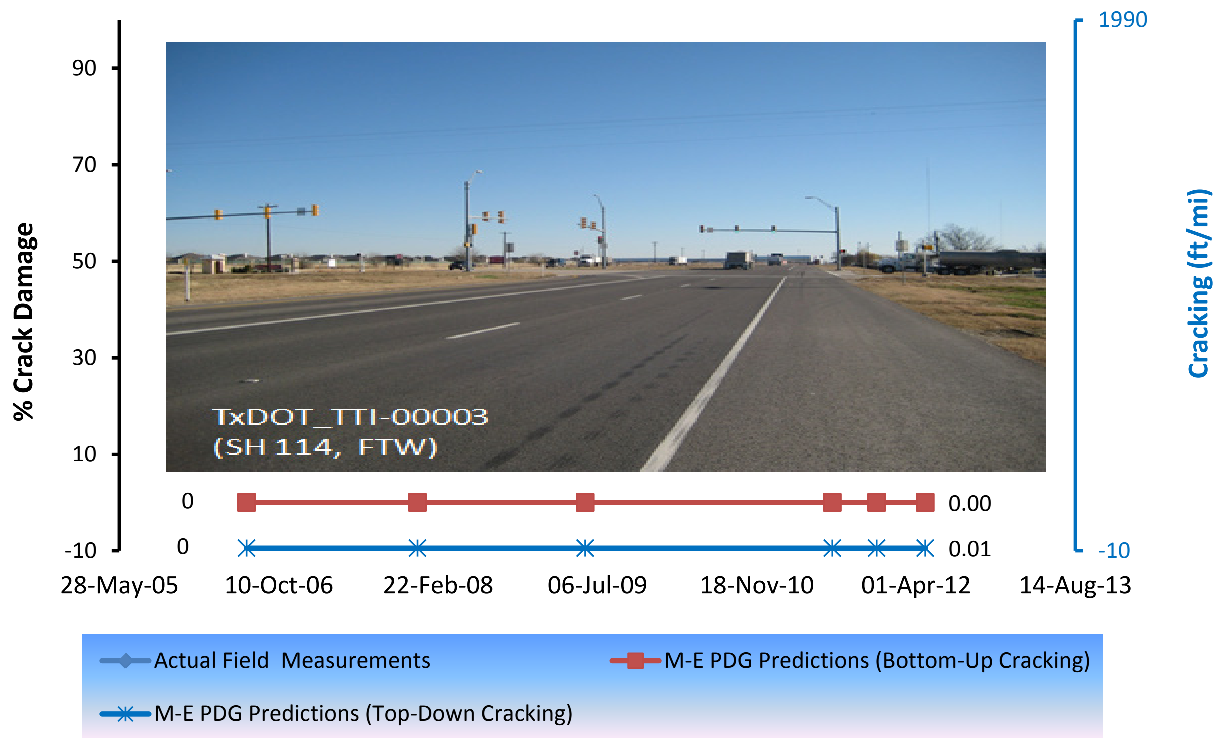


Figure 8-8. Comparison of Cracking Results (TxDOT_TTI-00003).

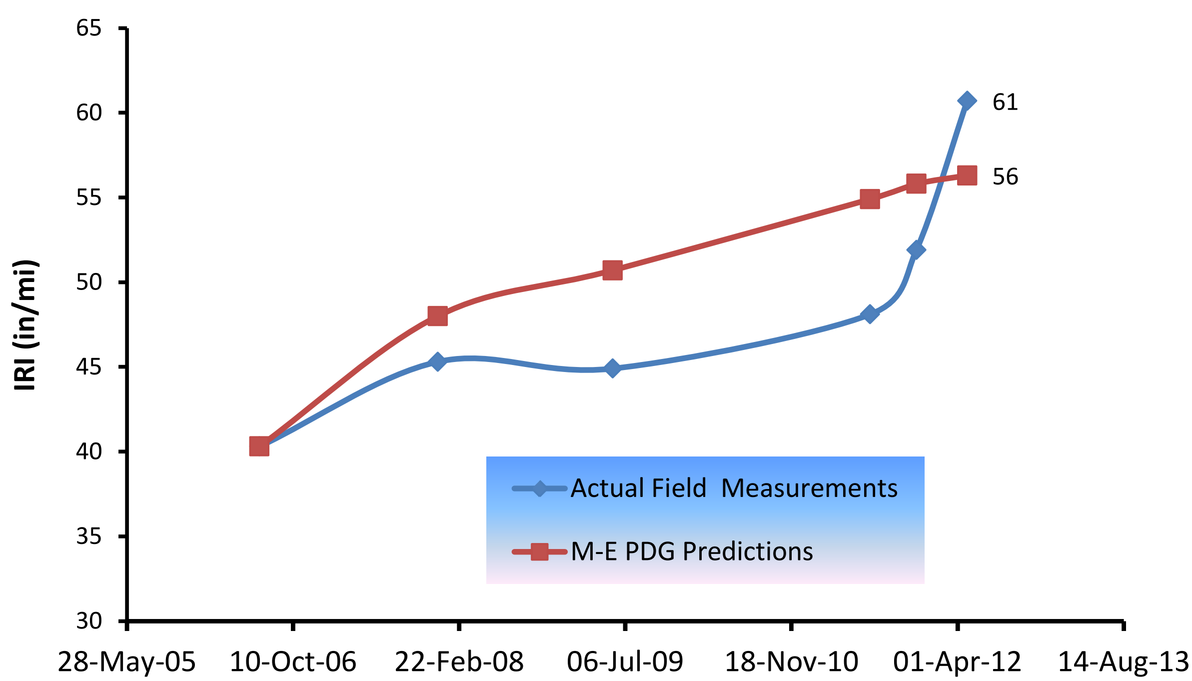


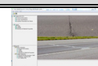
Figure 8-9. Comparison of IRI Results (TxDOT_TTI-00003).

SOFTWARE COMPARISONS – CHALLENGES AND LIMITATIONS

A comprehensive comparative evaluation of the software was also completed and the corresponding comparisons are summarized in Table 8-1. These software packages including step-by-step PPT instructions on how to run them using the DSS are contained in the accompanying CD. More details can be found elsewhere (Scullion et al., 2006; AASHTO, 2008; Zhou et al., 2008, 2009, 2010, 2011).

Table 8-2 provides a subjective comparison of the M-E models and related software based solely on the test sections evaluated in this study and on the authors' experience with these types of software.

Table 8-1. Software Comparisons.

Item	FPS 21W	TxACOL	TxM-E	M-E PDG
Icon			-	
Layer thickness design	Yes	Possible; but main purpose is design check!		
Alternative thickness designs (I.e., multiple design options)	Yes	Possible; but main purpose is design check!		
Layers	≤ 7	≤ 6 with a maximum of 2 AC overlay layers	-	> 7 with a maximum of 4 HMA layers
Input data	Simple	Simple	Comprehensive	Comprehensive
Output data	Alternative designs, performance life, & extensive structural analyses	Reflective cracking & rutting predictions as a function of time	Extensive performance analysis as function of time	Extensive performance analysis as function of time
Climatic consideration	Simple	Comprehensive	Comprehensive	Comprehensive
Analysis period	> 20 yrs	> 20 yrs	-	> 20 yrs
Stress-strain check	Yes	No	-	No
Performance analysis	Simple	Simple	-	Comprehensive
Extensive lab testing required	No (uses FWD data)	Yes (DM, RLPD tests), but has default values with no testing required	-	Yes (DSR & DM tests), but has Level 3 option with no testing required

Calibration necessary	Yes (Rutting & fatigue crack models)	Yes	Yes	Yes (All models need to be calibrated to Texas local conditions)
Running time	< 5 min	< 5 min	-	> 25 min
User-friendliness	Good	Good	-	Moderate
Applicability	Flexible HMA structures	AC overlay design and analysis	-	HMA & concrete structures including overlays, but not ideal for thin HMA surfaces (i.e., < 2 inches)

Table 8-2. Software Merits and Demerits.

Test	Advantages and Applications	Challenges and Limitations
FPS	– Simple to enter input parameters – Short running time (≤ 5 min.) – Flexible pavements – User friendly – PVMNT layer thickness design – Multiple design options – Cost analysis – Ideal for design analysis – Has default values for some input parameters	– Does not predict performance as a function of time – Not good for overlay designs or concrete pavements – Limited to two distresses only (rutting & fatigue cracking) – Not very good for distress analysis & performance predictions
TxACOL	– Simple to enter input parameters – Short running time (≤ 5 min.) – Possible to analyze single or double AC overlay layers – Support default values for material properties – Generating both tabular and graphical formats of performance prediction as a function of time – Support a function to calibrate performance models – Ideal for design check analysis	– Specifically developed for AC overlay design/analyses – Specifically developed for two main overlay distresses, namely reflective cracking & rutting – Need of extensive lab testing for highly accurate performance prediction, e.g., RLPD, etc. – Gives option to select only one main cracking distress on existing AC surface – cannot select multiple cracks – No option for AC overlay (s) over existing HMA over concrete; Use AC overlay (s) over existing HMA over CTB for simplicity – No cost analysis
TxM-E	– Generating both tabular and graphical formats of performance prediction as a function of time – Support a function to calibrate performance models – Ideal for design check analysis	– Need for extensive lab testing for Level 1 input data such as DM, etc (DSR data not necessary). – No cost analysis

M-E PDG	–Has default values for some input parameters –Generating both tabular and graphical formats of performance prediction –Predicts performance as a function of time –Support a function to calibrate performance models –Applicable for use at national level –Ideal for design check analysis	–Lengthy time to run depending on PVMNT design type & input data –Need for extensive lab testing for Level 1 input data such as DM, DSR, etc. –No cost analysis

SUMMARY

This chapter presented a preliminary comparative evaluation of the predictive potential of the M-E models/ software relative to actual field performance data. However, these were merely preliminary analyses with some input data such as traffic and material properties (i.e., HMA fracture parameters *A* and *n*) assumed or default values used. Therefore, the analyses presented in this chapter should not in any way be used to judge the capability, accuracy, and applicability of the M-E models and related software. The analyses was simply provided as an insight into how the M-E models will be calibrated/evaluated and related to field conditions once all the relevant data has been generated in the DSS. Consequently, more long-term performance data on numerous test sections will need to be evaluated during the calibration and validation processes. As such, it will be imperative to populate the DSS with a minimum of 5 years' field performance data for each test section including traffic load spectra data.

CHAPTER 9: SUMMARY AND RECOMMENDATIONS

As discussed in the preceding chapters, the primary objective of this interim report was to document and provide an outline of the work plans for calibrating the M-E models using the Project 0-6658 DSS, namely the following:

1) FPS.
2) TxACOL.
3) TxM-E.
4) M-E PDG.

This chapter summarizes and highlights the key points, major findings, and recommendations including the following:

THE CALIBRATION WORKPLANS

- Calibration of the M-E models and associated software will involve comprehensive iterative and sensitivity analysis to develop local calibration factors by matching analytical predictions with actual measured field performance data and supplemented with laboratory test data.
- Visual graphs (i.e., scatter plots) and statistical analysis tools such as t-tests, correlations, regressions, optimizations, ANOVA, Tukey's HSD, etc., will be used for comparing the model analytical predictions and actual measured values at three reliability levels (namely, 80, 90, and 95 percent). Thus, each calibration factor to be developed will also be associated with some degree of accuracy in terms of the reliability level and error tolerance or variance.
- A similar iterative and sensitivity analysis like for the calibration process will be adapted for the validation process, albeit that different test sections and data sets will be utilized.
- The scope of work will be limited only to developing calibration factors and, if needed, making recommendations for modifications to the M-E models and/or transfer functions and the associated software. Actual M-E model and/or software code modification is outside the scope of the study.

- The matrix plan for the calibration and validation processes will utilize a minimum of three variables per characteristic factor including PVMNT type and structure, material type, climatic and environmental type, traffic level, distress type, etc.

M-E MODELS AND THE PROJECT 0-6658 DSS

- Four M-E models and associated software—namely the FPS, TxACOL, TxM-E, and M-E PDG—are earmarked for calibration and validation in this study. This will be achieved through comprehensive iterative and sensitivity analyses to develop and recommend some calibration factors meeting the local Texas conditions and the actual measured field performance of the Hwy test sections.
- While all the other M-E models and related software are operational and accessible to these researchers, the TxM-E, which is assumed to similar to the M-E PDG, is still under development in Study 0-6622 and was not discussed in greater details in this interim report. Reference should instead be made to the work of Hu (2012a,b).
- Along with Study 0-6622, the Project 0-6658 DSS will be used as the data source for running and calibrating the M-E models and associated software. As evident in this interim report, the DSS structure and its data content that includes the following are sufficient to satisfactorily run and calibrate the M-E models and related software discussed in this interim report:
    - PVMNT structure data.
    - Construction data.
    - Laboratory tests and material property data.
    - Field tests and performance data.
    - Climatic data.
    - Traffic data.
- Example demonstrations for running the M-E software using data from the DSS were given and proved that both the DSS structural layout and data content are sufficient for undertaking these tasks albeit that the DSS still need to be continuously populated with more data. Step-by-step instructions for using the DSS and running the respective M-E software are included in the accompanying CD. A list of data types for each respective software and location in the DSS are included in the appendices of this interim report.

- Not discounting the deficiencies/inaccuracies in some of the input data (i.e., traffic, fracture parameters *A* and *n*, etc), the limited examples run with the respective software in this interim report suggested the need to modify some of the M-E calibration factors to match the Texas local conditions and the actual measured field performance of the Hwy test sections. However, more long-term performance data (that is also accurate and site specific) on numerous test sections are still needed to conduct comprehensive sensitivity analyses to reliably develop local calibration factors with acceptable confidence and accuracy.
- While it is acceptable that no data storage system will fully meet the input data requirements for each M-E model and associated software, one of the key challenges of the current version of the DSS is the need to develop a bridging platform for automatically exporting the data into the respective software. In the current setup, the data has to be entered manually into the respective software, which is a tedious and error-prone process. Therefore, these researchers will explore the possibilities of automating the data export from the DSS into the respective software.
- As an ongoing process, the DSS need to be continuously populated and updated with data including traffic load spectra data that will hopefully be generated from the ongoing cluster analysis.

COMPARISON OF THE M-E MODELS AND SOFTWARE

- Not discounting the deficiencies/inaccuracies in some of the input data (i.e., traffic, fracture parameters *A* and *n*, etc.), preliminary comparative evaluations of the software based on three test sections from the DSS suggested the need to calibrate some of the M-E models. However, more long-term performance data on numerous test sections will need to be evaluated during the calibration and validation processes.
- The DSS must be continuously populated with a minimum of 5 years' field performance data for each test section. This is a very critical aspect to ensure an acceptable level of reliability and confidence in the local calibration factors to be developed and recommended for the respective M-E models and related software.
- However, it should be emphasized that the analyses presented in this interim report were preliminary and should not be used to judge the capability, accuracy, and/or applicability

of the M-E models and related software. The intent was merely to outline the proposed calibration work plans and demonstrate how the data from the DSS will be utilized to run the software. Comprehensive M-E analyses and software runs will be conducted in due course as more data is collected during the study.

RECOMMENDATIONS AND ONGOING WORK

Based on the foregoing discussions, the following recommendations were made and are concurrently being executed as an ongoing work:

- Continue populating the DSS with more test sections and associated data including construction, traffic, climatic, laboratory (material properties), and field data.
- Continuously update and, if need be, modify the DSS structural format and data content to include as much as possible most of the input and output data associated with the M-E models and software discussed in this interim report, namely the FPS, TxACOL, TxM-E, and M-E PDG. However, such modifications to the DSS should not comprise data quality, usefulness, or user-friendliness in terms of accessibility.
- Explore and, if possible, develop a bridging platform for automatically exporting data from the DSS directly into the respective software.
- Continue and finalize the calibration and validation processes of the M-E models and associated software, namely:
    - Develop or modify and recommend local calibration factors.
    - If needed, recommend modifications to the M-E models, transfer functions, and/or the software code.
- Where applicable and as part of the validation process, conduct sensitivity analysis to establish some correlations between the M-E models and field/laboratory data. An analysis of this nature will aid in authenticating the conceptual validity and accuracy of some of the M-E models relative to field conditions.

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APPENDIX A: THE PROJECT 0-6658 DSS DATA CONTENT

Figure A-1. Type of Data Content in the DSS – Main Screen, Forms, Tables, PVMNT Structure, Construction, and Asphalt-Binders.

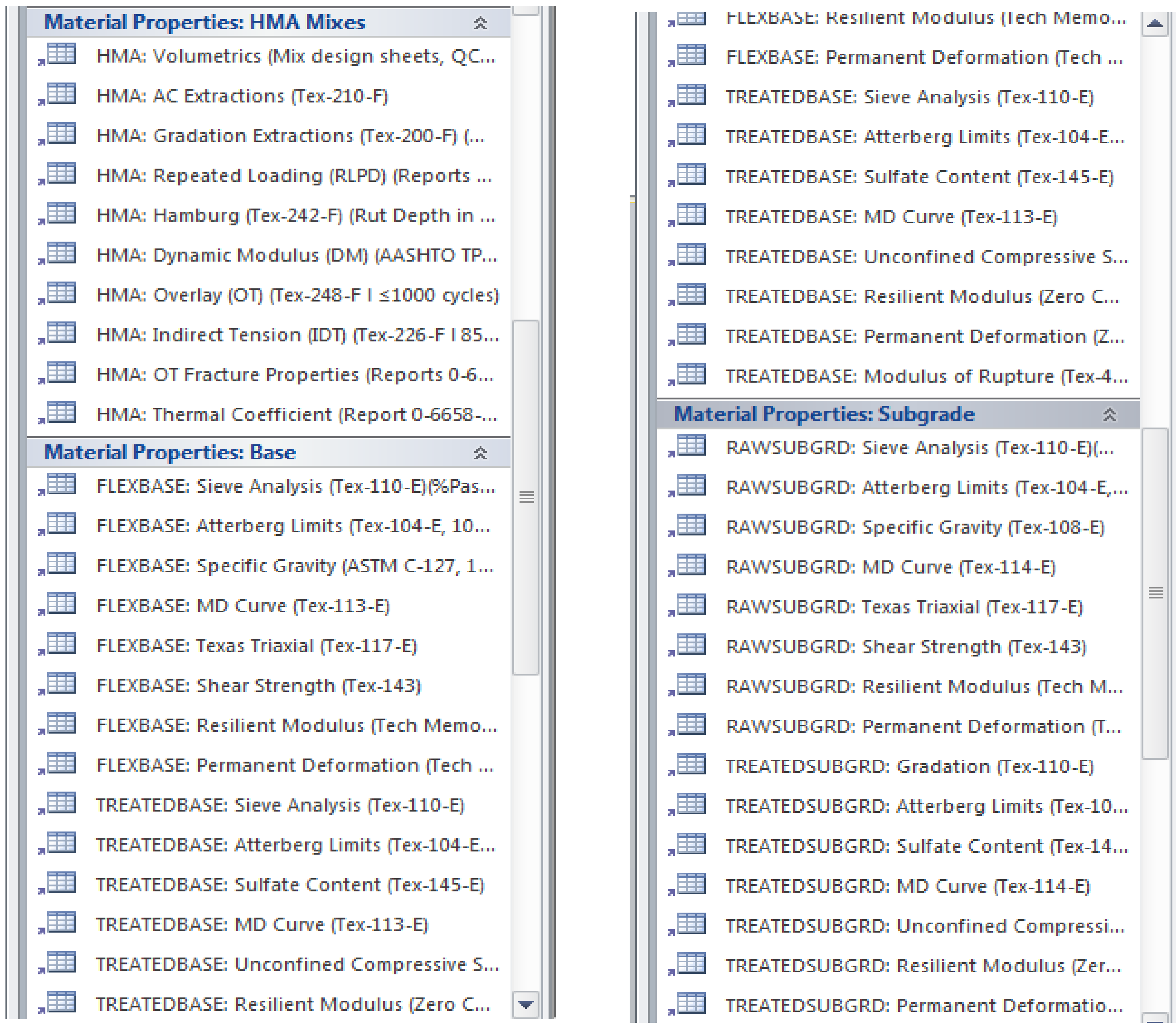

Figure A-2. Type of Data Content in the DSS – HMA Mixes, Base, and Subgrade.

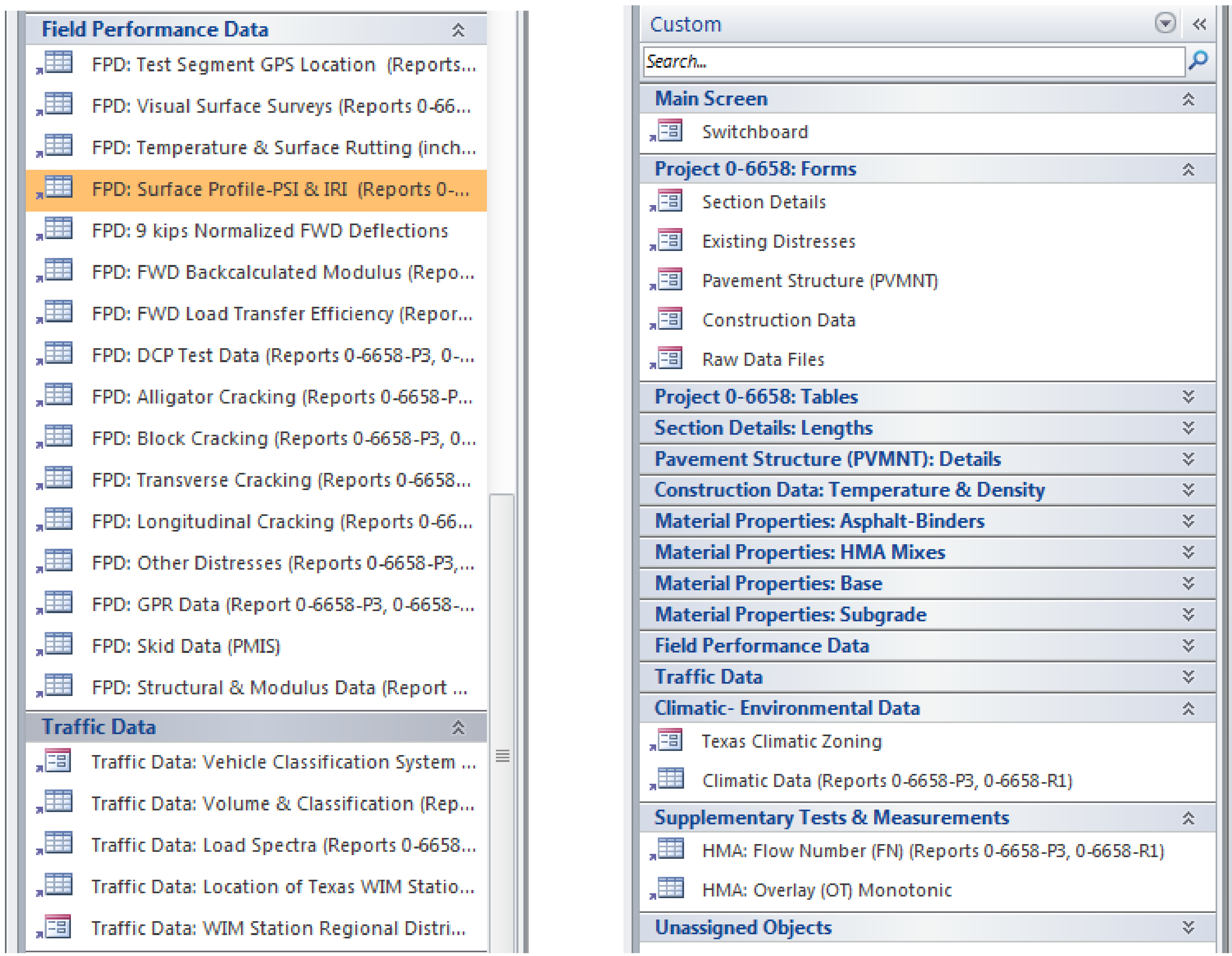

Figure A-3. Type of Data Content in the DSS – Field Performance, Traffic, and Climate.

APPENDIX B: THE FPS RELATED DATA

Table B-1: List of Input Parameters for FPS and Location in the Project 0-6658 DSS.

#	Item	#	Description	Data Source/ Location in the DSS
1	General Information	a.	Problem#	User Input
		b.	Highway, District, County	DSS: PVMNT Section Details
		c.	Control, Section, & Job#	DSS: PVMNT Section Details
		d.	Date	User Input
2	Basic Design Criteria	a.	Length of analysis period (yrs)	User Input
		b.	Min. time to first overlay (yrs)	User Input
		c.	Min. time between overlays (yrs)	User Input
		d.	Design confidence level	User input based on help file guidelines
		e.	Initial & final serviceability index	User input based on help file guidelines
		g.	Serviceability index after overlay	User input based on help file guidelines
		h.	District temperature constant	User input based on help file guidelines
		i.	Interest rate (%)	User Input
3	Program Controls	a.	Max. funds/Sq. YD, INIT Const.	User Input
		b.	Max. thickness, INIT Const.	User Input
		c.	Max. thickness, all overlays	User Input
4	Traffic Data	a.	ADT begin (veh/day)	DSS: Traffic Data\Volume & Classification, (& Excel Macro)
		b.	ADT end 20 Yr (veh/day)	
		c.	18 kip ESALs 20 Yr – 1 Direction (millions)	
		d.	Avg. App. Speed to OV Zone	User Input
		e.	Avg. Speed OV & Non-OV Direction	User Input
		g.	Percent ADT/HR Construction	User Input
		h.	Percent trucks in ADT	DSS: Traffic Data\Volume & Classification
5	Const. & Maint. Data	a.	Min. Overlay thickness (in)	User Input
		b.	Overlay const. time, Hr/Day	User Input
		c.	ACP comp. density, Tons/CY	User Input
		d.	ACP production rate, Tons/Hr	User Input
		e.	Width of each lane, ft.	DSS: PVMNT Section Details
		f.	First year cost, RTN Maint.	User Input
		g.	Ann. Inc. Incr. in Maint. Cost	User Input
6	Detour Design for Overlays	a.	Detour Model during Overlays	User Input
		b.	Total number of lanes	DSS: PVMNT Section Details
		c.	Num. open lanes, overlay direction	User Input
		d.	Num. open lanes, NON OV direction	User Input
		e	Dist. Traffic slowed, OV direction	User Input
		f.	Dist. Traffic slowed, Non-OV direction	User Input
		g.	Detour distance, overlay zone	User Input
7	Structure & Material Properties	a.	Layer & material name	DSS: PVMNT Structure Details
		c.	Cost per CY	User Input
		d.	Modulus E (ksi)	DSS: Field Performance Data\FWD Back-Calculated Modulus
		e.	Min & Max Depth	DSS: PVMNT Structure Details
		g.	Salvage PCT	User Input
		h.	Poisson’s ratio	User input or default value

Table B-2: Additional FPS Input Parameters (Kept the same for all Sections in this Report).

Category	Value	Comment
Basic Design Criteria		
– Min. time to first overlay	10 years	
– Min. time between overlays	8 years	
– District temperature constant	31 ^{o}F	
– Interest rate	7%	
Traffic		
– Avg. approach speed to overlay zone	69 mph	Parameters used for computing the cost of delaying traffic during overlay operations
– Avg. speed overlay direction	45 mph	
– Avg. speed non-overlay direction	50 mph	
– % ADT per hr of construction	6%	
Program Controls		
– Max. funds (initial construction)	$200/sq yard	Inputs to serve as design constraints/controls
– Max. thickness initial construction	60.0 inch	
– Max. thickness overlays	6.0 inch	
Constuction & Maintenance Data		
– Min. overlay thickness	1.0 inch	Inputs primarily used for cost estimation
– Overlay construction time	12 hr/day	
– ACP compaction density	2.00 ton/CY	
– ACP production rate	200 ton/hr	
– Width of each lane	12 ft	
– First year construction routine maintenance	$500.00	
– Annual increment in maintenance cost	$200.00	
Detour Design for Overlays		
– Detour model during overlays	3	Inputs to calculate cost due to traffic delay during overlay construction
– Total number of lanes (for 2 directions)	4	
– Number of open lanes (overlay direction)	1	
– Number of open lanes (non-overlay direction)	2	
– Distance of traffic slowed (overlay direction)	0.6	
– Distance of traffic slowed (non-overlay direction)	0.6	

APPENDIX C1: THE TxACOL RELATED DATA

Table C-1. List of Input Parameters Required for TxACOL and Location in the Project 0-6658 DSS (General, Traffic, and Climatic Information).

Item	Description	Location in Data Storage System: Group	Location in Data Storage System: Table	Comment
General Information	Type of AC overlay design	Tables	Section Details	
		PVMNT: Details	PVMNT Structure Details	
	Analysis/design life (yrs)	N/A		User input
	Pavement overlay construction month & year	Tables	Construction Data	
	Traffic open month & year	PVMNT: Details	PVMNT Structure Details	
Project Identification	District, County, CSJ	Tables	Section Details	
	Functional Class	Traffic Data	Traffic Data: Classification	
	Date	User input		
	Reference mark format(Lat/Long) Reference mark (start-end)	Tables	Section Details	
Analysis Parameters & Performance Criteria	Reflective cracking rate (%)	N/A		User input
	AC rutting (in)	N/A		User input
Traffic	ADT begin (veh/day) ADT end 20 Yr (veh/day) 18 kip ESALs 20 yr – 1 Direction (millions) Operation speed (mph)	Traffic Data	Volume & Classification	
Climate	EICM weather station data	Attachment	Raw data files (EICM files stored in DSS & Raw Data Files)	Can also be user input
	Latitude and longitude (degrees.minutes) Elevation (ft)	Tables	Section Details	

Table C-2. List of Input Parameters Required for TxACOL and Location in the Project 0-6658 DSS (Structural and Material Information)

Layer	Material	Description	Location in Data Storage System		Comment
			Group	Table	
Overlay	HMA	Layer thickness (in)	PVMNT: Details	PVMNT Structure Details	
		Material type	PVMNT: Details	PVMNT Structure Details	
		Thermal coefficient of expansion	Material Properties HMA Mixes	HMA: Thermal Coefficient	
		Poisson's ratio	N/A		Default value
		Superpave PG Binder Grading	PVMNT: Details	PVMNT Structure Details	
		Dynamic modulus by temperature and frequency	Material Properties HMA Mixes	HMA: Dynamic Modulus (DM)	Export from raw data file (*.dm)
		Fracture property data: temperature, A and n	Material Properties HMA Mixes	HMA: OT Fracture Properties	
		Rutting property data: temperature, α and μ	Material Properties HMA Mixes	HMA: Repeated Loading (RLPD)	
Existing Surface	HMA	Layer thickness (inches)	PVMNT: Details	PVMNT Structure Details	
		Material type	PVMNT: Details	PVMNT Structure Details	
		Thermal Coefficient of Expansion	N/A		Default value
		Poisson's ratio	N/A		Default value
		Main Cracking Pattern			
		1) Alligator/longitudinal/block cracking			
		a) Severity Level (Low/Medium/High)	Form	Existing Distress	
		b) FWD Temperature (°F) & Modulus (ksi)	Field Performance Data	FWD Back-calculated Modulus	
		2) Transverse cracking			
		a) Crack Spacing (ft), Severity Level, LTE	Form	Existing Distress	
		b) FWD Temperature (°F) & Modulus (ksi)	Field Performance Data	FWD Back-calculated Modulus	
	JPCP/ CRCP	Layer thickness (in)	PVMNT: Details	PVMNT Structure Details	
		Material type	PVMNT: Details	PVMNT Structure Details	
		Thermal Coefficient of Expansion	N/A		Default value
		Poisson's ratio	N/A		Default value
		Joint/Crack Spacing (ft)	Field Performance Data	Transverse Cracking	
		PCC Modulus (ksi)	Field Performance Data	FWD Back-calculated Modulus	
		LTE (%) & LTE Standard deviation	Field Performance Data	FWD Load Transfer Efficiency	

Table C-2. List of Input Parameters Required for TxACOL and Location in the Project 0-6658 DSS (Structural and Material Information–Continued)

Layer	Materials	Description	Position in Data Storage System		Comment
			Group	Table	
Existing Subsurface	Granular Base	Layer thickness (in)	PVMNT: Details	PVMNT Structure Details	
		Material type	PVMNT: Details	PVMNT Structure Details	
		Poisson's ratio	N/A		Default value
		Modulus (ksi)	Field Performance Data	FWD Back-calculated Modulus	
	Stabilized Base/ Subbase	Layer thickness (in)	PVMNT: Details	PVMNT Structure Details	
		Material type	PVMNT: Details	PVMNT Structure Details	
		Poisson's ratio	N/A		Default value
		Thermal Coefficient of Expansion	N/A		Default value
		Modulus (ksi)	Field Performance Data	FWD Back-calculated Modulus	
	Subgrade	Layer thickness (inches)	PVMNT: Details	PVMNT Structure Details	
		Material type	PVMNT: Details	PVMNT Structure Details	
		Poisson's ratio	N/A		Default value
		Modulus (ksi)	Field Performance Data	FWD Back-calculated Modulus	

APPENDIX C2: THE TXACOL RE-ANALYSIS OF TxDOT_TTI-00001 (US 59)

- TxACOL analyzes the development of reflective cracking based on the assumption that the existing AC layer has cracked through the whole AC thickness.
- For accurate crack prediction at this point:

1) The crack depth of the existing AC layer should be considered as an existing AC layer.
2) The rest of the un-cracked thickness of the AC layer is treated as a granular base layer.
3) The modulus of the granular base layer should be the same as that of existing AC layer (at a reference temperature of 77°F).

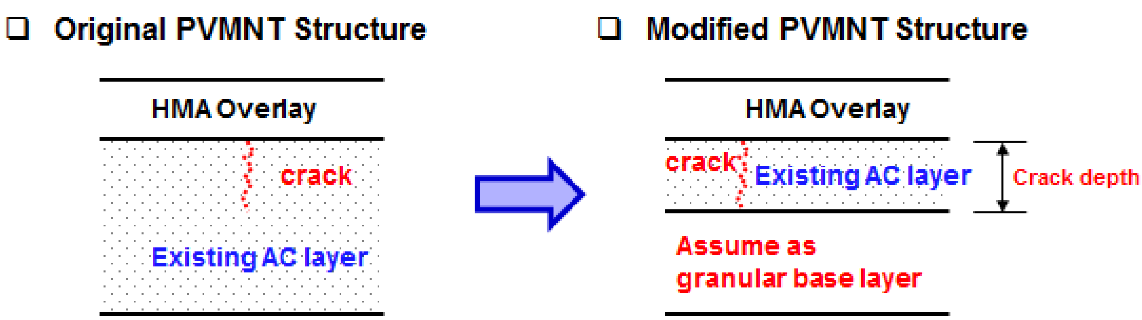

Figure C-1. Issues with the TxACOL Software.

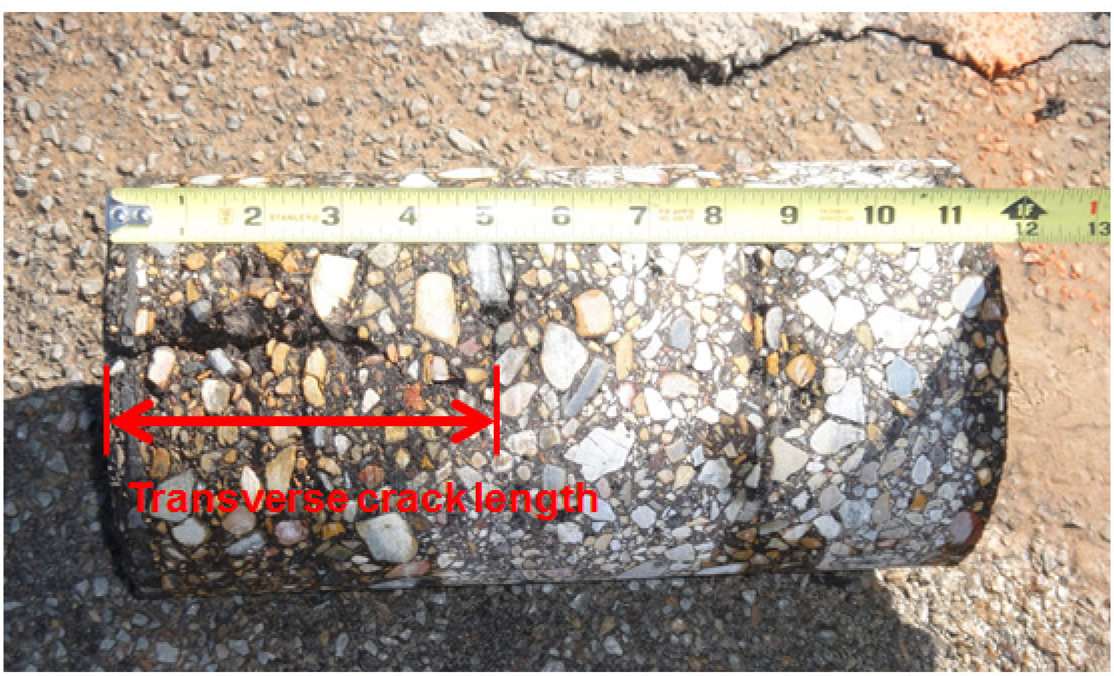

Figure C-2. TxDOT_TTI-00001: Existing US 59 AC Layer (s) prior to an Overlay.

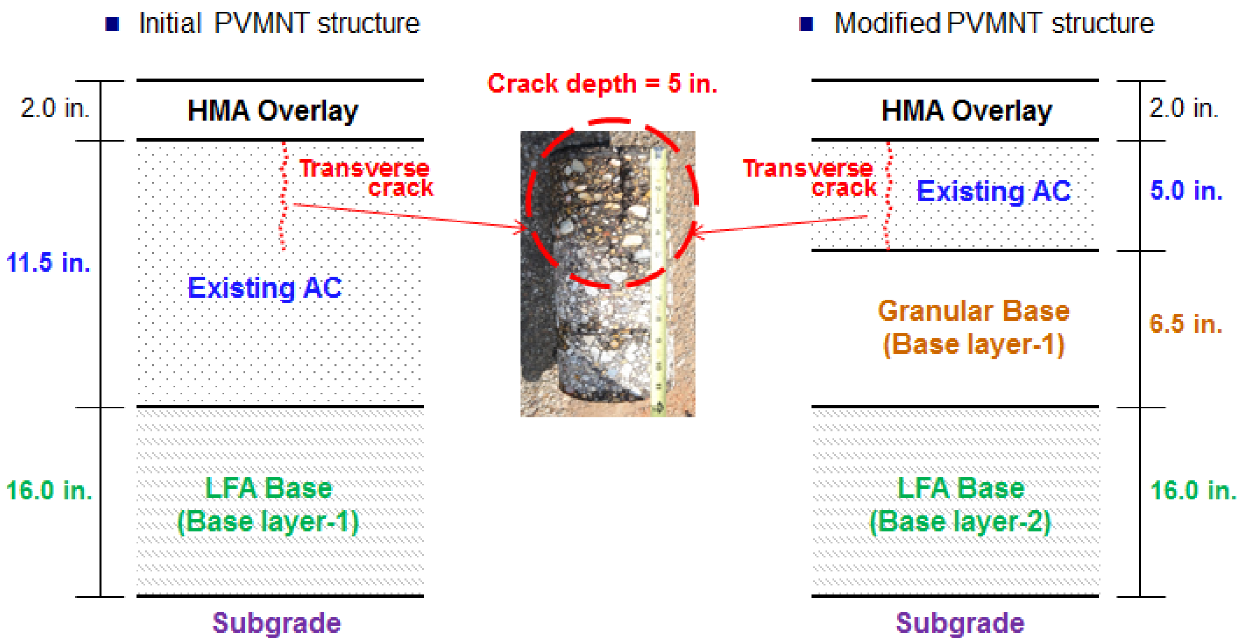

Figure C-3. TxDOT_TTI-00001: Initial and Modified US 59 PVMNT Structure.

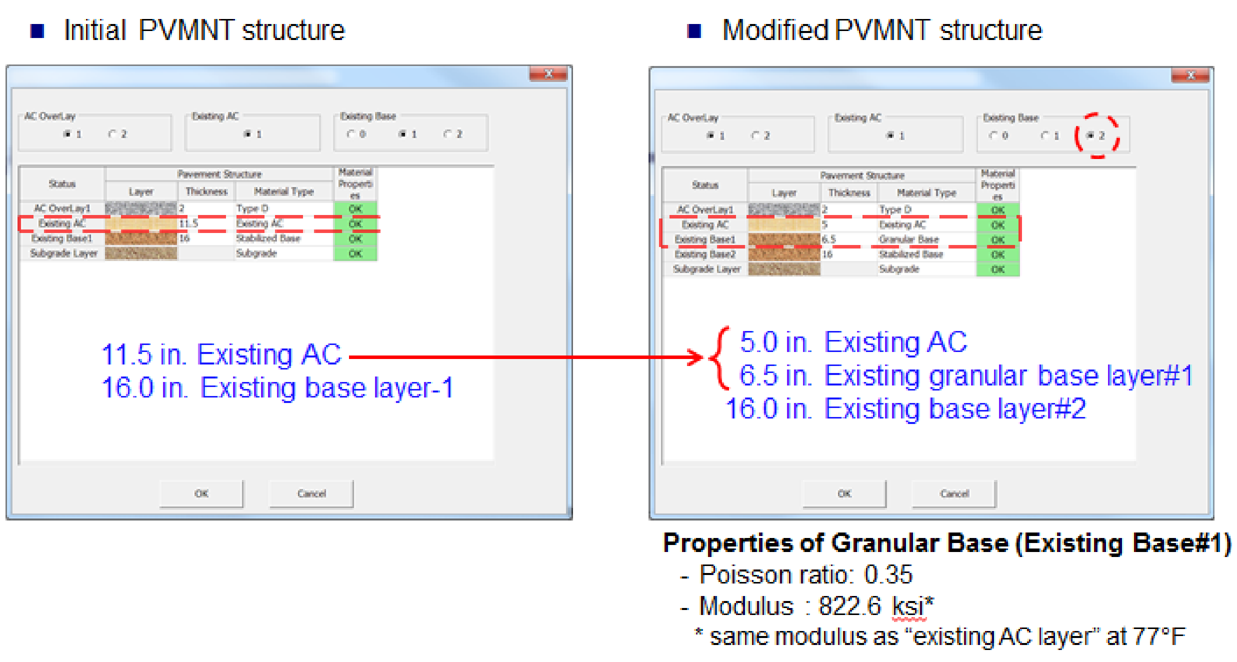

Figure C-4. TxDOT_TTI-00001: PVMNT Structure Input in TxACOL Software.

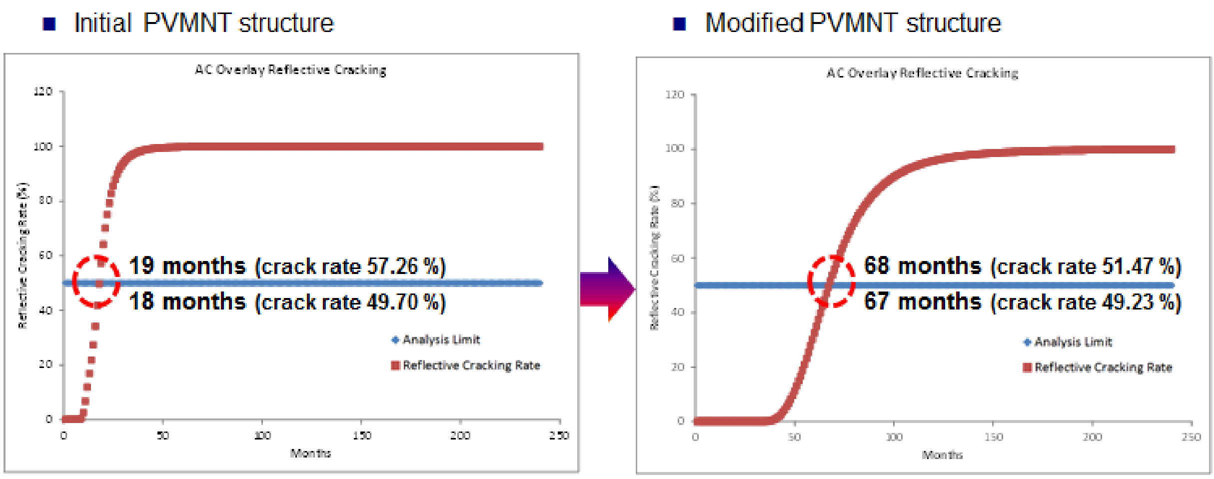

Figure C-5. TxDOT_TTI-00001: TxACOL Reflective Crack Analysis.

Without doubt Figure C-5 above shows that the modification of the PVMNT structure due to the transverse crack depth of the existing AC layer has a significant effect on the reflective cracking prediction. It has yielded a reflective crack life prediction of over 5 years, which is considered reasonable. The crack depth of existing AC layer should thus be always measured to get highly accurate crack prediction with the TxACOL analysis.

APPENDIX D: THE TxM-E RELATED DATA

Table D-1. Example List of Input Parameters Required for TxM-E and Location in DSS.

#	Item	#	Description	Location in the DSS
1	General information	a.	Design life (yrs)	User defined
		b.	Construction month & yr	Construction data
		c.	Traffic open month & yr	Construction data
2	Project Identification	a.	District	Section details
		b.	County	Section details
		c.	CSJ#	Section details
		d.	Functional Class	Section details
		e.	Date	Section details
		f.	Reference mark format	Section details
		g.	Reference mark (start-end)	Section details
3	General pavement structure information	a.	Material type	PVMNT structure details
		b.	Number layers & thicknesses	PVMNT structure details
		c.	Etc.	
4	Traffic	a.	Average of the ten heaviest (single axle) wheel loads, dual tire spacing, and tire pressure	
		b.	Average of the ten heaviest tandem axle wheel loads, axle spacing, dual tire spacing, tire pressure	
		c.	ESALs (ADT begin [veh/day], ADT end 20 Yr [veh/day], 18 kip ESALs 20 Yr – 1 Direction [millions])	Traffic data – volume & classification
		d.	Or load spectra (Growth rate, ADT, % trucks, speed, etc.)	
5	Environment	a.	EICM weather station data	Climatic data
		b.	Lat. & long. location (degrees.minutes), and elevation	Climatic data
		c.	Seasonal water table	Climatic data
6.1	Material Properties – HMA/WMA/RAP	a.	Asphalt-binder DSR properties (PG grade, viscosity, etc.)	Material properties - binders
		b.	Volumetrics (AC content, AV, aggregate specific gravity, VMA, gradations, etc.)	Material properties - HMA
		c.	Dynamic modulus	
		d.	Poisson's ratio	User defined or default

Table D-1. Example List of Input Parameters Required for TxM-E and Location in DSS (Continued).

#	Item	#	Description	Location in the DSS
6.2	Material Properties - Granular Base	a.	Resilient modulus, Mr	Material properties - base
		b.	Permanent deformation parameters: alpha & mu	Material properties - base
		c.	Grade & gradations (matching EICM requirements)	Material properties - base
		d.	Poisson's ratio	User defined or default
		e.	Soil classification (optional)	
		f.	Atterberg limit: Plasticity Index and Liquid limit	Material properties - base
		g.	Maximum dry unit weight	Material properties - base
		h.	Specific gravity, Gs	Material properties - base
		i.	Optimum gravimetric moisture content	
		j.	Saturated hydraulic conductivity	
		k.	Soil water characteristic Curve coefficients	
6.3	Material Properties - Subgrade Soils	a.	Resilient modulus, Mr	Material properties - subgrade
		b.	Permanent deformation parameters: alpha & mu	Material properties - subgrade
		c.	Shear failure: C-phi values and corresponding moisture content	Material properties - subgrade
		d.	Grade & gradations (matching EICM requirements)	Material properties - subgrade
		e.	Poisson's ratio	User defined or default
		f.	Soil classification (optional)	
		g.	Atterberg limit: Plasticity Index and Liquid limit	Material properties - subgrade
		h.	Maximum dry unit weight	Material properties - subgrade
		i.	Specific gravity, Gs	Material properties - subgrade
		j.	Optimum gravimetric moisture content	
		k.	Saturated hydraulic conductivity	
		l.	Soil water characteristic Curve coefficients	
6.4	Material Properties - Stabilized materials	a.	Resilient modulus (or seismic modulus)	Material properties – base or subgrade
		b.	Modulus of rupture	Material properties – base or subgrade
		c.	UCS – unconfined compression strength	Material properties – base or subgrade
		d.	Crushing resistance/model parameters	Material properties – base or subgrade
		e.	Poisson's ratio	User defined or default

APPENDIX E: THE M-E PDG RELATED DATA

Table E-1. Example List of Input Parameters Required for M-E PDG and Location in DSS.

#	Item	#	Description	Location in the DSS
1	General Information	a.	Project Name	
		b.	Design Life (yrs.)	User input
		c.	Base/Subgrade Construction Month/Year	Construction data
		d.	Pavement Construction Month/Year	Construction data
		e.	Traffic Open Month/Year	Construction data
		f.	Section	Section details
		g.	Date	Section details
		h.	Job	Section details
		i.	Type of Design	Section details
2	Site/Project Identification	a.	Location	Section details
		b.	Project ID	Section details
		c.	Section ID	Section details
		d.	Date	Section details
		e.	Station/milepost format	Section details
		f.	Station/milepost begin	Section details
		g.	Station/milepost end	Section details
		h.	Traffic direction	Section details
3	Analysis Parameters	a.	Project Name	Section details
		b.	Initial IRI (in/mi)	Field performance data: Surface profiles – PSI & IRI
		c.	Terminal IRI (in/mi)	User defined or default values
		d.	AC surface down cracking long. Cracking (ft/mi)	User defined or default values
		e.	AC bottom up cracking. Alligator Cracking (%)	User defined or default values
		f.	AC thermal fracture (ft/mi)	User defined or default values
		g.	Chemically stabilized layer fatigue fracture (%)	User defined or default values
		h.	Permanent Deformation – Total Pavement (inches)	User defined or default values
		i.	Permanent Deformation – AC only (in)	User defined or default values

Table E-1. Example List of Input Parameters Required for M-E PDG and Location in DSS (Continued).

#	Item	#	Description	Location in the DSS
4	Traffic	a.	Design Life (yrs.)	User defined
		b.	Opening Date	Construction data
		c.	Initial two-way AADTT	Traffic data – volume & classification
		d.	Number of lanes in design direction	
		e.	Percent of trucks in design direction (%)	
		f.	Percent of trucks in design lane (%)	Traffic data – volume & classification
		g.	Operational Speed (mph)	Traffic data – volume & classification
4.1	Traffic Volume Adjustment Factors	a.	4.1.1. Monthly adjustment	
		b.	4.1.2. Vehicle Class Distribution	Traffic data – volume & classification
		c.	4.1.3. Hourly Distribution	Traffic data – volume & classification
		d.	4.1.4. Traffic growth factors	
4.2	Axle Load Distribution Factors	a.	Single axle	
		b.	Tandem axle	
		c.	Tridem axle	
		d.	Quad axle	
4.3	General Traffic Inputs	a.	Mean wheel location (inches from the lane marking)	
		b.	Traffic wander standard deviation (inches)	
		c.	Design lane width (ft.) (Note: Not slab width)	
4.3.1	Number Axles/Truck			
4.3.2	Axle Configuration	a.	Average Axle width (edge to edge) outside dimensions, ft.	
		b.	Dual tire spacing (inches)	
		c.	Tire Pressure (psi)	
		d.	Tandem Axle spacing (inches)	
		e.	Tridem Axle spacing (inches)	
		f.	Quad Axle spacing (inches)	
4.3.3	Wheelbase	a.	Average Axle spacing (ft.)	
		b.	Percent of trucks (%)	Traffic data – volume & classification

Table E-1. Example List of Input Parameters Required for M-E PDG and Location in DSS (Continued).

#	Item	#	Description	Location in the DSS
5	Climate	a.	Latitude (degrees.minutes)	Climatic data
		b.	Longitude (degrees.minutes)	Climatic data
		c.	Elevation (ft)	Climatic data
		d.	Depth of water table (ft) (Spring, Summer, Fall, Winter)	Climatic data
6	Structure	a.	Surface shortwave absorptivity	User defined or default value
		b.	Layer	PVMNT structure details
		c.	Type	PVMNT structure details
		d.	Material	PVMNT structure details
		e.	Thickness	PVMNT structure details
		f.	Interface	PVMNT structure details
		g.	For overlay design:	
		h.	Level 1: existing rutting & milled thickness	Construction data
		i.	Level 2: existing rutting, crack (%) in existing AC, & milled thickness	
		j.	Level 3: milled thickness, total rutting, & pavement rating (Excellent, Good, Fair, Poor, & Very Poor)	Construction data
		k.	Fatigue analysis endurance limit (national calibration based on no endurance limit	User defined or default value

Table E-1. Example List of Input Parameters Required for M-E PDG and Location in DSS (Continued).

#	Item	#	Description	Location in the DSS
7	HMA	a.	Dynamic modulus —Level 1	Material properties - HMA
	(Use Level 3 if most data is unavailable)	b.	DSR—Level 1 ~ 3	Material properties - Binders
		c.	Gradation—Level 2 & 3	Material properties - HMA
		d.	Effective binder content	Material properties - HMA
		e.	Air void	Material properties - HMA
		f.	Total unit weight	Material properties - HMA
		g.	Poisson's ratio	User defined or default value
		h.	Thermal conductivity	
		i.	Shear capacity asphalt	
		j.	Tensile strength & creep compliance	
8	Base & Subgrade (Use Level 3 if most data is unavailable)	a.	Resilient modulus	Material properties – Base & Subgrade
		b.	Soil classification	Material properties – Base & Subgrade
		c.	Gradation	Material properties – Base & Subgrade
		d.	Atterberg limits	Material properties – Base & Subgrade
		e.	Maximum dry unit weight	Material properties – Base & Subgrade
		f.	Specific gravity (calculated or tested)	Material properties – Base & Subgrade
		g.	Optimum gravimetric moisture content	Material properties – Base & Subgrade
		h.	Saturated hydraulic conductivity (calculated)	User defined or default values
		i.	Degree of saturation at optimum (calculated)	
		j.	Coefficient of later pressure	
		k.	Soil suction coefficients (tested or calculated)	User defined or default values
		l.	DCP data	