

MnPAVE User's Guide

July 2012

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, Traffic, and Structure; 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, which is calculated using a damage factor based on Miner's Hypothesis. Reliability is estimated using Monte Carlo simulation. 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

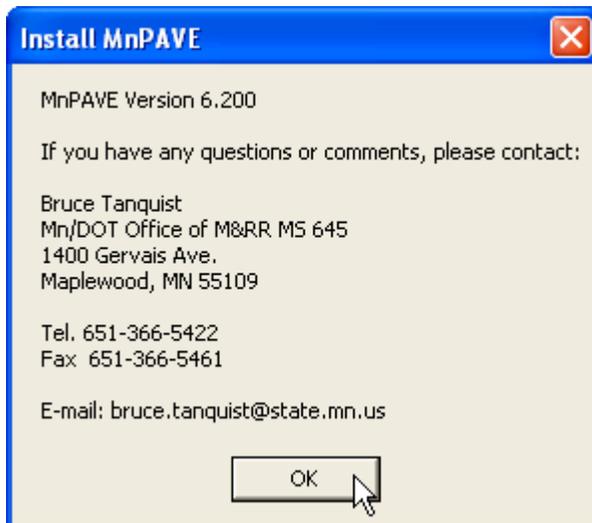
Weight		
1 lb	=	4.448222 N
1 kip	=	1000 lbs
1 kip	=	4.448222 kN

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

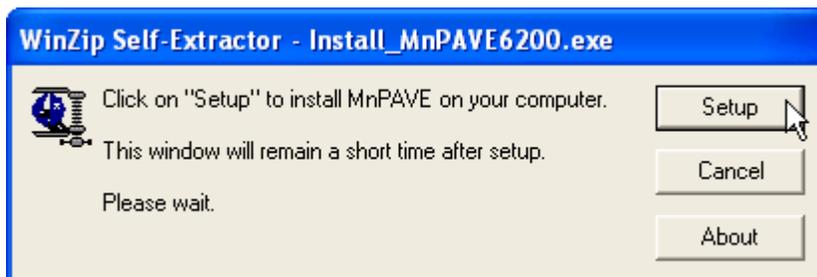
Installing MnPAVE

The installation file,  Install_MnPAVE6200.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:

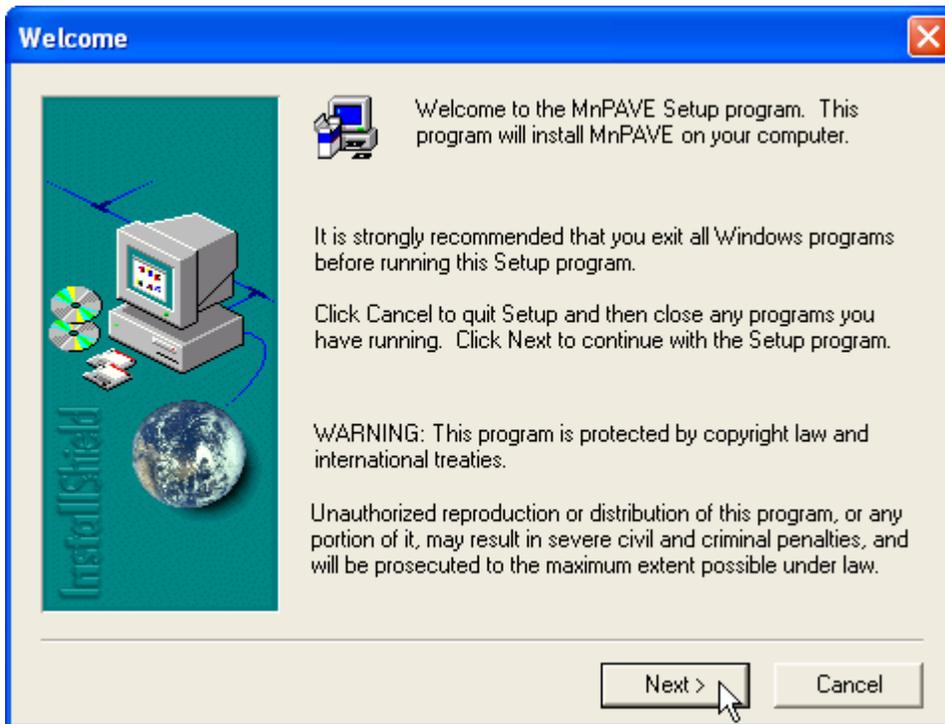
1. The first Install window contains version and contact information.



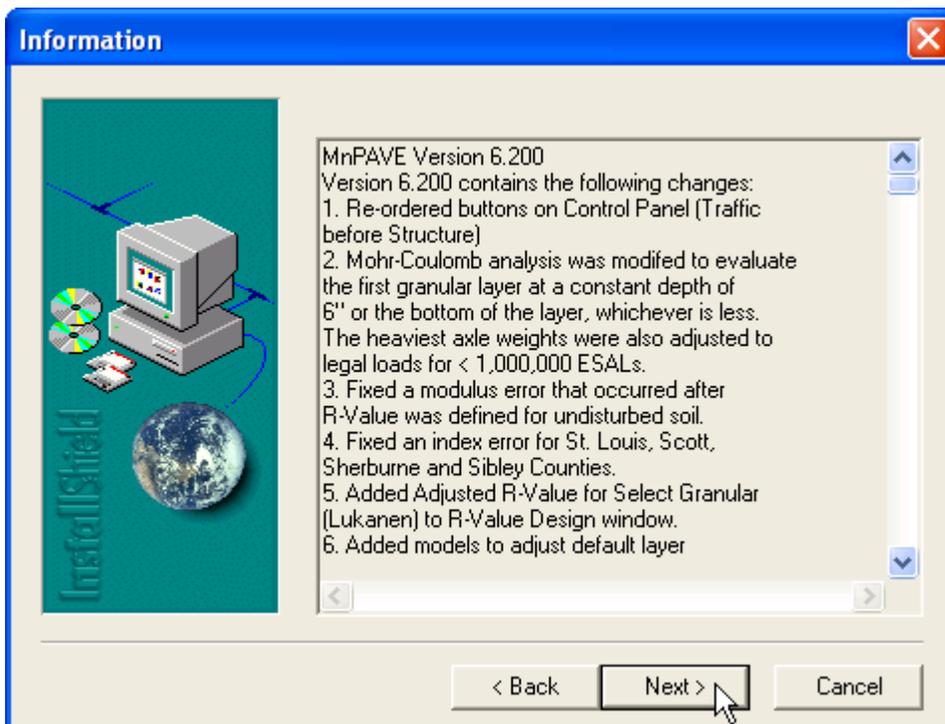
2. Clicking "Setup" in the Winzip Self-Extractor window initiates the installation process.



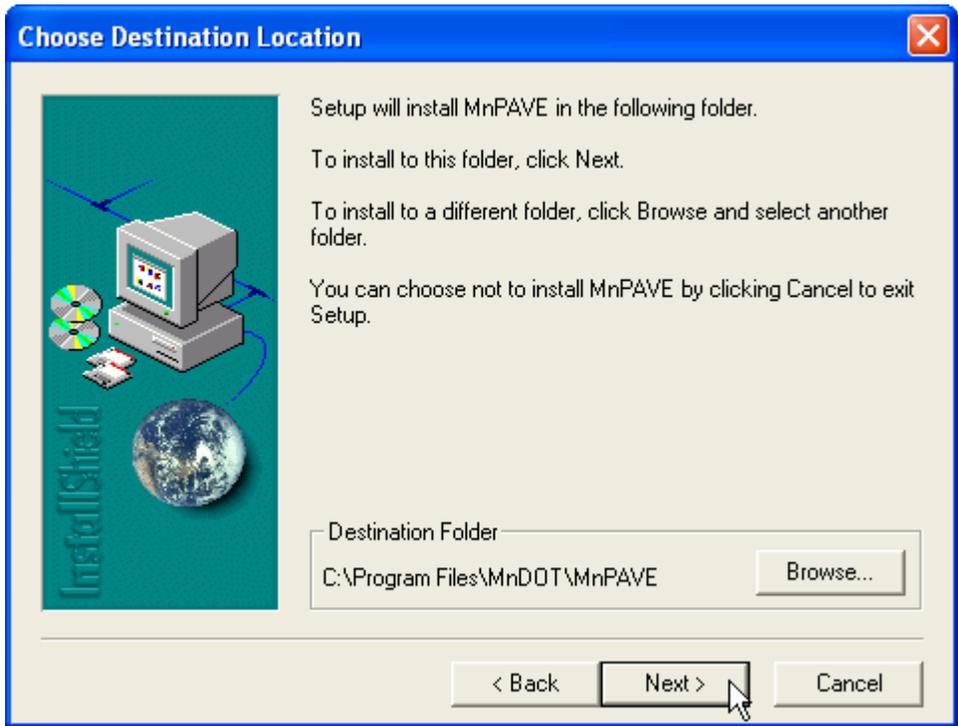
3. The Welcome window contains brief setup instructions.



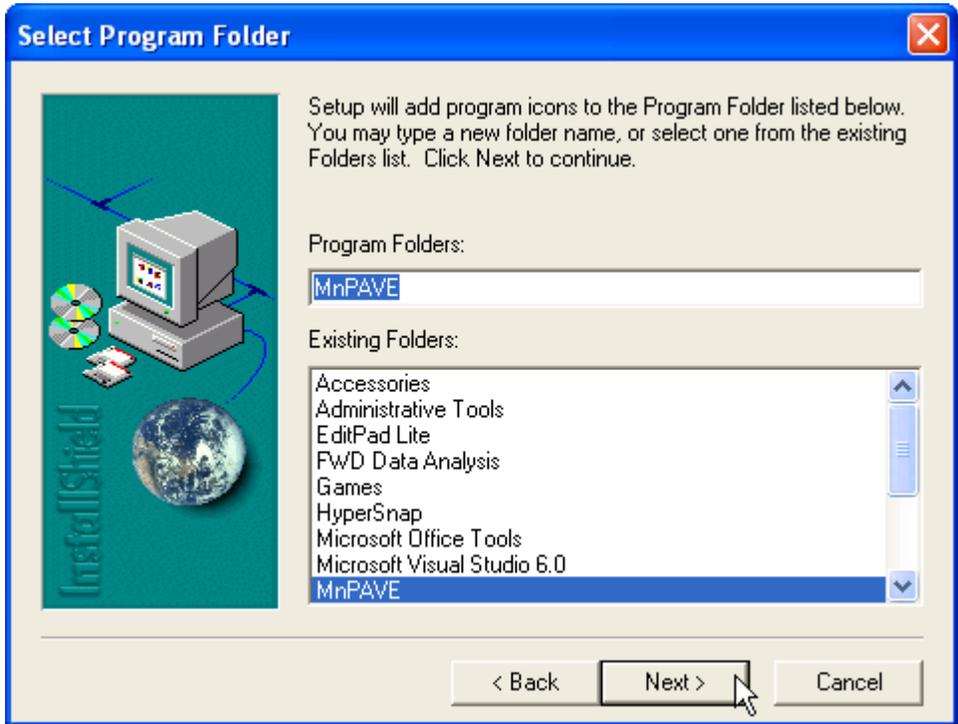
4. Update information is included in this window. This information can also be viewed at <http://www.dot.state.mn.us/app/mnpave/history.html> .



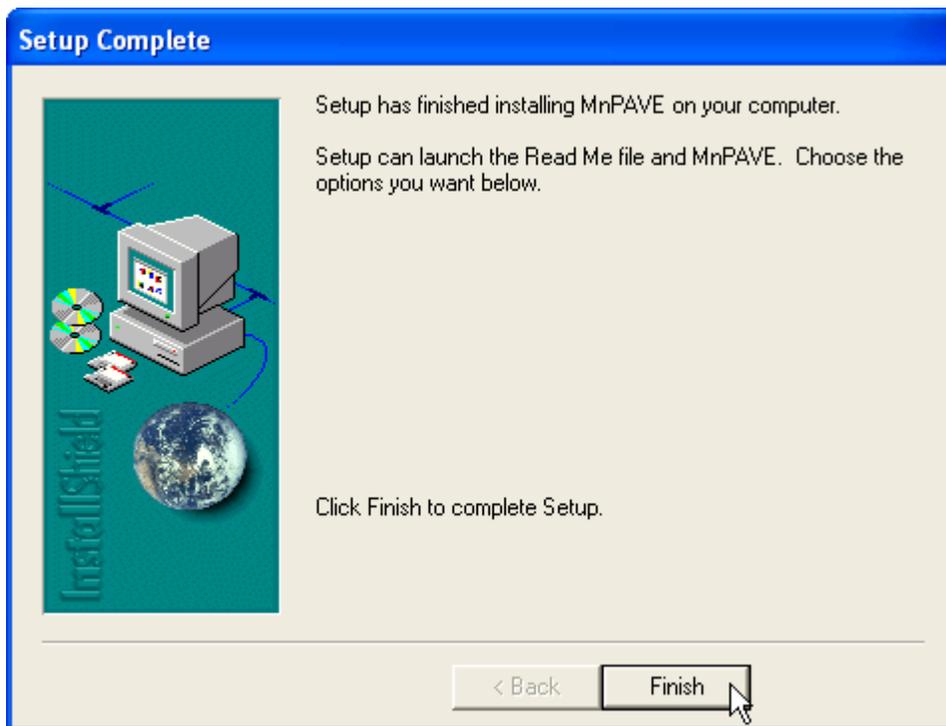
5. The executable MnPAVE.exe and Help files will be placed in Program Files\MnDOT\MnPAVE unless a different location is specified.



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



7. Finish

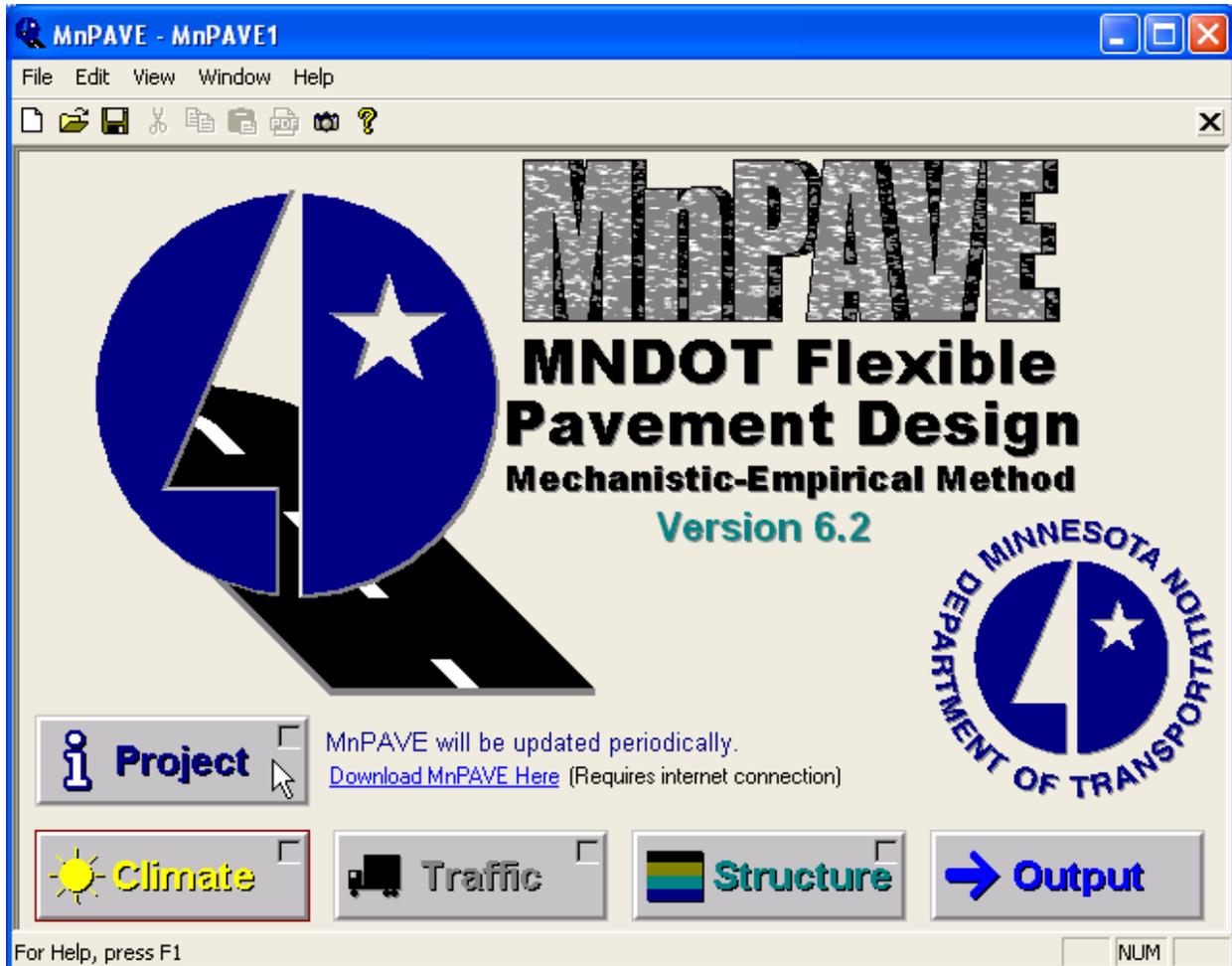


At this point there will be a MnPAVE icon  on the desktop and in the Windows  menu under the folder name specified in Step 6.

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.

i Project Information

District: 3 County: Crow Wing View: All Counties By District

Project No.: 100 Route: CR1331 City: n/a

Reference Post (RP): 0.00 to 2.00 Letting Date: 7/ 2/2012 Construction Type: 2360

Designer: MnPAVE Soils Engineer: MnPAVE

Notes: (Type any project details here that should be documented in the report.)

Go Back to Control Panel [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.

The screenshot shows the Climate software interface. On the left, there is a 'Seasons' table for 'Crow Wing County'. The table has columns for 'Days' and 'Pavement Temp. (°F)'. Below the table are 'Units' (English selected) and a 'Finished Climate Go to Control Panel' button. On the right, there is a 'Map' tab and a 'Details' tab. The 'Map' tab shows a map of Minnesota with Mn/DOT Districts numbered 1 through 8. A mouse pointer is over the 'Crow Wing' county in District 3. The 'Details' tab shows 'Selected County: Crow Wing', 'District: 3', and 'Click map or enter coordinates.' Below this are input fields for 'Latitude: 46 ° 14' and 'Longitude: 94 ° 20'. At the bottom of the details panel is a 'Pointer Text' section with radio buttons for 'Counties' (selected), 'Coordinates', 'Soil Class', and 'None'.

Seasons	Days	Pavement Temp. (°F)
Fall (Standard)	90	48
Winter (Frozen)	105	21
Early Spring (Base Thaw)	14	38
Late Spring (Soil Thaw)	58	59
Summer (High Temp.)	98	81

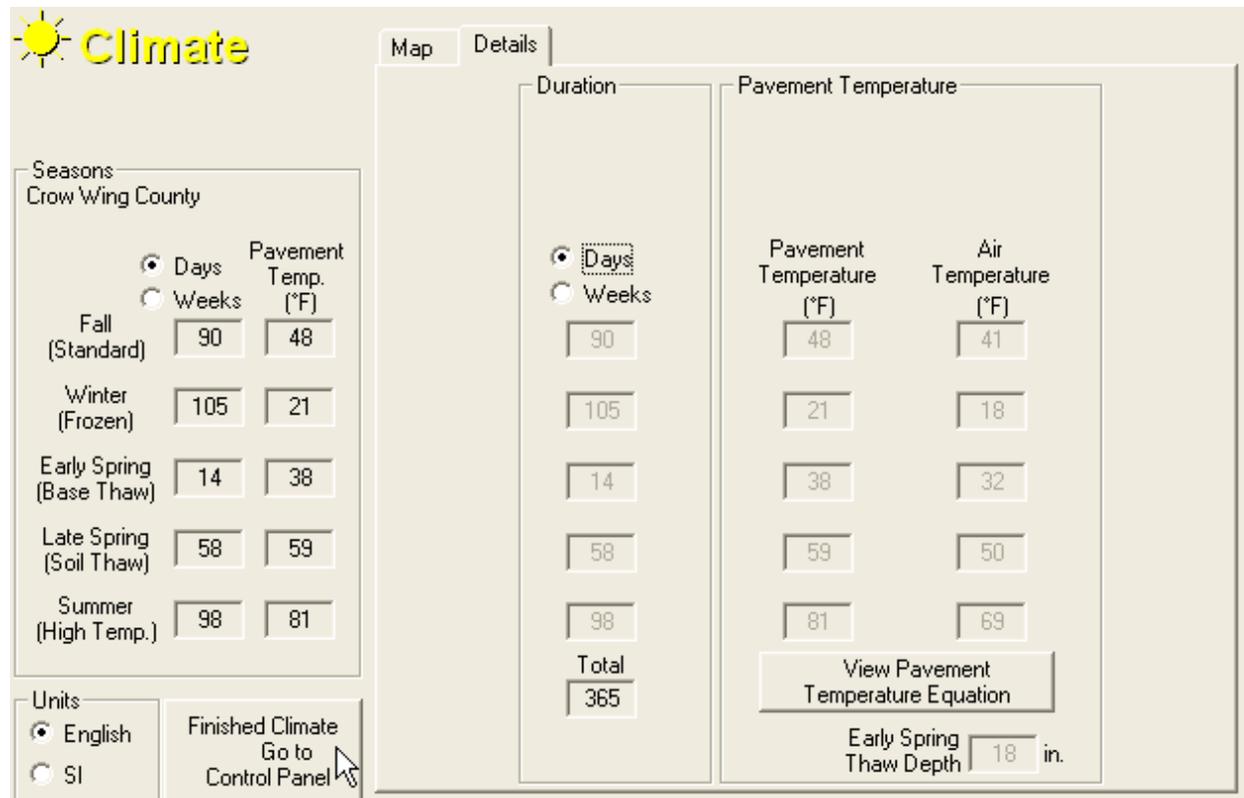
Climate Details

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 weather stations in a 75 mile (120 km) radius. 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. Seasonal modulus multipliers for the selected pavement materials can be viewed in Advanced Structure. If the thaw depth extends into a soil layer, then the Late Spring multiplier is used for the thawed portion of the soil.



Climate

Map Details

Seasons
Crow Wing County

Season	Duration	Pavement Temp. (°F)	Air Temperature (°F)
Fall (Standard)	90	48	41
Winter (Frozen)	105	21	18
Early Spring (Base Thaw)	14	38	32
Late Spring (Soil Thaw)	58	59	50
Summer (High Temp.)	98	81	69
Total	365		

Units
 English
 SI

Finished Climate
Go to Control Panel

View Pavement Temperature Equation

Early Spring Thaw Depth 18 in.

Traffic

ESAL (Equivalent Single Axle Load) is a simplified measure of traffic 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 Guide for Design of Pavement Structures.

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.

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).

ESAL

Note: In some windows, such as this one, the initial view shows only the details necessary for a basic pavement design. To view more details (as shown in this image), click the **Show Details** button.

Axle Configuration

Tire Pressure: 80 psi Wheel Spacing: 13.5 in.

Axle Weight: 18 kips

Wheel Weight: 4.5 kips

ESALs

Lifetime: 0.375 million

First Year: 0.0146 million (Calculated)

Design Period Length: 20 years

Annual Growth Rate (%): 3 (Simple Growth)

Units

English SI

Finished Traffic
Go to Control Panel

Hide Details

Allowable Stress Failure Criterion

	Axle Weight (kips)	Tire Pressure (psi)	Wheel Spacing (in.)
Heaviest Single Tire Axle	12	100	
Heaviest Dual Tire Axle	20	100	13.5

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 in this window represent the heaviest axles expected. The default values for low-volume roads (less than 1,000,000 ESALs) are legal axle weights in Minnesota. Values used for higher traffic volumes are consistent with data from around the state.

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.

To view more details about how HMA modulus is calculated, click on the “Show Details” button and then the Advanced button next to each lift.

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.

MnPAVE - HMA Mix Properties

Screen Capture Help

HMA Mix Properties

Layer 1 60 Expected traffic speed (mph) Hide Details OK

Equivalent Thickness HMA SN = 2.1

HMA Lift *	Binder Grade	Thickness (in.)	Binder content (% by wt. of mix)	Mn/DOT Spec.	Nom. Max. Size	Percent Passing				
						3/4"	3/8"	#4	#200	
<input type="radio"/> 1	PG58-34	4	5	2360 Fine	1/2"	100	85	63	5	Advanced
<input checked="" type="radio"/> 2	PG58-28	2	5	2360 Fine	1/2"	100	85	63	5	Advanced
<input type="radio"/> 3										

* The term "Lift" is used here to differentiate between HMA layers with different mix designs or densities.

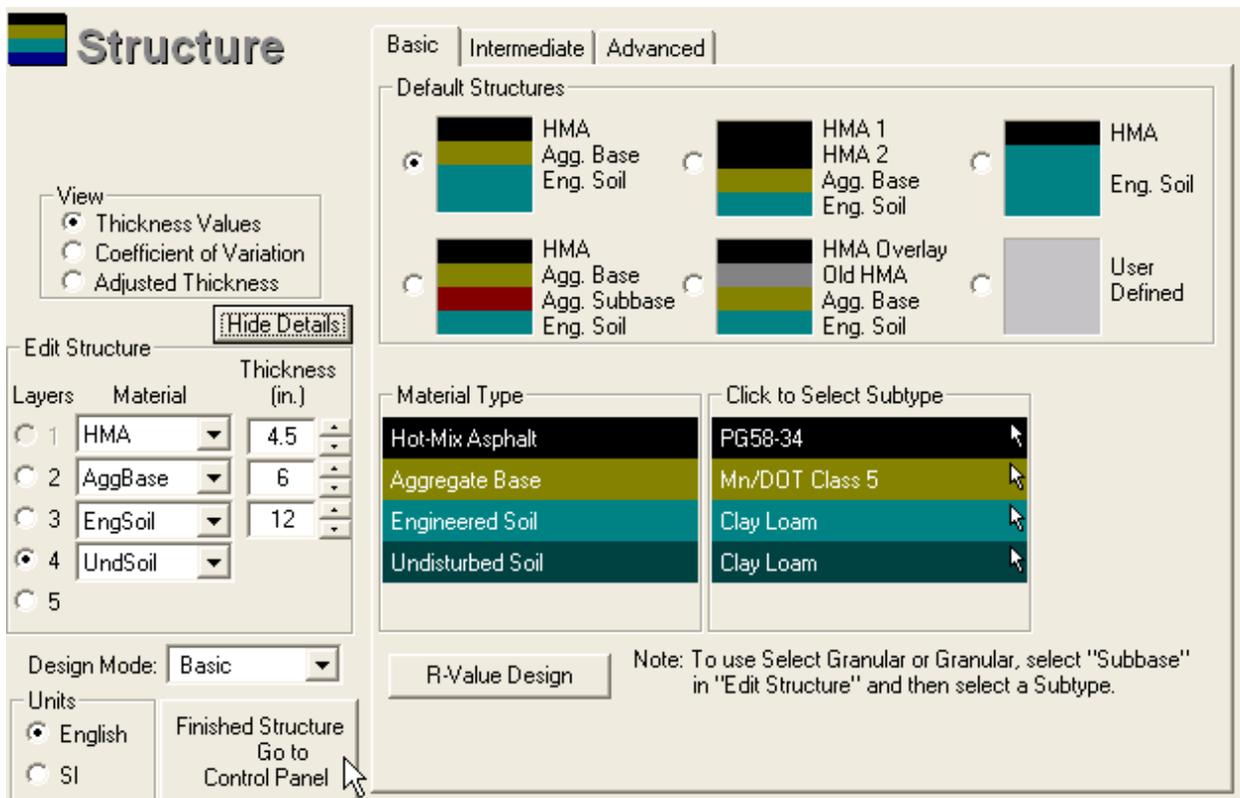
Basic Structure

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. R-Value Design can be clicked to view the traditional MNDOT design results for this structure.



The screenshot shows the MnPAVE Structure window with the following components:

- Structure** title bar with tabs for Basic, Intermediate, and Advanced.
- Default Structures** section with six radio buttons and corresponding layer diagrams:
 - Structure 1: HMA, Agg. Base, Eng. Soil
 - Structure 2: HMA 1, HMA 2, Agg. Base, Eng. Soil
 - Structure 3: HMA, Eng. Soil
 - Structure 4: HMA, Agg. Base, Agg. Subbase, Eng. Soil
 - Structure 5: HMA Overlay, Old HMA, Agg. Base, Eng. Soil
 - Structure 6: User Defined
- Edit Structure** section with a table:

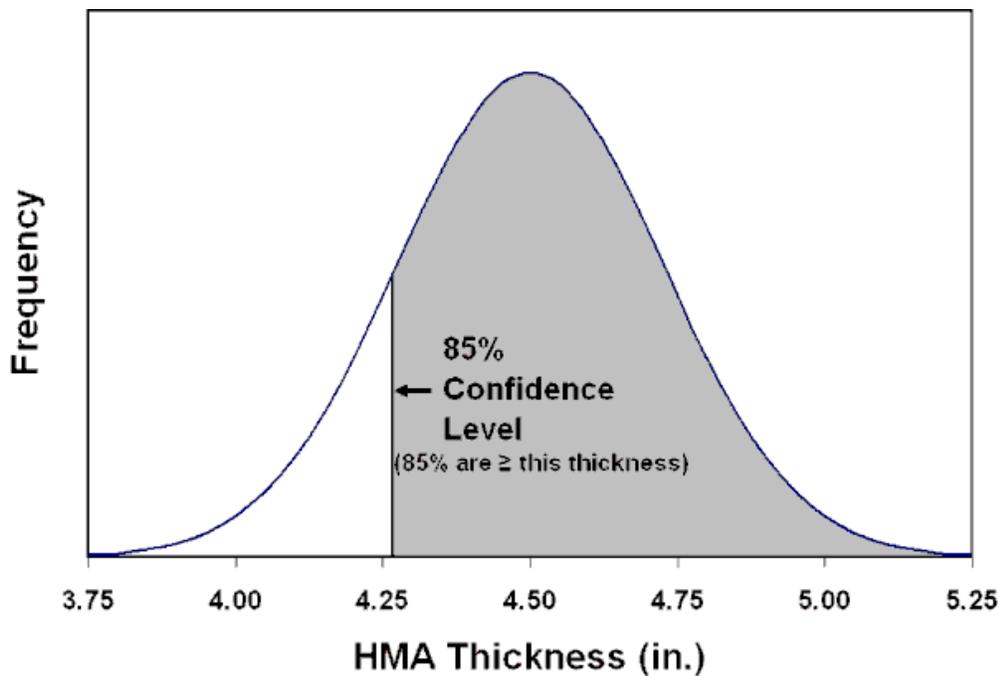
Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	4.5
<input type="radio"/> 2	AggBase	6
<input type="radio"/> 3	EngSoil	12
<input checked="" type="radio"/> 4	UndSoil	
<input type="radio"/> 5		
- Material Type** list: Hot-Mix Asphalt, Aggregate Base, Engineered Soil, Undisturbed Soil.
- Click to Select Subtype** list: PG58-34, Mn/DOT Class 5, Clay Loam, Clay Loam.
- Design Mode:** Basic
- Units:** English (selected), SI.
- Buttons:** Hide Details, R-Value Design, Finished Structure Go to Control Panel.
- Note:** To use Select Granular or Granular, select "Subbase" in "Edit Structure" and then select a 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

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. In Design Mode, the Confidence Level is set at a default value of 70%. It is adjustable in Research Mode.



Thickness Views

Thickness Values Displays the design thickness. These values are adjusted based on the Thickness Coefficient of Variation (COV) 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 Hide Details

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	4.5
<input type="radio"/> 2	AggBase	6
<input type="radio"/> 3	EngSoil	10
<input checked="" type="radio"/> 4	UndSoil	
<input type="radio"/> 5		

View

Thickness Values
 Coefficient of Variation
 Adjusted Thickness

Edit Structure Hide Details

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 Hide Details

Layers	Material	70% Conf. (in.)
<input type="radio"/> 1	HMA	4.38
<input type="radio"/> 2	AggBase	5.75
<input type="radio"/> 3	EngSoil	9.21
<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.

If **Other** is selected in the **Edit Structure** area, material properties are edited in **Intermediate** or **Advanced Structure**.

The screenshot shows the 'Structure' software interface. At the top, there are three tabs: 'Basic', 'Intermediate' (which is selected), and 'Advanced'. On the left side, there is an 'Edit Structure' panel with a 'Show Details' button. Below it is a table with columns for 'Layers', 'Material', and 'Thickness (in.)'. The table has five rows, with the fourth row selected. Below the table, there is a 'Design Mode' dropdown menu set to 'Intermediate'. At the bottom left, there are 'Units' options for 'English' (selected) and 'SI', and a 'Finished Structure Go to Control Panel' button. The main area of the interface is divided into four columns: 'HMA Modulus', 'Agg. Test Type', 'Soil Test Type', and 'Other'. The 'Agg. Test Type' column has a checked checkbox and a value of 70. The 'Soil Test Type' column has a checked checkbox and a value of 12, with a dropdown menu showing 'CL'. An 'R-Value Design' button is located at the bottom of the main area.

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.

Structure

Basic | Intermediate | **Advanced**

Design Mode

Use values from Basic Design Level

Use values from Intermediate Design Level

Advanced mode (enter values now)

Parameter Shown Below

Design Modulus, ksi Adjusted

Poisson's Ratio

Seasonal Modulus Multipliers

Modulus Coefficient of Variation, %

Structural Number = 2.2

Edit Structure Show Details

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	4.5
<input type="radio"/> 2	AggBase	6
<input type="radio"/> 3	EngSoil	10
<input checked="" type="radio"/> 4	UndSoil	
<input type="radio"/> 5		

Design Mode: **Advanced**

Units

English SI

Finished Structure
Go to Control Panel

Fall	Winter	Early Spring	Late Spring	Summer
505.6	1412	755.9	336.6	144.2
27	50	9.72	22.68	27.54
9.566	50	50	6.697	8.132
5.551	50	50	3.886	4.719

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).

Parameter Shown Below: Design Modulus, ksi Adjusted Structural Number = 2.2

Poisson's Ratio
 Seasonal Modulus Multipliers
 Modulus Coefficient of Variation, %

Fall	Winter	Early Spring	Late Spring	Summer
505.6	1412	755.9	336.6	144.2
27	50	9.72	22.68	27.54
9.566	50	50	6.697	8.132
5.551	50	50	3.886	4.719

Parameter Shown Below: Design Modulus, ksi Adjusted Structural Number = 2.2

Poisson's Ratio
 Seasonal Modulus Multipliers
 Modulus Coefficient of Variation, %

Fall	Winter	Early Spring	Late Spring	Summer
446.8	1248	668.1	297.5	127.4
22.17	41.06	7.982	18.62	22.61
7.257	37.93	37.93	5.08	6.169
3.129	28.18	28.18	2.19	2.659

Parameter Shown Below: Design Modulus, ksi Adjusted Structural Number = 2.2

Poisson's Ratio
 Seasonal Modulus Multipliers
 Modulus Coefficient of Variation, %

Fall	Winter	Early Spring	Late Spring	Summer
0.35	0.35	0.35	0.35	0.35
0.4	0.4	0.4	0.4	0.4
0.45	0.45	0.45	0.45	0.45
0.45	0.45	0.45	0.45	0.45

Parameter Shown Below: Design Modulus, ksi Adjusted Structural Number = 2.2

Poisson's Ratio
 Seasonal Modulus Multipliers
 Modulus Coefficient of Variation, %

Fall	Winter	Early Spring	Late Spring	Summer
1	1	1	1	1
1	10	0.36	0.84	1.02
1	10	10	0.7	0.85
1	10	10	0.7	0.85

Modulus Coefficient of Variation (COV) shows the expected variability in modulus for each layer along with the assumed distribution shape. This data is used to determine the adjusted modulus values used in the simulation and the data set used for the Monte Carlo simulation in Output.

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 Structural Number = 2.2

Design Modulus, ksi Adjusted
 Poisson's Ratio
 Seasonal Modulus Multipliers
 Modulus Coefficient of Variation, %

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

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.

The screenshot shows the 'Structure' software interface with the 'Basic' tab selected. The 'Default Structures' section displays five radio button options for overlay structures:

- Option 1: HMA, Agg. Base, Eng. Soil
- Option 2: HMA 1, HMA 2, Agg. Base, Eng. Soil
- Option 3: HMA, Eng. Soil
- Option 4: HMA, Agg. Base, Agg. Subbase, Eng. Soil (This option is selected by the mouse cursor)
- Option 5: HMA Overlay, Old HMA, Agg. Base, Eng. Soil
- Option 6: User Defined

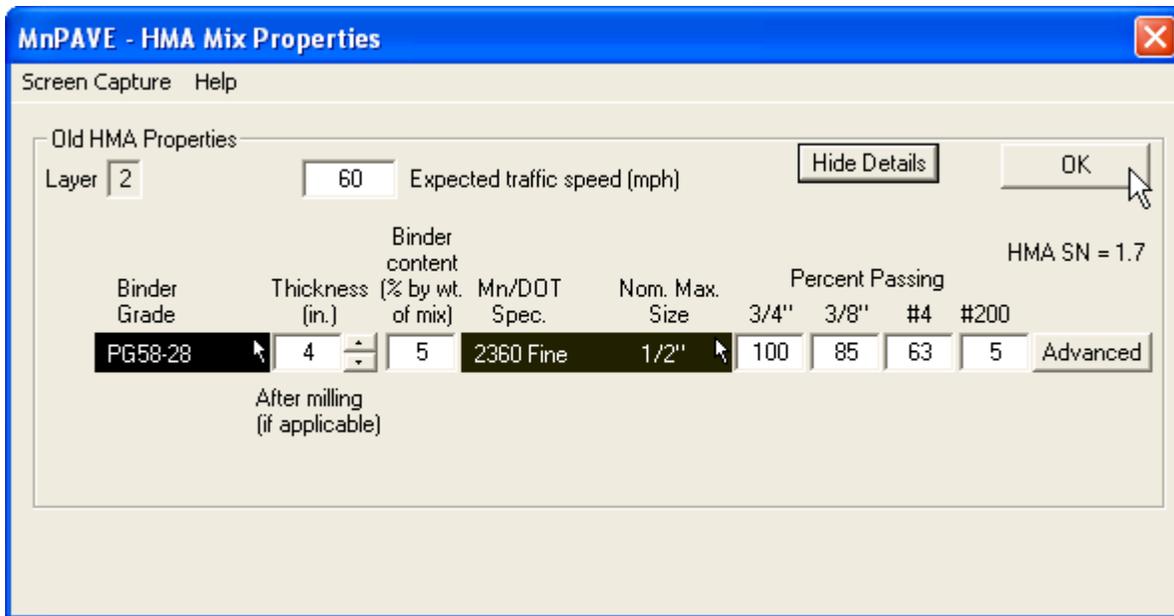
Below the 'Default Structures' section, there are two columns of material types:

- Material Type:** Hot-Mix Asphalt, Old HMA, Aggregate Base, Engineered Soil, Undisturbed Soil
- Click to Select Subtype:** PG58-34, PG58-28, Mn/DOT Class 5, Clay Loam, Clay Loam

At the bottom of the interface, there is a 'Design Mode' dropdown set to 'Basic', a 'Units' section with 'English' selected, and a 'Finished Structure Go to Control Panel' button. A note states: 'Note: To use Select Granular or Granular, select "Subbase" in "Edit Structure" and then select a Subtype.'

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 screenshot shows the MnPAVE Structure software interface. The 'Structure' title bar is visible at the top left. The 'Intermediate' tab is selected, and the 'FWD Deflections' radio button is chosen under 'Old HMA Modulus'. The 'Layers' table is as follows:

Layers	Material	Thickness (in.)
1	HMA	4
2	Old HMA	4
3	AggBase	12
4	EngSoil	12
5	UndSoil	

The 'Agg. Test Type' is set to 'DCP, mm/blow'. The 'Soil Test Type' is set to 'Soil R-Value'. The 'Other' section is empty. The 'FWD Data' button is visible. The 'R-Value Design' button is also visible. The 'Design Mode' is set to 'Intermediate'. The 'Units' are set to 'English'. The 'Finished Structure' button is visible.

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 Est. AADT

Calculate BELLS3 Temperature Units English SI

Air Temperature for 7/1/2012 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	18.3	16.1	13.2	5.1	
2	1:05 PM	61.1	8.44	18.5	16.1	13.2	5.1	
3	1:05 PM	61.1	8.51	18.5	16.1	13.2	5.1	
4	1:07 PM	61.1	8.41	18.9	15.4	11.0	7.7	
5	1:07 PM	61.1	8.46	19.1	15.6	11.2	7.7	
6	1:07 PM	61.1	8.41	18.7	15.4	11.0	7.7	
7	1:10 PM	61.1	8.48	20.5	16.7	11.7	7.7	
8	1:10 PM	61.1	8.51	20.5	16.7	11.7	7.7	
9	1:10 PM	61.1	8.46	20.5	16.5	11.7	7.7	
10	1:12 PM	61.1	8.41	19.8	16.3	11.4	7.5	
11	1:12 PM	61.1	8.43	19.8	16.3	11.4	7.5	

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 7/1/2012 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.

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	58.4	8.40	21.4	2,223	9.9	4.50	
16	1:17 PM	58.4	8.41	19.0	1,913	10.0	3.50	
17	1:17 PM	58.4	8.44	19.0	1,983	10.0	3.50	
18	1:17 PM	58.4	8.41	19.0	1,970	10.0	3.50	
19	1:20 PM	58.5	8.40	20.8	1,355	10.0	4.00	
20	1:20 PM	58.5	8.43	20.9	1,303	10.0	4.00	
21	1:20 PM	58.5	8.44	20.9	1,288	10.0	4.00	
	Mean	58.4	8.43	20.6	1,949	10.0	4.00	Mean
	Std. Dev.	0.0	0.04	1.0	469.2	0.07	0.387	Std. Dev.

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.

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

Screen Capture Help

Allowed Repetitions for Fatigue

$$N_F = C_F K_{F1} \varepsilon_h^{K_{F2}} E^{K_{F3}}$$

Where

C_F = Correction factor

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

E = HMA Dynamic Modulus (psi)

Use polymer shift factor for fatigue

Model: MnPAVE

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

Constant Calculated

K_{F1}

K_{F2}

K_{F3}

Buttons: Add, Delete

Allowed Repetitions for Rutting

$$N_R = C_R K_{R1} \varepsilon_v^{K_{R2}}$$

Where

C_R = Correction factor

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

Use polymer shift factor for rutting

Model: MnPAVE

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

Constant Calculated

K_{R1}

K_{R2}

Buttons: Add, Delete, H.B. Kim Model

Buttons: Cancel, OK

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

Initial 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.

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.

The screenshot shows the 'Output' software interface. On the left, there is a 'Preliminary Design' section with 'Thickness Goal Seek' selected. Below it, 'Layer 1' is selected, and 'Years' is set to '>50'. 'Fatigue' is at 21 and 'Rutting' is at 21. The 'Adjust Materials' section shows a list of materials with their thicknesses in inches: HMA: PG58-34 (4.5), AggBase: CL5 (6), EngSoil: CL (10), and UndSoil: CL. A 'Recalculate' button is below this list. At the bottom left, 'Units' are set to 'English', and there is a 'Go Back to Control Panel' button. On the right, the 'Reliability' section is active, showing 'Basic' mode. It includes a 'Quick Reliability Estimate' box with 'Run Quick Reliability' and 'Fatigue Estimate' (0%) and 'Rutting Estimate' (0%) buttons. A 'Monte Carlo Reliability' box has 'Run Monte Carlo Simulation' and 'Fatigue Reliability' (0%) and 'Rutting Reliability' (0%) buttons. At the bottom right, 'Number of Monte Carlo Cycles' is set to 2500, with an 'Edit Cycles' button.

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.

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 Quick Reliability** button 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.

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.

The screenshot displays the 'Output' window of a pavement design software. On the left, there are input fields for ESALs (375,000), Preliminary Design (Thickness Goal Seek), Layer selection (Layer 1 selected), Years (>50), Fatigue (21), and Adjust Materials (HMA: PG58-34, AggBase: CI.5, EngSoil: CL, UndSoil: CL). A 'Recalculate' button is below these. At the bottom left, there are 'Units' (English selected) and a 'Go Back to Control Panel' button. The main area is titled 'Reliability' and has tabs for 'Basic' and 'Batch Mode'. It contains a text box explaining that Quick Reliability is for preliminary design and Monte Carlo is for final design, with a recommendation of 85% for under 1 million ESALs and 90% for over 1 million. Below this are two panels: 'Quick Reliability Estimate' with a 'Run Quick Reliability' button and values of 100% for Fatigue Estimate and 85% for Rutting Estimate; and 'Monte Carlo Reliability' with a 'Run Monte Carlo Simulation' button and values of 100% for Fatigue Reliability and 88.6% for Rutting Reliability. At the bottom right, there is a 'Number of Monte Carlo Cycles' field set to 2500 and an 'Edit Cycles' button.

Reports

A summary report can be saved as PDF file by clicking on the PDF icon  or by selecting "PDF Design Summary" from the "File" menu

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

Basic Output

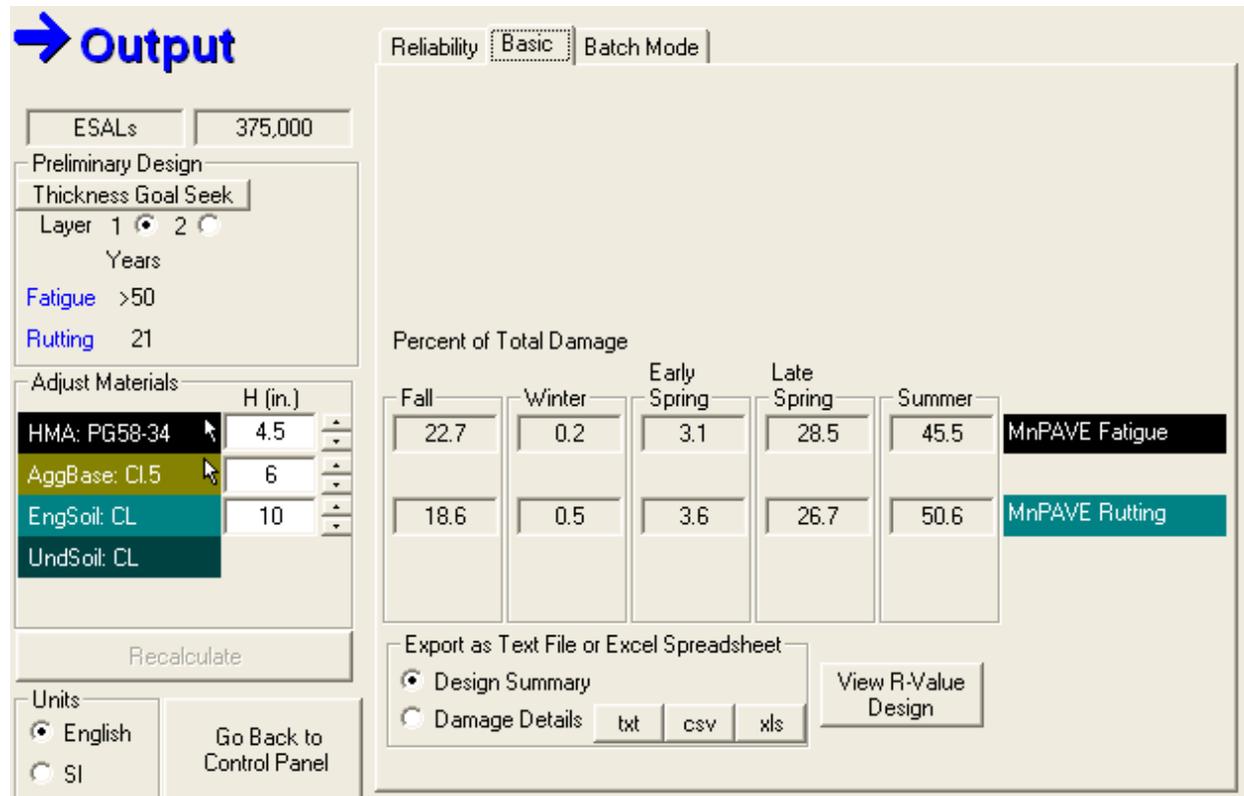
Basic Output displays the expected years of pavement life based on calculated fatigue and rutting damage. The pavement damage is also expressed as a percent contribution by each season.

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.



The screenshot shows the 'Output' software interface. On the left, there are input fields for ESALs (375,000), Preliminary Design (Thickness Goal Seek), Layer (1 selected, 2 unselected), Years (>50), Fatigue (>50), and Rutting (21). Below these are material layers: HMA: PG58-34 (4.5 in.), AggBase: CL5 (6 in.), EngSoil: CL (10 in.), and UndSoil: CL. A 'Recalculate' button is present. At the bottom left, units are set to English, and there is a 'Go Back to Control Panel' button. The main area shows 'Reliability: Basic' and 'Batch Mode'. The 'Percent of Total Damage' table is as follows:

	Fall	Winter	Early Spring	Late Spring	Summer	
MnPAVE Fatigue	22.7	0.2	3.1	28.5	45.5	
MnPAVE Rutting	18.6	0.5	3.6	26.7	50.6	

At the bottom, there are options to 'Export as Text File or Excel Spreadsheet' with radio buttons for 'Design Summary' (selected) and 'Damage Details', and buttons for 'txt', 'csv', and 'xls'. A 'View R-Value Design' button is also present.

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.

Selecting one of the output format buttons Save As Text or Excel will prompt the user for a file name and then run the batch process.

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 the software interface with the following components:

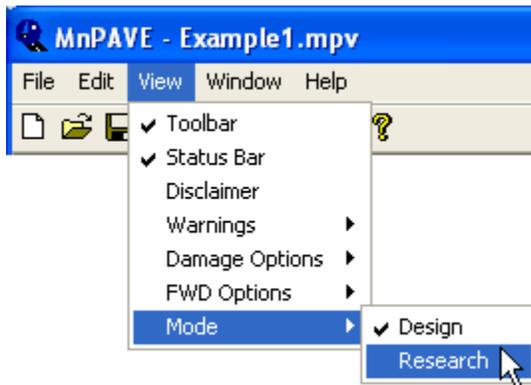
- Output Panel:** A blue arrow icon and the word "Output".
- ESALs:** A text box containing "375,000".
- Preliminary Design:** A section with "Thickness Goal Seek", "Layer 1" selected, "Years" set to ">50", and "Rutting" set to "21".
- Adjust Materials:** A table with columns for material name and thickness H (in.):

Material	H (in.)
HMA: PG58-34	4.5
AggBase: CI.5	6
EngSoil: CL	10
UndSoil: CL	
- Recalculate:** A button.
- Units:** Radio buttons for "English" (selected) and "SI".
- Go Back to Control Panel:** A button.
- Batch Mode Tab:** Contains:
 - Set Damage Limits:** A checked checkbox with "Minimum" (0.1) and "Maximum" (1) input boxes. A note below states: "Batch cycles where MnPAVE damage is not within limits will be excluded from output."
 - Batch Input:** A table for layer thickness variations:

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	12	2	<input type="checkbox"/>
<input type="checkbox"/>	10	10	1	<input type="checkbox"/>
 - Batch Cycles:** A text box containing "24".
 - Save As Text or Excel:** Buttons for "txt", "csv", and "xls".

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, since data entered in Research Mode may fall outside the range of date used to calibrate MnPAVE, Research Mode is not recommended for pavement design.

References

AASHTO (American Association of State Highway & Transportation Officials)

444 North Capitol Street N.W., Suite 249

Washington, DC 20001

Phone: (202) 624-5800

Fax: (202) 624-5806

Email: info@aaashto.org

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

WESLEA

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Contact Information

Bruce Tanquist

Assistant Pavement Design Engineer

Minnesota Department of Transportation

1400 Gervais Ave.

Mail Stop 645

Maplewood, MN 55109-2044

Phone: 651-366-5422

Fax: 651-366-5461

bruce.tanquist@state.mn.us

<http://www.dot.state.mn.us/materials/pvmtdesign>

LRRB (Minnesota Local Road Research Board)

Sandy McCully

Mn/DOT - Office of Investment Management

Research Services

Phone: 651-366-3768

sandy.mccully@state.mn.us

<http://www.lrrb.org/>

Mn/DOT State Aid for Local Transportation

395 John Ireland Boulevard

St. Paul, MN 55155-1899

Mail Stop 500

Phone: 651-366-3800

Fax: 651-366-3801

<http://www.dot.state.mn.us/stateaid/>