



Local Road Material Properties and Calibration for MnPAVE Summary Report

Minnesota
Department of
Transportation

**RESEARCH
SERVICES**

Office of
Policy Analysis,
Research &
Innovation

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Materials & Road Research

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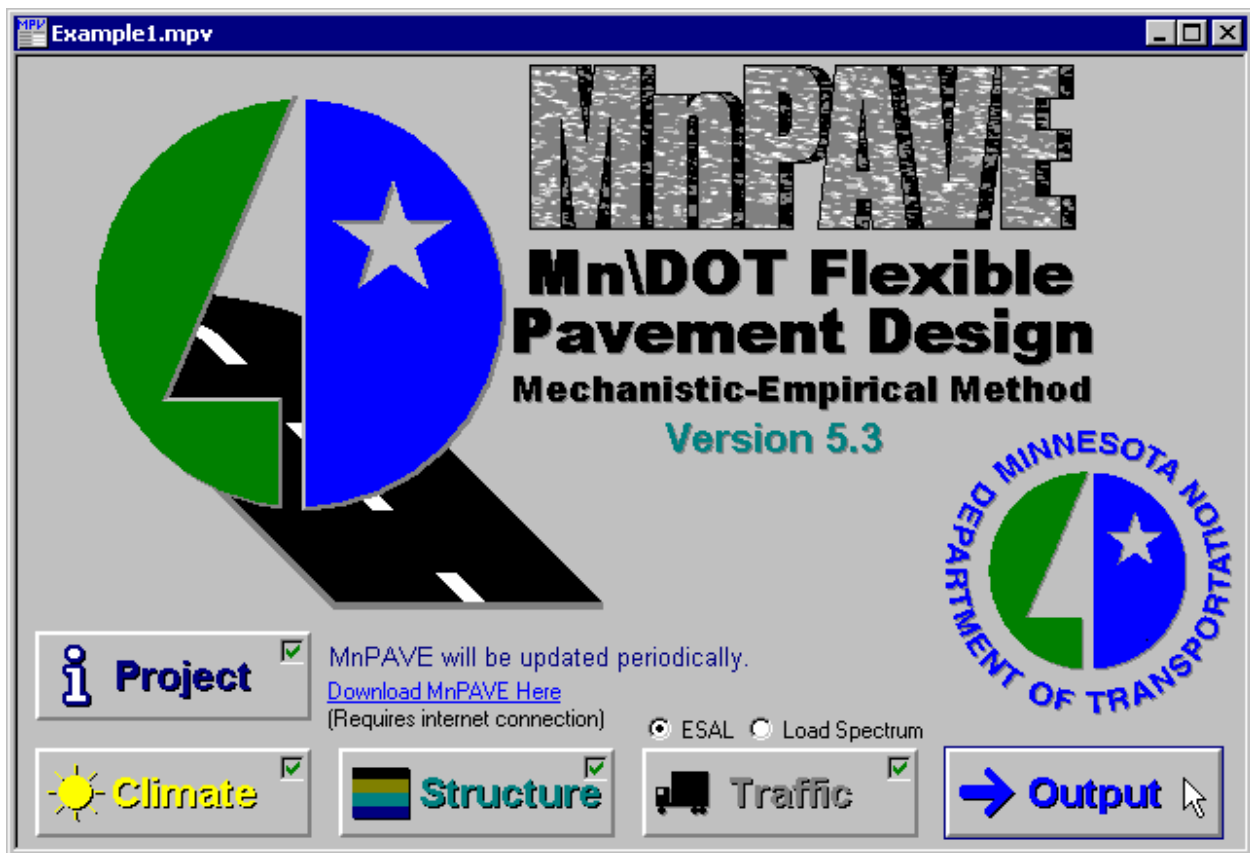


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Technical Report Documentation Page

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16. Abstract (Limit: 250 words) Minnesota's M-E design program began as a Mn/DOT-funded research project at the University of Minnesota in the mid 1990's. The outcome of that research was a computer program called ROADENT. In 2000, Mn/DOT expanded the ROADENT software into a new design program called MnPAVE. This software was calibrated using existing R-Value and Soil Factor designs, and validated using MnROAD test sections. A statewide MnPAVE training program was conducted in 2002. The current project was funded by the Local Road Research Board to determine material properties and model calibrations for use on local road designs.			
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MnPAVE User's Guide

May 2008

Minnesota Department of Transportation

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Introduction

MnPAVE is a computer program that combines known empirical relationships with a representation of the physics and mechanics behind flexible pavement behavior. The mechanistic portions of the program rely on finding the tensile strain at the bottom of the asphalt layer, the compressive strain at the top of the subgrade, and the maximum principal stress in the middle of the aggregate base layer.

MnPAVE consists of three input modules: Climate, Structure, and Traffic; and three design levels: Basic, Intermediate, and Advanced. The level is selected based on the amount and quality of information known about the material properties and traffic data. In the basic mode, only a general knowledge of the materials and traffic data are required. The intermediate level corresponds to the amount of data currently required for Mn/DOT projects. The advanced level requires the determination of modulus values for all materials over the expected operating range of moisture and temperature.

MnPAVE simulates traffic loads on a pavement using a Layered Elastic Analysis (LEA) called WESLEA. It is a five-layer isotropic system program written in 1987 by Frans Van Cauwelaert at the Catholic Superior Industrial Institute Department of Civil Engineering in Belgium and modified in 1989 by Don R. Alexander at the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi. All layers are assumed to be isotropic in all directions and infinite in the horizontal direction. The fifth layer is assumed to be semi-infinite in the vertical direction. Material inputs include layer thickness, modulus, Poisson's ratio, and an index indicating the degree of slip between layers. MnPAVE assumes zero slip at all layer interfaces. Other inputs include load and evaluation locations. Loads are characterized by pressure and radius. The LEA program calculates normal and shear stress, normal strain, and displacement at specified locations.

MnPAVE output includes the expected life of the pavement, the damage factor based on Miner's Hypothesis. Reliability has been incorporated into the latest version. There is also a batch section for testing a range of layer thicknesses. In Research Mode (accessible from the "View" menu in the main MnPAVE window), output includes various pavement responses for each season.

Units


The default system of engineering units is English, however the system of units can be changed in any of the main modules. System International (SI) or English units may be selected.

English		SI
Length		
1 in	=	25.4 mm
1 ft	=	0.3048 m
1 mi	=	1.609344 km

Weight		
1 lb	=	4.448222 N
1 kip	=	1000 lbs
1 kip	=	4.448222 kN

Pressure (Modulus)		
1 psi	=	6.894757 kPa
(pounds per square inch)		
1 ksi = 1000 psi	=	6.894757 MPa

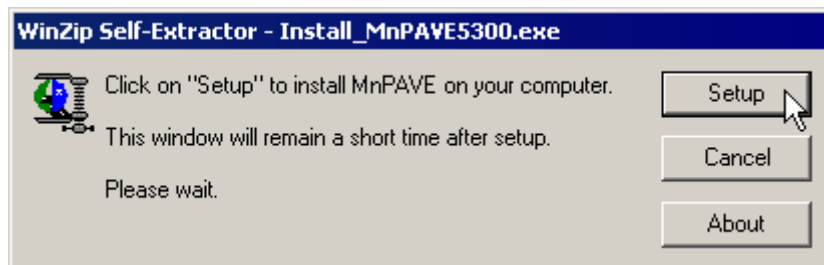
Installing MnPAVE

The installation file,  Install_MnPAVE5300.exe can be downloaded from the MnPAVE web site: <http://www.dot.state.mn.us/app/mnpave> . Double click on and follow the instructions in the following installation windows:

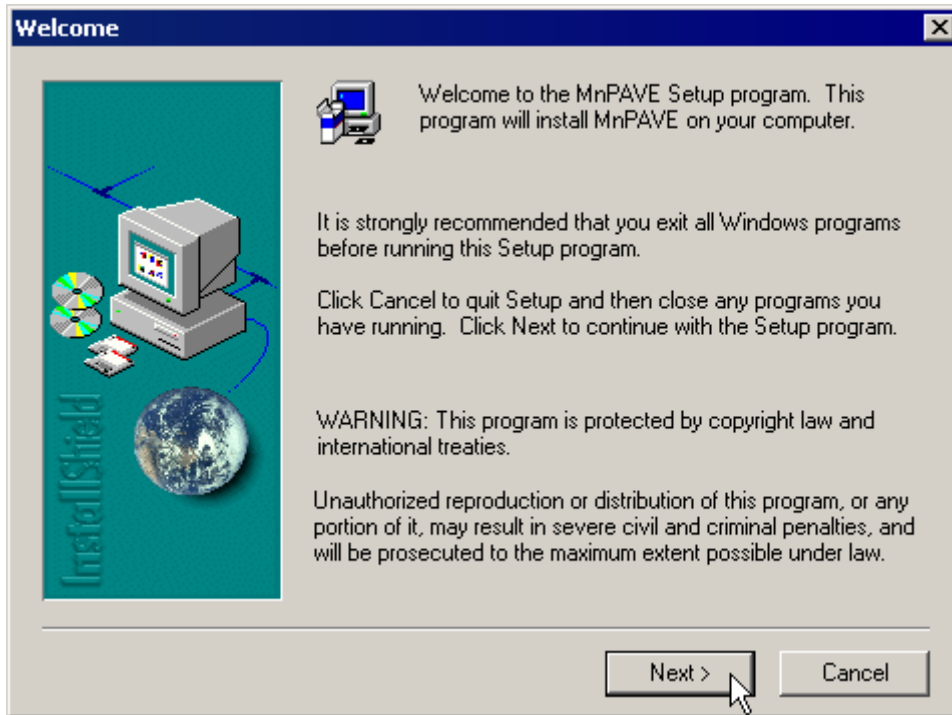
1. The first Install window contains version and contact information.



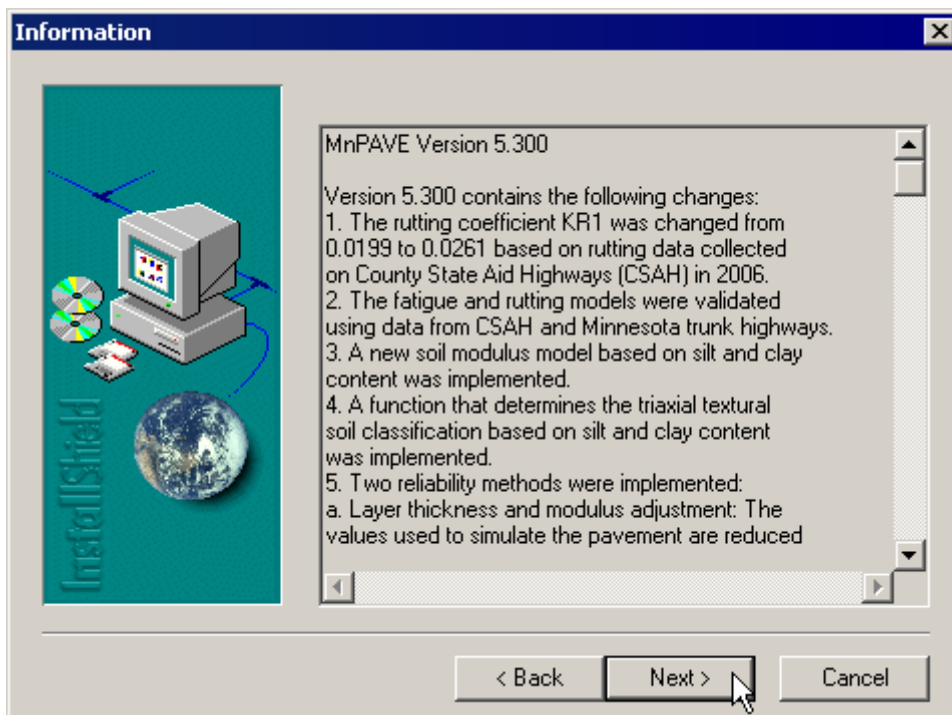
2. Clicking "Setup" in the Winzip Self-Extractor window initiates the installation process.



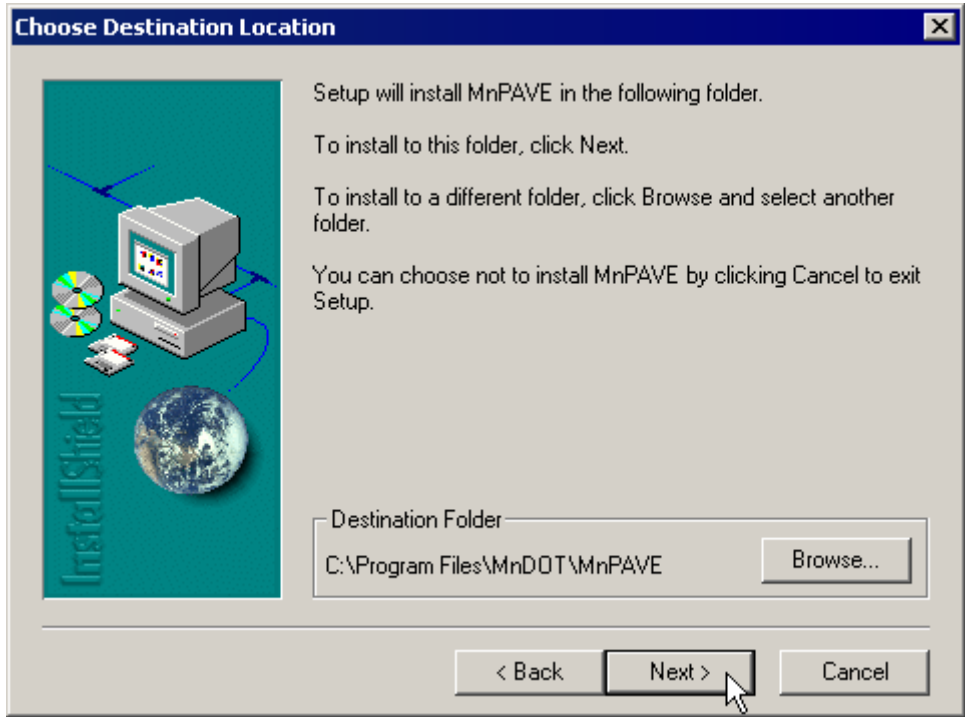
3. The Welcome window contains brief setup instructions.




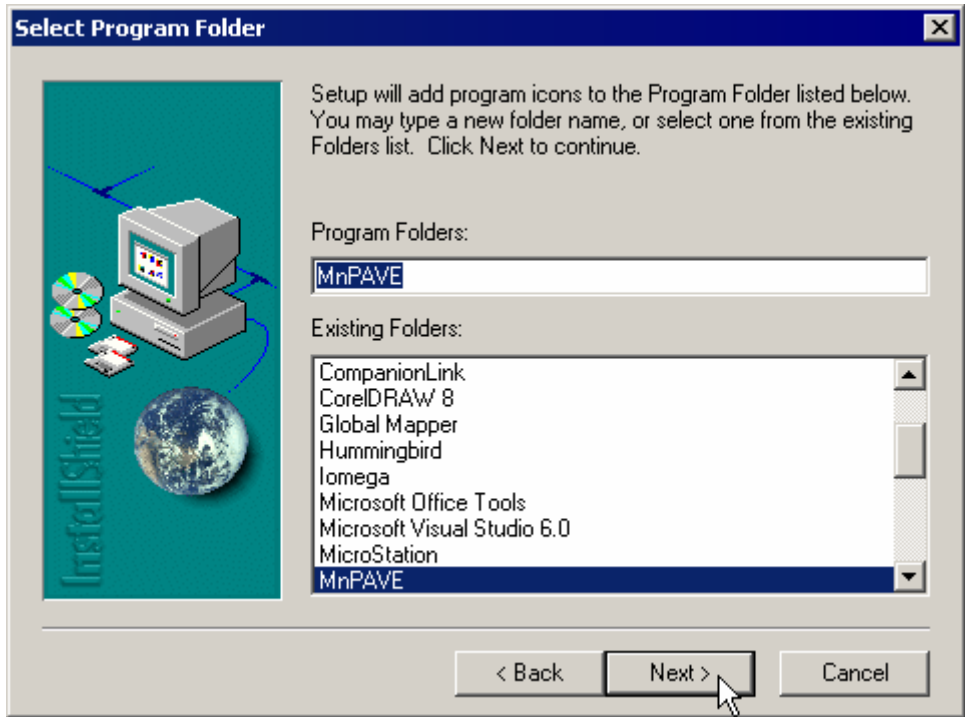
4. Update information is included in this window. This information can also be viewed at <http://www.dot.state.mn.us/app/mnpave/history.html> .



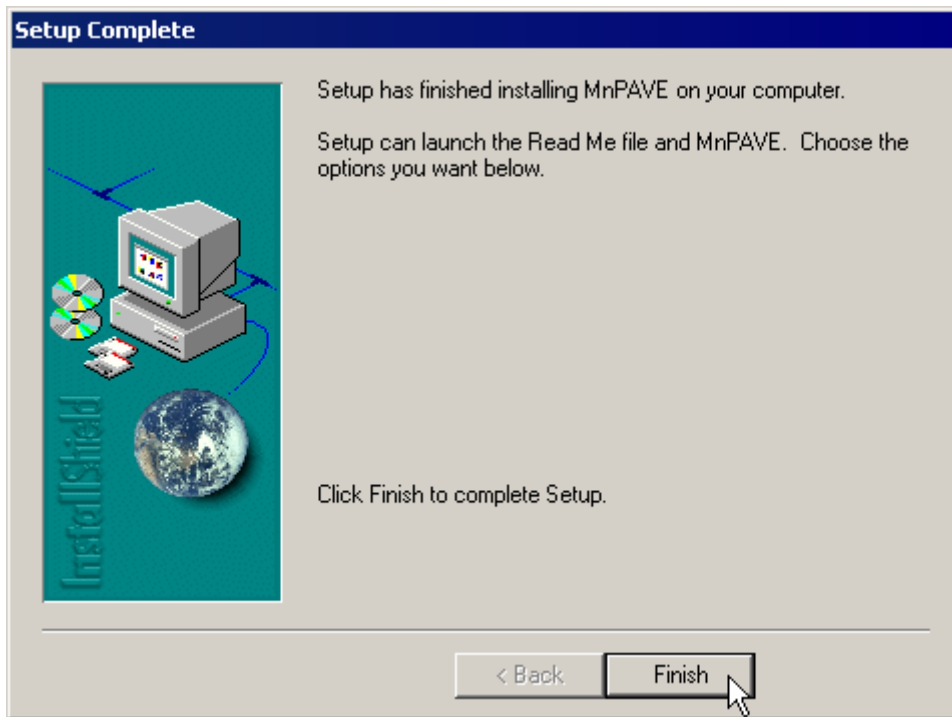
5. The executable MnPAVE.exe and Help files will be placed in Program Files\MnDOT\MnPAVE unless a different location is specified.




6. A MnPAVE folder will be added to the Windows  Menu, unless a different folder is specified.





7. Finish

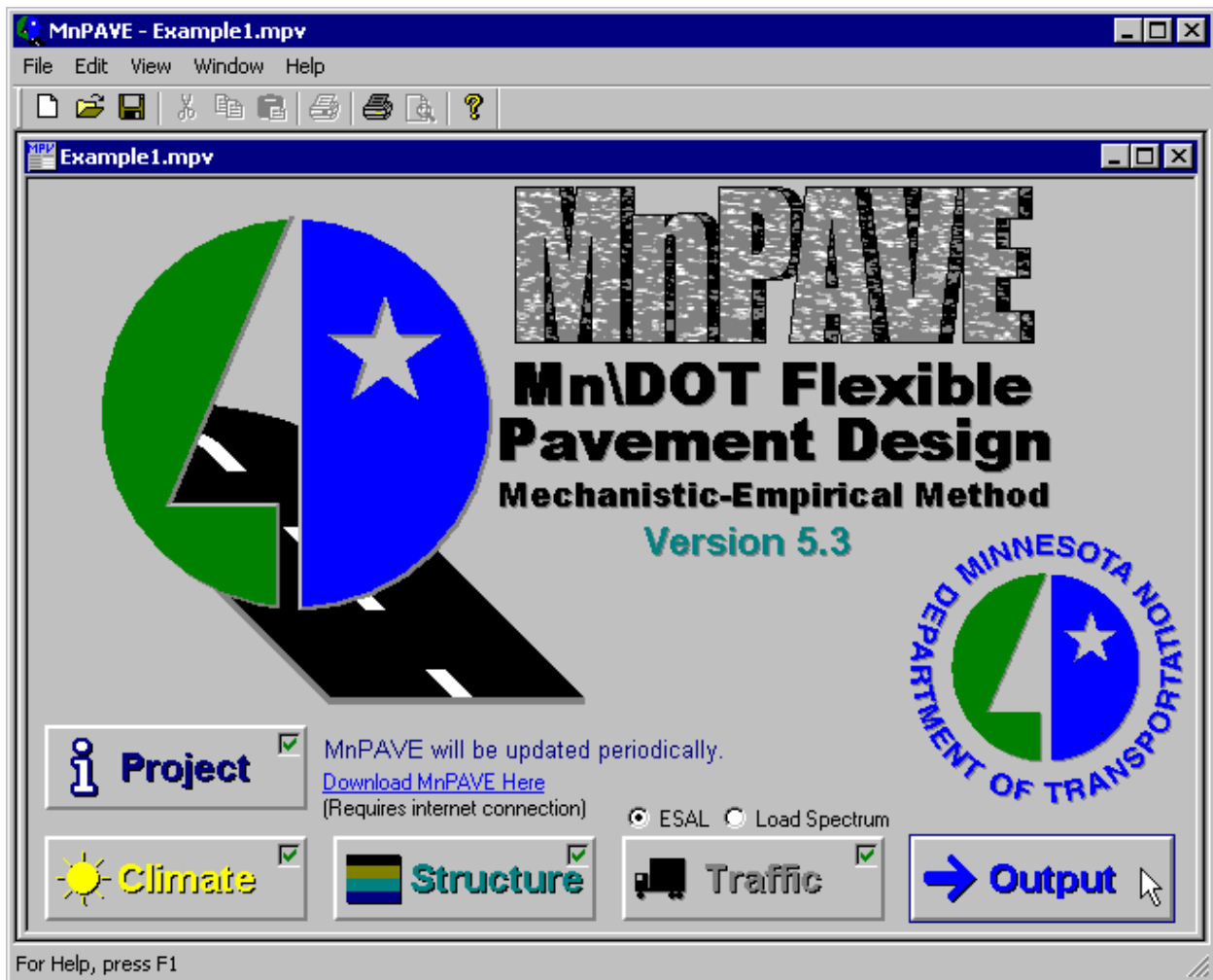



At this point there will be a MnPAVE icon  on the desktop and in the Windows  menu under the folder name specified in Step 6.


Starting MnPAVE


The program can be started by double-clicking on the MnPAVE icon  on the desktop or selecting MnPAVE from the Windows  menu under the folder name specified in Step 6 of **Installing MnPAVE**.

At this point, the Main Control Panel is visible:



A new MnPAVE file can be opened by clicking on the  icon or by selecting "New" from the "File" menu..

An existing MnPAVE file can be opened by clicking on the  icon or by selecting "Open" from the file menu. A recently saved file can also be selected from the list at the bottom of the "File" menu.

Changes to the current file can be saved by clicking on the  or by selecting "Save" from the "File" menu. Changes can be saved as a new file name by selecting "Save As" from the "File" menu.

Project Information

Project information is a form for entering information necessary to identify a MnPAVE project. Mn/DOT District, county, city, highway, construction type, design engineer and project notes are entered in this module.

The screenshot shows a web browser window titled "Example1.mpv" displaying a form titled "Project Information". The form contains the following fields and controls:

- District:** A dropdown menu with the value "3".
- County:** A dropdown menu with the value "Crow Wing".
- City:** An empty text input field.
- View:** A group box containing two radio buttons: "All Counties" (unselected) and "By District" (selected).
- Project No.:** A text input field with the value "100".
- Highway Number:** A text input field with the value "CR131".
- Reference Post (RP) from:** A text input field with the value "0.00".
- to:** A text input field with the value "2.00".
- Letting Date:** A dropdown menu with the value "2/12/2009".
- Construction Type:** A text input field with the value "2360".
- Designer:** A text input field with the value "MnPAVE".
- Soils Engineer:** A text input field with the value "MnPAVE".
- Notes:** A large, empty text area with a vertical scrollbar.
- Buttons:** A "Go Back to Control Panel" button and a blue hyperlink "View Mn/DOT Bituminous Specifications (Requires internet connection)".

Climate

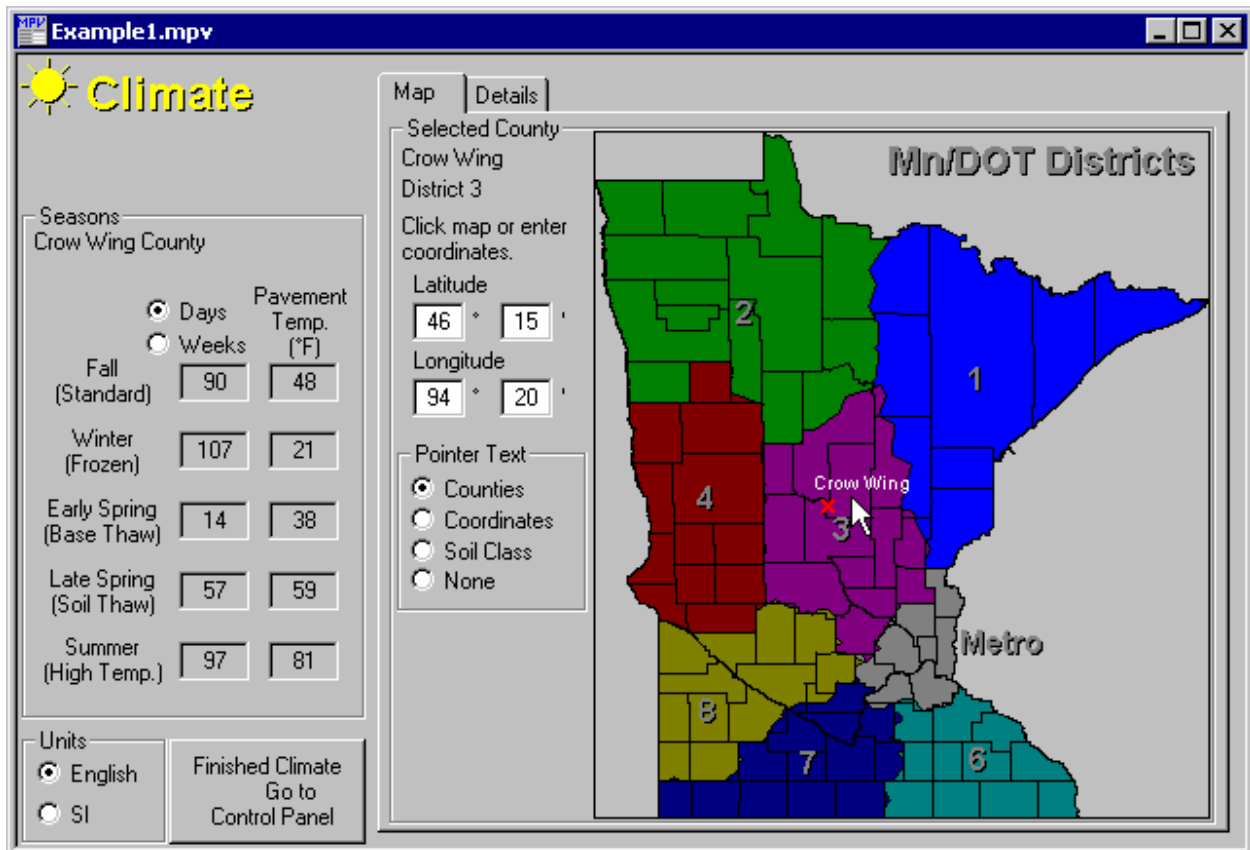
Climate contains a map of Minnesota where more specific location data can be entered. MnPAVE calculates season lengths and temperatures for each location using data from surrounding weather stations.

MnPAVE has five default seasons based on material properties measured at the Mn/ROAD research site throughout the year. Spring is divided into two seasons because of the drastic changes in aggregate base and subgrade soil properties during the Spring thaw period.

MnPAVE calculates the average pavement temperature for each season based on data from surrounding weather stations. Details of this calculation can be viewed in the Details window.

The county and district can be selected from menus in the Project Information window. Clicking on the map will also select them. The season lengths and average seasonal temperatures are shown in the left portion of the Climate window.


As the pointer moves over the map, the current district, county, and coordinates under the pointer are displayed to the left under Pointer Location. Click the left mouse button to select this location. The district and county can also be selected in Project Information.



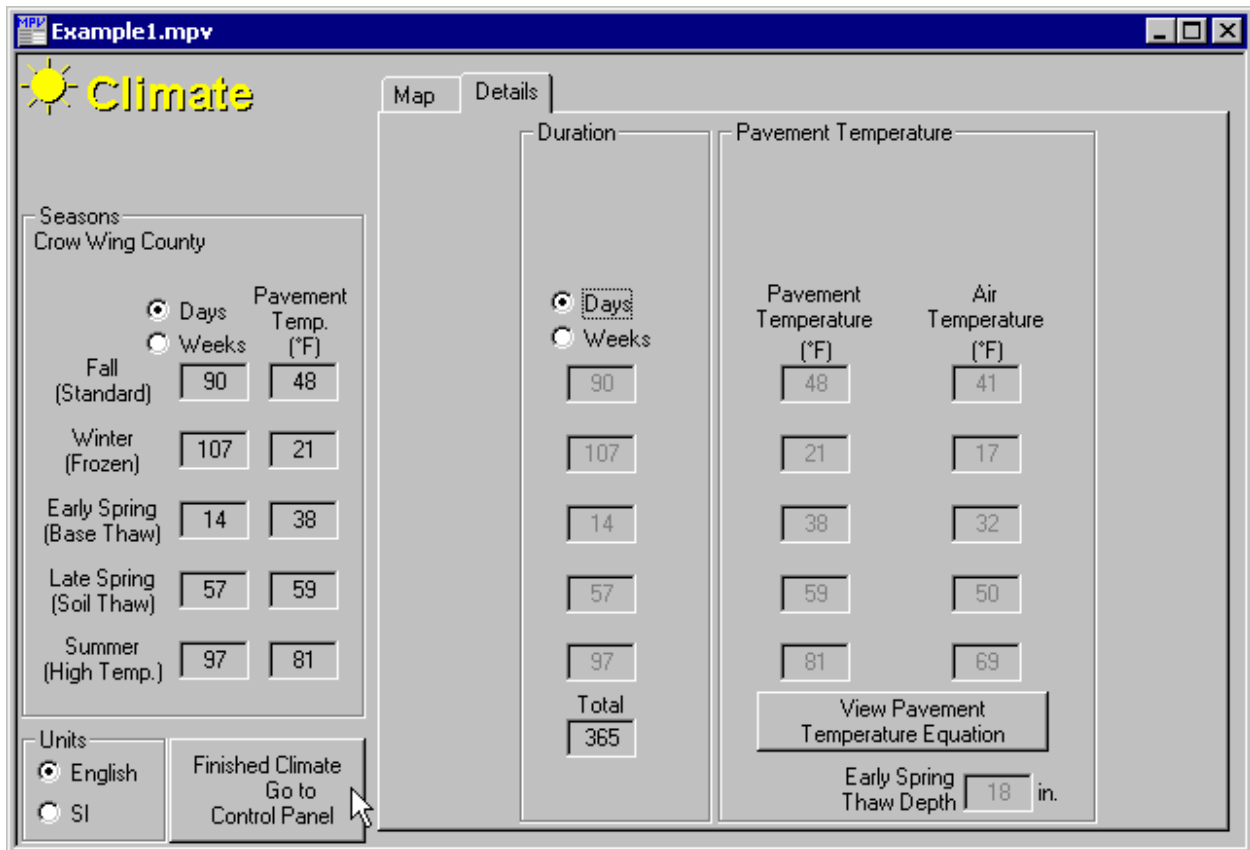
Climate Details

Seasonal air and pavement temperatures can be viewed in this window.

The air temperature at the selected location is based on a weighted average of data from 47 weather stations around Minnesota. Each seasonal air temperature value represents the average daily temperature for that season. The equation used to convert air temperature to pavement temperature can be seen by clicking the

 button.

Early Spring Thaw Depth is the assumed depth of the thawed/frozen interface during Early Spring. The thawed portion of the base and/or soil is assumed to have a high moisture content and low modulus. The sea



Climate

Example 1.mpv

Map Details

Seasons
Crow Wing County

Season	Duration	Pavement Temp. (°F)	Air Temperature (°F)
Fall (Standard)	90	48	41
Winter (Frozen)	107	21	17
Early Spring (Base Thaw)	14	38	32
Late Spring (Soil Thaw)	57	59	50
Summer (High Temp.)	97	81	69
Total	365		

View Pavement Temperature Equation

Early Spring Thaw Depth 18 in.

Units: English SI

Finished Climate Go to Control Panel

Structure

When Structure is opened for the first time in a project, the **HMA Mix Properties** Window opens to make sure all mix design information is entered correctly. Mix design information such as asphalt binder content and gradation are required to estimate the HMA dynamic modulus. Currently, the selection of a binder grade serves only to document the binders used in the design. Only PG 58-28 data was available for the current MnPAVE calibration, so all HMA layers will have PG 58-28 properties regardless of the binder type selected.

Up to three HMA types can be defined for layer 1. Since the LEA procedure only allows five layers, multiple HMA layers are combined into a single layer using the equivalent thickness method.

Click on the colored bar to select a default gradation based on a Mn/DOT specification. A custom gradation can be defined by entering numbers in the "Percent Passing" edit boxes.

The Advanced button next to each lift can be clicked to view more details about how HMA modulus is calculated.

The Structural Number (SN) is calculated using the method described in Section 2.3.5 of the 1993 AASHTO Guide for Design of Pavement Structures.

HMA Mix Properties

Print Window Help

Layer Expected traffic speed (mph) Note: Multiple HMA Lifts cannot be selected if there are multiple HMA layers. OK

Equivalent Thickness

HMA SN = 2.5

HMA Lift *	Binder Grade**	Thickness (in.)	Binder content (% by wt. of mix)	Mn/DOT Spec.	Nom. Max. Size	Percent Passing				Advanced
						3/4"	3/8"	#4	#200	
<input type="radio"/> 1	PG 58-34	4	5	2350	1/2"	100	62	50	5	Advanced
<input checked="" type="radio"/> 2	PG 58-28	2	5	2350	1/2"	100	62	50	5	Advanced
<input type="radio"/> 3										


* The term "Lift" is used here to differentiate between HMA layers with different mix designs or densities.
 ** In Standard Mode, binder grade is for documentation only. MnPAVE is calibrated for PG 58-28 properties only.

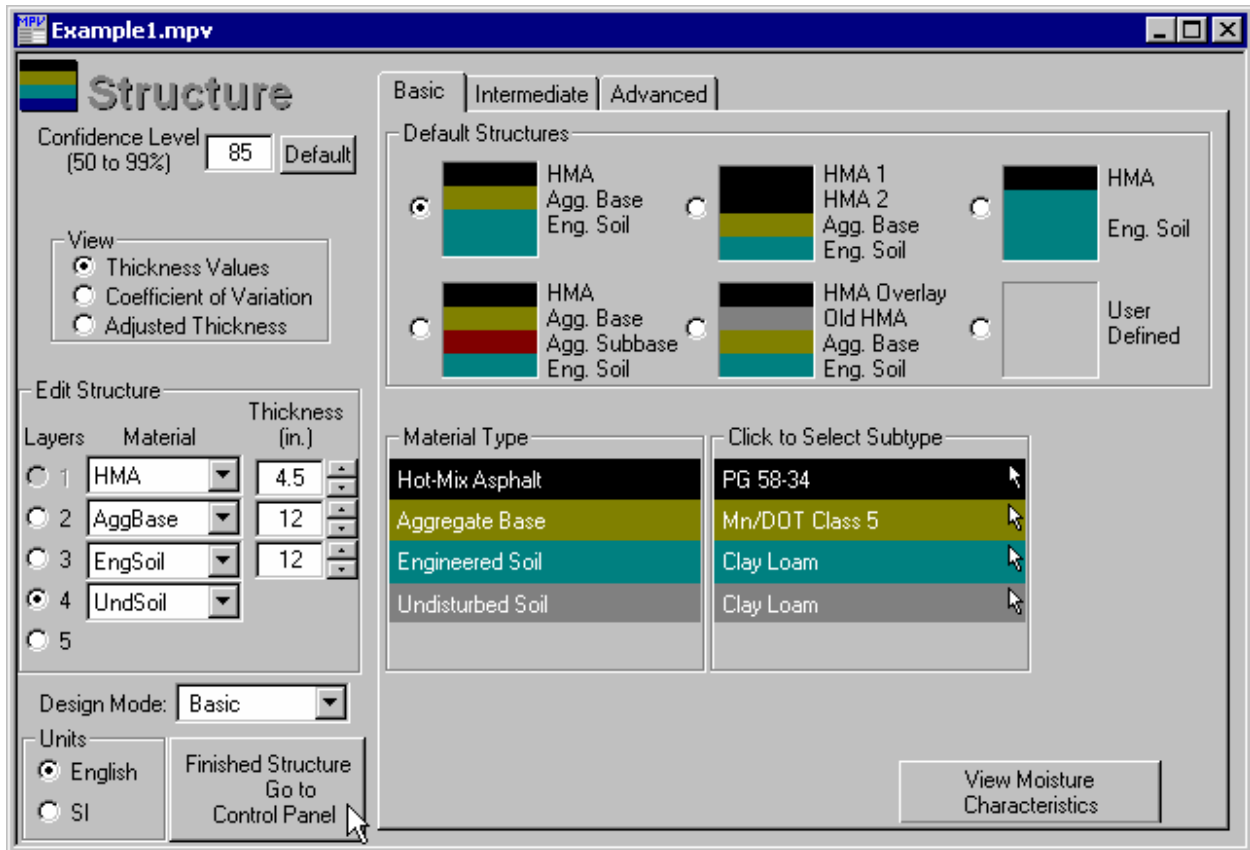
Basic Structure

Basic Structure is intended for low-volume roads or designs that don't require a high degree of reliability. MnPAVE uses default design modulus values. These modulus values are adjusted for seasonal variations in moisture and temperature.

Click on a layer button to select the number of layers in the pavement structure. The bottom layer is always semi-infinite. A MnPAVE pavement structure must have between two and five layers. Due to limitations in the LEA procedure, layer 5 cannot be analyzed for rutting. Therefore layers 2 through 4 must contain at least one engineered soil¹ or undisturbed soil² layer.

The **Default Structures** area provides shortcuts for several common pavement structures. Select the desired pavement structure, then adjust the layer thicknesses and material subtypes.

Material Types for each layer are selected on the left side of the Structure window under **Edit Structure**. Layers with a white pointer arrow  can be clicked to select a different subtype.



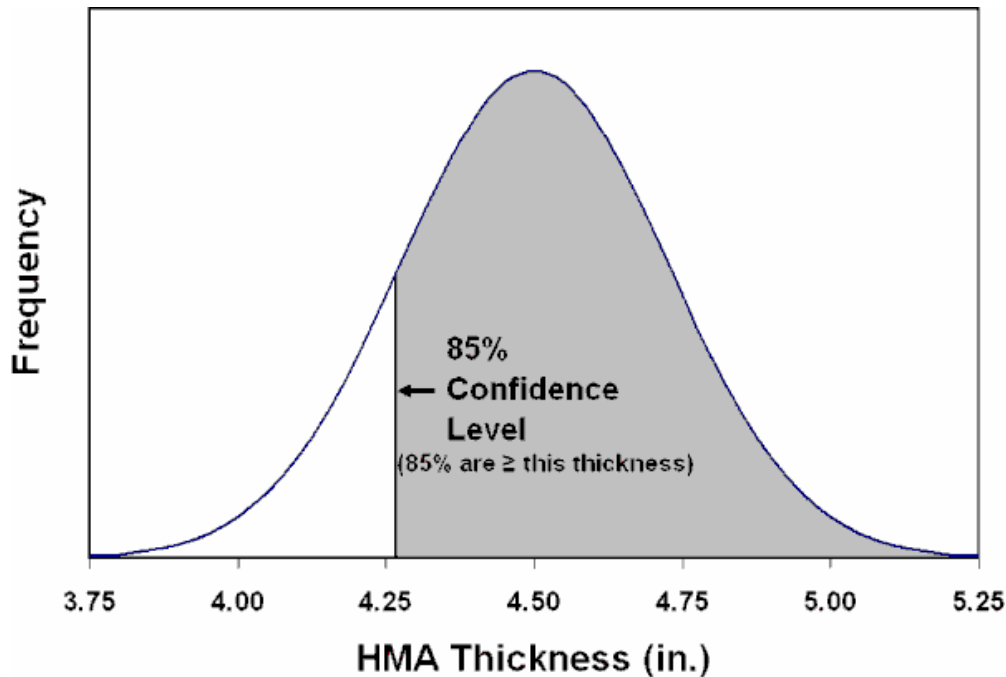
¹ Soil that has been blended and compacted prior to construction.

² Existing soil that has not been reworked. Because of uncertainty in the quality and uniformity of the material, the default undisturbed soil modulus is equal to half of the corresponding engineered soil modulus.

Confidence Level

Confidence Level (50 to 99%)

This value is used to adjust layer thickness and modulus values to assure that a proportion of the pavement area meets or exceeds the desired values, based on the coefficient of variation (COV). The higher the confidence level and COV the more the value is reduced. A confidence level of 50% results in no reduction (the mean value is used in the simulation). The Confidence Level differs from the reliability value calculated in the Output Monte Carlo simulation. The Confidence Level reduces the values for all layers and acts as a factor of safety to account for variability and uncertainty. A Monte Carlo simulation should be run on the final design to determine reliability. If the user intends to use Monte Carlo simulation to determine the final layer thicknesses, selecting a Confidence Level of 10 to 15% less than the desired reliability may be helpful.



Thickness Views

Thickness Values Displays the design thickness. If the Confidence Level is 50%, the design thickness will be used in the simulation. Higher confidence levels result in an adjusted thickness for the simulation.

Thickness Coefficient of Variation indicates the variability of the thickness value of each layer.

$$\text{COV (\%)} = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100$$

Adjusted Thickness Displays the reduced thickness used in the pavement simulation.

View

Thickness Values
 Coefficient of Variation
 Adjusted Thickness

Edit Structure

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	4.5
<input type="radio"/> 2	AggBase	12
<input type="radio"/> 3	EngSoil	12
<input checked="" type="radio"/> 4	UndSoil	
<input type="radio"/> 5		

View

Thickness Values
 Coefficient of Variation
 Adjusted Thickness

Edit Structure

Layers	Material	COV (%)
<input type="radio"/> 1	HMA	5
<input type="radio"/> 2	AggBase	8
<input type="radio"/> 3	EngSoil	15
<input checked="" type="radio"/> 4	UndSoil	
<input type="radio"/> 5		

View

Thickness Values
 Coefficient of Variation
 Adjusted Thickness

Edit Structure

Layers	Material	85% Conf. (in.)
<input type="radio"/> 1	HMA	4.27
<input type="radio"/> 2	AggBase	11
<input type="radio"/> 3	EngSoil	10.13
<input checked="" type="radio"/> 4	UndSoil	
<input type="radio"/> 5		

Intermediate Structure

Intermediate Structure has a form for entering test data for aggregate base and subgrade soils. These values are converted to design modulus and adjusted for seasonal variations. If no test has been performed on a given material, its box can be left unchecked to use default Basic material properties. Basic HMA data is used in this mode. A material subtype need not be selected if test data is entered. If the material subtype is known, it can be selected by clicking on the pointer arrow to the right of the edit box. If the material subtype is not known, select **Unknown** from the list. To view the calculated moduli, click on the **Advanced** tab.

The View selection allows the user to view test values, resistance factors, or COV. Resistance factors are multiplied by the modulus values of aggregate base and subgrade soil to adjust for seasonal moisture conditions.

If **Other** is selected in the **Edit Structure** area, material properties are edited in **Intermediate** or **Advanced Structure**. Design Modulus, Poisson's Ratio, and COV. must be entered.

The **Moisture Data** button shows a prototype unsaturated soil model that will be used in a future version of MnPAVE to provide more accurate seasonal material properties.

The **Mohr-Coulomb** button illustrates the method used to analyze shear stress in the base layer.

The screenshot shows the 'Structure' software window with the 'Intermediate' tab selected. The interface includes a 'View' section with radio buttons for 'Test Results', 'Resistance Factors', and 'Coefficient of Variation'. A 'View' sub-section has radio buttons for 'Thickness Values', 'Coefficient of Variation', and 'Adjusted Thickness'. The 'Edit Structure' section shows a table of layers with columns for 'Layers', 'Material', and 'Thickness (in.)'. The 'Design Mode' is set to 'Intermediate'. The 'Units' section has radio buttons for 'English' and 'SI'. The 'Finished Structure' button is highlighted. The main area displays material properties for 'PG 58-34' and 'CL'.

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	4.5
<input type="radio"/> 2	AggBase	12
<input type="radio"/> 3	EngSoil	12
<input checked="" type="radio"/> 4	UndSoil	
<input type="radio"/> 5		

Design Mode: Intermediate

Units: English SI

Finished Structure
Go to Control Panel

View: Test Results Resistance Factors Coefficient of Variation

View: Thickness Values Coefficient of Variation Adjusted Thickness

Check box to enter test data. Uncheck to use Basic defaults.

HMA Modulus

Agg. Test Type: Lab Mr, ksi R-Value DCP, mm/blow

Soil Test Type: Lab Mr, ksi R-Value DCP, mm/blow Silt % Clay %

Other: Design Modulus, ksi Poisson's Ratio

PG 58-34

70

44 23

CL

Moisture Data

Mohr-Coulomb

Advanced Structure

Advanced Structure requires the input of design modulus values for every layer and every layer.

Design Mode: Click on Basic, Intermediate, or Advanced to view the corresponding material properties below. Selecting Basic or Intermediate displays values calculated based on data from those modules. In Advanced mode, all material properties must be entered manually.

The screenshot shows the 'Structure' software window with the following details:

- Confidence Level:** 85 (50 to 99%)
- View:** Thickness Values (selected), Coefficient of Variation, Adjusted Thickness
- Edit Structure:**

Layers	Material	Thickness (in.)
1	HMA	4.5
2	AggBase	12
3	EngSoil	12
4	UndSoil	
5		
- Design Mode:** Advanced
- Parameter Shown Below:** Design Modulus, ksi (Adjusted) (selected), Poisson's Ratio, Seasonal Modulus Multipliers, Modulus Coefficient of Variation, %
- Structural Number:** 2.6
- Design Modulus Table:**

	Fall	Winter	Early Spring	Late Spring	Summer
1	1017	2789	1561	637.9	223.5
2	27	50	8.1	18.9	23
3	9.6	50	50	6.7	8.1
4	5.5	50	50	3.9	4.7
- Buttons:** Import HMA Moduli from Basic, Import Other Moduli from Basic

The design mode is displayed above the “Finished” button to confirm that the correct mode is selected. Any editing that is done in the Basic, Intermediate, or Advanced windows will change the mode. If any editing causes the wrong mode to be selected, this can be corrected prior to clicking on the “Finished” button.

Import Moduli

These buttons appear in the **Advanced Structure** window when **Advanced Mode** is selected. Basic default modulus values can be imported into Advanced Mode when custom values are not available for all layers and seasons.

Import HMA Moduli from Basic
Import Other Moduli from Basic

Structure Views

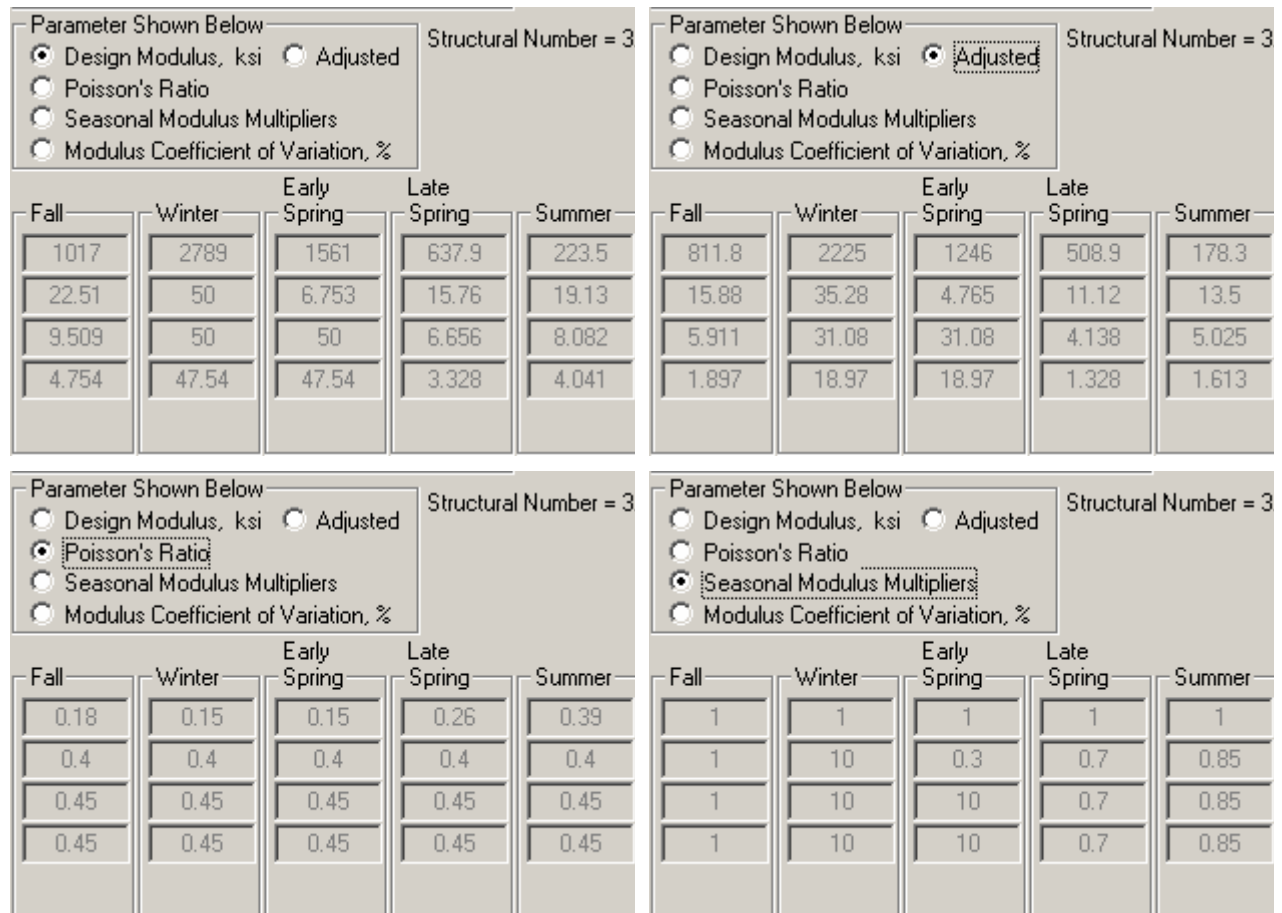
Structure views for all design levels can be viewed by clicking the **Advanced** tab.

Design Modulus displays design modulus values. For pavement simulations these values are adjusted according to the Confidence Level.

Adjusted Modulus indicates how values used in the pavement simulation are adjusted according to the Confidence Level.

Poisson's Ratio is a measure of a material's tendency to expand in the horizontal direction when it is compressed in the vertical direction. Poisson's Ratio is used in Layered Elastic Analysis (LEA) simulations.

Seasonal Modulus Multipliers displays seasonal multipliers for each aggregate base, subbase, and soil material (HMA moduli are calculated for each season). Multipliers indicate moisture susceptibility and the state of the material (frozen or thawed).



Modulus Coefficient of Variation (COV)

The default modulus data used in MnPAVE fits a lognormal distribution (log-transformed data fits a normal distribution). The COV of this data is calculated as follows:

$$COV = \sqrt{e^{\sigma^2} - 1} \times 100$$

Where

COV = Coefficient of Variation (%)

σ^2 = variance of log-transformed data

Parameter Shown Below

Design Modulus, ksi Adjusted

Poisson's Ratio

Seasonal Modulus Multipliers

Modulus Coefficient of Variation, %

Structural Number = 3.1

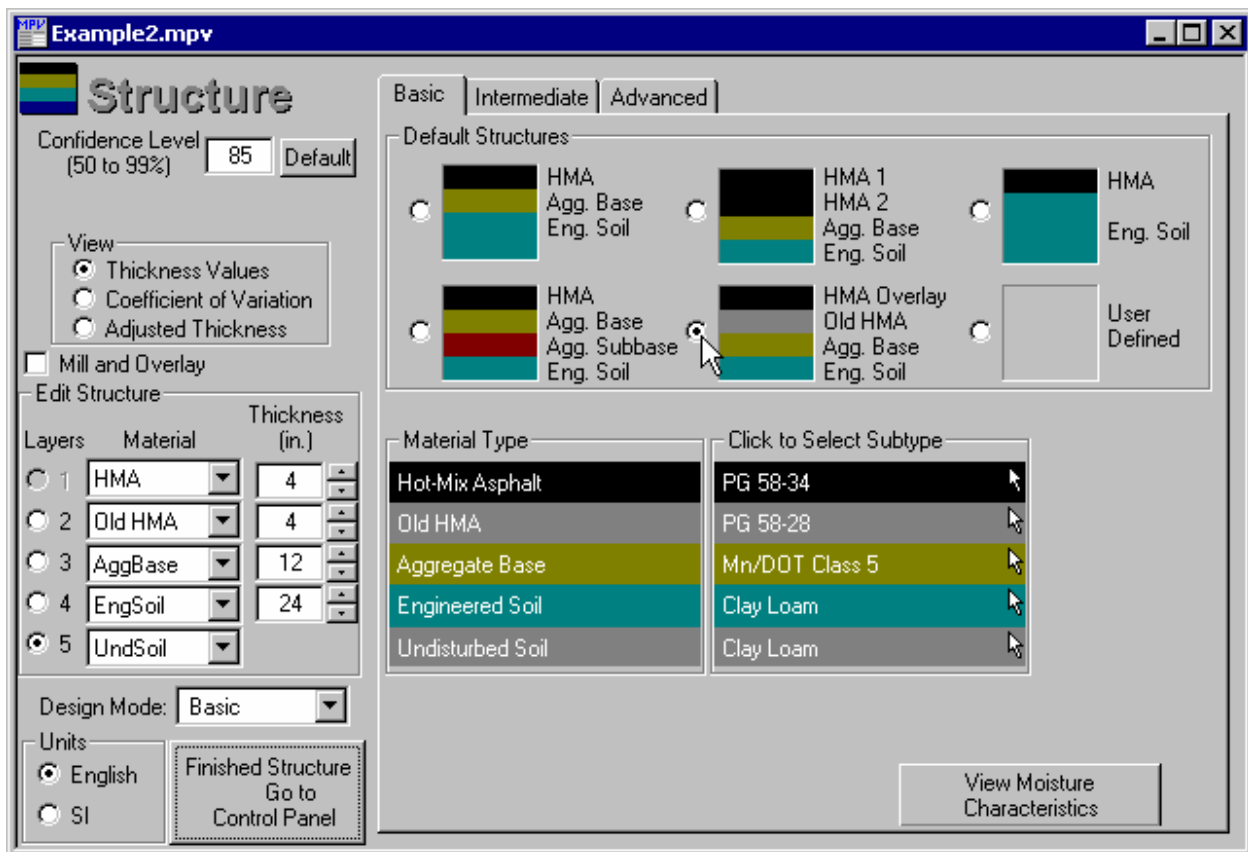
Fall	Winter	Early Spring	Late Spring	Summer	Distribution
20	20	20	20	20	Lognormal ▼
30	30	30	30	30	Lognormal ▼
40	40	40	40	40	Lognormal ▼
75	75	75	75	75	Lognormal ▼

Overlay Design

While a complete Mechanistic-Empirical overlay design method has not yet been developed for MnPAVE, overlays can be designed using the conventional fatigue and rutting criteria to check for structural capacity. In addition, FWD³ deflections and the TONN method can be used to determine the necessary overlay thickness to avoid the need for Spring load restrictions.

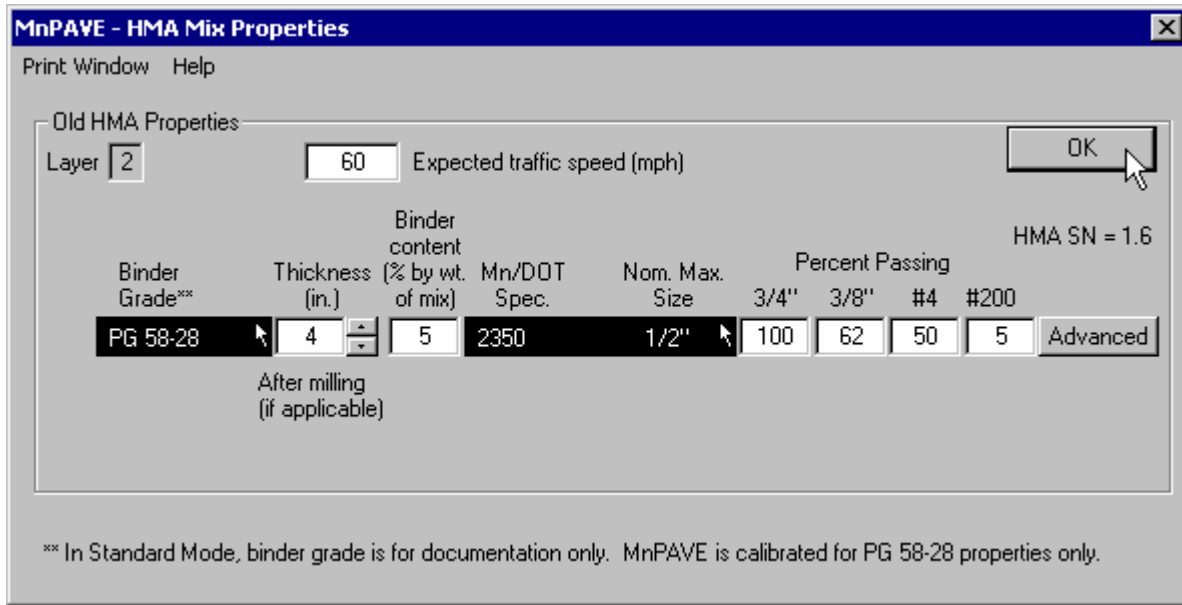
Basic Overlay Design Procedure

While MnPAVE can check for fatigue, rutting, and shear failure in the aggregate base, these are often not the primary factors in determining overlay thickness. When designing overlays in Basic mode, the designer must also rely on other overlay design methods and guidelines. Do Project Information and Climate, and then go to Structure.



Select the default overlay structure. If the old HMA properties for this layer have not yet been defined, the HMA Mix Properties window will open up.

³ Falling-Weight Deflectometer: A device that measures deflections that result from a weight dropped onto the pavement. These deflections can be used to determine the modulus of the pavement layers.



If the HMA Mix Properties window did not open, click on the gray Old HMA subtype bar. Select the binder grade of the old HMA and any other mix properties that are known and click OK.

Check the Mill and Overlay checkbox if applicable (the old HMA thickness should be the thickness after milling).

Define the HMA properties for the new (overlay) HMA.

Define the other pavement layers to the extent that their material types and thicknesses are known.

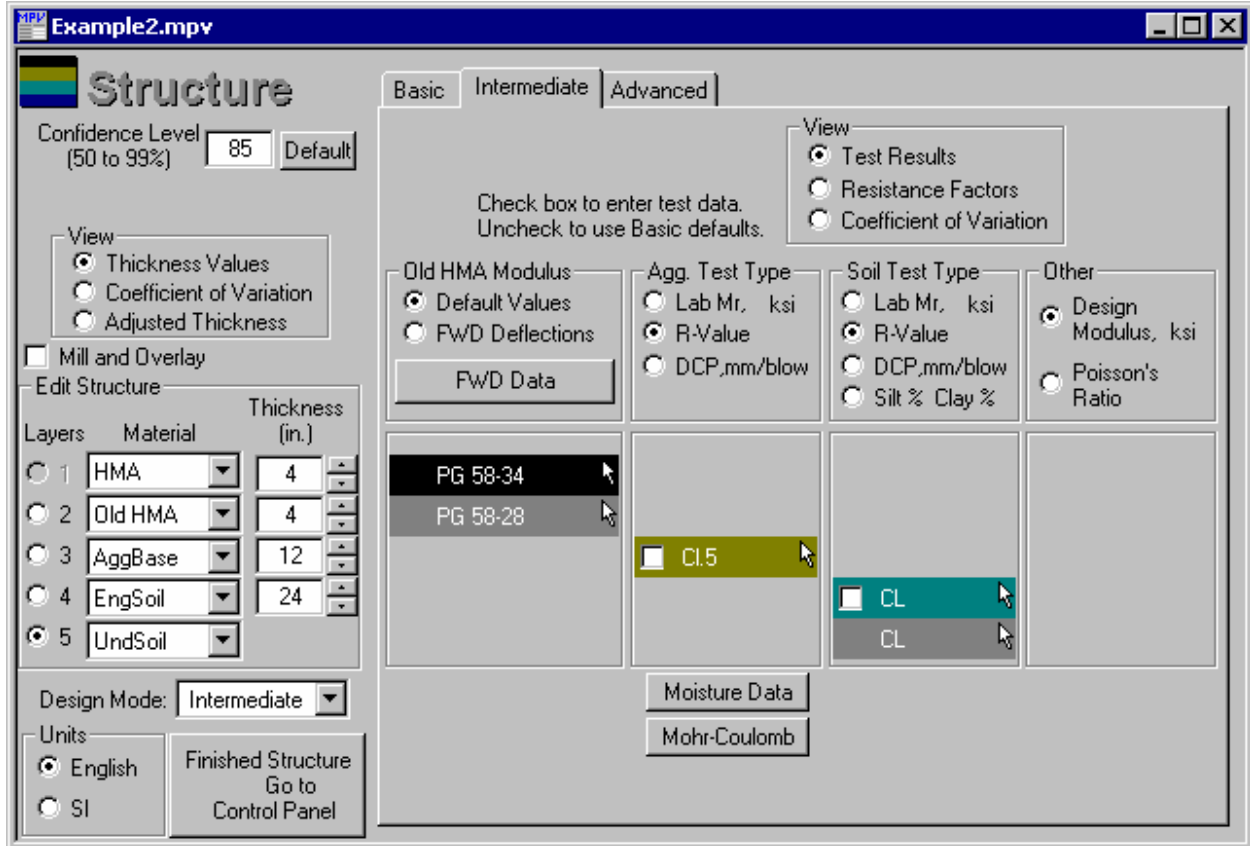
Continue to Traffic and Output.

If this is a Mill and Overlay project, HMA fatigue and subgrade rutting results will be displayed. If it is not a Mill and Overlay project and rutting has been observed in the old HMA, check the Rutting is present in old HMA box. If rutting is not present in the existing HMA, it is not necessary to check for subgrade rutting.

Intermediate Overlay Design Procedure

Select material types and subtypes for the layers, with HMA overlay in layer 1 and Old HMA in layer 2.

Click on the Intermediate tab and select FWD Deflections.



The FWD Data window will open. FWD loads and deflections must be entered in the spreadsheet. Data entry is greatly simplified by opening the FWD deflection file in a spreadsheet such as Excel, cutting and pasting to put the data in the appropriate columns, and then pasting the data into MnPAVE.

MnPAVE - FWD Data

Edit Print Window Help

Test Date Overlay (in.) Design Lane AADT

Calculate BELLS3 Temperature Units English SI

Air Temperature for 5/15/2003 Low High °F

Loc. No.	Test Time	I.R. Surface Temp. (°F)	FWD Load (kips)	FWD Deflections (mils)				Comments
				Offset (in.)				
				0	12	24	36	
1	1:05 PM	61.1	8.48	8.3	7.3	6.0	2.3	
2	1:05 PM	61.1	8.44	8.4	7.3	6.0	2.3	
3	1:05 PM	61.1	8.51	8.4	7.3	6.0	2.3	
4	1:07 PM	61.1	8.41	8.6	7.0	5.0	3.5	
5	1:07 PM	61.1	8.46	8.7	7.1	5.1	3.5	
6	1:07 PM	61.1	8.41	8.5	7.0	5.0	3.5	
7	1:10 PM	61.1	8.48	9.3	7.6	5.3	3.5	
8	1:10 PM	61.1	8.51	9.3	7.6	5.3	3.5	
9	1:10 PM	61.1	8.46	9.3	7.5	5.3	3.5	
10	1:12 PM	61.1	8.41	9.0	7.4	5.2	3.4	
11	1:12 PM	61.1	8.43	9.0	7.4	5.2	3.4	

FWD Plate Radius: 6.0 in. Soil is Reduction Rate

Pavement temperature can be entered by two methods. If the pavement temperature is known, uncheck the Calculate BELLS3 Temperature checkbox and enter the known pavement temperature values in column 2. If the pavement temperature is not known, it can be estimated using the BELLS 3 method. Enter the previous day's high and low air temperatures in the appropriate boxes and the infrared surface temperatures in column


2. Air Temperature for 5/15/2003 Low High °F

If Mill and Overlay was checked, the button must be clicked to define the old HMA thickness at the time of the FWD testing and after milling.

Annual Average Daily Traffic (AADT) must also be entered. If this value is not known, it can be estimated from the design ESALs and the road type by clicking on the button.

Select the soil plasticity at the bottom by clicking on the button. Clicking on the button toggles through three levels: Plastic, Semi-Plastic, and Non-Plastic. If this property is unknown, assume the soil is plastic.

The value is used in the TONN procedure. This value is typically 0.11 and ordinarily does not need to be changed.

Once all data has been entered, click on the  button.

MnPAVE - FWD Data

Edit Print Window Help

Test Date: 5/16/2003 Overlay (in.): 4 Old HMA Design Lane AADT: 2,113 Est. AADT

Calculate BELLS3 Temperature

Air Temperature for 5/15/2003: Low: 40 High: 60 °F

Units: English SI

Loc. No.	Test Time	BELLS3 Temp. (°F)	FWD Load (kips)	Normalized 9-kip D0	Calculated Modulus (ksi)	TONN SLR (tons)	TONN Overlay (in.)	Comments
15	1:15 PM	57.7	8.40	9.8	2,392	10.0	0	
16	1:17 PM	57.7	8.41	8.7	2,230	10.0	0	
17	1:17 PM	57.7	8.44	8.6	2,301	10.0	0	
18	1:17 PM	57.7	8.41	8.7	2,287	10.0	0	
19	1:20 PM	57.7	8.40	9.4	1,674	10.0	0	
20	1:20 PM	57.7	8.43	9.5	1,614	10.0	0	
21	1:20 PM	57.7	8.44	9.5	1,599	10.0	0	
22	1:27 PM	57.8	8.35	12.5	855	10.0	0	
	Mean	57.7	8.43	9.5	2,145	10.0	0	Mean
	Std. Dev.	0.1	0.04	0.8	592	0	0	Std. Dev.

FWD Plate Radius: 6.0 in. Soil is: Plastic Reduction Rate: 0.11 Restore Default

If BELLS3 was used, column 2 displays the estimated pavement temperatures at 1/3 of the pavement depth. Column 3 displays the fwd load, and column 4 displays the center deflection normalized to a 9 kip (40 kN) load (all deflections are normalized for the calculations). Column 5 displays the calculated HMA modulus and column 6 displays the Spring Load Restriction recommended by the TONN procedure for the selected overlay thickness. Column 7 displays the overlay thickness recommended by the TONN procedure. The mean and standard deviation for these values is displayed at the bottom of the table.

Traffic

Traffic loads are simulated in MnPAVE to estimate the life of a given pavement design. The default traffic load type in MnPAVE is the ESAL (Equivalent Single Axle Load).

ESAL is a means of simplifying traffic data for pavement design. An ESAL is defined as an 18 kip (80 kN) dual tire axle with a tire pressure of 80 psi (552 kPa). Other axle loads and configurations can be converted to ESALs by using Load Equivalency Factors (LEF) as defined in Appendix D of the 1993 AASHTO AASHTO Guide for Design of Pavement Structures. An LEF is the number of 18 kip ESALs required to cause the same amount of damage as the axle in question.

Load Spectrum is a more comprehensive way to characterize the expected traffic for a pavement design. Load applications are categorized by axle type and load range.

ESAL

Lifetime ESALs are the number of ESALs expected during the number of years specified in Design Period Length.

The First Year value is calculated based on the Design Period Length and Growth Rate.

If only First Year ESALs are known, it can be entered here and Lifetime ESALs will be calculated based on the Design Period Length and Growth Rate.

The Design Period Length is typically 20 years. This value can be adjusted by the user.

The Annual Growth Rate determines the amount that traffic increases during each year of the Design Period. Traffic analysis conducted by Mn/DOT has indicated that a simple growth model is appropriate for most Minnesota routes (traffic increases by a fixed amount each year).

Allowable Stress is used to protect against failure in the aggregate base layer due to a single heavy load event. For this reason, the axle weights entered in this window represent the heaviest axles expected. The default values are consistent with data from around the state and do not correspond to legal load limits. Unless the designer has specific data to indicate lower axle weights are appropriate, the default values should be used.

The screenshot shows a software window titled "Example1.mpv" with a sub-header "ESAL". The interface is divided into several sections:

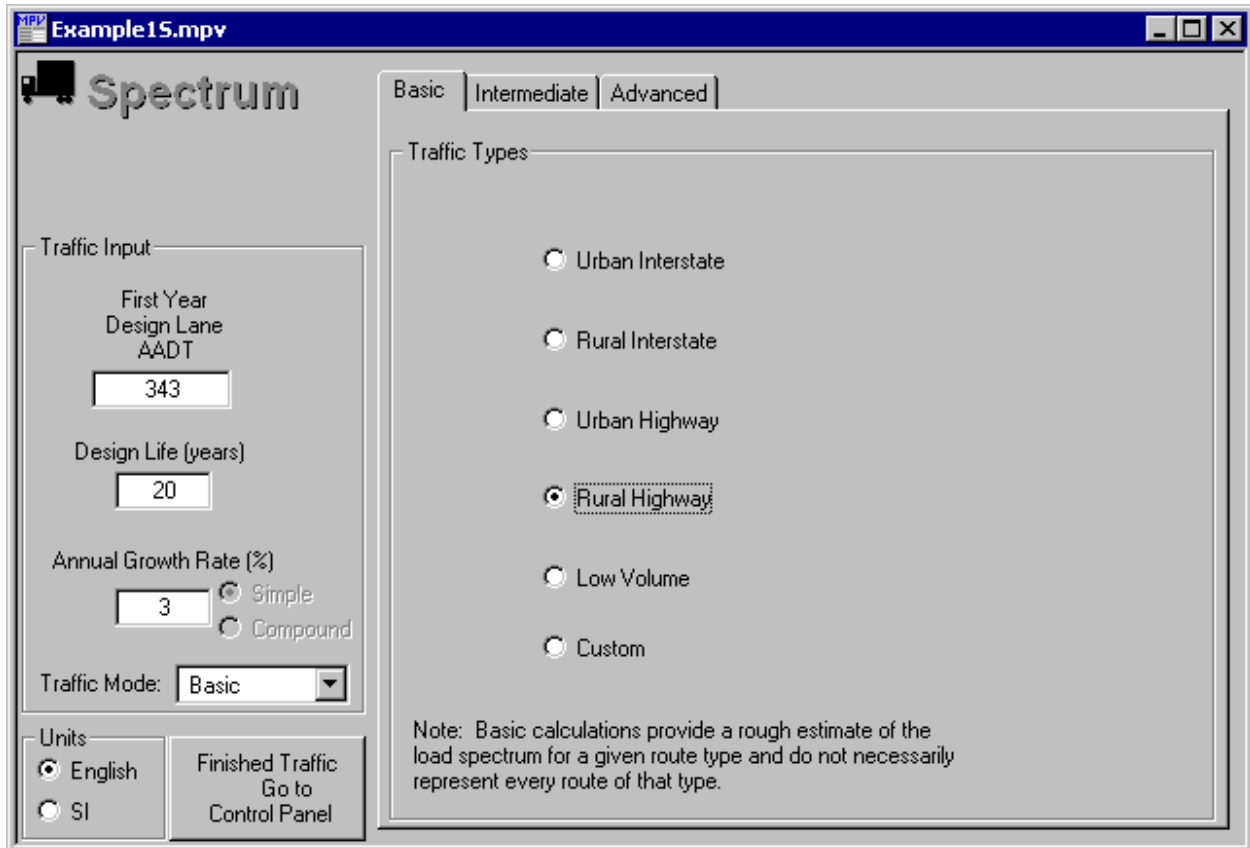
- Axle Configuration:** Includes input fields for Tire Pressure (80 psi), Axle Weight (18 kips), and Wheel Weight (4.5 kips).
- ESALs:** Features radio buttons for "Lifetime" (selected) and "First Year". The Lifetime field is set to 0.324 million, and the First Year field is 0.0126 million (Calculated). Other fields include Design Period Length (20 years) and Annual Growth Rate (3% Simple Growth).
- Units:** Radio buttons for "English" (selected) and "SI". A button labeled "Finished Traffic Go to Control Panel" is also present.
- Allowable Stress Failure Criterion:** A table with columns for Axle Weight (kips), Tire Pressure (psi), and Wheel Spacing (in.). It lists "Heaviest Single Tire Axle" (22, 100) and "Heaviest Dual Tire Axle" (28, 100, 13.5). A "Restore Mn/ROAD Defaults" button is located below the table.

	Axle Weight (kips)	Tire Pressure (psi)	Wheel Spacing (in.)
Heaviest Single Tire Axle	22	100	
Heaviest Dual Tire Axle	28	100	13.5

Basic Spectrum

Basic Spectrum determines a load spectrum using design lane AADT, pavement life, growth rate, and route type.

When a traffic type is selected in Basic Spectrum, weigh-in-motion (WIM) data from routes of that type is used with the other traffic inputs to calculate the load spectrum used in the pavement simulation. Weigh-In-Motion (WIM): a device that measures wheel or axle loads on a pavement while the vehicle is in motion.



The screenshot shows the 'Spectrum' software window with the 'Basic' tab selected. The 'Traffic Input' section contains the following fields:

- First Year Design Lane AADT: 343
- Design Life (years): 20
- Annual Growth Rate (%): 3, with radio buttons for 'Simple' (selected) and 'Compound'.
- Traffic Mode: Basic (dropdown menu)

The 'Traffic Types' section has radio buttons for:

- Urban Interstate
- Rural Interstate
- Urban Highway
- Rural Highway (selected)
- Low Volume
- Custom

At the bottom left, there are radio buttons for 'English' (selected) and 'SI' units, and a button labeled 'Finished Traffic Go to Control Panel'. A note at the bottom right reads: 'Note: Basic calculations provide a rough estimate of the load spectrum for a given route type and do not necessarily represent every route of that type.'

First Year Design Lane AADT is determined by multiplying the average annual daily traffic forecast for the first year by a directional distribution factor (DD) and a lane distribution factor (DL):

$$\text{First Year Design Lane AADT} = \text{First Year AADT} \times \text{DD} \times \text{DL}$$

DD = 0.5 if traffic is approximately equal in both directions.

DL = 1.0 for 2-lane highways.

The 1993 AASHTO Guide for Design of Pavement Structures provides the following guidelines for DL on multi-lane highways:

Number of Lanes in Each Direction	Percent of Traffic in Design Lane
1	100
2	80 - 100
3	60 - 80
4	50 - 75

Intermediate Spectrum

Intermediate Spectrum determines a load spectrum using design lane AADT, pavement life, growth rate, and vehicle type percentages.

The screenshot shows the 'Spectrum' software interface with the 'Intermediate' tab selected. The 'Traffic Input' section contains the following values:

- First Year Design Lane AADT: 343
- Design Life (years): 20
- Annual Growth Rate (%): 3 (Simple)
- Traffic Mode: Intermediate

The 'Standard VehicleTypes' section shows the 'Mn/DOT' classification system selected. The table below lists the vehicle types and their percentages:

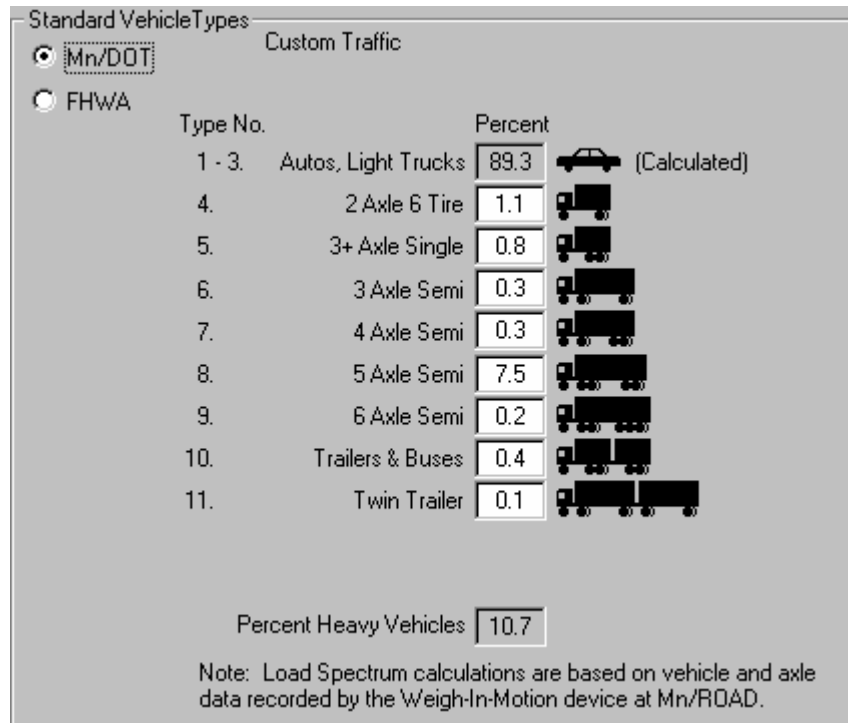
Type No.	Description	Percent
1 - 3.	Autos, Light Trucks	89.3 (Calculated)
4.	2 Axle 6 Tire	1.1
5.	3+ Axle Single	0.8
6.	3 Axle Semi	0.3
7.	4 Axle Semi	0.3
8.	5 Axle Semi	7.5
9.	6 Axle Semi	0.2
10.	Trailers & Buses	0.4
11.	Twin Trailer	0.1

Percent Heavy Vehicles: 10.7

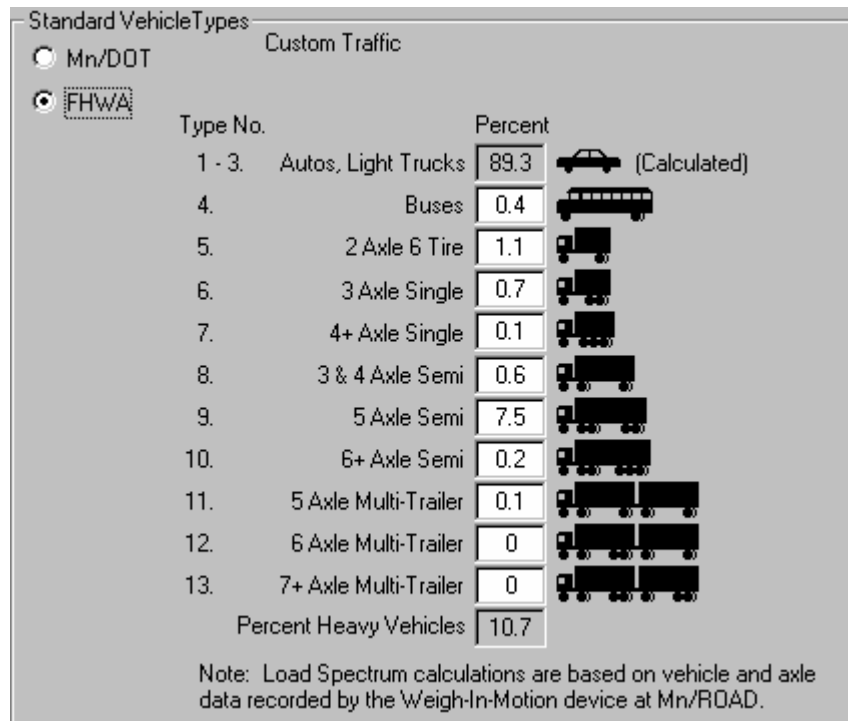
Note: Load Spectrum calculations are based on vehicle and axle data recorded by the Weigh-In-Motion device at Mn/ROAD.

Vehicle types are quantified in pavement design procedures to more accurately define the loads on the pavement. Vehicle type data can be obtained from manual counts or from automatic vehicle classification systems. The Mn/DOT classification system differs somewhat from the FHWA system. Data in FHWA format can be entered and MnPAVE will convert it into Mn/DOT format. Vehicle-specific axle weight distributions are used to convert vehicle type data into a load spectrum for pavement simulations.

Mn/DOT Classification System



FHWA Classification System



Advanced Spectrum

In Advanced Spectrum, the user can paste formatted load spectrum data or use Weigh-In-Motion (WIM) data.

The tire pressure, tire spacing, and axle spacing all affect the stresses and strains throughout the pavement structure. The default values shown are fairly typical of vehicles in the United States.

The data entry area is similar to a spreadsheet. Lifetime load spectrum data or WIM data can be formatted in a spreadsheet program such as Excel, then copied and pasted in the MnPAVE Load Spectrum window.

Weigh-In-Motion(WIM) data that is collected for a period of time can be pasted in the MnPAVE Load Spectrum window and MnPAVE will calculate the load spectrum for the pavement simulation.

The axle weights are divided into 2-kip (2000 lb or 9 kN) ranges as in the 1993 AASHTO Guide for Design of Pavement Structures.

Axle types can be checked or unchecked depending on what type of trucks traffic is expected on the pavement.

The screenshot shows the MnPAVE Spectrum software interface. The title bar reads "Example15.mpv". The main window has three tabs: "Basic", "Intermediate", and "Advanced", with "Advanced" selected. Below the tabs are input fields for "Tire Pressure...", "Tire Spacing...", and "Axle Spacing...".

The "Traffic Input" section on the left includes:

- First Year Design Lane AADT: 343
- Design Life (years): 20
- Annual Growth Rate (%): 3, with radio buttons for "Simple" and "Compound".
- Traffic Mode: Intermediate (dropdown menu)
- Units: English (selected) and SI.
- Finished Traffic Go to Control Panel (button)

The main table shows "Lifetime Axle Repetitions" for various axle weight ranges (kips) and axle types. The table has columns for Axle Weight (kips), Dual, Tandem, Tridem, Steer, Single, Tandem, and Tridem. The "Dual", "Tandem", and "Tridem" columns have checkboxes that are checked. The "Single" and "Tandem" columns have checkboxes that are unchecked. The "Tridem" column has a small upward arrow icon.

Axle Weight (kips)	Dual	Tandem	Tridem	Steer	Single	Tandem	Tridem
1 - 3	15,700	943	0	0			
3 - 5	32,342	3,446	2	47,197			
5 - 7	19,991	7,611	16	20,766			
7 - 9	14,896	20,187	74	49,002			
9 - 11	14,221	32,961	240	132,638			
11 - 13	12,115	42,426	555	74,368			
13 - 15	10,835	38,227	476	9,754			
15 - 17	12,338	30,499	229	6,481			
17 - 19	12,104	27,536	112	3,346			
19 - 21	4,372	27,273	106	506			
21 - 23	1,051	26,738	134	126			
23 - 25	500	23,748	137	43			
25 - 27	434	22,415	170	26			

Below the table are buttons for "Clear All" and "Custom Traffic". On the right, it says "Calculated ESALs = 323,313" and a "Show LEF" checkbox with a mouse cursor pointing to it.

If Seasonal Traffic is checked, data must be entered (or pasted) for each season. Select seasons by clicking on the "All Seasons" button (it will then advance to the next season with each click).

ESALs are calculated according to the 1993 AASHTO Guide for Design of Pavement Structures using Load Equivalency Factors (LEF).

LEFs are multiplied by the repetitions of the corresponding axle type and weight to obtain an equivalent number of 18,000-lb (80 kN) ESALs. These values are then summed to provide a single ESAL value that can be used in a variety of pavement design methods.

The screenshot shows the 'Spectrum' software interface with the 'Intermediate' tab selected. The 'Traffic Input' section on the left includes:

- First Year Design Lane AADT: 343
- Design Life (years): 20
- Annual Growth Rate (%): 3, with radio buttons for 'Simple' (selected) and 'Compound'.
- Traffic Mode: Intermediate (dropdown menu)
- Units: English (selected) and SI.
- Finished Traffic: Go to Control Panel.

 The main table displays 'Load Equivalency Factors' for various axle weight ranges. The columns are: Axle Weight (kips), Dual, Tandem, Tridem, Steer, Single, Tandem, and Tridem. The 'Use WIM Data' checkbox is unchecked. The 'Structural Number' is 3.2 and 'Pt' is 2.5. The 'Calculated ESALs' is 323,313. A 'Show LEF' checkbox is checked and highlighted by a mouse cursor.

Axle Weight (kips)	Dual	Tandem	Tridem	Steer	Single	Tandem	Tridem
1 - 3	0.0003	0.0001	0.0000	0.0003			
3 - 5	0.003	0.0004	0.0001	0.003			
5 - 7	0.016	0.002	0.0005	0.016			
7 - 9	0.049	0.005	0.001	0.049			
9 - 11	0.120	0.011	0.003	0.120			
11 - 13	0.230	0.022	0.005	0.230			
13 - 15	0.400	0.040	0.010	0.400			
15 - 17	0.650	0.067	0.016	0.650			
17 - 19	1.00	0.110	0.026	1.00			
19 - 21	1.48	0.160	0.040	1.48			
21 - 23	2.14	0.230	0.057	2.14			
23 - 25	3.01	0.310	0.081	3.01			
25 - 27	4.16	0.420	0.110	4.16			

Output

Output displays the expected life based on fatigue and rutting damage. Optimum layer thickness can be determined automatically in ESAL mode.

Fatigue and Rutting Models

The expected life of a pavement is calculated by simulating the strains due to traffic loads and using an empirical transfer function to determine the Allowed Repetitions⁴ for each load. If the applied load repetitions exceeds the allowed repetitions, the pavement is assumed to have failed.

MnPAVE - Damage Transfer Functions

Print Window Help

Allowed Repetitions for Fatigue

$$N_F = CK_{F1} \epsilon_h^{K_{F2}} E^{K_{F3}}$$

Where

C = Correction factor

Constant Calculated

ϵ_h = Horizontal tensile strain at bottom of HMA (in/in)

E = HMA Dynamic Modulus (psi)

Use polymer shift factor

Model: MnPAVE

To add a new model, type a name in the box and click "Add".

K_{F1}

K_{F2}

K_{F3}

Allowed Repetitions for Rutting

$$N_R = K_{R1} \epsilon_v^{K_{R2}}$$

Where

ϵ_v = Vertical compressive strain at top of subgrade (in/in)

Model: MnPAVE

To add a new model, type a name in the box and click "Add".

K_{R1}

K_{R2}

⁴ The number of repetitions of a given axle load that are assumed to cause pavement failure by fatigue cracking or rutting

Basic Output

Basic Output displays the expected years of pavement life based on calculated fatigue and rutting damage. The pavement damage is also expressed as a percent contribution by each season.

Click “Life” to view the expected years of pavement life based on an analysis of fatigue and rutting damage. Click “Damage” to view the corresponding damage factors (a value of 1 or greater indicates failure prior to end of the designated design period).

If fatigue or rutting values are too low or too high, Material subtypes and layer thicknesses can be adjusted. After each change “Recalculate” must be clicked to view the new results. For Basic designs, HMA and aggregate subtypes can be adjusted in Output. For Intermediate designs, only HMA can be adjusted in Output (other materials must be changed in Structure). In Advanced mode, all material types must be changed in Structure.

Percent of Total Damage				
Fall	Winter	Early Spring	Late Spring	Summer
15.2	1.3	1.6	24.6	57.3
17.2	0.6	1.7	27.0	53.5

Thickness Goal Seek is a tool for determining design layer thicknesses in ESAL mode. To adjust the HMA layer only, select “Layer 1” and click on **Thickness Goal Seek**. A number of cycles will be executed until the pavement fails in neither fatigue nor rutting.

When Thickness Goal Seek is done for non-HMA layers, the HMA layer will be adjusted for fatigue first (if necessary), and then the selected layer will be adjusted. This is because adjusting underlying layers has a relatively small effect on fatigue life and may result in a large number of cycles and very thick layers.

After running Thickness Goal Seek, layer thicknesses can be adjusted manually to obtain the desired structure.



The relative damage effect from each season is displayed on the right side of the window. These values are affected by both the magnitude of strain that occurs during each season as well as the season length.


Results can be exported to a text file (comma or tab delimited) or to an "Excel" file. The Excel file is actually a tab delimited text file with an "xls" file extension. Double-clicking on this file opens it in Excel, but it must be "Saved As" Excel to convert it to true Excel format.

The Design Summary contains expected life and damage, project information, and limited structural and traffic information.

Damage Details includes more seasonal and traffic information.

Printing

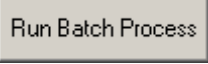
A summary report can be printed by clicking on the printer icon with the white paper  or by selecting "Print Design Summary" from the "File" menu. The summary report can be previewed by clicking on the  icon or by selecting "Print Preview" from the "File" menu.

A screen shot of the output window can be printed by clicking on the printer icon with the gray paper . Most other windows have a printer icon that can be clicked to print a screen shot.

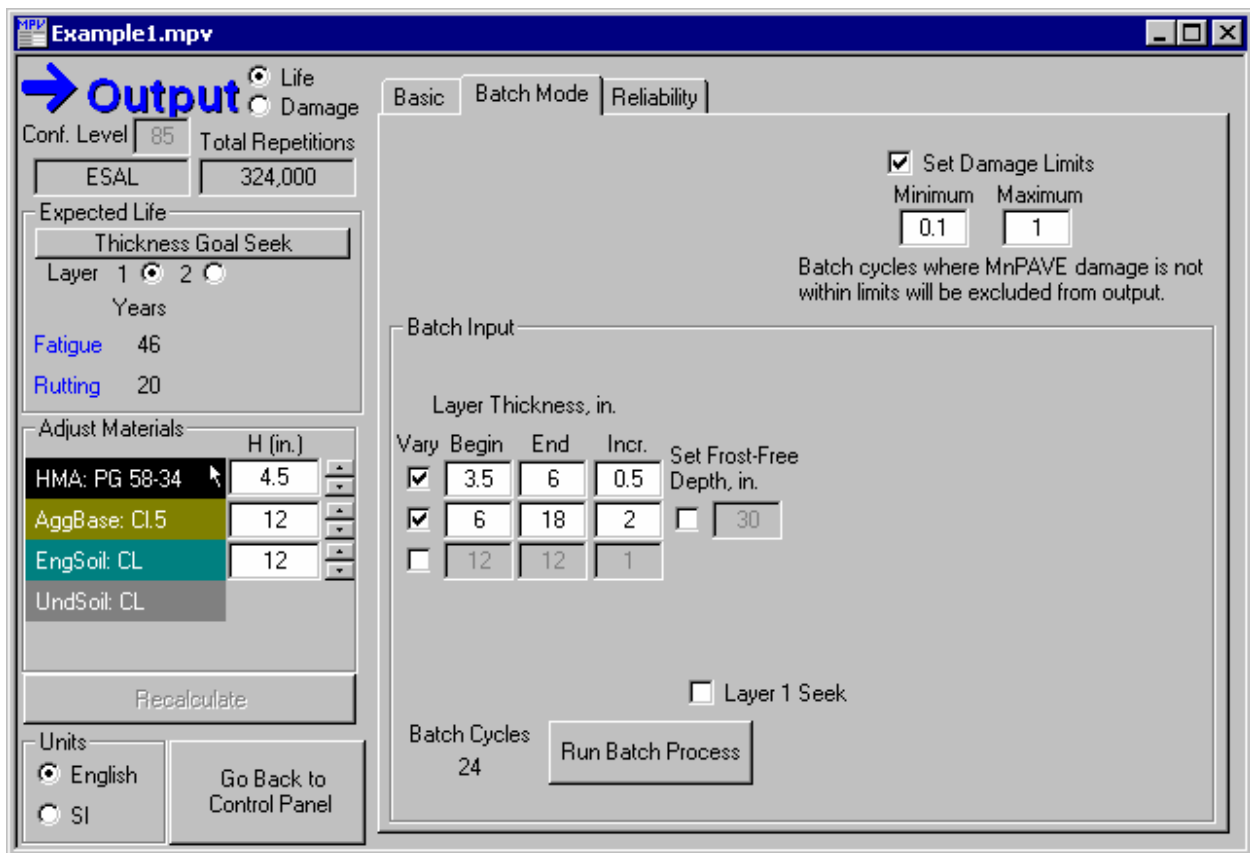
Batch Mode

The batch mode allows the user to specify a range of layer thickness values and have all results tabulated in a text file or spreadsheet.

Check the box for each layer for which the thickness will be varied. Type the thinnest value in the "Begin" box, the thickest value in the "End" box, and the amount to increase the thickness in the "Incr." box. Damage Limits are used to exclude extremely over- or under-designed structures from the output file. When Set Frost-Free Depth is selected, each simulated structure will be adjusted so that the specified thickness of granular or better material is placed above the subgrade soil.

The  button will prompt you for a filename in which to save the results. Excel (xls), tab-delimited text (txt) or comma-delimited text (csv) formats can be selected.

The value under **Batch Cycles** is the number of structures that will be simulated. If **Set Damage Limits** is checked, the number of lines in the output file may be fewer than this value.



The screenshot shows a software window titled "Example 1.mpv" with a "Batch Mode" tab selected. The interface includes several sections:

- Output Section:** Contains a blue arrow icon and radio buttons for "Life" (selected) and "Damage". Below are input fields for "Conf. Level" (85) and "Total Repetitions" (324,000), with "ESAL" selected. There is also a "Thickness Goal Seek" section with radio buttons for "Layer 1" (selected) and "2", and input fields for "Years", "Fatigue" (46), and "Rutting" (20).
- Adjust Materials Section:** A table with columns for material name and thickness "H (in.)":

Material	H (in.)
HMA: PG 58-34	4.5
AggBase: CI.5	12
EngSoil: CL	12
UndSoil: CL	
- Batch Input Section:** A table for "Layer Thickness, in." with columns "Vary", "Begin", "End", "Incr.", and "Set Frost-Free Depth, in.":

Vary	Begin	End	Incr.	Set Frost-Free Depth, in.
<input checked="" type="checkbox"/>	3.5	6	0.5	<input type="checkbox"/>
<input checked="" type="checkbox"/>	6	18	2	<input type="checkbox"/>
<input type="checkbox"/>	12	12	1	<input type="checkbox"/>
- Other Settings:** Includes a "Set Damage Limits" checkbox (checked) with "Minimum" (0.1) and "Maximum" (1) input fields. A note states: "Batch cycles where MnPAVE damage is not within limits will be excluded from output." There is also a "Layer 1 Seek" checkbox (unchecked).
- Bottom Section:** Shows "Batch Cycles" set to 24 and a "Run Batch Process" button.

Reliability

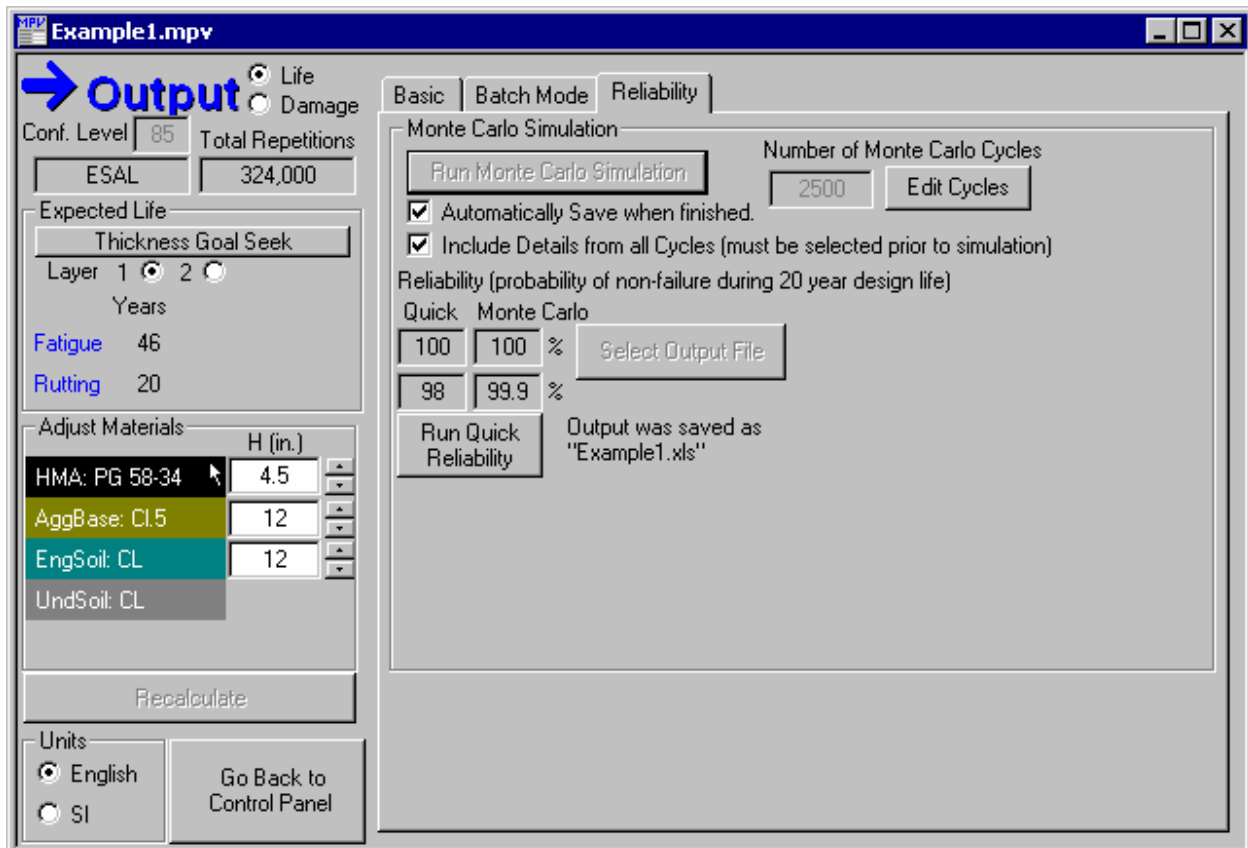
Output reliability considers the variability of the thickness and modulus values for each layer to determine a reliability value for the pavement design.

The reliability will not necessarily agree with the confidence level selected in Structure because the confidence level selects the "worst case" thickness and modulus value for each layer while the reliability analysis considers a random combination of thickness and modulus values.

The number of Monte Carlo cycles can be adjusted by clicking the **Edit Cycles** button. A sensitivity analysis was conducted to determine the optimum value of 2500 cycles.

The **Run Monte Carlo Simulation** button runs the selected number of Monte Carlo cycles. The time for this process ranges from less than one minute to a few minutes for an ESAL design (depending on the computer's processor speed) and up to several hours for a load spectrum design.

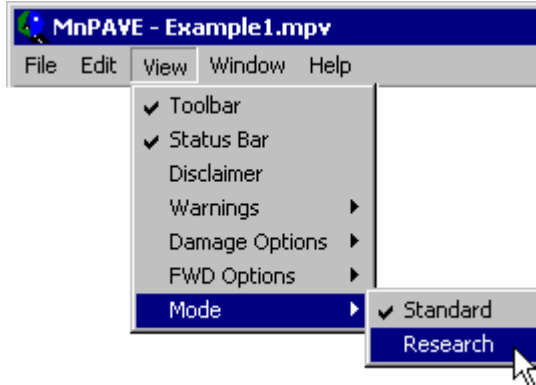
Check the **Automatically Save when finished** box to save the results in an Excel or text file at the end of the simulation.



Quick Reliability uses equations derived from running a range of full Monte Carlo simulations to estimate the Monte Carlo reliability for a given structure. This is a time-saving feature that allows quick adjustments in the structure. Once the desired quick reliability value is reached a full Monte Carlo reliability should be run for verification.

Research Mode

The standard design mode in MnPAVE provides the features necessary to complete a pavement design. Research Mode can be selected from the Main Control Panel from the View menu.



In Research Mode there are more features and more flexibility in entering data. However, there is one important difference in the way hot-mix asphalt (HMA) modulus is determined. In Standard Mode, all asphalt binders have the same properties as PG 58-28 for the following reasons:

1. PG 58-28 binder is essentially equivalent to the type of asphalt binder in most of the pavements used to calibrate MnPAVE.
2. The modulus-based simulation procedure does not account for the added benefits of polymers in some PG grades. As a result, the fatigue and rutting performance of polymer-modified asphalts may be misrepresented. A prototype polymer shift-factor based on torsional fatigue tests has been included in Research Mode.

In order to have comparable results when switching between Standard and Research modes, the binder selected in Research mode should be PG 58-28.

References

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<http://transportation.org/aaashto/organization.nsf/allpages/AboutUs>

WESLEA

Van Cauwelaert, F.J., Alexander, D.R., White, T.D., and Barker, W.R., "Multilayer Elastic Program for Backcalculating Layer Moduli in Pavement Evaluation," Nondestructive Testing of Pavements and Backcalculation of Moduli, ASTM STP 1026, A.J. Bush III and G.Y. Baladi, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 171-188.

"Illinois" Rutting Model

Thompson, M.R., "ILLI-PAVE Based Full-Depth Asphalt Concrete Pavement Design Procedure," Proceedings, Sixth International Conference on Structural Design of Asphalt Pavements, Ann Arbor, MI, 1987.

Asphalt Institute (Finn) Fatigue Model

Finn, F., Saraf, C.L., Kulkarni, R., Nair, K., Smith, W., and Abdullah, A., "Development of Pavement Structural Subsystems," NCHRP Report 291, National Cooperative Highway Research Program, Transportation Research Board, 1986.

Miner's Hypothesis

Miner, Milton A., "Estimation of Fatigue Life with Particular Emphasis on Cumulative Damage," Metal Fatigue, Sines and Waisman, Eds., McGraw Hill, 1959, pp. 278-289..

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WESLEA (wes5)	Frans J. Van Cauwelaert Don R. Alexander Thomas D. White Walter R. Barker Bjorn Birgisson
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Hyperlink (CHyperlink)	Giancarlo Iovino Chris Maunder
Image Tool Tips	Paul DiLascia
MFC Grid Control (CGridCtrl).....	Chris Maunder
Printing Class Library	Righard Stringer
Round to Decimal.....	Corey Spagnoli

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