Center for
Transportation
Infrastructure
Systems

A Users Manual for RECIPPE

Users Manual

Project Number 5-4046-01

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P.O. Box 5080
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Center for Transportation Infrastructure Systems

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A Users Manual for RECIPPE

by

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Users Manual

Performed in cooperation with

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Pilot Implementation of Software RECIPPE as a Quality Control Tool in Construction Projects

October 2007

The Center for Transportation Infrastructure Systems
The University of Texas at El Paso
El Paso, TX 79968-0516

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CHAPTER ONE - INTRODUCTION

The quality of construction is a very important factor in the life-cycle performance of flexible pavements. This is particularly true of the individual characteristics of construction and their relative effect on life-cycle performance of the pavement. It is crucial to determine both what these characteristics are and, to what degree their variability from the desired value affects the life-cycle performance of pavements. Knowing this will enable the transportation agencies to apply its limited inspection resources in the most effective manner. Therefore, the goal of this research was to identify construction parameters that have the greatest impact on the life-cycle performance of the pavement. In the long term, the results of this research should enable TxDOT to write more effective performance-based specifications for construction of pavements and determine the cost effectiveness of innovations in construction practices. This research was carried out in three phases.

In the research phase of this project, the first phase consisted of determining the characteristics of construction that have a significant effect on the life-cycle performance of pavements, and whether these characteristics are observable and measurable.

The second phase consisted of the prediction of how the variability of these construction characteristics affects the life-cycle performance of pavements by using mechanistic analysis. The mechanistic analysis should enable the engineers to predict the life-cycle performance of the pavement as the characteristics are varied.

The third phase consisted of field measurements to verify the predictions of the second phase. A list of characteristics of construction and the methodology to measure and analyze these characteristics available to TxDOT were developed.

The first two years of this project, which are documented in Research Report 0-4046-1 (Abdallah et al., 2004a) were focused on addressing the following items:

a) Information search on existing mechanistic models and ways that they can be used in developing an algorithm to relate the impact of construction parameters to performance was carried out. After a national search, several material models were identified, and feasible models were selected. Several popular and well-established performance-based models were also selected.

b) A probabilistic analysis tool was developed. The probabilistic approach differs from a deterministic approach by explicitly accounting for the variability of a parameter. A random parameter can take a range of values and can be represented by different types of probability distributions. The Monte Carlo simulation method, a common probabilistic method for simulating and accounting for the variability of a parameter, was used. Since many parameters are used in the analysis, the two-point mass method (TPM, Rosenblueth, 1981) was combined with the Monte Carlo method to accelerate the process. The TPM method can be used to approximate mean and standard deviation of random variables. The detail of both methods is provided in Chapter 2 of Report 0-4046-1 (Abdallah et al., 2004a).

c) Once the models were selected and the flow of probabilistic algorithm was defined, a prototype algorithm was developed. Figure 1.1 shows the general flow of information used in the mechanistic algorithm with the probabilistic methods. The detail and a case study of how to use the program were also provided in (Abdallah et al., 2004a).

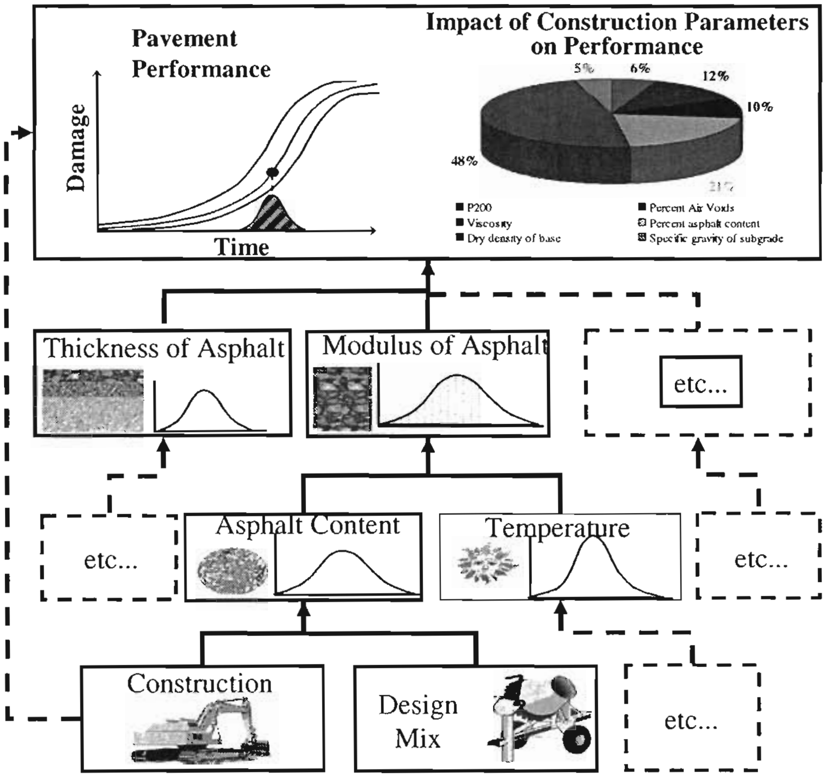


Figure 1.1 - Flowchart Depicting the Process of Utilizing A Probabilistic Approach in a Mechanistic Analysis

d) The mechanistic models selected provide a number of parameters that are used as a measure of construction practices. To optimize the process, a sensitivity analysis was conducted to primarily identify the relative importance of construction parameters on performance indicators. The results of this study, as presented in Abdallah et al. (2004a), provided an indication of important parameters for pavements with different traffic levels.

e) Based on results of the sensitivity study, a search to document methods on measuring important parameters was carried out. The document was embedded into software package RECIPPE. In that manner, the users can easily access the different ways to measure any given parameter. Another advantage of including the document into the program is that when new parameters are added, the document can be easily amended or updated. This document is included in Appendix A of Research Report 0-4046-2 (Abdallah et al, 2004b).

The third year of the research effort under this project focused on developing a document for validation using few of construction parameters and demonstrating the validation process using selected parameters. The details of these tasks were documented in Research Report 0-4046-2 (Abdallah et al, 2004b). The efforts are summarized below:

a) A validation of the algorithm to quantify the impact of construction parameters on performance is the initial step before being able to utilize RECIPPE with confidence. Three types of models make up the mechanistic algorithm developed: a) the material models, b) the structural models and c) the performance models. The material models were calibrated with information from existing databases and from field data collected at several sites in Texas. The structural and performance models incorporated into the algorithm are well-established. The structural model is based on a nonlinear model using equivalent linear algorithm. The equivalent linear model was developed under TXDOT Project 0-1780 (Ke et al., 2000, and Abdallah et al., 2003). The calibration and validation of these models are outside the scope of this project. Research Report 4046-2 (Abdallah et al, 2004b) provides the validation strategy to calibrate and validate the material models that are being incorporated into RECIPPE. The efforts in extracting data from the Long-Term Pavement Performance (LTPP) database for the asphalt-concrete (AC) layer material model were discussed. The protocol for targeting sites and collecting data for base and subgrade material models were presented. The calibration of the AC material model using data extracted from LTPP database for Texas sites was also presented in that report.

b) The probabilistic process to obtain the variability of performance based on the uncertainty in construction parameters using mechanistic analysis was also validated. Two techniques were used in the probabilistic process. The advantages and disadvantages of each technique and a comparison of their effect on producing the Impact Chart (a chart used to identify significant parameters) were documented in that report.

c) The calibration of the AC material model using data collected from Texas sites was performed in three different ways. The first method was based on least squares single variable calibration. The second equation was based on modifying the existing coefficients of the current Witczak equation. The final approach was to develop a new model using similar parameters used by the Witczak equation. Summary of the results are presented in Research Report 0-4046-2 (Abdallah et al, 2004b).

d) A case study showing a limited implementation of the validation process was also presented in Research Report 0-4046-2 (Abdallah et al, 2004b). The validation process is presented by demonstrating the impact variability of one construction variable on the variability of performance.

The fourth year of the research effort under this project focused on adjustments to be made to the prototype of RECIPPE to provide optimal results. This includes:

a) enhancing the reliability analysis process,
b) automating the optimization algorithm,
c) incorporating a sampling frequency algorithm (including control charts),
d) incorporating a cost allocation algorithm and
e) incorporating a cost allocation equation.

These efforts also included replacing the programming platform from MS Excel to Borland C++.

In the fourth year of the project, new material models were developed and the existing models were calibrated. Data from sites collected throughout the research efforts of this project and from databases of previous research such as 0-1336 were used to calibrate existing models or to develop new base and subgrade material models. The outcomes of the fourth year efforts of this project were documented in Research Report 0-4046-3 (Haggerty et al., 2005).

In the implementation phase of this project, the program was used to shadow the current quality management practices on several sites. The results of that will be documented in the final report of the implementation phase.

This report contains a user's manual that provides several exercises that illustrate the use of this program. In addition, a brief background and methodology behind RECIPPE is presented. It also, includes the strategy of utilizing RECIPPE for quality management. Also, the following website allows users to go step by step through various exercises on how to use this program. At the end of the tutorial the RECIPPE program can be downloaded. The latest version of the software can be downloaded from.

http://ctis.utep.edu/training/

ORGRANIZATION OF REPORT

Chapter 2 provides a set of exercises that can help users understanding the way the RECIPPE works. Each exercise is directed to instruct users on the different aspects of the software. These exercises are included online and once users get user access to the website, he or she can start utilizing all the modules of the program. Upon completion of the tutorial the software becomes available for download and installation

Chapter 3 provides background on the methodology that illustrates the use of construction parameter variability to estimate variability on pavement performance. Also included in Chapter 2 is the description of the methodology used in RECIPPE in pre-construction mode to identify significant impacting parameters on variability of pavement performance, and in post-construction mode, which provides inspectors with tool for quality control.

Chapter 4 focuses on presenting the models for pavement performance and focusing on the material models that were identified in the literature and that are incorporated into the software.

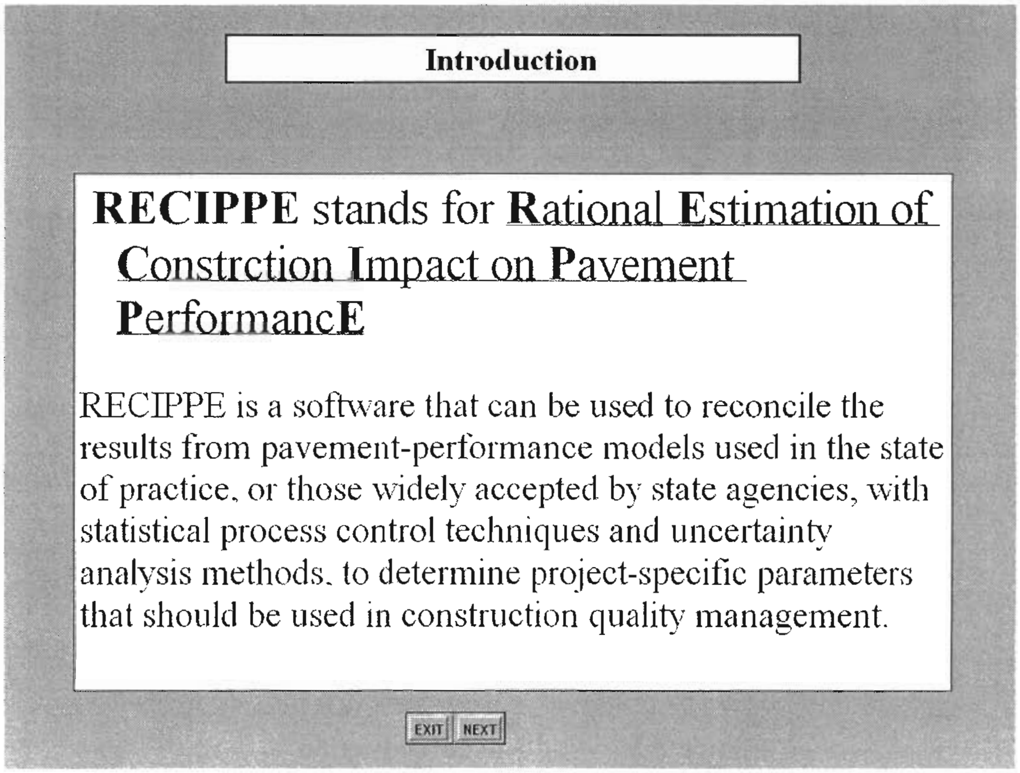
Chapter 5 covers the strategy to utilize RECIPPE for quality management. Several scenarios are presented that illustrate the input level for RECIPPE and recommendation of which level in most suitable for analysis.

Finally, Chapter 6 contains the summary, conclusion and future recommendations for this project.

CHAPTER TWO – TRAINING EXCERCISE

In this chapter, a set of exercises that can help users understanding the way the RECIPPE works are presented in slide show format. Users are required to register through the following website in order to learn how to use RECIPPE: ***http://ctis.utep.edu/training/***

The first module is an introduction of the concepts used in RECIPPE. Exercise 1 focuses on the general features of the program. Exercises 2 and 3 deal with the automatic reduction portion that can be used in the program. Exercises 4 and 5 illustrate the advance features incorporated into the program. In Exercise 6, the procedure to add new performance models is illustrated. Finally the last exercise shows users how to use the material model in the pavement evaluation process.

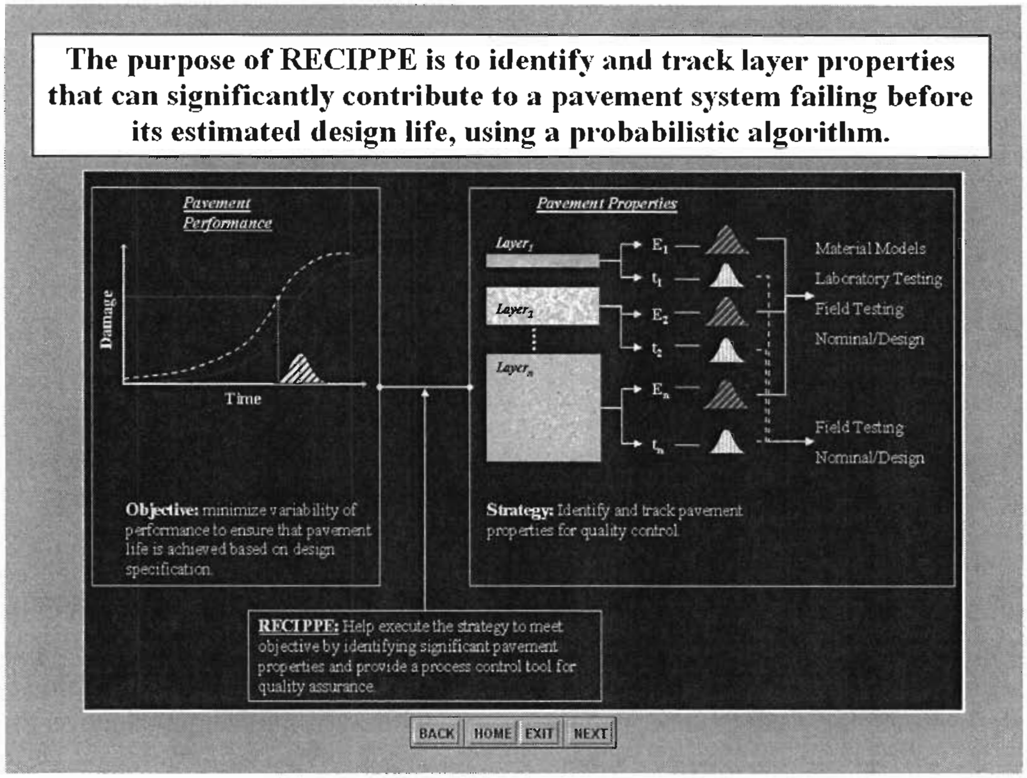


Introduction

RECIPPE stands for **R**ational **E**stimation of **C**onstrction **I**mpact on **P**avement **P**erformanc**E**

RECIPPE is a software that can be used to reconcile the results from pavement-performance models used in the state of practice, or those widely accepted by state agencies, with statistical process control techniques and uncertainty analysis methods, to determine project-specific parameters that should be used in construction quality management.

Figure 2.1 - Slide 1 of Introduction



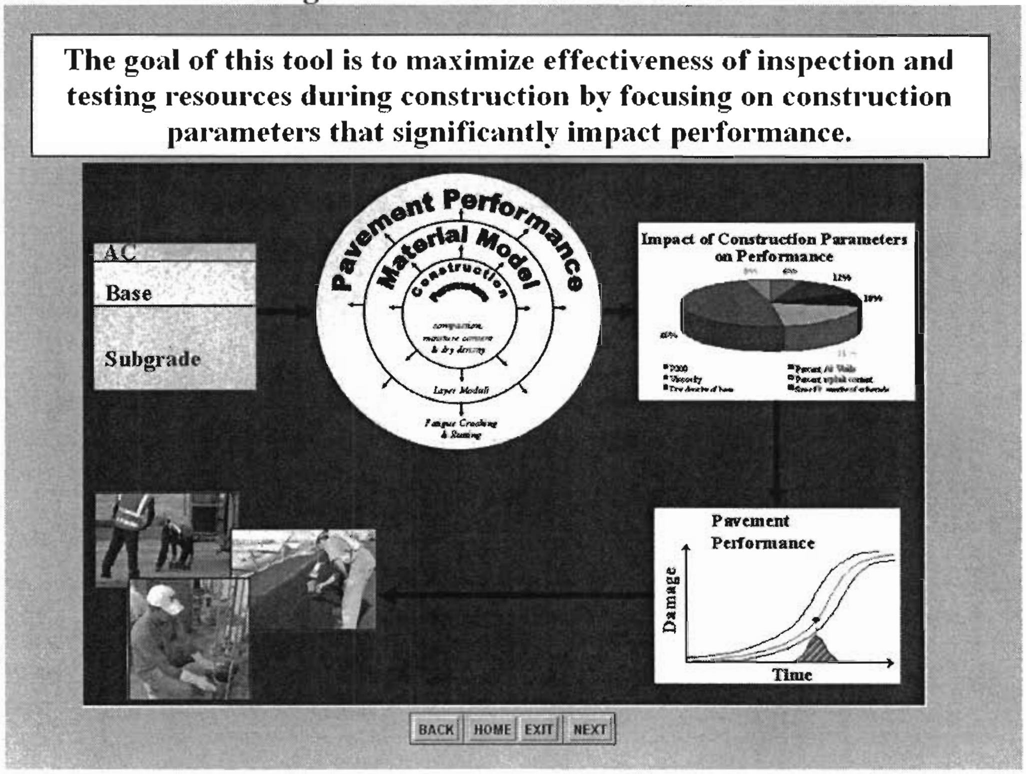
The purpose of RECIPPE is to identify and track layer properties that can significantly contribute to a pavement system failing before its estimated design life, using a probabilistic algorithm.

Objective: minimize variability of performance to ensure that pavement life is achieved based on design specification.

Strategy: Identify and track pavement properties for quality control.

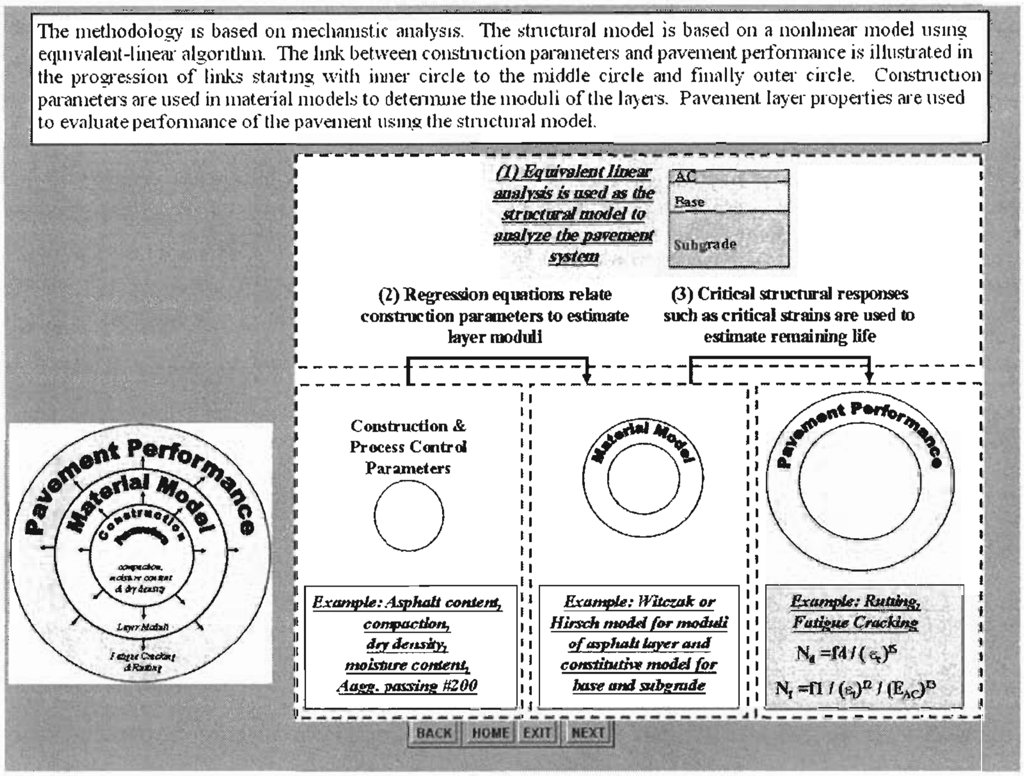
RECIPPE: Help execute the strategy to meet objective by identifying significant pavement properties and provide a process control tool for quality assurance.

Figure 2.2 - Slide 2 of Introduction



The goal of this tool is to maximize effectiveness of inspection and testing resources during construction by focusing on construction parameters that significantly impact performance.

Figure 2.3 - Slide 3 of Introduction



The methodology is based on mechanistic analysis. The structural model is based on a nonlinear model using equivalent-linear algorithm. The link between construction parameters and pavement performance is illustrated in the progression of links starting with inner circle to the middle circle and finally outer circle. Construction parameters are used in material models to determine the moduli of the layers. Pavement layer properties are used to evaluate performance of the pavement using the structural model.

(1) Equivalent linear analysis is used as the structural model to analyze the pavement system

(2) Regression equations relate construction parameters to estimate layer moduli

(3) Critical structural responses such as critical strains are used to estimate remaining life

Construction & Process Control Parameters

Example: Asphalt content, compaction, dry density, moisture content, Aagg. passing #200

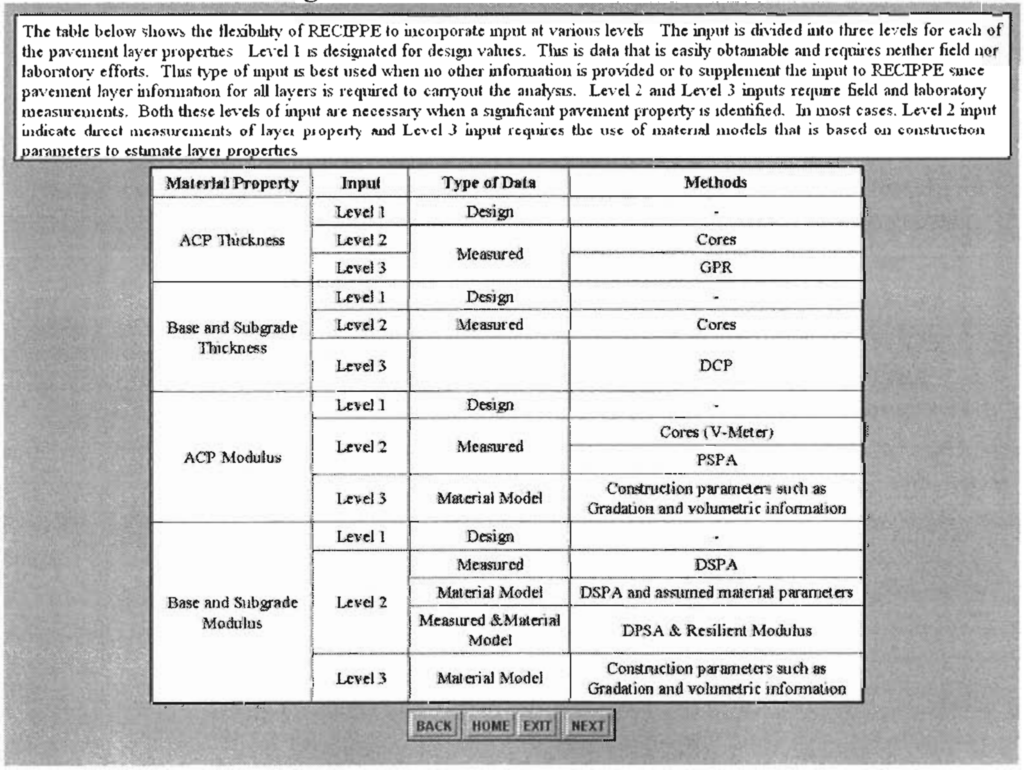
Example: Witczak or Hirsch model for moduli of asphalt layer and constitutive model for base and subgrade

Example: Rutting, Fatigue Cracking

$N_d = f4 / (\varepsilon_v)^{f5}$

$N_f = f1 / (\varepsilon_t)^{f2} / (E_{AC})^{f3}$

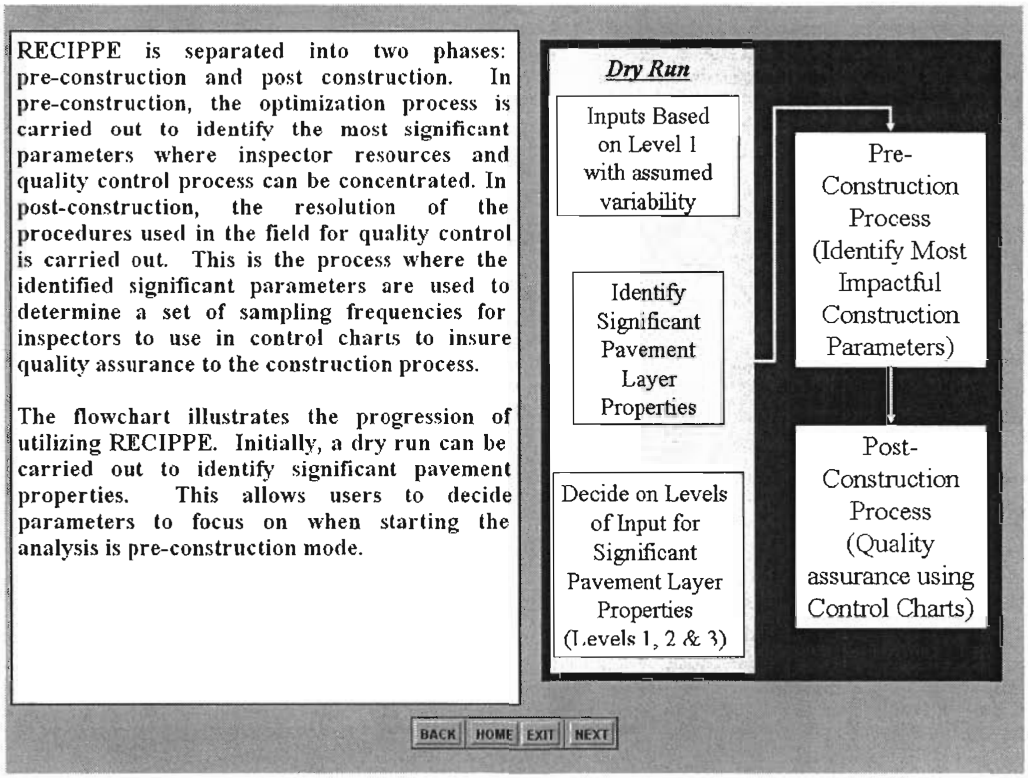
Figure 2.4 - Slide 4 of Introduction



The table below shows the flexibility of RECIPPE to incorporate input at various levels The input is divided into three levels for each of the pavement layer properties Level 1 is designated for design values. This is data that is easily obtainable and requires neither field nor laboratory efforts. This type of input is best used when no other information is provided or to supplement the input to RECIPPE since pavement layer information for all layers is required to carryout the analysis. Level 2 and Level 3 inputs require field and laboratory measurements. Both these levels of input are necessary when a significant pavement property is identified. In most cases. Level 2 input indicate direct measurements of layer property and Level 3 input requires the use of material models that is based on construction parameters to estimate layer properties

Material Property	Input	Type of Data	Methods
ACP Thickness	Level 1	Design	-
	Level 2	Measured	Cores
	Level 3		GPR
Base and Subgrade Thickness	Level 1	Design	-
	Level 2	Measured	Cores
	Level 3		DCP
ACP Modulus	Level 1	Design	-
	Level 2	Measured	Cores (V-Meter)
			PSPA
	Level 3	Material Model	Construction parameters such as Gradation and volumetric information
Base and Subgrade Modulus	Level 1	Design	-
	Level 2	Measured	DSPA
		Material Model	DSPA and assumed material parameters
		Measured &Material Model	DPSA & Resilient Modulus
	Level 3	Material Model	Construction parameters such as Gradation and volumetric information

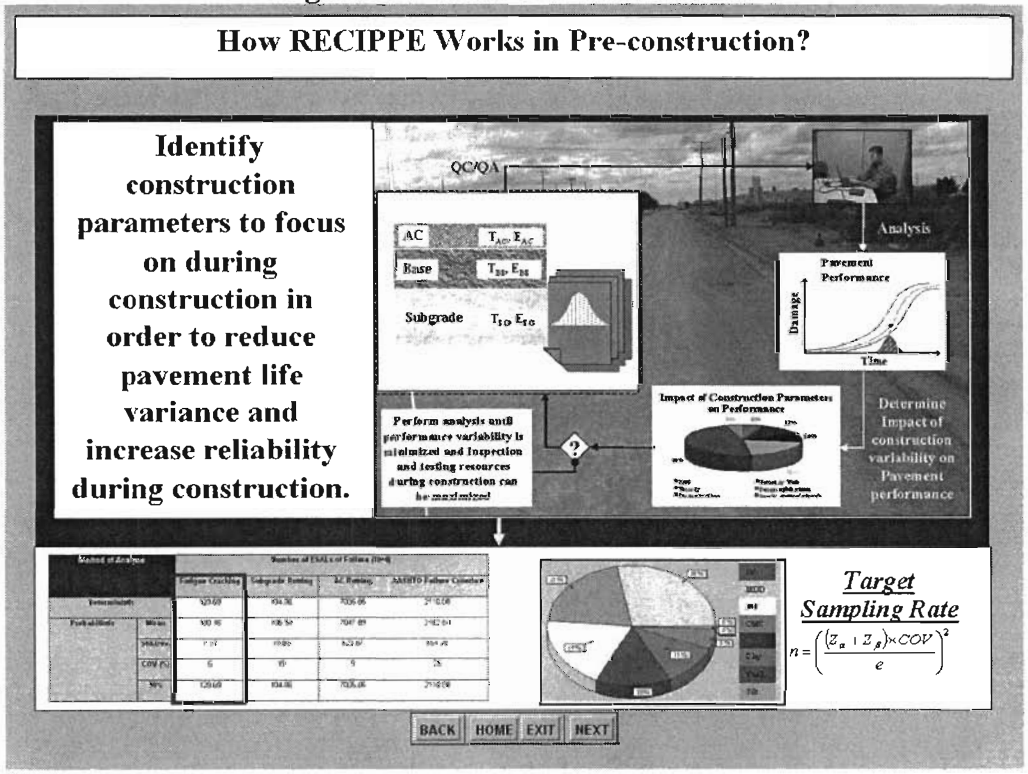
Figure 2.5 - Slide 5 of Introduction



RECIPPE is separated into two phases: pre-construction and post construction. In pre-construction, the optimization process is carried out to identify the most significant parameters where inspector resources and quality control process can be concentrated. In post-construction, the resolution of the procedures used in the field for quality control is carried out. This is the process where the identified significant parameters are used to determine a set of sampling frequencies for inspectors to use in control charts to insure quality assurance to the construction process.

The flowchart illustrates the progression of utilizing RECIPPE. Initially, a dry run can be carried out to identify significant pavement properties. This allows users to decide parameters to focus on when starting the analysis is pre-construction mode.

Figure 2.6 - Slide 6 of Introduction



How RECIPPE Works in Pre-construction?

Identify construction parameters to focus on during construction in order to reduce pavement life variance and increase reliability during construction.

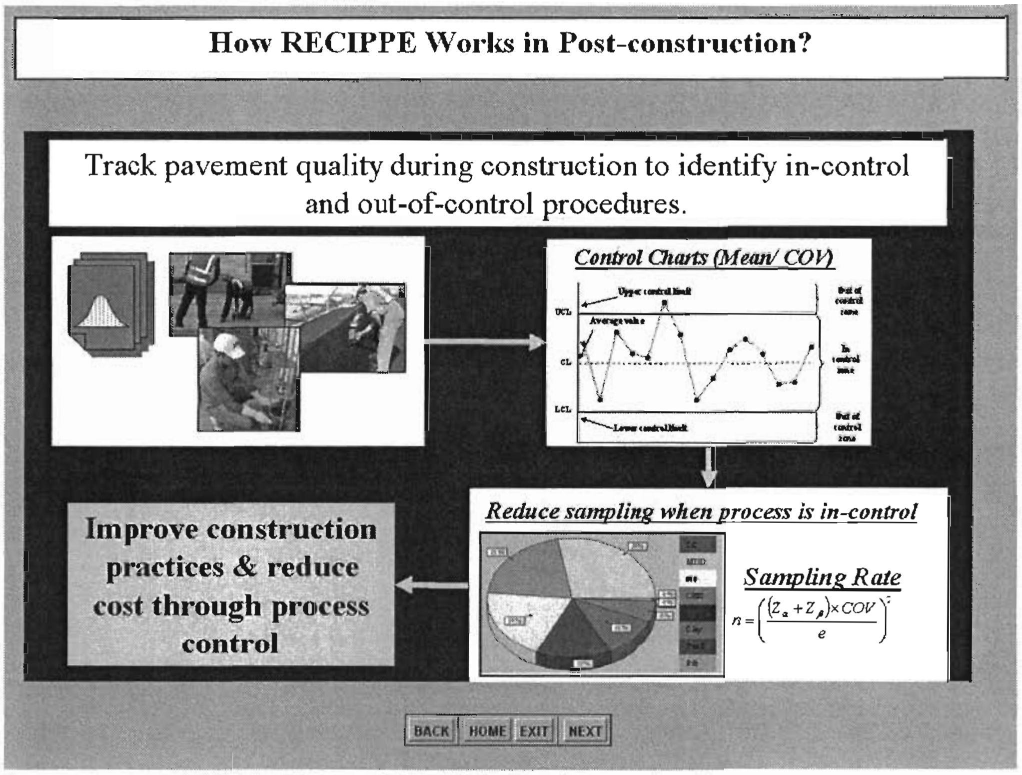
Perform analysis until performance variability is minimized and inspection and testing resources during construction can be maximized

Determine Impact of construction variability on Pavement performance

Target Sampling Rate

$$n = \left(\frac{(Z_\alpha + Z_\beta)\times COV}{e}\right)^2$$

Figure 2.7 - Slide 7 of Introduction



How RECIPPE Works in Post-construction?

Track pavement quality during construction to identify in-control and out-of-control procedures.

Control Charts (Mean/ COV)

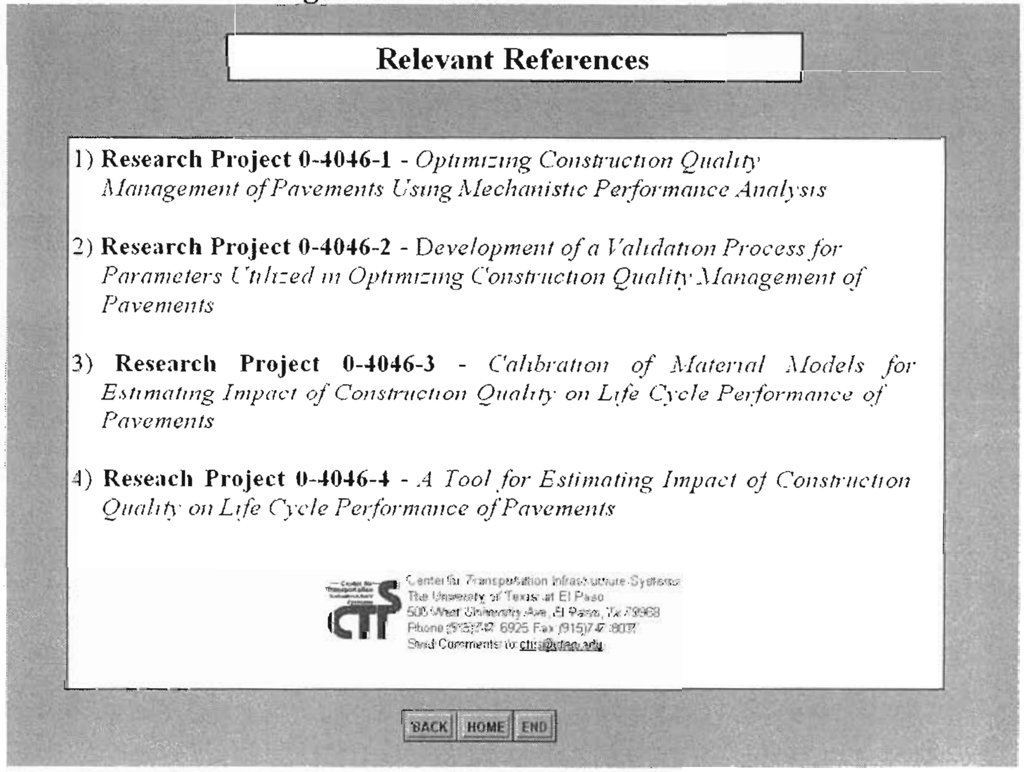
Reduce sampling when process is in-control

Sampling Rate

$$n = \left(\frac{(Z_\alpha + Z_\beta) \times COV}{e}\right)^2$$

Improve construction practices & reduce cost through process control

Figure 2.8 - Slide 8 of Introduction



Relevant References

1) **Research Project 0-4046-1** - *Optimizing Construction Quality Management of Pavements Using Mechanistic Performance Analysis*

2) **Research Project 0-4046-2** - *Development of a Validation Process for Parameters Utilized in Optimizing Construction Quality Management of Pavements*

3) **Research Project 0-4046-3** - *Calibration of Material Models for Estimating Impact of Construction Quality on Life Cycle Performance of Pavements*

4) **Reseach Project 0-4046-4** - *A Tool for Estimating Impact of Construction Quality on Life Cycle Performance of Pavements*

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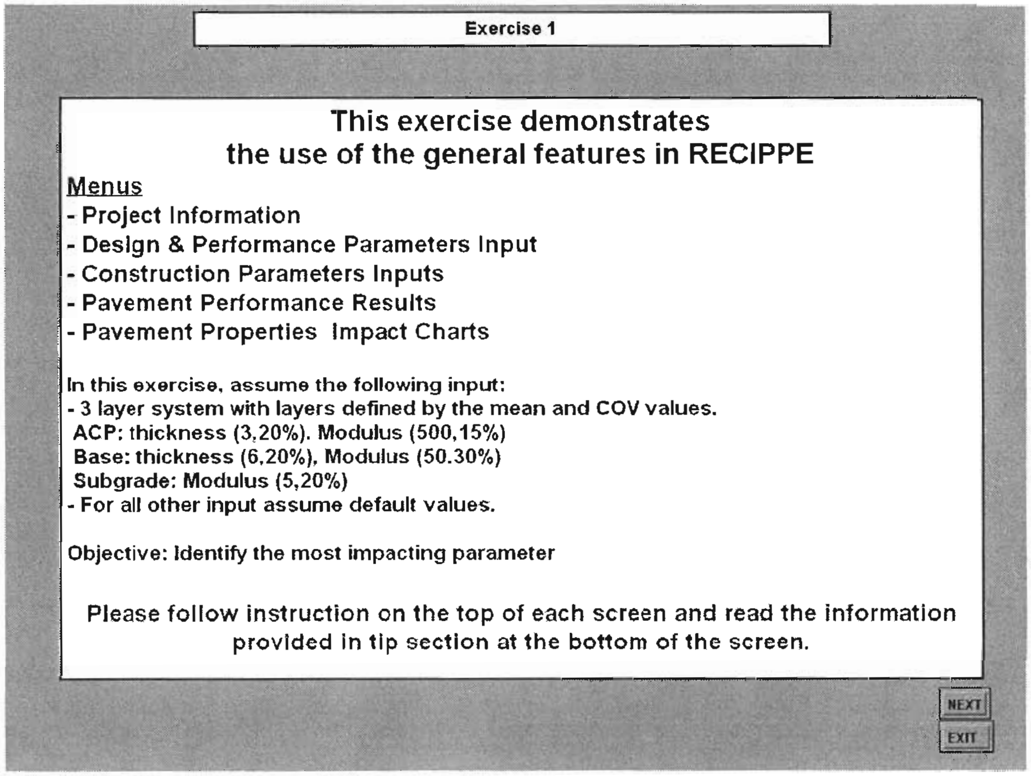
Figure 2.9 - Slide 9 of Introduction



Exercise 1

This exercise demonstrates
the use of the general features in RECIPPE

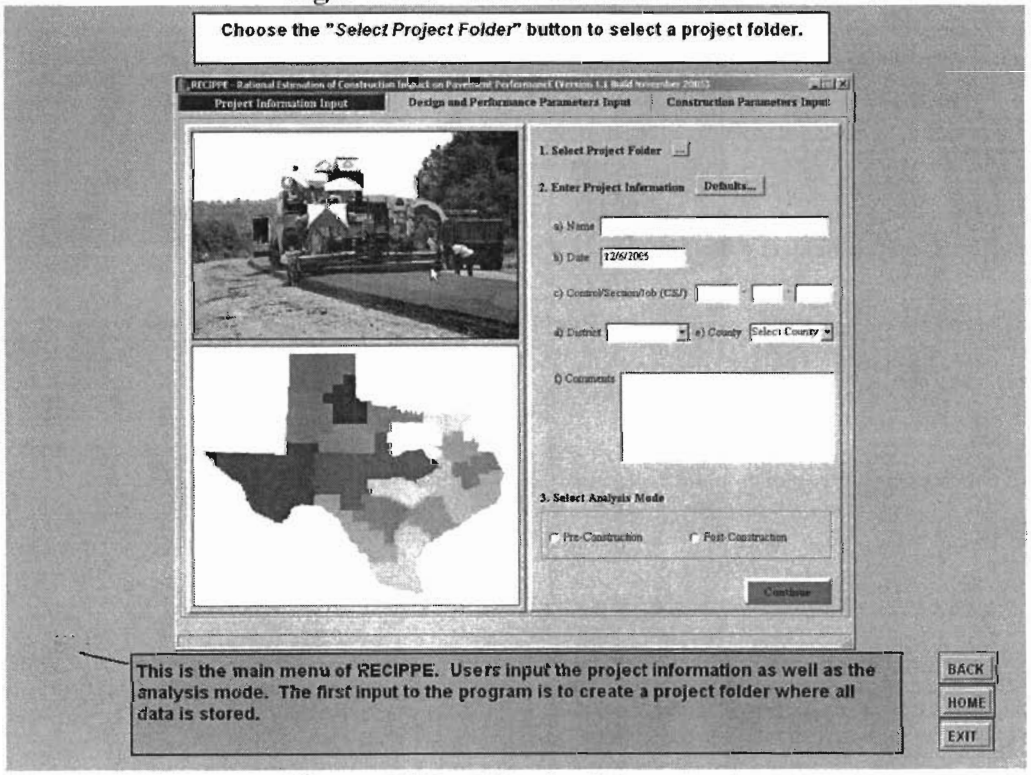
Menus
- Project Information
- Design & Performance Parameters Input
- Construction Parameters Inputs
- Pavement Performance Results
- Pavement Properties Impact Charts

In this exercise, assume the following input:
- 3 layer system with layers defined by the mean and COV values.
ACP: thickness (3,20%). Modulus (500,15%)
Base: thickness (6,20%). Modulus (50.30%)
Subgrade: Modulus (5,20%)
- For all other input assume default values.

Objective: Identify the most impacting parameter

Please follow instruction on the top of each screen and read the information provided in tip section at the bottom of the screen.

Figure 2.10 - Slide 1 of Exercise 1



Choose the "*Select Project Folder*" button to select a project folder.

b) Date 12/6/2005

This is the main menu of RECIPPE. Users input the project information as well as the analysis mode. The first input to the program is to create a project folder where all data is stored.

Figure 2.11 - Slide 2 of Exercise 1

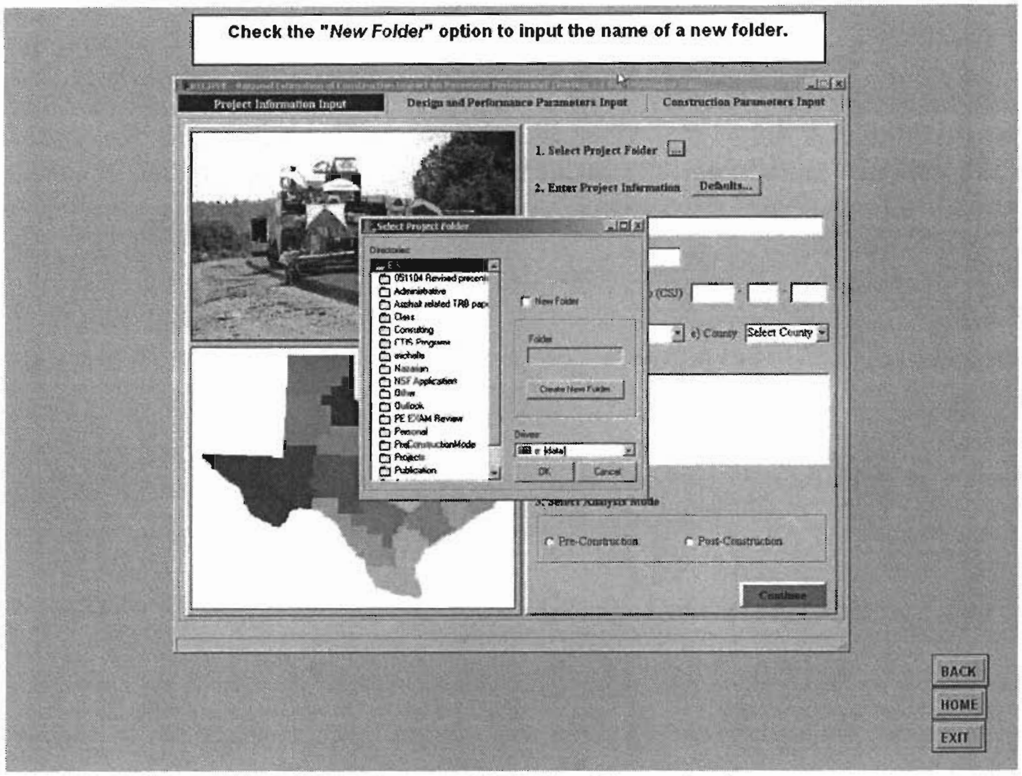
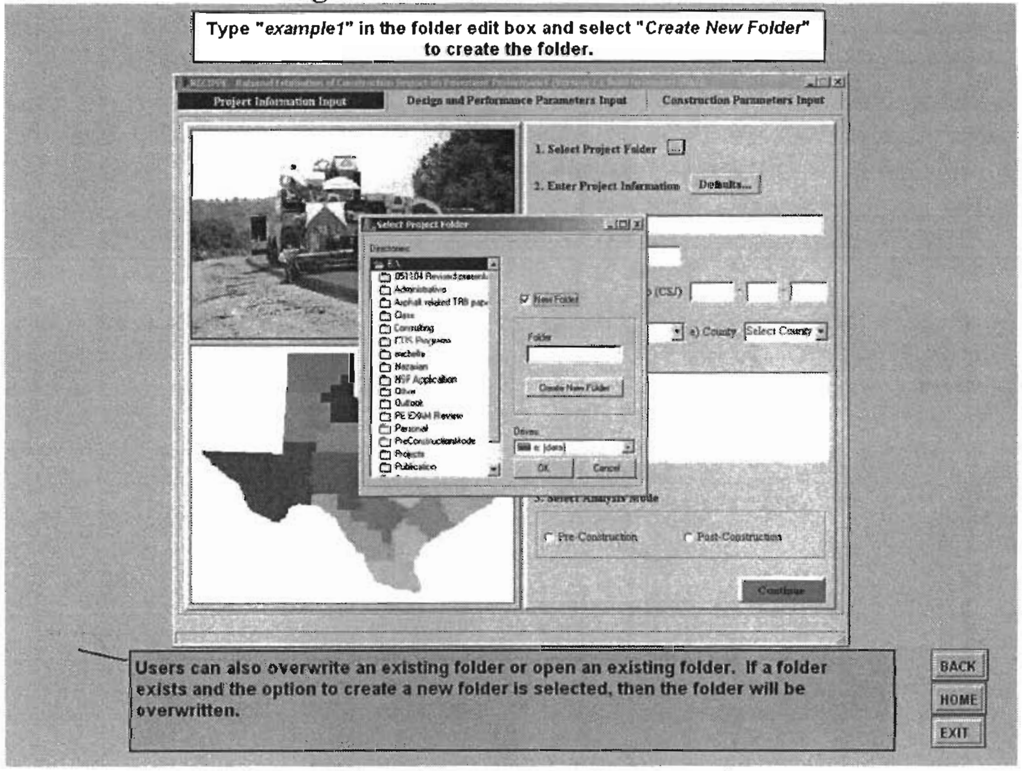
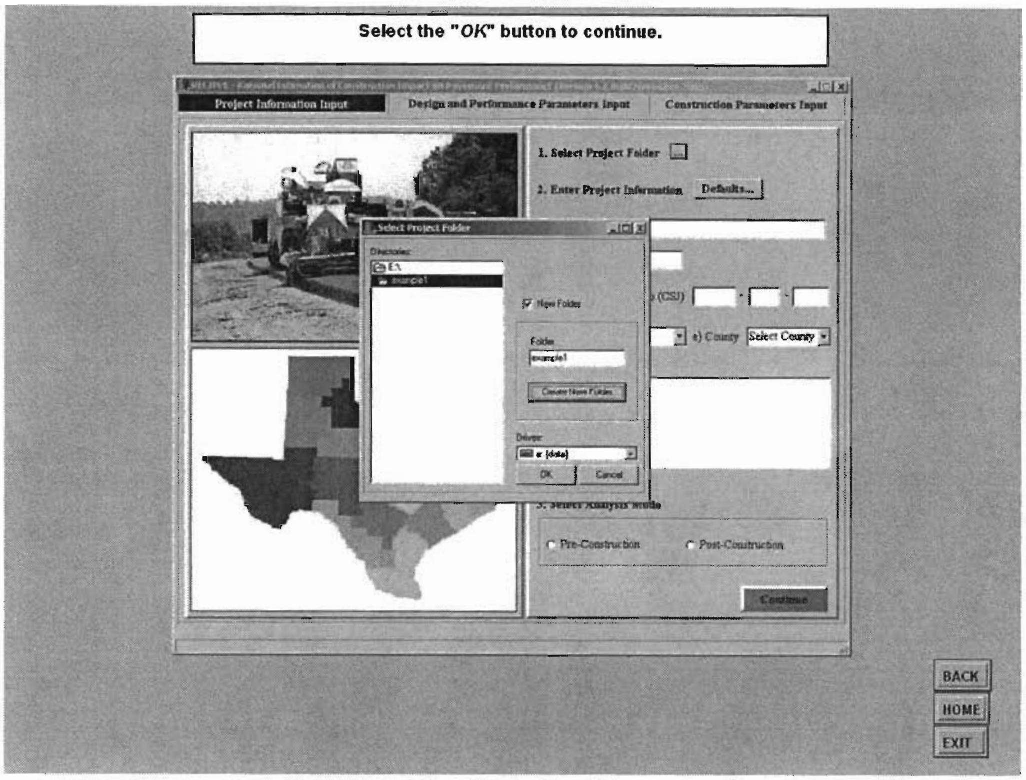

Check the "*New Folder*" option to input the name of a new folder.

Figure 2.12 - Slide 3 of Exercise 1


Type "*example1*" in the folder edit box and select "*Create New Folder*" to create the folder.

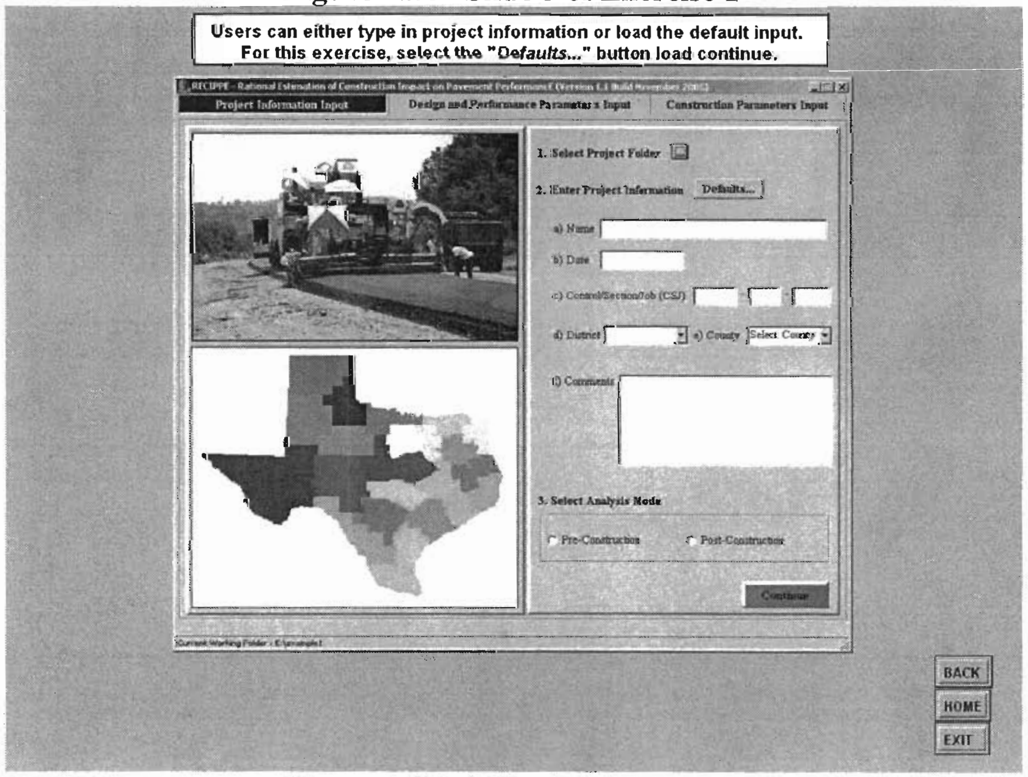
Users can also overwrite an existing folder or open an existing folder. If a folder exists and the option to create a new folder is selected, then the folder will be overwritten.

Figure 2.13 - Slide 4 of Exercise 1



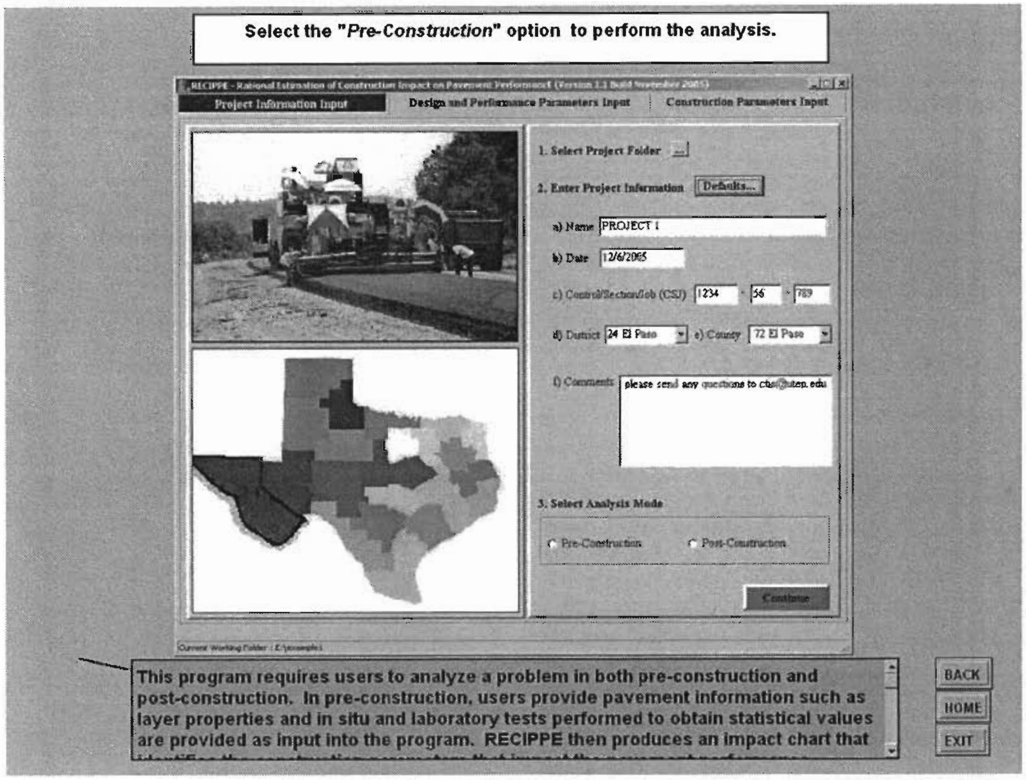
Select the "*OK*" button to continue.

Figure 2.14 - Slide 5 of Exercise 1



Users can either type in project information or load the default input.
For this exercise, select the "*Defaults...*" button load continue.

Figure 2.15 - Slide 6 of Exercise 1



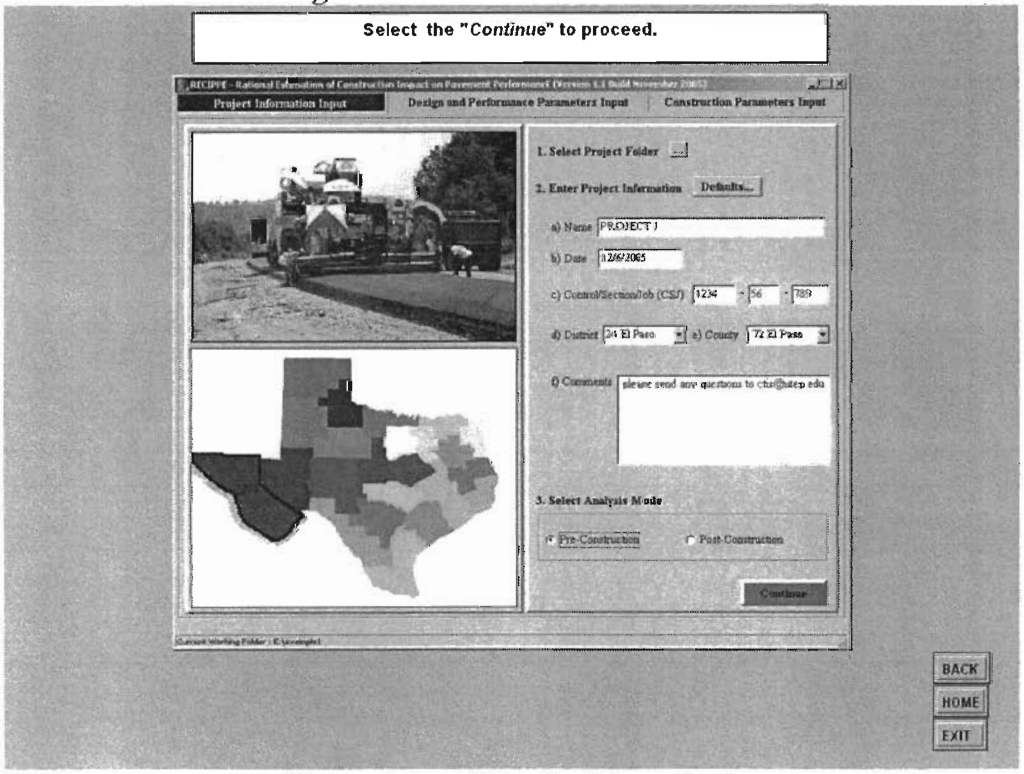
Select the "*Pre-Construction*" option to perform the analysis.

1. Select Project Folder
2. Enter Project Information
a) Name: PROJECT 1
b) Date: 12/6/2005
c) Control/Section/Job (CSJ): 1234 - 56 - 789
d) District: 24 El Paso e) County: 72 El Paso
f) Comments: please send any questions to ctis@utep.edu
3. Select Analysis Mode
○ Pre-Construction ○ Post-Construction

Current Working Folder : E:\example1

This program requires users to analyze a problem in both pre-construction and post-construction. In pre-construction, users provide pavement information such as layer properties and in situ and laboratory tests performed to obtain statistical values are provided as input into the program. RECIPPE then produces an impact chart that

Figure 2.16 - Slide 7 of Exercise 1

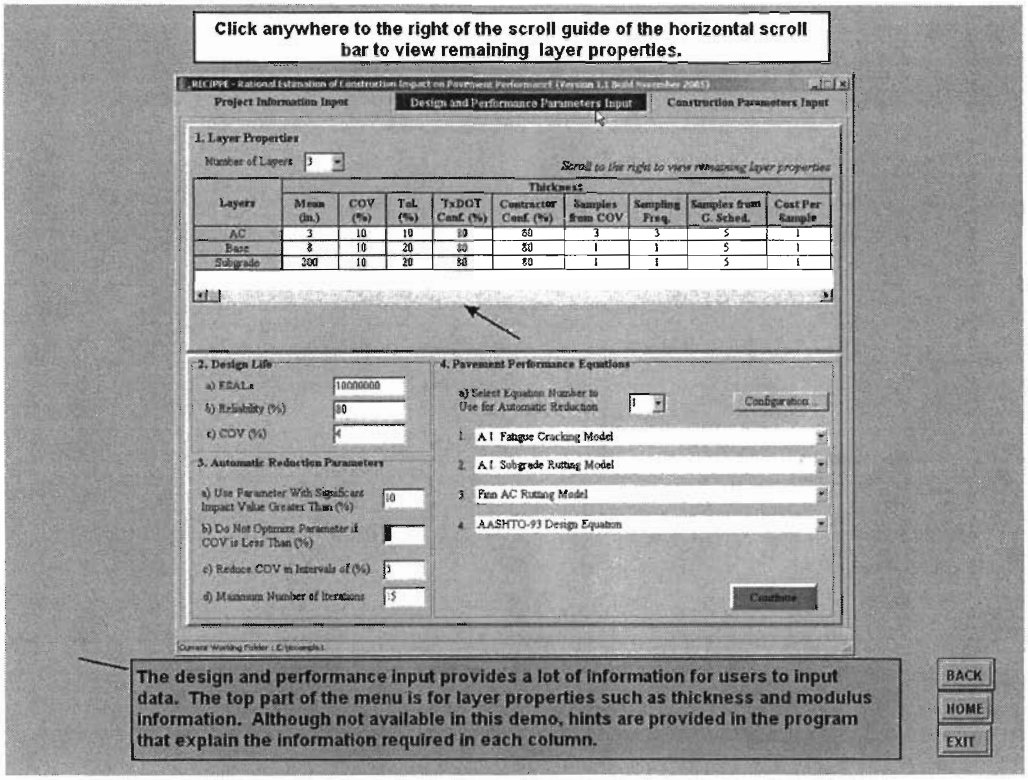


Select the "*Continue*" to proceed.

1. Select Project Folder
2. Enter Project Information
a) Name: PROJECT 1
b) Date: 12/6/2005
c) Control/Section/Job (CSJ): 1234 - 56 - 789
d) District: 24 El Paso e) County: 72 El Paso
f) Comments: please send any questions to ctis@utep.edu
3. Select Analysis Mode
● Pre-Construction ○ Post-Construction

Current Working Folder : E:\example1

Figure 2.17 - Slide 8 of Exercise 1


Click anywhere to the right of the scroll guide of the horizontal scroll bar to view remaining layer properties.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	10	10	80	80	3	3	5	1
Base	8	10	20	80	80	1	1	5	1
Subgrade	300	10	20	80	80	1	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%):

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 5

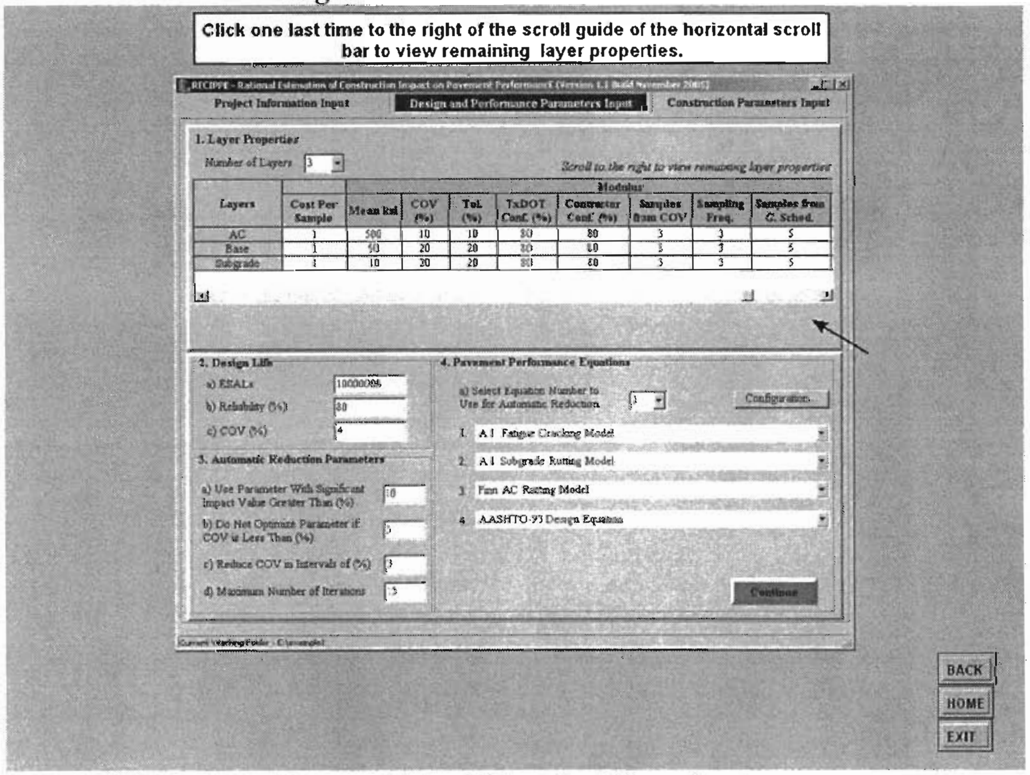
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

The design and performance input provides a lot of information for users to input data. The top part of the menu is for layer properties such as thickness and modulus information. Although not available in this demo, hints are provided in the program that explain the information required in each column.

Figure 2.18 - Slide 9 of Exercise 1


Click one last time to the right of the scroll guide of the horizontal scroll bar to view remaining layer properties.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers		Modulus							
	Cost Per Sample	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.
AC	1	500	10	10	80	80	3	3	5
Base	1	50	20	20	80	80	3	3	5
Subgrade	1	10	20	20	80	80	3	3	5

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 3

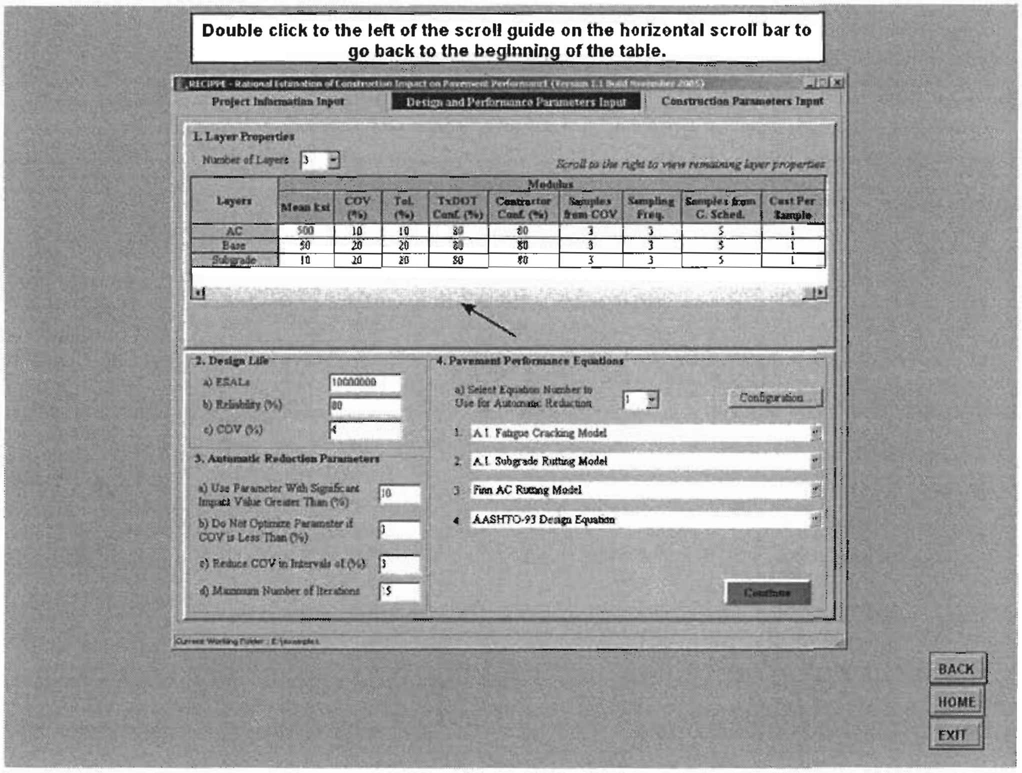
d) Maximum Number of Iterations: 5

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.19 - Slide 10 of Exercise 1



Double click to the left of the scroll guide on the horizontal scroll bar to go back to the beginning of the table.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	500	10	10	80	80	3	3	5	1
Base	50	20	20	80	80	3	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 5

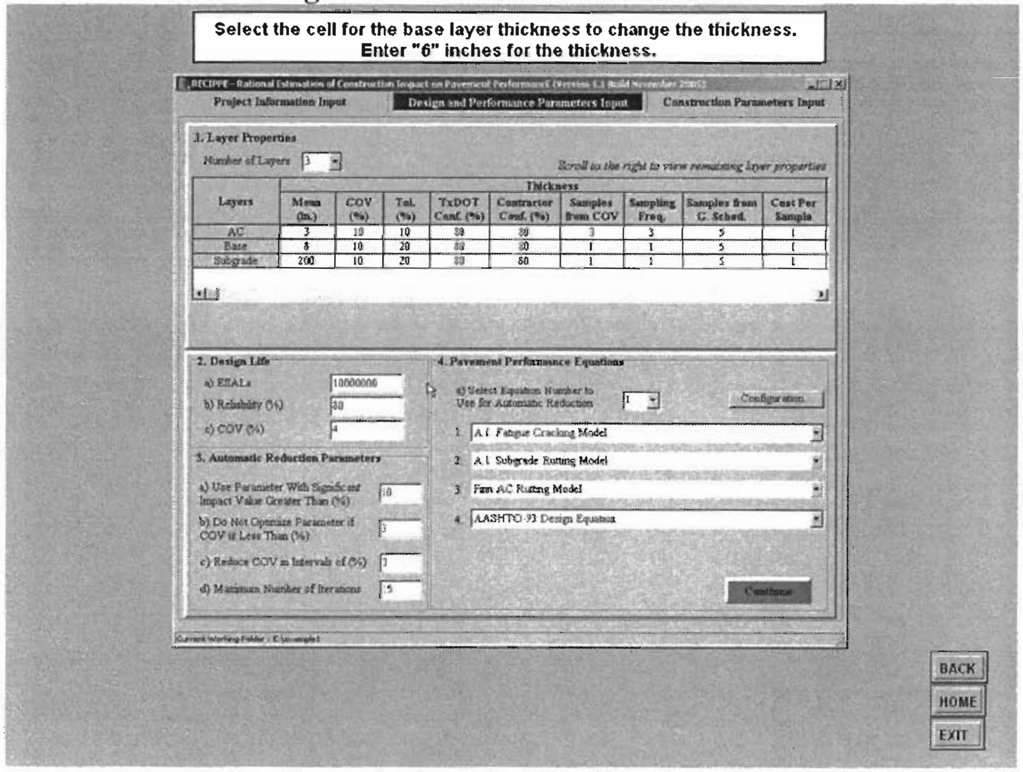
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\example1

Figure 2.20 - Slide 11 of Exercise 1



Select the cell for the base layer thickness to change the thickness. Enter "6" inches for the thickness.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	10	10	80	80	3	3	5	1
Base	8	10	20	80	80	1	1	5	1
Subgrade	200	10	20	80	80	1	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 5

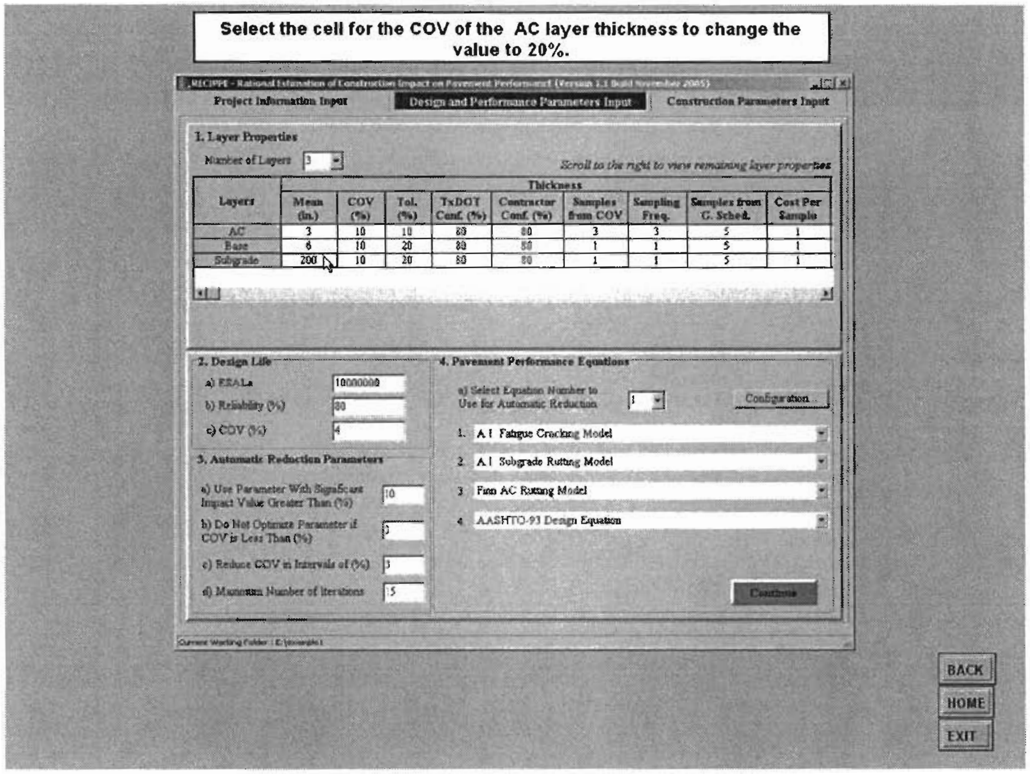
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\example1

Figure 2.21 - Slide 12 of Exercise 1


Select the cell for the COV of the AC layer thickness to change the value to 20%.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	10	10	80	80	3	3	5	1
Base	6	10	20	80	80	1	1	5	1
Subgrade	200	10	20	80	80	1	1	5	1

2. Design Life

a) ESALs 10000000

b) Reliability (%) 80

c) COV (%) 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%) 10

b) Do Not Optimize Parameter if COV is Less Than (%) 3

c) Reduce COV in Intervals of (%) 3

d) Maximum Number of Iterations 5

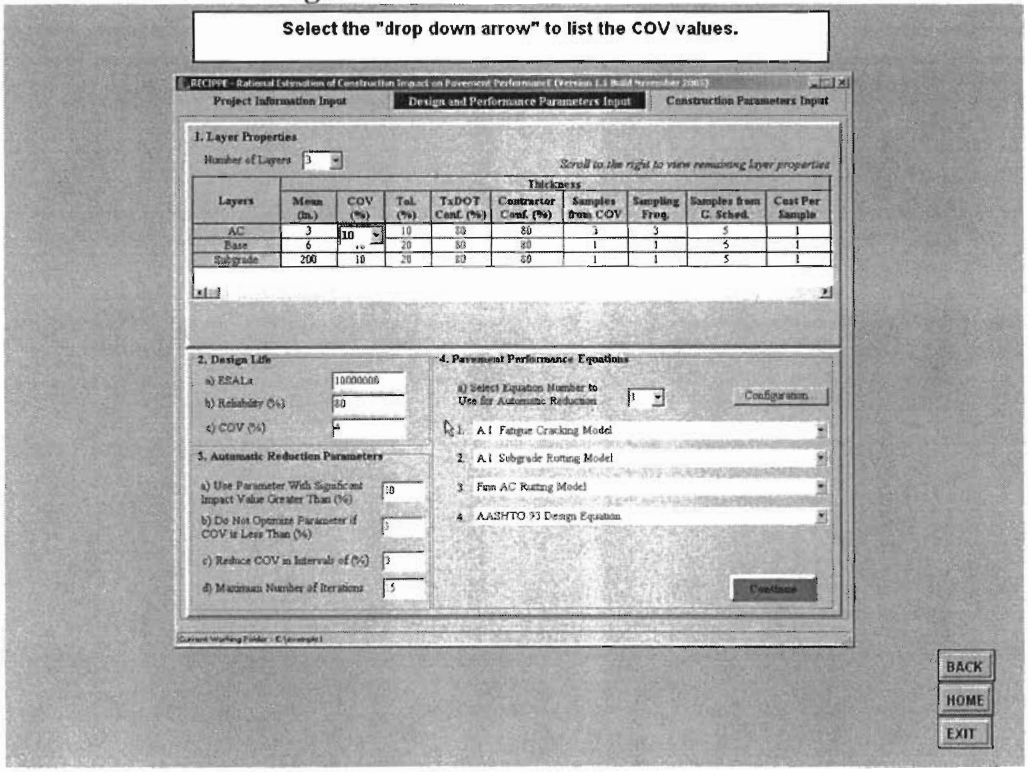
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\example1

Figure 2.22 - Slide 13 of Exercise 1


Select the "drop down arrow" to list the COV values.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	10	10	80	80	3	3	5	1
Base	6	10	20	80	80	1	1	5	1
Subgrade	200	10	20	80	80	1	1	5	1

2. Design Life

a) ESALs 10000000

b) Reliability (%) 80

c) COV (%) 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%) 10

b) Do Not Optimize Parameter if COV is Less Than (%) 3

c) Reduce COV in Intervals of (%) 3

d) Maximum Number of Iterations 5

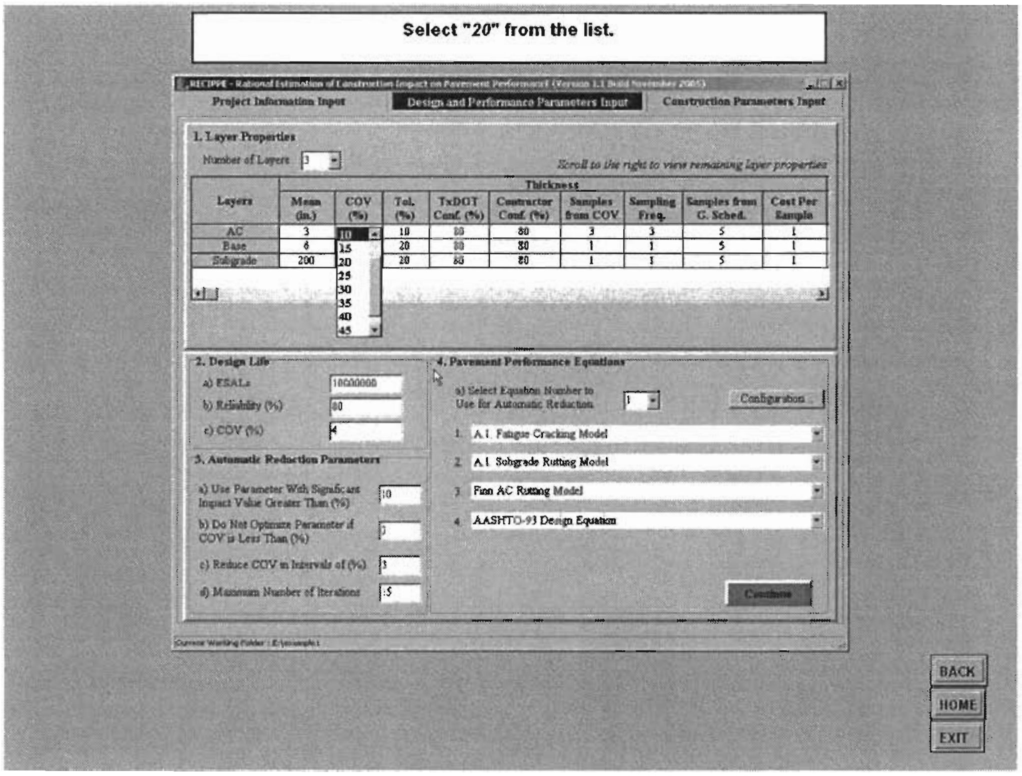
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\example1

Figure 2.23 - Slide 14 of Exercise 1



Select "*20*" from the list.

RECIPPE - Rational Estimation of Construction Impact on Pavement PerformancE (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	10	10	80	80	3	3	5	1
Base	6	15	20	80	80	1	1	5	1
Subgrade	200	20	20	80	80	1	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

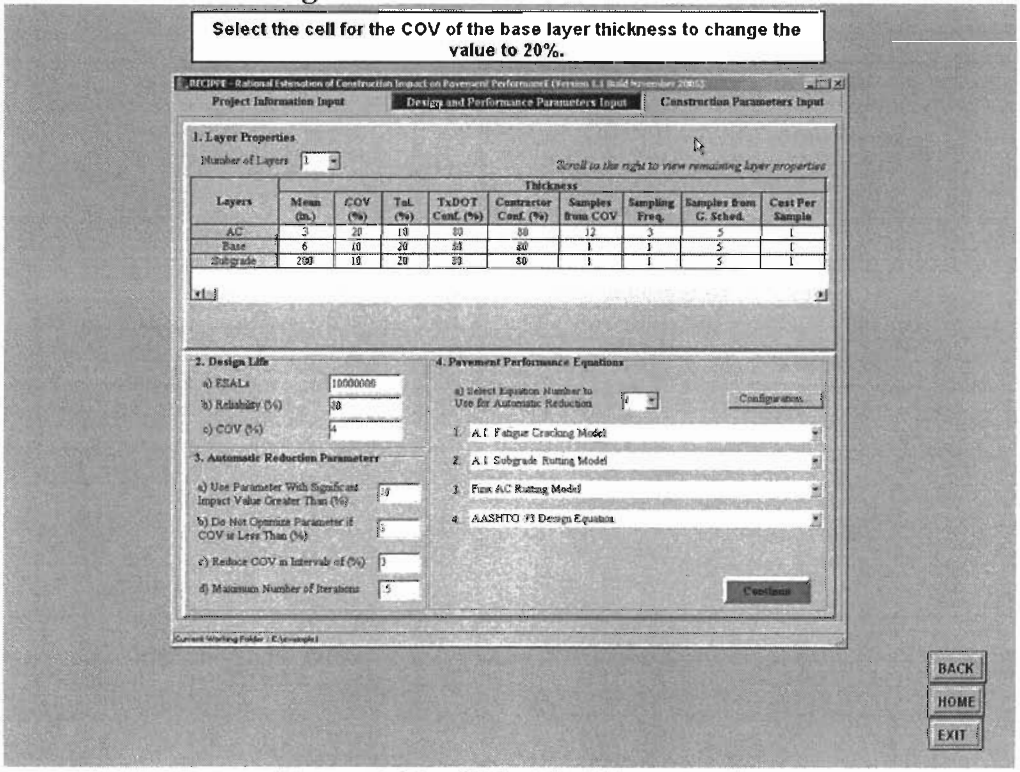
d) Maximum Number of Iterations: 5

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.24 - Slide 15 of Exercise 1



Select the cell for the COV of the base layer thickness to change the value to 20%.

RECIPPE - Rational Estimation of Construction Impact on Pavement PerformancE (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	10	20	80	80	1	1	5	1
Subgrade	200	10	20	80	80	1	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

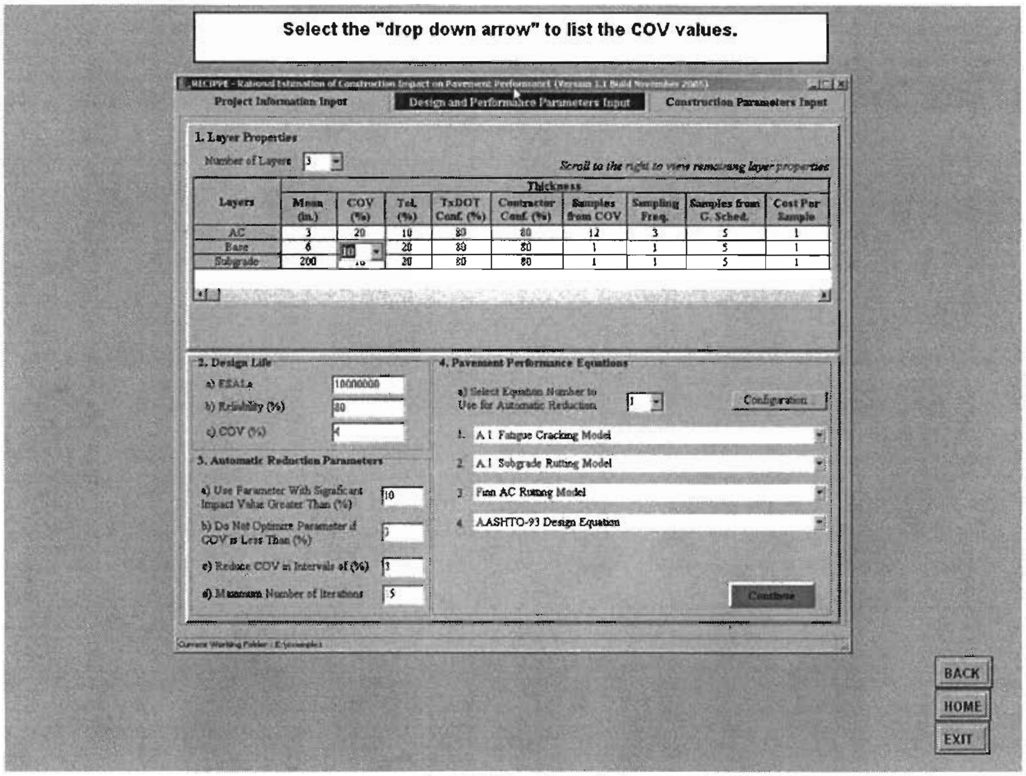
d) Maximum Number of Iterations: 5

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.25 - Slide 16 of Exercise 1


Select the "drop down arrow" to list the COV values.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	10	20	80	80	1	1	5	1
Subgrade	200	[illegible]	20	80	80	1	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

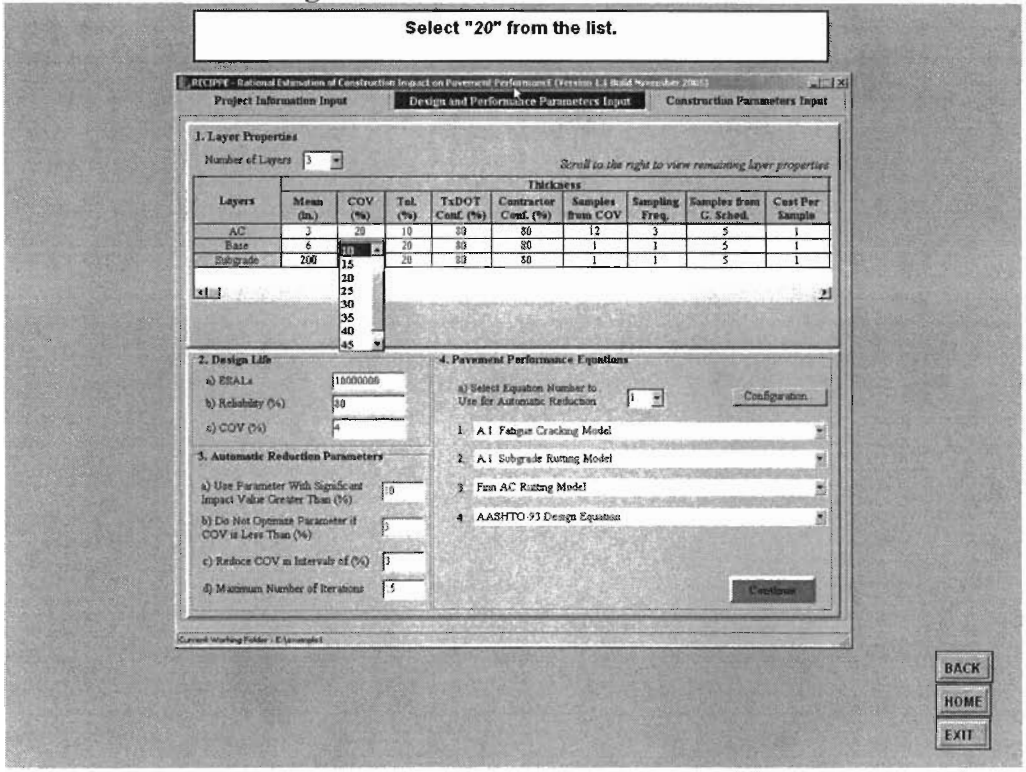
d) Maximum Number of Iterations: 5

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.26 - Slide 17 of Exercise 1


Select "20" from the list.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	10	20	80	80	1	1	5	1
Subgrade	200	[illegible]	20	80	80	1	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

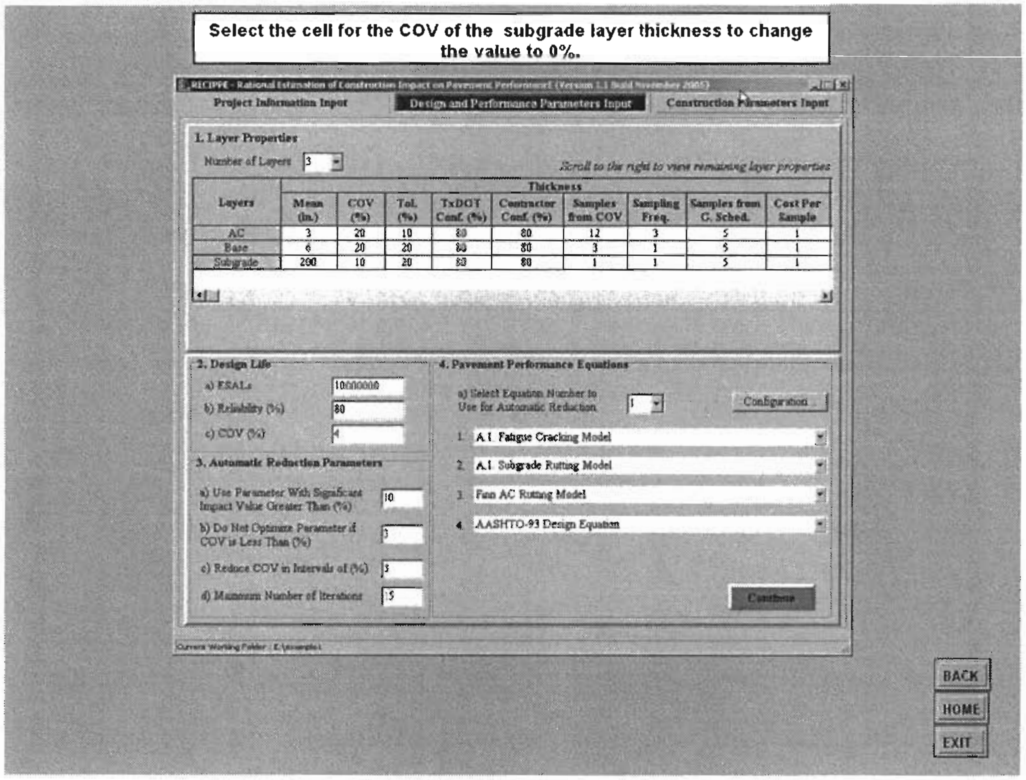
d) Maximum Number of Iterations: 5

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.27 - Slide 18 of Exercise 1


Select the cell for the COV of the subgrade layer thickness to change the value to 0%.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	10	20	80	80	1	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 15

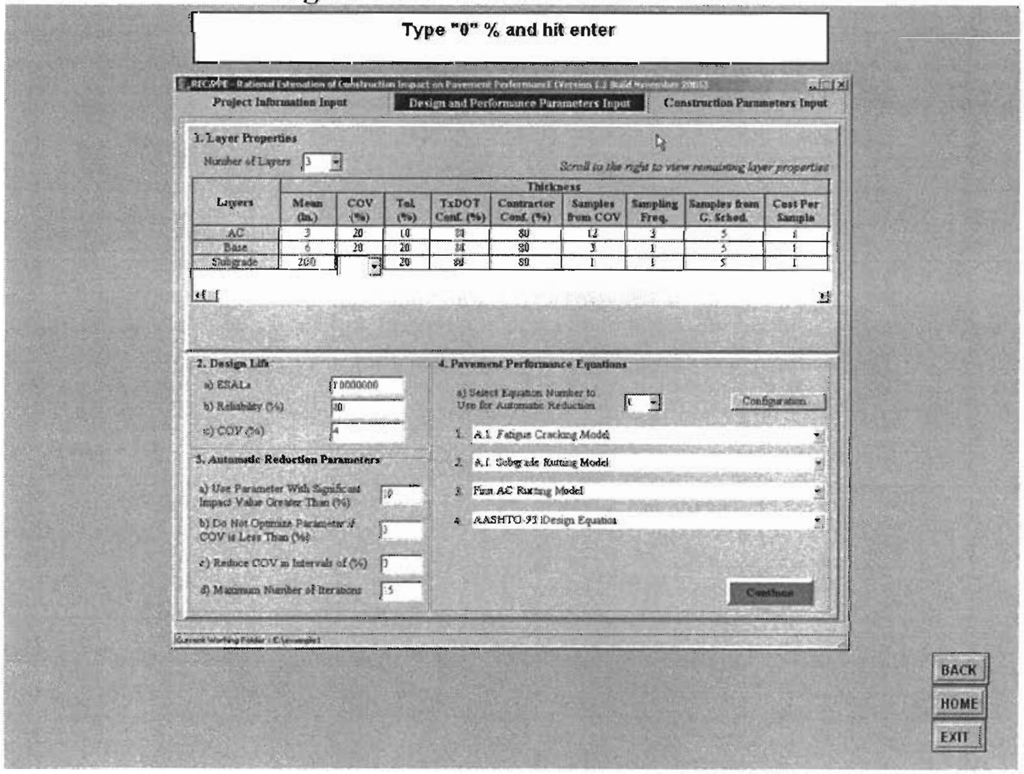
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\example1

Figure 2.28 - Slide 19 of Exercise 1


Type "0" % and hit enter

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200		20	80	80	1	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 15

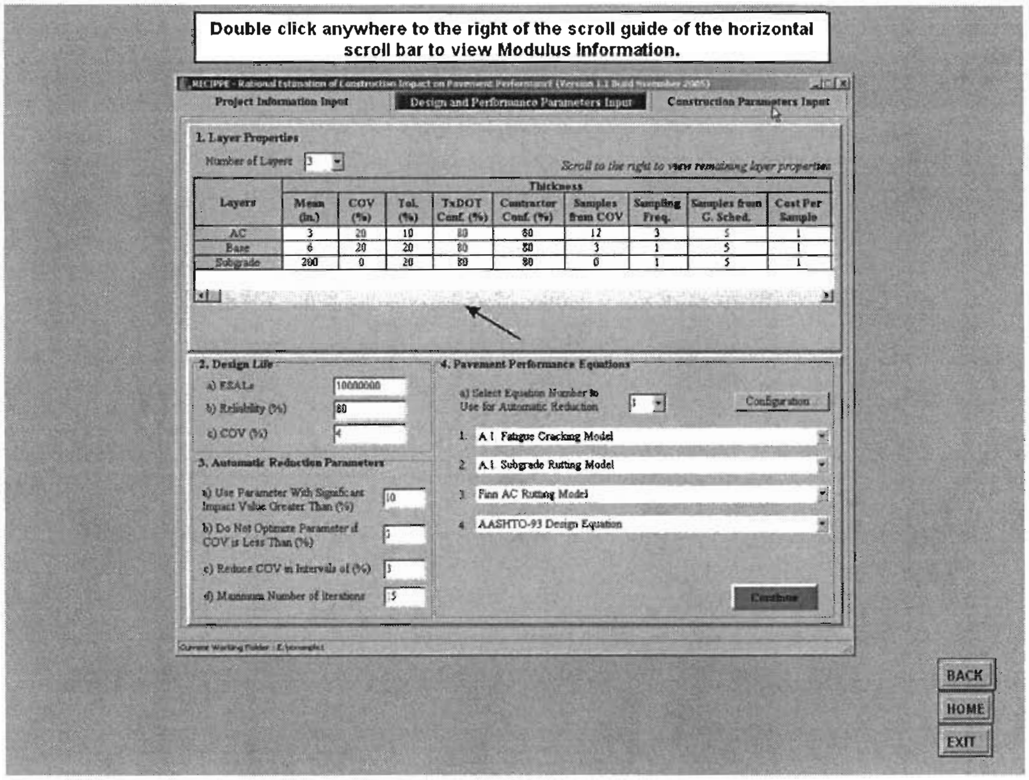
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\example1

Figure 2.29 - Slide 20 of Exercise 1



Double click anywhere to the right of the scroll guide of the horizontal scroll bar to view Modulus Information.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

	Thickness								
Layers	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 5

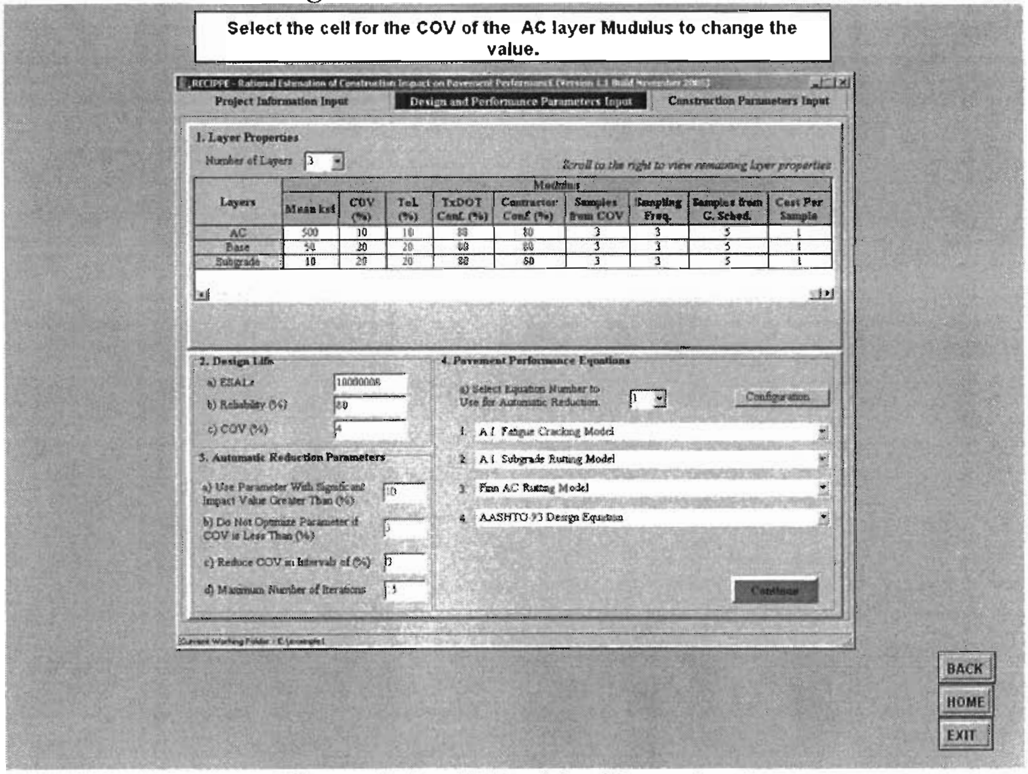
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\example1

Figure 2.30 - Slide 21 of Exercise 1



Select the cell for the COV of the AC layer Mudulus to change the value.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

	Modulus								
Layers	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	10	10	80	80	3	3	5	1
Base	50	20	20	80	80	3	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 5

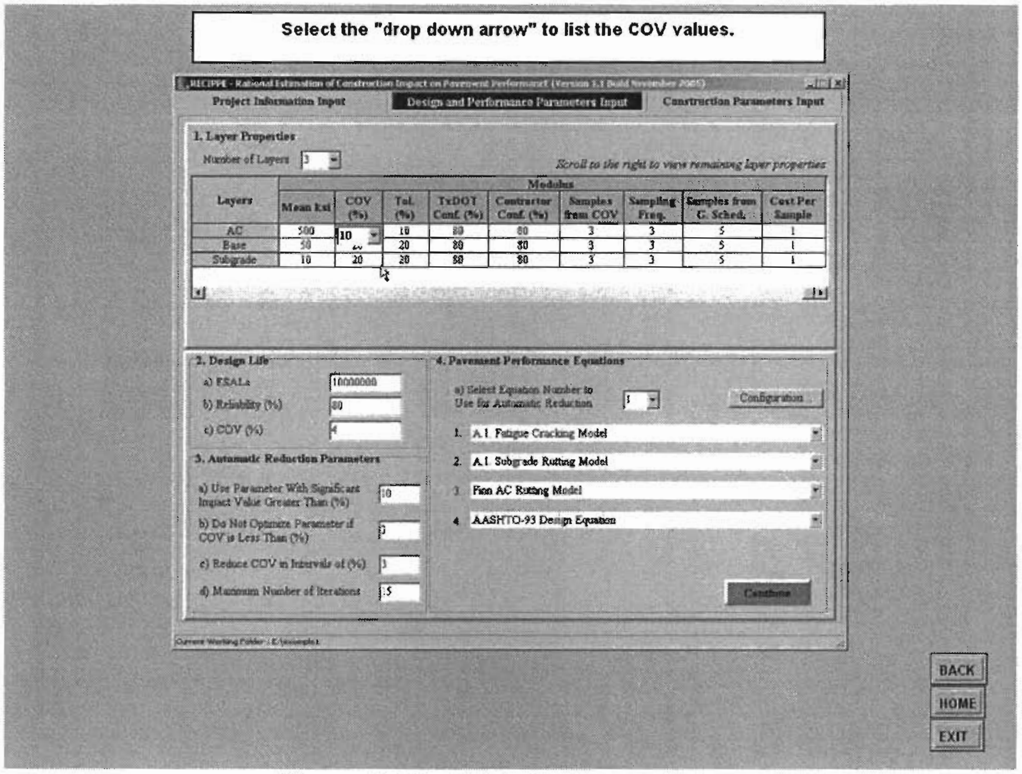
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\example1

Figure 2.31 - Slide 22 of Exercise 1



Select the "drop down arrow" to list the COV values.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	10	10	80	80	3	3	5	1
Base	50	20	20	80	80	3	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs 10000000

b) Reliability (%) 80

c) COV (%) 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%) 10

b) Do Not Optimize Parameter if COV is Less Than (%) 3

c) Reduce COV in Intervals of (%) 3

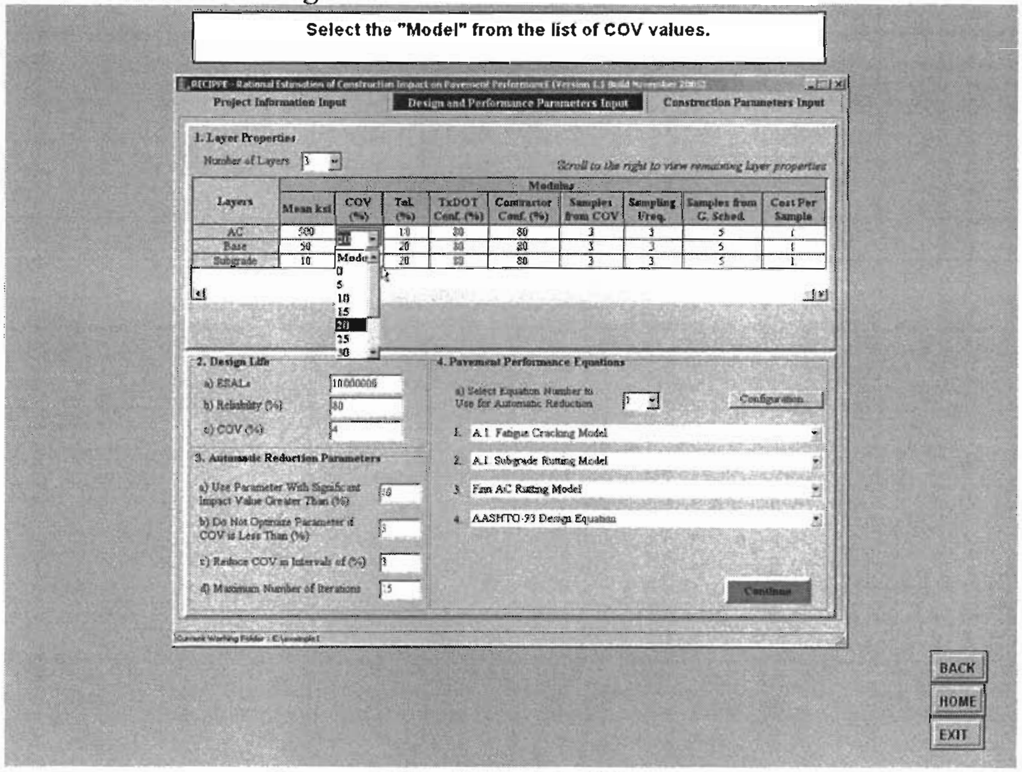
d) Maximum Number of Iterations 15

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction 1

1. A.1 Fatigue Cracking Model
2. A.1 Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.32 - Slide 23 of Exercise 1



Select the "Model" from the list of COV values.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	[illegible]	10	80	80	3	3	5	1
Base	50	[illegible]	20	80	80	3	3	5	1
Subgrade	10	[illegible]	20	80	80	3	3	5	1

2. Design Life

a) ESALs 10000000

b) Reliability (%) 80

c) COV (%) 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%) 10

b) Do Not Optimize Parameter if COV is Less Than (%) 3

c) Reduce COV in Intervals of (%) 3

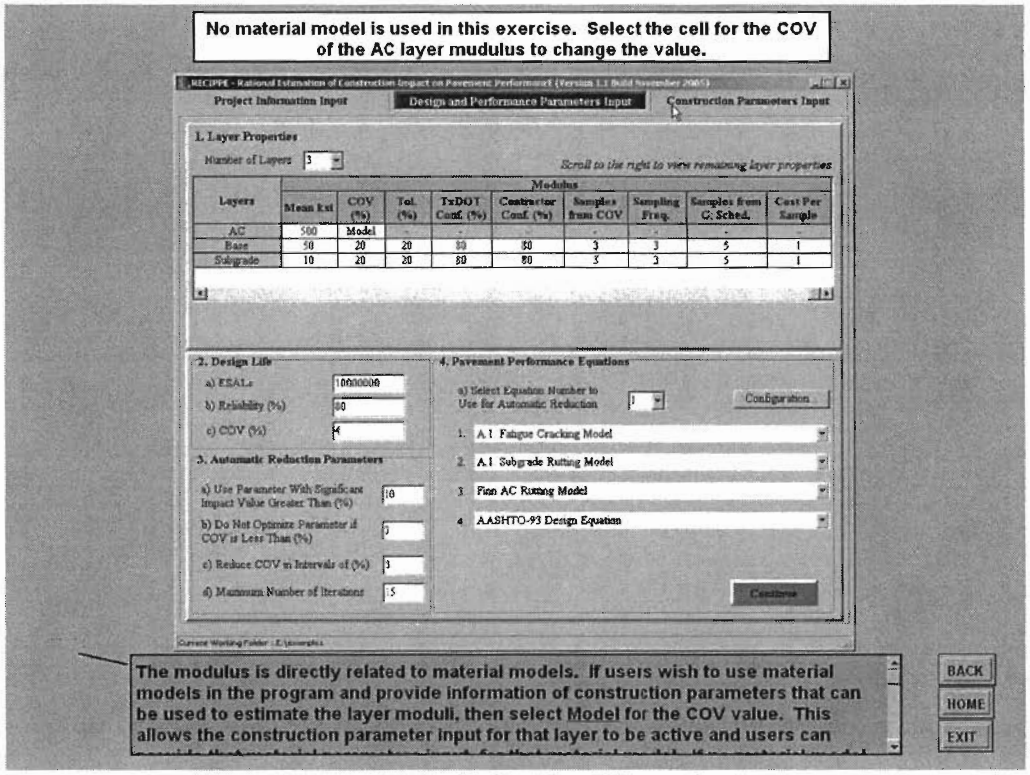
d) Maximum Number of Iterations 15

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction 1

1. A.1 Fatigue Cracking Model
2. A.1 Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.33 - Slide 24 of Exercise 1



No material model is used in this exercise. Select the cell for the COV of the AC layer mudulus to change the value.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	500	Model	-	-	-	-	-	-	-
Base	50	20	20	80	80	3	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 15

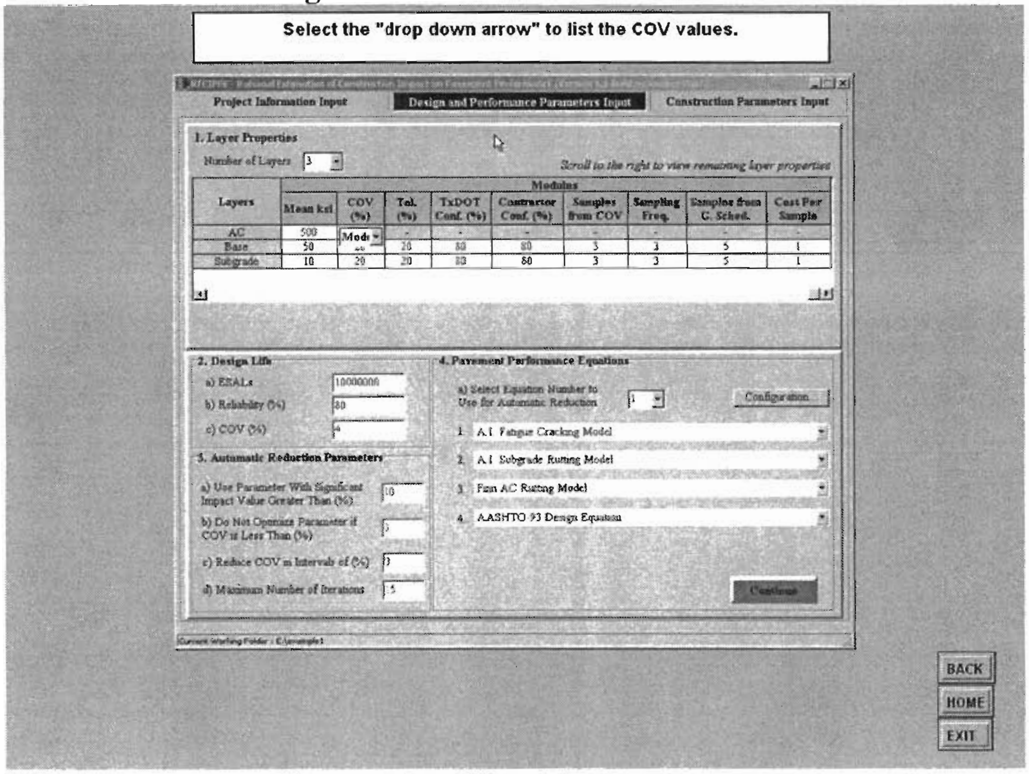
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.1 Fatigue Cracking Model
2. A.1 Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

The modulus is directly related to material models. If users wish to use material models in the program and provide information of construction parameters that can be used to estimate the layer moduli, then select Model for the COV value. This allows the construction parameter input for that layer to be active and users can

Figure 2.34 - Slide 25 of Exercise 1



Select the "drop down arrow" to list the COV values.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	500	Mode	-	-	-	-	-	-	-
Base	50	20	20	80	80	3	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

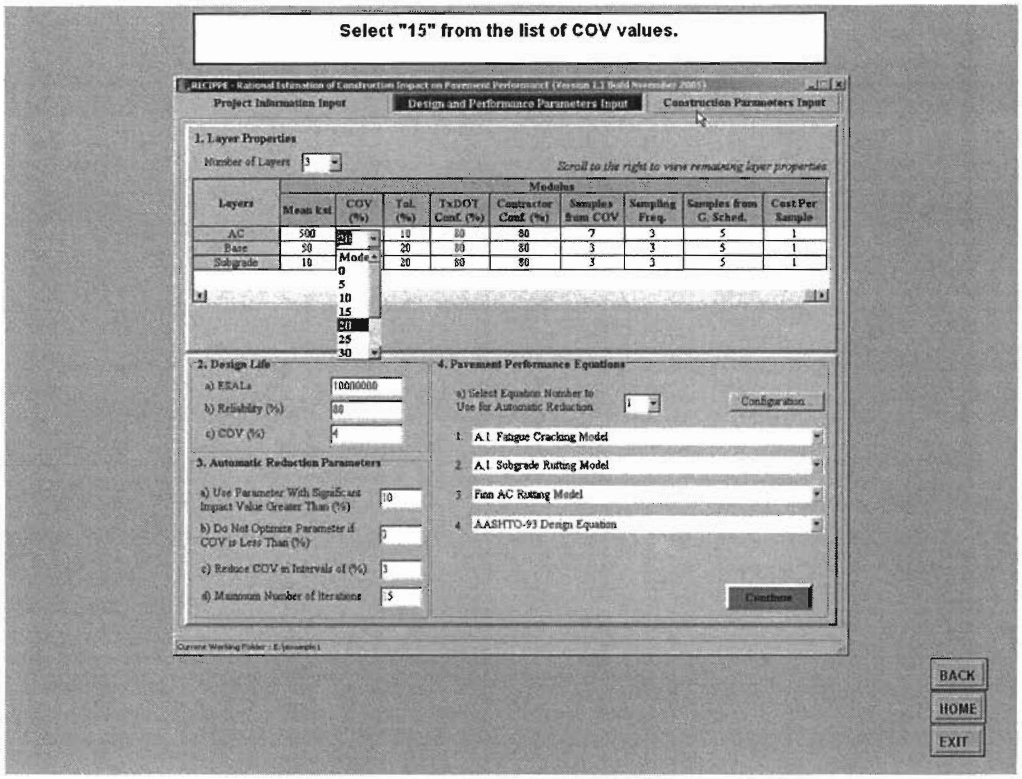
d) Maximum Number of Iterations: 15

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.1 Fatigue Cracking Model
2. A.1 Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.35 - Slide 26 of Exercise 1



Select "15" from the list of COV values.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	20	10	80	80	7	3	5	1
Base	50		20	80	80	3	3	5	1
Subgrade	10		20	80	80	3	3	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 3

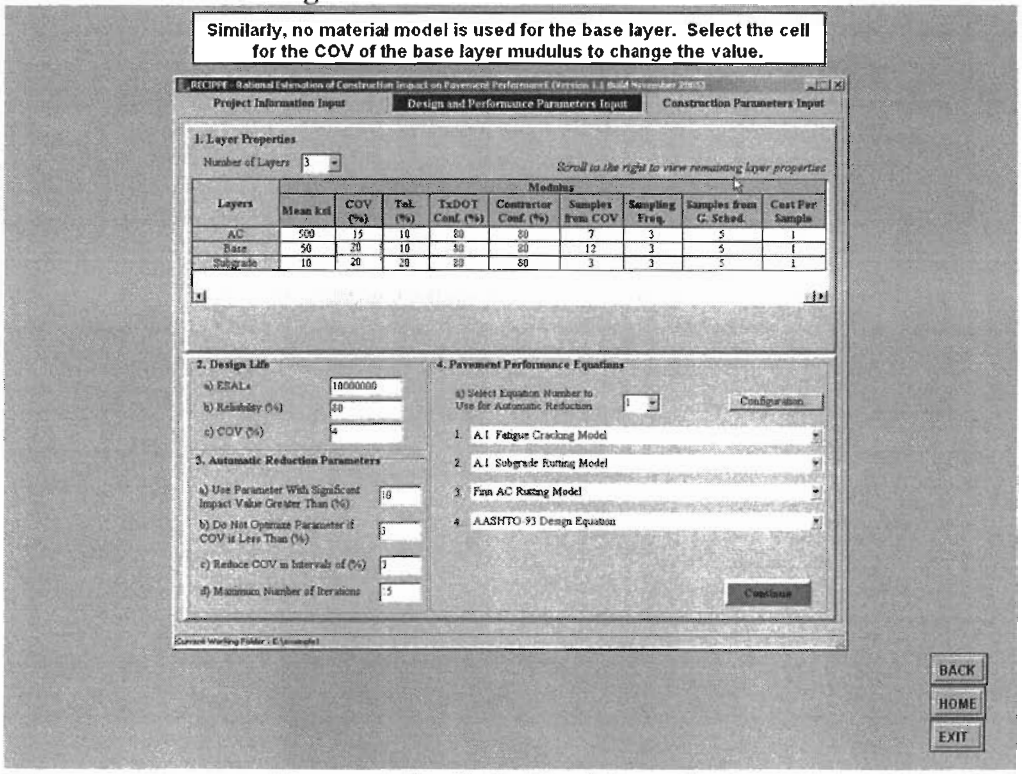
d) Maximum Number of Iterations: 5

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.36 - Slide 27 of Exercise 1



Similarly, no material model is used for the base layer. Select the cell for the COV of the base layer mudulus to change the value.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	15	10	80	80	7	3	5	1
Base	50	20	10	80	80	12	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 3

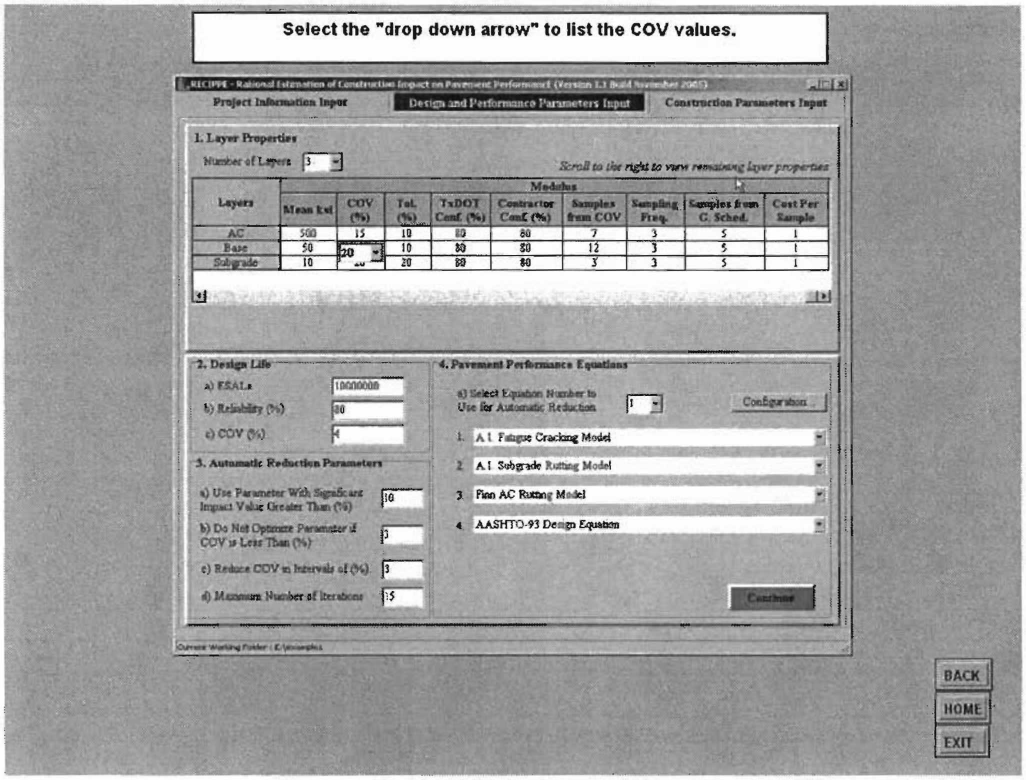
d) Maximum Number of Iterations: 5

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.37 - Slide 28 of Exercise 1



Select the "drop down arrow" to list the COV values.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

Project Information Input | Design and Performance Parameters Input | Construction Parameters Input

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	15	10	80	80	7	3	5	1
Base	50	20	10	80	80	12	3	5	1
Subgrade	10		20	80	80	3	3	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 15

4. Pavement Performance Equations

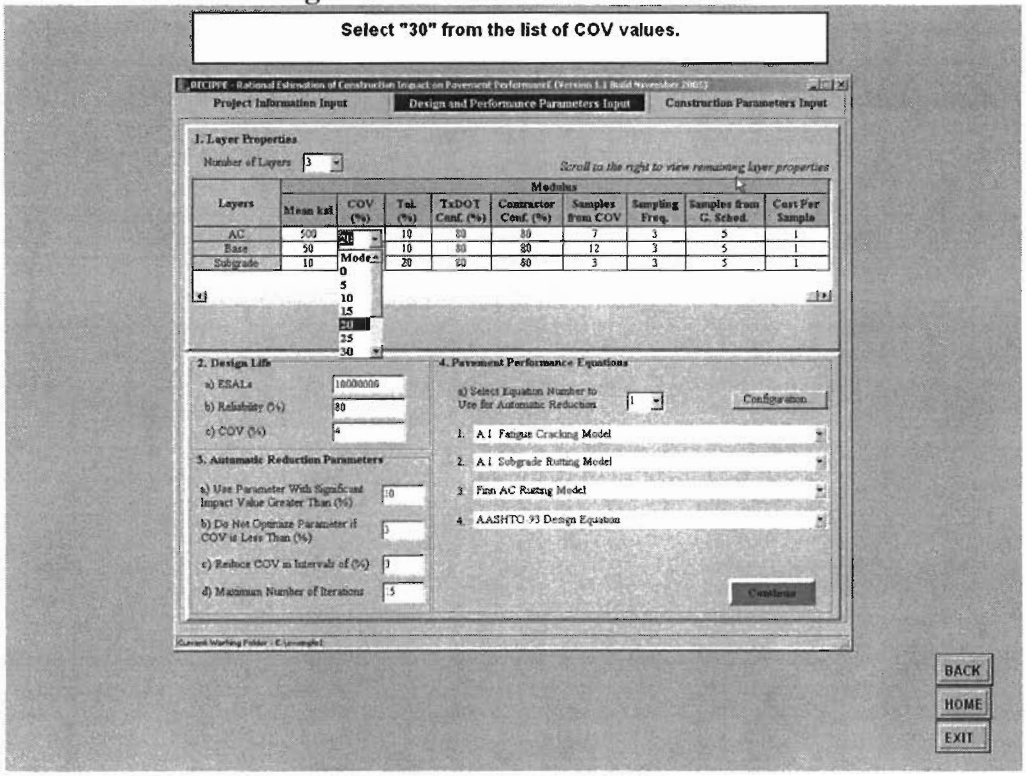
a) Select Equation Number to Use for Automatic Reduction: 1

Configuration

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Continue

Figure 2.38 - Slide 29 of Exercise 1



Select "30" from the list of COV values.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

Project Information Input | Design and Performance Parameters Input | Construction Parameters Input

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	20	10	80	80	7	3	5	1
Base	50		10	80	80	12	3	5	1
Subgrade	10		20	80	80	3	3	5	1

Mode
0
5
10
15
20
25
30

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 15

4. Pavement Performance Equations

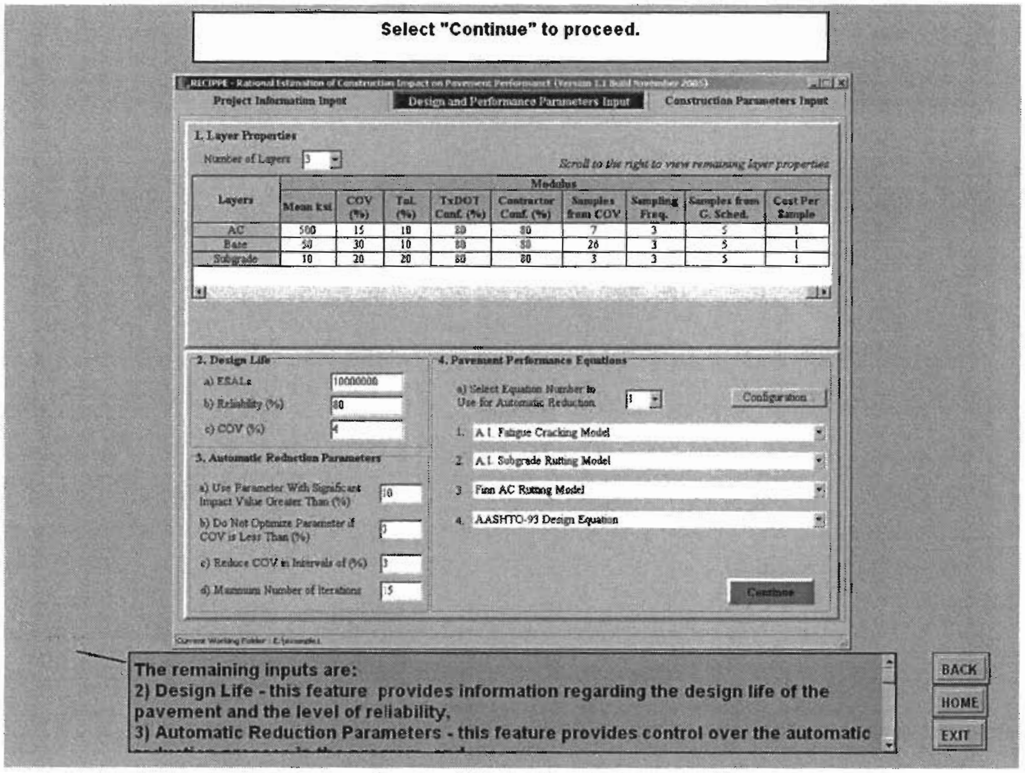
a) Select Equation Number to Use for Automatic Reduction: 1

Configuration

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Continue

Figure 2.39 - Slide 30 of Exercise 1



Select "Continue" to proceed.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	15	10	80	80	7	3	5	1
Base	50	30	10	80	80	26	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs: 10000000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 0

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 15

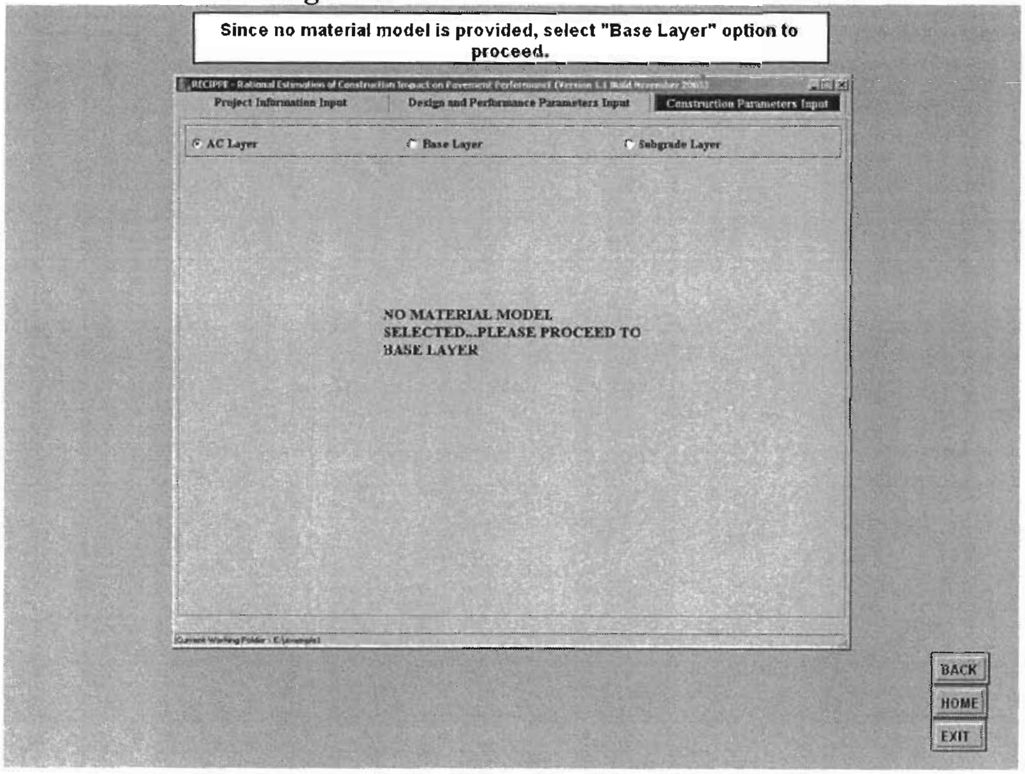
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 3

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

The remaining inputs are:
2) Design Life - this feature provides information regarding the design life of the pavement and the level of reliability.
3) Automatic Reduction Parameters - this feature provides control over the automatic

Figure 2.40 - Slide 31 of Exercise 1

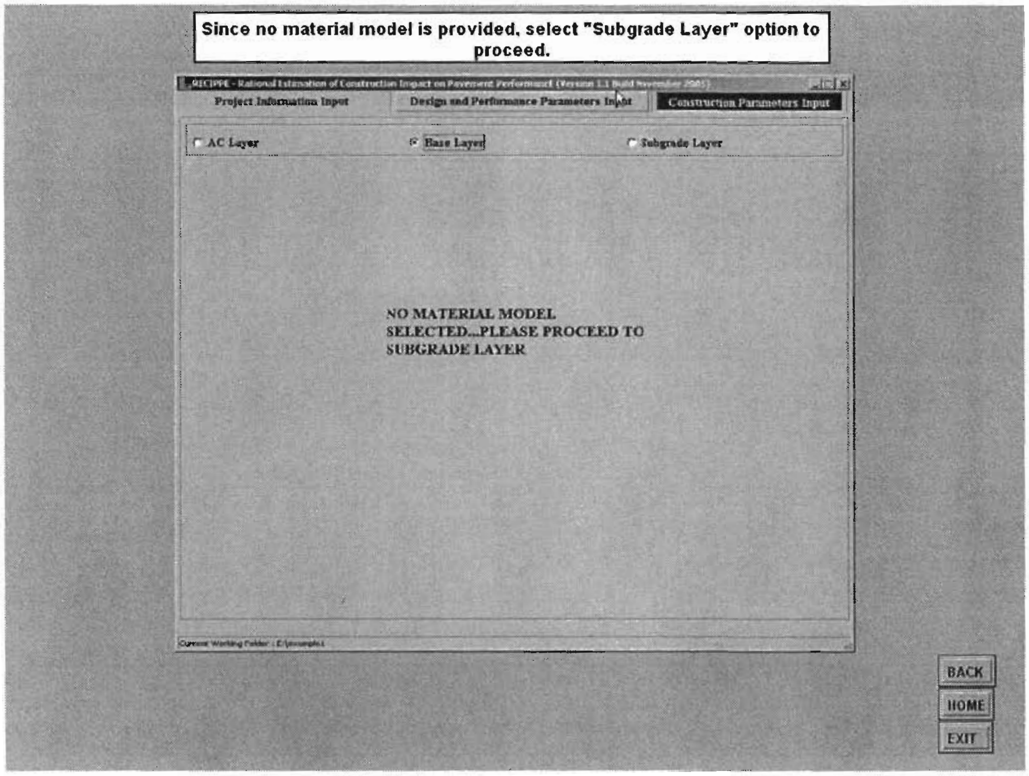


Since no material model is provided, select "Base Layer" option to proceed.

● AC Layer ○ Base Layer ○ Subgrade Layer

NO MATERIAL MODEL SELECTED...PLEASE PROCEED TO BASE LAYER

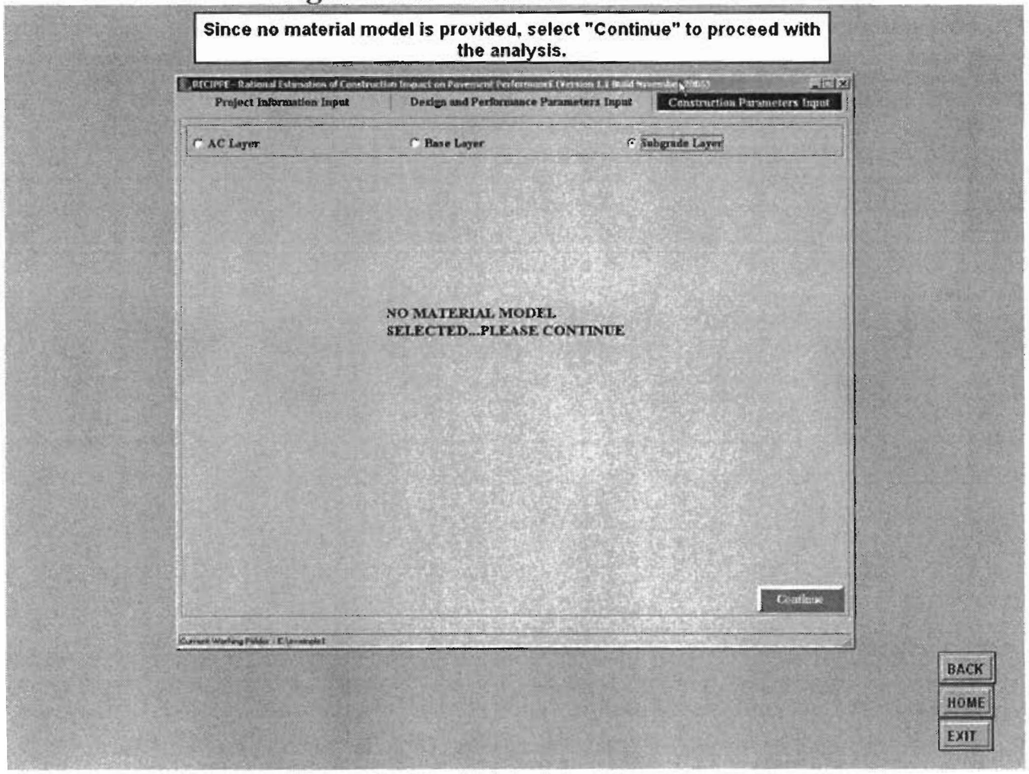
Figure 2.41 - Slide 32 of Exercise 1



Since no material model is provided, select "Subgrade Layer" option to proceed.

NO MATERIAL MODEL SELECTED...PLEASE PROCEED TO SUBGRADE LAYER

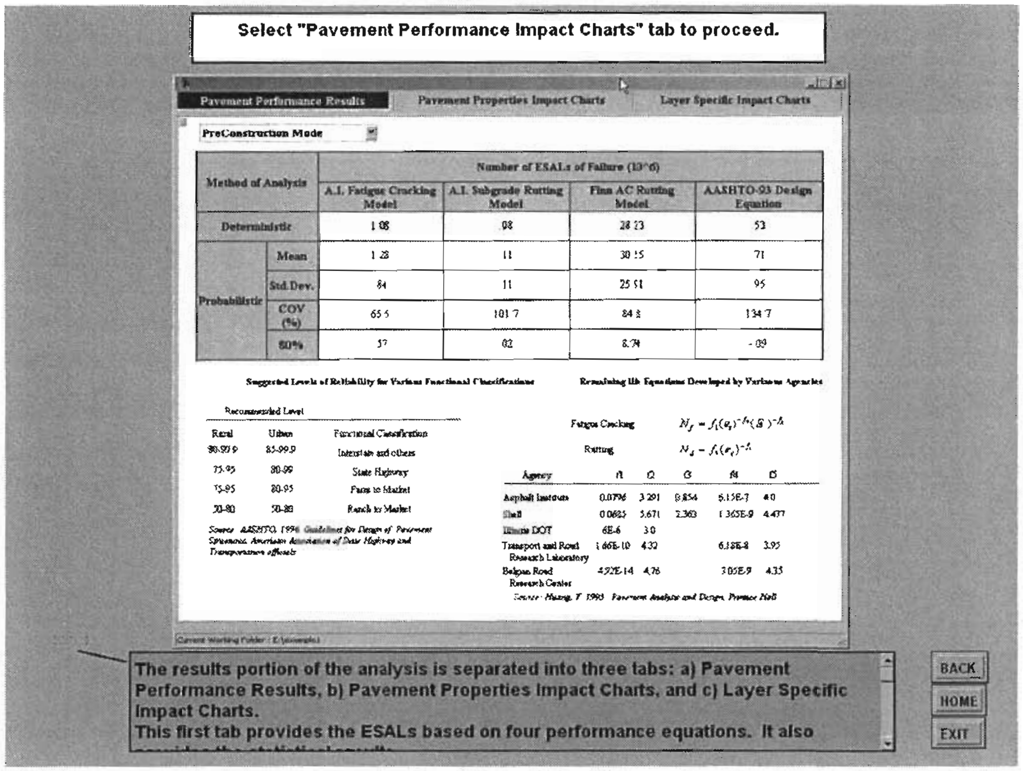
Figure 2.42 - Slide 33 of Exercise 1



Since no material model is provided, select "Continue" to proceed with the analysis.

NO MATERIAL MODEL SELECTED...PLEASE CONTINUE

Figure 2.43 - Slide 34 of Exercise 1



Select "Pavement Performance Impact Charts" tab to proceed.

PreConstruction Mode

Method of Analysis		Number of ESALs of Failure (10^6)			
		A.I. Fatigue Cracking Model	A.I. Subgrade Rutting Model	Finn AC Rutting Model	AASHTO-93 Design Equation
Deterministic		1 08	08	28 23	53
Probabilistic	Mean	1 28	11	30 15	71
	Std.Dev.	84	11	25 51	95
	COV (%)	65 5	101 7	84 8	134 7
	80%	57	02	8.74	- 09

Suggested Levels of Reliability for Various Functional Classifications

Recommended Level		
Rural	Urban	Functional Classification
80-99.9	85-99.9	Interstate and others
75-95	80-99	State Highway
75-95	80-95	Farm to Market
50-80	50-80	Ranch to Market

Source: AASHTO, 1986 Guidelines for Design of Pavement Structures, American Association of State Highway and Transportation officials

Remaining life Equations Developed by Various Agencies

Fatigue Cracking $N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3}$

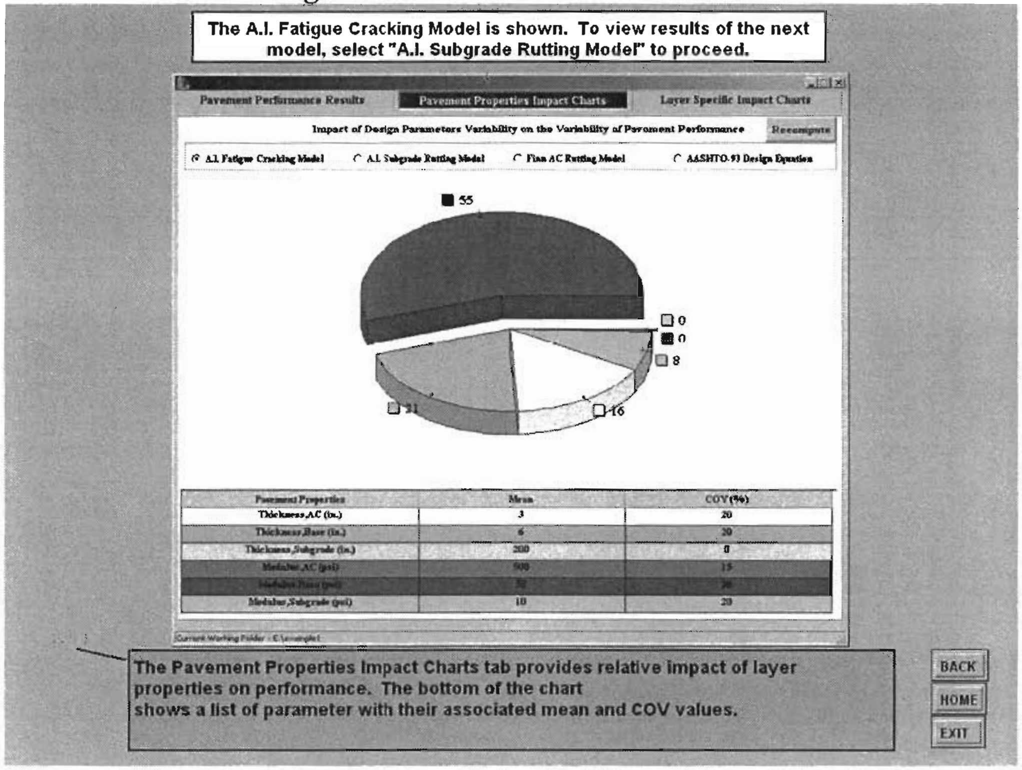
Rutting $N_d = f_4(\varepsilon_c)^{-f_5}$

Agency	f1	f2	f3	f4	f5
Asphalt Institute	0.0796	3.291	0.854	6.15E-7	4.0
Shell	0.0685	5.671	2.363	1.365E-9	4.477
Illinois DOT	6E-6	3.0			
Transport and Road Research Laboratory	1.66E-10	4.32		6.18E-8	3.95
Belgian Road Research Center	4.92E-14	4.76		3.05E-9	4.35

Source: Huang, Y. 1993. Pavement Analysis and Design, Prentice Hall

The results portion of the analysis is separated into three tabs: a) Pavement Performance Results, b) Pavement Properties Impact Charts, and c) Layer Specific Impact Charts.
This first tab provides the ESALs based on four performance equations. It also

Figure 2.44 - Slide 35 of Exercise 1



The A.I. Fatigue Cracking Model is shown. To view results of the next model, select "A.I. Subgrade Rutting Model" to proceed.

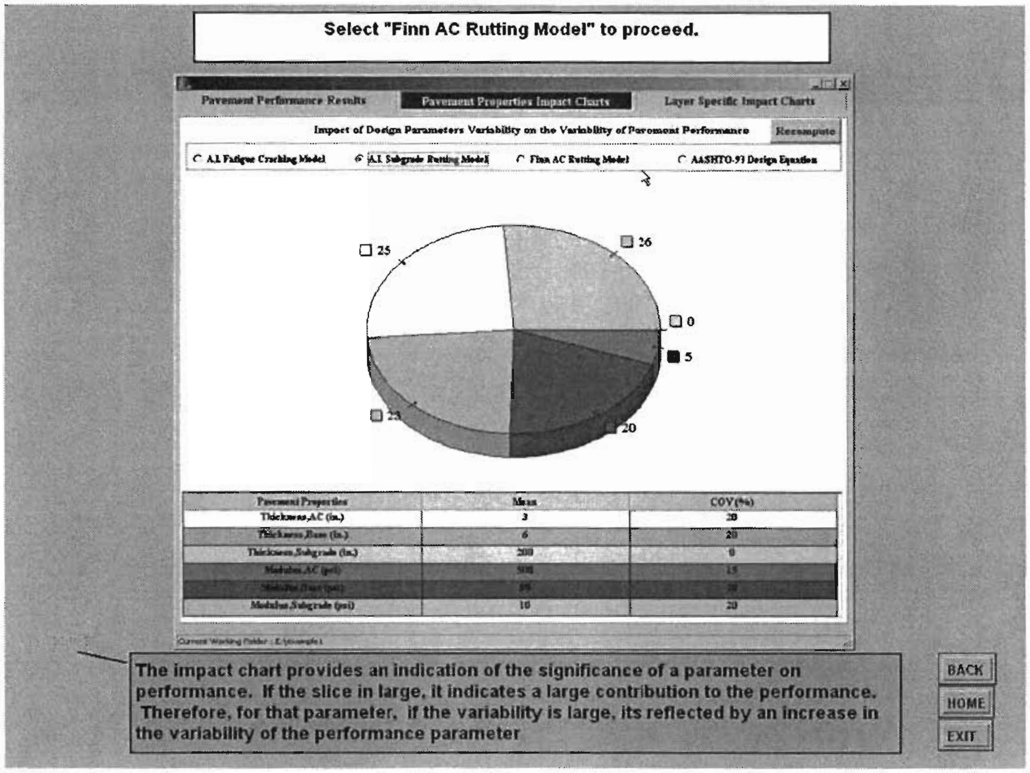
Impact of Design Parameters Variability on the Variability of Pavement Performance

● A.I. Fatigue Cracking Model ○ A.I. Subgrade Rutting Model ○ Finn AC Rutting Model ○ AASHTO-93 Design Equation

Pavement Properties	Mean	COV(%)
Thickness,AC (in.)	3	20
Thickness,Base (in.)	6	20
Thickness,Subgrade (in.)	200	0
Modulus,AC (psi)	500	15
Modulus,Base (psi)	[illegible]	[illegible]
Modulus,Subgrade (psi)	10	20

The Pavement Properties Impact Charts tab provides relative impact of layer properties on performance. The bottom of the chart
shows a list of parameter with their associated mean and COV values.

Figure 2.45 - Slide 36 of Exercise 1

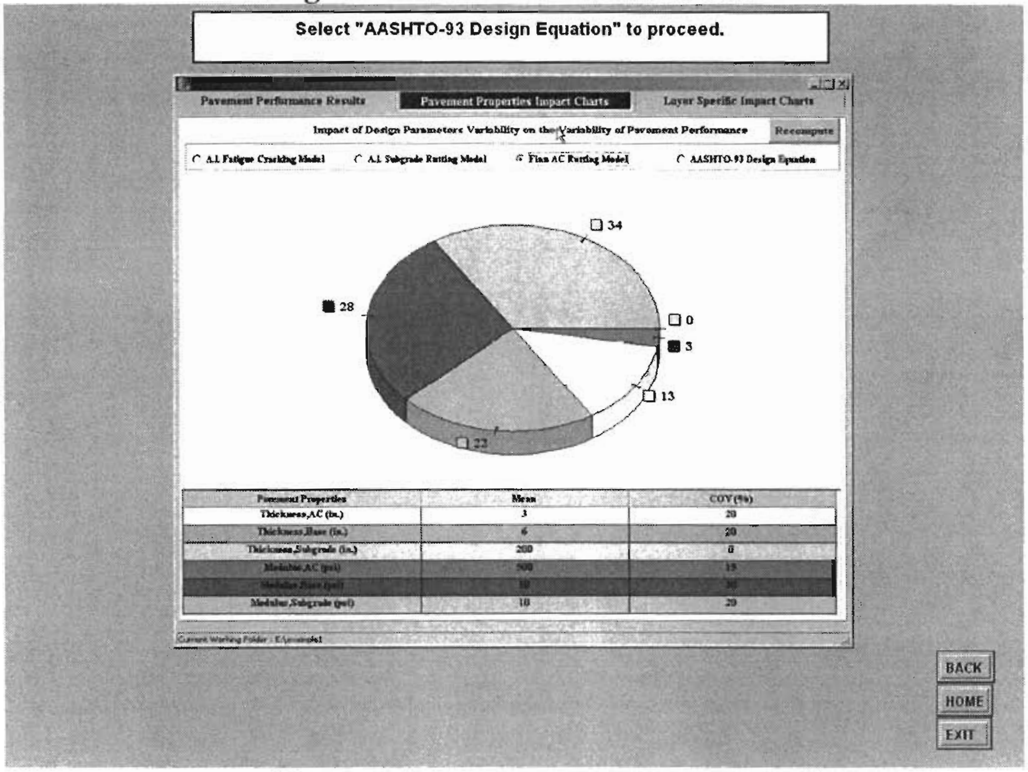


Select "Finn AC Rutting Model" to proceed.

Pavement Properties	Mean	COV(%)
Thickness,AC (in.)	3	20
Thickness,Base (in.)	6	20
Thickness,Subgrade (in.)	200	0
Modulus,AC (psi)	500	15
Modulus,Base (psi)	[illegible]	30
Modulus,Subgrade (psi)	10	20

The impact chart provides an indication of the significance of a parameter on performance. If the slice in large, it indicates a large contribution to the performance. Therefore, for that parameter, if the variability is large, its reflected by an increase in the variability of the performance parameter

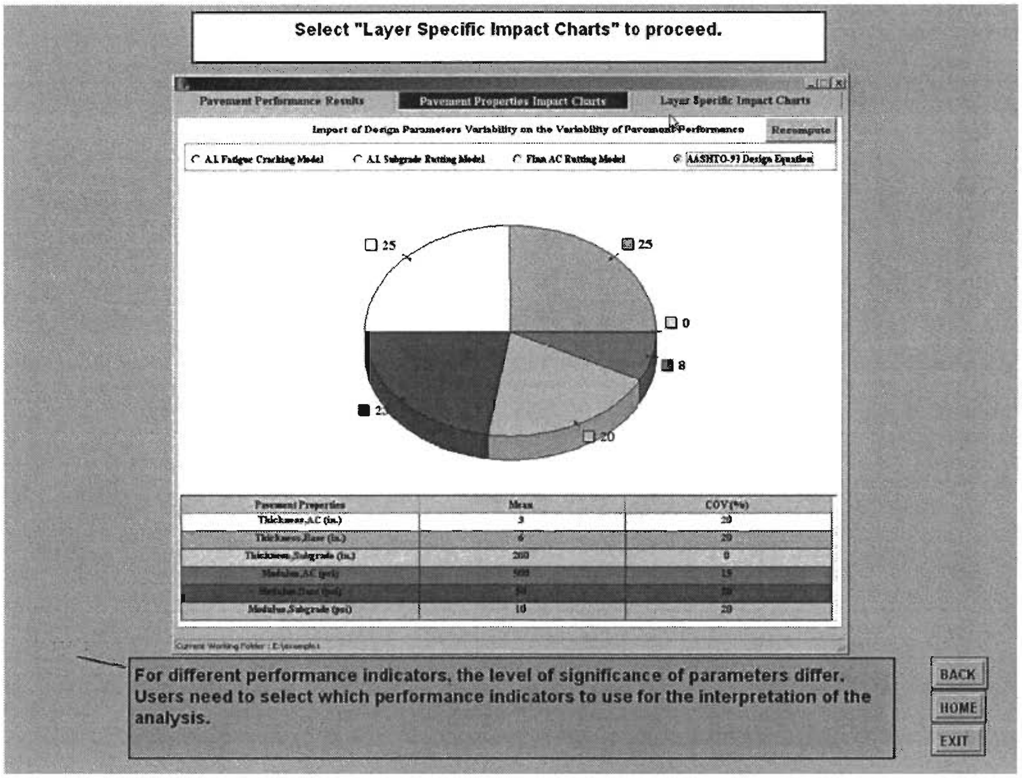
Figure 2.46 - Slide 37 of Exercise 1



Select "AASHTO-93 Design Equation" to proceed.

Pavement Properties	Mean	COV(%)
Thickness,AC (in.)	3	20
Thickness,Base (in.)	6	20
Thickness,Subgrade (in.)	200	0
Modulus,AC (psi)	500	15
Modulus,Base (psi)	10	30
Modulus,Subgrade (psi)	10	20

Figure 2.47 - Slide 38 of Exercise 1



Select "Layer Specific Impact Charts" to proceed.

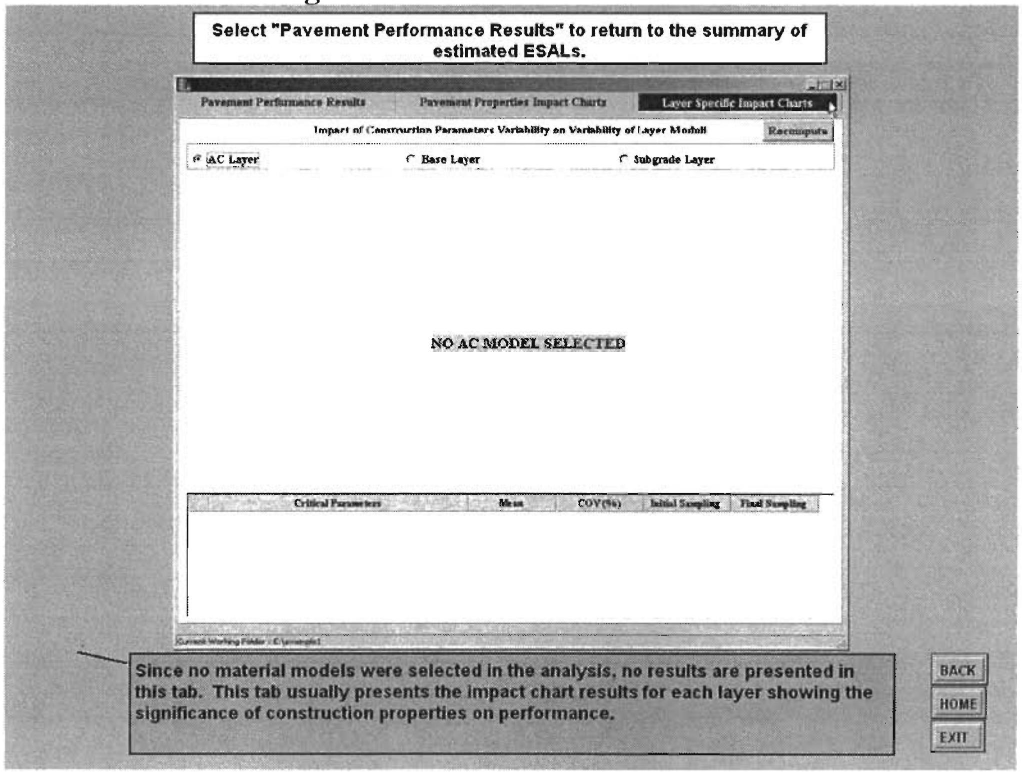
Import of Design Parameters Variability on the Variability of Pavement Performance

○ A.I. Fatigue Cracking Model ○ A.I. Subgrade Rutting Model ○ Finn AC Rutting Model ● AASHTO-93 Design Equation

Pavement Properties	Mean	COV(%)
Thickness,AC (in.)	3	20
Thickness,Base (in.)	6	20
Thickness,Subgrade (in.)	200	0
Modulus,AC (psi)	500	15
Modulus,Base (psi)	50	20
Modulus,Subgrade (psi)	10	20

For different performance indicators, the level of significance of parameters differ. Users need to select which performance indicators to use for the interpretation of the analysis.

Figure 2.48 - Slide 39 of Exercise 1



Select "Pavement Performance Results" to return to the summary of estimated ESALs.

Impact of Construction Parameters Variability on Variability of Layer Moduli

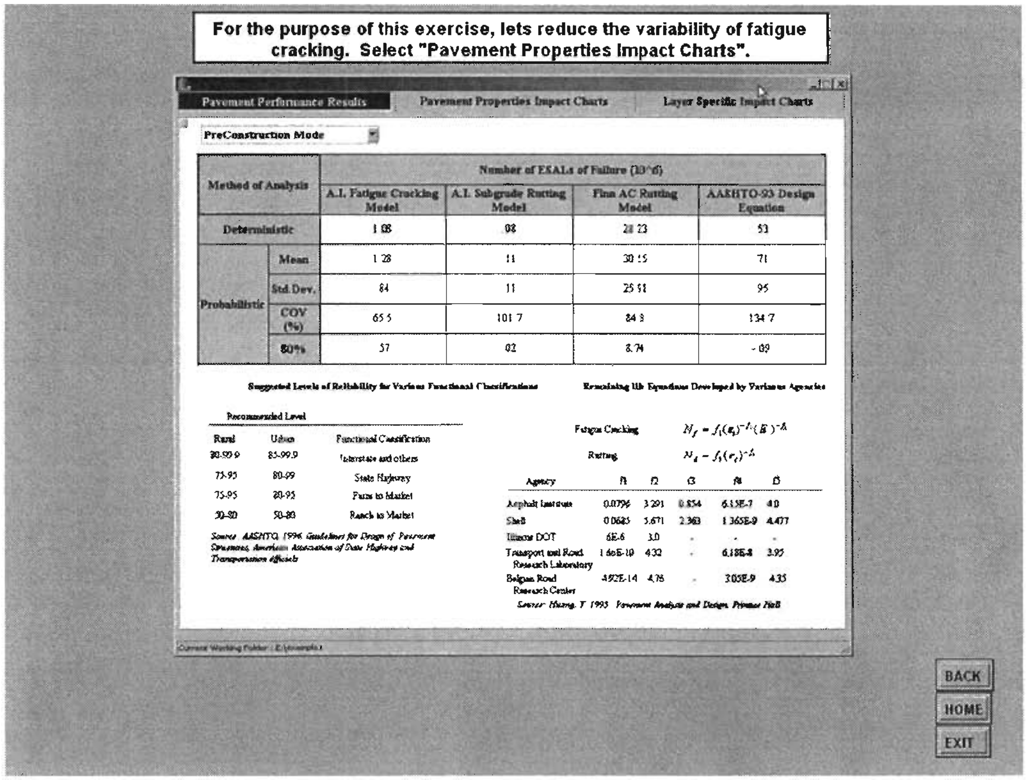
● AC Layer ○ Base Layer ○ Subgrade Layer

NO AC MODEL SELECTED

Critical Parameters	Mean	COV(%)	Initial Sampling	Final Sampling

Since no material models were selected in the analysis, no results are presented in this tab. This tab usually presents the impact chart results for each layer showing the significance of construction properties on performance.

Figure 2.49 - Slide 40 of Exercise 1



For the purpose of this exercise, lets reduce the variability of fatigue cracking. Select "Pavement Properties Impact Charts".

Method of Analysis		Number of ESALs of Failure (10^6)			
		A.I. Fatigue Cracking Model	A.I. Subgrade Rutting Model	Finn AC Rutting Model	AASHTO-93 Design Equation
Deterministic		1 08	08	28 23	53
Probabilistic	Mean	1 28	11	30 15	71
	Std.Dev.	84	11	25 51	95
	COV (%)	65 5	101 7	84 8	134 7
	80%	57	02	8.74	- 09

Suggested Levels of Reliability for Various Functional Classifications

Recommended Level		
Rural	Urban	Functional Classification
80-99.9	85-99.9	Interstate and others
75-95	80-99	State Highway
75-95	80-95	Farm to Market
50-80	50-80	Ranch to Market

Source: AASHTO, 1996 Guidelines for Design of Pavement Structures, American Association of State Highway and Transportation officials

Remaining life Equations Developed by Various Agencies

Fatigue Cracking $N_f = f_1(\varepsilon_t)^{-f_2}(E)^{-f_3}$

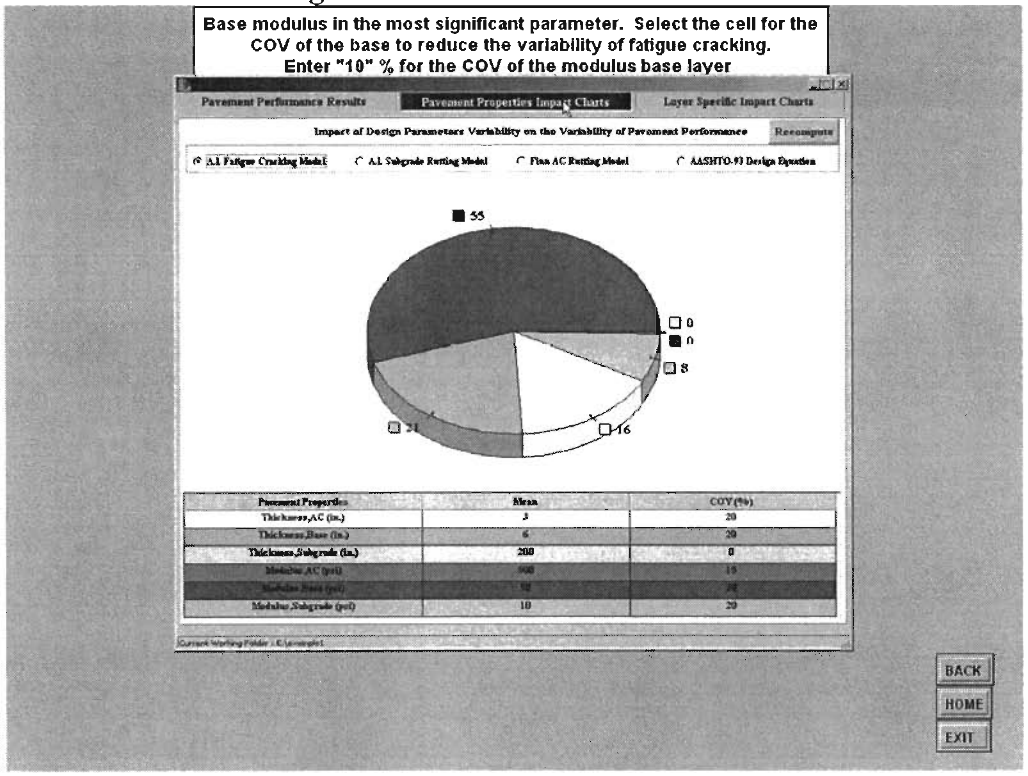
Rutting $N_d = f_4(\varepsilon_c)^{-f_5}$

Agency	f1	f2	f3	f4	f5
Asphalt Institute	0.0796	3.291	0.854	6.15E-7	4.0
Shell	0.0685	5.671	2.363	1.365E-9	4.477
Illinois DOT	6E-6	3.0	-	-	-
Transport and Road Research Laboratory	1.66E-10	4.32	-	6.18E-8	3.95
Belgian Road Research Center	4.92E-14	4.76	-	3.05E-9	4.35

Source: Huang, Y 1993 Pavement Analysis and Design, Prentice Hall

Current Working Folder : E:\example1

Figure 2.50- Slide 41 of Exercise 1



Base modulus in the most significant parameter. Select the cell for the COV of the base to reduce the variability of fatigue cracking.
Enter "10" % for the COV of the modulus base layer

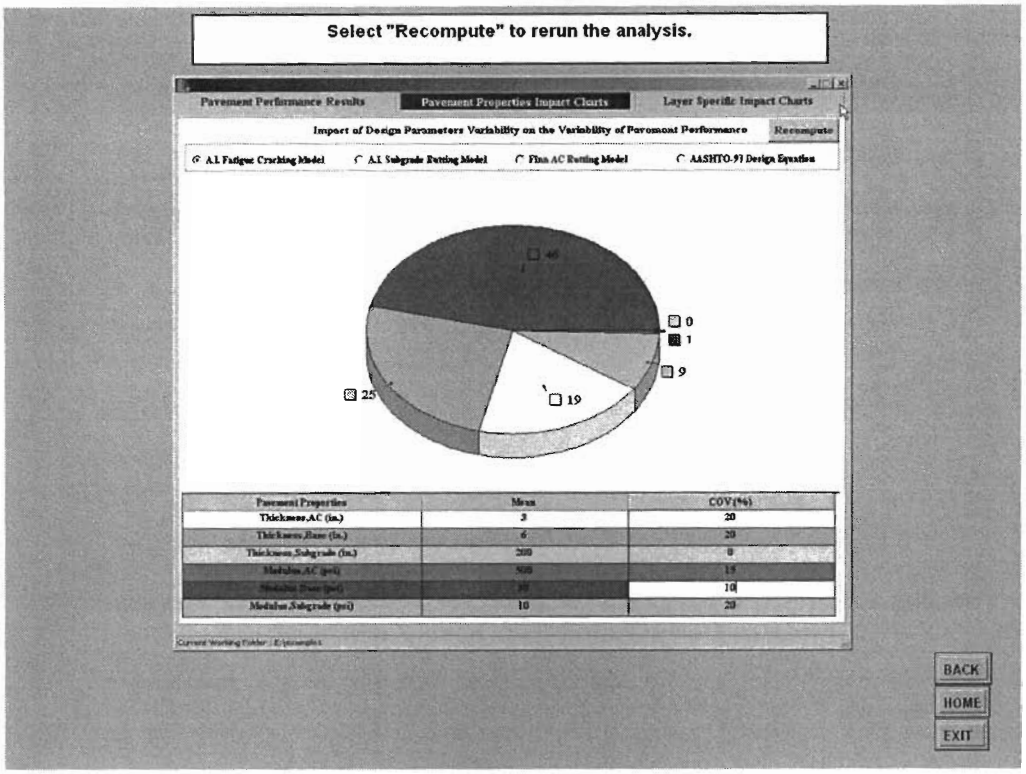
Impact of Design Parameters Variability on the Variability of Pavement Performance

● A.I Fatigue Cracking Model ○ A.I. Subgrade Rutting Model ○ Finn AC Rutting Model ○ AASHTO-93 Design Equation

Pavement Properties	Mean	COV(%)
Thickness,AC (in.)	3	20
Thickness,Base (in.)	6	20
Thickness,Subgrade (in.)	200	0
Modulus,AC (psi)	500	15
Modulus,Base (psi)	50	[illegible]
Modulus,Subgrade (psi)	10	20

Current Working Folder : E:\example1

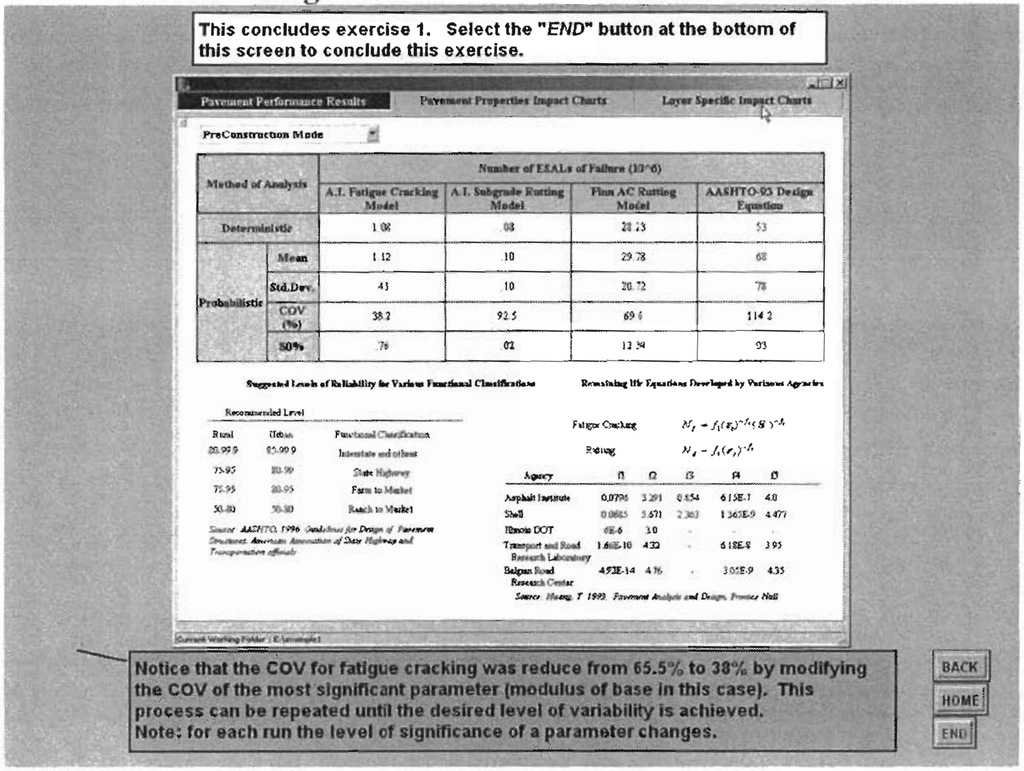
Figure 2.51 - Slide 42 of Exercise 1



Select "Recompute" to rerun the analysis.

Pavement Properties	Mean	COV(%)
Thickness,AC (in.)	3	20
Thickness,Base (in.)	6	20
Thickness,Subgrade (in.)	200	0
Modulus,AC (psi)	500	15
Modulus,Base (psi)	30	10
Modulus,Subgrade (psi)	10	20

Figure 2.52 - Slide 43 of Exercise 1



This concludes exercise 1. Select the "*END*" button at the bottom of this screen to conclude this exercise.

Method of Analysis		Number of ESALs of Failure (10^6)			
		A.I. Fatigue Cracking Model	A.I. Subgrade Rutting Model	Finn AC Rutting Model	AASHTO-93 Design Equation
Deterministic		1.08	.08	28.23	53
Probabilistic	Mean	1.12	.10	29.78	68
	Std.Dev.	.43	.10	20.72	78
	COV (%)	38.2	92.5	69.6	114.2
	50%	.76	.02	13.39	.93

Suggested Levels of Reliability for Various Functional Classifications

Recommended Level		
Rural	Urban	Functional Classification
80-99.9	85-99.9	Interstate and others
75-95	80-99	State Highway
75-95	80-95	Farm to Market
50-80	50-80	Ranch to Market

Source: AASHTO, 1996. Guidelines for Design of Pavement Structures. American Association of State Highway and Transportation officials

Remaining life Equations Developed by Various Agencies

Fatigue Cracking $N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3}$

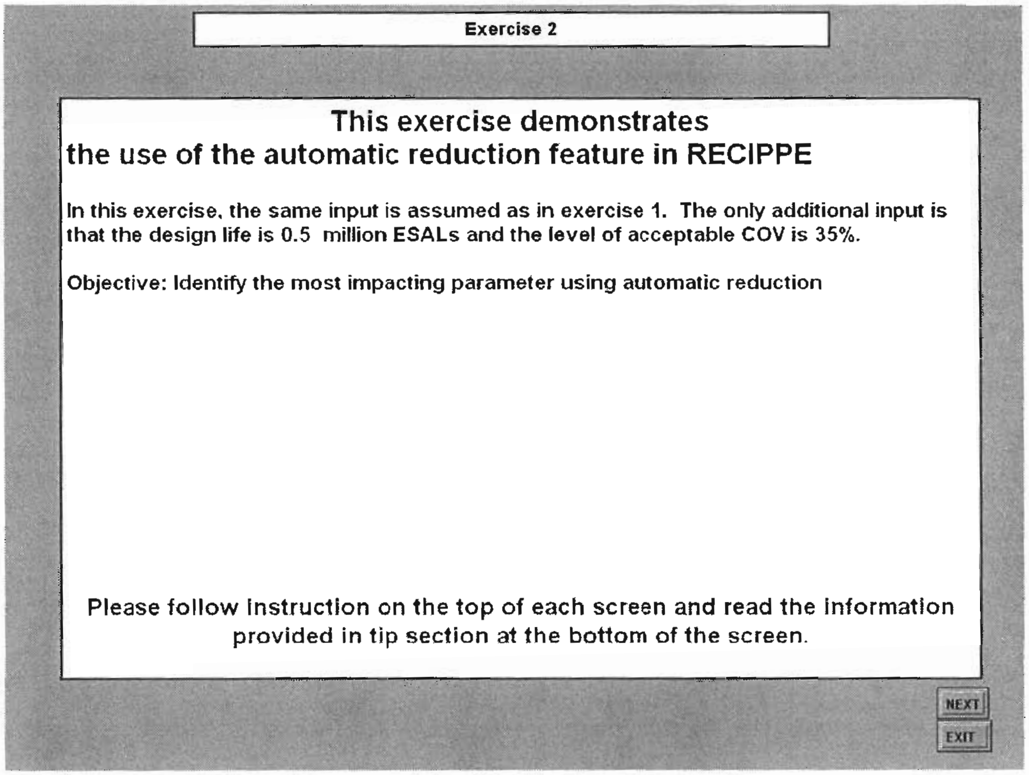
Rutting $N_d = f_4(\varepsilon_c)^{-f_5}$

Agency	f_1	f_2	f_3	f_4	f_5
Asphalt Institute	0.0796	3.291	0.854	6.15E-7	4.0
Shell	0.0685	5.671	2.363	1.365E-9	4.477
Illinois DOT	5E-6	3.0	-	-	-
Transport and Road Research Laboratory	1.66E-10	4.32	-	6.18E-8	3.95
Belgian Road Research Center	4.92E-14	4.76	-	3.05E-9	4.35

Source: Huang, Y. 1993. Pavement Analysis and Design, Prentice Hall

Notice that the COV for fatigue cracking was reduce from 65.5% to 38% by modifying the COV of the most significant parameter (modulus of base in this case). This process can be repeated until the desired level of variability is achieved.
Note: for each run the level of significance of a parameter changes.

Figure 2.53 - Slide 44 of Exercise 1


Exercise 2

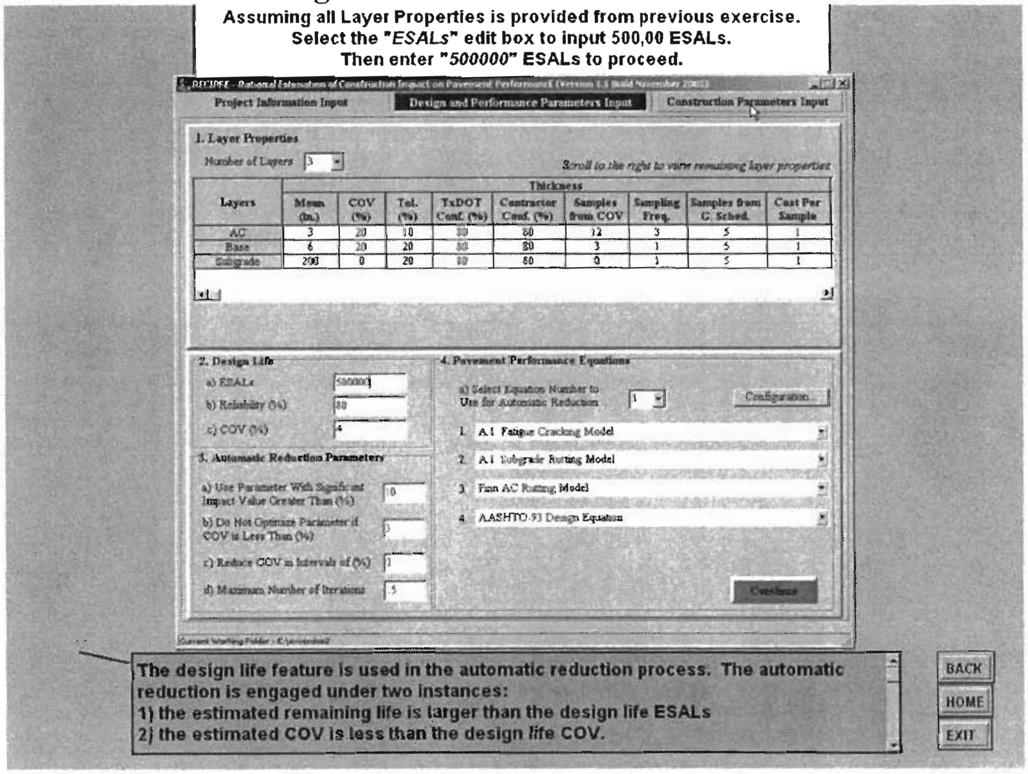
This exercise demonstrates
the use of the automatic reduction feature in RECIPPE

In this exercise, the same input is assumed as in exercise 1. The only additional input is that the design life is 0.5 million ESALs and the level of acceptable COV is 35%.

Objective: Identify the most impacting parameter using automatic reduction

Please follow instruction on the top of each screen and read the information provided in tip section at the bottom of the screen.

Figure 2.54 - Slide 1 of Exercise 2


Assuming all Layer Properties is provided from previous exercise.
Select the "*ESALs*" edit box to input 500,00 ESALs.
Then enter "*500000*" ESALs to proceed.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	290	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 0

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 5

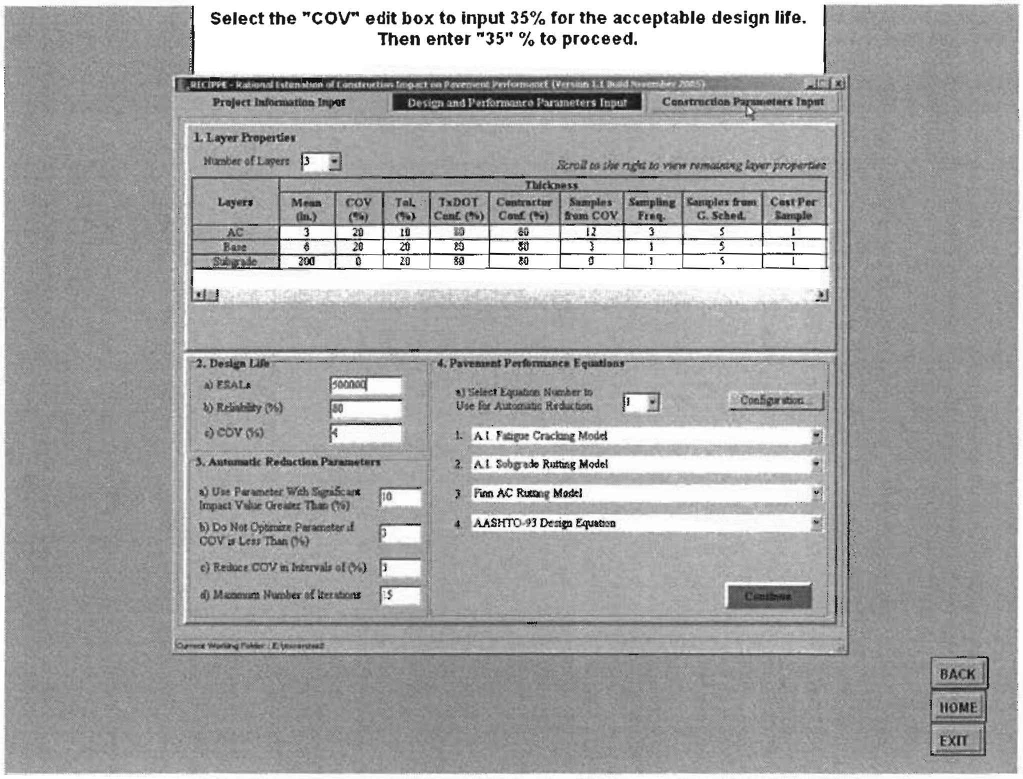
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I Fatigue Cracking Model
2. A.I Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

The design life feature is used in the automatic reduction process. The automatic reduction is engaged under two instances:
1) the estimated remaining life is larger than the design life ESALs
2) the estimated COV is less than the design life COV.

Figure 2.55 - Slide 2 of Exercise 2


Select the "COV" edit box to input 35% for the acceptable design life. Then enter "35" % to proceed.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 4

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

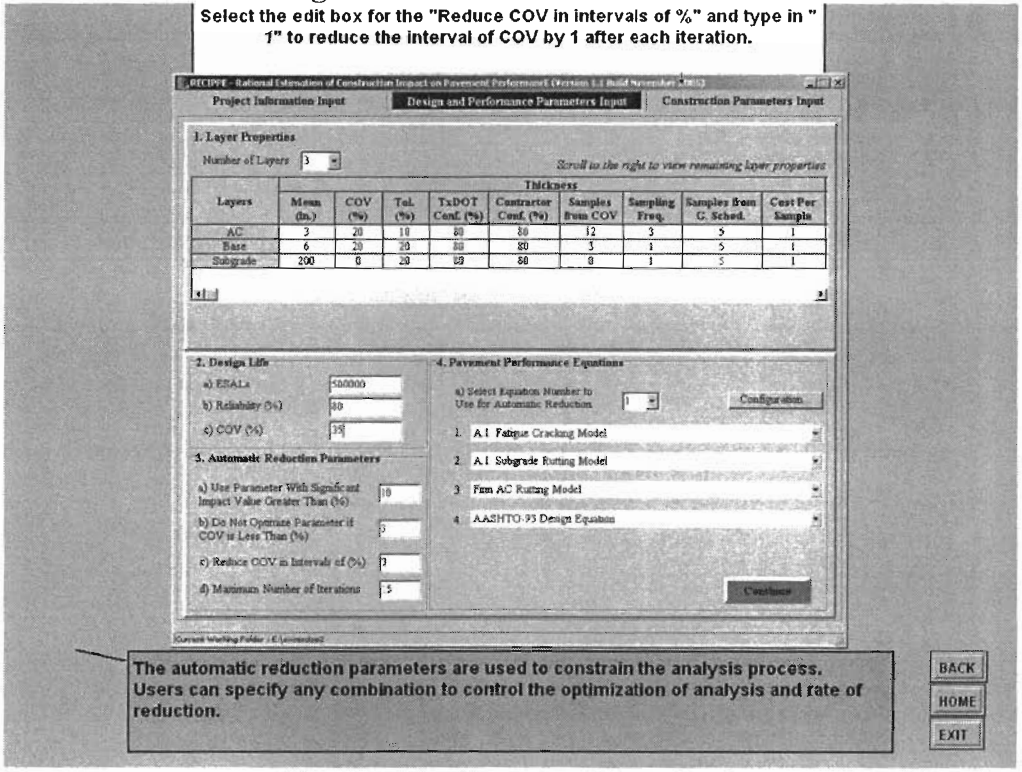
d) Maximum Number of Iterations: 15

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.56 - Slide 3 of Exercise 2


Select the edit box for the "Reduce COV in intervals of %" and type in " 1" to reduce the interval of COV by 1 after each iteration.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

d) Maximum Number of Iterations: 15

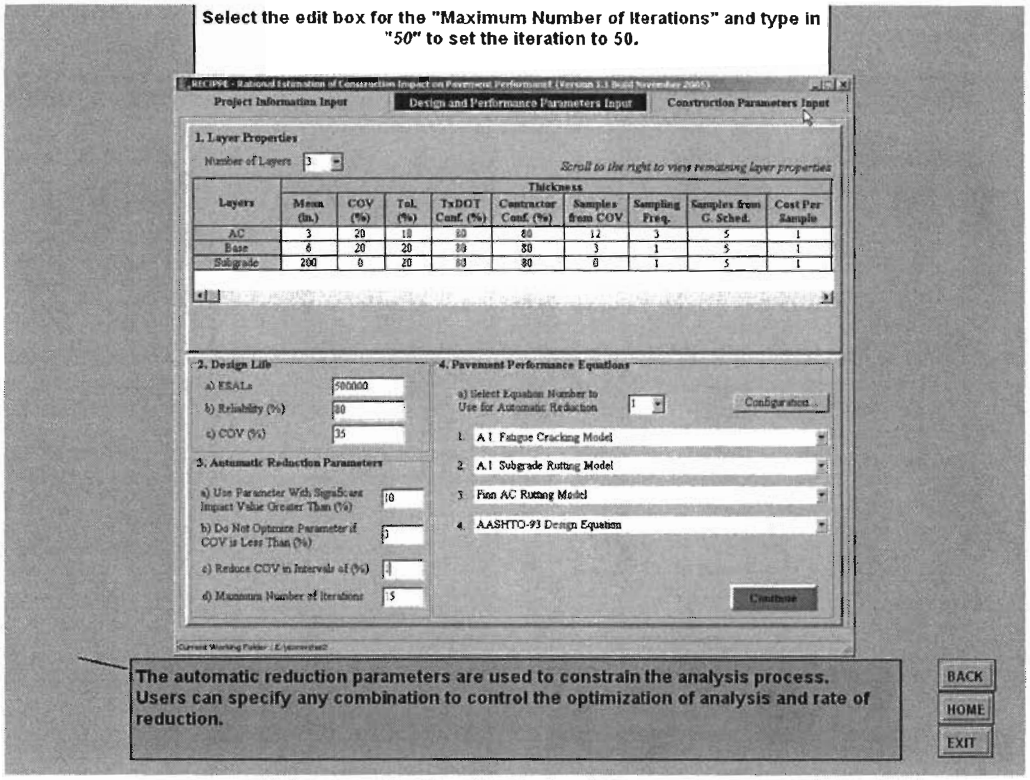
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

The automatic reduction parameters are used to constrain the analysis process. Users can specify any combination to control the optimization of analysis and rate of reduction.

Figure 2.57 - Slide 4 of Exercise 2



Select the edit box for the "Maximum Number of Iterations" and type in "*50*" to set the iteration to 50.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000
b) Reliability (%): 80
c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 3
c) Reduce COV in Intervals of (%): 1
d) Maximum Number of Iterations: 15

4. Pavement Performance Equations

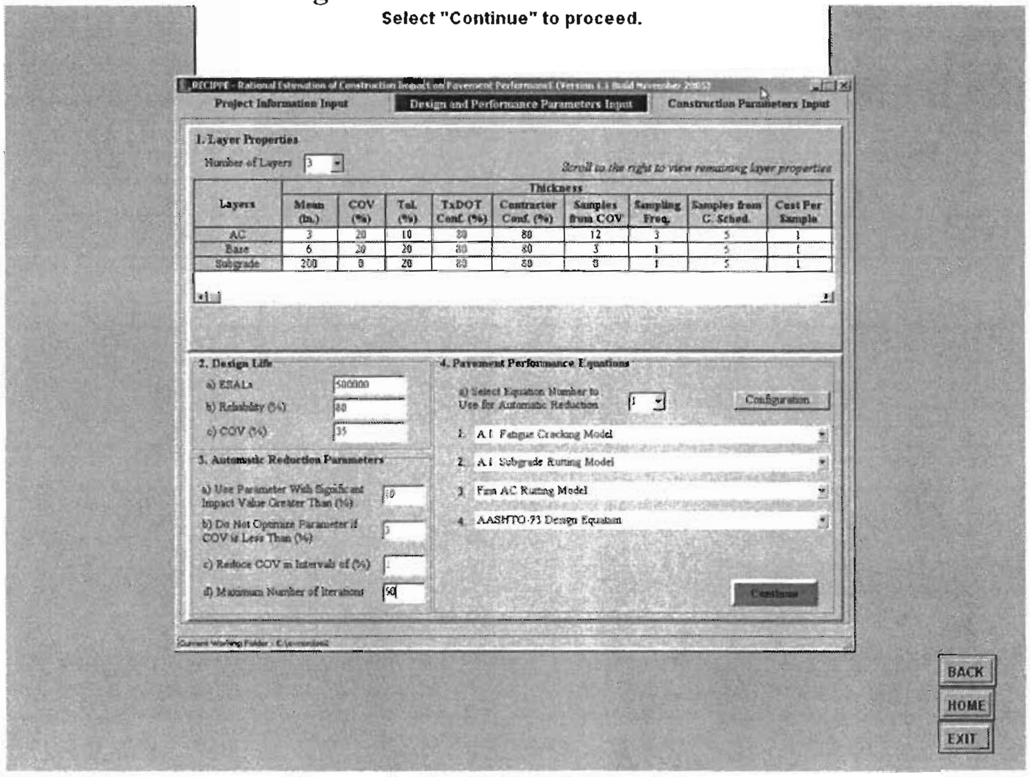
a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\...

The automatic reduction parameters are used to constrain the analysis process. Users can specify any combination to control the optimization of analysis and rate of reduction.

Figure 2.58 - Slide 5 of Exercise 2



Select "Continue" to proceed.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000
b) Reliability (%): 80
c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 3
c) Reduce COV in Intervals of (%): 1
d) Maximum Number of Iterations: 50

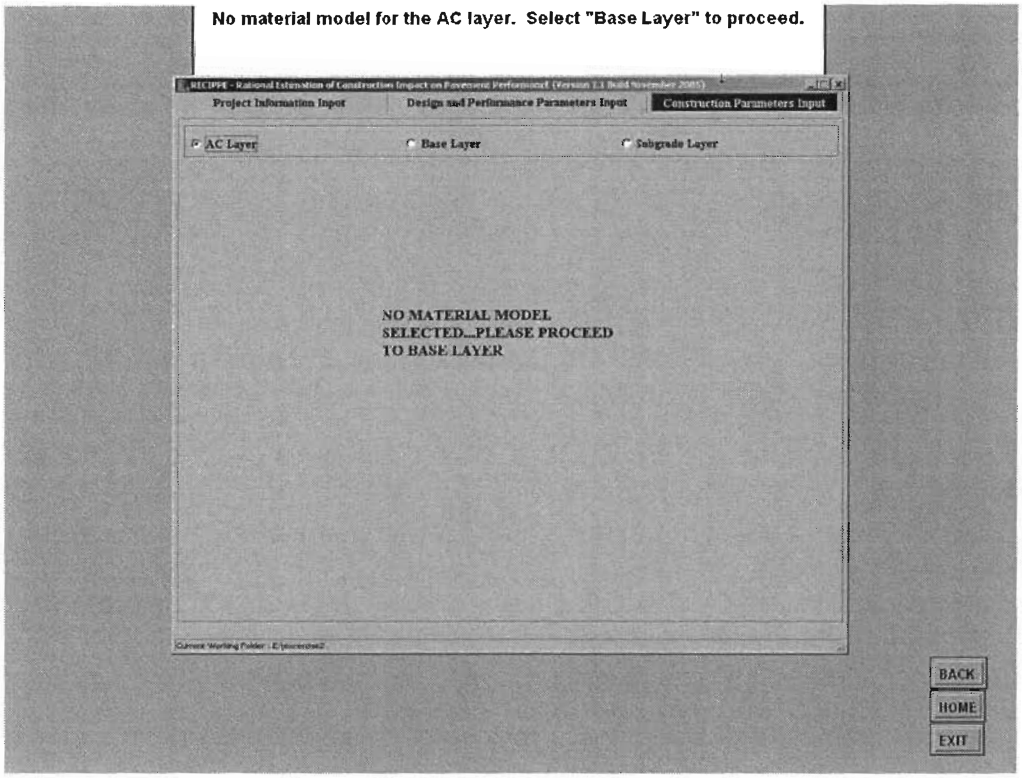
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

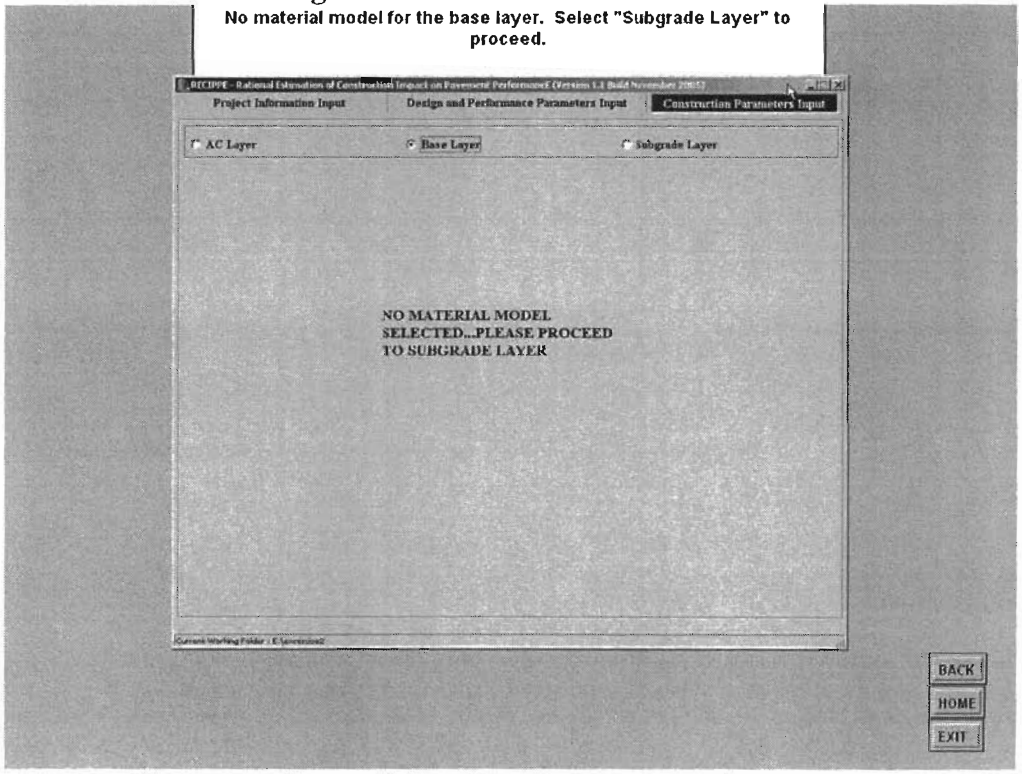
Current Working Folder : E:\...

Figure 2.59 - Slide 6 of Exercise 2


No material model for the AC layer. Select "Base Layer" to proceed.

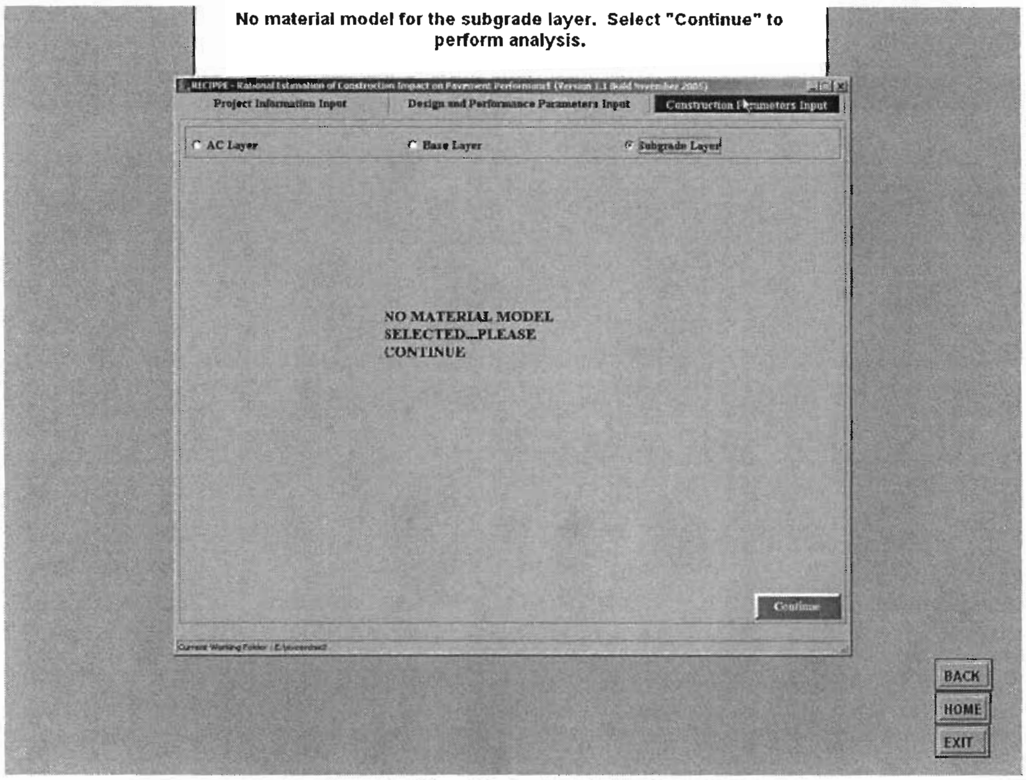
NO MATERIAL MODEL
SELECTED...PLEASE PROCEED
TO BASE LAYER

Figure 2.60 - Slide 7 of Exercise 2


No material model for the base layer. Select "Subgrade Layer" to proceed.

NO MATERIAL MODEL
SELECTED...PLEASE PROCEED
TO SUBGRADE LAYER

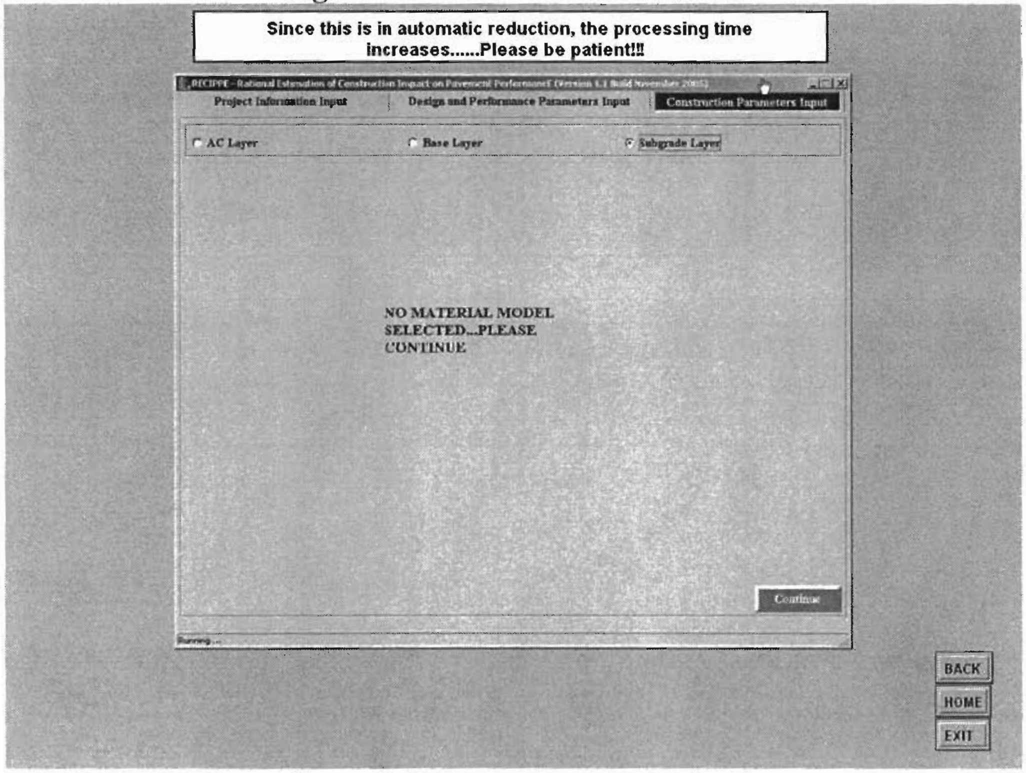
Figure 2.61 - Slide 8 of Exercise 2



No material model for the subgrade layer. Select "Continue" to perform analysis.

NO MATERIAL MODEL SELECTED...PLEASE CONTINUE

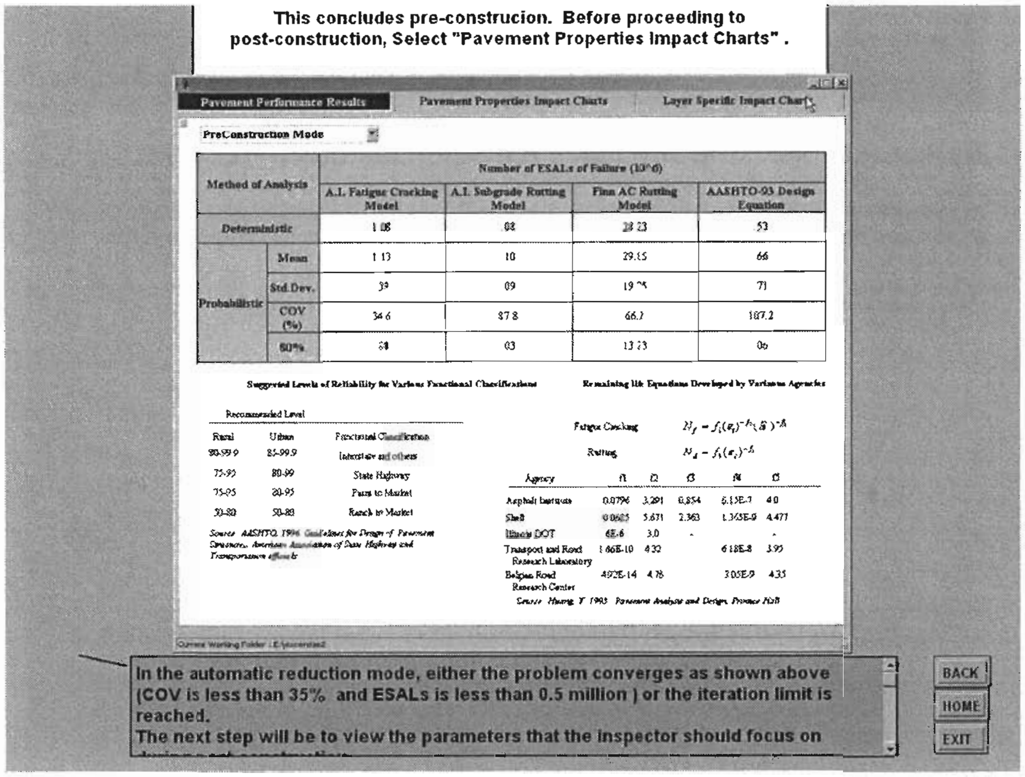
Figure 2.62 - Slide 9 of Exercise 2



Since this is in automatic reduction, the processing time increases......Please be patient!!!

NO MATERIAL MODEL SELECTED...PLEASE CONTINUE

Figure 2.63 - Slide 10 of Exercise 2



This concludes pre-construcion. Before proceeding to post-construction, Select "Pavement Properties Impact Charts" .

Method of Analysis		Number of ESALs of Failure (10^6)			
		A.I. Fatigue Cracking Model	A.I. Subgrade Rutting Model	Finn AC Rutting Model	AASHTO-93 Design Equation
Deterministic		1.08	.08	28.23	.53
Probabilistic	Mean	1.13	10	29.15	66
	Std.Dev.	39	09	19.[illegible]	71
	COV (%)	34.6	87.8	66.[illegible]	107.2
	80%	84	03	13.73	06

Suggested Levels of Reliability for Various Functional Classifications

Recommended Level		
Rural	Urban	Functional Classification
80-99.9	85-99.9	Interstate and others
75-95	80-99	State Highway
75-95	80-95	Farm to Market
50-80	50-80	Ranch to Market

Source: AASHTO. 1996. Guidelines for Design of Pavement Structures, American Association of State Highway and Transportation officials

Remaining life Equations Developed by Various Agencies

Fatigue Cracking $N_f = f_1(\varepsilon_t)^{-f_2}(E)^{-f_3}$

Rutting $N_d = f_4(\varepsilon_c)^{-f_5}$

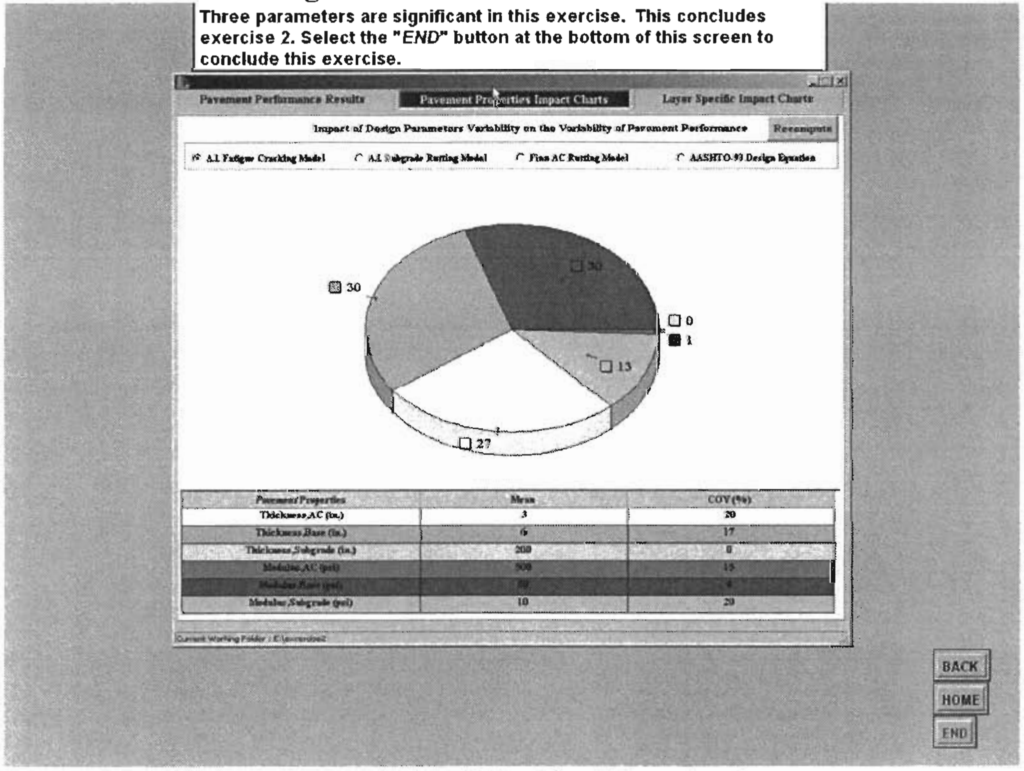
Agency	f1	f2	f3	f4	f5
Asphalt Institute	0.0796	3.291	0.854	1.365E-9	4.0
Shell	0.0685	5.671	2.363	1.365E-9	4.477
Illinois DOT	5E-6	3.0	-		-
Transport and Road Research Laboratory	1.66E-10	4.32		6.18E-8	3.95
Belgian Road Research Center	4.92E-14	4.76		3.05E-9	4.35

Source: Huang, Y. 1993. Pavement Analysis and Design, Prentice Hall

Current Working Folder : E:\exercise2

In the automatic reduction mode, either the problem converges as shown above (COV is less than 35% and ESALs is less than 0.5 million) or the iteration limit is reached.
The next step will be to view the parameters that the inspector should focus on

Figure 2.64 - Slide 11 of Exercise 2

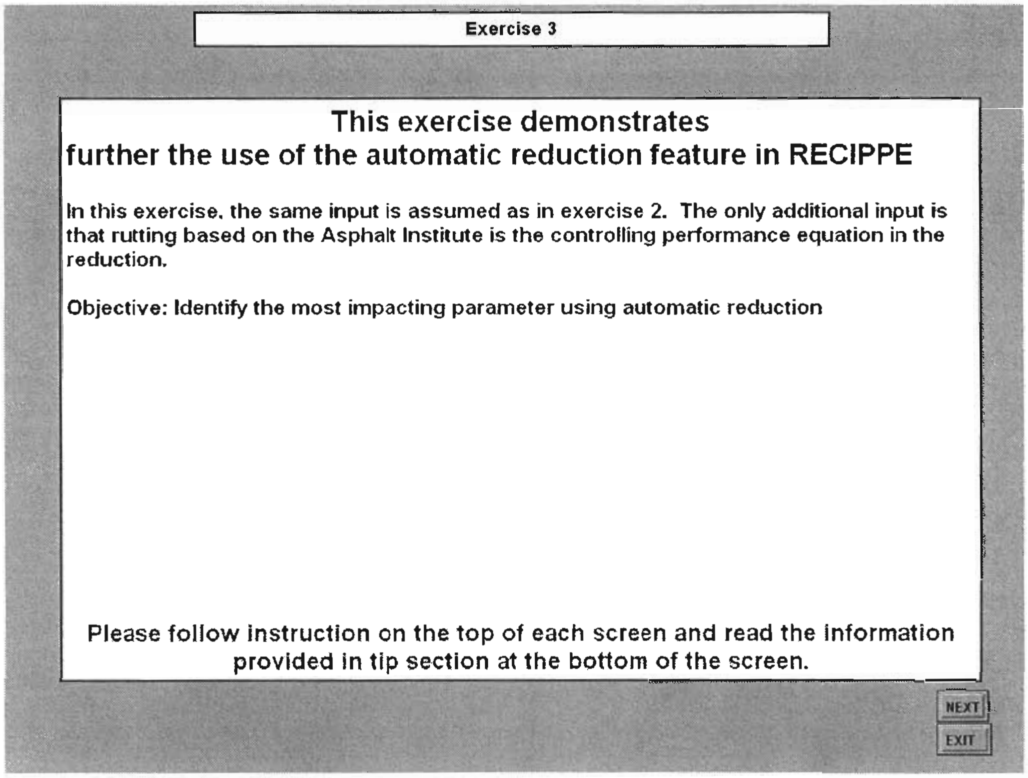


Three parameters are significant in this exercise. This concludes exercise 2. Select the "*END*" button at the bottom of this screen to conclude this exercise.

Pavement Properties	Mean	COV (%)
Thickness,AC (in.)	3	20
Thickness,Base (in.)	6	17
Thickness,Subgrade (in.)	200	0
Modulus,AC (psi)	500	15
Modulus,Base (psi)	[illegible]	4
Modulus,Subgrade (psi)	10	20

Current Working Folder : E:\exercise2

Figure 2.65 - Slide 12 of Exercise 2



Exercise 3

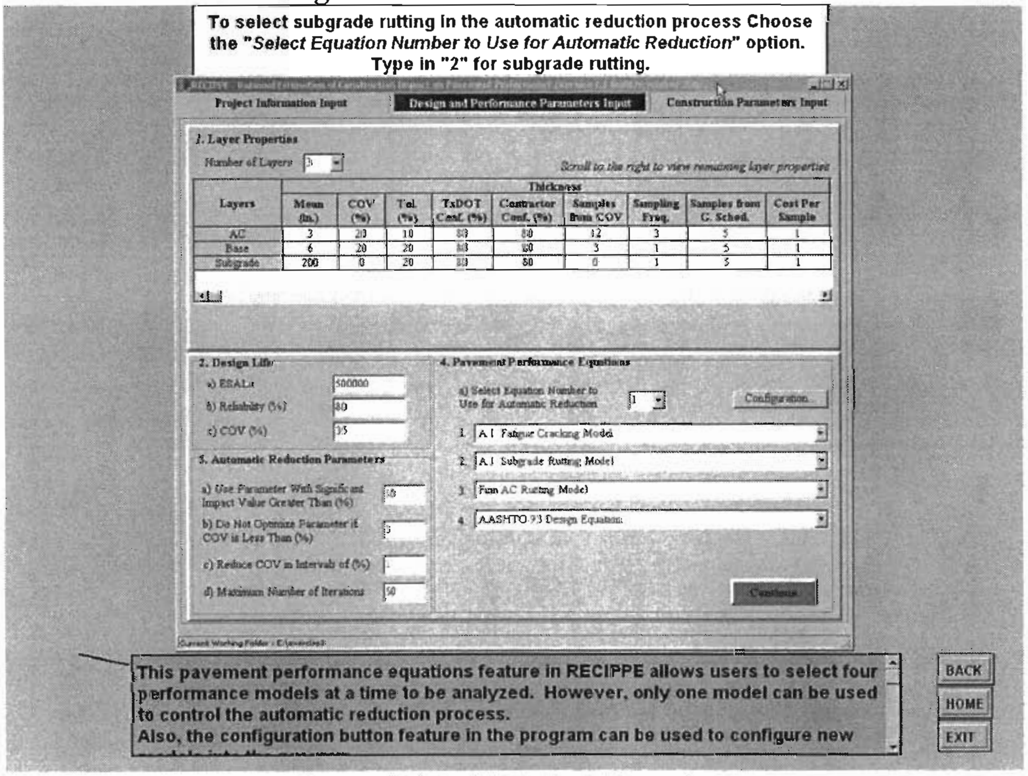
This exercise demonstrates further the use of the automatic reduction feature in RECIPPE

In this exercise, the same input is assumed as in exercise 2. The only additional input is that rutting based on the Asphalt Institute is the controlling performance equation in the reduction.

Objective: Identify the most impacting parameter using automatic reduction

Please follow instruction on the top of each screen and read the information provided in tip section at the bottom of the screen.

Figure 2.66 - Slide 1 of Exercise 3



To select subgrade rutting in the automatic reduction process Choose the "*Select Equation Number to Use for Automatic Reduction*" option. Type in "2" for subgrade rutting.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

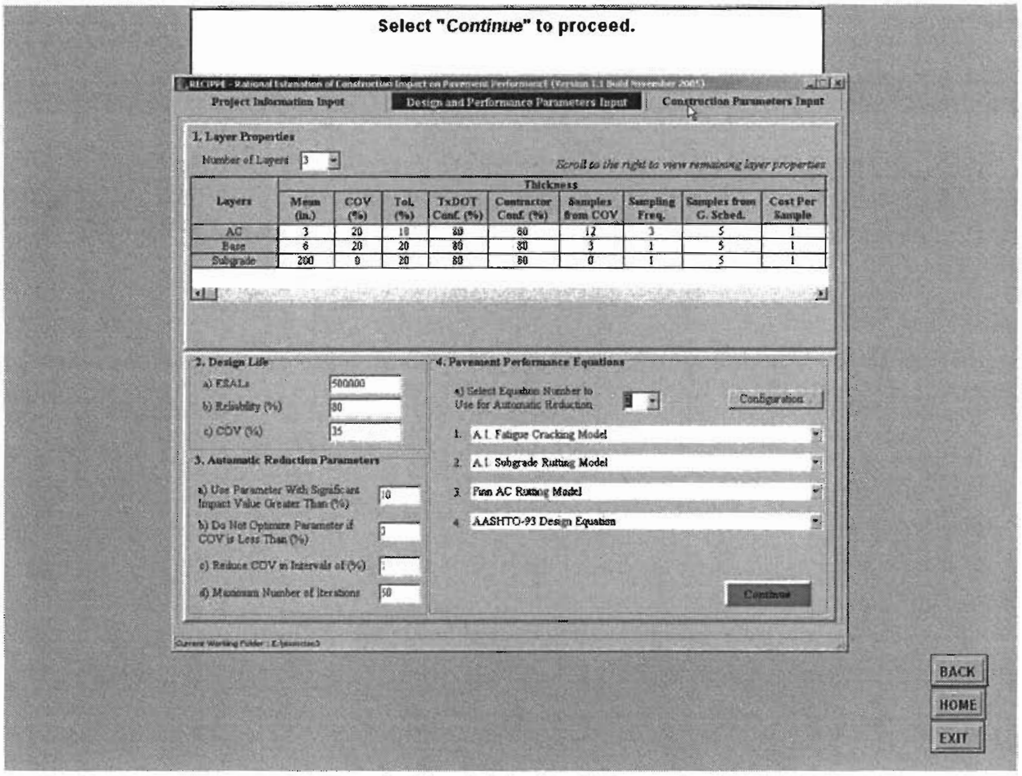
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO 93 Design Equation

This pavement performance equations feature in RECIPPE allows users to select four performance models at a time to be analyzed. However, only one model can be used to control the automatic reduction process.
Also, the configuration button feature in the program can be used to configure new

Figure 2.67 - Slide 2 of Exercise 3



Select "*Continue*" to proceed.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

	Thickness								
Layers	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 1

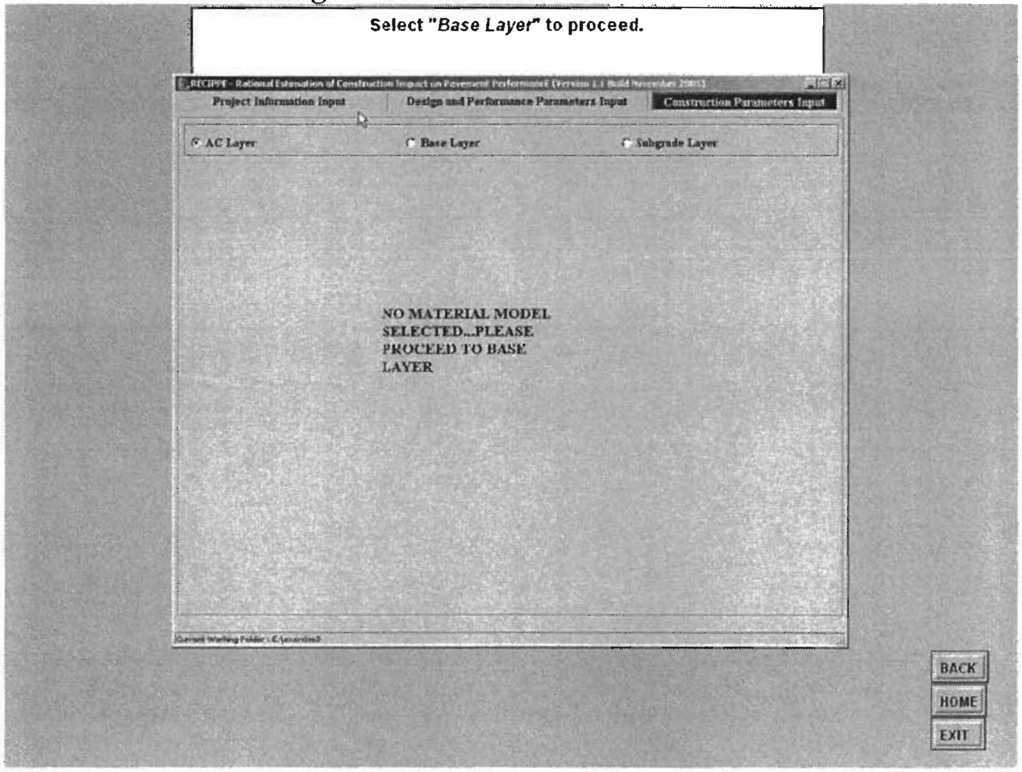
d) Maximum Number of Iterations: 50

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

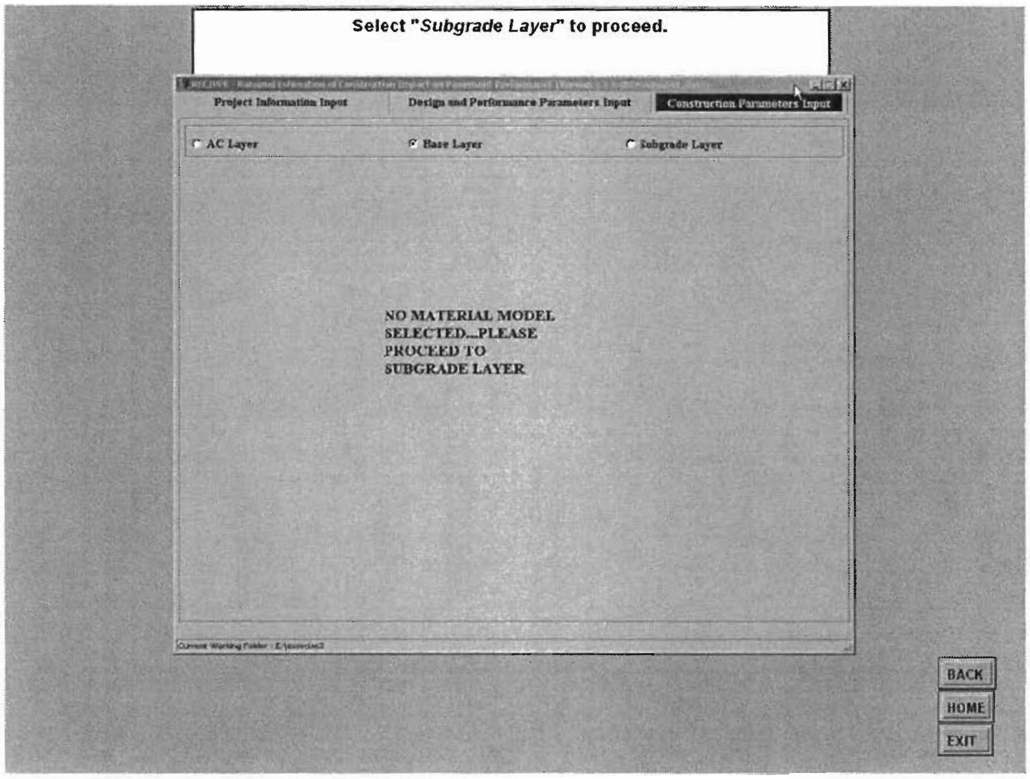
Figure 2.68 - Slide 3 of Exercise 3



Select "*Base Layer*" to proceed.

NO MATERIAL MODEL SELECTED...PLEASE PROCEED TO BASE LAYER

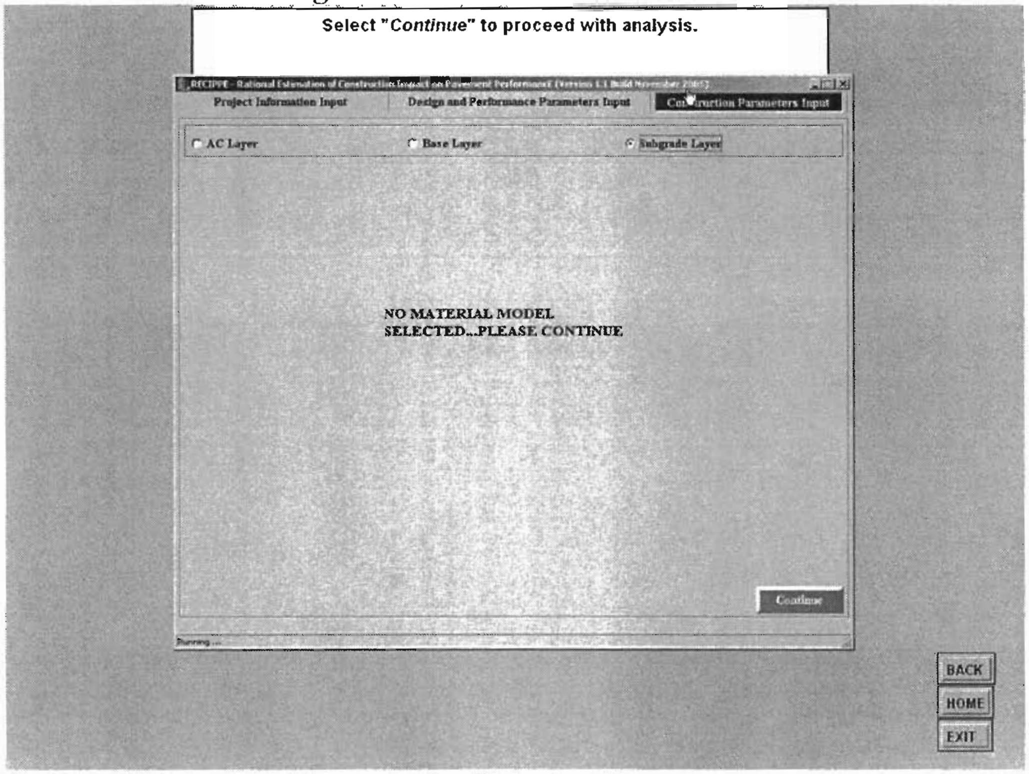
Figure 2.69 - Slide 4 of Exercise 3



Select "*Subgrade Layer*" to proceed.

NO MATERIAL MODEL
SELECTED...PLEASE
PROCEED TO
SUBGRADE LAYER

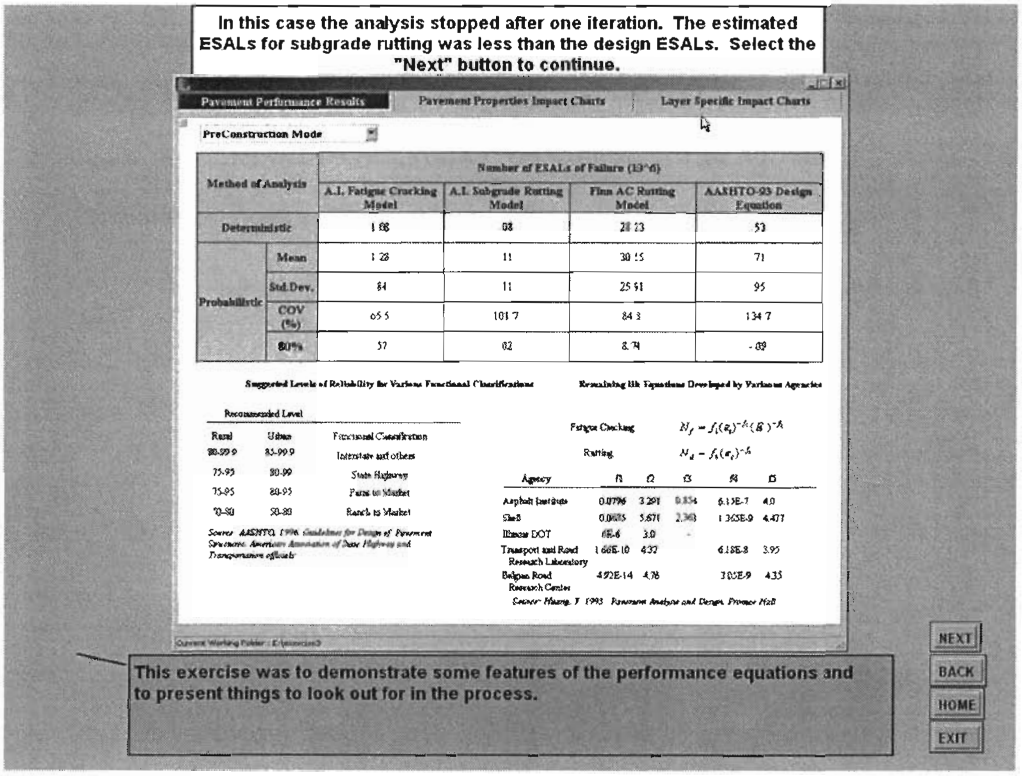
Figure 2.70 - Slide 5 of Exercise 3



Select "*Continue*" to proceed with analysis.

NO MATERIAL MODEL
SELECTED...PLEASE CONTINUE

Figure 2.71 - Slide 6 of Exercise 3



In this case the analysis stopped after one iteration. The estimated ESALs for subgrade rutting was less than the design ESALs. Select the "Next" button to continue.

Method of Analysis		Number of ESALs of Failure (10^6)			
		A.I. Fatigue Cracking Model	A.I. Subgrade Rutting Model	Finn AC Rutting Model	AASHTO-93 Design Equation
Deterministic		1.88	03	28.23	53
Probabilistic	Mean	1.28	11	30.15	71
	Std.Dev.	84	11	25.91	95
	COV (%)	65.5	101.7	84.3	134.7
	80%	57	02	8.74	-.09

Suggested Levels of Reliability for Various Functional Classifications

Recommended Level		
Rural	Urban	Functional Classification
80-99.9	85-99.9	Interstate and others
75-95	80-99	State Highway
75-95	80-95	Farm to Market
50-80	50-80	Ranch to Market

Source: AASHTO, 1996. Guidelines for Design of Pavement Structures. American Association of State Highway and Transportation officials

Remaining life Equations Developed by Various Agencies

Fatigue Cracking $N_f = f_1(\varepsilon_t)^{-f_2}(E)^{-f_3}$

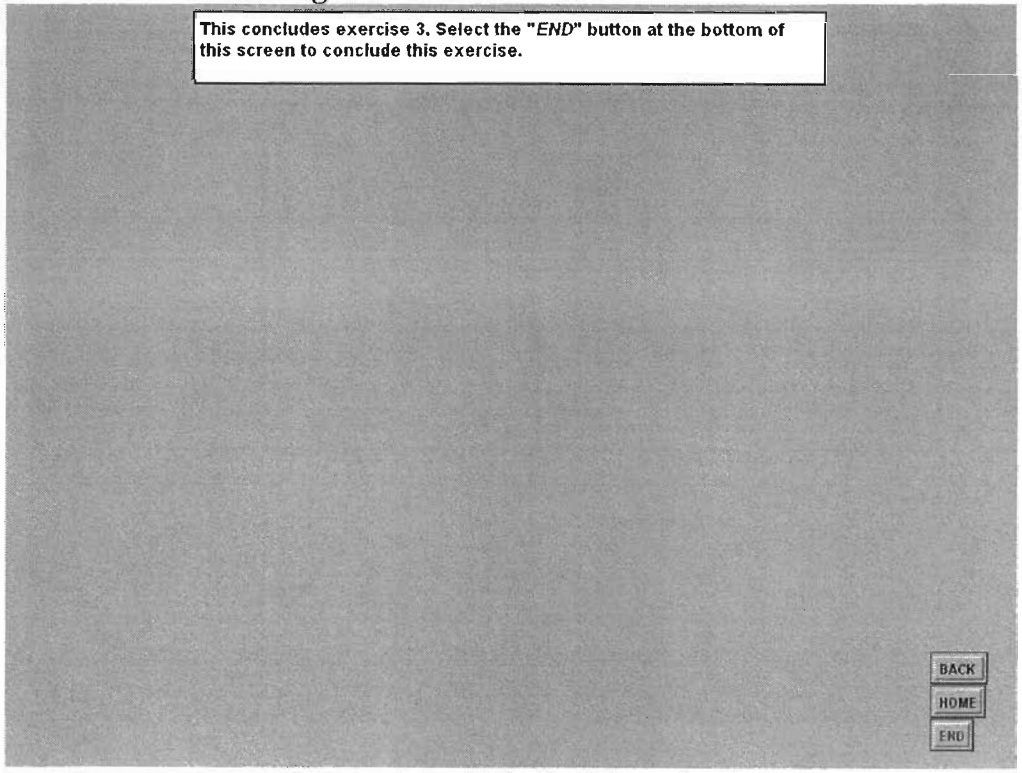
Rutting $N_d = f_4(\varepsilon_c)^{-f_5}$

Agency	f1	f2	f3	f4	f5
Asphalt Institute	0.0796	3.291	0.854	6.15E-7	4.0
Shell	0.0685	5.671	2.363	1.365E-9	4.477
Illinois DOT	5E-6	3.0	-		
Transport and Road Research Laboratory	1.66E-10	4.32		6.18E-8	3.95
Belgian Road Research Center	4.92E-14	4.76		3.05E-9	4.35

Source: Huang, Y. 1993. Pavement Analysis and Design. Prentice Hall

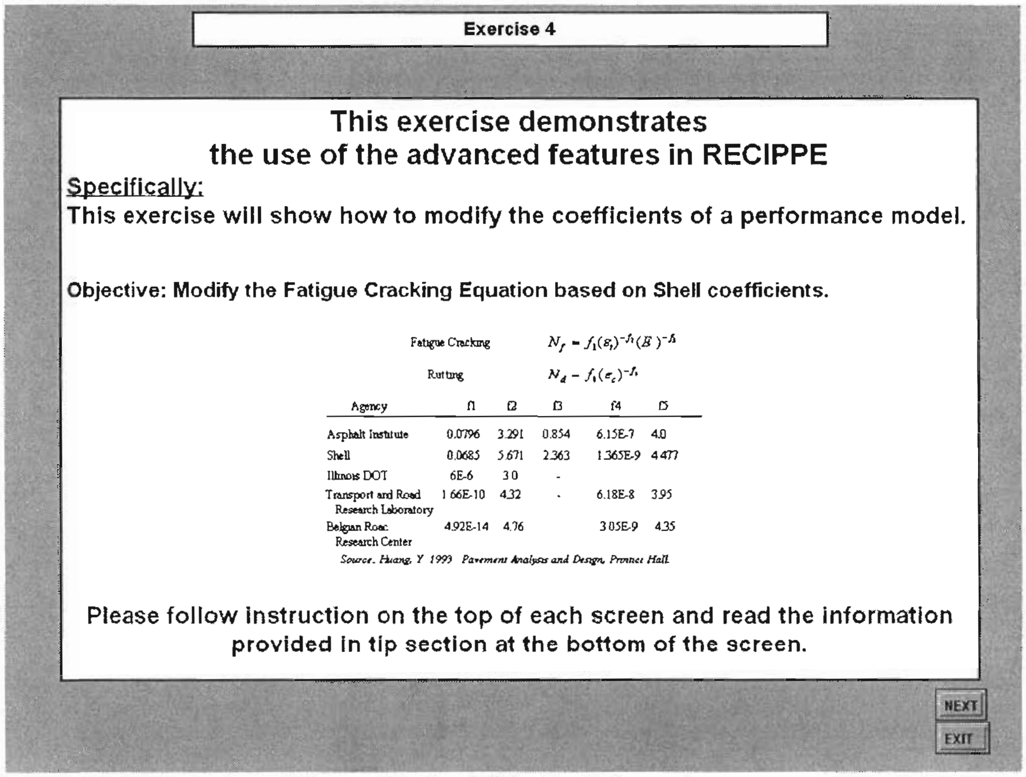
This exercise was to demonstrate some features of the performance equations and to present things to look out for in the process.

Figure 2.72 - Slide 7 of Exercise 3



This concludes exercise 3. Select the "*END*" button at the bottom of this screen to conclude this exercise.

Figure 2.73 - Slide 8 of Exercise 3



Exercise 4

This exercise demonstrates the use of the advanced features in RECIPPE

Specifically:

This exercise will show how to modify the coefficients of a performance model.

Objective: Modify the Fatigue Cracking Equation based on Shell coefficients.

Fatigue Cracking $N_f = f_1(\varepsilon_t)^{-f_2}(E)^{-f_3}$

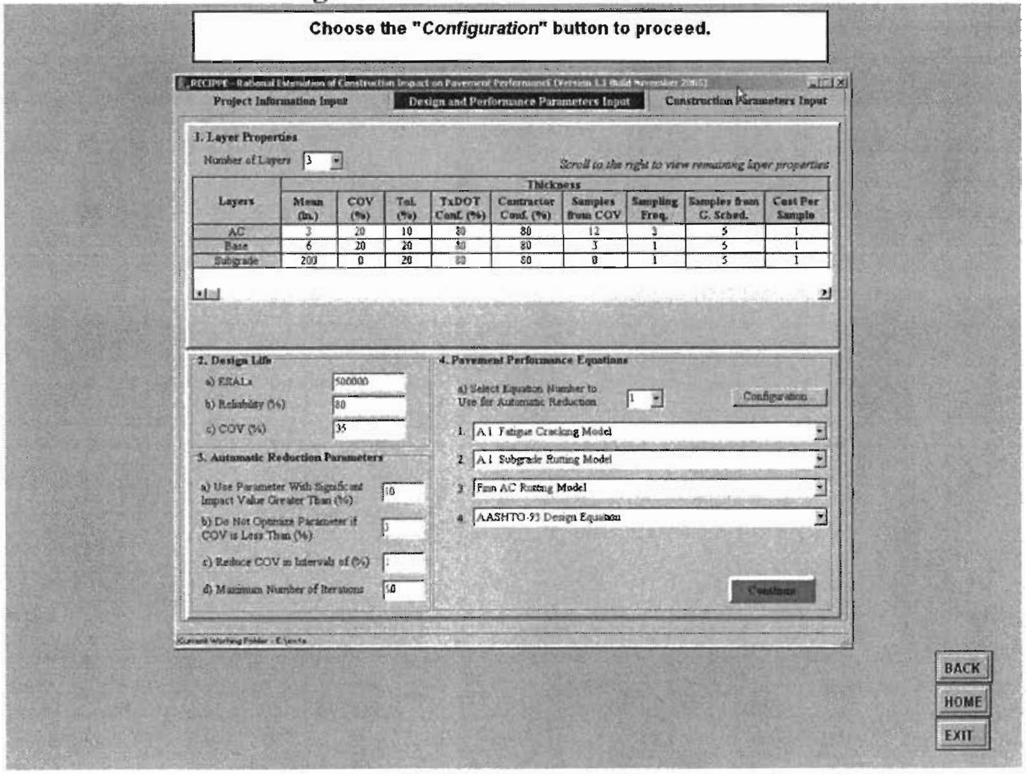
Rutting $N_d = f_4(\varepsilon_c)^{-f_5}$

Agency	f1	f2	f3	f4	f5
Asphalt Institute	0.0796	3.291	0.854	6.15E-7	4.0
Shell	0.0685	5.671	2.363	1.365E-9	4.477
Illinois DOT	6E-6	3.0	-		
Transport and Road Research Laboratory	1.66E-10	4.32	-	6.18E-8	3.95
Belgian Road Research Center	4.92E-14	4.76		3.05E-9	4.35

Source. Huang, Y. 1993. Pavement Analysis and Design, Prentice Hall.

Please follow instruction on the top of each screen and read the information provided in tip section at the bottom of the screen.

Figure 2.74 - Slide 1 of Exercise 4



Choose the "*Configuration*" button to proceed.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 1

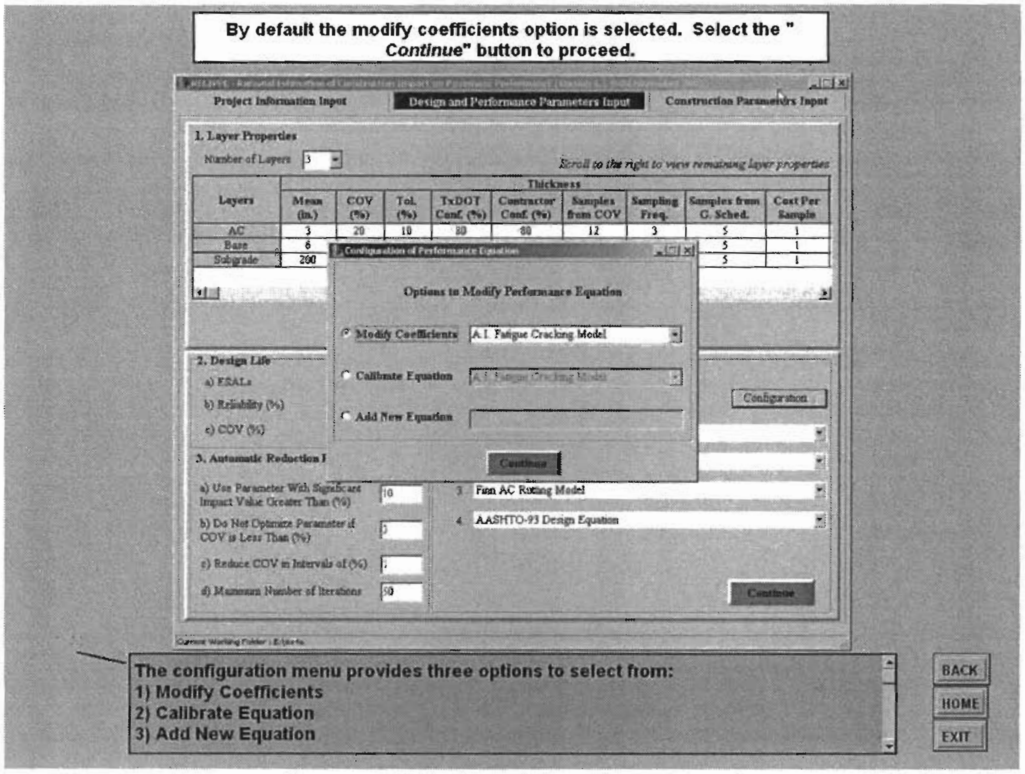
d) Maximum Number of Iterations: 50

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.1 Fatigue Cracking Model
2. A.1 Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.75 - Slide 2 of Exercise 4



By default the modify coefficients option is selected. Select the "*Continue*" button to proceed.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6							5	1
Subgrade	200							5	1

2. Design Life
a) ESALs
b) Reliability (%)
c) COV (%)

3. Automatic Reduction
a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 5
c) Reduce COV in Intervals of (%): 1
d) Maximum Number of Iterations: 50

3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

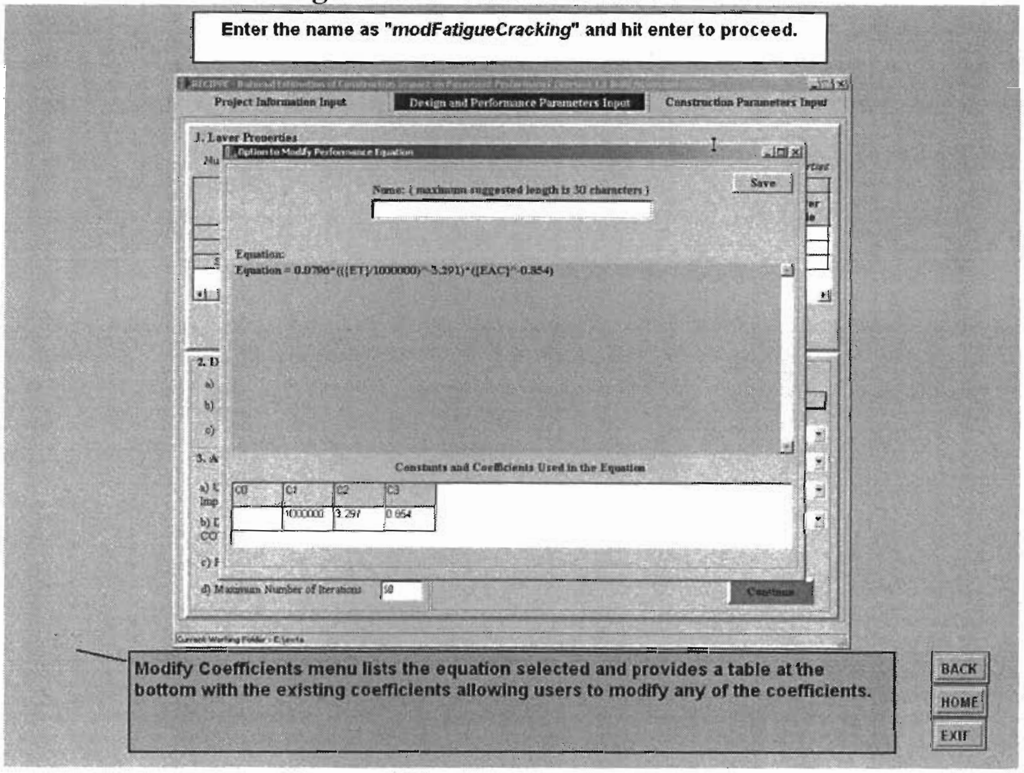
Configuration of Performance Equation

Options to Modify Performance Equation

● Modify Coefficients: A.I. Fatigue Cracking Model
○ Calibrate Equation: A.I. Fatigue Cracking Model
○ Add New Equation

The configuration menu provides three options to select from:
1) Modify Coefficients
2) Calibrate Equation
3) Add New Equation

Figure 2.76 - Slide 3 of Exercise 4



Enter the name as "*modFatigueCracking*" and hit enter to proceed.

Option to Modify Performance Equation

Name: (maximum suggested length is 30 characters)

Equation:
Equation = 0.0796*((({ET}/1000000)^-3.291)*({EAC}^-0.854)

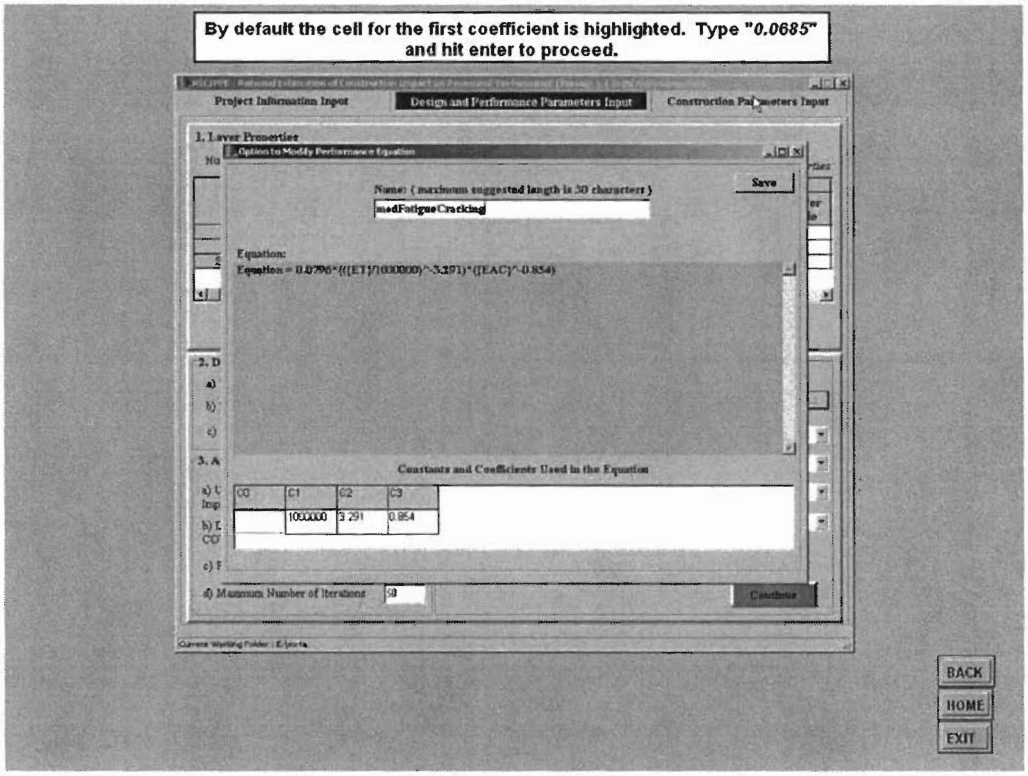
Constants and Coefficients Used in the Equation

C0	C1	C2	C3
	1000000	3.291	0.854

d) Maximum Number of Iterations: 50

Modify Coefficients menu lists the equation selected and provides a table at the bottom with the existing coefficients allowing users to modify any of the coefficients.

Figure 2.77 - Slide 4 of Exercise 4



By default the cell for the first coefficient is highlighted. Type "*0.0685*" and hit enter to proceed.

Name: (maximum suggested length is 30 characters)

medFatigueCracking

Equation:

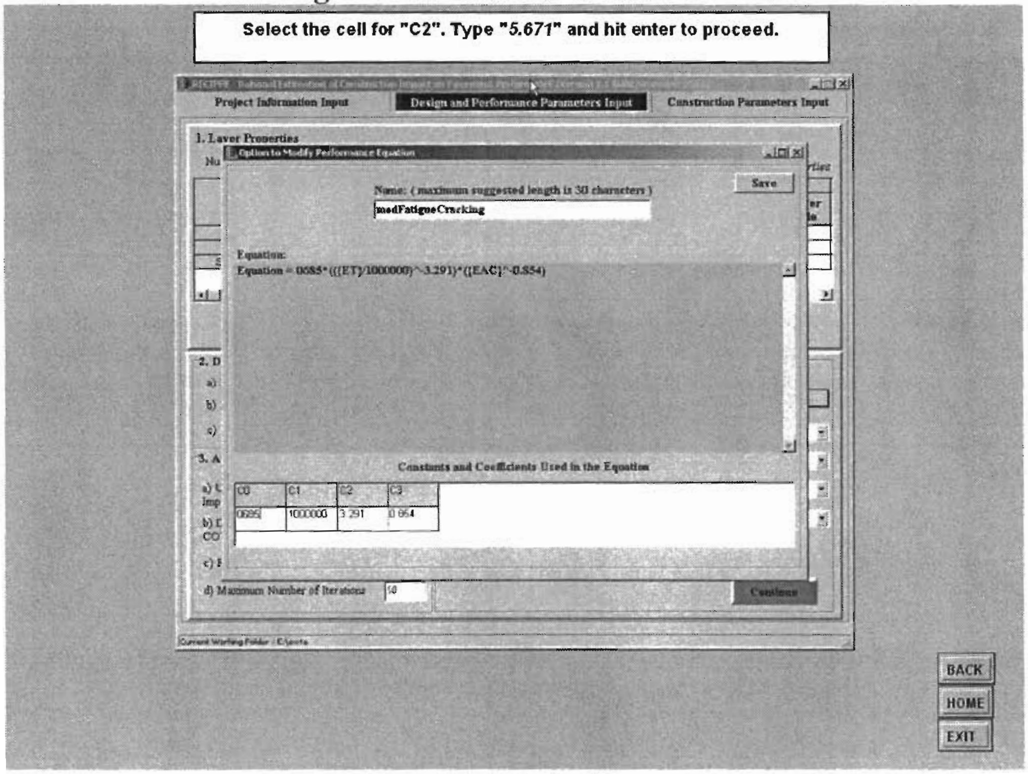
Equation = 0.0796*(([ET]/1000000)^-3.291)*([EAC]^-0.854)

Constants and Coefficients Used in the Equation

C0	C1	C2	C3
	1000000	3.291	0.854

d) Maximum Number of Iterations 50

Figure 2.78 - Slide 5 of Exercise 4



Select the cell for "C2". Type "*5.671*" and hit enter to proceed.

Name: (maximum suggested length is 30 characters)

medFatigueCracking

Equation:

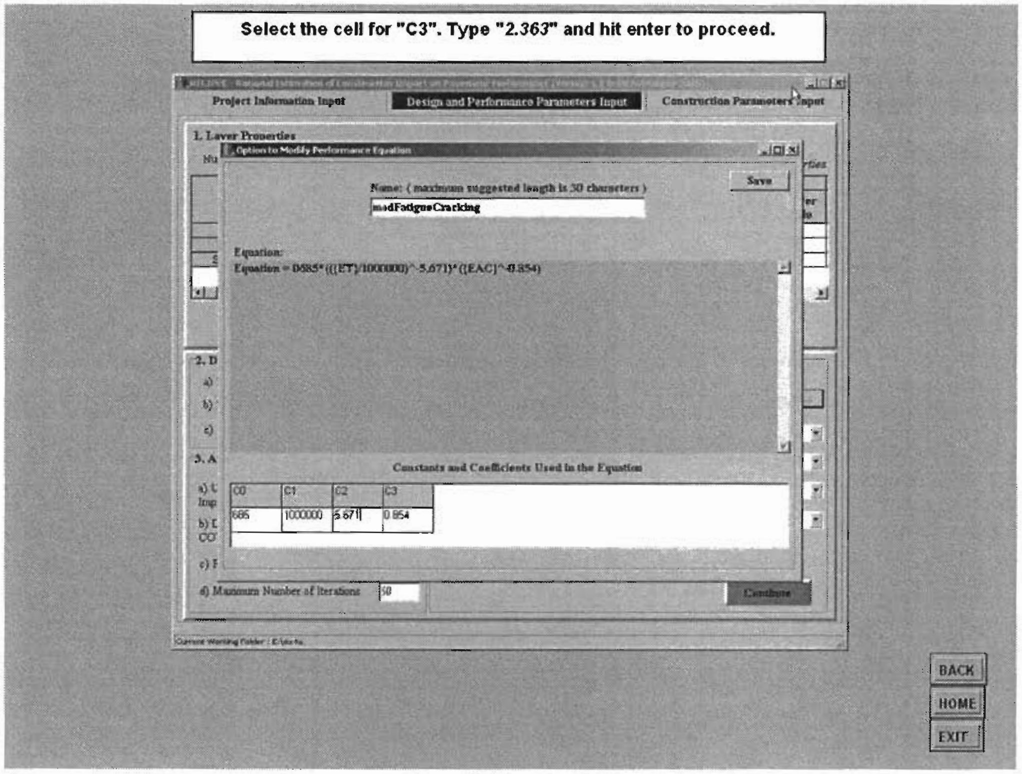
Equation = 0685*(([ET]/1000000)^-3.291)*([EAC]^-0.854)

Constants and Coefficients Used in the Equation

C0	C1	C2	C3
0685	1000000	3.291	0.854

d) Maximum Number of Iterations 50

Figure 2.79 - Slide 6 of Exercise 4



Select the cell for "C3". Type "*2.363*" and hit enter to proceed.

Name: (maximum suggested length is 30 characters)
modFatigueCracking

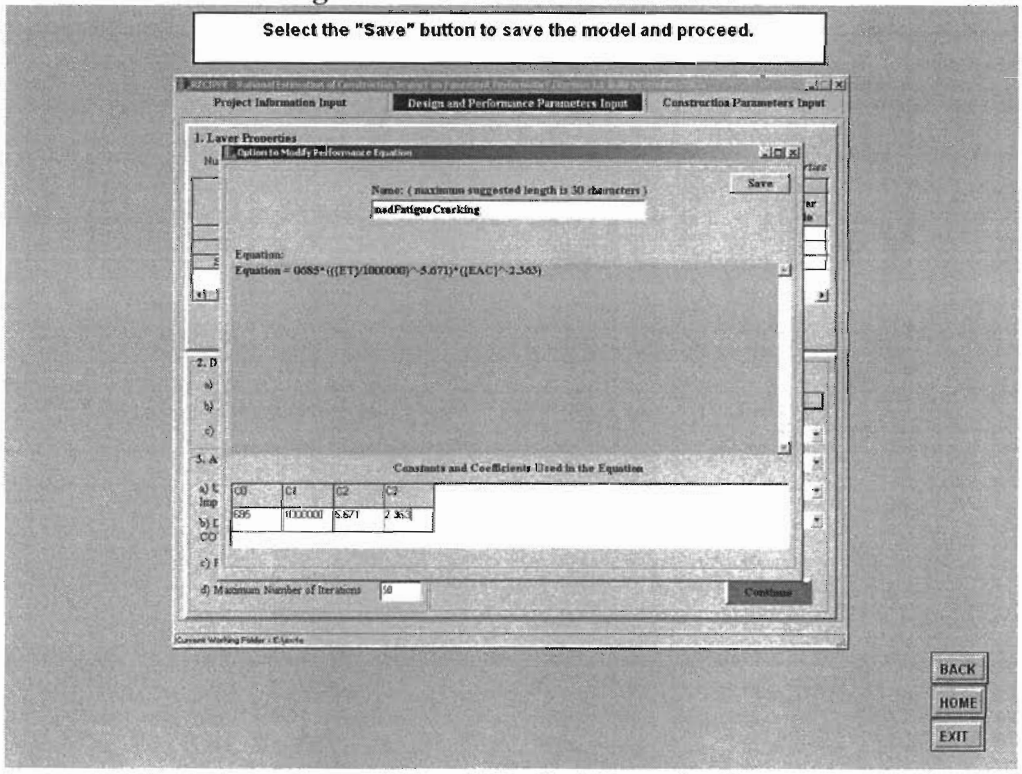
Equation:
Equation = 0685*(((ET)/1000000)^-5.671)*((EAC)^-0.854)

Constants and Coefficients Used in the Equation

C0	C1	C2	C3
686	1000000	5.671	0.854

d) Maximum Number of Iterations 50

Figure 2.80 - Slide 7 of Exercise 4



Select the "Save" button to save the model and proceed.

Name: (maximum suggested length is 30 characters)
modFatigueCracking

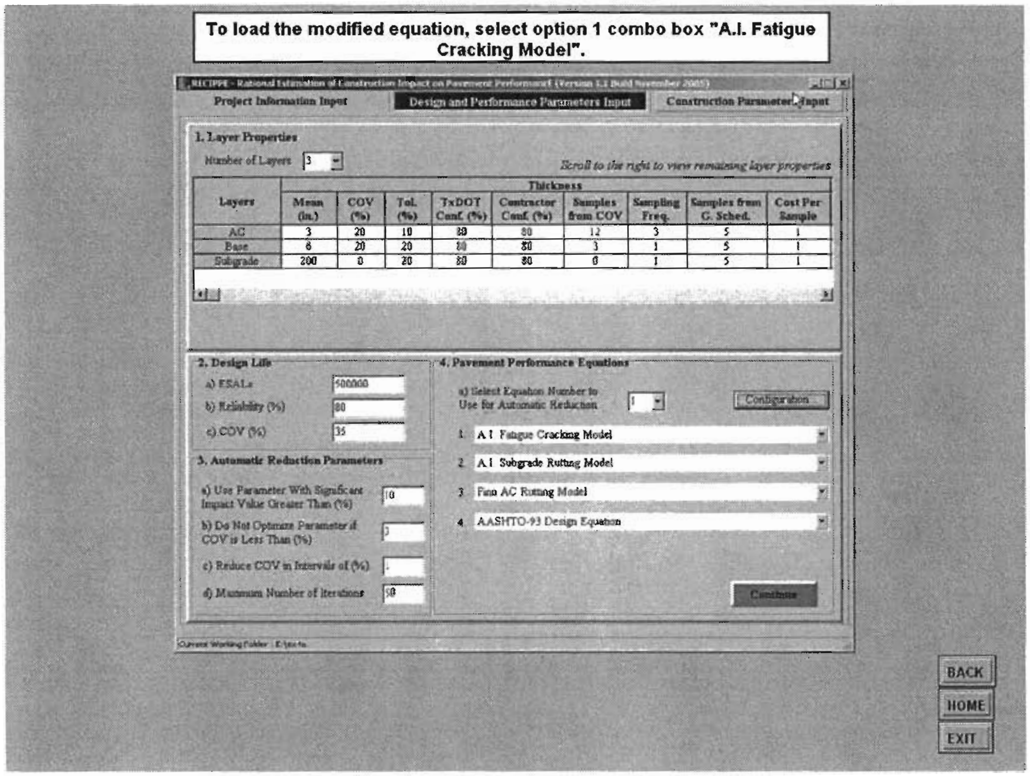
Equation:
Equation = 0685*(((ET)/1000000)^-5.671)*((EAC)^-2.363)

Constants and Coefficients Used in the Equation

C0	C1	C2	C3
685	1000000	5.671	2.363

d) Maximum Number of Iterations 50

Figure 2.81 - Slide 8 of Exercise 4



To load the modified equation, select option 1 combo box "A.I. Fatigue Cracking Model".

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

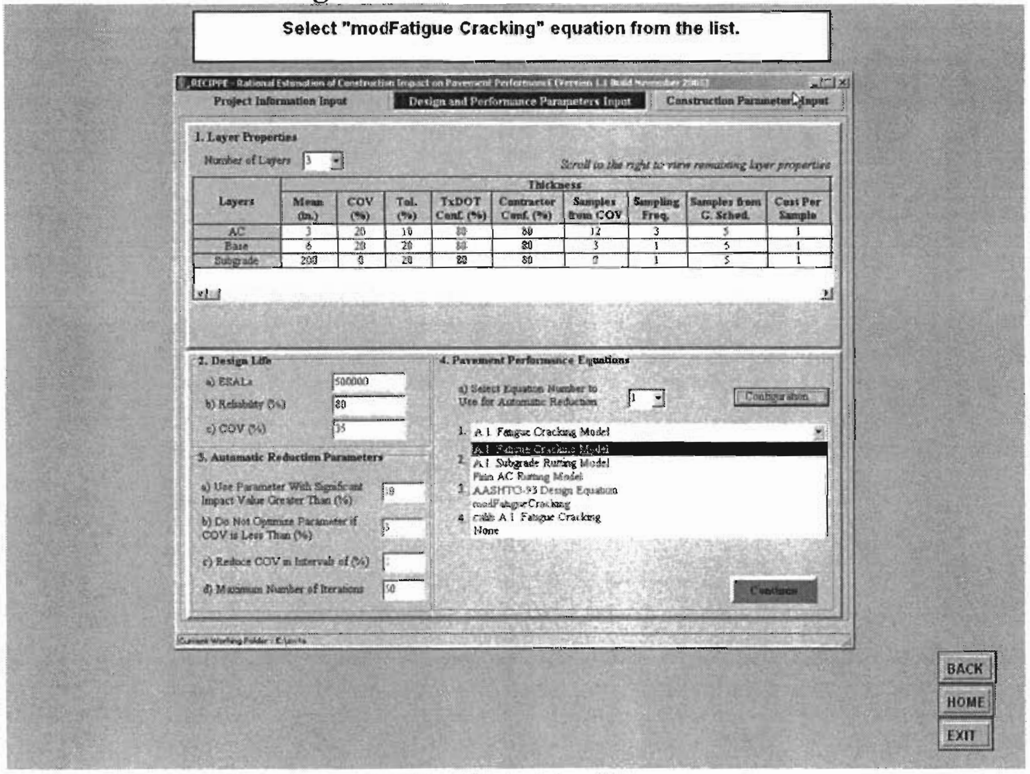
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\recte

Figure 2.82 - Slide 9 of Exercise 4



Select "modFatigue Cracking" equation from the list.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

4. Pavement Performance Equations

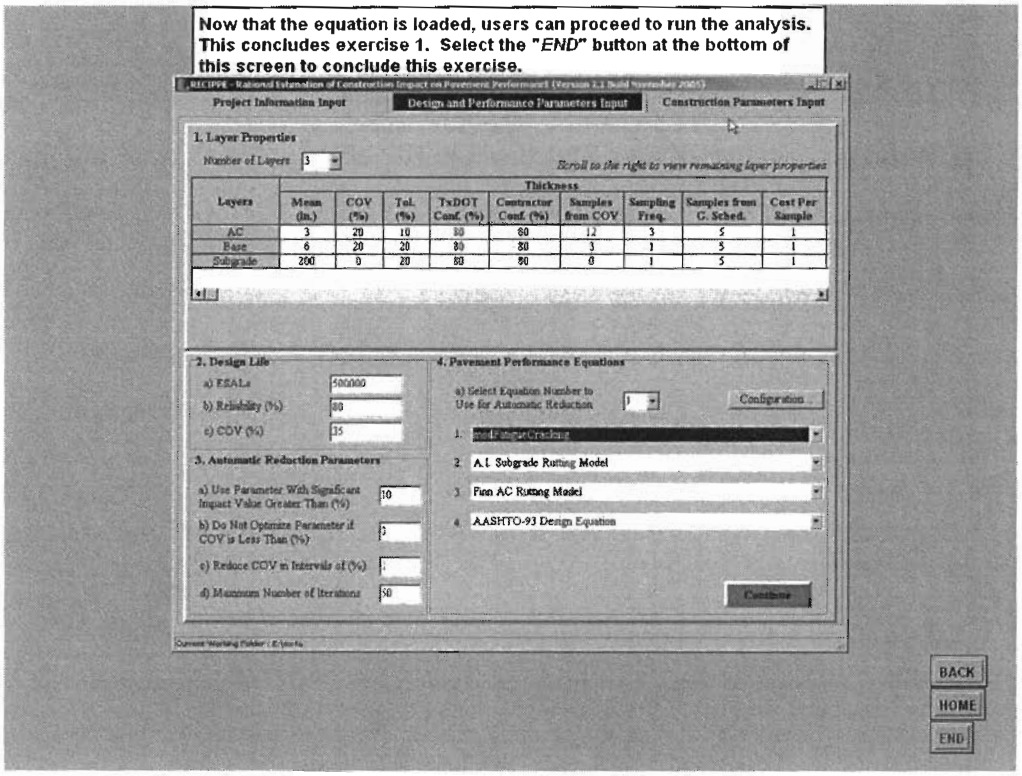
a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model

- A.I. Fatigue Cracking Model
- A.I. Subgrade Rutting Model
- Finn AC Rutting Model
- AASHTO-93 Design Equation
- modFatigueCracking
- calib A.I. Fatigue Cracking
- None

Current Working Folder : E:\recte

Figure 2.83 - Slide 10 of Exercise 4



Now that the equation is loaded, users can proceed to run the analysis. This concludes exercise 1. Select the "*END*" button at the bottom of this screen to conclude this exercise.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 2.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

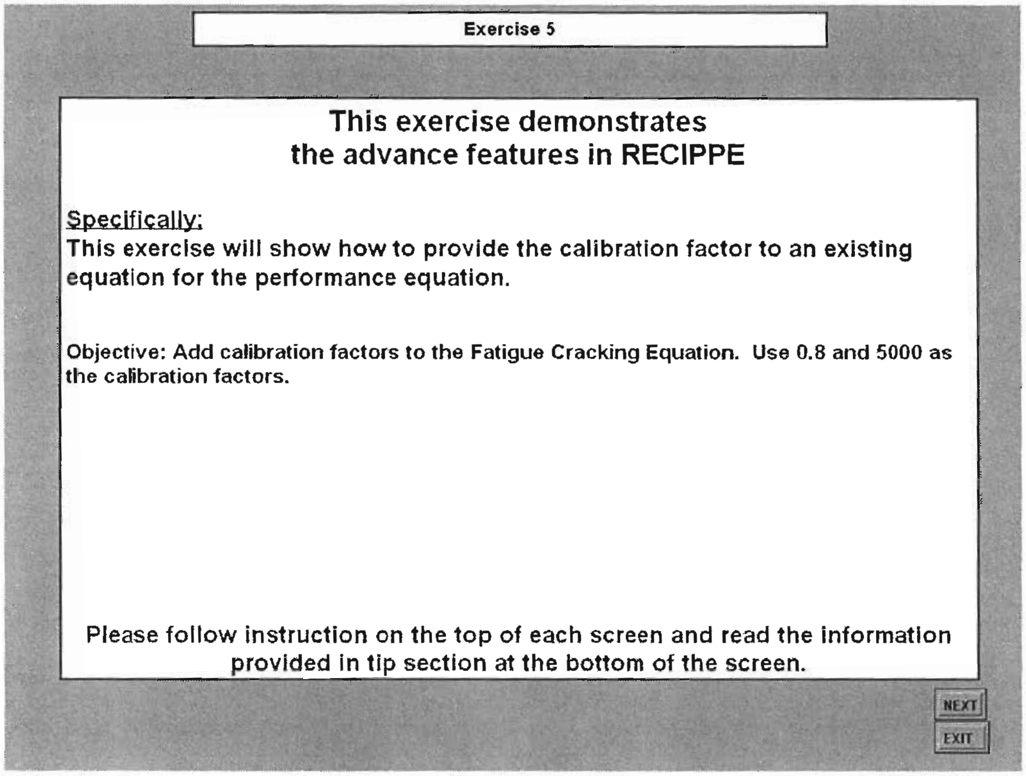
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. modFatigueCracking
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder: E:\works

Figure 2.84 - Slide 11 of Exercise 4



Exercise 5

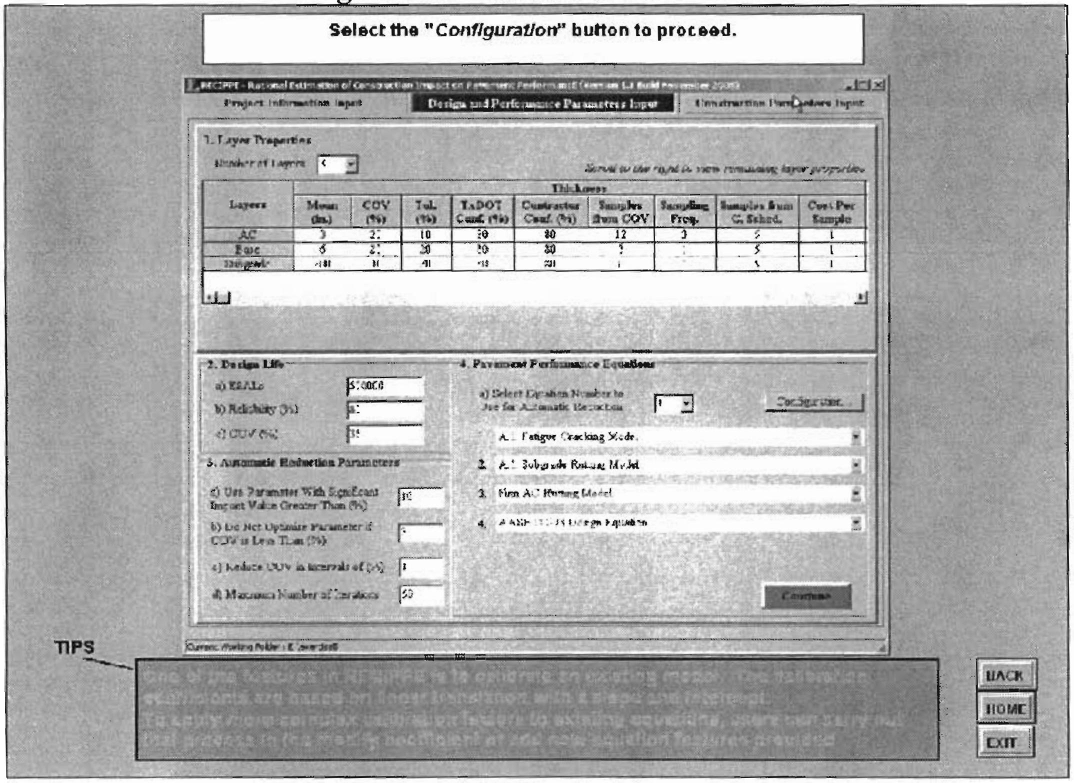
This exercise demonstrates
the advance features in RECIPPE

Specifically:
This exercise will show how to provide the calibration factor to an existing equation for the performance equation.

Objective: Add calibration factors to the Fatigue Cracking Equation. Use 0.8 and 5000 as the calibration factors.

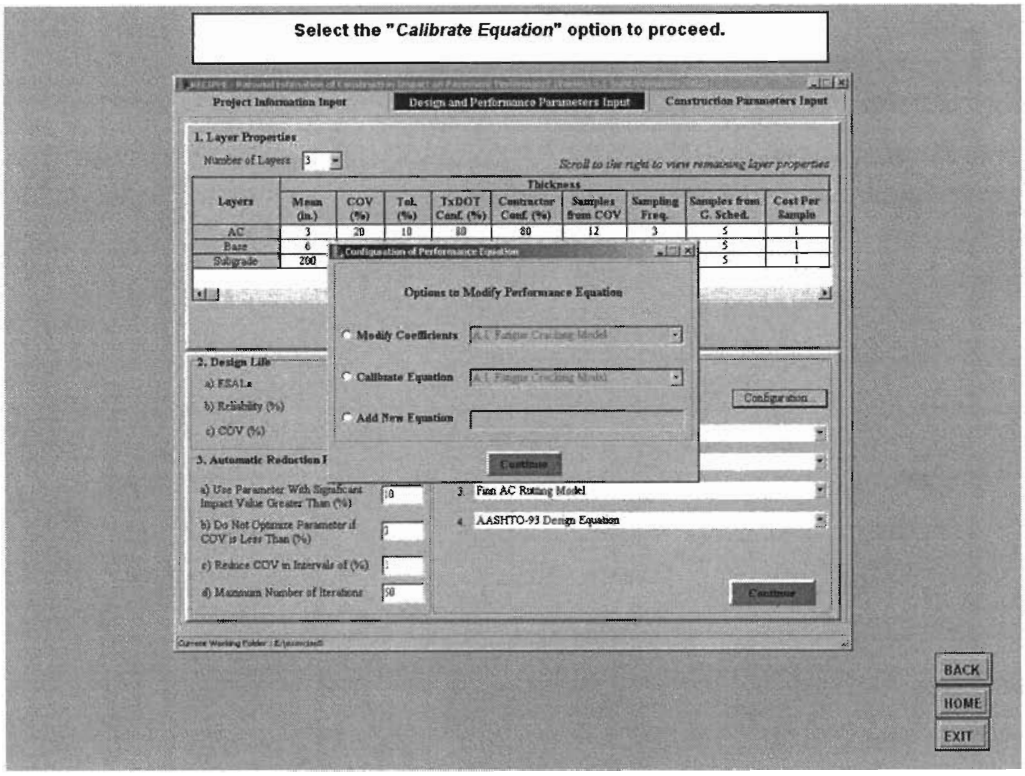
Please follow instruction on the top of each screen and read the information provided in tip section at the bottom of the screen.

Figure 2.85 - Slide 1 of Exercise 5



Select the "*Configuration*" button to proceed.

Figure 2.86 - Slide 2 of Exercise 5


Select the "*Calibrate Equation*" option to proceed.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6							5	1
Subgrade	200							5	1

Configuration of Performance Equation

Options to Modify Performance Equation

○ Modify Coefficients: A.1. Fatigue Cracking Model

○ Calibrate Equation: A.1. Fatigue Cracking Model

○ Add New Equation:

2. Design Life

a) ESALs

b) Reliability (%)

c) COV (%)

3. Automatic Reduction I

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

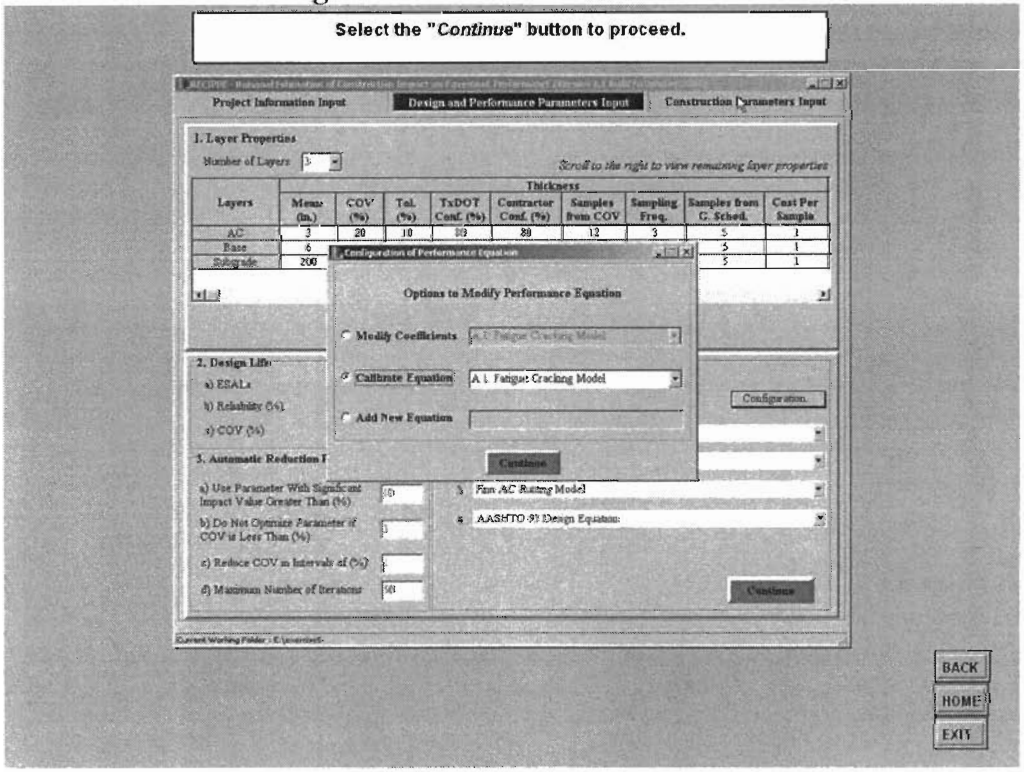
c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

3. Finn AC Rutting Model

4. AASHTO-93 Design Equation

Figure 2.87 - Slide 3 of Exercise 5


Select the "*Continue*" button to proceed.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6							5	1
Subgrade	200							5	1

Configuration of Performance Equation

Options to Modify Performance Equation

○ Modify Coefficients: A.1. Fatigue Cracking Model

● Calibrate Equation: A.1. Fatigue Cracking Model

○ Add New Equation:

2. Design Life

a) ESALs

b) Reliability (%)

c) COV (%)

3. Automatic Reduction I

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

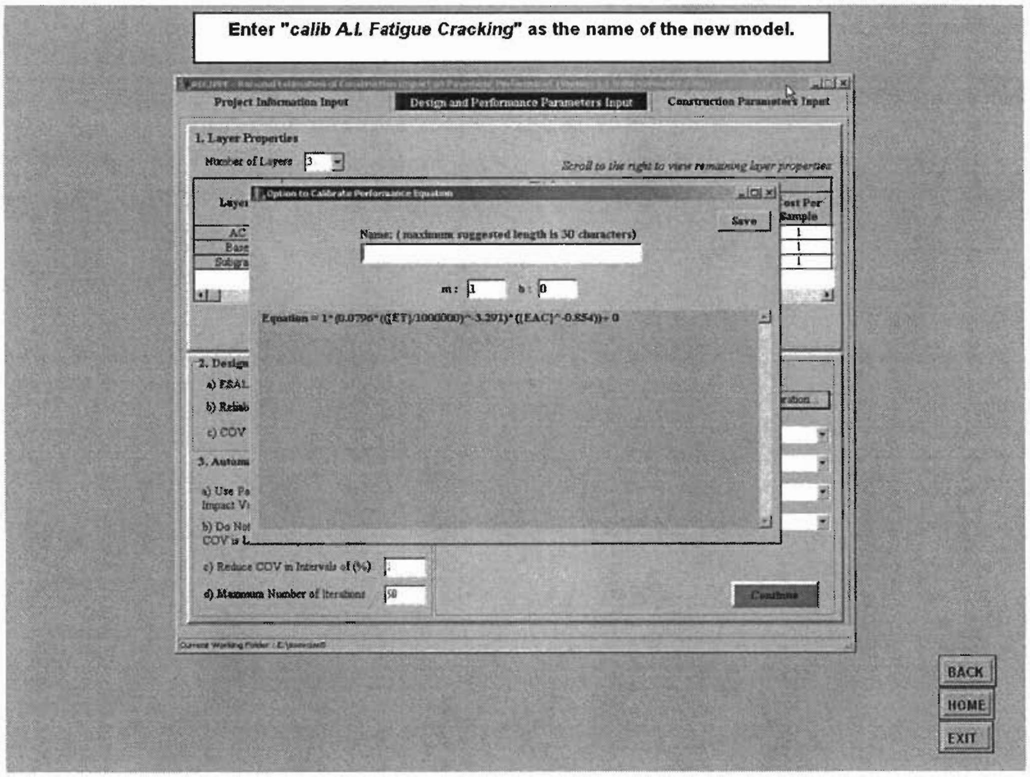
c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

3. Finn AC Rutting Model

4. AASHTO-93 Design Equation

Figure 2.88 - Slide 4 of Exercise 5



Enter "*calib A.I. Fatigue Cracking*" as the name of the new model.

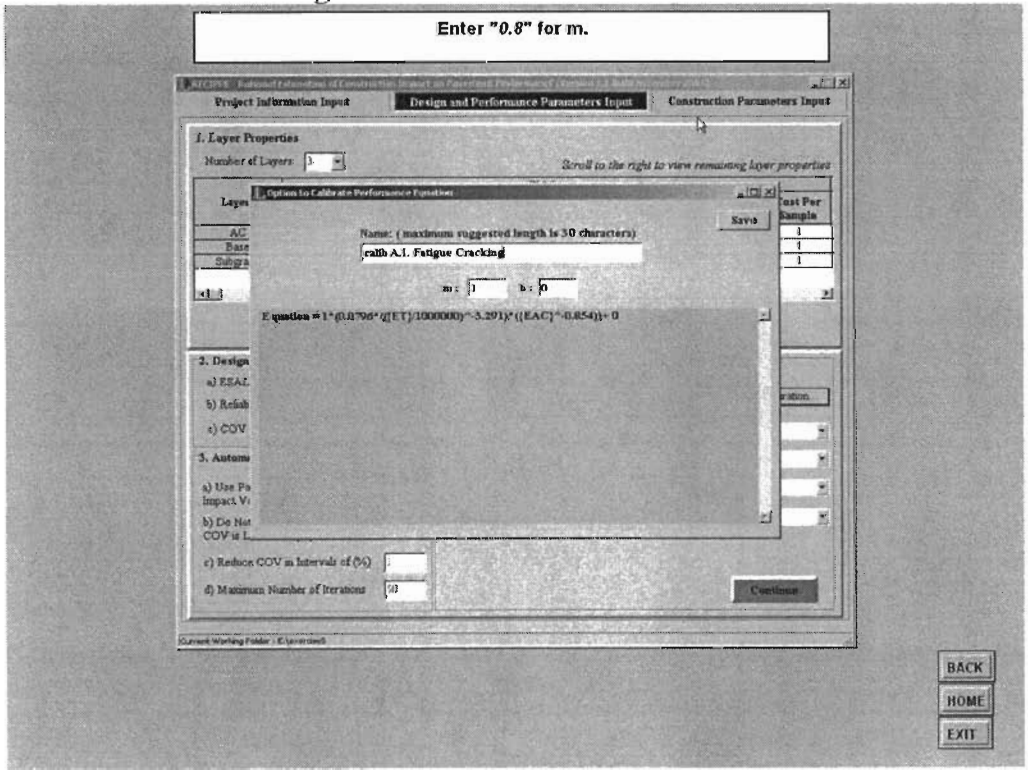
Option to Calibrate Performance Equation

Name: (maximum suggested length is 30 characters)

m : 1   b : 0

Equation = 1*(0.0796*(([ET]/1000000)^-3.291)*([EAC]^-0.854))+ 0

Figure 2.89 - Slide 5 of Exercise 5



Enter "*0.8*" for m.

Option to Calibrate Performance Equation

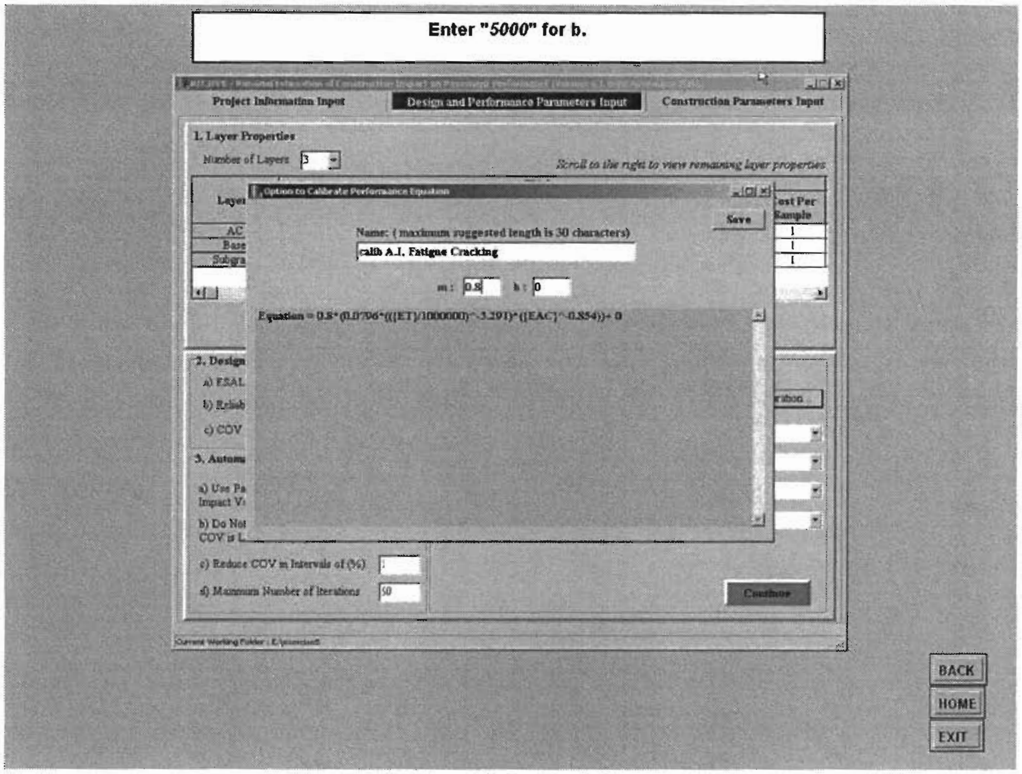
Name: (maximum suggested length is 30 characters)

calib A.I. Fatigue Cracking

m : 1   b : 0

Equation = 1*(0.0796*(([ET]/1000000)^-3.291)*([EAC]^-0.854))+ 0

Figure 2.90 - Slide 6 of Exercise 5



Enter "*5000*" for b.

Number of Layers: 3

Name: (maximum suggested length is 30 characters) calib A.I. Fatigue Cracking

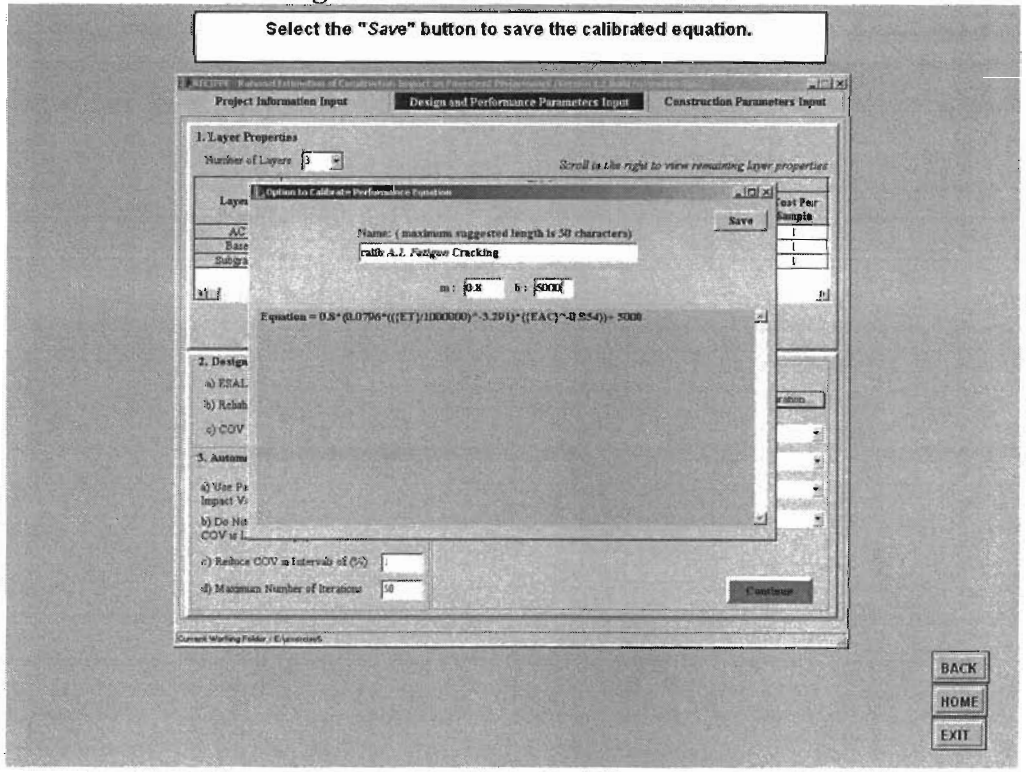
m: 0.8 b: 0

Equation = 0.8*(0.0796*(([ET]/1000000)^-3.291)*([EAC]^-0.854))+ 0

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

Figure 2.91 - Slide 7 of Exercise 5



Select the "*Save*" button to save the calibrated equation.

Number of Layers: 3

Name: (maximum suggested length is 30 characters) calib A.I. Fatigue Cracking

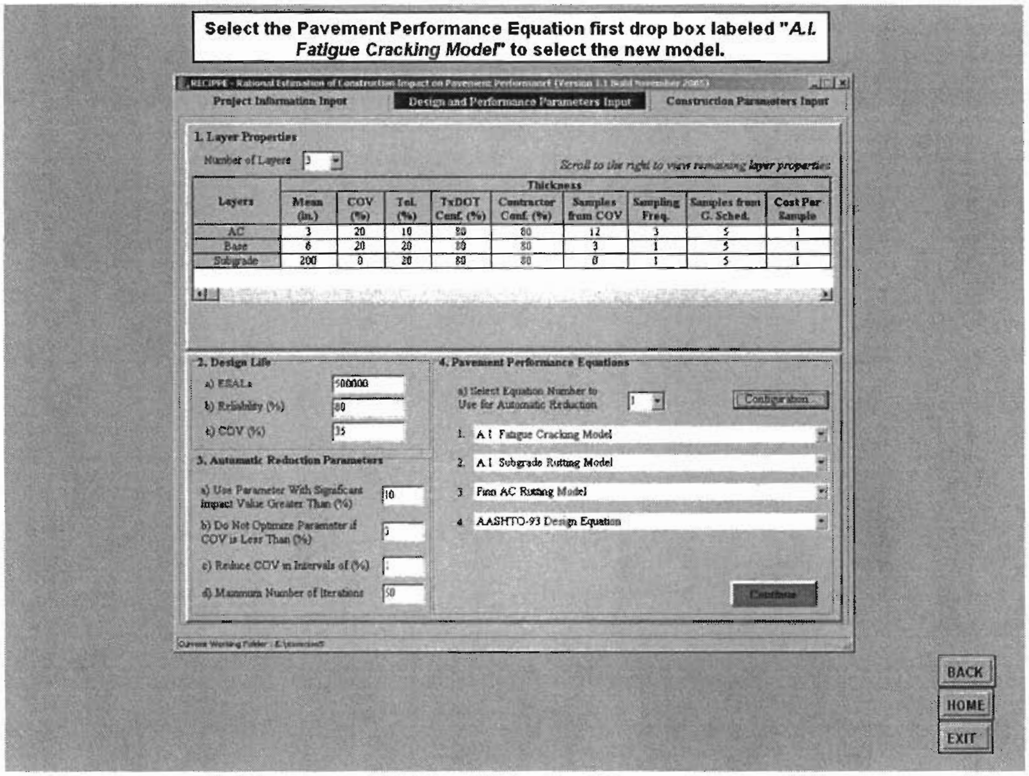
m: 0.8 b: 5000

Equation = 0.8*(0.0796*(([ET]/1000000)^-3.291)*([EAC]^-0.854))+ 5000

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

Figure 2.92 - Slide 8 of Exercise 5



Select the Pavement Performance Equation first drop box labeled "*A.I. Fatigue Cracking Model*" to select the new model.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

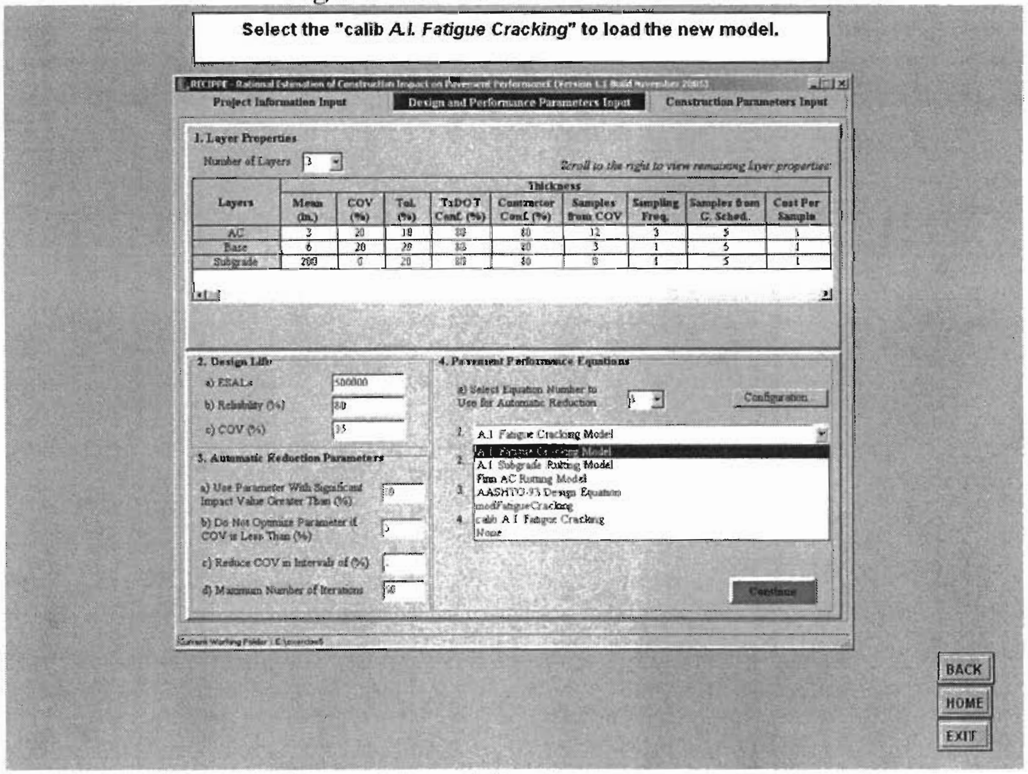
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\exercise5

Figure 2.93 - Slide 9 of Exercise 5



Select the "calib *A.I. Fatigue Cracking*" to load the new model.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

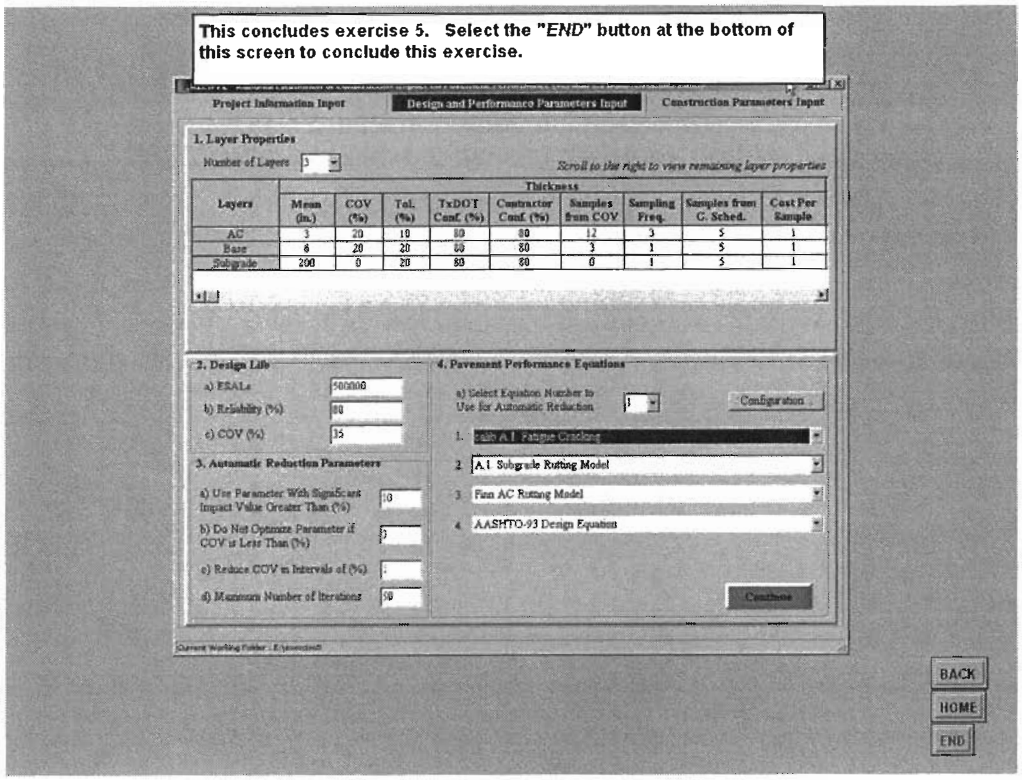
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model

Current Working Folder : E:\exercise5

Figure 2.94 - Slide 10 of Exercise 5



This concludes exercise 5. Select the "*END*" button at the bottom of this screen to conclude this exercise.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): [illegible]

d) Maximum Number of Iterations: 50

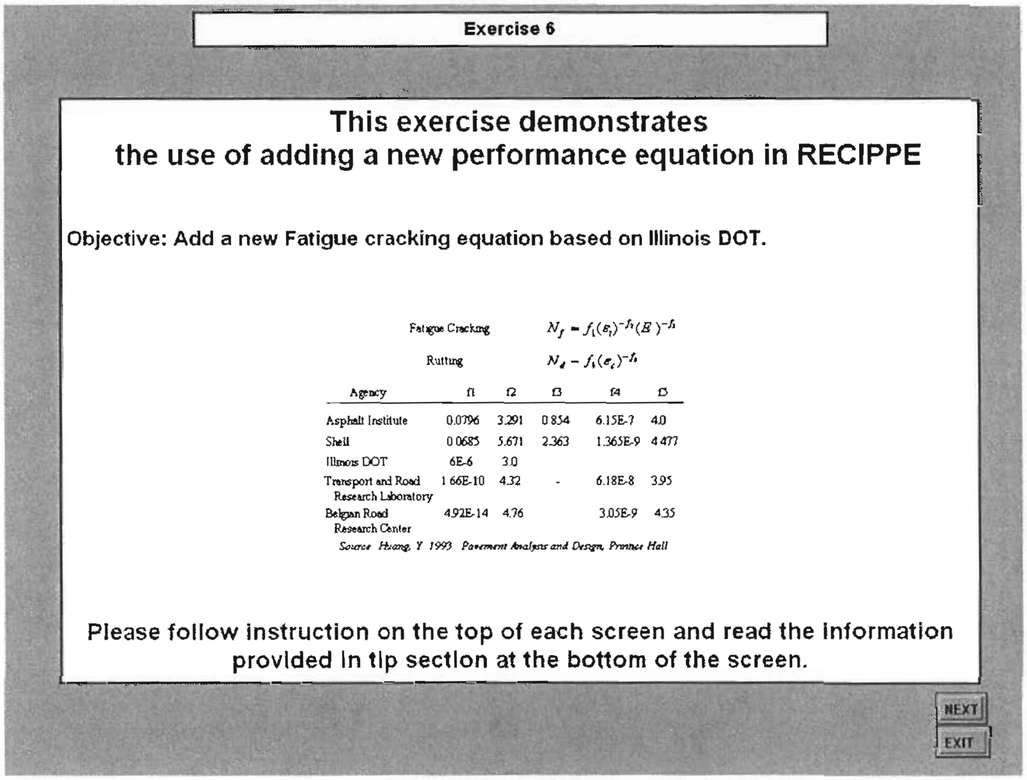
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. ...aih A.1 Fatigue Cracking
2. A.1 Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\[illegible]

Figure 2.95 - Slide 11 of Exercise 5



Exercise 6

This exercise demonstrates the use of adding a new performance equation in RECIPPE

Objective: Add a new Fatigue cracking equation based on Illinois DOT.

Fatigue Cracking $N_f = f_1(\varepsilon_t)^{-f_2}(E)^{-f_3}$

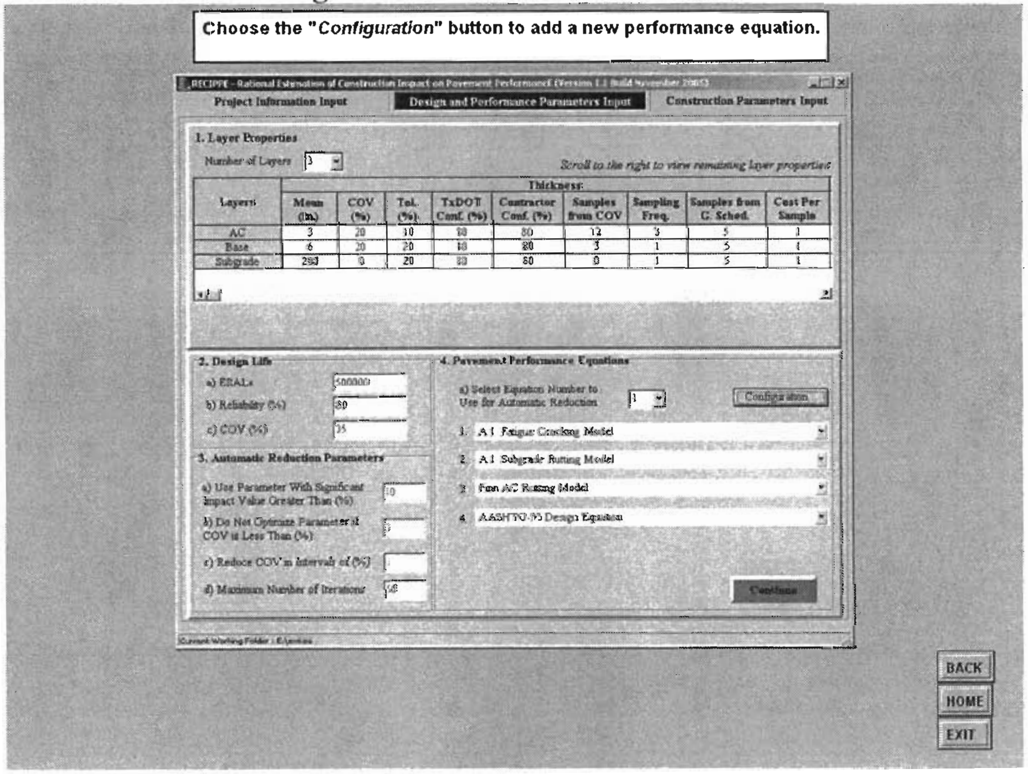
Rutting $N_d = f_4(\varepsilon_c)^{-f_5}$

Agency	f1	f2	f3	f4	f5
Asphalt Institute	0.0796	3.291	0.854	6.15E-7	4.0
Shell	0.0685	5.671	2.363	1.365E-9	4.477
Illinois DOT	6E-6	3.0			
Transport and Road Research Laboratory	1.66E-10	4.32	-	6.18E-8	3.95
Belgian Road Research Center	4.92E-14	4.76		3.05E-9	4.35

Source: Huang, Y. 1993. Pavement Analysis and Design, Prentice Hall

Please follow instruction on the top of each screen and read the information provided in tip section at the bottom of the screen.

Figure 2.96 - Slide 1 of Exercise 6



Choose the "*Configuration*" button to add a new performance equation.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness:								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	293	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 5

c) Reduce COV in Intervals of (%): 1

d) Maximum Number of Iterations: 50

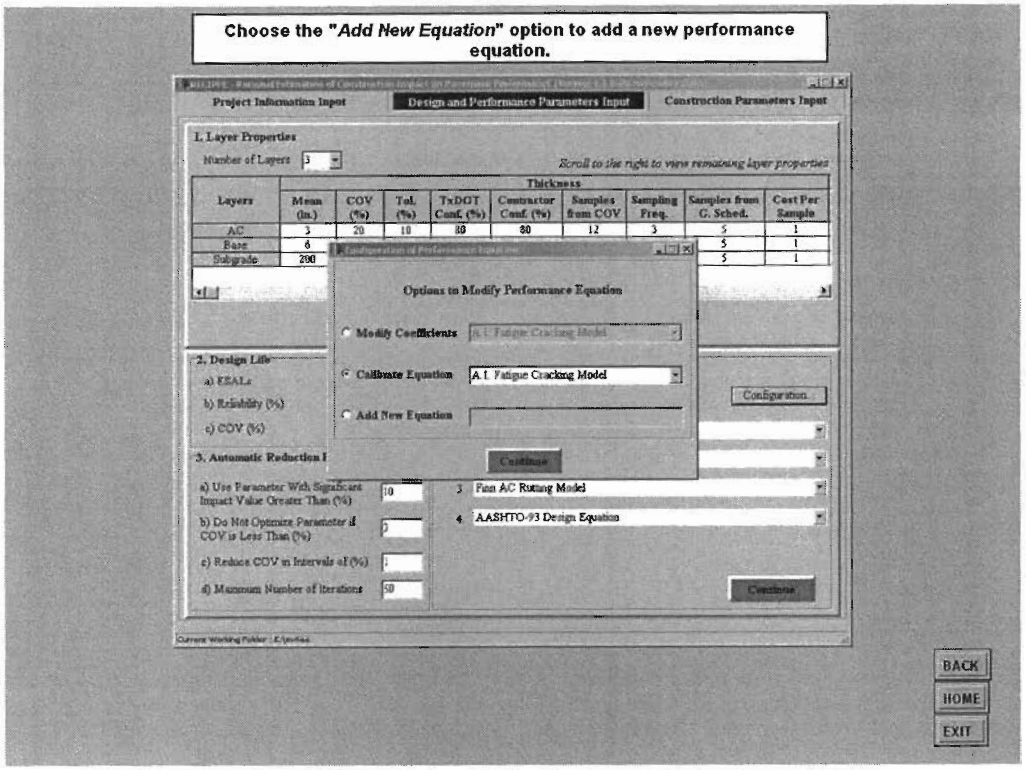
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Current Working Folder : E:\...

Figure 2.97 - Slide 2 of Exercise 6



Choose the "*Add New Equation*" option to add a new performance equation.

Number of Layers 3

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6							5	1
Subgrade	200							5	1

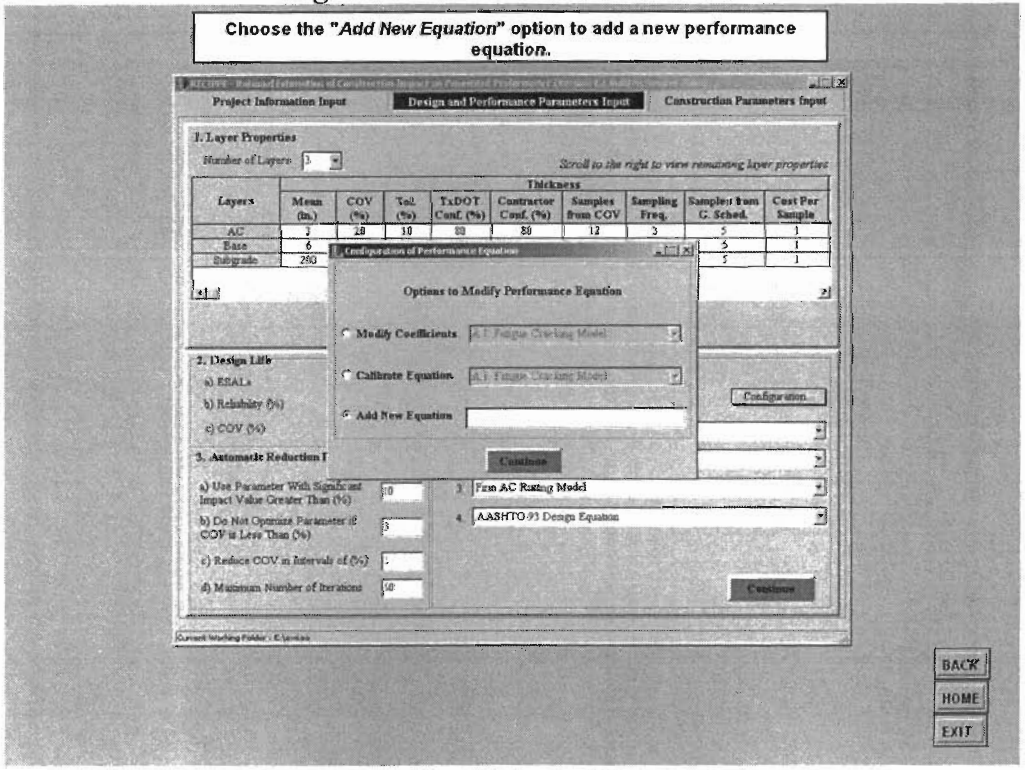
a) Use Parameter With Significant Impact Value Greater Than (%) 10
b) Do Not Optimize Parameter if COV is Less Than (%) 3
c) Reduce COV in Intervals of (%) 1
d) Maximum Number of Iterations 50

3 Finn AC Rutting Model
4 AASHTO-93 Design Equation

Options to Modify Performance Equation

○ Modify Coefficients A.1. Fatigue Cracking Model
● Calibrate Equation A.1. Fatigue Cracking Model
○ Add New Equation

Figure 2.98 - Slide 3 of Exercise 6



Choose the "*Add New Equation*" option to add a new performance equation.

Number of Layers 3

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6							5	1
Subgrade	200							5	1

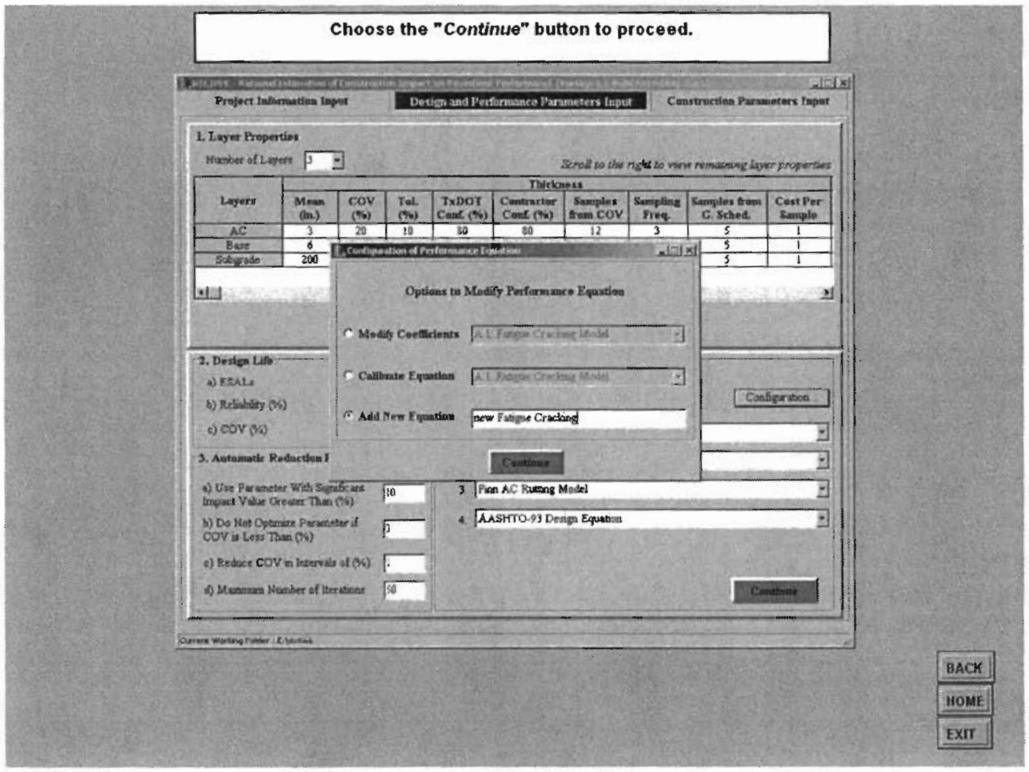
a) Use Parameter With Significant Impact Value Greater Than (%) 10
b) Do Not Optimize Parameter if COV is Less Than (%) 3
c) Reduce COV in Intervals of (%) 1
d) Maximum Number of Iterations 50

3 Finn AC Rutting Model
4 AASHTO-93 Design Equation

Options to Modify Performance Equation

○ Modify Coefficients A.1. Fatigue Cracking Model
○ Calibrate Equation A.1. Fatigue Cracking Model
● Add New Equation

Figure 2.99 - Slide 4 of Exercise 6



Choose the "*Continue*" button to proceed.

Project Information Input | Design and Performance Parameters Input | Construction Parameters Input

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

	Thickness								
Layers	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6							5	1
Subgrade	200							5	1

2. Design Life
a) ESALs
b) Reliability (%)
c) COV (%)

3. Automatic Reduction
a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 3
c) Reduce COV in Intervals of (%): 1
d) Maximum Number of Iterations: 50

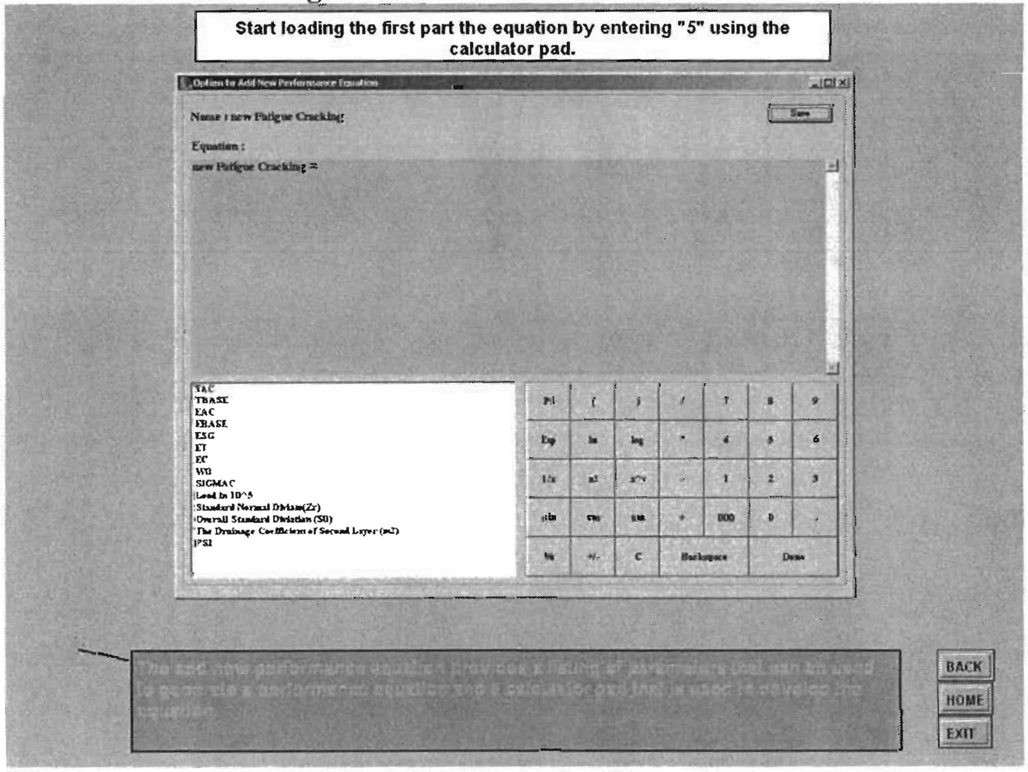
3 Penn AC Rutting Model
4 AASHTO-93 Design Equation

Configuration of Performance Equation

Options to Modify Performance Equation

○ Modify Coefficients: A.1. Fatigue Cracking Model
○ Calibrate Equation: A.1. Fatigue Cracking Model
● Add New Equation: new Fatigue Cracking

Figure 2.100 - Slide 5 of Exercise 6



Start loading the first part the equation by entering "5" using the calculator pad.

Option to Add New Performance Equation

Name : new Fatigue Cracking

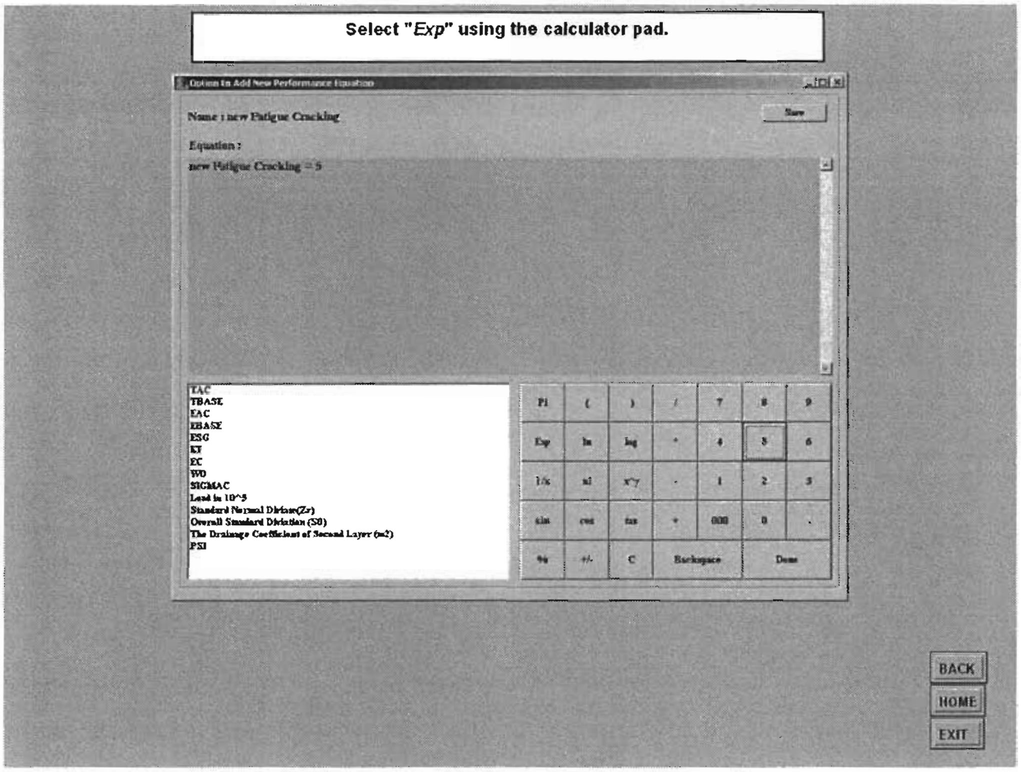
Equation :

new Fatigue Cracking =

TAC
TBASE
EAC
EBASE
ESG
ET
EC
WB
SIGMAC
Load In 10^5
Standard Normal Deviate(Zr)
Overall Standard Deviation (S0)
The Drainage Coefficient of Second Layer (m2)
PSI

The add new performance equation provides a listing of parameters that can be used to generate a performance equation and a calculator pad that is used to develop the equation.

Figure 2.101 - Slide 6 of Exercise 6



Select "*Exp*" using the calculator pad.

Option to Add New Performance Equation

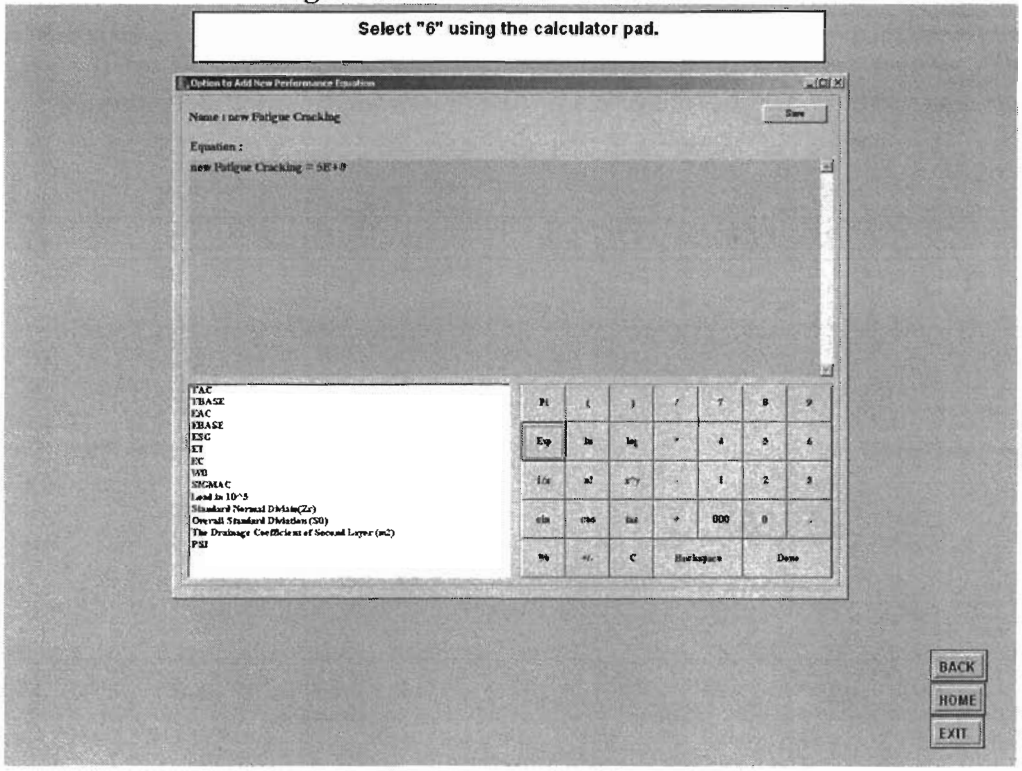
Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5

TAC
TBASE
EAC
EBASE
ESG
KT
EC
WO
SIGMAC
Load in 10^5
Standard Normal Diviate(Zr)
Overall Standard Diviation (S0)
The Drainage Coefficient of Second Layer (m2)
PSI

Figure 2.102 - Slide 7 of Exercise 6



Select "6" using the calculator pad.

Option to Add New Performance Equation

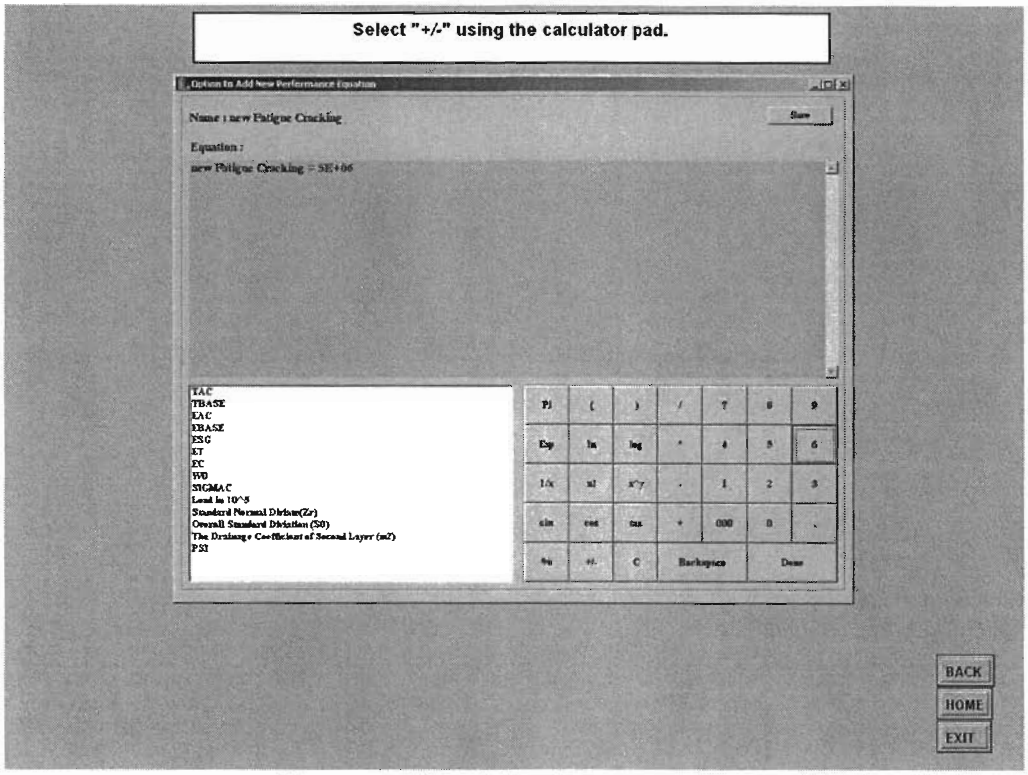
Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E+0

TAC
TBASE
EAC
EBASE
ESG
KT
EC
WO
SIGMAC
Load in 10^5
Standard Normal Diviate(Zr)
Overall Standard Diviation (S0)
The Drainage Coefficient of Second Layer (m2)
PSI

Figure 2.103 - Slide 8 of Exercise 6



Select "+/-" using the calculator pad.

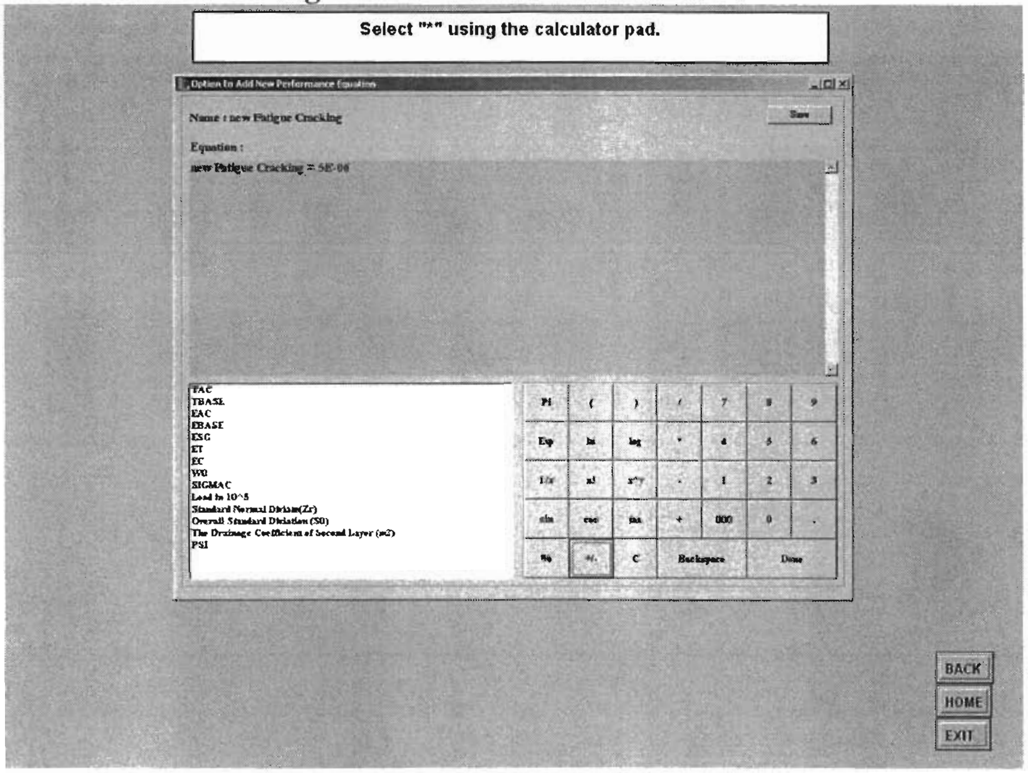
Option to Add New Performance Equation

Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E+06

Figure 2.104 - Slide 9 of Exercise 6



Select "*" using the calculator pad.

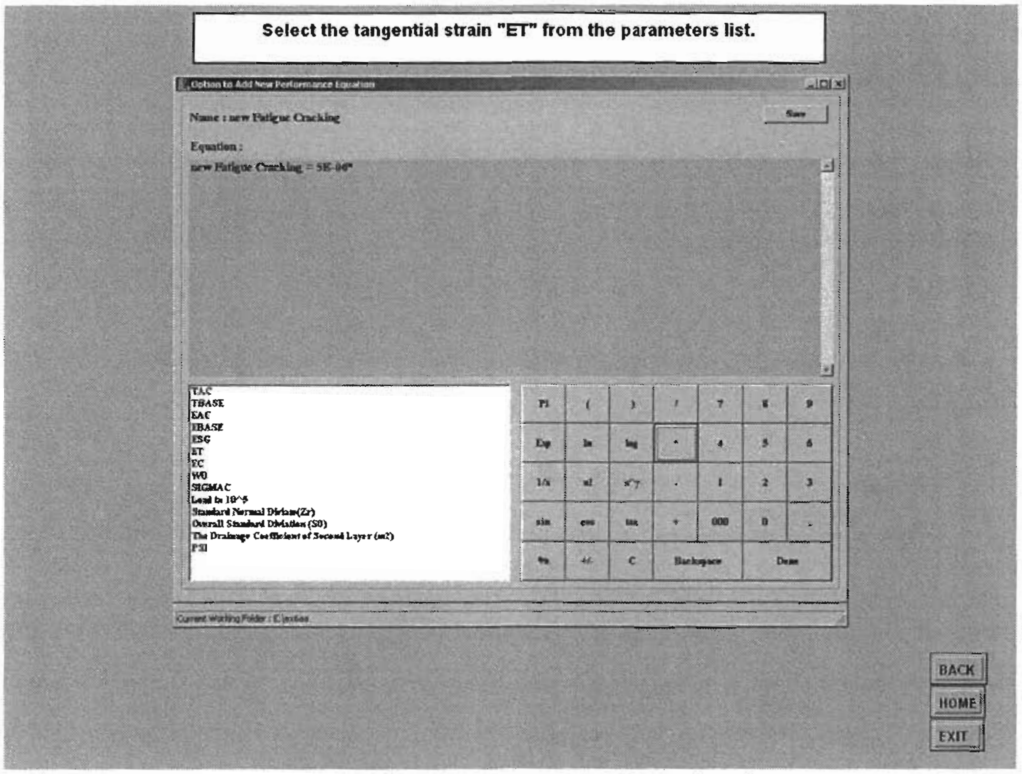
Option to Add New Performance Equation

Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E-06

Figure 2.105 - Slide 10 of Exercise 6



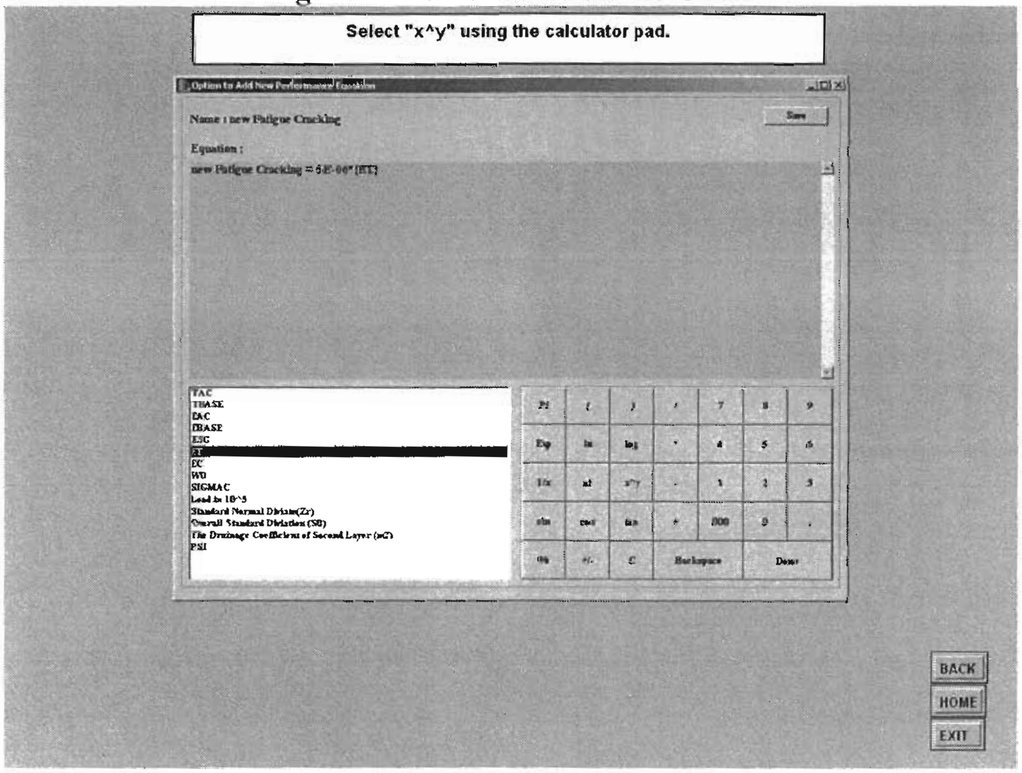
Select the tangential strain "ET" from the parameters list.

Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E-06*

Figure 2.106 - Slide 11 of Exercise 6



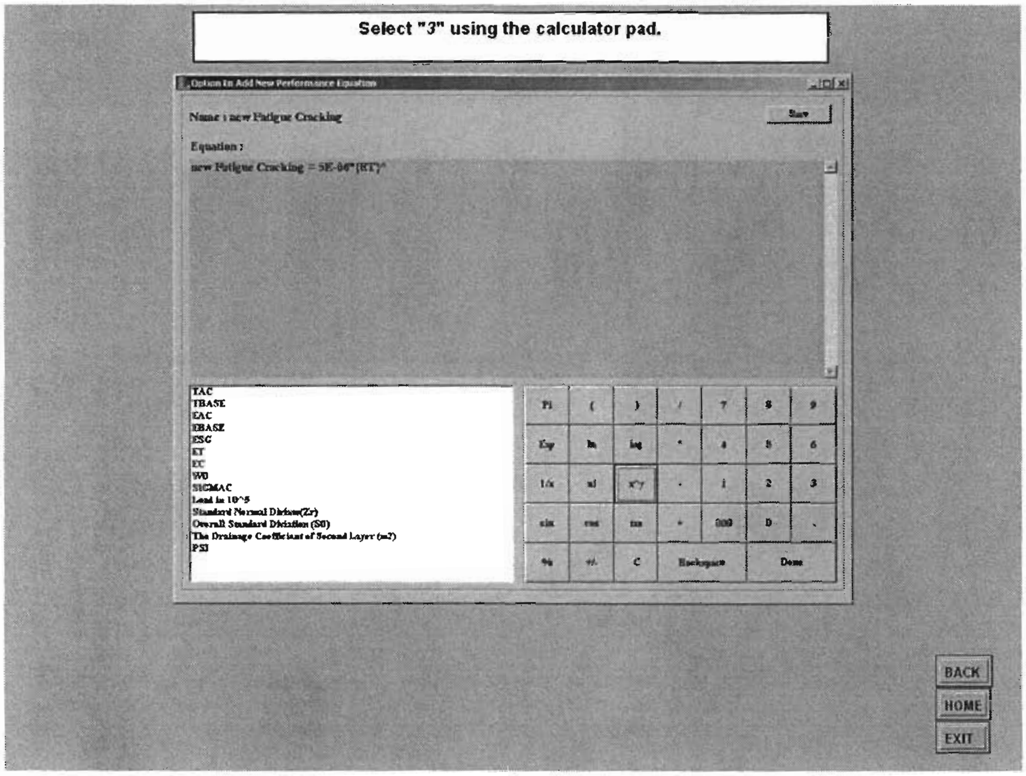
Select "x^y" using the calculator pad.

Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E-06* [ET]

Figure 2.107 - Slide 12 of Exercise 6



Select "3" using the calculator pad.

Option to Add New Performance Equation

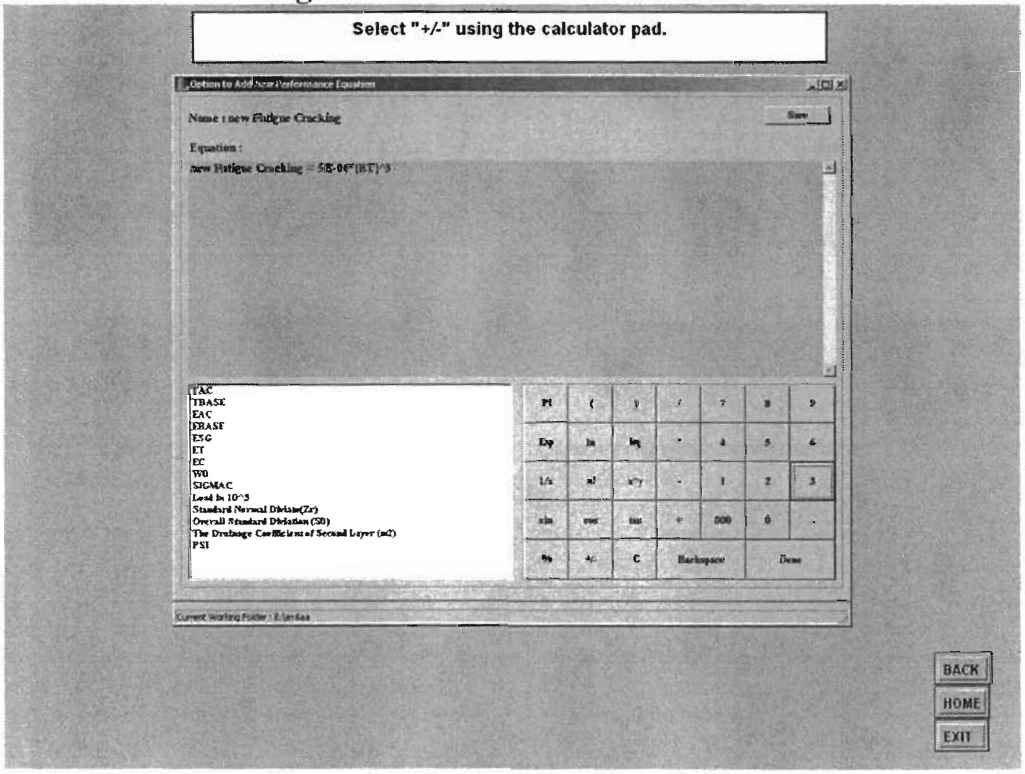
Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E-06*(ET)^

TAC
TBASE
EAC
EBASE
ESG
ET
EC
W0
SIGMAC
Load in 10^5
Standard Normal Deviate(Zr)
Overall Standard Deviation (S0)
The Drainage Coefficient of Second Layer (m2)
PSI

Figure 2.108 - Slide 13 of Exercise 6



Select "+/-" using the calculator pad.

Option to Add New Performance Equation

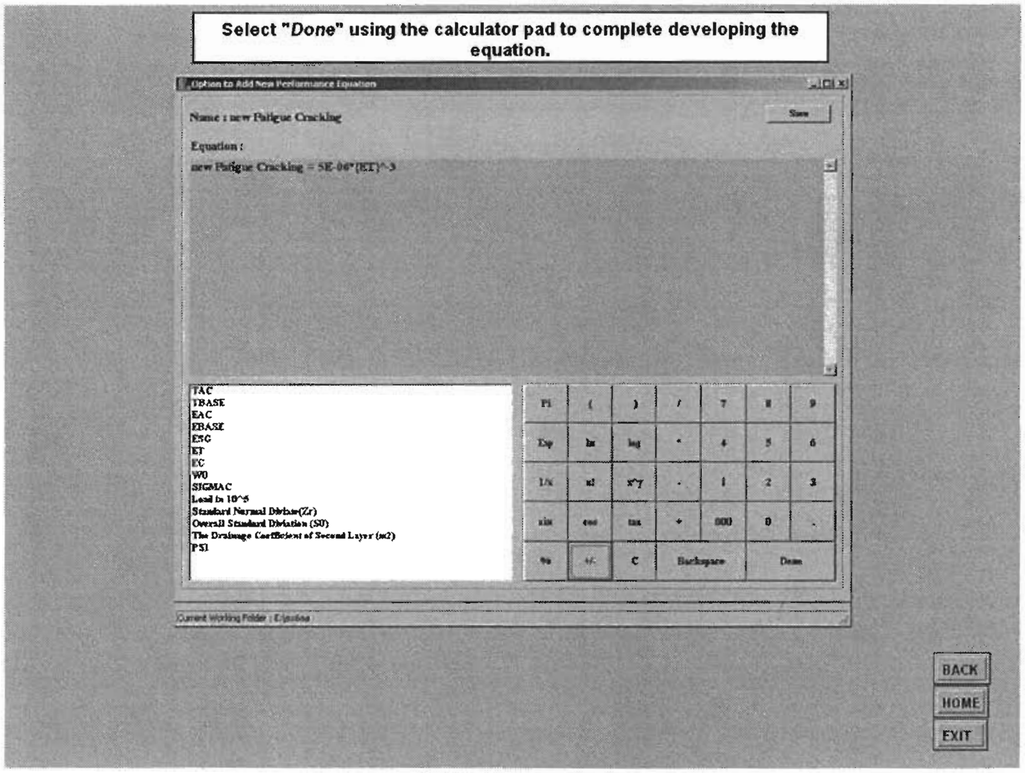
Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E-06*(ET)^3

TAC
TBASE
EAC
EBASE
ESG
ET
EC
W0
SIGMAC
Load in 10^5
Standard Normal Deviate(Zr)
Overall Standard Deviation (S0)
The Drainage Coefficient of Second Layer (m2)
PSI

Figure 2.109 - Slide 14 of Exercise 6

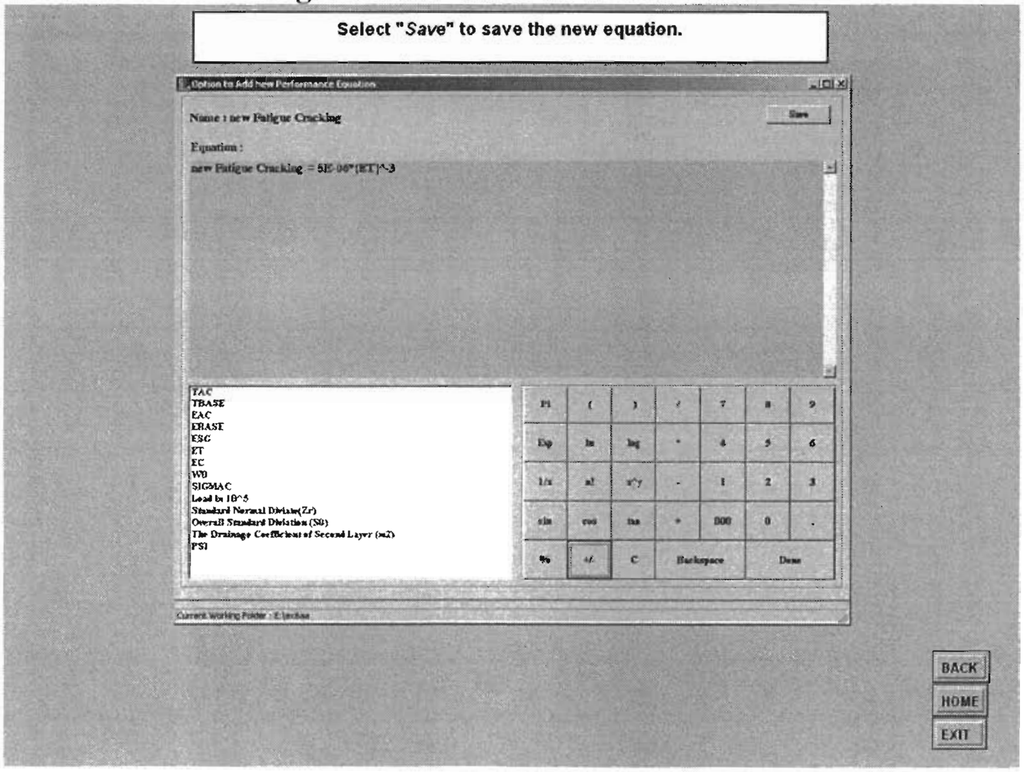

Select "*Done*" using the calculator pad to complete developing the equation.

Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E-06*(ET)^-3

Figure 2.110 - Slide 15 of Exercise 6

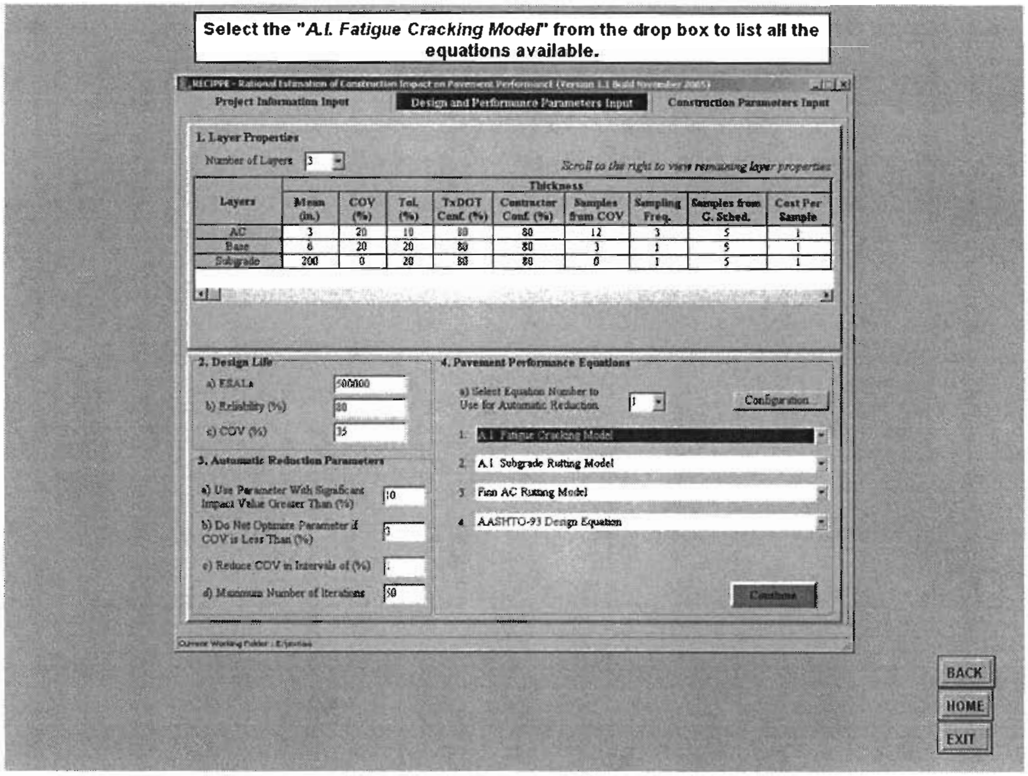

Select "*Save*" to save the new equation.

Name : new Fatigue Cracking

Equation :

new Fatigue Cracking = 5E-06*(ET)^-3

Figure 2.111 - Slide 16 of Exercise 6



Select the "*A.I. Fatigue Cracking Model*" from the drop box to list all the equations available.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000
b) Reliability (%): 80
c) COV (%): 35

3. Automatic Reduction Parameters

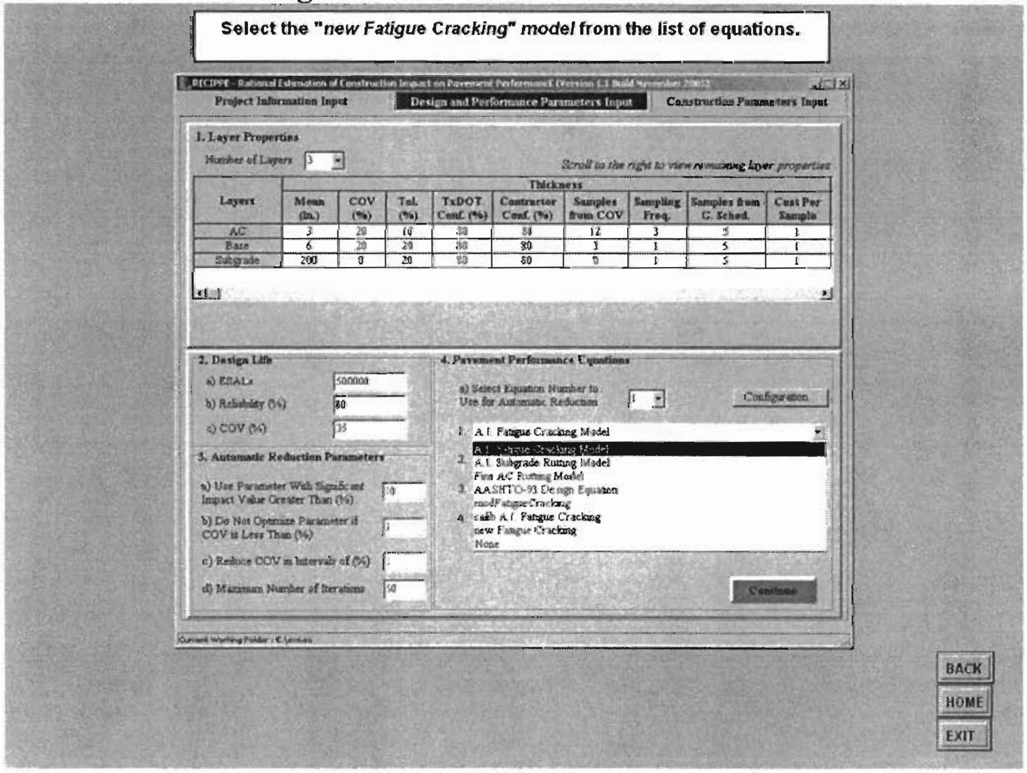
a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 3
c) Reduce COV in Intervals of (%): [illegible]
d) Maximum Number of Iterations: 50

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.112 - Slide 17 of Exercise 6



Select the "*new Fatigue Cracking*" *model* from the list of equations.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000
b) Reliability (%): 80
c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 3
c) Reduce COV in Intervals of (%): [illegible]
d) Maximum Number of Iterations: 50

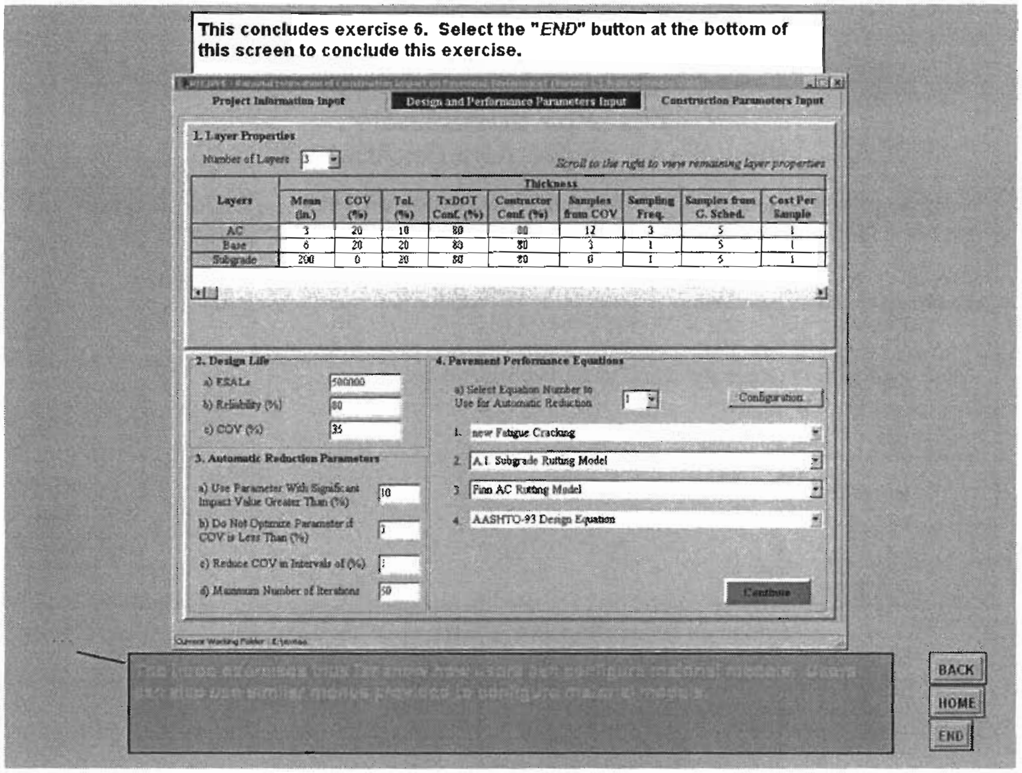
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.I. Fatigue Cracking Model

A.I. Fatigue Cracking Model
A.I. Subgrade Rutting Model
Finn AC Rutting Model
AASHTO-93 Design Equation
modFatigueCracking
calib A.I. Fatigue Cracking
new Fatigue Cracking
None

Figure 2.113 - Slide 18 of Exercise 6



This concludes exercise 6. Select the "*END*" button at the bottom of this screen to conclude this exercise.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000

b) Reliability (%): 80

c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10

b) Do Not Optimize Parameter if COV is Less Than (%): 3

c) Reduce COV in Intervals of (%): 3

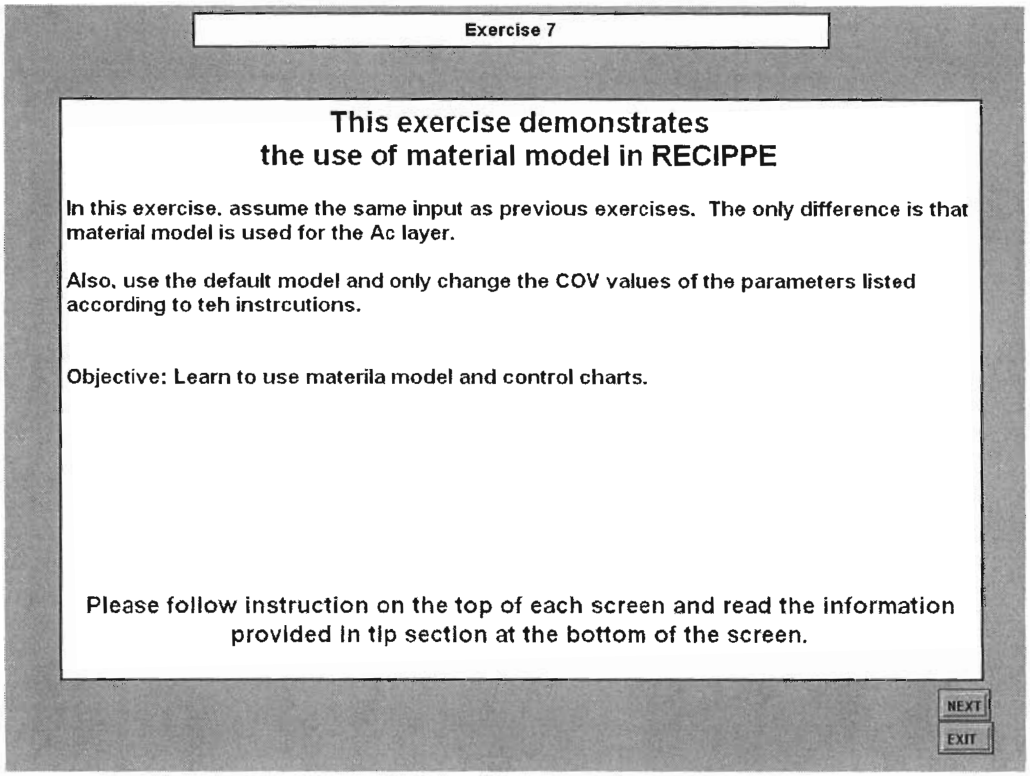
d) Maximum Number of Iterations: 50

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. new Fatigue Cracking
2. A.I. Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.114 - Slide 19 of Exercise 6



Exercise 7

This exercise demonstrates
the use of material model in RECIPPE

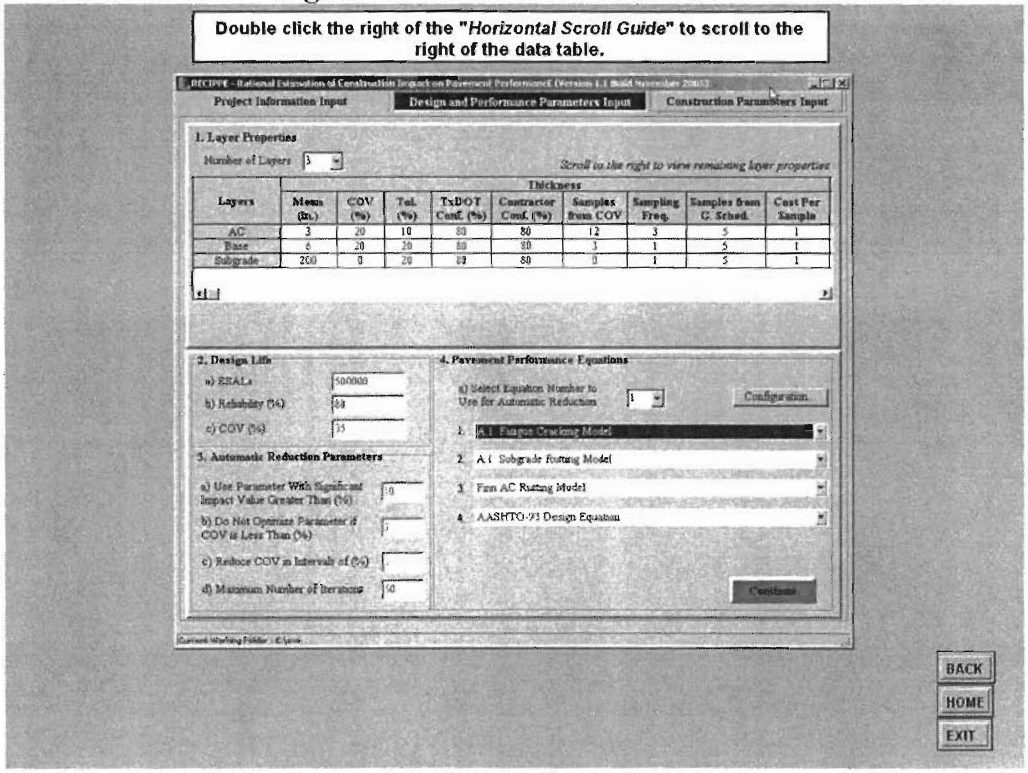
In this exercise. assume the same input as previous exercises. The only difference is that material model is used for the Ac layer.

Also, use the default model and only change the COV values of the parameters listed according to teh instrcutions.

Objective: Learn to use materila model and control charts.

Please follow instruction on the top of each screen and read the information provided in tip section at the bottom of the screen.

Figure 2.115 - Slide 1 of Exercise 7



Double click the right of the "*Horizontal Scroll Guide*" to scroll to the right of the data table.

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Thickness								
	Mean (in.)	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from C. Sched.	Cost Per Sample
AC	3	20	10	80	80	12	3	5	1
Base	6	20	20	80	80	3	1	5	1
Subgrade	200	0	20	80	80	0	1	5	1

2. Design Life

a) ESALs: 500000
b) Reliability (%): 80
c) COV (%): 35

3. Automatic Reduction Parameters

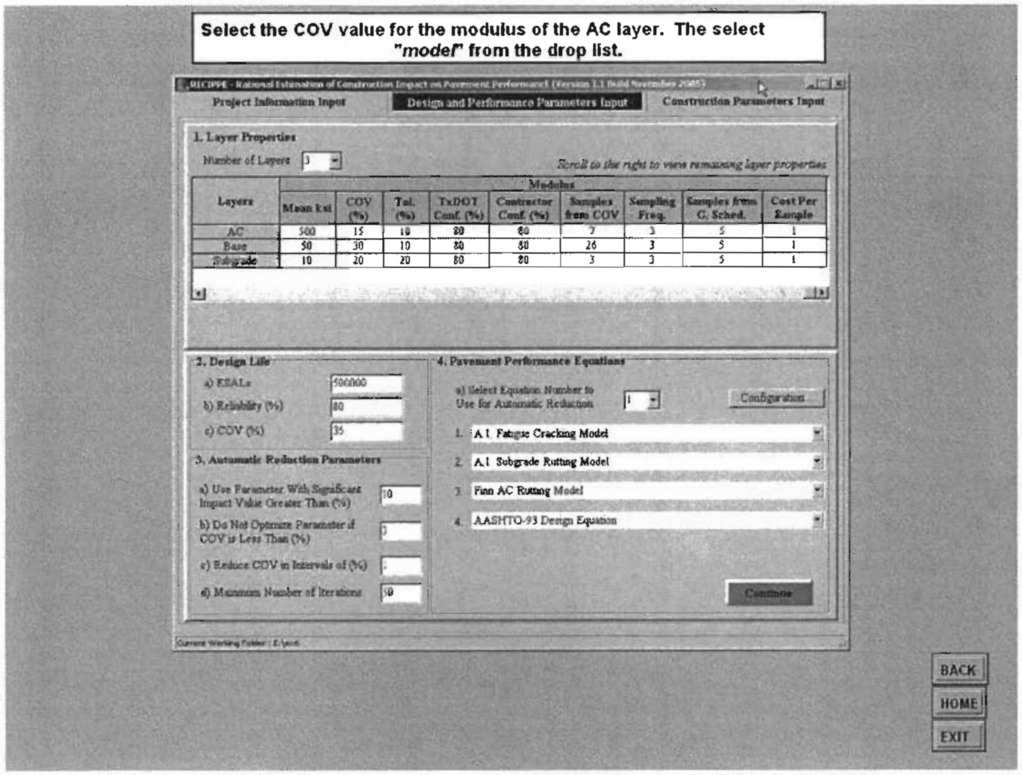
a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 5
c) Reduce COV in Intervals of (%):
d) Maximum Number of Iterations: 50

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. A.1 Fatigue Cracking Model
2. A.1 Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.116 - Slide 2 of Exercise 7



Select the COV value for the modulus of the AC layer. The select *"model"* from the drop list.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	15	10	80	80	7	3	5	1
Base	50	30	10	80	80	26	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs: 500000
b) Reliability (%): 80
c) COV (%): 35

3. Automatic Reduction Parameters

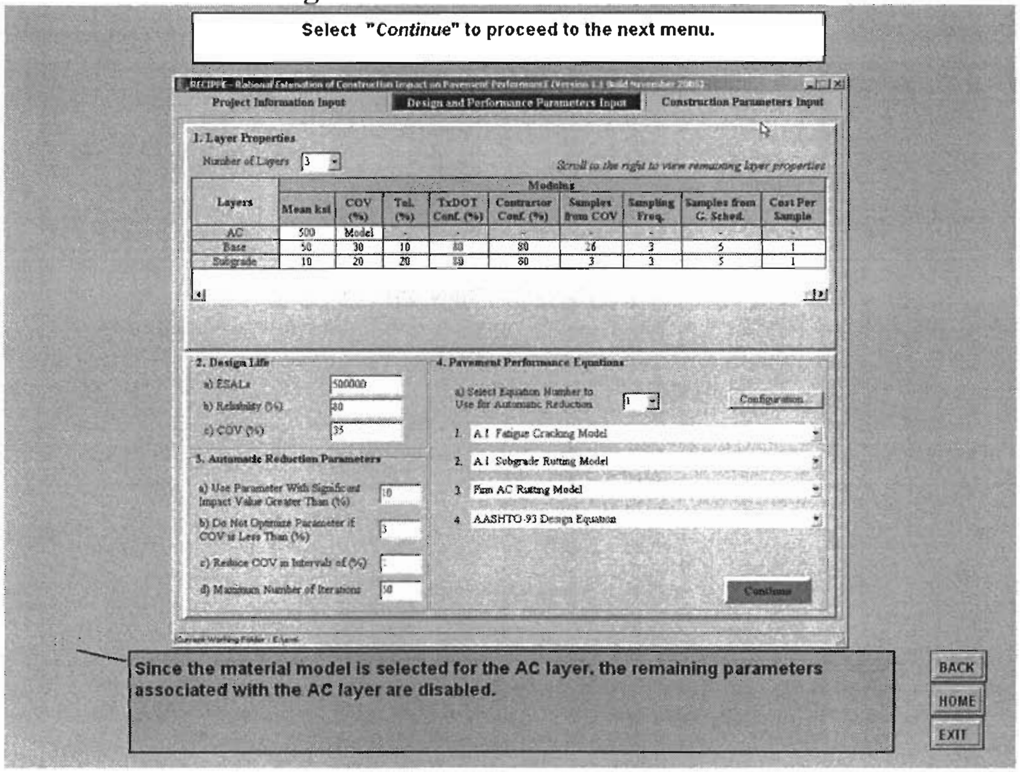
a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 3
c) Reduce COV in Intervals of (%): 1
d) Maximum Number of Iterations: 50

4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Figure 2.117 - Slide 3 of Exercise 7



Select *"Continue"* to proceed to the next menu.

RECIPPE - Rational Estimation of Construction Impact on Pavement Performance (Version 1.1 Build November 2005)

1. Layer Properties

Number of Layers: 3

Scroll to the right to view remaining layer properties

Layers	Modulus								
	Mean ksi	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
AC	500	Model	-	-	-	-	-	-	-
Base	50	30	10	80	80	26	3	5	1
Subgrade	10	20	20	80	80	3	3	5	1

2. Design Life

a) ESALs: 500000
b) Reliability (%): 80
c) COV (%): 35

3. Automatic Reduction Parameters

a) Use Parameter With Significant Impact Value Greater Than (%): 10
b) Do Not Optimize Parameter if COV is Less Than (%): 3
c) Reduce COV in Intervals of (%): 1
d) Maximum Number of Iterations: 50

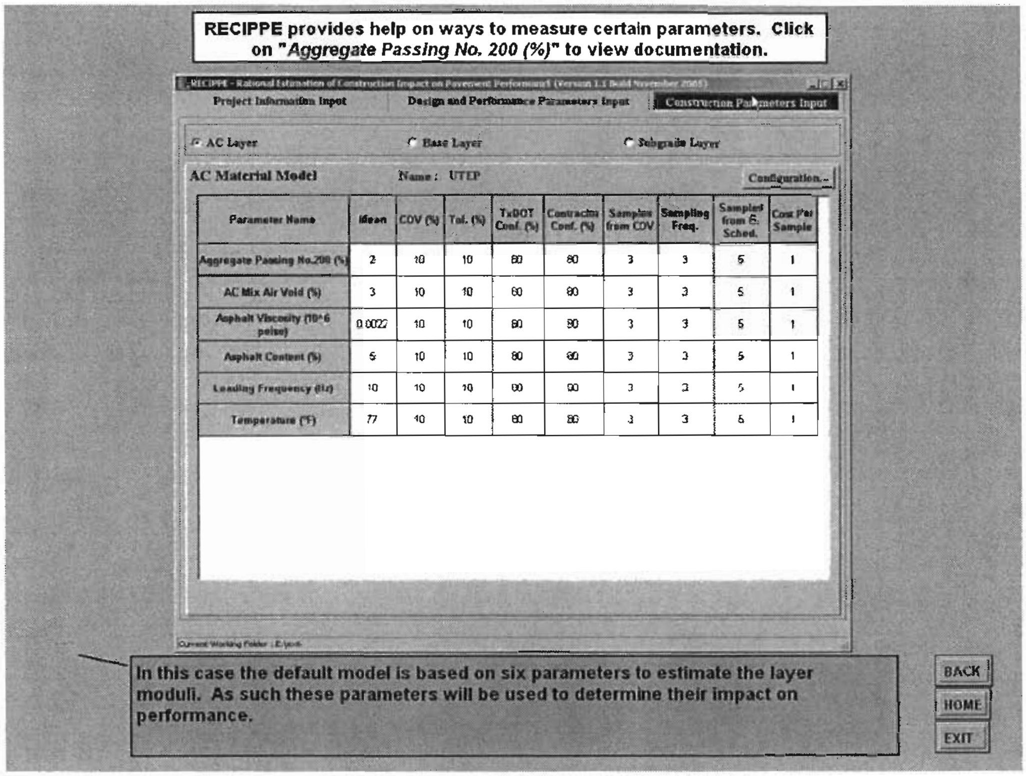
4. Pavement Performance Equations

a) Select Equation Number to Use for Automatic Reduction: 1

1. AI Fatigue Cracking Model
2. AI Subgrade Rutting Model
3. Finn AC Rutting Model
4. AASHTO-93 Design Equation

Since the material model is selected for the AC layer, the remaining parameters associated with the AC layer are disabled.

Figure 2.118 - Slide 4 of Exercise 7



RECIPPE provides help on ways to measure certain parameters. Click on "*Aggregate Passing No. 200 (%)*" to view documentation.

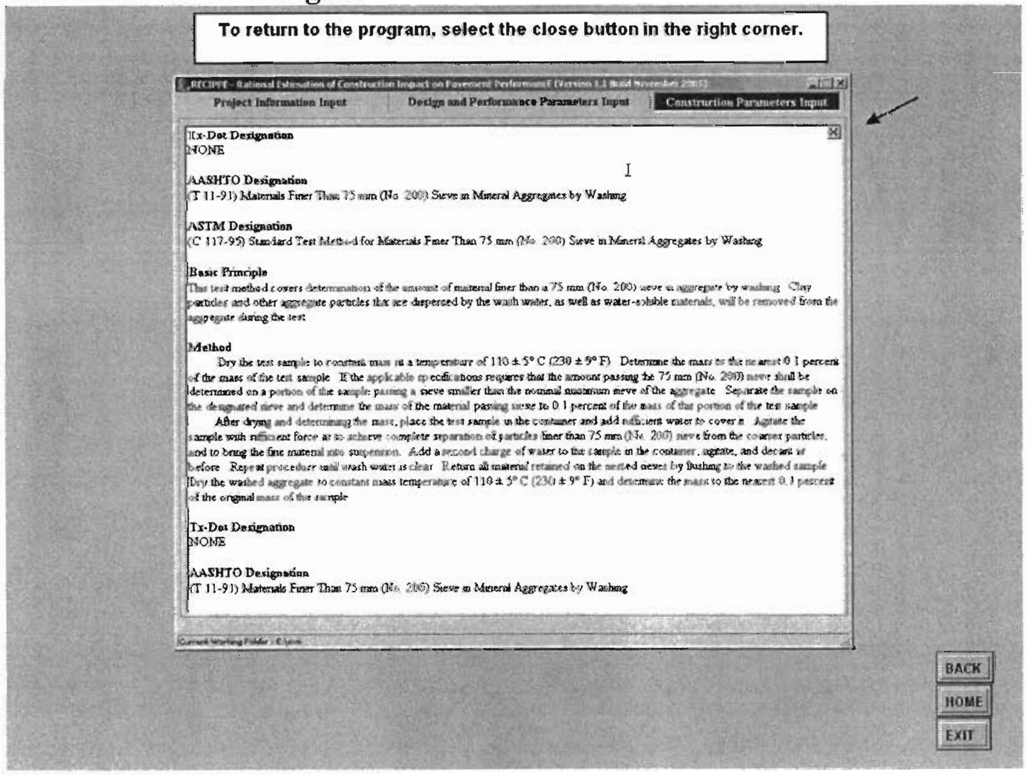
● AC Layer ○ Base Layer ○ Subgrade Layer

AC Material Model Name : UTEP

Parameter Name	Mean	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from S. Sched.	Cost Per Sample
Aggregate Passing No.200 (%)	2	10	10	80	80	3	3	5	1
AC Mix Air Void (%)	3	10	10	80	80	3	3	5	1
Asphalt Viscosity (10^6 poise)	0.0022	10	10	80	80	3	3	5	1
Asphalt Content (%)	5	10	10	80	80	3	3	5	1
Loading Frequency (Hz)	10	10	10	80	80	3	3	5	1
Temperature (°F)	77	10	10	80	80	3	3	5	1

In this case the default model is based on six parameters to estimate the layer moduli. As such these parameters will be used to determine their impact on performance.

Figure 2.119 - Slide 5 of Exercise 7



To return to the program, select the close button in the right corner.

Tx-Dot Designation
NONE

AASHTO Designation
(T 11-91) Materials Finer Than 75 mm (No. 200) Sieve in Mineral Aggregates by Washing

ASTM Designation
(C 117-95) Standard Test Method for Materials Finer Than 75 mm (No. 200) Sieve in Mineral Aggregates by Washing

Basic Principle
This test method covers determination of the amount of material finer than a 75 mm (No. 200) sieve in aggregate by washing. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, will be removed from the aggregate during the test.

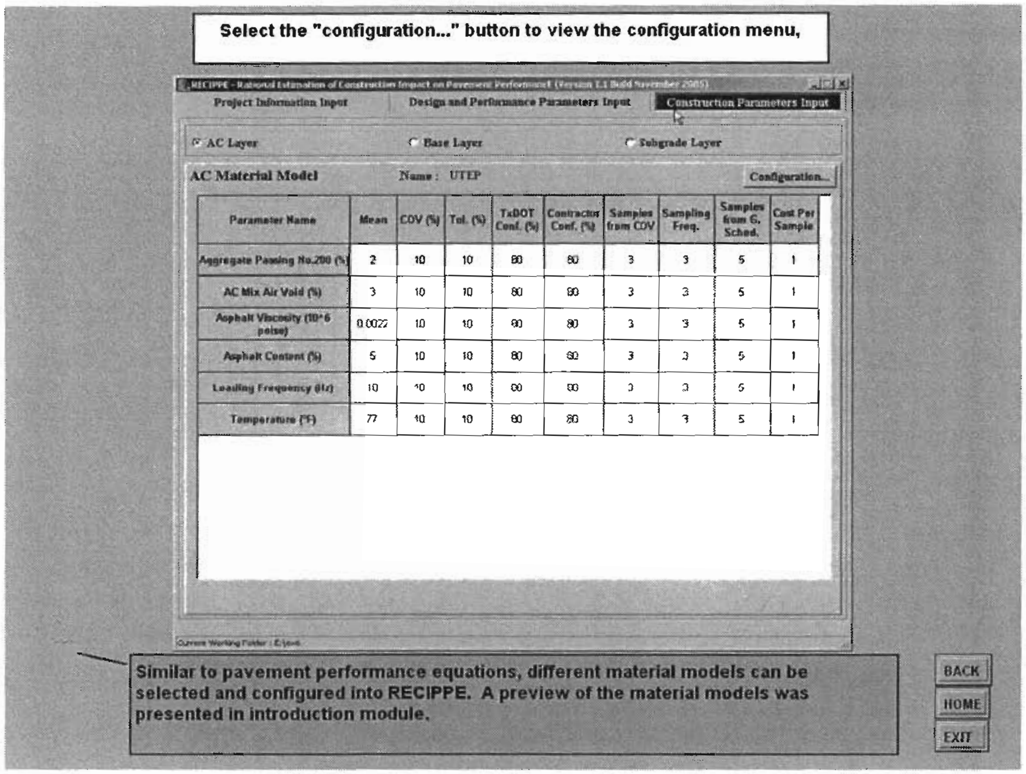
Method
Dry the test sample to constant mass at a temperature of 110 ± 5° C (230 ± 9° F). Determine the mass to the nearest 0.1 percent of the mass of the test sample. If the applicable specifications requires that the amount passing the 75 mm (No. 200) sieve shall be determined on a portion of the sample passing a sieve smaller than the nominal maximum sieve of the aggregate. Separate the sample on the designated sieve and determine the mass of the material passing sieve to 0.1 percent of the mass of this portion of the test sample.

After drying and determining the mass, place the test sample in the container and add sufficient water to cover it. Agitate the sample with sufficient force as to achieve complete separation of particles finer than 75 mm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension. Add a second charge of water to the sample in the container, agitate, and decant as before. Repeat procedure until wash water is clear. Return all material retained on the nested sieves by flushing to the washed sample. Dry the washed aggregate to constant mass temperature of 110 ± 5° C (230 ± 9° F) and determine the mass to the nearest 0.1 percent of the original mass of the sample.

Tx-Dot Designation
NONE

AASHTO Designation
(T 11-91) Materials Finer Than 75 mm (No. 200) Sieve in Mineral Aggregates by Washing

Figure 2.120 - Slide 6 of Exercise 7



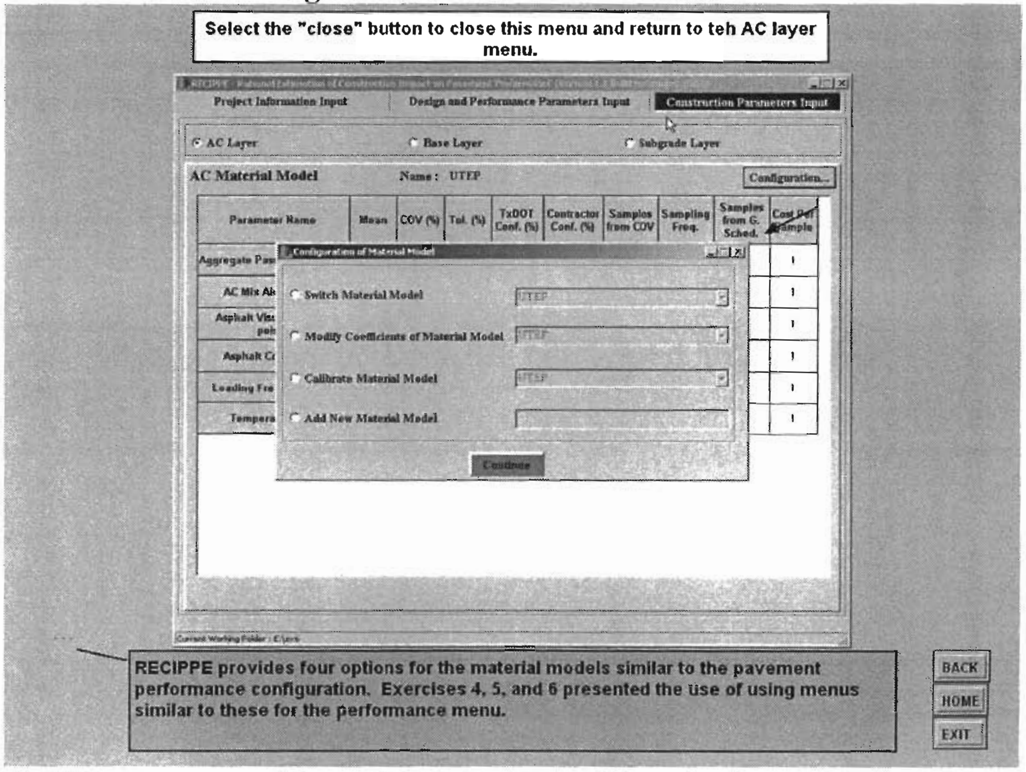
Select the "configuration..." button to view the configuration menu,

AC Material Model Name : UTEP

Parameter Name	Mean	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
Aggregate Passing No.200 (%)	2	10	10	80	80	3	3	5	1
AC Mix Air Void (%)	3	10	10	80	80	3	3	5	1
Asphalt Viscosity (10^6 poise)	0.0022	10	10	80	80	3	3	5	1
Asphalt Content (%)	5	10	10	80	80	3	3	5	1
Loading Frequency (Hz)	10	10	10	80	80	3	3	5	1
Temperature (°F)	77	10	10	80	80	3	3	5	1

Similar to pavement performance equations, different material models can be selected and configured into RECIPPE. A preview of the material models was presented in introduction module.

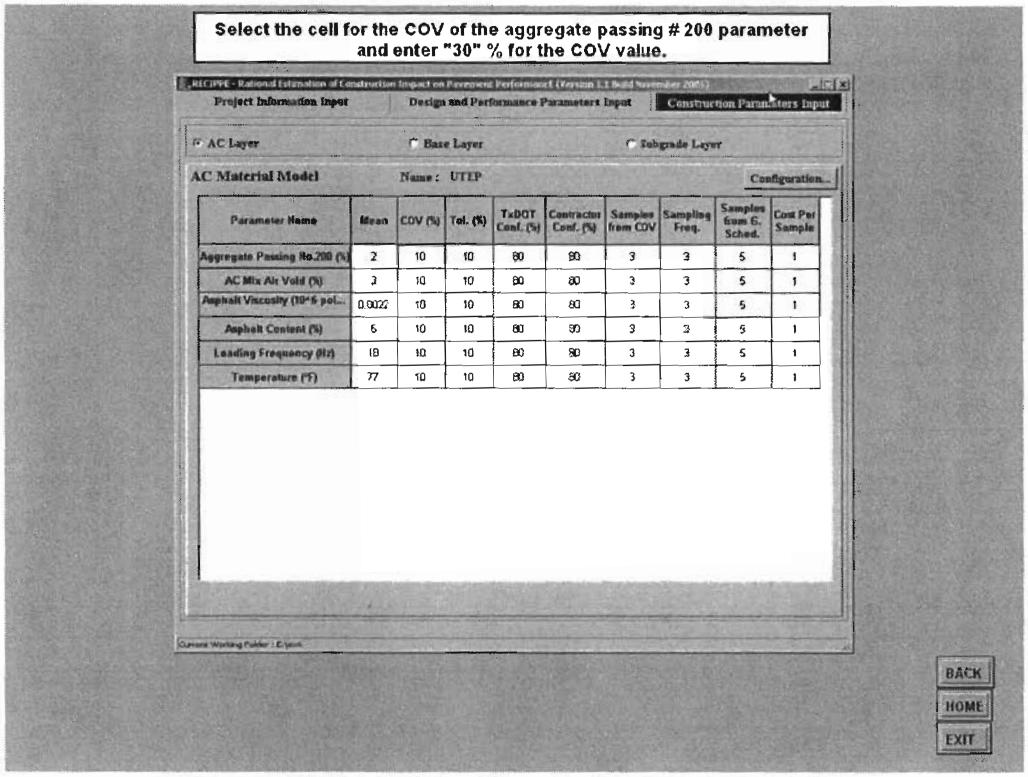
Figure 2.121 - Slide 7 of Exercise 7



Select the "close" button to close this menu and return to teh AC layer menu.

RECIPPE provides four options for the material models similar to the pavement performance configuration. Exercises 4, 5, and 6 presented the use of using menus similar to these for the performance menu.

Figure 2.122 - Slide 8 of Exercise 7



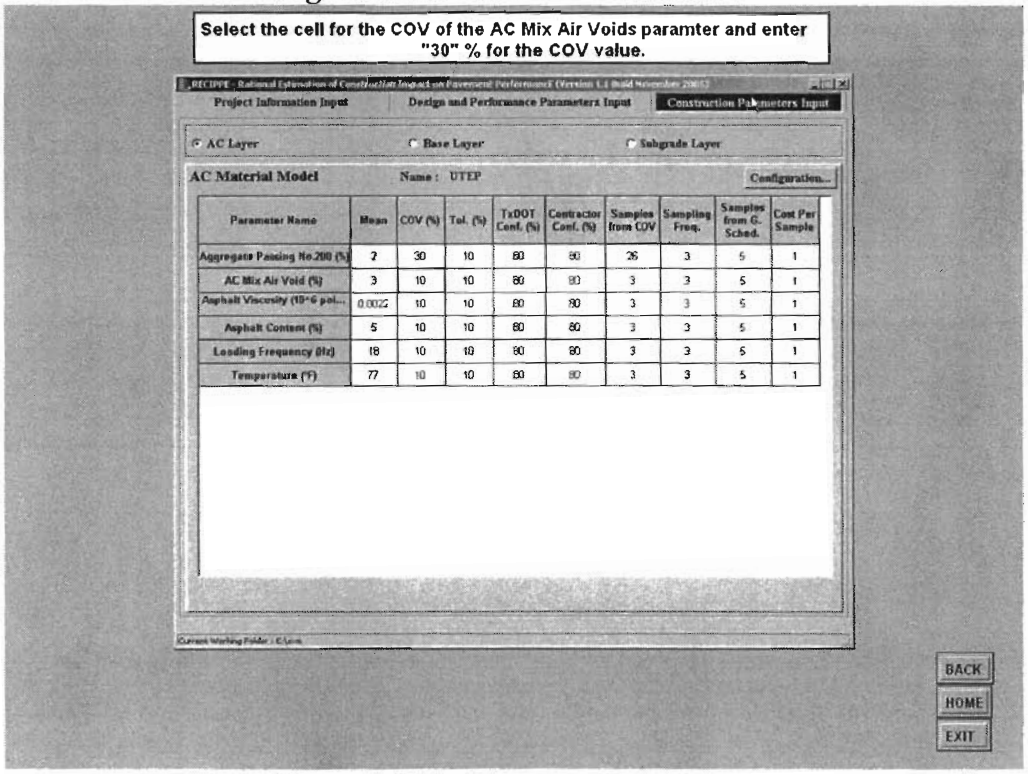
Select the cell for the COV of the aggregate passing # 200 parameter and enter "30" % for the COV value.

● AC Layer ○ Base Layer ○ Subgrade Layer

AC Material Model Name : UTEP

Parameter Name	Mean	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
Aggregate Passing No.200 (%)	2	10	10	80	80	3	3	5	1
AC Mix Air Void (%)	3	10	10	80	80	3	3	5	1
Asphalt Viscosity (10^6 poi...	0.0022	10	10	80	80	3	3	5	1
Asphalt Content (%)	6	10	10	80	80	3	3	5	1
Loading Frequency (Hz)	18	10	10	80	80	3	3	5	1
Temperature (°F)	77	10	10	80	80	3	3	5	1

Figure 2.123 - Slide 9 of Exercise 7



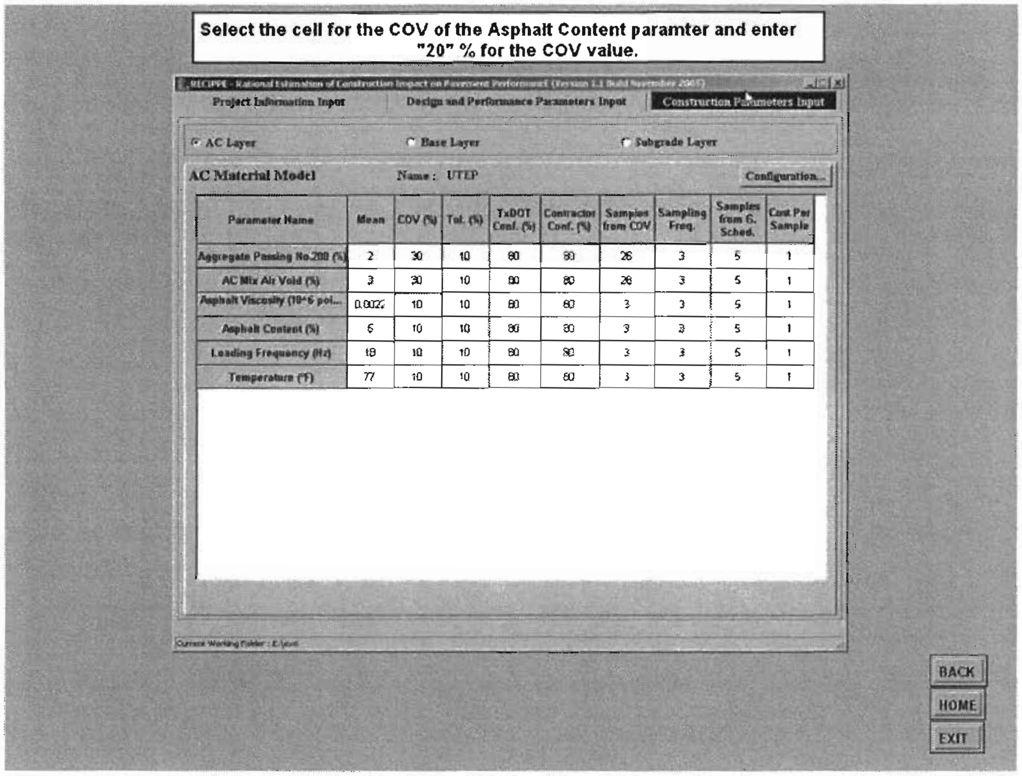
Select the cell for the COV of the AC Mix Air Voids paramter and enter "30" % for the COV value.

● AC Layer ○ Base Layer ○ Subgrade Layer

AC Material Model Name : UTEP

Parameter Name	Mean	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
Aggregate Passing No.200 (%)	2	30	10	80	80	26	3	5	1
AC Mix Air Void (%)	3	10	10	80	80	3	3	5	1
Asphalt Viscosity (10^6 poi...	0.0022	10	10	80	80	3	3	5	1
Asphalt Content (%)	5	10	10	80	80	3	3	5	1
Loading Frequency (Hz)	18	10	10	80	80	3	3	5	1
Temperature (°F)	77	10	10	80	80	3	3	5	1

Figure 2.124 - Slide 10 of Exercise 7



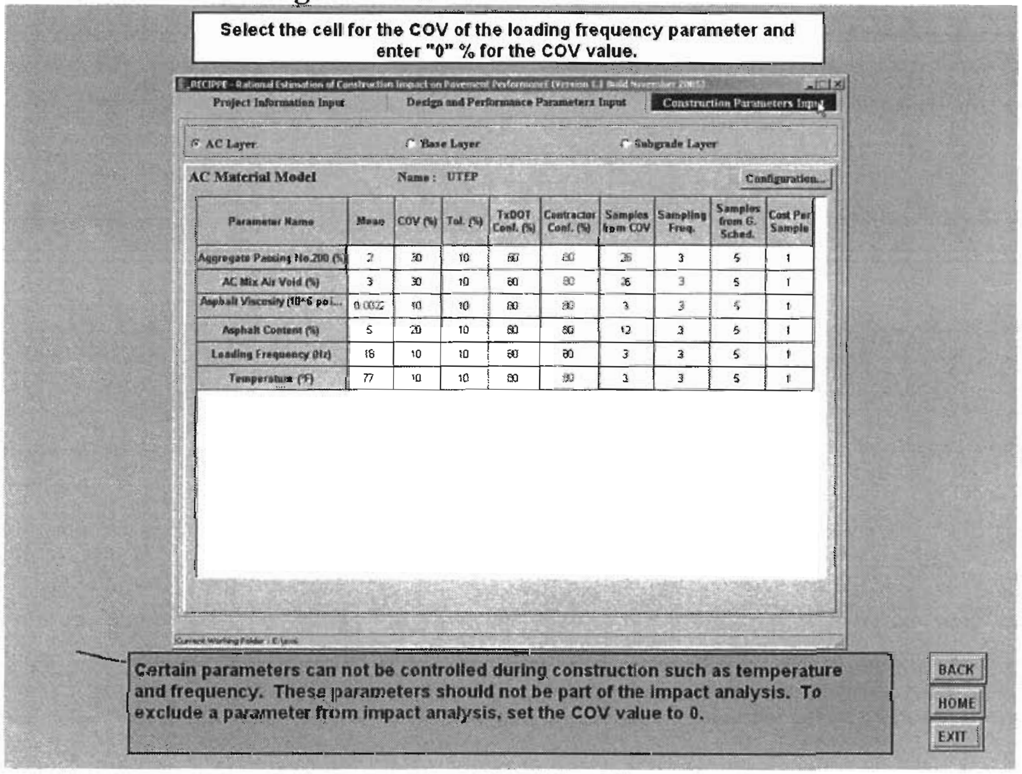
Select the cell for the COV of the Asphalt Content paramter and enter "20" % for the COV value.

AC Material Model

Name : UTEP

Parameter Name	Mean	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
Aggregate Passing No.200 (%)	2	30	10	80	80	26	3	5	1
AC Mix Air Void (%)	3	30	10	80	80	26	3	5	1
Asphalt Viscosity (10^6 poi...	0.0022	10	10	80	80	3	3	5	1
Asphalt Content (%)	6	10	10	80	80	3	3	5	1
Loading Frequency (Hz)	18	10	10	80	80	3	3	5	1
Temperature (°F)	77	10	10	80	80	3	3	5	1

Figure 2.125 - Slide 11 of Exercise 7



Select the cell for the COV of the loading frequency parameter and enter "0" % for the COV value.

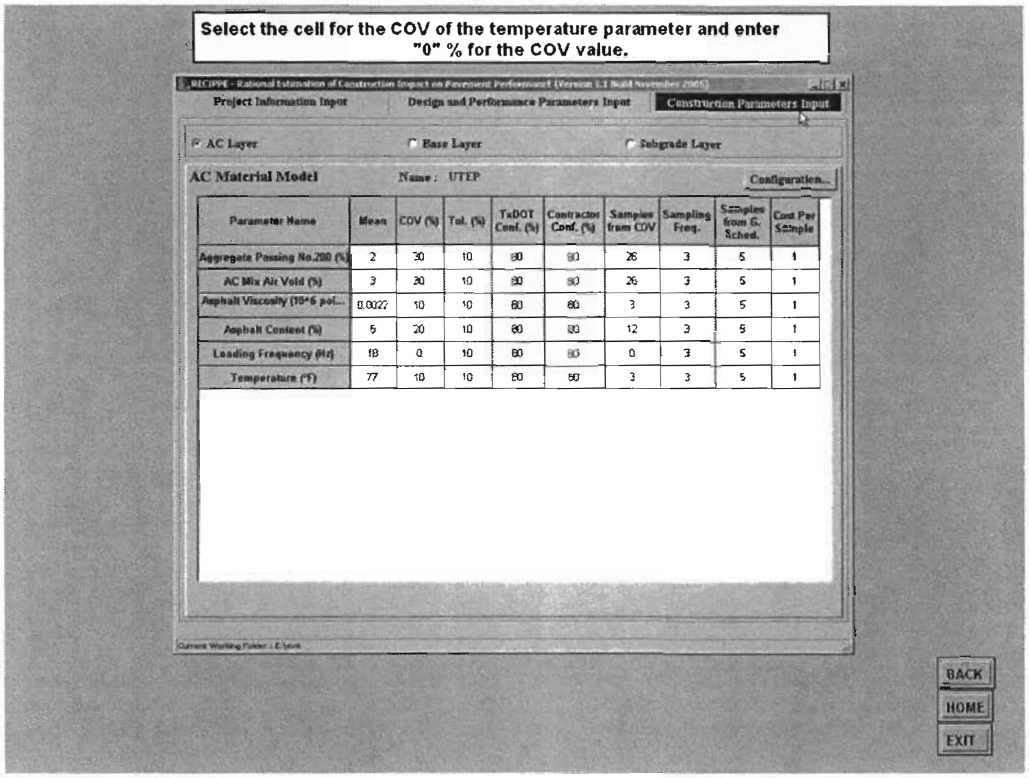
AC Material Model

Name : UTEP

Parameter Name	Mean	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
Aggregate Passing No.200 (%)	2	30	10	80	80	26	3	5	1
AC Mix Air Void (%)	3	30	10	80	80	26	3	5	1
Asphalt Viscosity (10^6 poi...	0.0022	10	10	80	80	3	3	5	1
Asphalt Content (%)	5	20	10	80	80	12	3	5	1
Loading Frequency (Hz)	16	10	10	80	80	3	3	5	1
Temperature (°F)	77	10	10	80	80	3	3	5	1

Certain parameters can not be controlled during construction such as temperature and frequency. These parameters should not be part of the impact analysis. To exclude a parameter from impact analysis, set the COV value to 0.

Figure 2.126 - Slide 12 of Exercise 7



Select the cell for the COV of the temperature parameter and enter "0" % for the COV value.

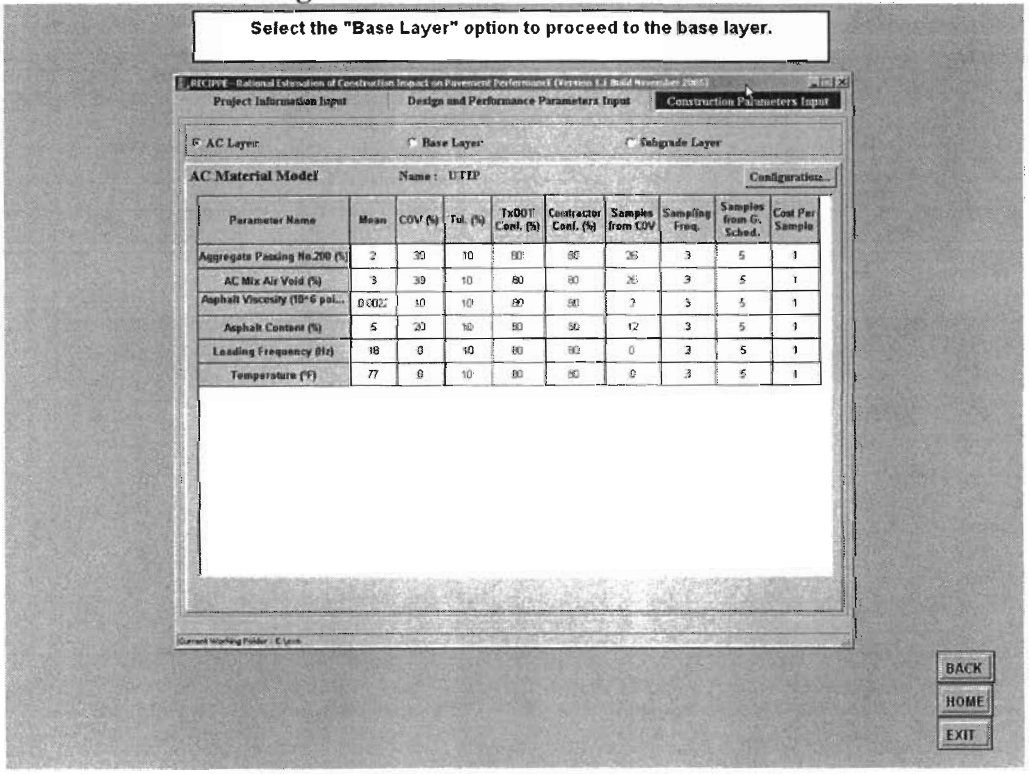
RECIPPE - Rational Estimation of Construction Impact on Pavement PerformancE (Version 1.1 Build November 2005)

AC Material Model

Name : UTEP

Parameter Name	Mean	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
Aggregate Passing No.200 (%)	2	30	10	80	80	26	3	5	1
AC Mix Air Void (%)	3	30	10	80	80	26	3	5	1
Asphalt Viscosity (10^6 poi...	0.0027	10	10	80	80	3	3	5	1
Asphalt Content (%)	5	20	10	80	80	12	3	5	1
Loading Frequency (Hz)	18	0	10	80	80	0	3	5	1
Temperature (°F)	77	10	10	80	80	3	3	5	1

Figure 2.127 - Slide 13 of Exercise 7



Select the "Base Layer" option to proceed to the base layer.

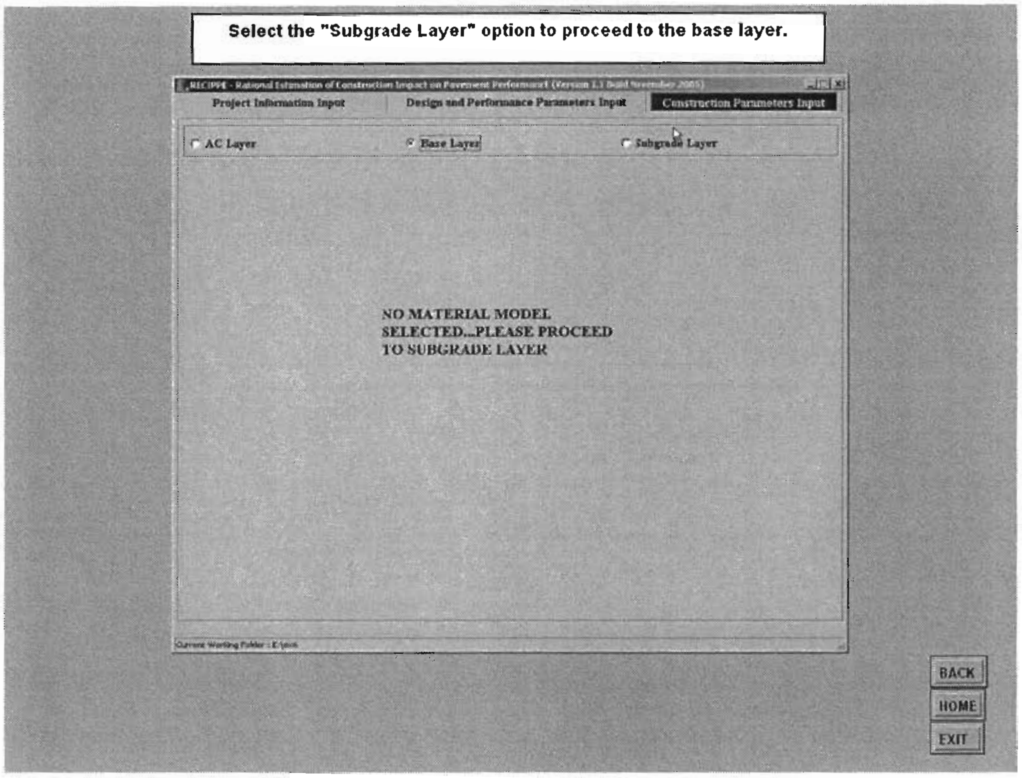
RECIPPE - Rational Estimation of Construction Impact on Pavement PerformancE (Version 1.1 Build November 2005)

AC Material Model

Name : UTEP

Parameter Name	Mean	COV (%)	Tol. (%)	TxDOT Conf. (%)	Contractor Conf. (%)	Samples from COV	Sampling Freq.	Samples from G. Sched.	Cost Per Sample
Aggregate Passing No.200 (%)	2	30	10	80	80	26	3	5	1
AC Mix Air Void (%)	3	30	10	80	80	26	3	5	1
Asphalt Viscosity (10^6 poi...	0.0027	10	10	80	80	3	3	5	1
Asphalt Content (%)	5	20	10	80	80	12	3	5	1
Loading Frequency (Hz)	18	0	10	80	80	0	3	5	1
Temperature (°F)	77	0	10	80	80	0	3	5	1

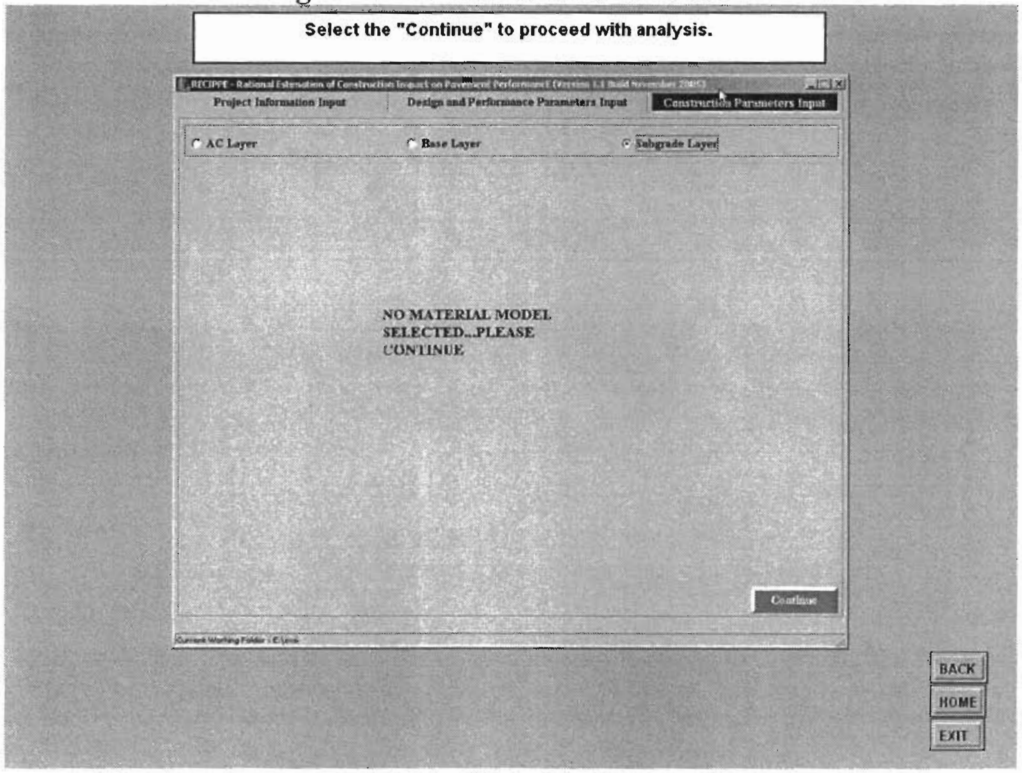
Figure 2.128 - Slide 14 of Exercise 7



Select the "Subgrade Layer" option to proceed to the base layer.

NO MATERIAL MODEL
SELECTED...PLEASE PROCEED
TO SUBGRADE LAYER

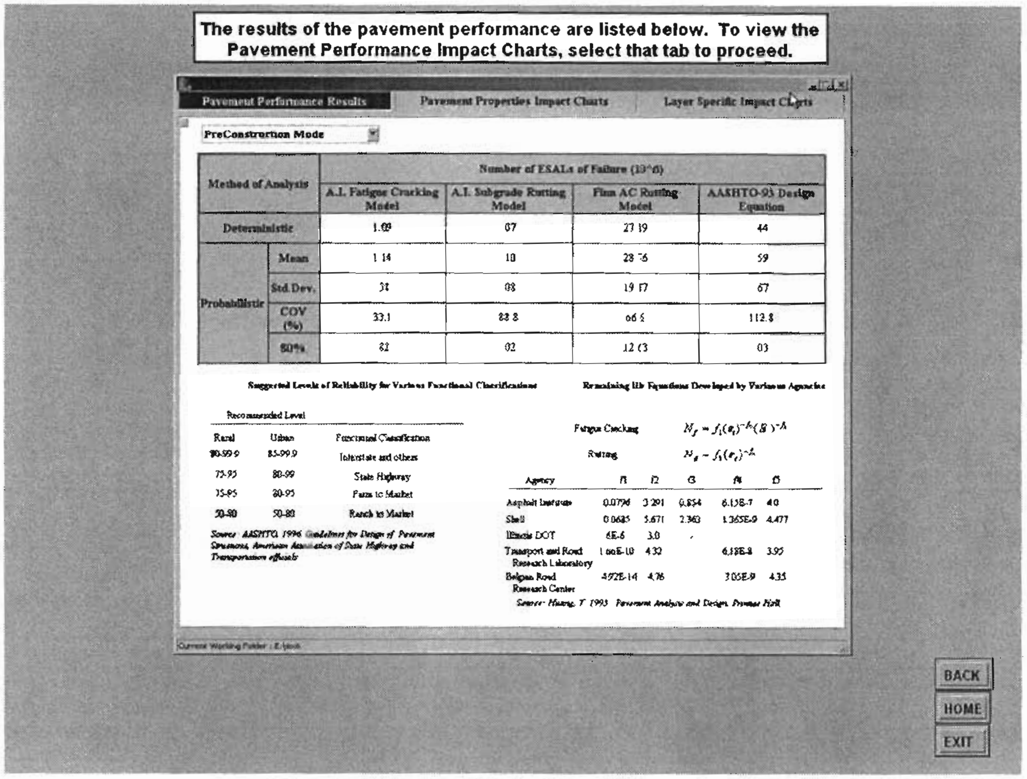
Figure 2.129 - Slide 15 of Exercise 7



Select the "Continue" to proceed with analysis.

NO MATERIAL MODEL
SELECTED...PLEASE
CONTINUE

Figure 2.130 - Slide 16 of Exercise 7



The results of the pavement performance are listed below. To view the Pavement Performance Impact Charts, select that tab to proceed.

Method of Analysis		Number of ESALs of Failure (10^6)			
		A.I. Fatigue Cracking Model	A.I. Subgrade Rutting Model	Finn AC Rutting Model	AASHTO-93 Design Equation
Deterministic		1.09	07	27 19	44
Probabilistic	Mean	1 14	10	28 76	59
	Std.Dev.	38	08	19 17	67
	COV (%)	33.1	88 8	66 5	112.8
	80%	82	02	12 63	03

Suggested Levels of Reliability for Various Functional Classifications

Recommended Level		
Rural	Urban	Functional Classification
80-99.9	85-99.9	Interstate and others
75-95	80-99	State Highway
75-95	80-95	Farm to Market
50-80	50-80	Ranch to Market

Source: AASHTO, 1996 Guidelines for Design of Pavement Structures, American Association of State Highway and Transportation officials

Remaining life Equations Developed by Various Agencies

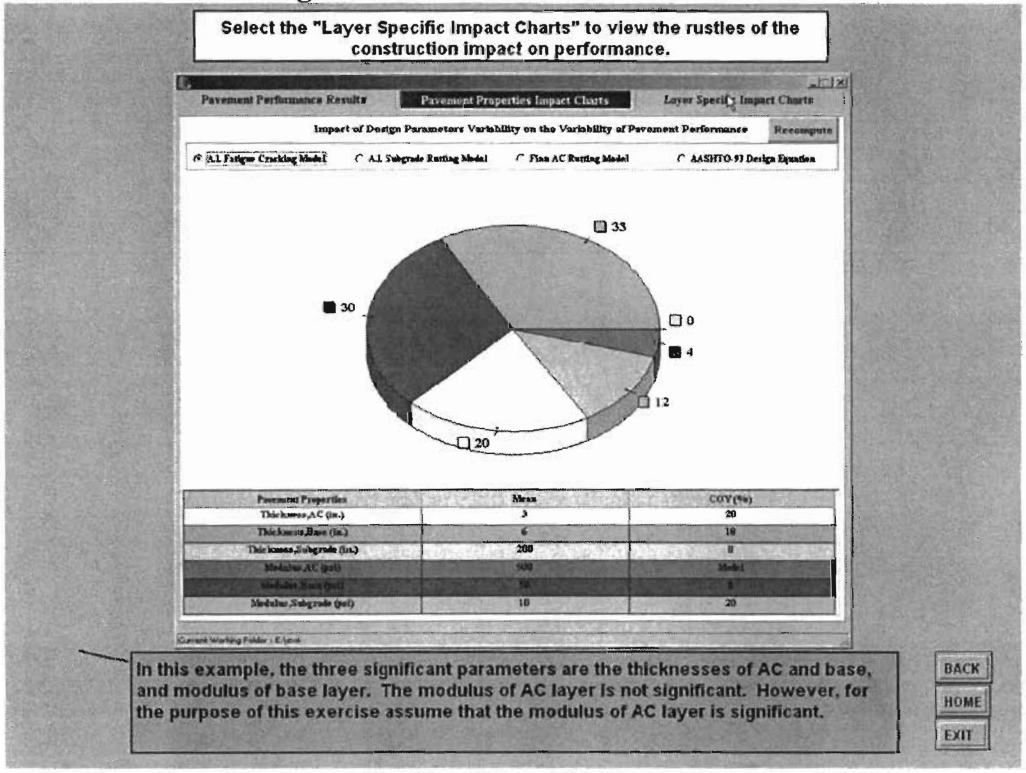
Fatigue Cracking $N_f = f_1(\epsilon_t)^{-f_2}(E)^{-f_3}$

Rutting $N_d = f_4(\epsilon_c)^{-f_5}$

Agency	f1	f2	f3	f4	f5
Asphalt Institute	0.0796	3.291	0.854	6.15E-7	4.0
Shell	0.0685	5.671	2.363	1.365E-9	4.477
Illinois DOT	6E-6	3.0			
Transport and Road Research Laboratory	1.66E-10	4.32		6.18E-8	3.95
Belgian Road Research Center	4.92E-14	4.76		3.05E-9	4.35

Source: Huang, Y 1993 Pavement Analysis and Design, Prentice Hall

Figure 2.131 - Slide 17 of Exercise 7



Select the "Layer Specific Impact Charts" to view the rustles of the construction impact on performance.

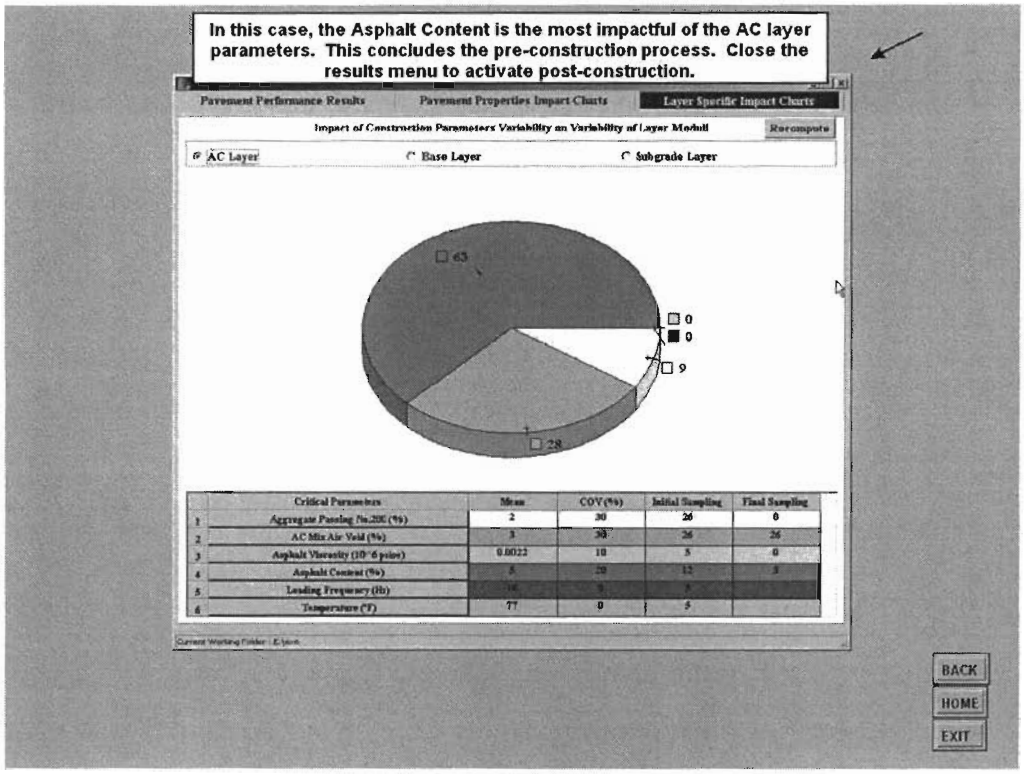
Impact of Design Parameters Variability on the Variability of Pavement Performance

● A.I. Fatigue Cracking Model ○ A.I. Subgrade Rutting Model ○ Finn AC Rutting Model ○ AASHTO-93 Design Equation

Pavement Properties	Mean	COV(%)
Thickness,AC (in.)	3	20
Thickness,Base (in.)	6	10
Thickness,Subgrade (in.)	200	0
Modulus,AC (psi)	500	Model
Modulus,Base (psi)	50	[illegible]
Modulus,Subgrade (psi)	10	20

In this example, the three significant parameters are the thicknesses of AC and base, and modulus of base layer. The modulus of AC layer is not significant. However, for the purpose of this exercise assume that the modulus of AC layer is significant.

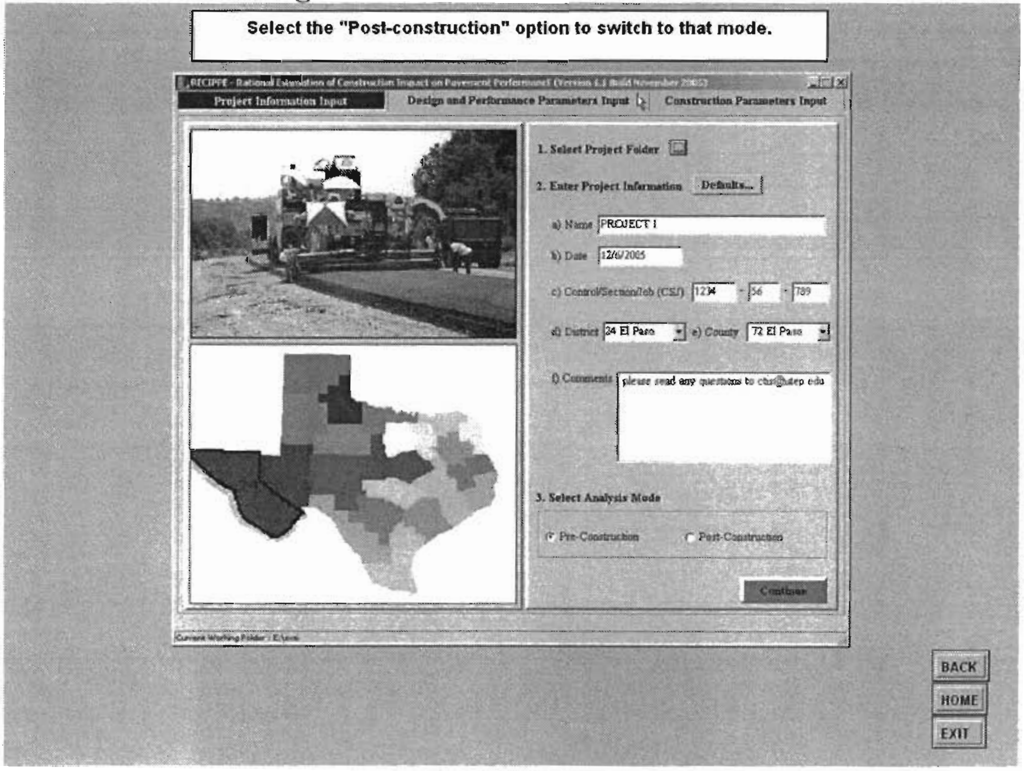
Figure 2.132 - Slide 18 of Exercise 7



In this case, the Asphalt Content is the most impactful of the AC layer parameters. This concludes the pre-construction process. Close the results menu to activate post-construction.

	Critical Parameters	Mean	COV(%)	Initial Sampling	Final Sampling
1	Aggregate Passing No.200 (%)	2	30	26	0
2	AC Mix Air Void (%)	3	30	26	26
3	Asphalt Viscosity (10^6 poise)	0.0022	10	5	0
4	Asphalt Content (%)	5	20	12	3
5	Loading Frequency (Hz)	10	5	5	
6	Temperature (°F)	77	0	5	

Figure 2.133 - Slide 19 of Exercise 7



Select the "Post-construction" option to switch to that mode.

1. Select Project Folder

2. Enter Project Information Defaults...

a) Name PROJECT 1

b) Date 12/6/2005

c) Control/Section/Job (CSJ) 1234 - 56 - 789

d) District 24 El Paso e) County 72 El Paso

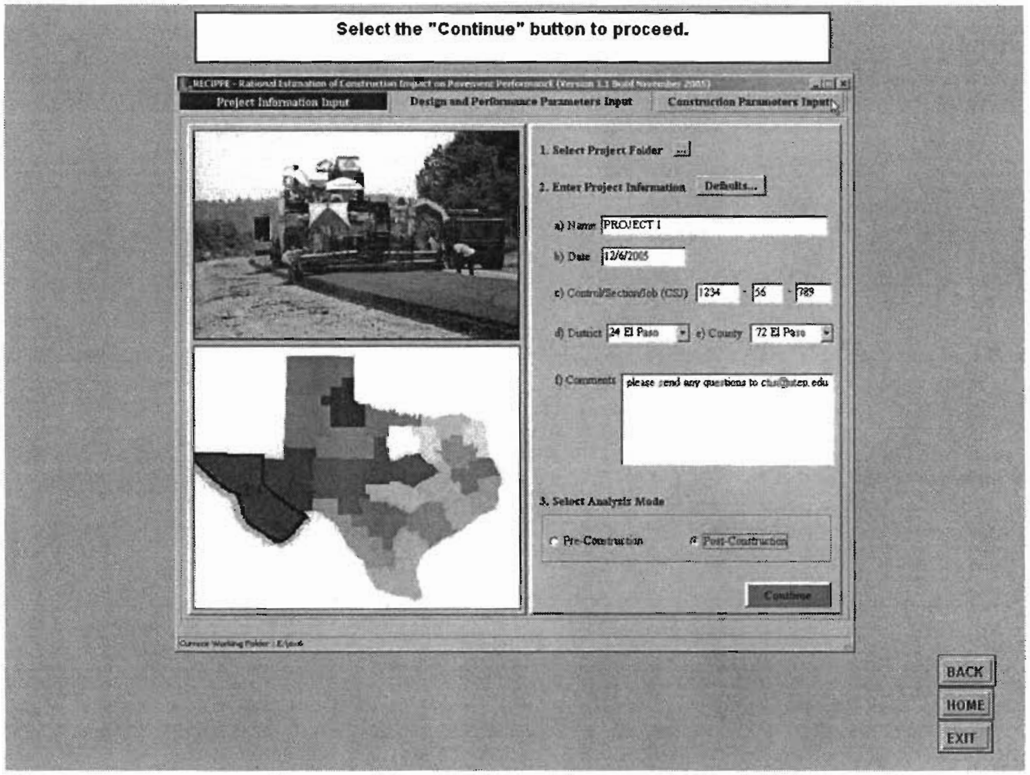
f) Comments please send any questions to chs[illegible]utep.edu

3. Select Analysis Mode

● Pre-Construction ○ Post-Construction

Continue

Figure 2.134 - Slide 20 of Exercise 7



Select the "Continue" button to proceed.

1. Select Project Folder

2. Enter Project Information

a) Name: PROJECT 1

b) Date: 12/6/2005

c) Control/Section/Job (CSJ): 1234 - 56 - 789

d) District: 24 El Paso

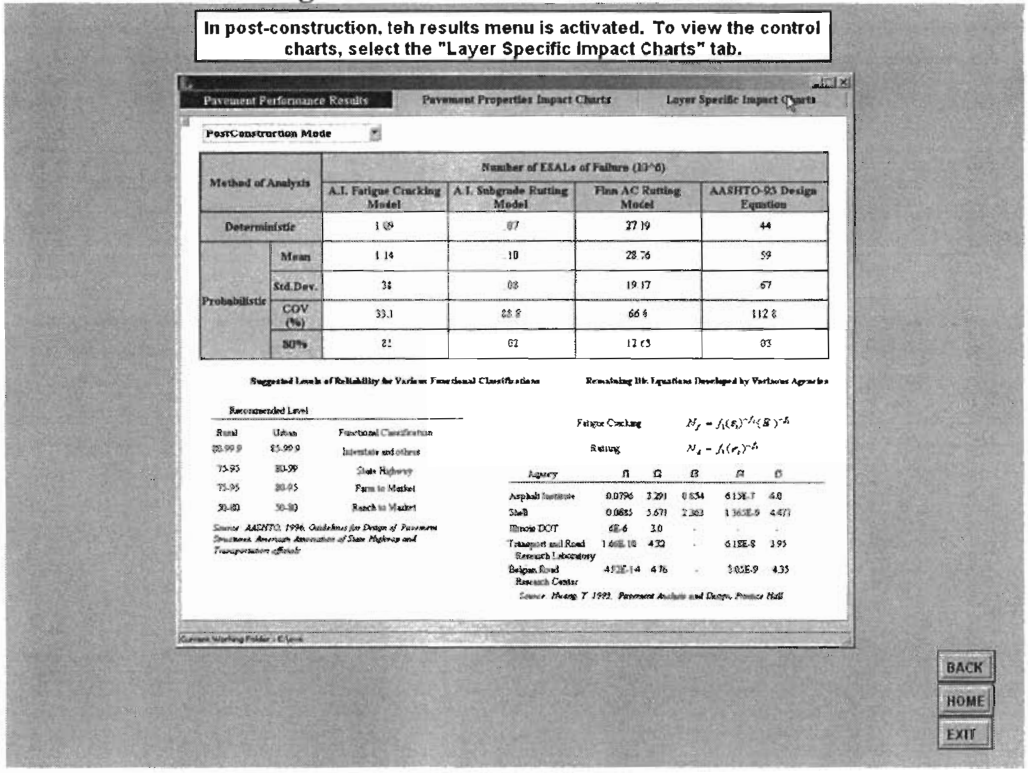
e) County: 72 El Paso

f) Comments: please send any questions to c[illegible]@utep.edu

3. Select Analysis Mode

○ Pre-Construction ● Post-Construction

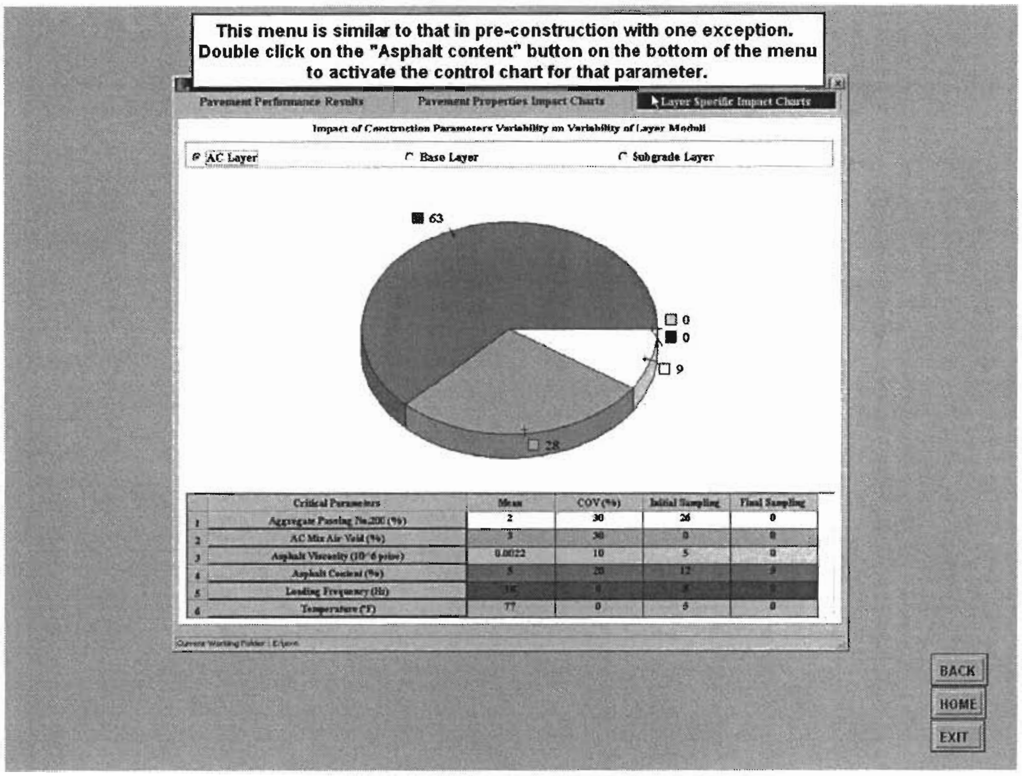
Figure 2.135 - Slide 21 of Exercise 7



In post-construction, teh results menu is activated. To view the control charts, select the "Layer Specific Impact Charts" tab.

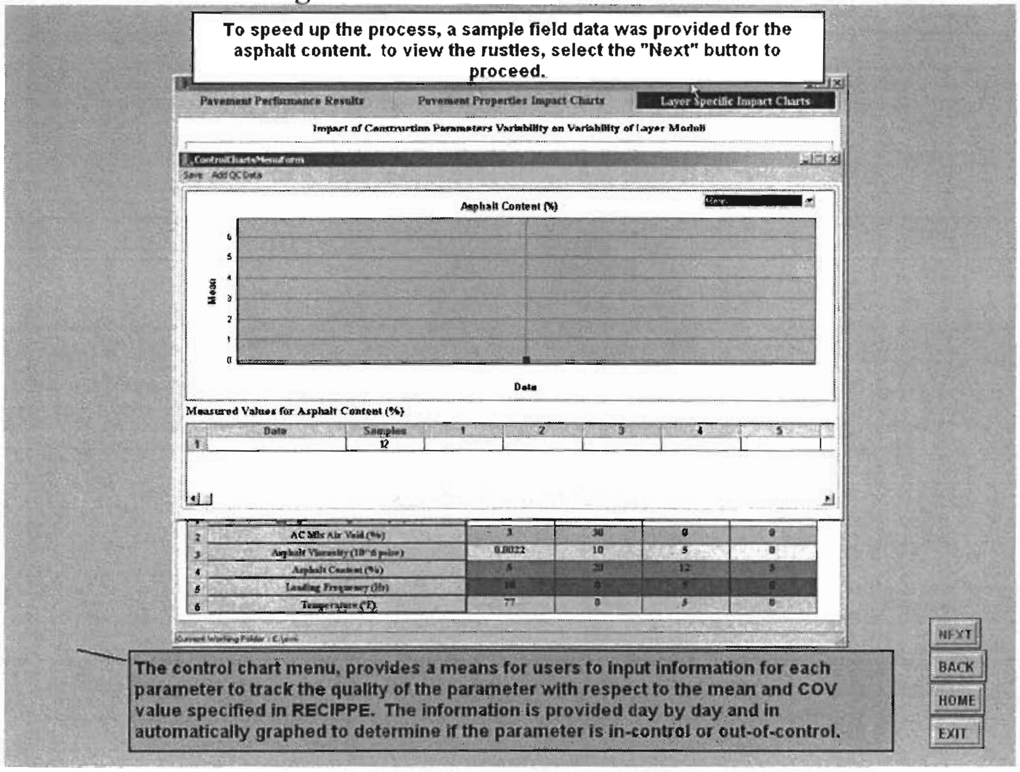
Method of Analysis		Number of ESALs of Failure (10^6)			
		A.I. Fatigue Cracking Model	A.I. Subgrade Rutting Model	Finn AC Rutting Model	AASHTO-93 Design Equation
Deterministic		1.09	.07	27.19	.44
Probabilistic	Mean	1.14	.10	28.76	.59
	Std.Dev.	.38	.08	19.17	.67
	COV (%)	33.1	88.8	66.4	112.8
	80%	.82	.02	12.63	.03

Figure 2.136 - Slide 22 of Exercise 7


This menu is similar to that in pre-construction with one exception. Double click on the "Asphalt content" button on the bottom of the menu to activate the control chart for that parameter.

	Critical Parameters	Mean	COV(%)	Initial Sampling	Final Sampling
1	Aggregate Passing No.200 (%)	2	30	26	0
2	AC Mix Air Void (%)	3	30	0	0
3	Asphalt Viscosity (10^6 poise)	0.0022	10	5	0
4	Asphalt Content (%)	5	20	12	9
5	Loading Frequency (Hz)	10	0	5	0
6	Temperature (°F)	77	0	5	0

Figure 2.137 - Slide 23 of Exercise 7


To speed up the process, a sample field data was provided for the asphalt content. to view the rustles, select the "Next" button to proceed.

Measured Values for Asphalt Content (%)

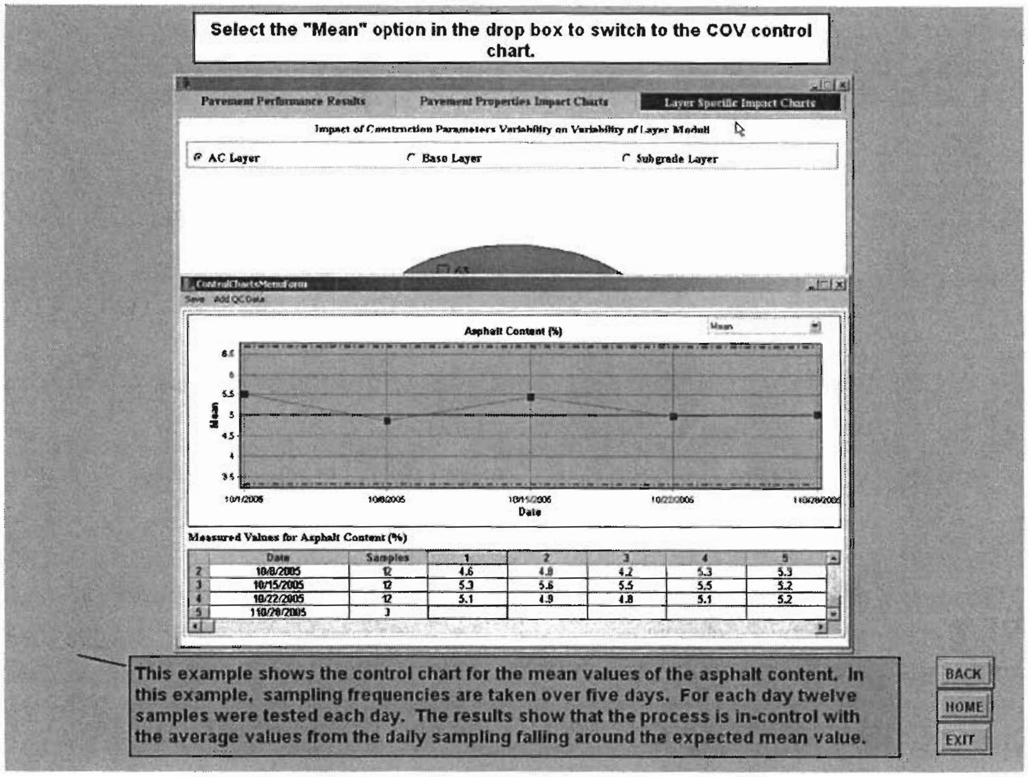
	Date	Samples	1	2	3	4	5
1		12					

2	AC Mix Air Void (%)	3	30	0	0
3	Asphalt Viscosity (10^6 poise)	0.0022	10	5	0
4	Asphalt Content (%)	5	20	12	5
5	Loading Frequency (Hz)	10	0	5	0
6	Temperature (°F)	77	0	5	0

The control chart menu, provides a means for users to input information for each parameter to track the quality of the parameter with respect to the mean and COV value specified in RECIPPE. The information is provided day by day and in automatically graphed to determine if the parameter is in-control or out-of-control.

Figure 2.138 - Slide 24 of Exercise 7

Select the "Mean" option in the drop box to switch to the COV control chart.



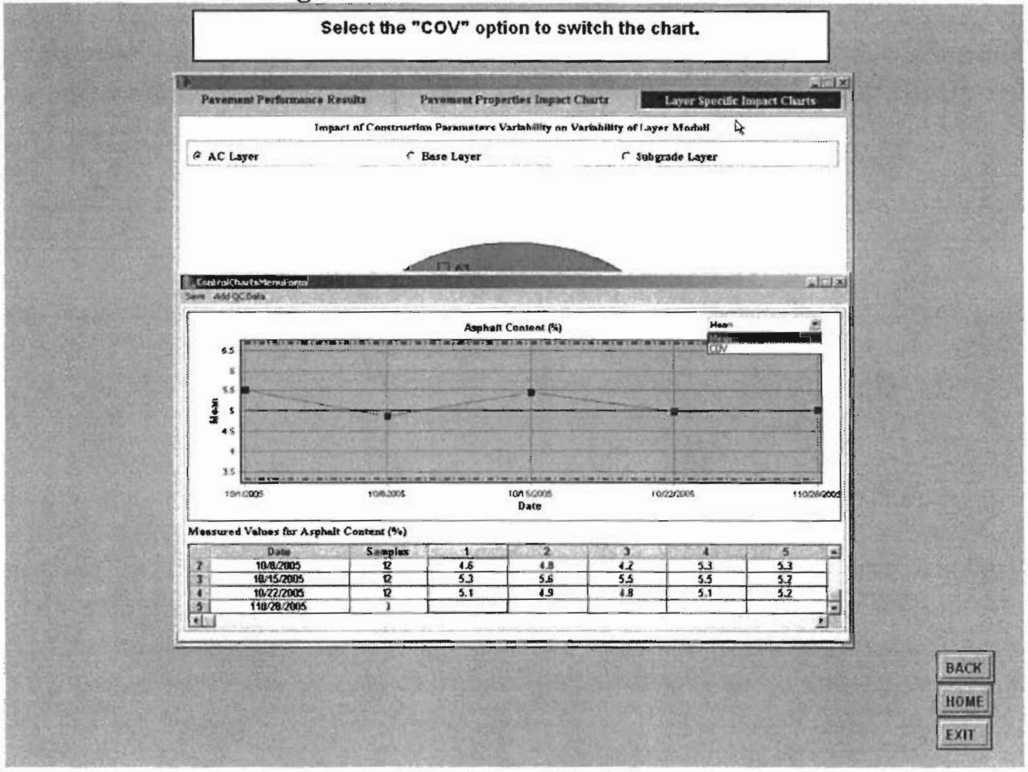
Measured Values for Asphalt Content (%)

	Date	Samples	1	2	3	4	5
2	10/8/2005	12	4.6	4.8	4.2	5.3	5.3
3	10/15/2005	12	5.3	5.6	5.5	5.5	5.2
4	10/22/2005	12	5.1	4.9	4.8	5.1	5.2
5	110/28/2005	3					

This example shows the control chart for the mean values of the asphalt content. In this example, sampling frequencies are taken over five days. For each day twelve samples were tested each day. The results show that the process is in-control with the average values from the daily sampling falling around the expected mean value.

Figure 2.139 - Slide 25 of Exercise 7

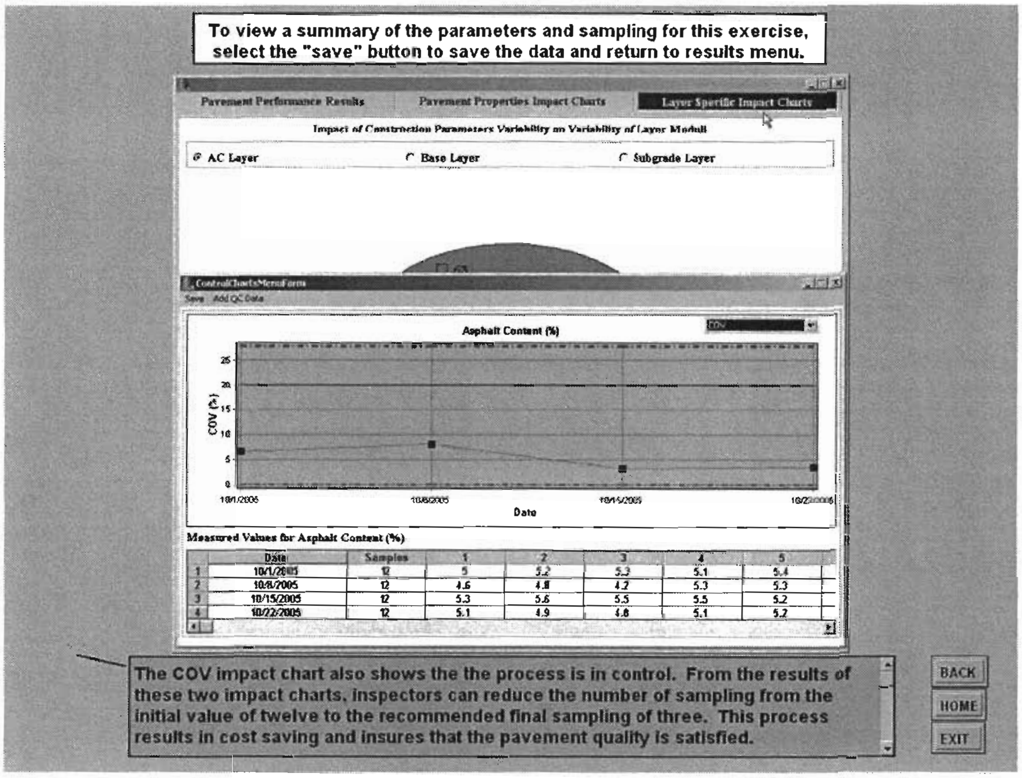
Select the "COV" option to switch the chart.



Measured Values for Asphalt Content (%)

	Date	Samples	1	2	3	4	5
2	10/8/2005	12	4.6	4.8	4.2	5.3	5.3
3	10/15/2005	12	5.3	5.6	5.5	5.5	5.2
4	10/22/2005	12	5.1	4.9	4.8	5.1	5.2
5	110/28/2005	3					

Figure 2.140 - Slide 26 of Exercise 7



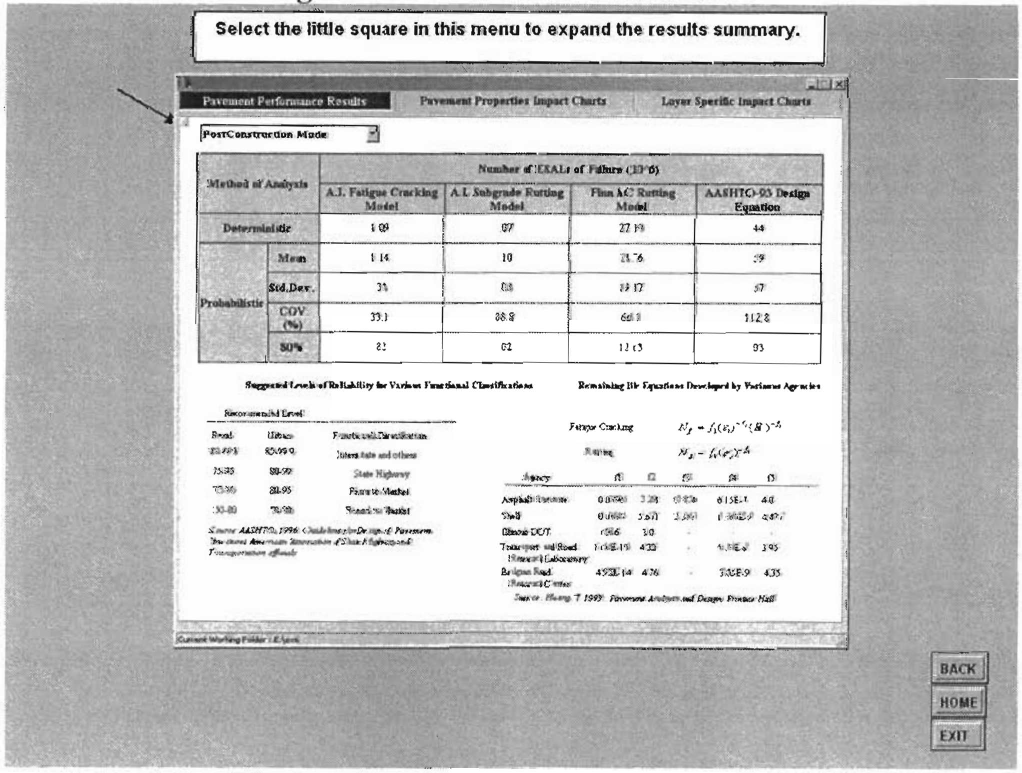
To view a summary of the parameters and sampling for this exercise, select the "save" button to save the data and return to results menu.

Measured Values for Asphalt Content (%)

	Date	Samples	1	2	3	4	5
1	10/1/2005	12	5	5.2	5.3	5.1	5.4
2	10/8/2005	12	4.6	4.8	4.2	5.3	5.3
3	10/15/2005	12	5.3	5.6	5.5	5.5	5.2
4	10/22/2005	12	5.1	4.9	4.8	5.1	5.2

The COV impact chart also shows the the process is in control. From the results of these two impact charts, inspectors can reduce the number of sampling from the initial value of twelve to the recommended final sampling of three. This process results in cost saving and insures that the pavement quality is satisfied.

Figure 2.141 - Slide 27 of Exercise 7



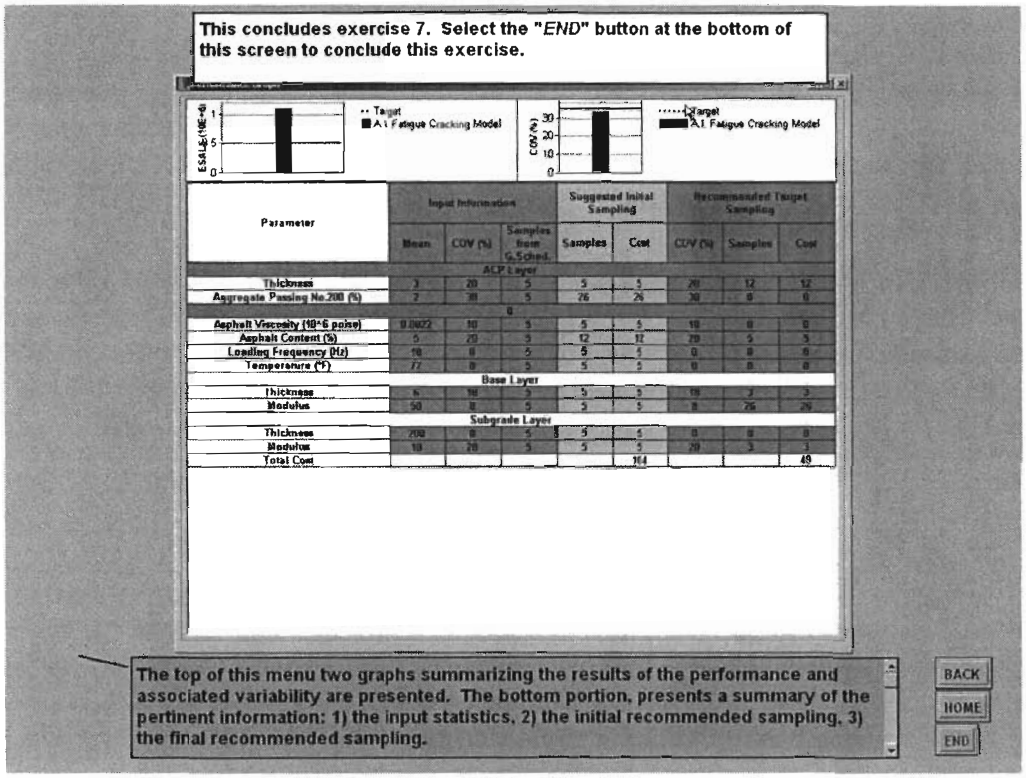
Select the little square in this menu to expand the results summary.

Method of Analysis		Number of ESALs of Failure (10^6)			
		A.I. Fatigue Cracking Model	A.I. Subgrade Rutting Model	Finn AC Rutting Model	AASHTO-93 Design Equation
Deterministic		1.09	.07	27.19	.44
Probabilistic	Mean	1.14	.10	21.76	.59
	Std.Dev.	.38	.03	19.17	.67
	COV (%)	33.1	38.8	68.1	112.8
	80%	.83	.02	13.13	.93

Suggested Levels of Reliability for Various Functional Classifications

Remaining life Equations Developed by Various Agencies

Figure 2.142 - Slide 28 of Exercise 7


This concludes exercise 7. Select the "*END*" button at the bottom of this screen to conclude this exercise.

Parameter	Input Information			Suggested Initial Sampling		Recommended Target Sampling		
	Mean	COV (%)	Samples from G.Sched.	Samples	Cost	COV (%)	Samples	Cost
ACP Layer								
Thickness	3	20	5	5	5	20	12	12
Aggregate Passing No.200 (%)	2	30	5	26	26	30	0	0
0								
Asphalt Viscosity (10^6 poise)	0.0022	10	5	5	5	10	0	0
Asphalt Content (%)	5	20	5	12	12	20	5	5
Loading Frequency (Hz)	10	0	5	5	5	0	0	0
Temperature (°F)	77	0	5	5	5	0	0	0
Base Layer								
Thickness	6	10	5	5	5	10	3	3
Modulus	50	0	5	5	5	0	26	26
Subgrade Layer								
Thickness	200	0	5	5	5	0	0	0
Modulus	10	20	5	5	5	20	3	3
Total Cost					104			49

The top of this menu two graphs summarizing the results of the performance and associated variability are presented. The bottom portion, presents a summary of the pertinent information: 1) the input statistics, 2) the initial recommended sampling, 3) the final recommended sampling.

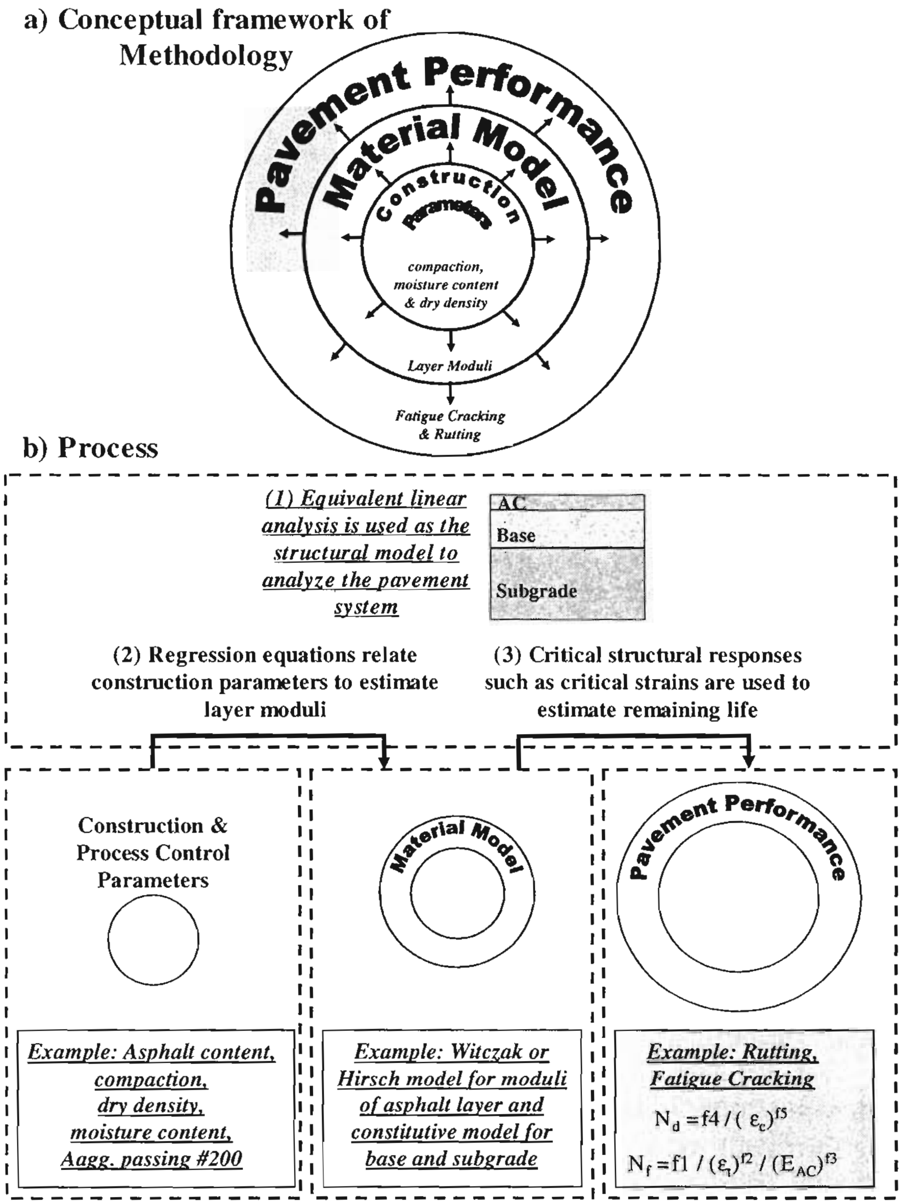
Figure 2.143 - Slide 29 of Exercise 7

CHAPTER THREE - BACKGROUND

METHODOLOGY

The methodology developed under this project provides a link between construction and performance. Figure 3.1a provides a conceptual representation of the methodology starting from the center, or inner circle and moving to the outer circle. The three circles presented in the figure represent the main features in the methodology. The process starts from construction parameters, which is represented by the inner circle. These parameters are used to estimate the layer moduli via material models for the different layers of a pavement system. The material characteristic models, represented by the middle circle, are the links between the construction and pavement performance. Pavement performance is represented by the outer circle, which is based on the layer moduli and other pavement properties so that the pavement system performance can be determined.

In Figure 3.1b the process is further clarified. The core of this methodology is based on mechanistic analysis. The structural model is based on a nonlinear model using equivalent-linear algorithm. The equivalent-linear model was developed under TXDOT Project 0-1780 (Ke et al. 2000, and Abdallah et al., 2003). The structural model, designated as *(1)* in Figure 2.1b serves as the engine that performs all numerical calculations such as determining the nonlinear layer moduli and appropriate stresses and strains in the pavement analysis process. The next process illustrates the link of the inner circle and the middle circle *(2)*. Construction parameters are used in material models to determine the moduli of the layers. For example, the modulus of ACP is estimated using a model that incorporates as input construction parameters such as air voids, asphalt content, asphalt viscosity, etc. The last step illustrated in the process shows the link between the middle circle, material models, and the outer circle, performance models *(3)*. This step depicts the process of estimating the critical strains based on the layer properties (thickness, modulus, etc…) to determine performance of the pavement using the structural model. The process described thus far allows the estimation of pavement performance based on construction parameters. As such, this analysis only represents a deterministic analysis. The uncertainties that are associated with the input parameters are not accounted for. However, engineering measurement associated with a construction parameter demonstrates a certain variation. Therefore, a probabilistic approach is a more rational approach and was incorporated into the process.


a) Conceptual framework of Methodology

b) Process

Figure 3.1 - Conceptual Framework of Methodology and Process for Determining Pavement Performance from Construction Parameters

Probabilistic Approach and Generation of Impact Chart

In this research project, for practical consideration, all input parameters are assumed to be normally distributed. Once variability of input parameters is incorporated into the system, performance outputs will also retain variability. By accounting for variability in the analysis, the impact of construction variability on the variability of pavement performance is determined. This impact is estimated using an "impact chart". The impact chart compares the influence of each construction parameter on the remaining life. The probabilistic analysis employed in this project is based on two methods: 1) Monte Carlo Simulation and 2) Two Point Mass (TPM) Simulation.

Monte Carlo simulations technique randomly generates values to represent variables with uncertainty. For this case, the construction parameters are randomly created multiple times to simulate a continuous model. Similarly, the TPM simulation is used to approximate low-order moments of functions (e.g., mean and coefficient of variation, COV) for construction parameters (Rosenblueth, 1981). This is achieved by replacing continuously randomly-generated values with two discrete values.

The major difference between the Monte Carlo and TPM simulations is the number of iterations it takes to complete a simulation. With a Monte Carlo simulation, 500 simulations are considered adequate enough to model a normal distribution in this study (Abdallah et al., 2004a), while the number of iterations for TPM varies with the number of random variables represented by:

$$\text{Iterations}_{\text{TPM}} = 2^{\text{Number of Random Variables}} \tag{3.1}$$

For the algorithm developed in this research, two types of statistical analyzes are performed: 1) varying values for a single construction parameter and 2) varying all parameters at once. Figure 3.2 illustrates the concept of the simulation process. Any input parameter is described with a normal distribution represented by a mean and a coefficient of variation (COV). As illustrated in part one of Figure 3.2, each parameter is simulated individually and is processed through the system to determine its impact on the variation of pavement performance. This process is repeated for each parameter, and as such, for each construction parameter, the impact of that parameter can be determined.

The impact of each parameter does not account for the joint effect of all parameters impacting performance. Therefore, processing of all input parameters simultaneously through the system is required (the second part illustrated in Figure 3.2). The program developed in this project uses Monte Carlo simulation and TPM simulations in unison. The TPM simulations can be used to calculate the variance of the remaining life when one parameter is varied, and the Monte Carlo simulations can be used when all of the construction parameters are varied together.

The last part of the figure depicts the use of the impact values to develop the impact chart. To prioritize the significance of different construction parameters relative to one another, the approach described next is followed. When the simulation is carried out for a single construction parameter, it is possible to create pie charts showing how each parameter impacts the variability of a performance model with respect to the other construction parameters. The values that are entered into the pie charts are called normalized impact values, shown in Equation 3.2:

$$\mathbf{NIV_i} = \frac{\mathbf{COV_i}}{\sum_{i=1}^{n} \mathbf{COV_i}} \tag{3.2}$$

where NIV is the normalized impact value for construction parameter i and the COV_i is the coefficient of variation of the pavement performance model for construction parameter i. By

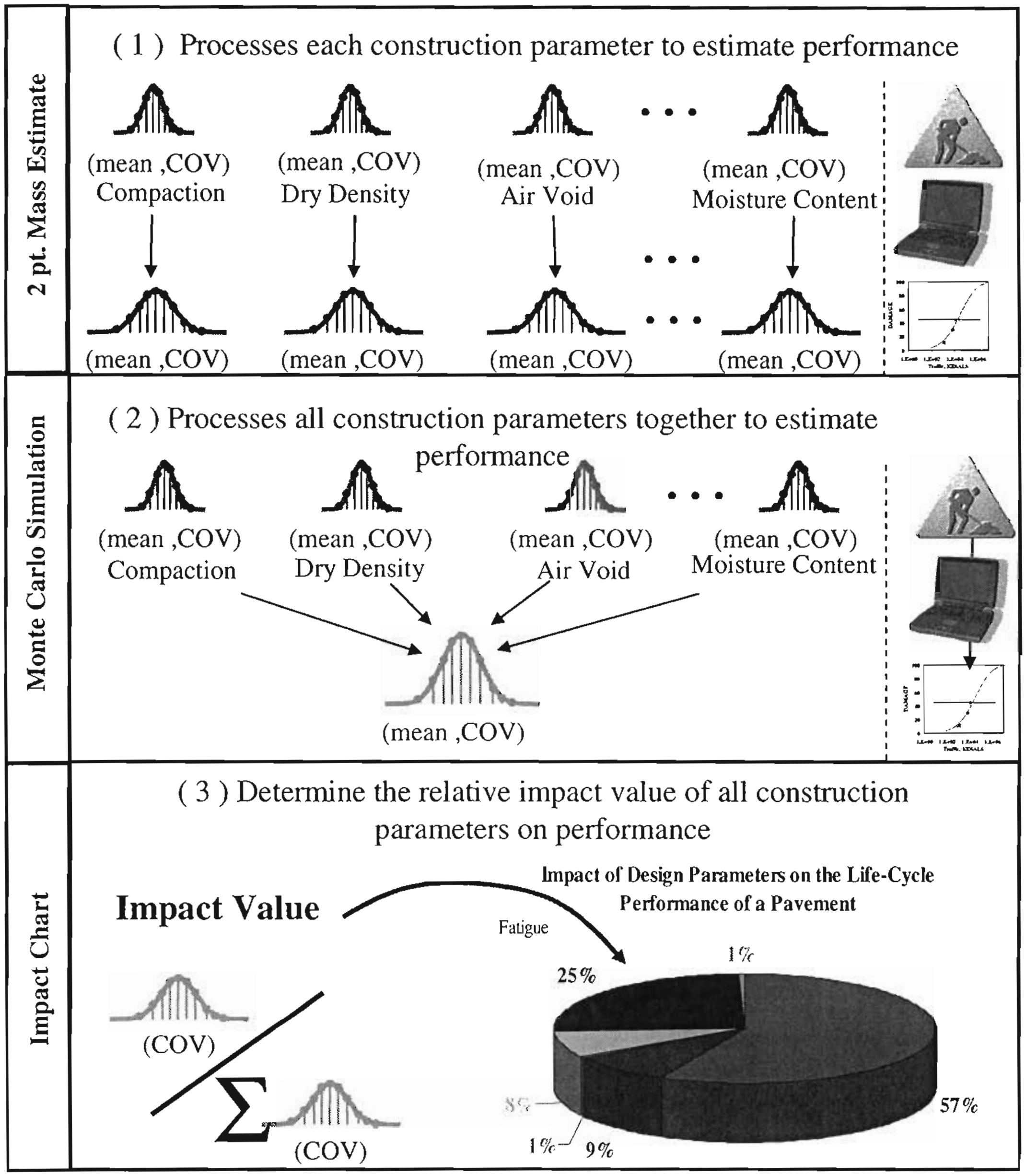


Figure 3.2 - Probabilistic Analysis Process used in Developing the Impact Chart

placing all of the *NIV*s in a pie chart, an impact chart can be created to identify significant construction parameters. The figure in the last part of Figure 3.2 is a representation of an impact chart, where each parameter is represented by an impact value. Parameters with large impact values indicate significant parameters and should be focused on in controlling performance. However, parameters with very low impact values indicate no significance, and resources for controlling variability should be focused elsewhere. If one is interested in changing the mean and COV of the performance indicator associated with these parameters, she/he should focus on reducing the COV for those parameters with significant impact values, therefore reducing performance variance.

Pre-Construction Process - Optimization Process to Identify Significant Parameters

The process presented thus far illustrates the procedure to determine the impact of construction variability on the variability of performance using the impact chart. The next step is to demonstrate the optimization process in the program.

Figure 3.3 illustrates the use of the impact chart to identify significant parameters through an optimization process. Initially, input information, as shown in Figure 3.3, is based on the mean and variance of each construction constituent found either in historical data or required specifications. These constituents are then simulated in the statistics-based algorithm by varying the inputs according to a normal distribution and using the simulated values in material models to estimate layer moduli. The results from the material models are then used to estimate pavement performance. The output is the pavement performance based on the input values and the performance variance based on the variability of the input. If the simulated pavement life meets the design specifications, the algorithm terminates and significant impact values are identified from the impact chart, and provided to those involved in the construction and inspection. If the variability in the performance is larger than specified, the COV values for parameters that are identified as significant are reduced, and the analysis is repeated. This process continues until the pavement performance specifications are met. The program provides means to adjust the number of significant parameters that are reduced, the increment of reduced variability after each iteration, and constraint of the minimum value of variability. The process is the pre-construction phase of this program. The next phase is post-construction.

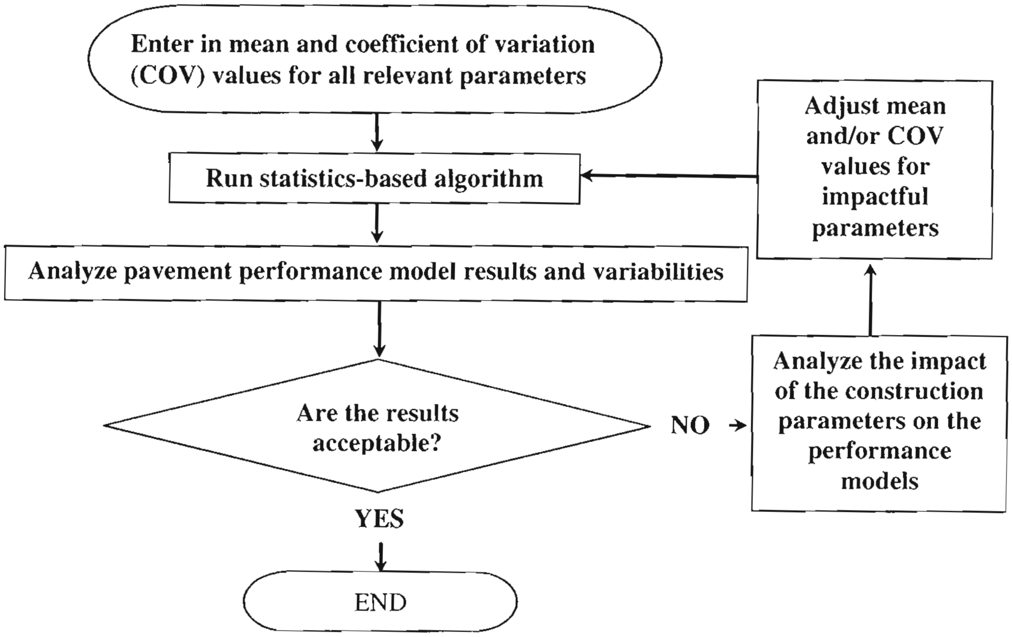


Figure 3.3 - General Flow of Optimization Process

Post-Construction Process - Quality Control Process

In pre-construction, the optimization process identifies the significant parameters for inspectors to focus on. Along with identifying significant parameters, the number of necessary samples for each parameter is determined based on the optimization process.

Number of Samples and Sampling Frequencies

The process of developing the number of samples based on the COV of each parameter is thoroughly documented in Research Report 0-4046-3 (Haggerty et al., 2005). Equation 3.3 represents the sample size equation used in the program.

$$n = \left(\frac{(Z_\alpha + Z_\beta) \times COV}{e} \right)^2 \qquad (3.3)$$

where n is the sample size, e represents the tolerable error or tolerance, COV represents the coefficient of variation for an individual construction parameter, Z_α defines the normalized standard deviation value based upon the level of significant (α), and Z_β defines the normalized standard deviation value based upon the level of significant (β) found as the standard deviation divided by the mean.

For the purpose of this report, α and β are related to confidence level of the seller (contractor) and buyer (TxDOT), respectively. Zhang et al. (2001) presents definitions of those parameters as follows:

- Seller's Risk (α): The risk of rejecting "good" material. In highway construction this is associated with the risk of a contractor having good material rejected by the owner.
- Buyer's Risk (β): The risk of accepting "bad" material at reduced or full payment. In highway construction, this risk is associated with the owner's risk of accepting what is actually bad material.

The α-risk affects the contractor because it is probable that the agency may reject, what is in fact, acceptable work. The β-risk affects the agency because it is probable that the agency may accept, what is in fact, unacceptable work. The true meaning of risk is how much one is willing to lose in terms of dollars if an action is taken.

After determining the sample size, the testing frequencies can be determined. Zhang et al. (2001) shows example of two ways of determining testing frequency:

a) *Time-based testing frequency:* TF = daily production / sample size
b) *Quantity-based testing frequency:* TF = batch quantity / sample size

Once the testing frequency is determined, control charts can be used to provide quality control by the inspector.

Control Charts

Control chart is one way of conducting inspection. Control charts help identify instability and unusual circumstances in production processes. This implies that, based upon allowable variances, inspectors can randomly sample road specimens and determine whether or not the pavement, statistically, will be stable over time (in-control or out-of-control, respectively).

To assist in monitoring the important parameters during construction, the program provides control charts (CC) for the mean and COV of a specified parameter. The CC based on the mean has three limits: a) the center line (CL) defined by the mean and b) upper and lower control limits (UCL, LCL) defined by one deviation from the mean. The CC for the COV shows the trend of the QC variability with respect to the allowable COV value specified in preconstruction. Research Report 0-4046-3 (Haggerty et al., 2005) depicts the development, rules and examples of using control charts.

Cost Analysis

With the information that has been described, thus far, a quantitative value can be provided for inspection costs, which will be discussed in this section. Production expenditures, due to rehabilitation and maintenance, are intuitively calculated in a qualitative manner, because the basic concept of the program is to minimize variability thereby increasing the longevity of pavement.

The program estimates the minimum number of tests to be run for inspecting a single parameter. Hence, for each test run there is a corresponding cost, which can be related as a unit price (i.e. $10.00/Nuclear Density Gauge). If the unit price is known for each test to be run, then the total inspection costs can be found using a simple mathematical operation:

$$TotalCost_{inspection} = \sum_{i=1}^{m} C_i n_i \tag{3.4}$$

where C_i is the unit price for parameter i and n_i is the sample size for parameter i. Typical costs for some parameters of ACP, base and subgrade layers in Texas are shown in Table 3.1. These costs are estimated for the entire state of Texas. The program can modify this program if necessary.

Table 3.1 - Typical Inspection Tests & Costs for Texas Pavements

STANDARD		TEST	Unit	STATEWIDE AVG.		2 Year Avg.
				FY 2002	FY 2003	
Tex	103	Moisture Content	each	$6.00	$27.00	$16.50
Tex	106	Plasticity Index	each	$33.75	$71.00	$52.38
Tex	110, Pt1	Gradation	each	$32.50	$60.00	$46.25
Tex	110, Pt2	Gradation	each	-	$150.00	$150.00
Tex	113	M-D Curve for Base	each	$162.50	$330.00	$246.25
Tex	114	M-D Curve for Base	each	$155.00	$330.00	$242.50
Tex	115	Nuclear Density	hour	$31.50	$37.50	$34.50
Tex	116	Wet Ball	each	$135.00	$200.00	$167.50

CHAPTER FOUR – MODELS USED IN RECIPPE

PERFORMANCE MODELS

The three performance models investigated in the study were:

1) Permanent deformation in the ACP layer (Finn et al., 1984):

   ACP layers that are less than 6 in. thick

   $$\log RR = -5.617 + 4.343\log w_0 - 0.167\log(N_{18}) - 1.118\log\sigma_c \tag{4.1}$$

   ACP layers equal to or greater than 6 in. in thickness:

   $$\log RR = -1.173 + 0.717\log w_0 - 0.658\log(N_{18}) + 0.666\log\sigma_c \tag{4.2}$$

   where RR is the rate of rutting in micro-inches (1 μin. $=10^{-6}$ in.) per axle load repetition, w_o is the surface deflection in mil (1 mil$=10^{-3}$ in.), σ_c is the vertical compressive stress within the AC layer in psi, and N_{18} is the equivalent 18-kip single-axle load in 10^5 ESALS.

2) Permanent deformation in the subgrade (Huang, 1993):

   $$N_d = f_4(\varepsilon_c)^{-f_5} \tag{4.3}$$

   where N_d is the allowable number of load repetitions to prevent rutting, ε_c is the compressive strain at the top of subgrade and parameters f_4 and f_5 are design constants.

3) Pavement failure as a result of fatigue cracking (Huang, 1993):

   $$N_f = f_1(\varepsilon_t)^{-f_2}(E_{ACP})^{-f_3} \tag{4.4}$$

   where N_f is the allowable number of load repetitions to prevent fatigue cracking, ε_t is the tensile strain at the bottom of the ACP layer, E_{ACP} is the elastic modulus of asphalt-concrete layer (in psi), and parameters f_1 through f_3 are design constants.

Table 4.1 provide a list of coefficients for performance models in Equations 4.3 and 4.4. These models can be used in the mechanistic analysis developed for this project and can be incorporated into the program. The calibration and validation of these models are outside the scope of this project.

Table 4.1- Fatigue Cracking Model and Rutting Model Parameters used to Determine Remaining Life of a Flexible Pavement

Model	***Fatigue Cracking Model*** $N_f = f_1 (\varepsilon_t)^{-f_2} (E_{AC})^{-f_3}$			***Subgrade Rutting Model*** $N_d = f_4 (\varepsilon_c)^{-f_5}$	
	f_1	f_2	f_3	f_4	f_5
Asphalt Institute	0.0796	3.291	0.854	$1.365\text{x}10^{-9}$	4.477
Shell	0.0685	5.671	2.363	$6.15\text{x}10^{-7}$	4.0
Shell (50% reliability)	-	-	-	$6.15\text{x}10^{-7}$	4
Shell (85% reliability)	-	-	-	$1.94\text{x}10^{-7}$	4
Shell (95% reliability)	-	-	-	$1.05\text{x}10^{-7}$	4
Illinois Dept. of Transportation	5E-6	3	-	3	-
Transport and Road Research Laboratory	$1.66*10^{-10}$	4.32	-	4.32	-
U.K Research & Road Research Laboratory (85% reliability)	-	-	-	$6.18\text{x}10^{-8}$	3.95
University of Nottingham	-	-	-	$1.13\text{x}10^{-6}$	3.571
Belgian Road Research Center	$4.92*10^{-14}$	4.76	-	$3.05\text{x}10^{-9}$	4.35
New Mechanistic Design Guide (MDG) (National Calibration Factors[1]) for top –bottom cracking $k^*_1 = \frac{1}{0.000398 + \frac{0.003602}{1+e^{(11.02-3.49h_{AC})}}}$ for bottom-top cracking, $k^*_1 = \frac{1}{0.000398 + \frac{0.003602}{1+e^{(15.676-2.8186h_{AC})}}}$ h_{AC} is thickness of ACP layer and C is laboratory to field adjustment factor	$0.00432k^*_1C$	3.9492	*1*	-	-

Note: constants are for US customary units

MATERIAL MODELS

As illustrated in Chapter Two, the methodology of the program depends on the material characteristics models and pavement performance models. Throughout the research of this project, several material models were identified that could be used in the program.

ACP Models

The material models selected for the ACP layer are summarized the Table 4.2. The Witczak 1982 model was first used in the study to determine the feasibility in the use of the methodology developed in this project. The other models were subsequently added to the software package RECIPPE.

Base and Subgrade Models

Several material models were discovered during the literature review phase of this project for the base and subgrade layers. Some of the models are summarized in Table 4.3. All these models can be generalized by the following constitutive model:

$$M_R = k_1 P_a \left[\frac{\theta}{P_a} \right]^{k_2} \left[\frac{\tau_{oct}}{P_a} \right]^{k_3} \tag{4.5}$$

where $\theta = \sigma_1 + \sigma_2 + \sigma_3$ = bulk stress; τ_{oct} = octahedral shear stresses; P_a = atmospheric pressure, and k_1, k_2 and k_3 are multiple regression constants evaluated from resilient modulus test data from equations developed from a regression procedure that relate the regression constants to construction parameters.

One of the biggest challenges in this study was finding regression constants that relate construction parameters. The first success in finding such parameters was from a study carried out for Georgia DOT. Santha (1994) presented equations for regression constants defined for both granular and cohesive soils. Those equations were used in most part of the research study and are set as the default values in the program. At the latter part of the study, regression equations from Minnesota and Indiana DOTs were found. The regression equations for the material model parameters are summarized in Table 4.4 and 4.5.

Table 4.2 - Summary of Material Models for ACP Layer

Witczak 1982 Model (Asphalt Institute, 1982)	$\log E_{AC} = 5.553833 + 0.028829 \dfrac{P_{200}}{f^{0.17033}} - 0.03476\, V_V + 0.070377\, \eta + 0.000005\, t_p^{(1.3+0.49825 \log f)} P_{ac}^{0.5} - 0.00189\, t_p^{(1.3+0.49825 \log f)} \dfrac{P_{ac}^{0.5}}{f^{1.1}} + 0.931757\, f^{-0.02774} + \backepsilon$ E_{AC} = dynamic modulus of AC mix (in psi), η = bitumen viscosity (in 10^6 poise) at 70°F, f = load frequency (in Hz), V_v = percent air voids in the mix by volume, P_{ac} = percent effective bitumen content by volume, and P_{200} = percent passing No. 200 sieve by total aggregate weight.
Witczak 1995 Model (Ayres and Witczak, 1998)	$\log \lvert E_{AC} \rvert = -1.249937 + 0.029232\, P_{200} - 0.001767\, (P_{200})^2 + 0.002841\, P_4 - 0.058097\, V_a - 0.808808 \dfrac{V_{beff}}{(V_{beff} + V_a)} + \dfrac{[3.871977 - 0.0021\, P_4 + 0.003958\, P_{38} - 0.000017\, (P_{38})^2 + 0.00547\, P_{34}]}{1 + e^{(-0.603313 - 0.31335 \log(f) - 0.393532 \log(\eta))}}$ E_{AC} = dynamic modulus of AC mix (in 10^5 psi), η = bitumen viscosity (in 10^6 poise) at 70°F, f = load frequency (in Hz), V_a = percent air voids in the mix by volume, V_{beff} = percent effective bitumen content by volume, and P_{200} = percent passing No. 200 sieve by total aggregate weight, P_4 = cumulative percent retained No. 4 sieve by total aggregate weight, P_{34} = cumulative percent retained No. 3/4 sieve by total aggregate weight, and $P_{3/8}$ = cumulative percent retained No. 3/8 sieve by total aggregate weight.
Witczak Model 2000 (Witczak, 2003)	$\log \lvert E_{AC} \rvert = -0.261 + 0.008225\, P_{200} - 0.00000101\, (P_{200})^2 + 0.00196\, P_4 - 0.03157\, V_a - 0.415 \dfrac{V_{beff}}{(V_{beff} + V_a)} + \dfrac{[1.87 + 0.002808\, P_4 + 0.00000404\, P_{38} - 0.0001786\, (P_{38})^2 + 0.0164\, P_{34}]}{1 + e^{(-0.716 \log(f) - 0.7425 \log(\eta))}}$
Hirsch Model (Bonaquist, R., 2005)	$\lvert E^* \rvert_{mix} = P_c \left[4{,}200{,}000 \left(1 - \dfrac{VMA}{100} \right) + 3 \lvert G^* \rvert_{binder} \left(\dfrac{VFA\, x VMA}{10{,}000} \right) \right] + \dfrac{1 - P_c}{\left[\dfrac{\left(1 - \dfrac{VMA}{100} \right)}{4{,}200{,}000} + \dfrac{VMA}{3VFA \lvert G^* \rvert_{binder}} \right]}$ $P_c = \dfrac{\left(20 + \dfrac{VFA\, x 3 \lvert G^* \rvert_{binder}}{VMA} \right)^{0.58}}{650 + \left(\dfrac{VFA\, x 3 \lvert G^* \rvert_{binder}}{VMA} \right)^{0.58}}$ VMA = Voids in mineral aggregates (%), VFA = Voids filled with asphalt (%), and $\lvert G^* \rvert_{binder}$ = shear complex modulus of binder (psi)

Table 4.3 - Summary of Material Models for Base and Subgrade Layers (Thompson et al., 1998)

K - Θ Model	$M_R = k_1\theta^{k_2}$
Uzan Model	$M_R = k_1\theta^{k_2}\sigma_d^{k_3}$ $\sigma_d = \sigma_1 - \sigma_3$ = deviator stress
Octahedral Shear Stress Model	$M_R = k_1 P_a \left[\frac{\theta}{P_a}\right]^{k_2} \left[\frac{\tau_{oct}}{P_a}\right]^{k_3}$
Itani Model	$M_R = k_1 P_a \left[\frac{\theta}{3}\right]^{k_2} \sigma_d^{k_{3a}} \sigma_3^{k_{3b}}$ where σ_3 = confining stress; k_{3a} and k_{3b} are multiple regression constants
UTEP Model	$M_R = k_1\theta^{k_2}(\varepsilon_a)^{k_3}$ ε_a = induced resilient axial strain
UT-Austin Model	$M_R = k_1\theta^{k_2}\sigma_3^{k_3}$ σ_3 = confining stress
Bilinear Approximation (Arithmetic Model)	$M_R = k_1 + k_{3a}(k_2 - \sigma_d)$ when $\sigma_d < k_2$ $M_R = K_1 + k_{3b}(\sigma_d - k_2)$ when $\sigma_d > k_2$

Table 4.4 - Summary of Regression Equations for k-Parameters of Equation 3.5 Developed for GaDOT

Granular Soils	$Log(k_1) = 3.479 - 0.07MC + 0.24MCR + 3.681COMP + 0.011SLT + 0.006CLY$ $-0.025SW - 0.039DEN + 0.004\left(\frac{SW^2}{CLY}\right) + 0.003\left(\frac{DEN^2}{S40}\right)$ MCR represents the ratio of moisture content (MC) to optimum moisture content, COMP is the degree of compaction and SATU is the degree of saturation, S40 represents the percent passing sieve #40, SLT is the percent of silt, CLY is the percent of clay, SW is the percent of swell value, SH is the percent of shrinkage, DEN is the maximum dry density (in pcf) and CBR is the California bearing ratio
	$k_2 = 6.044 - 0.053OMC - 2.076COMP + 0.0053SATU - 0.0056CLY + 0.0088SW$ $-0.0069SH - 0.027DEN + 0.012CBR + 0.003\left(\frac{SW^2}{CLY}\right) - 0.31\frac{(SW + SH)}{CLY}$ OMC is the optimum moisture content
	$k_3 = 3.752 - 0.068MC + 0.309MCR - 0.006SLT + 0.0053SLY + 0.026SH$ $-0.033DEN - 0.0009\left(\frac{SW^2}{CLY}\right) + 0.00004\left(\frac{SATU^2}{SH}\right) - 0.0026CBR(SH)$
Cohesive Soils	$Log(k_1) = 19.813 - 0.045OMC - 0.131MC - 9.171COMP + 0.0037SLT + 0.015LL$ $-0.016PI - 0.021SW - 0.052DEN + 0.00001S40(SATU)$ PI and LL values, which stand for the plasticity index and liquid limit, respectively
	$k_2 = 0$
	$k_3 = 10.274 - 0.097 * MOIST - 1.06 * MCR - 3.471COMP + 0.0088S40$ $-0.0087PI + 0.014SH - 0.046 * DEN$

Table 4.5 - Regression Equations of Material Models for Subgrade Layers Developed Based on Research of Transportation Agencies of Minnesota and Indiana

Minnesota DOT (Uzan Model)	Cohesive Soils	$k_1 = 5770.8 - 520.98DEN^{0.5} - 3941.8MC^{0.5} + 33.1PI - 36.62LL - 17.93P200$ MC is the moisture content, DEN is the maximum dry density (in pcf), P200 represents the percent passing sieve #200, PI and LL values stand for the plasticity index and liquid limit, respectively
		$k_2 = 5409.9 - 306.18DEN^{0.1} - 82.63MC + 0.033PI + 0.138SAND - 0.041LL$ SAND is the percent of SAND
		$k_3 = -5.334 + 0.000316DEN^3 + 9.686MC - 0.054PI + 0.046LL + 0.022P200$
Indiana DOT (Equation 3.10)	Fine-grained Soils	$Log(k_1) = 6.660876 - 0.22136OMC - 0.04437MC - 0.92743MCR - 0.06133DEN + 10.64862COMP + 0.328465SATU - 0.04434SAND - 0.04349SLT - 0.01832CLY + 0.027832LL - 0.01665PI$ MCR represents the ratio of moisture content (MC) to optimum moisture content (OMC), COMP is the degree of compaction and SATU is the degree of saturation, SLT is the percent of silt, CLY is the percent of clay, and SW is the percent of swell value
		$k_2 = 3.952635 - 0.33897OMC + 0.076116MC - 2.45921MCR - 0.06462DEN + 6.012966COMP + 1.559769SATU + 0.020286SAND + 0.002321SLT + 0.011056CLY + 0.077436LL - 0.05367PI$
		$k_3 = 2.634084 + 0.12447OMC - 0.09277MC + 0.366778MCR - 0.01168DEN - 1.32637COMP + 1.297904SATU - 0.01226SAND - 0.00512SLT + 0.00492CLY - 0.05083LL + 0.018864PI$

CHAPTER FIVE - STRATEGY TO UTILIZE RECIPPE FOR QUALITY ASSURANCE

The methodology presented in this research provides a means of assessing construction consistency for a flexible pavement system. Thus far, the methodology and the algorithms were discussed and documented. Also, material model development, calibration and development were presented. To assist in utilizing RECIPPE, a strategy is provided in this chapter.

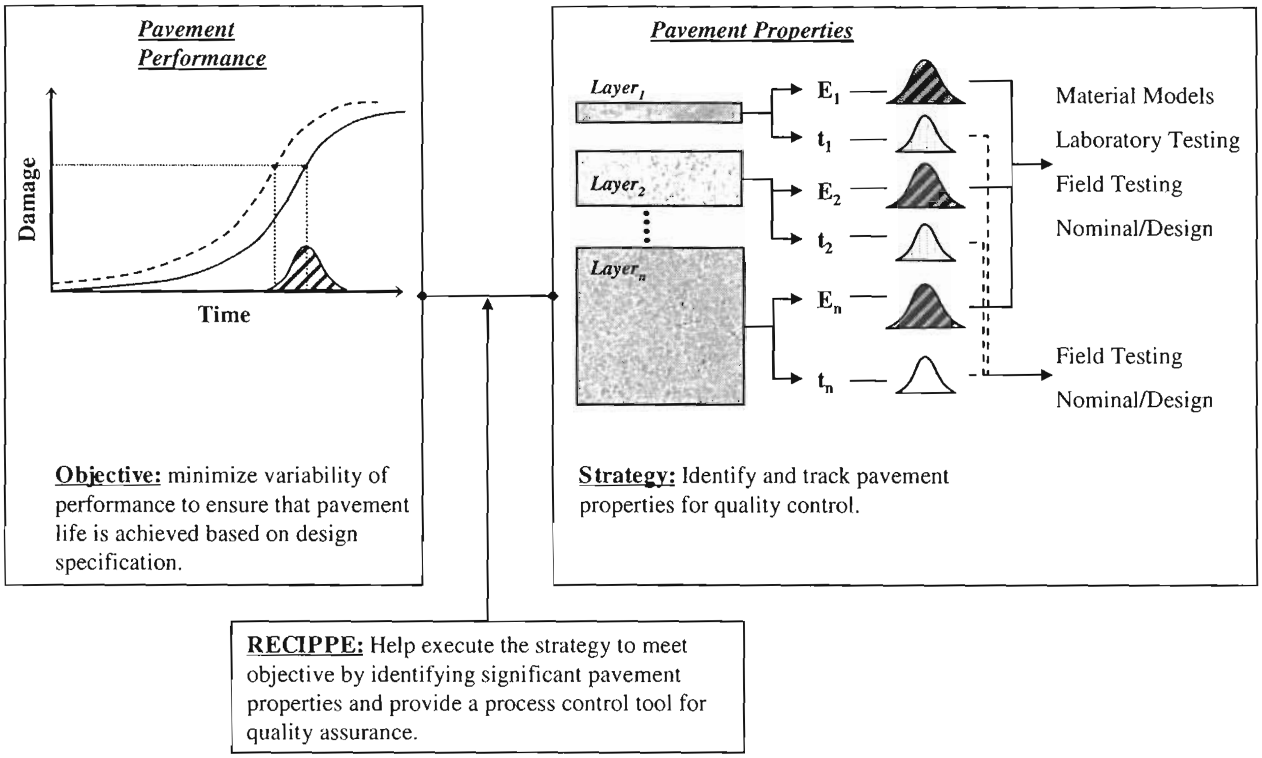
The main purpose of this research was developing a tool to ultimately optimize effectiveness of inspection and testing resources during construction given TxDOT limited resources by:

1. Estimating if variability of construction parameters meets the owner's expectations for a reasonably uniform pavement life.
2. Identifying the construction parameters to focus on during construction inspection, in order to reduce pavement life variance and increase reliability.
3. Tracking and identifying out of control procedures during construction.
4. Improving construction practices through process control.

Figure 5.1 outlines the overall purpose of RECIPPE. The first part of the figure shows a representation of pavement performance. As depicted in the figure, pavement performance can be specified based on level of damage with time. Therefore, for a certain specified time period, a pavement is designed to withstand a certain level of damage caused be traffic loading and environmental factors. However, due to inconsistencies in construction practices along the length of the pavement, the pavement quality varies from one section to the next, and as a result damage is accumulated faster than estimated in the inferior sections, and therefore, the life of the pavement is shortened.

The primary objective for this research was to develop a tool to minimize variability of performance to ensure that pavement life is achieved based on design specification (listed in the right side of Figure 5.1). To address this objective, the strategy was to develop a tool that can be used to identify and track pavement properties for quality control. In this case, pavement properties are the layer thickness and layer moduli. These parameters are the main components used in estimating the pavement performance. For each of these parameters, certain variability exists, and depending on the pavement system, these parameters can contribute differently to performance. This means that by identifying which of these parameters is found significant and by controlling the variability of those parameters, variability of performance can be managed.

To address this strategy and meet the objective, RECIPPE was developed to identify significant pavement properties and provide a process control tool for quality assurance.



Objective: minimize variability of performance to ensure that pavement life is achieved based on design specification.

Strategy: Identify and track pavement properties for quality control.

RECIPPE: Help execute the strategy to meet objective by identifying significant pavement properties and provide a process control tool for quality assurance.

Figure 5.1 - Process of using RECIPPE to Ensure Uniform Pavement by Monitoring Pavement Layer Information

In order to present different ways that RECIPPE can be utilized, it is beneficial to first summarize the different types and levels of input that can be incorporated into the program. Table 5.1 provides a summary of inputs categorized by levels according to the type of data used. In this table the input levels are divided into three categories for each of the pavement layer properties. Level 1 is designated for design values. This is data that is easily obtainable and requires neither field nor laboratory efforts. This type of input is best used when no other information is provided or to supplement the input to RECIPPE since pavement layer information for all layers is required to carryout the analysis. Level 2 and Level 3 inputs require field and laboratory measurements. Both these levels of input are necessary when a significant pavement property is identified. In most cases, Level 2 input indicate direct measurements of layer property and Level 3 input requires the use of material models that is based on construction parameters to estimate layer properties.

For the layer thickness, the ACP layer can be measured from cores and or Ground Penetrating Radar (GPR), and the base and subgrade layer can be measured form cores or Dynamic core penetrometer (DCP). For the ACP modulus the information can be provided based on V-meter test using cores and or PSPA field measurements (Level 2) and material model such as those presented in Table 4.2. Finally, the base and subgrade modulus can be measured using devices such as the Dirt Seismic Pavement Analyzer (DSPA) or an equivalent system in the field and or laboratory testing such as resilient modulus with in-situ material from the field (Level 2). The DSPA is one tool that can be used for quality control to measure the elastic moduli of base and subgrade layers. For Level 3 input, material models, such as those presented in Figures 4.3 through 4.5, can be used for estimating the layer moduli.

Table 5.1 - Input Levels for Estimating Pavement Layer Properties

Material Property	Input	Type of Data	Methods
ACP Thickness	Level 1	Design	Nominal
	Level 2	Measured	Cores
	Level 3		GPR
Base and Subgrade Thickness	Level 1	Design	Nominal
	Level 2	Measured	Cores
	Level 3		DCP
ACP Modulus	Level 1	Design	Nominal
	Level 2	Measured	Cores (V-Meter)
			PSPA
	Level 3	Material Model	Construction parameters such as Gradation and volumetric information
Base and Subgrade Modulus	Level 1	Design	Nominal
	Level 2	Measured	DSPA
		Material Model	DSPA and assumed material parameters
		Measured & Material Model	DPSA & Resilient Modulus
	Level 3	Material Model	Construction parameters such as Gradation and volumetric information

RECIPPE is separated into two phases: pre-construction and post construction. Figure 5.2 is a flowchart of the progression of utilizing different levels of inputs in RECIPPE. For the pre-construction phase, a dry-run can be initially carried out based on Level 1 input. Level 1 input is based on the pavement system design values with their associated variability, which can be assumed base on experience and or historical information. Based on results of the dry-run, significant pavement parameters can be identified. This allows users to decide on the input levels to use when stating the analysis is pre-construction mode. Level 1 inputs can be used for the parameters not found significant. The inputs for the more significant parameters can be measured based on the Levels 2 and 3 protocols. Once the levels of inputs are defined, RECIPPE can be processed in pre-construction mode followed by post-construction mode.

In the post-construction phase, the parameters that are identified as significant are used to determine a set of sampling frequencies for inspectors to use in control charts to ensure quality of the construction process in an optimized manner.

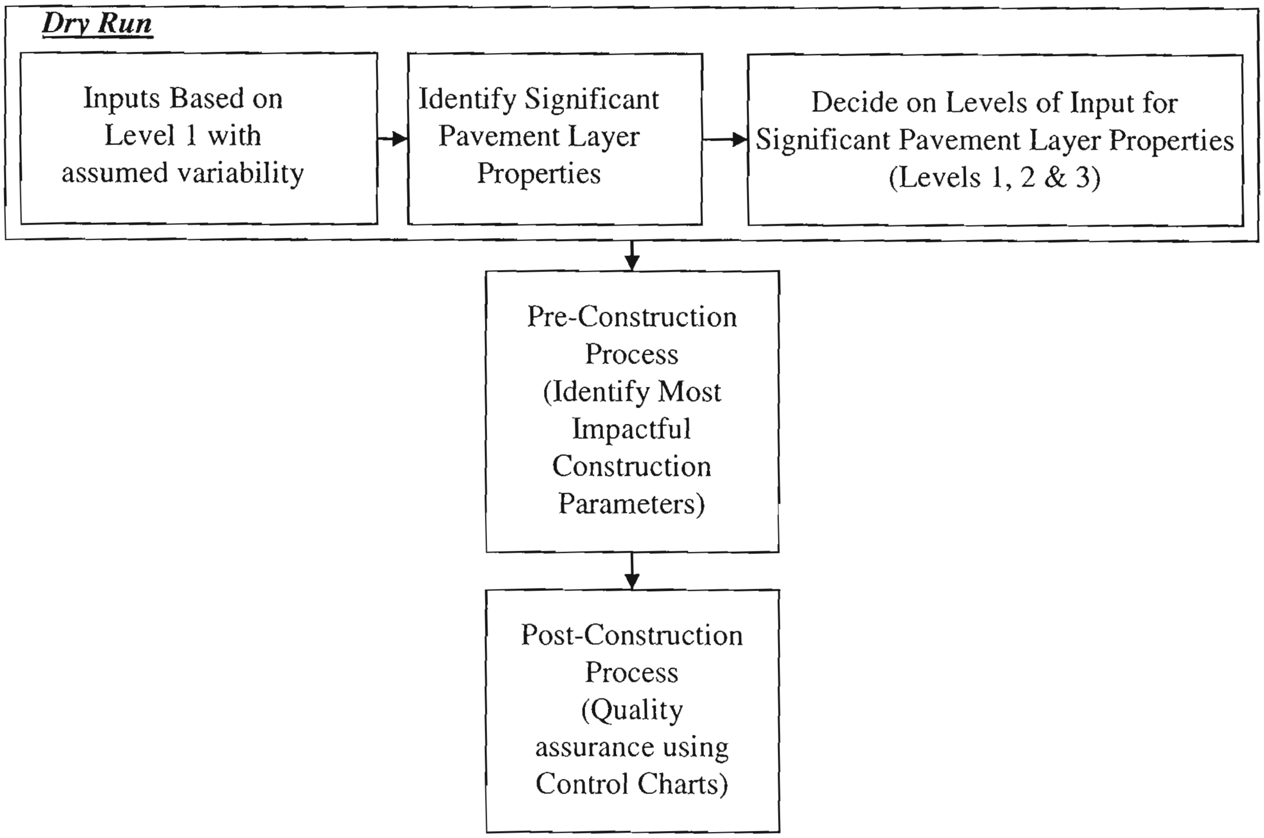


Figure 5.2 - Flowchart of RECIPPE to Ensuring Uniform Pavement Construction

Three general scenarios are presented to illustrate how RECIPPE can be used at different stages and with different levels of input. Table 5.2 presents a general scenario for a pavement where the subgrade layer properties were identified as significant. The information in the table presents the levels of input for the layer moduli. For this scenario, the input to the RECIPPE for the top layers can be provided as Level 1 input. However, the input for the subgrade layer moduli can be provided either based on Level 2 input or Level 3 input. Based on Table 5.2, Level 2 input could be a direct field measurement using a device such as the DSPA. This would measure the elastic modulus of the layer and thereby uses the linear elastic algorithm in the program for the subgrade layer. The other Level 2 option is to combine the field measurements from DSPA with laboratory tests such as the resilient modulus test that is used for determining the k-parameters of the nonlinear model. The modulus from the DSPA can be used to calculated k_1 and the results of the resilient modulus for k_2 and k_3 parameters. This allows the constitutive model listed in Table 5.2 as the material model for the analysis. The last input level is Level 3, which requires the use of constitutive models that uses regression equations to estimate the k-parameters. These regression equations are functions of construction parameters. Chapter 3 provides a list of regression equations from various regions in the country that can be used to estimate the k-parameters. Also, Equations 4.12 through 4.14 developed under this project with a limited database can be used for Level input. At the present time, due to the lack of comprehensive models for Texas, it is not recommended to use Level 3 input.

Table 5.2 - Input Levels of Design Parameters for Subgrade Layer

Parameter	Input	Material Type	Methods
Thickness	Level 3	-	Cores
Modulus	Level 2	Linear Elastic $M_R = k_1 P_a \left[\frac{\Theta}{P_a}\right]^{k_2} \left[\frac{\sigma_d}{P_a}\right]^{k_3}$	DSPA used in the field for quality control to measure layer moduli directly
		Nonlinear based on Constitutive Model	- DSPA is used to Estimate k_1 - k_2, and k_3 are assume from literature based on material quality
			- DSPA is used to Estimate k_1 - Resilient Modulus performed in the laboratory on in-situ material to determine k_2, and k_3
	Level 3	Nonlinear based on Constitutive Model (same as equation in Level 2)	k_1, k_2, k_3 are estimated based on regression equations that are functions of construction parameters

Note: 1) ACP and Base layer information are based on design values.

The next scenario is for a pavement system where base layer properties were identified as significant. In this case, the input to RECIPPE for the top layer can be provided as Level 1 input, and input to the subgrade layer could be the results from scenario one represented as a mean and standard deviation. For the base layer moduli (significant parameter) information from either Level 2 input or Level 3 input can be used. The information in Table 4.3 presents the levels of input for both the layer thickness and the layer moduli. The two main properties for the base layer are the thickness and layer moduli. For the base layer thickness, the monitoring tool can either be to measure cores directly (Level 2) or DCP field testing (Level 3).

Based on Table 5.3, Level 2 input for the base layer moduli is similar to the Level 2 input for the subgrade layer. This can be a direct field measurement using DSPA (or an equivalent device) or a combined field measurements from DSPA and laboratory tests using the resilient modulus results. Also, Level 3 input is same as that presented in for Level 3 input of the subgrade layer, which is to use regression equations to estimate the k-parameters of the constitutive model.

The last scenario presented involves an analysis where ACP layer properties were identified as significant. Input levels for the top layer are summarized in Table 5.4. The thickness of the top layer can be monitored either by cores or GPR, which are designated as Levels 2 and 3, respectively. For the layer moduli Level 2 input, two options are presented: a) V-meter measurements of cores to estimate layer moduli directly and b) direct measurement of the modulus in the field using the PSPA or an equivalent system. For Level 3 input the material models listed in Table 4.2 can be selected to estimate the layer moduli based on construction parameters. The input for the lower layers in this scenario can be provided as Level 1 input. If any parameter of the lower layers was found significant, then the statistics from that analysis can be incorporated into this scenario.

Table 5.3 - Input Levels of Design Parameters for Base Layer

Parameter	Input	Material Type	Methods
Thickness	Level 2	$M_R = k_1 P_a \left[\frac{\Theta}{P_a}\right]^{k_2} \left[\frac{\sigma_d}{P_a}\right]^{k_3}$	Cores
	Level 3		DCP can be used to estimate thickness value
Modulus	Level 2	Linear Elastic	DSPA used in the field for quality control to measure layer moduli directly
		Nonlinear based on Constitutive Model	- DSPA is used to Estimate k_1 - k_2, and k_3 are assume from literature based on material quality
			- DSPA is used to Estimate k_1 - Resilient Modulus performed in the laboratory on in-situ material to determine k_2, and k_3
	Level 3	Nonlinear based on Constitutive Model (same as equation in Level 2)	k_1, k_2, k_3 are estimated based on regression equations that are functions of construction parameters

Note: 1) ACP layer information are based on design values.
2) Subgrade layer information is based on either design values or actual field data estimated in Scenario 1 from either level 2 or level 3 inputs.

As demonstrated from the three scenarios presented, RECIPPE can be used at different stages of a construction project and at different levels of input to monitor variability of construction. At this stage of the program, a combination of Level 1 and Level 2 inputs are recommended in the analysis until more elaborate material models can be developed and calibrated for Texas. However, Level 3 inputs provided in the program should be investigated further since for that level, construction parameters can be related directly to performance. A user's guide for RECIPPE is included in Appendix A. Also, a training web site located at http://ctis.utep.edu makes available training modules for the program.

Table 5.4 - Input Levels of Design Parameters for ACP Layer

Parameter	Input	Material Type	Methods
Thickness	Level 2	-	Cores
	Level 3		GPR
Modulus	Level 2	Linear Visco-elastic	V-Meter to measure layer elastic moduli directly from cores Lab testing to determine the viscous properties of the material
			PSPA used in the field for quality control to measure layer moduli directly Lab testing to determine the representative viscous properties of the material
	Level 3	Linear Visco-elastic (Material Model such as regression equations based on Master Curve)	Construction parameters such as Gradation and volumetric information

Note: **1) Base and subgrade layer information is based on either design values, level 1input, or actual field data estimated in Scenarios 1 and 2 from either level 2 or level 3 input.**

CHAPTER SIX - SUMMARY AND CONCLUSION

SUMMARY

The goal of this project was to develop a rational algorithm that can be used in practice for the quality control of construction of pavements. As such, a method was developed, which for a given project, will guide TxDOT personnel to determine what parameters would significantly impact the performance, what parameters will moderately impact and those that are of small importance. The level of acceptable deviations from the target design value for each parameter is established based on quantification of the variability of the construction parameters introduced by: (a) the construction processes, (b) the material properties, (c) the models used to predict pavement performance and those used for data analysis, and (d) the resolution of the procedures used in the field for quality control.

The software developed utilizing the algorithm is called Rational Estimation of Construction Impact on Pavement Performance (RECIPPE). It can be used to reconcile the results from pavement-performance models used in the state of practice, or those widely accepted by state agencies, with statistical process control techniques and uncertainty analysis methods, to determine project-specific parameters that should be used in construction quality management.

This is the fourth report in this project. The first report introduced the algorithm and the link between the construction processes and performance parameters. The second report provided a limited validation of the methodology. The third report focused on presenting the enhanced features of the program RECIPPE and the calibration and development of the material models. This report discusses the final phase of the project. The validation of the models is presented and the application of RECIPPE based on different input levels is discussed.

CONCLUSIONS

RECIPPE presents a process that can be used in a practical manner to optimize pavement performance. Furthermore, the latest version of the process is versatile and avails complete modularity, which allows for new material and performance models to be inputted and/or calibrated as needed. Even though a limited number of sites were used to develop calibrated material models the results from RECIPPE and the methodology presented in this study is a step towards a more rational estimation of pavement remaining life from construction parameters.

The current RECIPPE program can be used to:

- Generate constructions parameter values that will meet owner's needs for pavement life
- Identify the construction parameters to focus on, in order to reduce pavement life variance and increase reliability
- Track and identify out of control procedures during construction
- Reduce sampling costs by optimizing the frequency of testing
- Create databases that can be used in future projects
- Lower variability of construction practices
- Perform quality control and/or quality assurance of construction practices
- Focus manpower on specific parameters and reduce costs

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