

MnPAVE User's Guide

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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.

Install MnPAVE
MnPAVE Version 5.300
If you have any questions or comments, please contact:
Bruce Chadbourn Mn/DOT Office of Materials MS 645 1400 Gervais Ave. Maplewood, MN 55109
Tel. 651-366-5422 Fax 651-366-5461
E-mail: bruce.chadbourn@dot.state.mn.us
ССК

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.

Choose Destination Loca	ition 🗙		
	Setup will install MnPAVE in the following folder.		
	To install to a different folder, click Browse and select another folder.		
	You can choose not to install MnPAVE by clicking Cancel to exit Setup.		
Instal	Destination Folder C:\Program Files\MnDOT\MnPAVE Browse		
	< Back Next > Cancel		

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

7. Finish

Setup Complete				
	Setup has finished installing MnPAVE on your computer.			
	Setup can launch the Read Me file and MnPAVE. Choose the options you want below.			
Instal Ishald	Click Finish to complete Setup.			
	< Back Finish			

At this point there will be a MnPAVE icon **4** on the desktop and in the Windows **2** start menu under the folder name specified in Step 6.

Starting MnPAVE

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

At this point, the Main Control Panel is visibile:



A new MnPAVE file can be opened by clicking on the D 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 by 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.

Example1.mpv	
Project Information District 3 City	View C All Counties © By District
Project No. 100 Highway Number CR131 Reference Post (RP) from 0.00 to 2.00 Letting Date 2/12/2009 Construction Type 2360 Designer MnPAVE Soils Engineer MnPAVE	
Notes Go Back to Control Panel (Requires internet connection)	X

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 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

View Pavement

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.

Example1.mpv		l ×
🔆 Climate	Map Details Pavement Temperature	
Seasons Crow Wing County		
© Days Pavement Temp. © Weeks (*F) Fall 90 48	O DaysPavementAirC Weeks(°F)(°F)904841	
Winter 107 21 (Frozen)	107 21 17	
Early Spring (Base Thaw) 14 38	14 38 32	
Late Spring (Soil Thaw) 57 59	57 59 50	
Summer (High Temp.) 97 81	97 81 69	
_ Units	Total View Pavement 365 Temperature Equation	
English Finished Climate Go to C SI Control Panel	Early Spring Thaw Depth 18 in.	

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.

MnPAVE - HMA Mix P	roperties							×
Print Window Help								
HMA Mix Properties Layer 1 Equivalent Thickness HMA Lift * Binder Grade** O 1 PG 58-34 O 2 PG 58-28	60 E: Bind cont Thickness (% by (in.) of n 4 ÷ 5 2 ÷ 5	pected traffic s ent wt. Mn/DOT ix) Spec. 2350 2350	peed (mph) Nom. Max Size 1/2'' 1/2''	Note: M cannot b are multip 3/4" 100 100	ultiple H e select ole HMA ercent P 3/8'' 62 62	MA Lift ed if thi layers. assing #4 50 50	s ere H #200 5 5	OK MA SN = 2.5 Advanced Advanced
* The term "Lift" is used ** In Standard Mode, bi	here to differentia nder grade is for c	ite between HM ocumentation o	1A layers with d only. MnPAVE i	iifferent mix is calibrate	: design: d for PG	s or der i 58-28	nsities. properti	es 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 $\[b]$ 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

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. In Version 5.306 the Confidence Level was set at a default value of 70% for the Standard Design Mode. It is adjustable in Research Mode.



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.

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

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

View



Coefficient of Variation Adjusted Thickness				
	nucluie			
Layers	Material		COV (%)	
O 1	НМА	•	5	
O 2	AggBase	•	8	
O 3	EngSoil	•	15	
• 4	UndSoil	•		
05				

C Thickness Values C Coefficient of Variation C (Adjusted Thickness)					
-Edit 9	itructure		85% Conf		
Layers	Material		(in.)		
O 1.	НМА	•	4.27		
O 2	AggBase	•	11		
O 3	EngSoil	•	10.13		
• 4	UndSoil	•			
0.5					

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, it's 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 k 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.

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.

Example1.mpv		_ 🗆 ×
View Thickness Values Coefficient of Variation Adjusted Thickness Layers Material (in.) 1 HMA 4.5 12 3 EngSoil 12 4 UndSoil 5	Basic Intermediate Advanced Design Mode Use values from Basic Design Level Use values from Intermediate Design Level O Use values from Intermediate Design Level Advanced mode (enter values now) Parameter Shown Below Structural Number = 2.6 O Design Modulus, ksi Adjusted O Design Modulus, ksi Adjusted O Design Modulus Kultipliers Structural Number = 2.6 Poisson's Ratio Spring Seasonal Modulus Multipliers Spring Modulus Coefficient of Variation, % Spring Fall Winter Spring Spring 9.6 50 50 50 50 50 50 50 50 50	
Design Mode: Advanced Units C English SI C SI Control Panel	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 (%)

 $\sigma^{\rm 2}$ = variance of log-transformed data

Parameter C Design C Poissor C Seasor O Modulu	Shown Below Modulus, ksi n's Ratio nal Modulus M is Coefficient (C Adjuster ultipliers of Variation, %	d Structura	l 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.

MnPAVE - HMA Mix Properties	×
Print Window Help	
Old HMA Properties Layer 2 60 Expected traffic speed (mph)	ОК
Binder content Binder Thickness (% by wt. Mn/DOT Nom. Max. Percent Passing Grade** (in.) of mix) Spec. Size 3/4'' 3/8'' #4 PG 58-28 № 4 ÷ 5 2350 1/2'' № 100 62 50 After milling (if applicable)	HMA SN = 1.6 #200 5 Advanced
** In Standard Mode, binder grade is for documentation only. MnPAVE is calibrated for PG 58-2	8 properties only.

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.

Example2.mpv	
Structure	Basic Intermediate Advanced
View Thickness Values Coefficient of Variation Adjusted Thickness Mill and Overlay Edit Structure Layers Material 1 HMA 1 HMA 2 Old HMA 4 3 AggBase 12 4 EngSoil 24 5 UndSoil Design Mode: Intermediate Control Panel SI	Check box to enter test data. Uncheck to use Basic defaults. Old HMA Modulus © Default Values PWD Deflections PWD Data PG 58-28 Moisture Data Moisture Data View © Test Results © Resistance Factors © Coefficient of Variation Soil Test Type © Lab Mr, ksi © R-Value © DCP,mm/blow © Silt % Clay % © CL CL Moisture Data Mohr-Coulomb

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.

MnPAV	'E - FWD D)ata						X
Edit F	rint Window	Help						
Test D	Test Date 5/16/2003 🔹 Overlay (in.) 4 🗧 Old HMA Design Lane AADT 2,113 Est. AADT							
🔽 Ca	Calculate BELLS3 Temperature Insert Row(s) Paste Excel Data							
Air Te for 5/	mperature /15/2003	Low High 40 60	°F Dele	ete Row(s)	Calculat	e 0	SI	Cancel
		I.R.	FWD		FWD Deflec	tions (mils)		
Loc.		Surface	Load		Offse	t (in.)		
No.	Test Time	Temp. ("F)	(kips)	0	12	24	36	Comments
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 Radiu	ıs: 6.0 in.		Soil is <u>P</u>	lastic Re	duction Rate	0.11 <u>F</u>	estore Default

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 Low High 60 °F

If Mill and Overlay was checked, the Old HMA 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 Est. AADT button.

Select the soil plasticity at the bottom by clicking on the Soil is Plastic 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 Reduction Rate 0.11 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 en	tered, click on the
---------------------------	---------------------

Calculate

button.

MnPAV	'E - FWD D) ata						×
Edit P	Print Window	Help						
Test D	ate 5/16/	2003 🔽 🛛 Oʻ	verlay (in.)	4 ÷ 0	id HMA De:	sign Lane AA	DT 2,113	Est. AADT
🔽 Ca	Calculate BELLS3 Temperature Insert Bow(s) Paste Excel Data Units							
Air Te for 5/	mperature /15/2003	Low High 40 60	*F Dele	te Row(s)	Input Da	ta O	English - SI	Cancel
		BELLS3	FWD	Normal-	Calculated	TONN	TONN	
Loc.		Temp.	Load	ized	Modulus	SLR	Overlay	
No.	Test Time	(°F)	(kips)	9-kip D0	(ksi)	(tons)	(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.
								_
1								
FWD	Plate Radiu	is: 6.0 in.		Soil is <u>P</u> I	astic Re	duction Rate	0.11 F	estore 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 kipkip (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 AASHTOAASHTO 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.

Example1.mpv		_ 🗆 🗡
ESAL		
Axle Configuration Tire Pressure 80 psi Axle Weight 18 kips Wheel Weight 4.5 kips ESALs Ifetime 0.324 million Ifetime 0.324 million Calculated) Design Period Length 20 years Annual Growth Rate (%) 3 (Simple Growth) Units Finished Traffic Go to Control Panel Si Control Panel	Allowable Stress Failure Criterion Axle Tire Weight Pressure S (kips) (psi) Heaviest Single Tire Axle 22 100 Heaviest Dual Tire Axle 28 100 Restore Mn/ROAD De	Wheel Spacing (in.) 13.5 efaults

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.

Example15.mpv		_ 🗆 🗵
🖷 Spectrum	Basic Intermediate Advanced	
	Traffic Types	
– Traffic Input	O Urban Interstate	
First Year Design Lane ADT	O Rural Interstate	
343 Design Life (years)	🔿 Urban Highway	
20	Rural Highway	
Annual Growth Rate (%)	O Low Volume	
Traffic Mode: Basic	O Custom	
Units C English Finished Traffic G SI Control Panel	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):

First Year Design Lane AADT = First Year AADT x DD x DL

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

DL = 1.0 for 2-lane highways.

The 1993 <u>AASHTO</u> 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.

Example15.mpv		- 🗆 ×
Spectrum Spectrum	Basic Intermediate Advanced Standard VehicleTypes Custom Traffic	
Traffic Input First Year Design Lane AADT 343	 ○ FHWA Type No. Percent 1 - 3. Autos, Light Trucks 89.3 ↔ (Calculated) 4. 2 Axle 6 Tire 1.1 5. 3+ Axle Single 0.8 	
Design Life (years) 20 Annual Growth Rate (%)	6. 3 Axie Semi 0.3	
3 C Compound Traffic Mode: Intermediate ▼ Units © English © SI Control Panel	Percent Heavy Vehicles 10.7 Note: Load Spectrum calculations are based on vehicle and ax data recorded by the Weigh-In-Motion device at Mn/ROAD.	le

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

 Standard VehicleTypes 	
Mn/DOT	Custom Traffic
O FHWA	
Type No	. 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 🖓 🗰 🗰 💩
Pe	rcent Heavy Vehicles 10.7
Note: data re	Load Spectrum calculations are based on vehicle and axle corded by the Weigh-In-Motion device at Mn/ROAD.

FHWA Classification System

 Standard VehicleType 	es
O Mn/DOT	Custom Traffic
6 F0520	
• FHWA	No. Percent
1-3	3. Autos, Light Trucks 89.3 🗭 (Calculated)
4.	Buses 0.4
5.	2 Axle 6 Tire 1.1 🚛
6.	3 Axle Single 0.7 🚛
7.	4+ Axle Single 0.1
8.	3 & 4 Axle Semi 0.6 📲 💭
9.	5 Axle Semi 7.5 🕊 🚛
10.	6+ Axle Semi 0.2
11.	5 Axle Multi-Trailer 0.1 🕊 🐻 🐻 🐻
12.	6 Axle Multi-Trailer 0 📲 🚛 🐻 🐻
13.	7+ Axle Multi-Trailer 0 🗣 🗰 🗰
	Percent Heavy Vehicles 10.7
Not dat	e: Load Spectrum calculations are based on vehicle and axle a recorded by the Weigh-In-Motion device at Mn/ROAD.

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.

Example15.mpv								_	
💶 Spectrum	Basic Interm	nediate /	Advanced]					
	Tire Pressure	100	100	100	100				
	Tire Spacing	13.50	13.50	13.50					
	Axle Spacing		54.00	54.00					
_ Traffic Input	Lifetime Axle Re	epetitions	🗆 🗆 S	easonal Ti	affic		🗆 🗆 L	lse WIM D)ata
First Year	Axle Weight (kips)	0) 🔽 Dual	00) 🗹 Tandem	000 I	0 🗹 Steer	0 🗖 Single	00) 🗖 Tandem	000) [Tridem	FI.
Design Lane	1-3	15,700	943	D	D		.		1
	3-5	32,342	3,446	2	47,197				
343	5-7	19,991	7,611	16	20,766				
	7-9	14,896	20,187	74	49,002				
Design Life (years)	9 - 11	14,221	32,961	240	132,638				
20	11 - 13	12,115	42,426	555	74,368				
	13 - 15	10,835	38,227	476	9,754				
Annual Growth Rate (%)	15 - 17	12,338	30,499	229	6,481				
Simple	17 - 19	12,104	27,536	112	3,346				
	19 - 21	4,372	27,273	106	506				
C Composita	21 - 23	1,051	26,738	134	126				
Traffic Mode: Intermediate 💌	23 - 25	500	23,748	137	43				
	25 - 27	434	22,415	170	26				
■ Units ■ English Finished Traffic Go to	Clear All	Custom T	raffic			Calcu	ilated ESA	Ls = 323,3	313
C SI Control Panel								2 show	

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.

Example15.mpv							_ 🗆 ×
💻 Spectrum	Basic Interm	nediate A	dvanced]			
	Tire Pressure	100	100	100	100		
	Tire Spacing	13.50	13.50	13.50			
	Axle Spacing		54.00	54.00			
Traffic Input	Structural Numb	ber = 3.2	Pt 🛛	2.5			Use WIM Data
_ First Year	Axle Weight (kips)	Dual	00) 🔽 Tandem	Tridem	0 🔽 Steer	0 🗖 00 🗖 Single Tandem	000 🗖 🔺
Design Lane	1-3	0.0003	0.0001	0.0000	0.0003		
	3-5	0.003	0.0004	0.0001	0.003		
343	5 - 7	0.016	0.002	0.0005	0.016		
5 · 17 / 3	7-9	0.049	0.005	0.001	0.049		
Design Life (years)	9 - 11	0.120	0.011	0.003	0.120		
20	11 - 13	0.230	0.022	0.005	0.230		
	13 - 15	0.400	0.040	0.010	0.400		
Annual Growth Rate (%)	15 - 17	0.650	0.067	0.016	0.650		
Simple	17 - 19	1.00	0.110	0.026	1.00		
G Compound	19 - 21	1.48	0.160	0.040	1.48		
O composita	21 - 23	2.14	0.230	0.057	2.14		
Traffic Mode: Intermediate 💌	23 - 25	3.01	0.310	0.081	3.01		
	25 - 27	4.16	0.420	0.110	4.16		<u> </u>
Units English Finished Traffic Go to	Clear All	Load Equ	ivalency F	actors		Calculated ES/	ALs = 323,313
Uontrol Panel							

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 $N_F = CK_{F1} \varepsilon_h^{K_{F2}} E^{K_{F3}}$ Where C = Correction factor 0.314	Model [To add a new model, type a name in the box and click "Add". [C C C Constant C Calculated HMA (in/in)	MnPAVE Add K_{F1} K_{F2} K_{F3}	Delete 1.2 -3.291 -0.854
E = HMA Dynamic Modulus (psi)			
🔲 Use polymer shift factor			
Allowed Repetitions for Rutting $N_R = K_{R1} arepsilon_{ u}^{K_R}$ Where	Model [To add a new model, type a name in the box and click "Add".	MnPAVE Add	Delete 0.0261
$c_{\mathcal{V}}$ = vertical compressive strain at top of	H.B. Kim Model	K_{R2}	-2.35
	C	ancel	OK

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.

Example1.mpv	
Conf. Level 85 Total Repetitions ESAL 324,000 Expected Life Thickness Goal Seek Layer 1 © 2 O Years Fatigue 46	Basic Batch Mode Reliability
Rutting 20 Adjust Materials H (in.) HMA: PG 58-34 ₹ AggBase: CL5 12 EngSoil: CL 12 UndSoil: CL	Early Late Fall Winter Spring Summer 15.2 1.3 1.6 24.6 57.3 MnPAVE Fatigue 17.2 0.6 1.7 27.0 53.5 MnPAVE Rutting
Recalculate Units Go Back to Control Panel	Export C Design Summary C Damage Details Export to File

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 <u>Thickness Goal Seek</u>. 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 the control 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 a. 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.

Run Batch Process

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.

Example1.mpv	
Example 1.mpv Conf. Level 85 ESAL 324,000 Expected Life Thickness Goal Seek Layer 1 • 2 • Years Fatigue 46 Rutting 20 Adjust Materials H (in.) HMA: PG 58-34 * 4.5 • AggBase: Cl.5 12 •	Basic Batch Mode Reliability ■ Set Damage Limits Minimum Maximum 0.1 1 Batch cycles where MnPAVE damage is not within limits will be excluded from output. Batch Input Layer Thickness, in. Vary Begin End Incr. Set Frost-Free ■ 3.5 6 0.5 Depth, in. ■ 6 18 2 30
EngSoit CL 12 UndSoit CL Recalculate Units © English © SI Go Back to Control Panel	I2 I2 Layer 1 Seek Batch Cycles 24 Run Batch Process

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 <u>Edit Cycles</u> 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.

Example1.mpv		_ 🗆 ×
Output Life Conf. Level 85 Total Repetitions ESAL 324,000 Expected Life Thickness Goal Seek Layer 1 Years Fatigue 46 Rutting 20 Adjust Materials H (in.) HMA: PG 58-34 4.5 AggBase: CL 12 EngSoit CL Recelculate Units Go Back to Control Panel	Basic Batch Mode Reliability Monte Carlo Simulation Rum Monte Carlo Simulation Automatically Save when finished. Automatically Save when finished. Automatically Save when finished. Include Details from all Cycles (must be selected prior to simulation) Reliability (probability of non-failure during 20 year design life) Quick Monte Carlo 100 100 % Select Output File 98 99.9 % Run Quick Output was saved as "Example1.xls"	

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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WESLEA

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