Pavement Structural Analysis Tool (PSAT) for Iowa Local Roads

User Guide
March 2023

IOWA STATE UNIVERSITY
Institute for Transportation

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16. Abstract

Iowa has three classes of public roads: state primary highways, county (secondary) roads, and city streets. Among these, Iowa county roads serve rural Iowa transport needs by assuring a public road connection (i.e., to local access roads) for serving as conduits that channel the flow of people and commodities to and from towns and terminals (i.e., farm-to-market roads). Many Iowa county pavement systems are multilayered structures that have experienced multiple cycles of construction and renewal that make it more complex to estimate pavement structures' current structural capacities.

This study developed a Microsoft Excel macro and Visual Basic for Applications (VBA)-based automated Pavement Structural Analysis Tool (PSAT) with three analyzing options—asphalt concrete (AC) pavement systems with 1 to 10 layers on a (1) stabilized base, (2) granular base, and (3) stabilized base and granular base—to estimate the current structural capacities of in-service pavement systems by following consecutive sections within the user-friendly platform. In addition, the equivalent layer theory (ELT) concept was integrated into the PSAT to simplify multilayered pavement systems into three-layered systems—an asphalt layer, a base layer, and a subgrade layer. Thus, it could make it easier for an Iowa county engineer to understand the current structural capacities of in-service county pavements. Mechanistic- and empirical-based approaches were also integrated into the tool to estimate the remaining service life (RSL) associated with two types of major failures for flexible pavements, namely fatigue and rutting failures.

The PSAT is expected to be used as part of routine pavement analysis, design, and asset management practices for better prioritization and allocation of resources, as well as to support effective communication related to pavement needs both with the public and with elected officials.

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PAVEMENT STRUCTURAL ANALYSIS TOOL (PSAT) FOR IOWA LOCAL ROADS

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User Guide
March 2023

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USING THE PSAT

The Pavement Structural Analysis Tool (PSAT) is a Microsoft Excel, macro, and Visual Basic for Applications (VBA)-based automation tool that is comprised of several consecutive subsections. Depending on the version of the operating system, various security warning messages may appear, or the tool may appear in a different font when the tool is first run. The system requirements to run this tool are Excel 2016 and VBA in Windows and Excel 2022–2023 and VBA in Mac.

It should be noted that the PSAT is a macro-enabled automation tool. The question "This workbook contains macros. Do you want to disable macros before opening the file?" may be asked to the user while opening the PSAT. The user should click Enable Macros before proceeding further. For Windows users, when clicking any macro-based button in the tool, if the error of "Run-time error '1004': No link to paste" appears, click "OK" to ignore this error, and click the macro-based button again.

Document Scope

This user guide describes a systematic procedure on how to use the PSAT that helps local agencies more effectively make decisions related to routine pavement analysis, design, and asset management practices and to support their communication related to pavement needs both with the public and with elected officials.

Overview of PSAT Features

The tool has been developed to navigate subsections and analyze three different pavement types: (1) asphalt concrete (AC) on a stabilized base, (2) AC on a granular base, and (3) AC on a stabilized base and granular base.

Artificial intelligence (AI)-based models have been used to predict critical deflections and strains, and the predicted pavement responses have been used to identify mechanistic-based (fatigue and rutting failures) and empirical-based (structural number [SN]) failures. The damage due to fatigue and rutting has then been calculated for specified traffic levels and results from the failure model. The remaining service life (RSL) has been estimated based on current damage. In addition, the equivalent layer theory (ELT) concept was integrated into the PSAT to simplify multilayered pavement systems into three-layered systems—an asphalt layer, a base layer, and a subgrade layer—for better understanding the current structural capacities of in-service county pavements.

The PSAT has also been developed to simultaneously analyze two pavement systems, helping to compare two different pavement sections at the same time, and to analyze them from beginning to end on the same platform, i.e., from predicting critical pavement responses to estimating their RSLs based on major flexible pavement failures.

Overall, the PSAT allows the user to analyze two different pavement systems and one pavement system for multiple purposes under the following scenarios:

- *Structural capacity comparison*: Two different pavement systems (given as PS-1 and PS-2) simultaneously to compare them structurally
- *Traffic effect*: One pavement system entered in both the PS-1 and PS-2 sections using different axle load weight to understand the traffic effect on the results
- *Modulus effect*: One pavement system entered in both the PS-1 and PS-2 sections using different equivalent modulus to understand the modulus effect on the equivalent thickness
- *Structural capacity*: One pavement system at a time (entered in either PS-1 or PS-2)

PSAT Data Entry Features

Within the PSAT, cell representation is presented as legend including the following (Figure 1):

- The red-colored cells indicate subsection titles
- The green-colored cells indicate positions for user input
- The white-colored cells indicate either predicted/computed outputs or unit conversions
- The gray-colored boxes indicate macro-based buttons that users should click to make selections
- The other colors in the cells are for labeling inputs or outputs

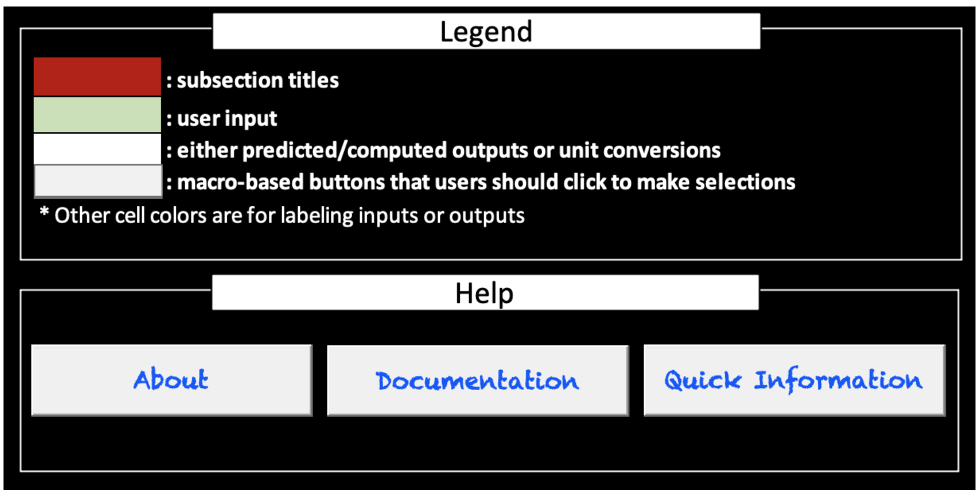


Figure 1. PSAT cell representation

The PSAT tool also provides a Help section that includes the following (see Figure 1):

- *About*: Information about the tool development and developers
- *Documentation*: Links to access final report and PSAT user guide
- *Quick Information:* Brief information about the analysis concepts used in the PSAT

The user is asked to enter and/or edit data only within green-colored cells and is not allowed to change information in other cells, i.e., all cells except green-colored cells are locked and protected within the tool. While US units were mainly used in developing the models and algorithms, the tool can convert its data to the International System of Units (SI) for illustration purposes, although input parameters must be entered in US units.

The tool first asks users to enter the following project information (Figure 2):

- Project Name: Descriptions for the road, e.g., street name
- County Name
- Project No.: Number (ID) of the project
- BPRJ: Beginning of the project
- EPRJ: Ending of the project

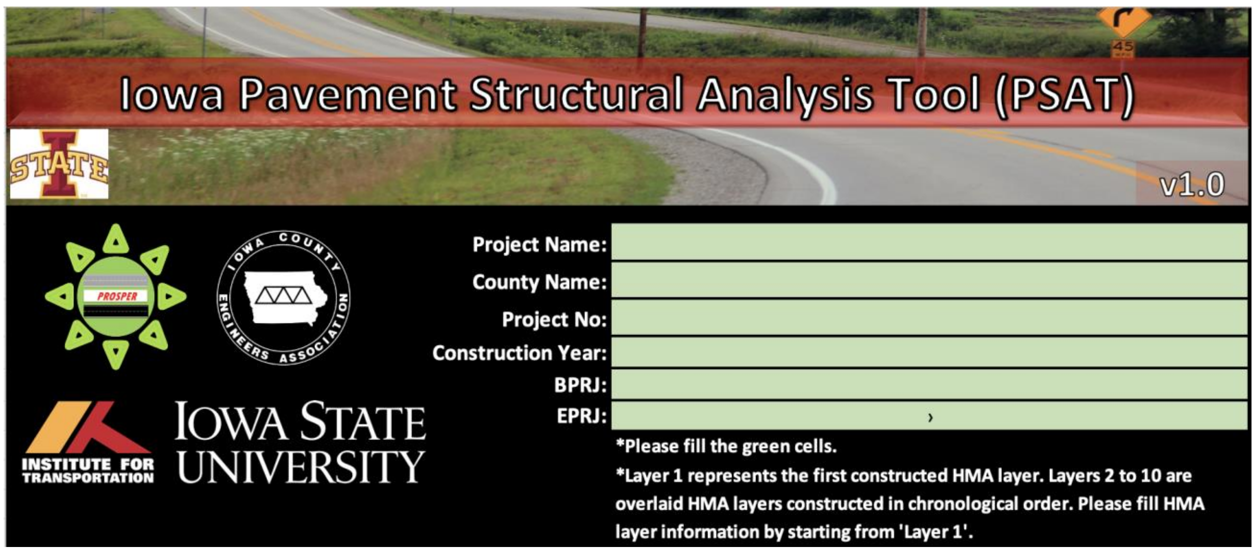
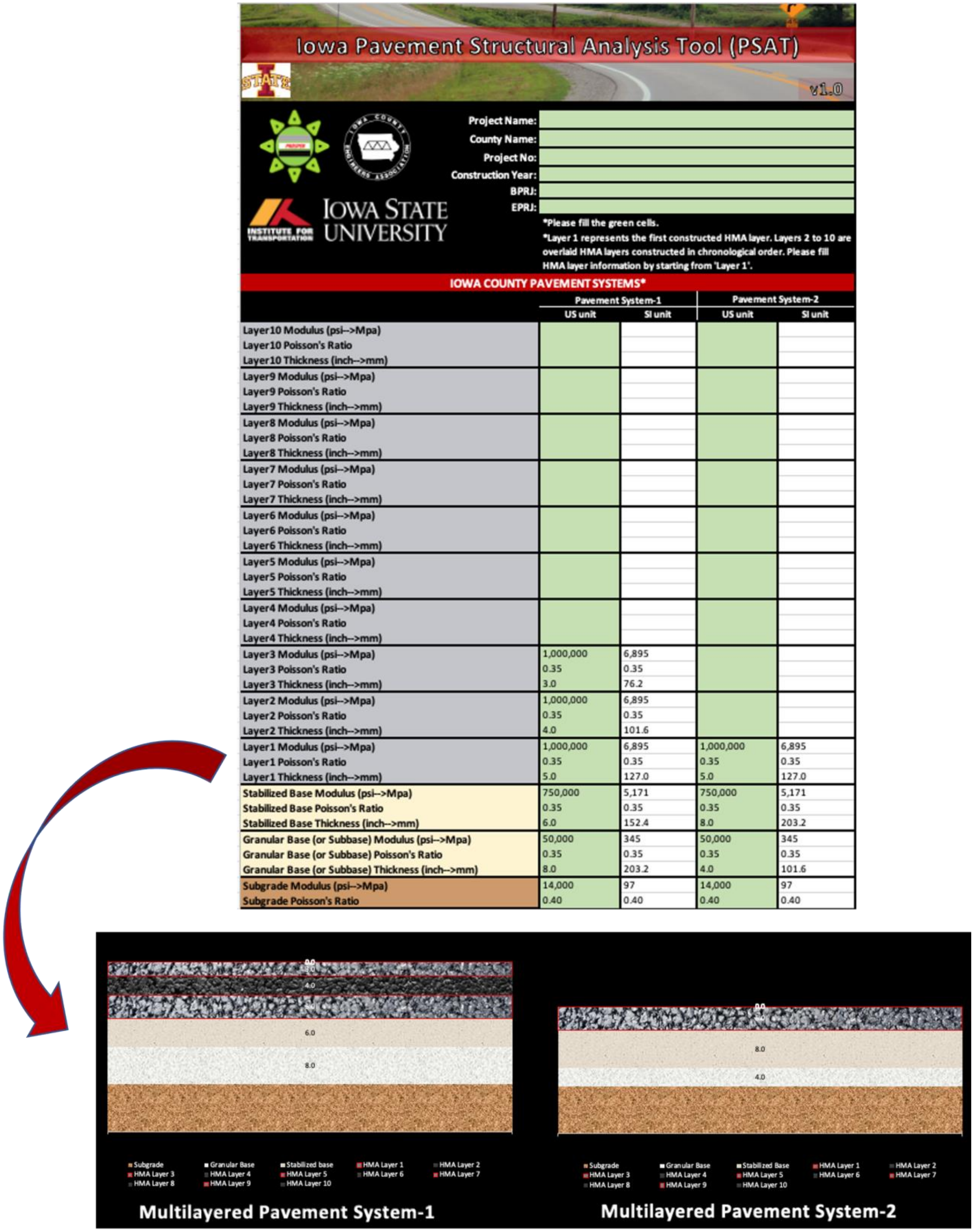


Figure 2. PSAT project information

PSAT Section Panels

Input Panel

The input panel under the heading Iowa County Pavement Systems (Figure 3) requests the user to enter input parameters related to structural design and mechanical properties of pavement layers for a pavement system (i.e., elastic modulus, Poisson’s ratio, and layer thickness). Pavement System-1 and Pavement Sytem-2 represent two different pavement systems for which a user can provide pavement information and analyze simultaneously.


Iowa Pavement Structural Analysis Tool (PSAT)

v1.0

Project Name:
County Name:
Project No:
Construction Year:
BPRJ:
EPRJ:

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*Please fill the green cells.
*Layer 1 represents the first constructed HMA layer. Layers 2 to 10 are overlaid HMA layers constructed in chronological order. Please fill HMA layer information by starting from 'Layer 1'.

IOWA COUNTY PAVEMENT SYSTEMS*

	Pavement System-1		Pavement System-2	
	US unit	SI unit	US unit	SI unit
Layer10 Modulus (psi-->Mpa)				
Layer10 Poisson's Ratio				
Layer10 Thickness (inch-->mm)				
Layer9 Modulus (psi-->Mpa)				
Layer9 Poisson's Ratio				
Layer9 Thickness (inch-->mm)				
Layer8 Modulus (psi-->Mpa)				
Layer8 Poisson's Ratio				
Layer8 Thickness (inch-->mm)				
Layer7 Modulus (psi-->Mpa)				
Layer7 Poisson's Ratio				
Layer7 Thickness (inch-->mm)				
Layer6 Modulus (psi-->Mpa)				
Layer6 Poisson's Ratio				
Layer6 Thickness (inch-->mm)				
Layer5 Modulus (psi-->Mpa)				
Layer5 Poisson's Ratio				
Layer5 Thickness (inch-->mm)				
Layer4 Modulus (psi-->Mpa)				
Layer4 Poisson's Ratio				
Layer4 Thickness (inch-->mm)				
Layer3 Modulus (psi-->Mpa)	1,000,000	6,895		
Layer3 Poisson's Ratio	0.35	0.35		
Layer3 Thickness (inch-->mm)	3.0	76.2		
Layer2 Modulus (psi-->Mpa)	1,000,000	6,895		
Layer2 Poisson's Ratio	0.35	0.35		
Layer2 Thickness (inch-->mm)	4.0	101.6		
Layer1 Modulus (psi-->Mpa)	1,000,000	6,895	1,000,000	6,895
Layer1 Poisson's Ratio	0.35	0.35	0.35	0.35
Layer1 Thickness (inch-->mm)	5.0	127.0	5.0	127.0
Stabilized Base Modulus (psi-->Mpa)	750,000	5,171	750,000	5,171
Stabilized Base Poisson's Ratio	0.35	0.35	0.35	0.35
Stabilized Base Thickness (inch-->mm)	6.0	152.4	8.0	203.2
Granular Base (or Subbase) Modulus (psi-->Mpa)	50,000	345	50,000	345
Granular Base (or Subbase) Poisson's Ratio	0.35	0.35	0.35	0.35
Granular Base (or Subbase) Thickness (inch-->mm)	8.0	203.2	4.0	101.6
Subgrade Modulus (psi-->Mpa)	14,000	97	14,000	97
Subgrade Poisson's Ratio	0.40	0.40	0.40	0.40

Figure 3. PSAT input panel

Not all green cells in the input panel need to be filled in, but the data for each pavement layer must be filled in. The panel inputs are as follows:

- Layer 10 Modulus, Poisson's Ratio, and Thickness
- Layer 9 Modulus, Poisson's Ratio, and Thickness
- Layer 8 Modulus, Poisson's Ratio, and Thickness
- Layer 7 Modulus, Poisson's Ratio, and Thickness
- Layer 6 Modulus, Poisson's Ratio, and Thickness
- Layer 5 Modulus, Poisson's Ratio, and Thickness
- Layer 4 Modulus, Poisson's Ratio, and Thickness
- Layer 3 Modulus, Poisson's Ratio, and Thickness
- Layer 2 Modulus, Poisson's Ratio, and Thickness
- Layer 1 Modulus, Poisson's Ratio, and Thickness
- Stabilized Base Modulus, Poisson's Ratio, and Thickness
- Granular Base Modulus, Poisson's Ratio, and Thickness
- Subgrade Modulus and Poisson's Ratio

It is important to note that Layer 1 represents the first constructed hot-mix asphalt (HMA) layer, while Layers 2 through 10 are overlaid HMA layers constructed in chronological order. For example, if the pavement system has four HMA layers, the user should enter the oldest layer as Layer 1 and the newest overlaid layer as Layer 4.

The visualization panel (see Figure 3) will display the multilayered pavement structure(s) entered through the input panel.

Pavement Response Prediction Panel

In the prediction of pavement responses panel (Figure 4, left panel), deflections and strains at specified points (e.g., surface, bottom of the asphalt layer, and top of the subgrade) are predicted when the Predict Deflections and Predict Strains buttons, respectively, are clicked.

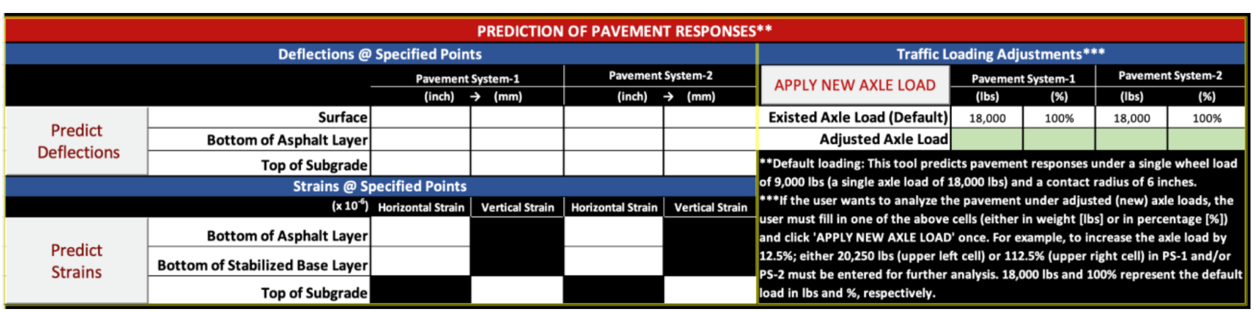

Figure 4. PSAT pavement response prediction panel

For the pavement types of "AC on a stabilized base" and "AC on a stabilized base and granular base," the following responses are predicted:

- Deflections on the surface
- Deflections at the bottom of the asphalt layer
- Deflections at the top of the subgrade
- Horizontal strains at the bottom of the asphalt layer
- Horizontal strains at the bottom of the stabilized base layer
- Vertical strains at the top of the subgrade

For the pavement type of “AC on a granular base,” the following responses are predicted:

- Deflections on the surface
- Deflections at the bottom of the asphalt layer
- Deflections at the top of the subgrade
- Horizontal strains at the bottom of the asphalt layer
- Vertical strains at the top of the subgrade

To accurately predict pavement responses, users should click the buttons (Predict Deflections and Predict Strains) after they change information in the input panel.

The PSAT predicts pavement responses under a single wheel load of 9,000 lb (a single axle load of 18,000 lb) and a contact radius of 6 in. If a user wants to analyze the pavement under adjusted (new) axle loads, the user should enter those data in the Traffic Loading Adjustments panel shown in Figure 4 (right panel). The adjusted axle load can be entered either in weight (lb) or in percentage (%). After the user clicks the APPLY NEW AXLE LOAD button once, the pavement responses (i.e., deflections and strains) shown in Figure 4 (left panel) for PS-1 and/or PS-2 are automatically predicted under the adjusted axle loading. For example, to increase the axle load by 12.5%, either 20,250 lb or 112.5% in PS-1 and/or PS-2 must be entered properly for further analysis. The default load is 18,000 lb and 100% for weight (lb) and percentage (%), respectively.

Equivalent Thickness Calculation Panel

There are two steps in calculation of equivalent thickness (Figure 5).

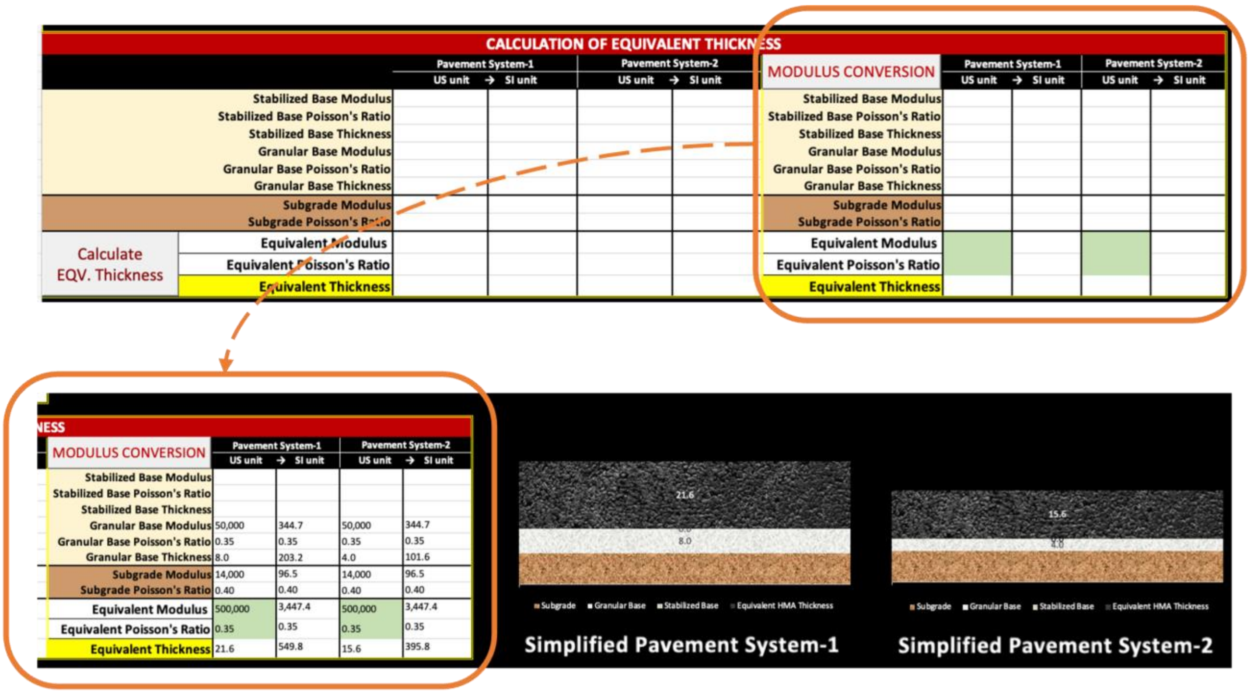

Figure 5. PSAT equivalent thickness calculation panel

In the first step (Figure 5, upper left panel), the equivalent thickness for the HMA layers based on the given inputs is calculated, i.e., a combination of overlaid layers with different thicknesses and moduli are simplified into one layer with an equivalent thickness. If the pavement system is AC on a stabilized base, the HMA layers over the stabilized base are simplified into one layer. If the pavement system is AC on a granular base, the HMA layers over the granular base are simplified into one layer. If the pavement system is AC on a stabilized base and granular base, the HMA layers and the stabilized base layer over the granular base are simplified. The final pavement simplified structure is always a three-layered system (i.e., an HMA layer, a base layer, and a subgrade layer).

The PSAT provides an option for simultaneously analyzing two pavement systems, and the user can simplify two different pavement structures at the same time in this panel. While the structural capacities of pavement systems are represented by equivalent thicknesses here (i.e., the higher the equivalent thickness, the higher the structural capacity), the equivalent moduli and Poisson’s ratios of the simplified structures might be different.

In the second step (modulus conversion under equivalent thickness calculation panel, Figure 5, upper right panel), the user might assign a constant equivalent modulus and Poisson’s ratio value to convert the calculated equivalent modulus and Poisson’s ratio from the first step for both pavement cases. When clicking the Modulus Conversion button, the equivalent thickness value for the HMA layers is shown for the given pavement systems with the same modulus and Poisson’s ratio.

This section of the tool will assist the user in visualizing different multilayered project-level pavement systems as three-layered pavement systems (an HMA layer, a base layer, and a subgrade layer) and compare them to seek better understanding of their structural capacities. The visualization panel (Figure 5, lower right panel) will display the simplified pavement structure(s) and reflect the results of the first step if the user has not used the Modulus Conversion section. If the user converts one modulus to a given modulus, the visualization panel will reflect the results from the second step.

Traffic Calculation Panel

In the calculation of traffic panel (Figure 6), the accumulated traffic value for the given pavement section is calculated using the parameters listed below.

CALCULATION OF ACCUMULATED TRAFFIC		
Calculation of Accumulated Traffic	Pavement System - 1	Pavement System- 2
Construction Year:		
ADT Year:		
Two-way ADT:		
Directional Distribution Factor (%):		
Design Lane Distribution Factor (%):		
Growth Rate (%):		
Percent Trucks (%):		
Truck Factor:		
Calculate Accumulated Traffic_current		

Figure 6. PSAT traffic calculation panel

Equation 1 from the American Association of State Highway and Transportation Officials (AASHTO) pavement design guide (AASHTO 1993) is used in the traffic calculation for equivalent single axle loads (ESALs), with the following parameters:

- Construction year
- Average daily traffic (ADT) year
- Two-way ADT
- Directional distribution factor (%), D_D
- Design lane distribution factor (%), D_L
- Growth rate (%), $GR_{\%}$
- Percent trucks (%), $T_{\%}$
- Truck factor, TF

ESALs = (two-way ADT) × (365 days/year) × $(T_{\%}) \times (GR_{\%}) \times (TF) \times (D_D) \times (D_L)$ **(1)**

Typical ranges for these parameters are as follows:

- **Two-way ADT:** Typical ranges are 50 to 800 vehicles for residential streets, 700 to 5,000 vehicles for collectors, and 3,000 to 50,000+ vehicles for arterials.
- **Directional distribution factor (%), $\boldsymbol{D_D}$:** A 50-50 split between traffic in each direction on the roadway typically is used (e.g., a Directional Distribution of 50%).
- **Design lane distribution factor (%), $\boldsymbol{D_L}$:** Design lane distribution refers to the percentage of vehicles in one direction that use one lane of the roadway the most. For example, on a four-lane divided highways (e.g., two lanes in each direction), 90% of the traffic on average uses the right (or driving) lane and 10% of the traffic uses the left (or passing) lane.
- **Growth rate (%), $\boldsymbol{GR_{\%}}$:** Growth rates typically range from 1% to 3% per year; this growth rate is applied to all traffic, not just trucks.
- **Percentage of trucks (%), $\boldsymbol{T_{\%}}$:** Typical ranges include 1% to 3% for residential streets, 3% to 15% for collectors, and 5% to 30% for arterials.
- **Truck factor, $\boldsymbol{TF}$:** The truck factor can be calculated using equation 2.

$$\mathrm{TF} = \left(\sum_{i=1}^{m} p_i F_i\right)(A) \qquad \textbf{(2)}$$

where:

TF = Truck factor
p_i = % of total repetitions for ith load group
F_i = Equivalent axle load factor (EALF) for ith load group
A = Average number of axles per truck

In the current version of the PSAT, the following assumptions are made: (1) p_i = 100% and (2) A = 1 due to the analysis done for a single axle load. The TF depends on the F_i value, which can be calculated by using the Fourth Power Law that states that the stress on the road increases proportionally to the fourth power of the axle load of the vehicle traveling on the road based on the empirical approach.

If the user does not adjust the axle load weight, F_i will be 1 for both PS-1 and PS-2, so TF is equal to 1. Keeping other traffic inputs in the traffic panel the same, the accumulated traffic will be same for both pavement cases. However, for example, when the adjusted (new) axle load is defined to be 20,250 lb instead of 18,000 lb, F_i would be $(20{,}250/18{,}000)^4 = 1.6$. Thus, TF will be calculated as (100% × 1.6) × (1) = 1.6. This computed value for TF is shown in the cell of Computed Truck Factor in the traffic panel and used to calculate accumulated traffic.

Failure Identification Panel

In the identification of failure panel (Figure 7), using the mechanistic-based approach, allowable load repetitions for fatigue and rutting failure are computed based on predicted pavement responses and given modulus values, while using the empirically based approach, the SN of pavement layers are computed based on given layer thickness values.

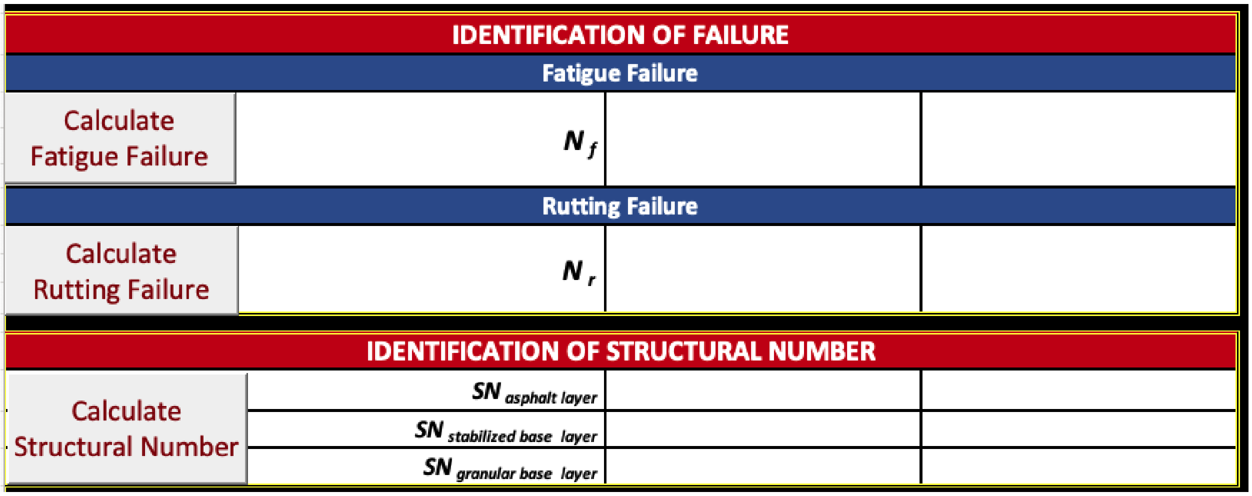

Figure 7. PSAT failure identification panel

Fatigue (N_f) and/or rutting (N_r) failure may not be calculated due to prediction of compressive or tensile strain, incorrect filling of the input panel, or no prediction of strain. In this case, the tool shows a message stating that no N_f/N_r is calculated (Figure 8).

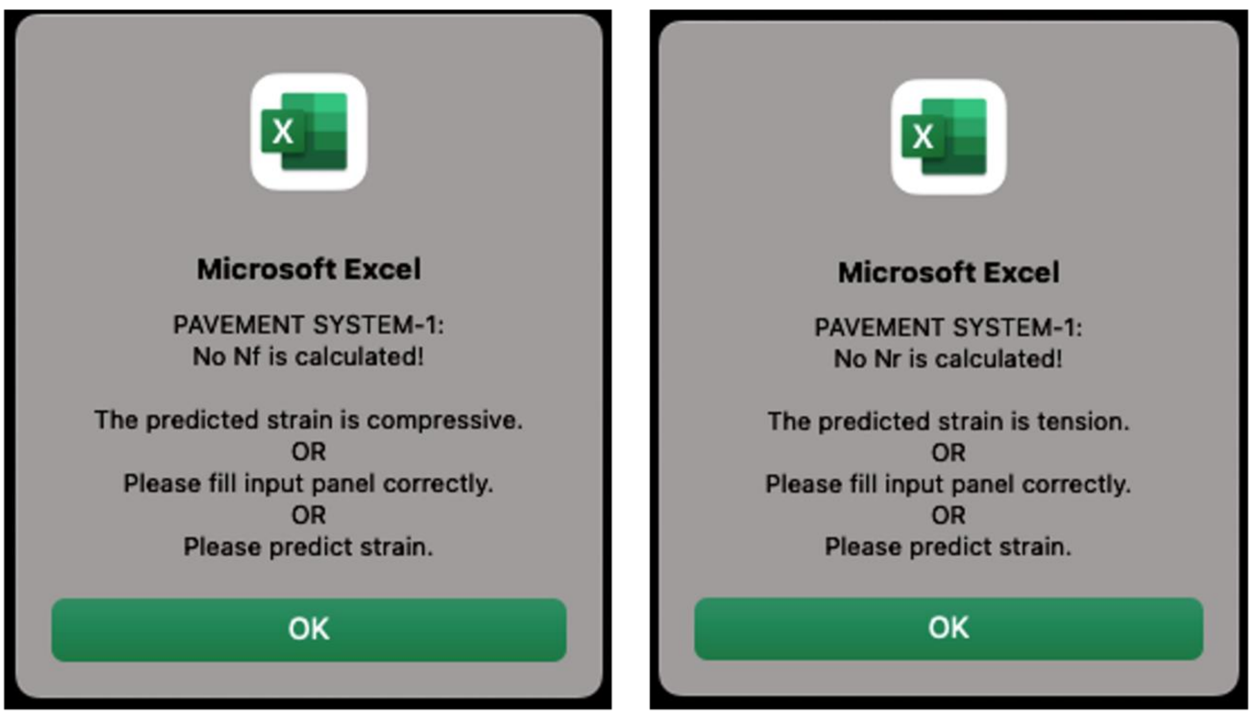

Figure 8. Message box for an error in failure identification

Damage Calculation Panel

In the calculation of damage panel (Figure 9), the damage ratio (DR), given as a percent, due to fatigue and rutting failure results is calculated. Here, the accumulated ESAL as current accumulated traffic should be entered so that damage can be computed.

CALCULATION OF DAMAGE			
Damage due to Fatigue			
Calculate Fatigue Damage	Accumulated ESAL_current		
	Damage_current (%)		
Damage due to Rutting			
Calculate Rutting Damage	Accumulated ESAL_current		
	Damage_current (%)		

Figure 9. PSAT damage calculation panel

If the user does not have the current ESAL value, the parameters in the traffic panel, including current ADT, should be known and can be used to calculate the accumulated traffic value, after which the tool automatically uses this calculated value for damage calculation. The user should enter the traffic information in either the Accumulated ESAL_current cell (Figure 9) or the traffic panel (see Figure 6).

RSL Estimation Panel

In the estimation of RSL panel (Figure 10), the RSL is estimated based on the predictions and calculations from previous sections. The user does need to enter the design life for a given road section.

ESTIMATION OF REMAINING SERVICE LIFE (RSL)			
RSL due to Fatigue			
Estimate RSL_fatigue	Design Life (years)		
	RSL_current (years)		
RSL due to Rutting			
Estimate RSL_rutting	Design Life (years)		
	RSL_current (years)		

Figure 10. PSAT RSL estimation panel

Then, the RSL is estimated using equation 3.

$$RSL = \text{Design life} - \text{Design life} \; x \; DR \quad \textbf{(3)}$$

ILLUSTRATIVE EXAMPLES: PAVEMENT ANALYSIS USING THE PSAT

Examples of a structural analysis of the pavement types of (1) AC on a stabilized base, (2) AC on a granular base, and (3) AC on a stabilized base and granular base using AI-based models and algorithms are examined in the following sections.

AC on a Stabilized Base Case

The input panel, shown in Figure 11, was filled with data for a given pavement structure as follows:

- Layer1 Modulus: 1,500,000 psi
- Layer1 Poisson’s Ratio: 0.35
- Layer1 Thickness: 4.0 in.
- Stabilized Base Modulus: 750,000 psi
- Stabilized Base Poisson’s Ratio: 0.35
- Stabilized Base Thickness: 6.0 in.
- Subgrade Modulus: 14,000 psi
- Subgrade Poisson’s Ratio: 0.40 in.

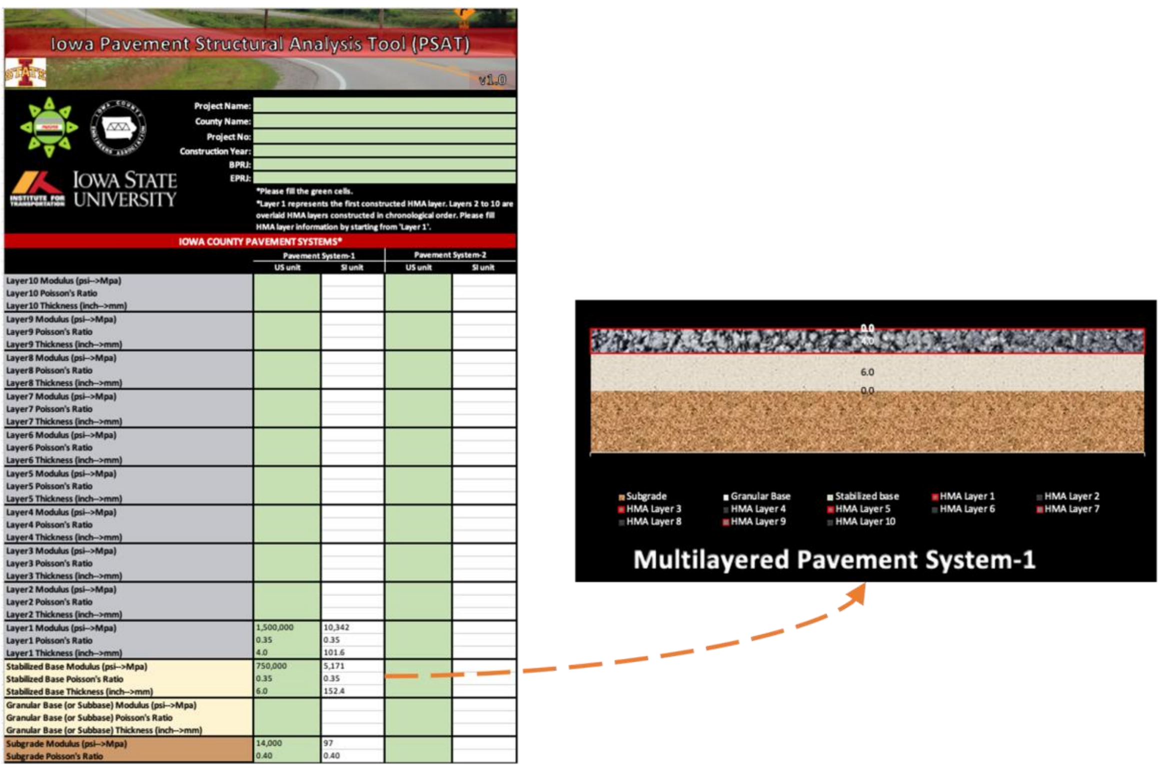

Figure 11. Fill the input panel: AC on stabilized base case

The Predict Deflections and Predict Strains buttons were then clicked, and the predicted pavement responses are shown in Figure 12.

PREDICTION OF PAVEMENT RESPONSES**

Deflections @ Specified Points		Pavement System-1 (inch)	→ (mm)	Pavement System-2 (inch)	→ (mm)
Predict Deflections	Surface	0.00868	0.220		
	Bottom of Asphalt Layer	0.00862	0.219		
	Top of Subgrade	0.00829	0.211		
Strains @ Specified Points					
	(x 10^{-6})	Horizontal Strain	Vertical Strain	Horizontal Strain	Vertical Strain
Predict Strains	Bottom of Asphalt Layer	18			
	Bottom of Stabilized Base Layer	78			
	Top of Subgrade		-225		

Traffic Loading Adjustments***	Pavement System-1 (lbs)	(%)	Pavement System-2 (lbs)	(%)
APPLY NEW AXLE LOAD				
Existed Axle Load (Default)	18,000	100%	18,000	100%
Adjusted Axle Load				

**Default loading: This tool predicts pavement responses under a single wheel load of 9,000 lbs (a single axle load of 18,000 lbs) and a contact radius of 6 inches.
***If the user wants to analyze the pavement under adjusted (new) axle loads, the user must fill in one of the above cells (either in weight [lbs] or in percentage [%]) and click 'APPLY NEW AXLE LOAD' once. For example, to increase the axle load by 12.5%; either 20,250 lbs (upper left cell) or 112.5% (upper right cell) in PS-1 and/or PS-2 must be entered for further analysis. 18,000 lbs and 100% represent the default load in lbs and %, respectively.

Figure 12. Predict pavement responses: AC on stabilized base case

The traffic panel was then filled with the required parameter values and the Calculate Accumulated Traffic_current button was clicked to convert a given ADT value to an accumulated traffic value (Figure 13).

CALCULATION OF ACCUMULATED TRAFFIC

Calculation of Accumulated Traffic	Pavement System - 1	Pavement System- 2
Construction Year:	2009	
ADT Year:	2018	
Two-way ADT:	500	
Directional Distribution Factor (%):	50	
Design Lane Distribution Factor (%):	100	
Growth Rate (%):	2.0	
Percent Trucks (%):	5.0	
Truck Factor:	1.0	
Calculate Accumulated Traffic_current	41,730	

Figure 13. Calculate accumulated ESAL: AC on a stabilized base case

In the failure and SN identification panels, the buttons Calculate Fatigue Failure, Calculate Rutting Failure, and Calculate Structural Number were clicked to predict the allowable load repetitions to fatigue (N_f) failure, rutting (N_r) failure, and SN (Figure 14).

IDENTIFICATION OF FAILURE			
Fatigue Failure			
Calculate Fatigue Failure	N_f	10,446,523	
Rutting Failure			
Calculate Rutting Failure	N_r	29,265,785	

IDENTIFICATION OF STRUCTURAL NUMBER			
Calculate Structural Number	$SN_{asphalt\ layer}$	2.6	
	$SN_{stabilized\ base\ layer}$	1.2	
	$SN_{granular\ base\ layer}$		

Figure 14. Identify failures and SN: AC on a stabilized base case

In the damage calculation panel, since the traffic panel was filled and the accumulated traffic value was calculated, so there is no need to enter any value into the Accumulated ESAL_current cell in Figure 15. The calculated accumulated traffic was automatically used in the calculation of fatigue and rutting damage.

CALCULATION OF DAMAGE			
Damage due to Fatigue			
Calculate Fatigue Damage	Accumulated ESAL_current		
	Damage_current (%)	0.40%	Please calculate Nf!
Damage due to Rutting			
Calculate Rutting Damage	Accumulated ESAL_current		
	Damage_current (%)	0.14%	Please calculate Nr!

Figure 15. Calculate fatigue and rutting damage: AC on a stabilized base case

When there is not enough information for the Pavement System-2 fields, the fatigue and rutting damage cannot be calculated, and the fatigue and rutting damage cells indicate “Please calculate Nf!” and “Please calculate Nr!,” respectively (Figure 15).

The design life was then specified, and the buttons Estimate RSL_fatigue and Estimate RSL_rutting were clicked to estimate RSLs related to fatigue and rutting damage (Figure 16).

ESTIMATION OF REMAINING SERVICE LIFE (RSL)			
RSL due to Fatigue			
Estimate RSL_fatigue	Design Life (years)	20	20
	RSL_current (years)	19.9	Please calculate Nf!
RSL due to Rutting			
Estimate RSL_rutting	Design Life (years)	20	20
	RSL_current (years)	20.0	Please calculate Nr!

Figure 16. Estimate RSL: AC on a stabilized base case

AC on a Granular Base Case

The input panel was filled with the pavement structure data as follows (Figure 17):

- Layer1 Modulus: 1,000,000 psi
- Layer1 Poisson's Ratio: 0.35
- Layer1 Thickness: 4.0 in.
- Granular Base (or Subbase) Modulus: 40,000
- Granular Base (or Subbase) Poisson's Ratio: 0.35
- Granular Base (or Subbase) Thickness: 4.0 in.
- Subgrade Modulus: 8,000 psi
- Subgrade Poisson's Ratio: 0.40 in.

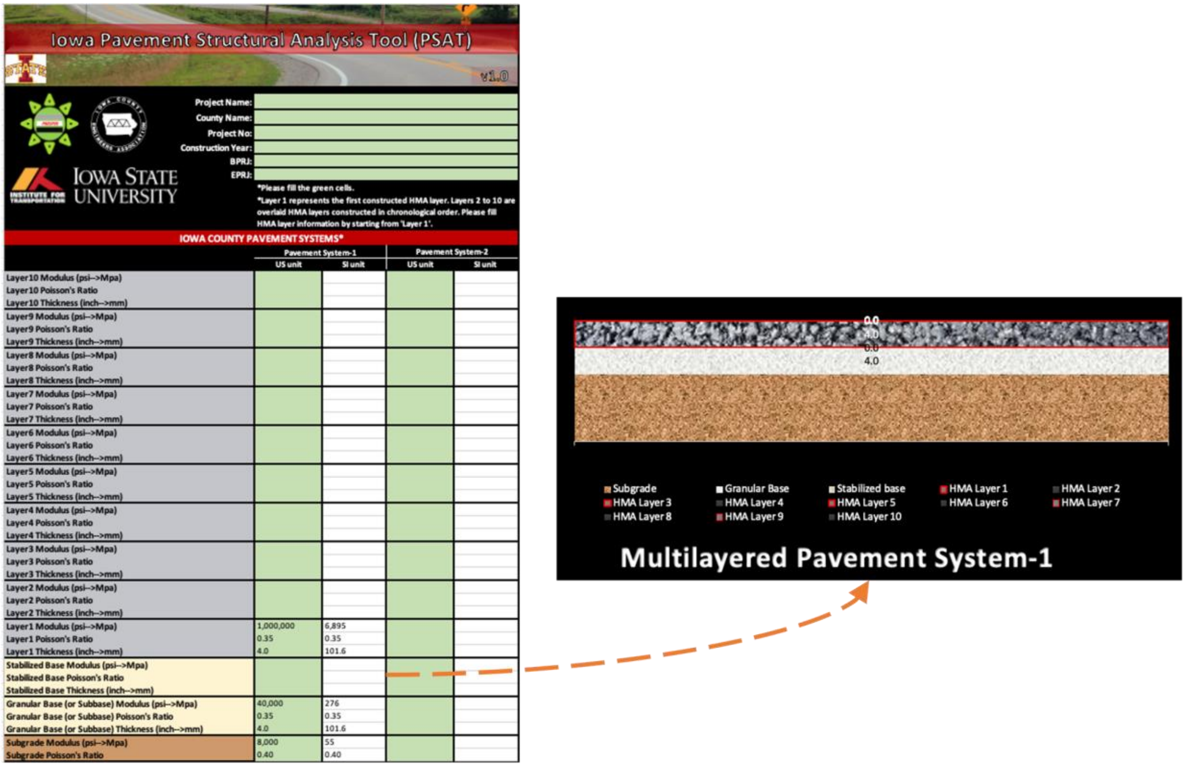

Figure 17. Fill the input panel: AC on a granular base case

The Predict Deflections and Predict Strains were next clicked, and the pavement responses were predicted (Figure 18).

PREDICTION OF PAVEMENT RESPONSES**

Deflections @ Specified Points		Pavement System-1 (inch)	→ (mm)	Pavement System-2 (inch)	→ (mm)
Predict Deflections	Surface	0.02593	0.659		
	Bottom of Asphalt Layer	0.02597	0.660		
	Top of Subgrade	0.02417	0.614		
Strains @ Specified Points	$(\times 10^{-6})$	Horizontal Strain	Vertical Strain	Horizontal Strain	Vertical Strain
Predict Strains	Bottom of Asphalt Layer	224			
	Bottom of Stabilized Base Layer				
	Top of Subgrade		-997		

Traffic Loading Adjustments***

APPLY NEW AXLE LOAD	Pavement System-1 (lbs)	Pavement System-1 (%)	Pavement System-2 (lbs)	Pavement System-2 (%)
Existed Axle Load (Default)	18,000	100%	18,000	100%
Adjusted Axle Load				

**Default loading: This tool predicts pavement responses under a single wheel load of 9,000 lbs (a single axle load of 18,000 lbs) and a contact radius of 6 inches.
***If the user wants to analyze the pavement under adjusted (new) axle loads, the user must fill in one of the above cells (either in weight [lbs] or in percentage [%]) and click 'APPLY NEW AXLE LOAD' once. For example, to increase the axle load by 12.5%; either 20,250 lbs (upper left cell) or 112.5% (upper right cell) in PS-1 and/or PS-2 must be entered for further analysis. 18,000 lbs and 100% represent the default load in lbs and %, respectively.

Figure 18. Predict pavement responses: AC on a granular base case

The traffic panel was next filled with the required parameters and the Calculate Accumulated Traffic_current button was clicked to convert a given ADT to an accumulated traffic (Figure 19).

CALCULATION OF ACCUMULATED TRAFFIC		
Calculation of Accumulated Traffic	**Pavement System - 1**	**Pavement System- 2**
Construction Year:	2009	
ADT Year:	2018	
Two-way ADT:	500	
Directional Distribution Factor (%):	50	
Design Lane Distribution Factor (%):	100	
Growth Rate (%):	2.0	
Percent Trucks (%):	5.0	
Truck Factor:	1.0	
Calculate Accumulated Traffic_current	41,730	

Figure 19. Calculate accumulated ESAL: AC on a granular base case

In the failure and SN identification panels, the buttons Calculate Fatigue Failure, Calculate Rutting Failure, and Calculate Structural Number were clicked to predict the allowable load repetitions to fatigue (N_f) failure, rutting (N_r) failure, and the SN (Figure 20).

IDENTIFICATION OF FAILURE			
Fatigue Failure			
Calculate Fatigue Failure	N_f	441,961	
Rutting Failure			
Calculate Rutting Failure	N_r	37,378	
IDENTIFICATION OF STRUCTURAL NUMBER			
Calculate Structural Number	$SN_{asphalt\ layer}$	2.3	
	$SN_{stabilized\ base\ layer}$	0.0	
	$SN_{granular\ base\ layer}$	0.8	

Figure 20. Identify failures and SN: AC on a granular base case

In the damage calculation panel, there is no need to enter any value for the Accumulated ESAL_current cell, since the information was entered in the traffic panel and thus the accumulated traffic value was calculated and automatically used in the calculation of fatigue and rutting damage (Figure 21).

CALCULATION OF DAMAGE			
Damage due to Fatigue			
Calculate Fatigue Damage	Accumulated ESAL_current		
	Damage_current (%)	9.44%	Please calculate Nf!
Damage due to Rutting			
Calculate Rutting Damage	Accumulated ESAL_current		
	Damage_current (%)	Failed!	Please calculate Nr!

Figure 21. Calculate fatigue and rutting damage: AC on a granular base case

Whenever the fatigue and/or rutting damage exceeds 100% damage, the cell for damage will display “Failed!” (Figure 21). As shown in Figure 21, the rutting damage is more than 100%, so the results show that the pavement section failed due to rutting. However, the fatigue damage is 9.44%.

The design life was specified and the buttons Estimate RSL_fatigue and Estimate RSL_rutting were clicked to estimate RSLs due to fatigue and rutting damage (Figure 22).

ESTIMATION OF REMAINING SERVICE LIFE (RSL)			
RSL due to Fatigue			
Estimate RSL_fatigue	Design Life (years)	20	20
	RSL_current (years)	18.1	Please calculate Nf!
RSL due to Rutting			
Estimate RSL_rutting	Design Life (years)	20	20
	RSL_current (years)	Failed!	Please calculate Nr!

Figure 22. Estimate RSL: AC on a granular base case

Whenever the fatigue and/or rutting damage exceeds 100% damage, the cell for RSL will display “Failed!” (Figure 22). In the calculation of damage panel (see the previous Figure 21), since the rutting damage exceeded 100% and it displayed as “Failed!,” there would be no RSL in terms of rutting for the given pavement section. Therefore, the cell for RSL in terms of rutting shows “Failed!” (Figure 22).

AC on a Stabilized Base and Granular Base (or Subbase) Case

The input panel was filled with the given pavement structure as follows (Figure 23):

- Layer1 Modulus: 1,500,000 psi
- Layer1 Poisson’s Ratio: 0.35
- Layer1 Thickness: 4.0 in.
- Stabilized Base Modulus: 750,000 psi
- Stabilized Base Poisson’s Ratio: 0.35

- Stabilized Base Thickness: 6.0 in.
- Granular Base (or Subbase) Modulus: 40,000 psi
- Granular Base (or Subbase) Poisson's Ratio: 0.35
- Granular Base (or Subbase) Thickness: 4.0 in.
- Subgrade Modulus: 8,000 psi
- Subgrade Poisson's Ratio: 0.40 in.

Figure 23. Fill the input panel: AC on stabilized + granular bases case

The Predict Deflections and Predict Strains buttons were clicked, and the pavement responses were predicted (Figure 24).

PREDICTION OF PAVEMENT RESPONSES**						
Deflections @ Specified Points		Pavement System-1		Pavement System-2		
		(inch) →	(mm)	(inch) →	(mm)	
Predict Deflections	Surface	0.01428	0.363			
	Bottom of Asphalt Layer	0.01426	0.362			
	Top of Subgrade	0.01322	0.336			
Strains @ Specified Points	(x 10⁻⁶)	Horizontal Strain	Vertical Strain	Horizontal Strain	Vertical Strain	
Predict Strains	Bottom of Asphalt Layer	31				
	Bottom of Stabilized Base Layer	109				
	Top of Subgrade		-343			

Traffic Loading Adjustments***	Pavement System-1		Pavement System-2	
APPLY NEW AXLE LOAD	(lbs)	(%)	(lbs)	(%)
Existed Axle Load (Default)	18,000	100%	18,000	100%
Adjusted Axle Load				

**Default loading: This tool predicts pavement responses under a single wheel load of 9,000 lbs (a single axle load of 18,000 lbs) and a contact radius of 6 inches.
***If the user wants to analyze the pavement under adjusted (new) axle loads, the user must fill in one of the above cells (either in weight [lbs] or in percentage [%]) and click 'APPLY NEW AXLE LOAD' once. For example, to increase the axle load by 12.5%; either 20,250 lbs (upper left cell) or 112.5% (upper right cell) in PS-1 and/or PS-2 must be entered for further analysis. 18,000 lbs and 100% represent the default load in lbs and %, respectively.

Figure 24. Predict pavement responses: AC on stabilized + granular bases case

The traffic panel was then filled with the required parameters and the Calculate Accumulated Traffic_current button was clicked to convert a given ADT value to an accumulated traffic value (Figure 25).

CALCULATION OF ACCUMULATED TRAFFIC		
Calculation of Accumulated Traffic	Pavement System - 1	Pavement System- 2
Construction Year:	2009	
ADT Year:	2018	
Two-way ADT:	500	
Directional Distribution Factor (%):	50	
Design Lane Distribution Factor (%):	100	
Growth Rate (%):	2.0	
Percent Trucks (%):	5.0	
Truck Factor:	1.0	
Calculate Accumulated Traffic_current	41,730	

Figure 25. Calculate accumulated ESAL: AC on stabilized + granular bases case

In the failure and SN identification panels, the buttons Calculate Fatigue Failure, Calculate Rutting Failure, and Calculate Structural Number were clicked to predict the allowable number of load repetitions to fatigue (N_f) and rutting (N_r) failures and the SN (Figure 26).

IDENTIFICATION OF FAILURE			
Fatigue Failure			
Calculate Fatigue Failure	N_f	3,888,105	
Rutting Failure			
Calculate Rutting Failure	N_r	4,452,797	
IDENTIFICATION OF STRUCTURAL NUMBER			
Calculate Structural Number	$SN_{asphalt\ layer}$	2.6	
	$SN_{stabilized\ base\ layer}$	0.8	
	$SN_{granular\ base\ layer}$	0.8	

Figure 26. Identify failures and SN: AC on stabilized + granular bases case

In the damage calculation panel, there is no need to enter a value for the Accumulated ESAL_current cell, since information was entered in the traffic panel and thus the accumulated traffic value was calculated and automatically used in the calculation of fatigue and rutting damage (Figure 27).

CALCULATION OF DAMAGE			
Damage due to Fatigue			
Calculate Fatigue Damage	Accumulated ESAL_current		
	Damage_current (%)	1.07%	Please calculate Nf!
Damage due to Rutting			
Calculate Rutting Damage	Accumulated ESAL_current		
	Damage_current (%)	0.94%	Please calculate Nr!

Figure 27. Calculate fatigue and rutting damage: AC on stabilized + granular bases case

The design life was specified, and the buttons Estimate RSL_fatigue and Estimate RSL_rutting were clicked to estimate RSLs due to fatigue and rutting damage (Figure 28).

ESTIMATION OF REMAINING SERVICE LIFE (RSL)			
RSL due to Fatigue			
Estimate RSL_fatigue	Design Life (years)	20	20
	RSL_current (years)	19.8	Please calculate Nf!
RSL due to Rutting			
Estimate RSL_rutting	Design Life (years)	20	20
	RSL_current (years)	19.8	Please calculate Nr!

Figure 28. Estimate RSL: AC on stabilized + granular bases case

Pavement System Comparisons Using the Equivalent Thickness Concept

Pavement System-1 in the input panel was filled with the pavement structure values as follows (Figure 29):

- Layer1 Modulus: 1,500,000 psi
- Layer1 Poisson's Ratio: 0.35
- Layer1 Thickness: 4.0 in.
- Granular Base (or Subbase) Modulus: 50,000
- Granular Base (or Subbase) Poisson's Ratio: 0.35
- Granular Base (or Subbase) Thickness: 8.0 in.
- Subgrade Modulus: 14,000 psi
- Subgrade Poisson's Ratio: 0.40 in.

	Pavement System-1		Pavement System-2	
	US unit	SI unit	US unit	SI unit
Layer10 Modulus (psi-->Mpa)				
Layer10 Poisson's Ratio				
Layer10 Thickness (inch-->mm)				
Layer9 Modulus (psi-->Mpa)				
Layer9 Poisson's Ratio				
Layer9 Thickness (inch-->mm)				
Layer8 Modulus (psi-->Mpa)				
Layer8 Poisson's Ratio				
Layer8 Thickness (inch-->mm)				
Layer7 Modulus (psi-->Mpa)				
Layer7 Poisson's Ratio				
Layer7 Thickness (inch-->mm)				
Layer6 Modulus (psi-->Mpa)				
Layer6 Poisson's Ratio				
Layer6 Thickness (inch-->mm)				
Layer5 Modulus (psi-->Mpa)				
Layer5 Poisson's Ratio				
Layer5 Thickness (inch-->mm)				
Layer4 Modulus (psi-->Mpa)			1,500,000	10,342
Layer4 Poisson's Ratio			0.35	0.35
Layer4 Thickness (inch-->mm)			2.0	50.8
Layer3 Modulus (psi-->Mpa)			1,000,000	6,895
Layer3 Poisson's Ratio			0.35	0.35
Layer3 Thickness (inch-->mm)			3.0	76.2
Layer2 Modulus (psi-->Mpa)			750,000	5,171
Layer2 Poisson's Ratio			0.35	0.35
Layer2 Thickness (inch-->mm)			2.0	50.8
Layer1 Modulus (psi-->Mpa)	1,500,000	10,342	500,000	3,447
Layer1 Poisson's Ratio	0.35	0.35	0.35	0.35
Layer1 Thickness (inch-->mm)	4.0	101.6	4.0	101.6
Stabilized Base Modulus (psi-->Mpa)				
Stabilized Base Poisson's Ratio				
Stabilized Base Thickness (inch-->mm)				
Granular Base (or Subbase) Modulus (psi-->Mpa)	50,000	345	50,000	345
Granular Base (or Subbase) Poisson's Ratio	0.35	0.35	0.35	0.35
Granular Base (or Subbase) Thickness (inch-->mm)	8.0	203.2	8.0	203.2
Subgrade Modulus (psi-->Mpa)	14,000	97	14,000	97
Subgrade Poisson's Ratio	0.40	0.40	0.40	0.40

Figure 29. Fill the input panel: two different pavement systems

Pavement System-2 in the input panel was filled (Figure 29) with the pavement structure values as follows:

- Layer4 Modulus: 1,500,000 psi
- Layer4 Poisson's Ratio: 0.35
- Layer4 Thickness: 2.0 in.

- Layer3 Modulus: 1,000,000 psi
- Layer3 Poisson’s Ratio: 0.35
- Layer3 Thickness: 3.0 in.
- Layer2 Modulus: 750,000 psi
- Layer2 Poisson’s Ratio: 0.35
- Layer2 Thickness: 2.0 in.
- Layer1 Modulus: 500,000 psi
- Layer1 Poisson’s Ratio: 0.35
- Layer1 Thickness: 4.0 in.
- Granular Base (or Subbase) Modulus: 50,000
- Granular Base (or Subbase) Poisson’s Ratio: 0.35
- Granular Base (or Subbase) Thickness: 8.0 in.
- Subgrade Modulus: 14,000 psi
- Subgrade Poisson’s Ratio: 0.40 in.

The Predict Deflections and Predict Strains buttons were then clicked, and the pavement responses were predicted (Figure 30).

PREDICTION OF PAVEMENT RESPONSES**

Deflections @ Specified Points

		Pavement System-1		Pavement System-2	
		(inch) →	(mm)	(inch) →	(mm)
Predict Deflections	Surface	0.01432	0.364	0.00808	0.205
	Bottom of Asphalt Layer	0.01418	0.360	0.00762	0.194
	Top of Subgrade	0.01154	0.293	0.00679	0.172

Strains @ Specified Points

	($x 10^{-6}$)	Horizontal Strain	Vertical Strain	Horizontal Strain	Vertical Strain
Predict Strains	Bottom of Asphalt Layer	132		51	
	Bottom of Stabilized Base Layer				
	Top of Subgrade		-453		-156

Traffic Loading Adjustments***

APPLY NEW AXLE LOAD	Pavement System-1		Pavement System-2	
	(lbs)	(%)	(lbs)	(%)
Existed Axle Load (Default)	18,000	100%	18,000	100%
Adjusted Axle Load				

**Default loading: This tool predicts pavement responses under a single wheel load of 9,000 lbs (a single axle load of 18,000 lbs) and a contact radius of 6 inches.

***If the user wants to analyze the pavement under adjusted (new) axle loads, the user must fill in one of the above cells (either in weight [lbs] or in percentage [%]) and click 'APPLY NEW AXLE LOAD' once. For example, to increase the axle load by 12.5%; either 20,250 lbs (upper left cell) or 112.5% (upper right cell) in PS-1 and/or PS-2 must be entered for further analysis. 18,000 lbs and 100% represent the default load in lbs and %, respectively.

Figure 30. Predict pavement responses: two different pavement systems

In the Calculation of Equivalent Thickness panel, the Calculate EQV Thickness button was clicked to calculate the equivalent modulus, Poisson’s ratio, and thickness for the given pavement systems. As shown in Figure 31, the pavement systems’ moduli might be different, in which case, the Modulus Conversion button in the second step can be clicked to convert their moduli to a given modulus value.

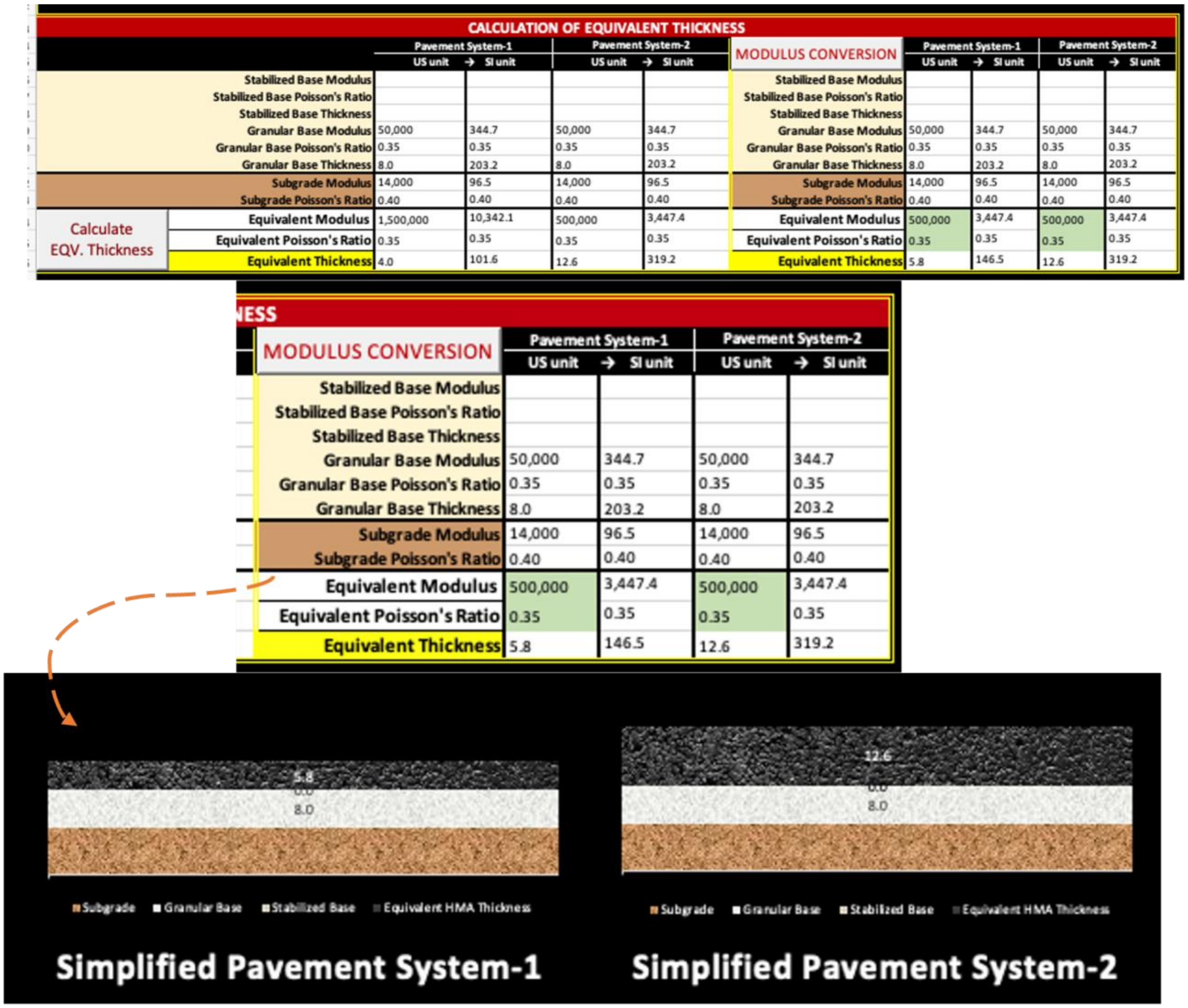

Figure 31. Calculate equivalent thickness: two different pavement systems

This allows comparison of the updated equivalent thicknesses of both pavement systems, and the result can be interpreted as indicating that the thicker pavement has more structural capacity. Based on the example given in Figure 31, Pavement System-2 seems to have a thicker HMA layer, suggesting that this pavement is stronger than Pavement System-1.

The traffic panel was next filled with the required parameters and the Calculate Accumulated Traffic_current button was clicked to convert a given ADT to an accumulated traffic (Figure 32).

CALCULATION OF ACCUMULATED TRAFFIC		
Calculation of Accumulated Traffic	**Pavement System - 1**	**Pavement System- 2**
Construction Year:	2009	2009
ADT Year:	2018	2018
Two-way ADT:	500	500
Directional Distribution Factor (%):	50	50
Design Lane Distribution Factor (%):	100	100
Growth Rate (%):	2.0	2.0
Percent Trucks (%):	5.0	5.0
Truck Factor:	1.0	1.0
Calculate Accumulated Traffic_current	41,730	41,730

Figure 32. Calculate accumulated ESAL: two different pavement systems

In the failure and SN identification panels, the buttons Calculate Fatigue Failure, Calculate Rutting Failure, and Calculate Structural Number were clicked to predict the number of allowable load repetitions to fatigue (N_f) and rutting (N_r) failures, and the SN (Figure 33).

IDENTIFICATION OF FAILURE			
Fatigue Failure			
Calculate Fatigue Failure	N_f	2,191,802	36,781,195
Rutting Failure			
Calculate Rutting Failure	N_r	1,280,611	150,244,036
IDENTIFICATION OF STRUCTURAL NUMBER			
Calculate Structural Number	$SN_{asphalt\ layer}$	2.6	6.0
	$SN_{stabilized\ base\ layer}$	0.0	
	$SN_{granular\ base\ layer}$	1.8	1.8

Figure 33. Identify failures and SN: two different pavement systems

In the damage calculation panel, there is no need to enter a value in the Accumulated ESAL_current cell, since information was entered in the traffic panel and thus the accumulated traffic value was already calculated and automatically used in the calculation of fatigue and rutting damage (Figure 34).

CALCULATION OF DAMAGE			
Damage due to Fatigue			
Calculate Fatigue Damage	Accumulated ESAL_current		
	Damage_current (%)	1.90%	0.11%
Damage due to Rutting			
Calculate Rutting Damage	Accumulated ESAL_current		
	Damage_current (%)	3.26%	0.03%

Figure 34. Calculate fatigue and rutting damage: two different pavement systems

The design life was then specified, and the buttons Estimate RSL_fatigue and Estimate RSL_rutting were clicked to estimate RSLs due to fatigue and rutting damage (Figure 35).

ESTIMATION OF REMAINING SERVICE LIFE (RSL)			
RSL due to Fatigue			
Estimate RSL_fatigue	Design Life (years)	20	20
	RSL_current (years)	19.6	20.0
RSL due to Rutting			
Estimate RSL_rutting	Design Life (years)	20	20
	RSL_current (years)	19.3	20.0

Figure 35. Estimate RSL: two different pavement systems

Based on the calculated damage (Figure 34) and estimated RSL (Figure 35), it appears that Pavement-System-2 has less damage and more RSL than Pavement System-1. This result supports the evaluation made in the equivalent calculation panel (see the previous Figure 31).

Pavement System Comparisons Using Different Traffic Loading

Pavement System-1 and Pavement System-2 in the input panel were filled with the same pavement structure values as follows (Figure 36):

- Layer1 Modulus: 1,500,000 psi
- Layer1 Poisson's Ratio: 0.35
- Layer1 Thickness: 4.0 in.
- Granular Base (or Subbase) Modulus: 50,000
- Granular Base (or Subbase) Poisson's Ratio: 0.35
- Granular Base (or Subbase) Thickness: 8.0 in.
- Subgrade Modulus: 14,000 psi
- Subgrade Poisson's Ratio: 0.40 in.

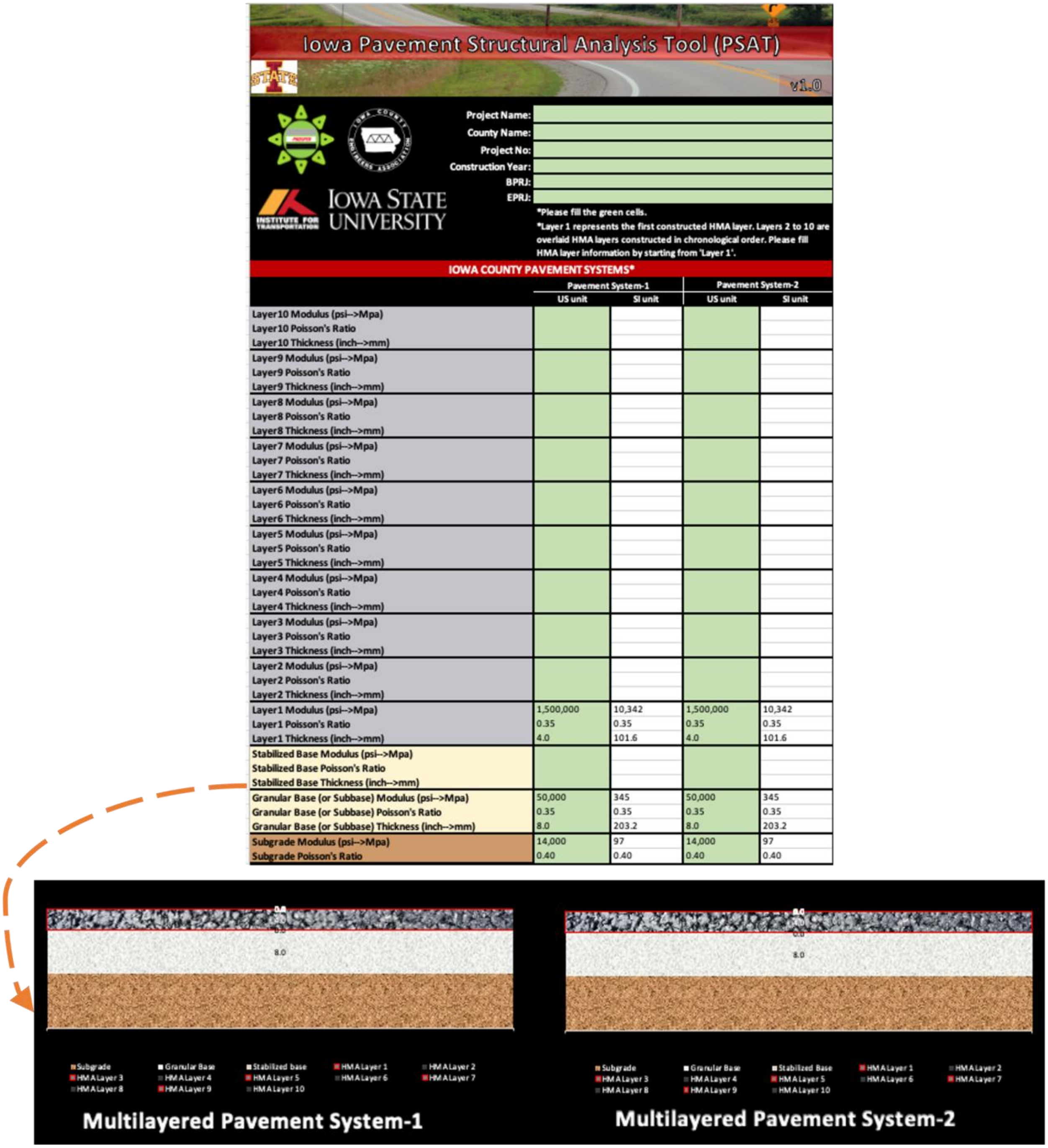

Figure 36. Fill the input panel: two same pavement systems

The Predict Deflections and Predict Strains buttons were then clicked, and the pavement responses were predicted for both pavement systems, which were the same values for both pavement systems (Figure 37).

PREDICTION OF PAVEMENT RESPONSES**

Deflections @ Specified Points

		Pavement System-1		Pavement System-2	
		(inch) →	(mm)	(inch) →	(mm)
Predict Deflections	Surface	0.01432	0.364	0.01432	0.364
	Bottom of Asphalt Layer	0.01418	0.360	0.01418	0.360
	Top of Subgrade	0.01154	0.293	0.01154	0.293

Strains @ Specified Points

	(x 10^{-6})	Horizontal Strain	Vertical Strain	Horizontal Strain	Vertical Strain
Predict Strains	Bottom of Asphalt Layer	132		132	
	Bottom of Stabilized Base Layer				
	Top of Subgrade		-453		-453

Traffic Loading Adjustments***

APPLY NEW AXLE LOAD	Pavement System-1		Pavement System-2	
	(lbs)	(%)	(lbs)	(%)
Existed Axle Load (Default)	18,000	100%	18,000	100%
Adjusted Axle Load				

**Default loading: This tool predicts pavement responses under a single wheel load of 9,000 lbs (a single axle load of 18,000 lbs) and a contact radius of 6 inches.
***If the user wants to analyze the pavement under adjusted (new) axle loads, the user must fill in one of the above cells (either in weight [lbs] or in percentage [%]) and click 'APPLY NEW AXLE LOAD' once. For example, to increase the axle load by 12.5%; either 20,250 lbs (upper left cell) or 112.5% (upper right cell) in PS-1 and/or PS-2 must be entered for further analysis. 18,000 lbs and 100% represent the default load in lbs and %, respectively.

Figure 37. Predict pavement responses: two same pavement systems

In the Traffic Loading Adjustments panel in Figure 38 (right panel), traffic loading was adjusted.

PREDICTION OF PAVEMENT RESPONSES**

Deflections @ Specified Points

		Pavement System-1		Pavement System-2	
		(inch) →	(mm)	(inch) →	(mm)
Predict Deflections	Surface	0.01432	0.364	0.01611	0.409
	Bottom of Asphalt Layer	0.01418	0.360	0.01595	0.405
	Top of Subgrade	0.01154	0.293	0.01299	0.330

Strains @ Specified Points

	(x 10^{-6})	Horizontal Strain	Vertical Strain	Horizontal Strain	Vertical Strain
Predict Strains	Bottom of Asphalt Layer	132		148	
	Bottom of Stabilized Base Layer				
	Top of Subgrade		-453		-509

Traffic Loading Adjustments***

APPLY NEW AXLE LOAD	Pavement System-1		Pavement System-2	
	(lbs)	(%)	(lbs)	(%)
Existed Axle Load (Default)	18,000	100%	18,000	100%
Adjusted Axle Load			20,250	

**Default loading: This tool predicts pavement responses under a single wheel load of 9,000 lbs (a single axle load of 18,000 lbs) and a contact radius of 6 inches.
***If the user wants to analyze the pavement under adjusted (new) axle loads, the user must fill in one of the above cells (either in weight [lbs] or in percentage [%]) and click 'APPLY NEW AXLE LOAD' once. For example, to increase the axle load by 12.5%; either 20,250 lbs (upper left cell) or 112.5% (upper right cell) in PS-1 and/or PS-2 must be entered for further analysis. 18,000 lbs and 100% represent the default load in lbs and %, respectively.

Figure 38. Predict pavement responses: two same pavement systems

The adjusted axle load applied on Pavement System -2 was increased by 12.5%, and entered in the weight (lb) cell as 20,250 lb. Instead of weight, 112.5% could be entered in the percentage (%) cell (see Figure 38). When the adjusted axle load was entered, the APPLY NEW AXLE LOAD button was clicked and then the pavement responses (i.e., deflections and strains) in Figure 38 (left panel) for Pavement System -2 was automatically predicted under the adjusted axle loading.

The traffic panel was next filled with the required parameters and the Calculate Accumulated Traffic_current button was clicked to convert a given ADT to an accumulated traffic (Figure 39).

CALCULATION OF ACCUMULATED TRAFFIC		
Calculation of Accumulated Traffic	Pavement System - 1	Pavement System- 2
Construction Year:	2009	2009
ADT Year:	2018	2018
Two-way ADT:	500	500
Directional Distribution Factor (%):	50	50
Design Lane Distribution Factor (%):	100	100
Growth Rate (%):	2.0	2.0
Percent Trucks (%):	5.0	5.0
Truck Factor:	1.0	1.6
Calculate Accumulated Traffic_current	41,730	66,844

Figure 39. Calculate accumulated ESAL: two same pavement systems

As shown in Figure 39, the truck factor was automatically calculated by using the Fourth Power Law and found to be 1.6. It can be stated that when the axle load increased by 12.5%, the damage increased 1.6 times based on the empirical approach.

In the failure and SN identification panels, the buttons Calculate Fatigue Failure, Calculate Rutting Failure, and Calculate Structural Number were clicked to predict the number of allowable load repetitions to fatigue (N_f) and rutting (N_r) failures, and the SN (Figure 40).

IDENTIFICATION OF FAILURE			
Fatigue Failure			
Calculate Fatigue Failure	N_f	2,191,802	1,539,373
Rutting Failure			
Calculate Rutting Failure	N_r	1,280,611	755,801
IDENTIFICATION OF STRUCTURAL NUMBER			
Calculate Structural Number	$SN_{asphalt\ layer}$	2.6	2.6
	$SN_{stabilized\ base\ layer}$	0.0	
	$SN_{granular\ base\ layer}$	1.8	1.8

Figure 40. Identify failures and SN: two same pavement systems

In the damage calculation panel, there is no need to enter a value in the Accumulated ESAL_current cell, since information was entered in the traffic panel and thus the accumulated traffic value was already calculated and automatically used in the calculation of fatigue and rutting damage (Figure 41).

CALCULATION OF DAMAGE			
Damage due to Fatigue			
Calculate Fatigue Damage	Accumulated ESAL_current		
	Damage_current (%)	1.90%	4.34%
Damage due to Rutting			
Calculate Rutting Damage	Accumulated ESAL_current		
	Damage_current (%)	3.26%	8.84%

Figure 41. Calculate fatigue and rutting damage: two same pavement systems

As shown in Figure 41, when the axle load increased by 12.5%, the fatigue damage increased 2.3 times (from 1.90% to 4.34%) and rutting damage increased 2.7 times (from 3.26% to 8.84%) based on the mechanistic-empirical approach. For the given case, it can be interpreted that the damage calculated using mechanistic results (i.e., N_f and N_r using pavement responses) is higher than the damage calculated using the empirical approach (i.e., Fourth Power Law).

The design life was then specified, and the buttons Estimate RSL_fatigue and Estimate RSL_rutting were clicked to estimate RSLs due to fatigue and rutting damage, respectively (Figure 42).

ESTIMATION OF REMAINING SERVICE LIFE (RSL)			
RSL due to Fatigue			
Estimate RSL_fatigue	Design Life (years)	20	20
	RSL_current (years)	19.6	19.1
RSL due to Rutting			
Estimate RSL_rutting	Design Life (years)	20	20
	RSL_current (years)	19.3	18.2

Figure 42. Estimate RSL: two same pavement systems

REFERENCE

AASHTO. 1993. *Guide for the Design of Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, DC.

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