

PASSFlex for Integration of Asphalt Mix Design, Pavement Design, and Performance-Related Specifications

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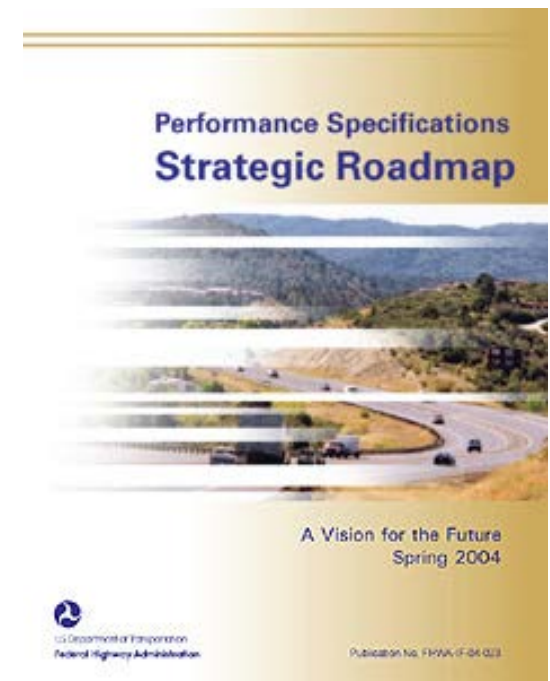
Outline

- ❑ What is PASSFlex?
- ❑ Test Methods, Models, and Software Programs
- ❑ Performance-Engineered Mix Design
- ❑ Performance-Related Specifications
- ❑ Concluding Remarks

Performance Specifications Strategic Roadmap: A Vision for the Future

Federal Highway Administration (2004)

- ❑ Vision: The performance of highway facilities will improve through **better translation of design intent and performance requirements into construction specifications.**
- ❑ Mission: To establish performance specifications as a viable contract option.
- ❑ ***"Freedom to innovate with accountability to deliver is the driving force behind the performance specification movement."*** - Ted Ferragut, TDC Partners, Ltd



What is PASSFlex?

- ❑ System of “tools” for asphalt mix design, pavement design, and performance-related specifications
 - Test methods using Asphalt Mixture Performance Tester (AMPT)
 - Mechanistic models
 - Software programs
- ❑ Based on fundamental engineering principles
 - Seamless integration of mix design, pavement design, and PRS
 - Efficient testing to cover a wide range of loading and environmental conditions

Distresses Covered

- Fatigue cracking (bottom-up and top-down)
- Thermal cracking
- Rutting
- Aging

PASSFlex

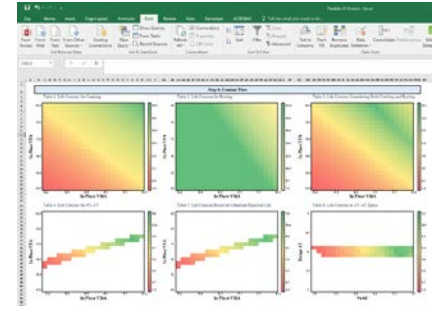
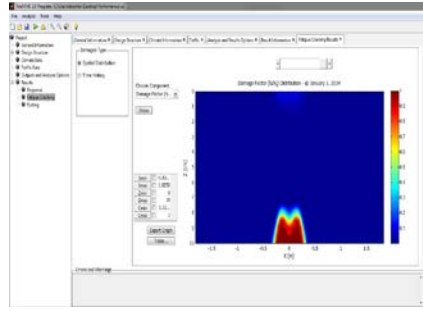
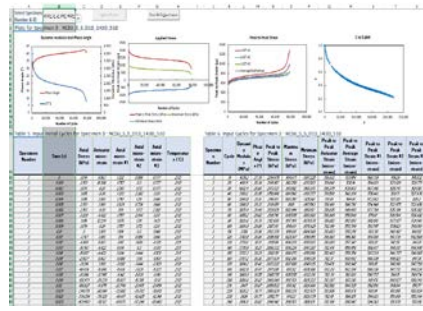


AMPT

FlexMAT™

FlexPAVE™

FlexMIX



**Mixture
Testing
System**

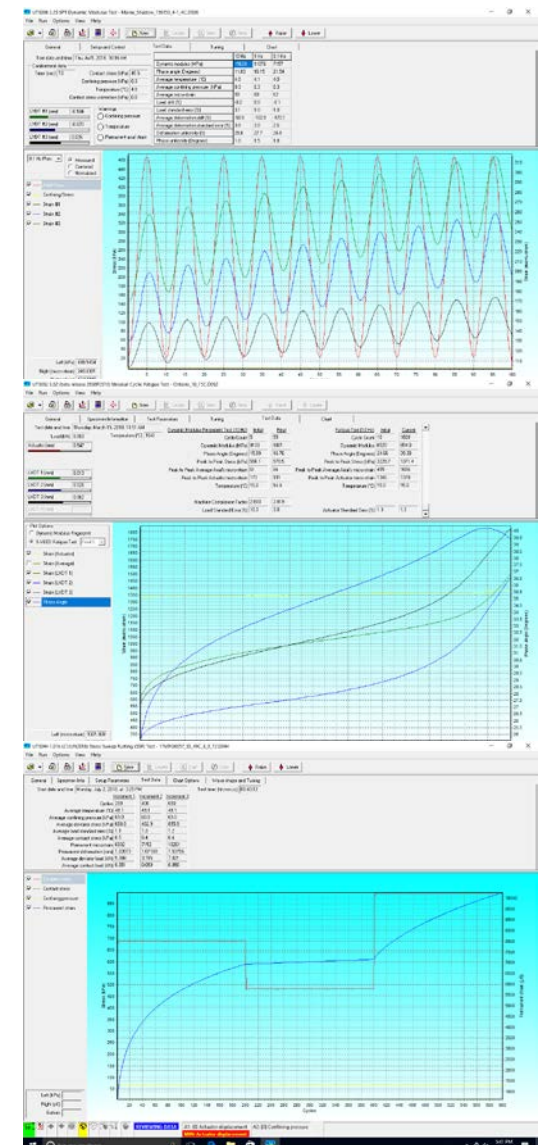
**Mixture
Analysis
Program**

**Pavement
Performance
Analysis
Program**

**Performance
Engineered
Mix Design**

AMPT Test Methods

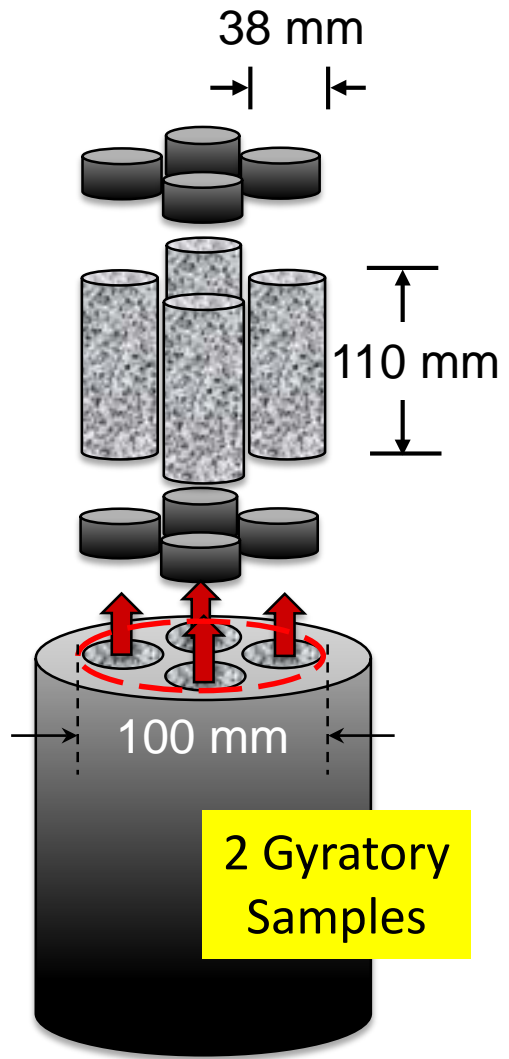
Asphalt Mixture Performance Tester



AMPT Performance Testing Suite

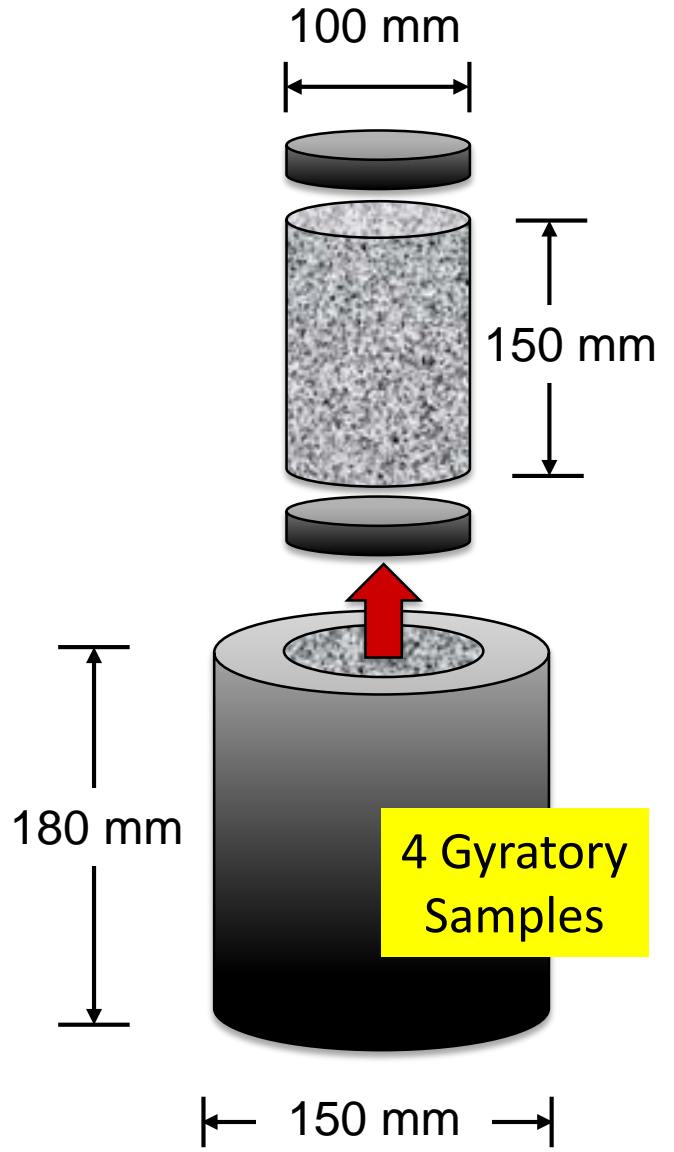
Test Method	AASHTO Spec.	Specimen Geometry	Material Properties	Index Parameter	Required Testing Time
Dynamic Modulus Test	PP 99/TP 132	38 mm D, 110 mm H	$ E^* $, phase angle, t-T shift factor	N/A	8 hrs
Cyclic Fatigue Test	PP 99/TP 133	38 mm D, 110 mm H	Damage characteristic curve, D^R failure criterion	S_{app}	5 hrs
Stress Sweep Rutting Test	TP 134	100 mm D, 150 mm H	Shift model coefficients	ATR	8 hrs

E* and Fatigue Test Specimen



2 Gyrotory Samples

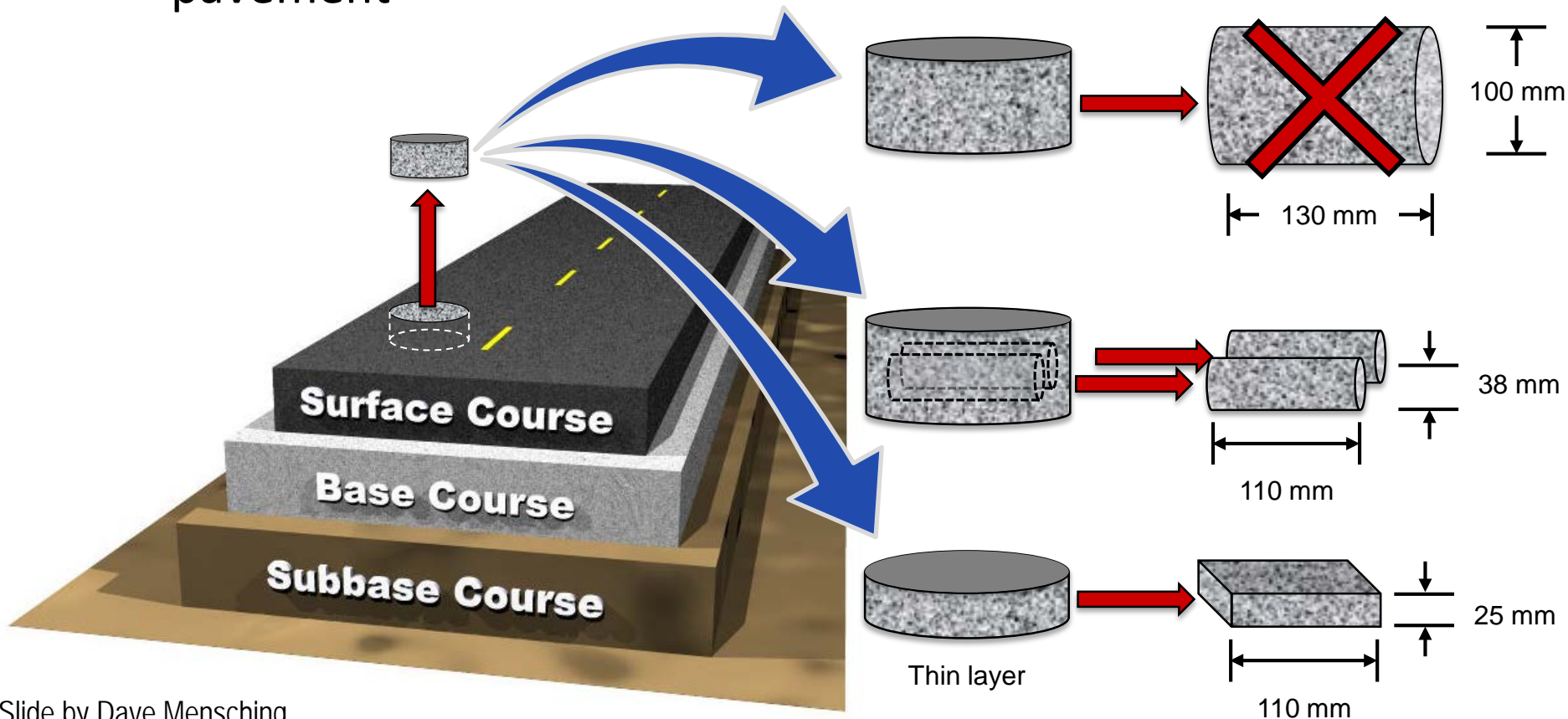
Rutting Test Specimen



4 Gyrotory Samples

38 mm Specimen from Field Cores

- ❑ Asphalt concrete layers are generally thinner than 100 mm
- ❑ Allow for performance testing individual layers of as-built pavement



FlexMAT™

Single Click Data Loading/Clearing

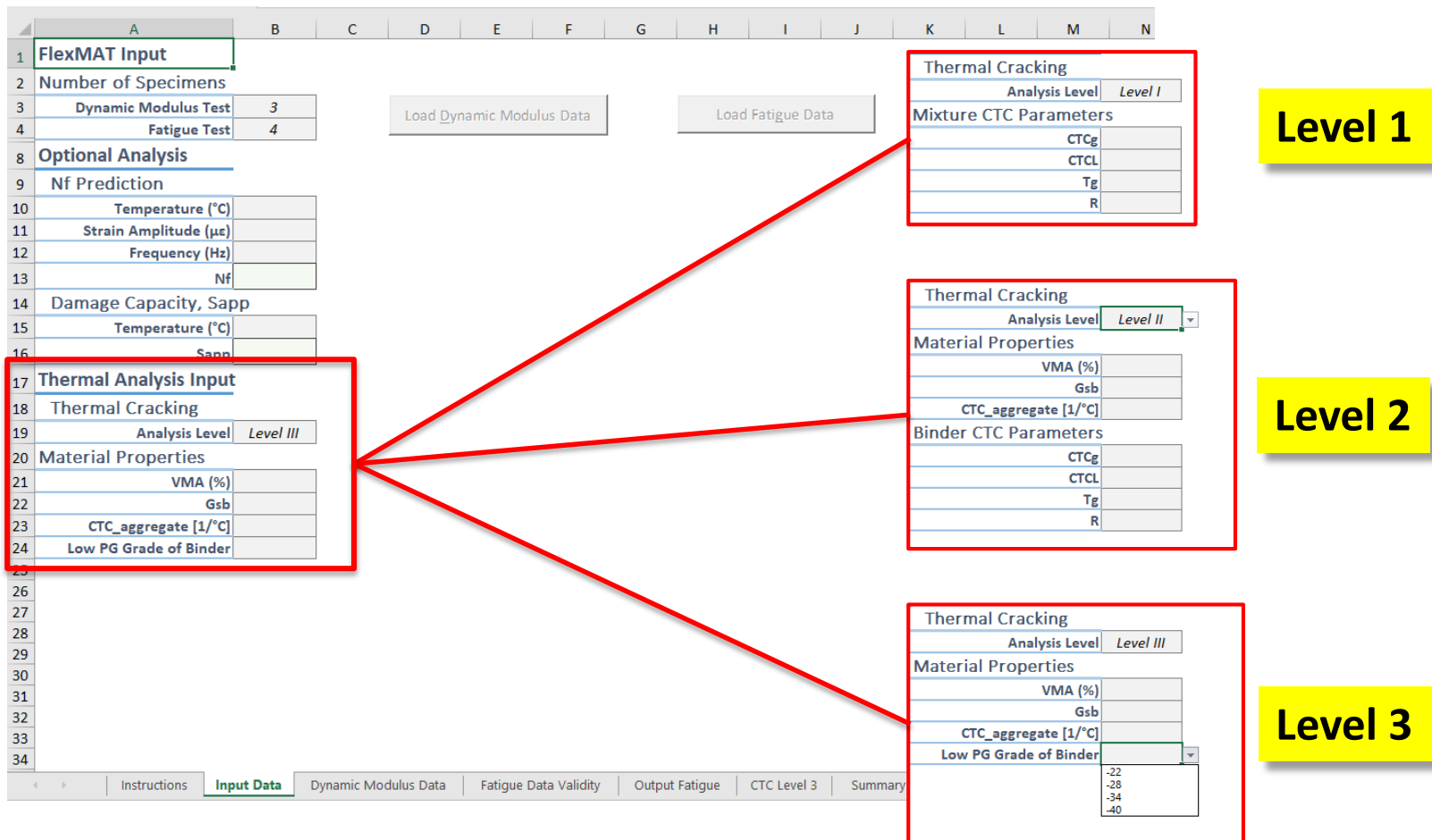
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	FlexMAT Input														
2	Number of Specimens														
3	Dynamic Modulus Test	1													
4	Fatigue Test	4													
8	Optional Analysis														
9	Nf Prediction														
10	Temperature (°C)														
11	Strain Amplitude (µε)														
12	Frequency (Hz)														
13	Nf														
14	Damage Capacity, Sapp														
15	Binder PG														
16	Sapp														
17	Thermal Analysis Inputs														
18	Coefficient of Thermal Contraction, CTC														
19	Analysis Level	Level I													
20	Mixture CTC Parameters														
21	CTCg														
22	CTCL														
23	Tg														
24	R														
25	Aging Analysis Input														
26	Analysis Level	Level II													
27	Binder STA Dynamic Shear Modulus at 10 rad/s (RTFO Aging)														
28	Testing Temperature (°C)	64													
29	Dynamic Shear Modulus (Pa)														
30	Binder LTA Dynamic Shear Modulus at 64°C, 10 rad/s (RTFO & PAV Aging)														
31	Aging Level	PAV	2xPAV												
32	Dynamic Shear Modulus (Pa)														

Load Dynamic Modulus Data

Load Fatigue Data

Clear All Inputs

Hierarchical Input Structure



Analysis Summary and Outputs

FlexPAVE Dynamic Modulus Inputs

Table 15. Linear Viscoelastic Properties

E_{inf}	3.48E+04
Poisson's Ratio	0.30
T_{REF} (°C)	21.10
Shift Factor a1	1.07E-03
Shift Factor a2	-1.71E-01
Shift Factor a3	3.13E+00

Table 16. 2S2P1D coefficients

δ	1.61E+00
k	9.85E-02
h	4.07E-01
β	1.00E+12
E_{00} [MPa]	3.48E+01
E_0 [MPa]	4.00E+04
$\log(\tau_e)$	-3.17E+00

Table 18. S-VECD Properties

alpha	3.72
C11	2.63E-03
C12	4.65E-01
DR	0.59
Sapp	22.02

Table 19. Thermal Properties

CTC_g	9.23E-06
CTC_L	1.06E-05
T_g	-2.53E+01
R	4.70E+00

Table 20. Aging Properties

c	1.508
$\log G^* _{STA}$	0.37
M	0.84

Pavement ME Dynamic Modulus Data

Table 21. Pavement ME Table Size

Number of frequencies	Units	Values
6	Hz	Default
Number of Temperatures	Units	Values
8	Celsius	Default

Table 22. Dynamic Modulus (MPa)

		Frequency (Hz)					
		0.1	0.5	1	5	10	25
Temperature (Celsius)	-30.0	2.74E+04	2.94E+04	2.99E+04	3.11E+04	3.15E+04	3.21E+04
	-20.0	2.31E+04	2.48E+04	2.54E+04	2.70E+04	2.76E+04	2.83E+04
	-10.0	1.73E+04	1.95E+04	2.04E+04	2.22E+04	2.30E+04	2.40E+04
	4	7.83E+03	1.06E+04	1.18E+04	1.45E+04	1.56E+04	1.70E+04
	10	4.59E+03	6.94E+03	8.08E+03	1.09E+04	1.21E+04	1.37E+04
	20	1.66E+03	2.85E+03	3.54E+03	5.57E+03	6.62E+03	8.12E+03
	40	2.82E+02	5.05E+02	6.50E+02	1.17E+03	1.49E+03	2.05E+03
	54	1.32E+02	2.24E+02	2.86E+02	5.11E+02	6.59E+02	9.20E+02

Input to
Pavement ME

Export to FlexPAVE 2.0

Export FlexPAVE qyn. Modulus Inputs

Export FlexPAVE Fatigue Inputs

←

Export to FlexPAVE™

Index Parameter

FlexPAVE™

FlexPAVE™ ver 1.1

Project: General Information, Design Structure, Climate Data, Traffic Data, Outputs and Analysis Options, Results

Design Vehicle Information

Choose a Vehicle:

Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	Single Axle	Single Tire	0 80

Design Velocity (m/s): 27

Traffic Information

AADTT: 750 Growth Type: Linear Growth Rate (%): 2

Lane Distribution Factor: 1

Monthly Adjustment Factor (MAF)

Month	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (HTD) (%)

Time	HTD (%)
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

FlexPAVE 1.0 Program: C:\Users\bkeshav\Desktop\Performance.lvt

File Analysis Tools Help

Project: General Information, Design Structure, Climate Data, Traffic Data, Outputs and Analysis Options, Results, Response, Fatigue Cracking, Rutting

Damages Type

- Spatial Distribution
- Time History

Choose Component: Damage Factor (N/h) [v]

Show

Damage Factor (N/h) Distribution - @ January 1, 2034

Xmin: -1.82 Xmax: 1.8250 Zmin: 0 Zmax: 10 Cmin: 1.32... Cmax: 1

Export Graph Table...

General Information, Design Structure

Structure General Information

Structure Name: Flexible 3-Layer Pavement Pavement/Lane Width (m): 3.65

Layer Properties

Layer: AC Thickness (cm): 10 Infinite Layer Material Type: Asphalt Concrete GR Based Criterion DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	Einf (KPa)	Alpha	Fatigue C11	Beta	Rutting Epsilon0	Rutting p1
0.3000	9.7300e+04	4	0.0017	0.8026	0.0052	0.6069
	5	C12	0.5449	Ni	0.8024	0.0396
	6.9619e-04	Initial C	0.8000	TR(C)	61	d2
	-0.1620	Gamma	1000000			1.6831
	0.7928		1.3500			

Layer Properties Table

	Ti (sec)	Ei (KPa)
1	2.0000e+16	757.4885
2	2.0000e+15	97.6079
3	2.0000e+14	267.7187
4	2.0000e+13	366.0952
5	2.0000e+12	686.5036
6	2.0000e+11	1.2298e+03
7	2.0000e+10	2.2287e+03
8	2.0000e+09	4.6690e+03

Please note that FlexPAVE 1.0 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

FlexPAVE 1.0 Program: C:\Users\bkeshav\Desktop\Performance.lvt

File Analysis Tools Help

Project: General Information, Design Structure, Climate Data, Traffic Data, Outputs and Analysis Options, Results, Response, Fatigue Cracking, Rutting

Choose Component: Rut Depth

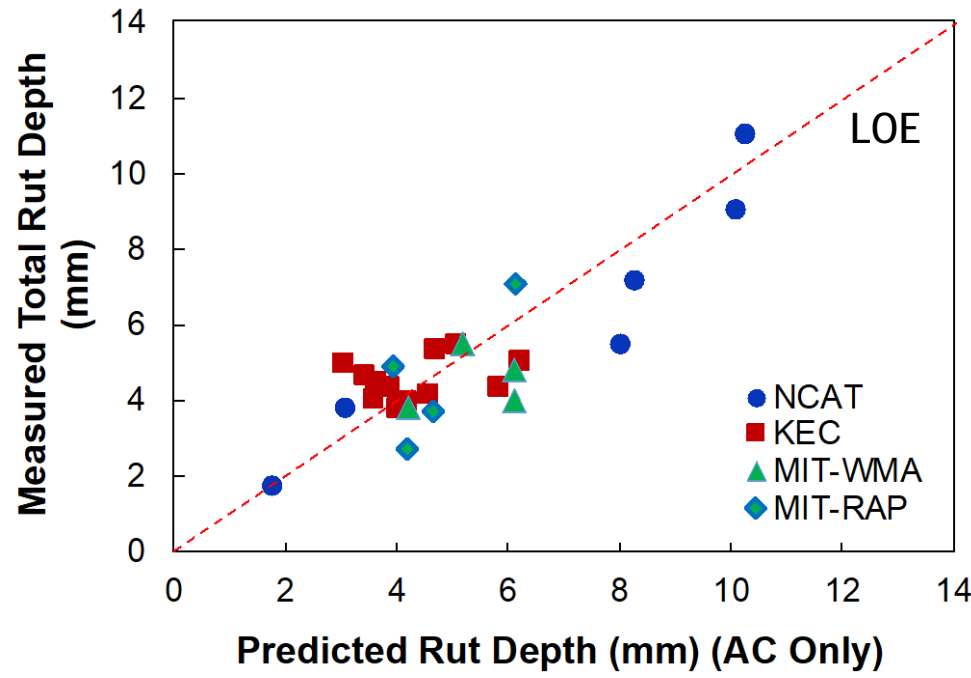
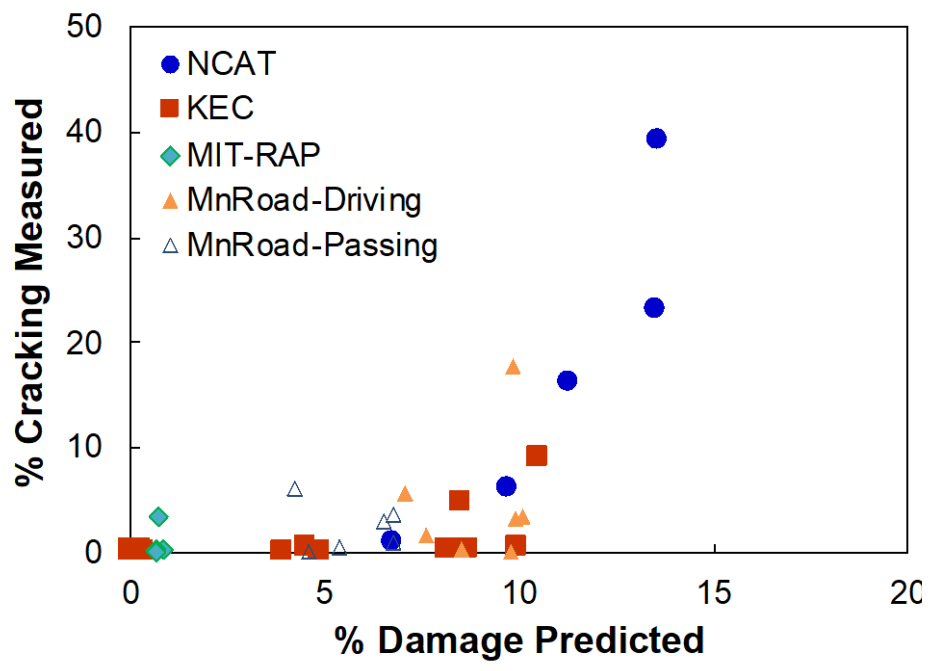
Show

Rut Depth (cm)

Export Graph Table...

Tmin: 0 Tmax: 240 Ymin: 0 Ymax: 1.4000

Field Validation



Performance-Engineered Mix Design

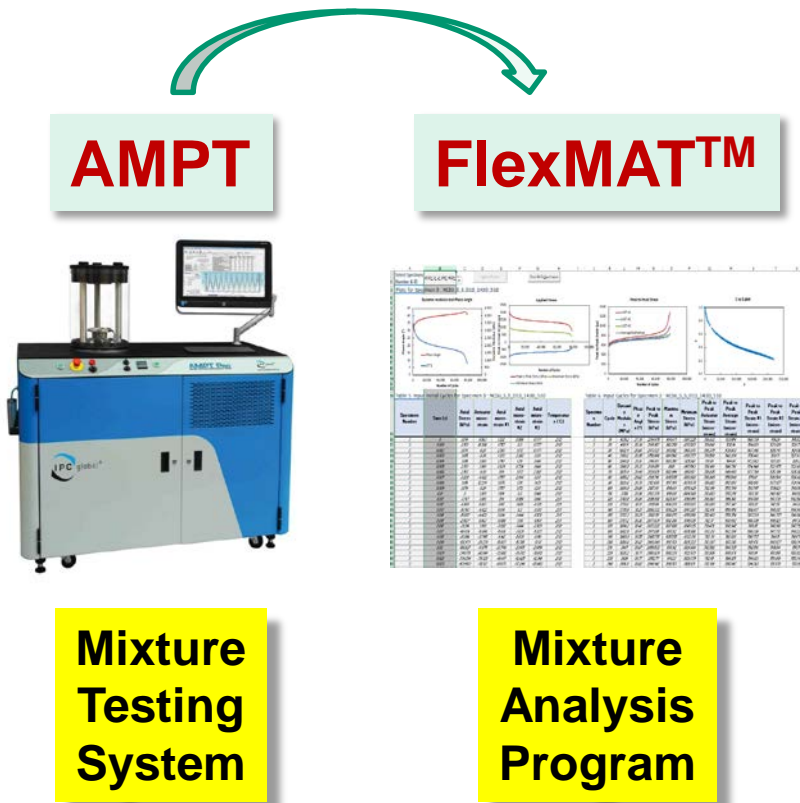
☐ Index-based PEMD

- Use index parameters to pass/reject volumetric mix design

☐ Predictive PEMD

- Use predicted life to optimize aggregate gradation and asphalt content for the design air voids
- Use performance-volumetric relationship (PVR) developed from 'four corners' of volumetric space
- Developed PVR can be used to develop pay tables in PRS.

Index Parameters



S_{app}
 Apparent
 Damage
 Capacity



ATR
 Allowable
 Traffic
 for Rutting



Thresholds of S_{app}

Traffic (million ESALs)	S_{app} Limits	Tier	Designation
Less than 10	$S_{app} > 8$	Standard	S
Between 10 and 30	$S_{app} > 24$	Heavy	H
Greater than 30	$S_{app} > 30$	Very Heavy	V
Greater than 30 and slow traffic	$S_{app} > 36$	Extremely Heavy	E

Thresholds of ATR

Traffic (million ESALs)	Tier	Designation
Less than 2	Light	L
Between 2 and 10	Standard	S
Between 10 and 30	Heavy	H
Greater than 30	Very Heavy	V
Greater than 30 and slow traffic	Extremely Heavy	E

Project	Location	Mix	Rutting Allowable Traffic	Cracking Allowable Traffic	Allowable Traffic	Dominant Distress
ALF	Washington DC	Control	H	S	S	Cracking
		CR-TB	E	H	H	Cracking
		SBS	E	V	V	Cracking
Maine - PEMD	Maine	AC-0.5%	E	S	S	Cracking
		AC-Target	V	S	S	Cracking
		AC+0.5%	H	S	S	Cracking
		AC+1%	S	H	S	Rutting
MIT-RAP	Manitoba, Canada	50RSB	L	H	L	Rutting
		C	L	S	L	Rutting
		15R	L	H	L	Rutting
		50R	L	H	L	Rutting
MIT- WMA	Manitoba, Canada	Advera	L	S	L	Rutting
		Control	L	S	L	Rutting
		Evotherm	L	S	L	Rutting
		Sasobit	L	S	L	Rutting
NC DOT - ABC Project	North Carolina	RB25.0B	E	S	S	Cracking
		RI19.0B	S	L	L	Cracking
		RI19.0C	V	S	S	Cracking
		RS9.5B	L	S	L	Rutting
		RS9.5C	V	S	S	Cracking
KEC	Korea	ASTM	L	S	L	Rutting
		PMA	V	S	S	Cracking

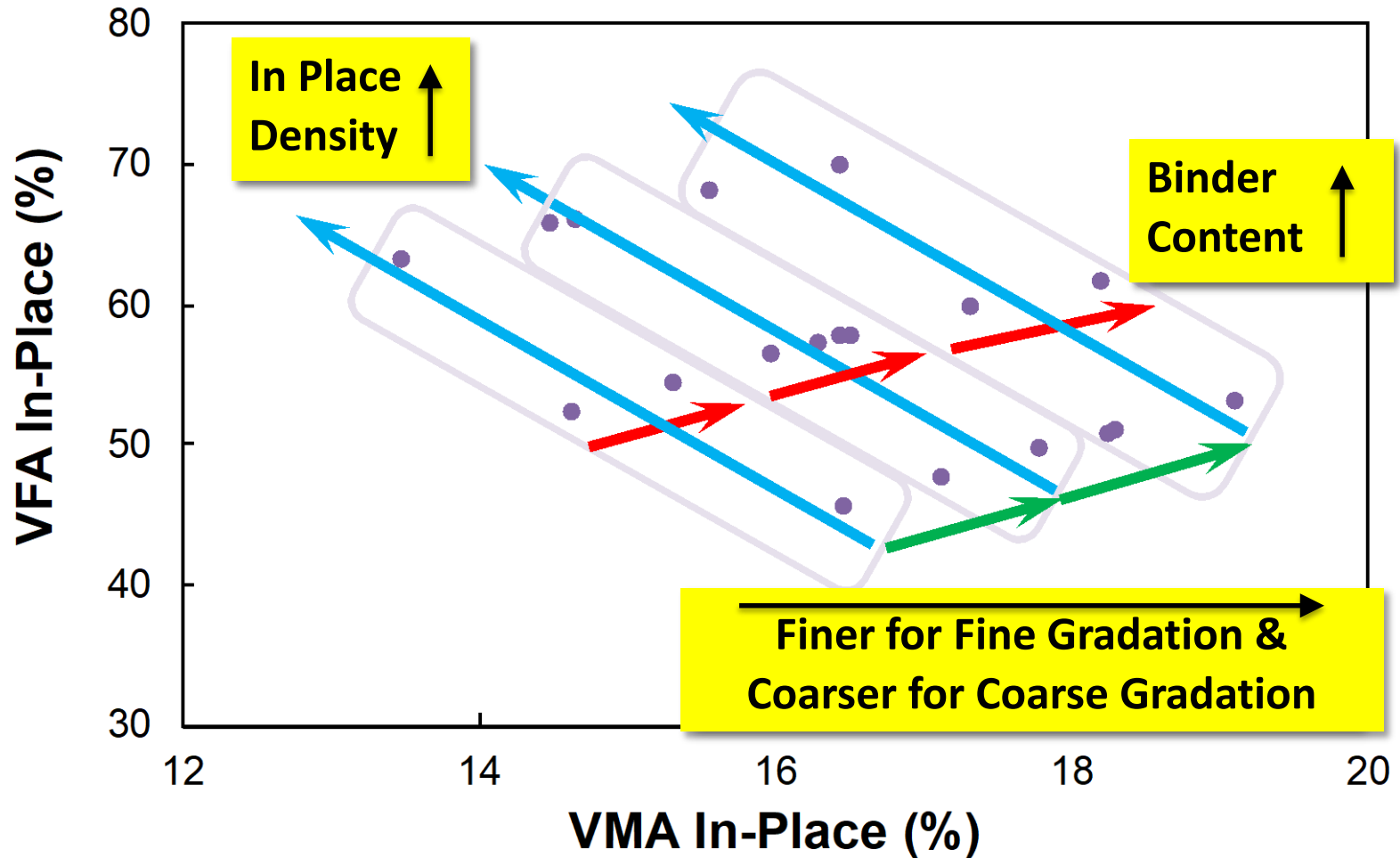
Performance-Volumetric Relationship (PVR)

- Functions to predict the pavement performance using measurable Acceptance Quality Characteristics (AQC's).

PVR $Performance = f(VMA_{IP}, VFA_{IP}, \%AC_{eff})$

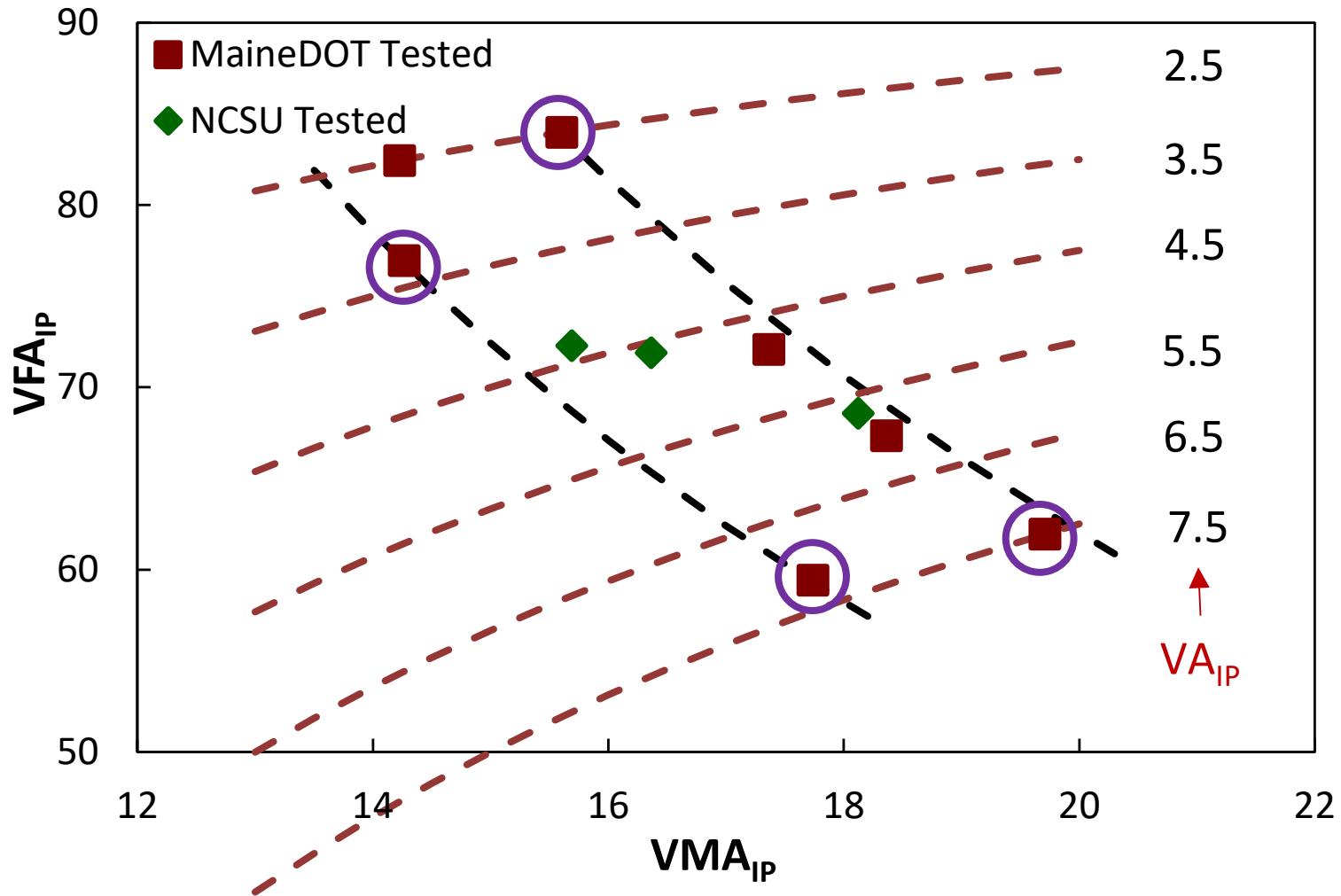
- Allows to use the current QA data collection methods in PRS applications

Analysis in Volumetric Space



Selection of PVR Calibration Conditions

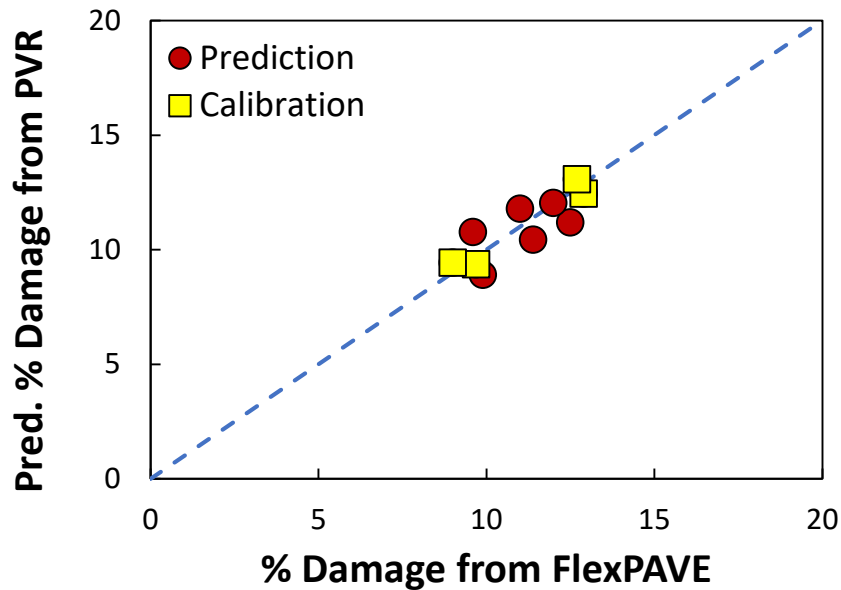
Findings with Maine Shadow Project Mixture



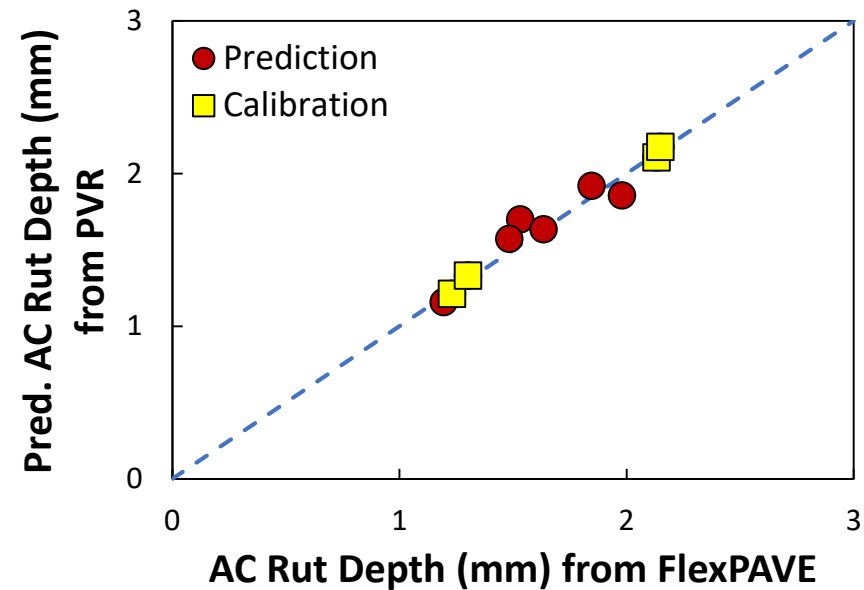
Selection of PVR Calibration Conditions

Findings with Maine Shadow Project Mixture

Cracking



Rutting

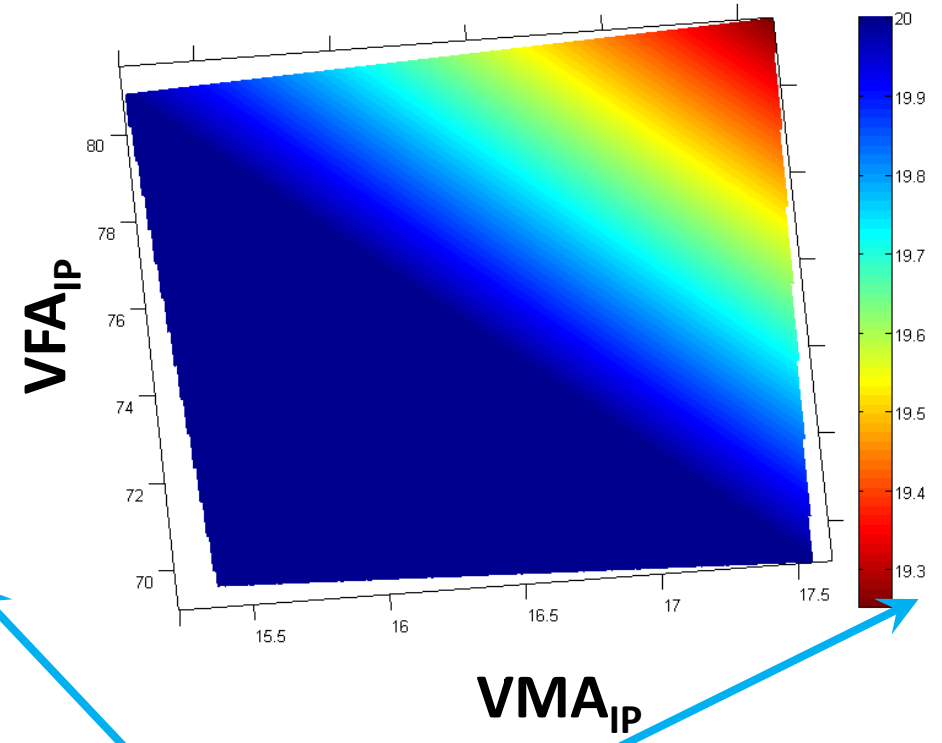
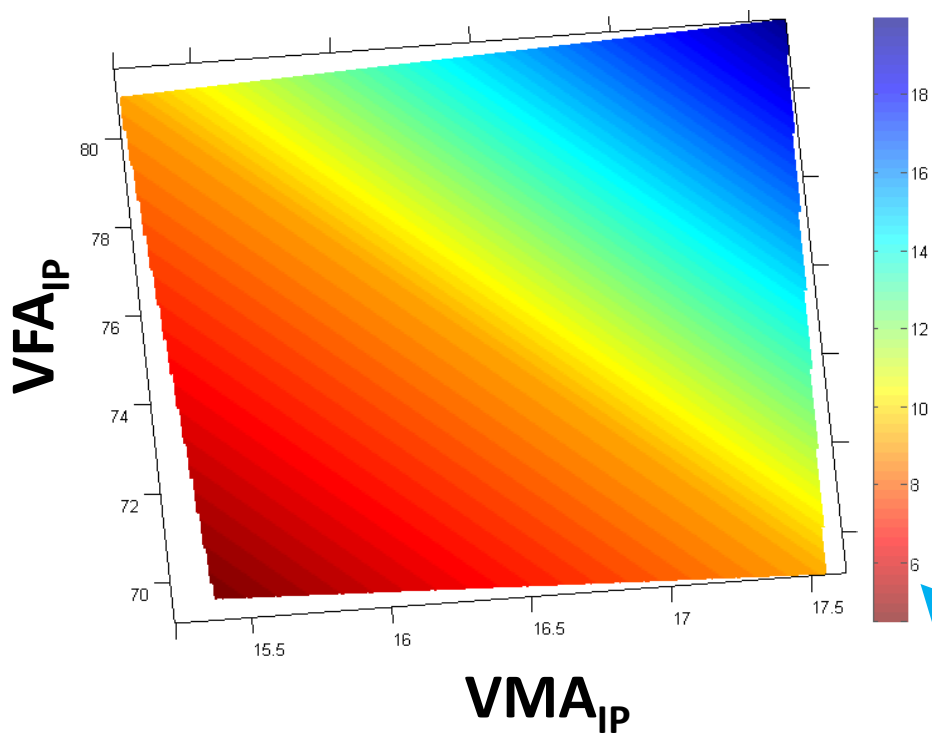


Predictive PEMD

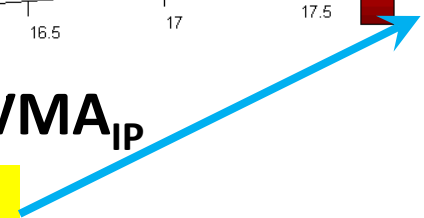
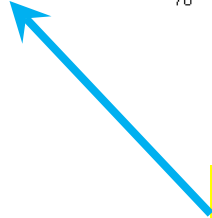
Example, PVR Function Predictions

Cracking

Rutting



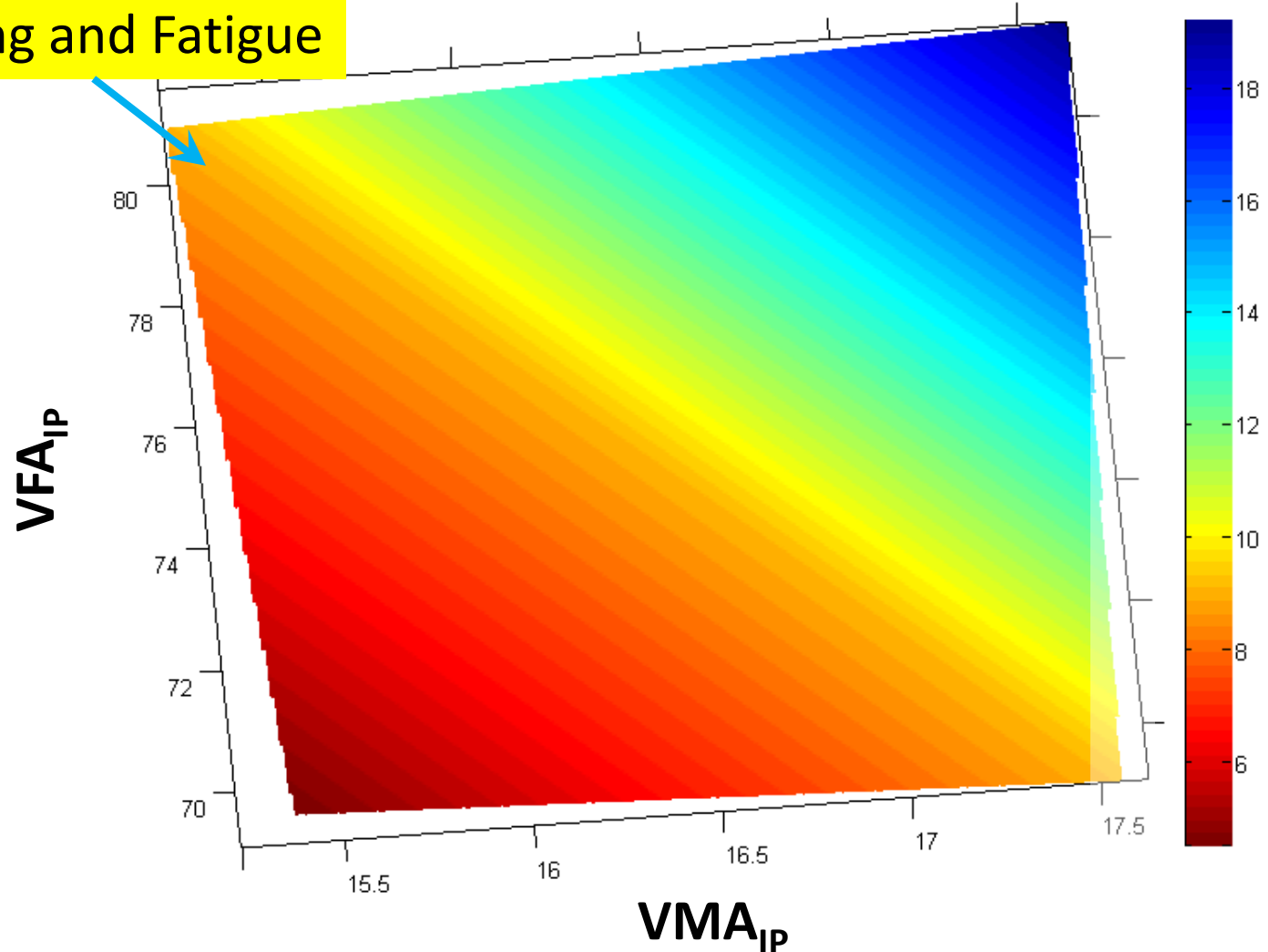
Life in Years



Predictive PEMD

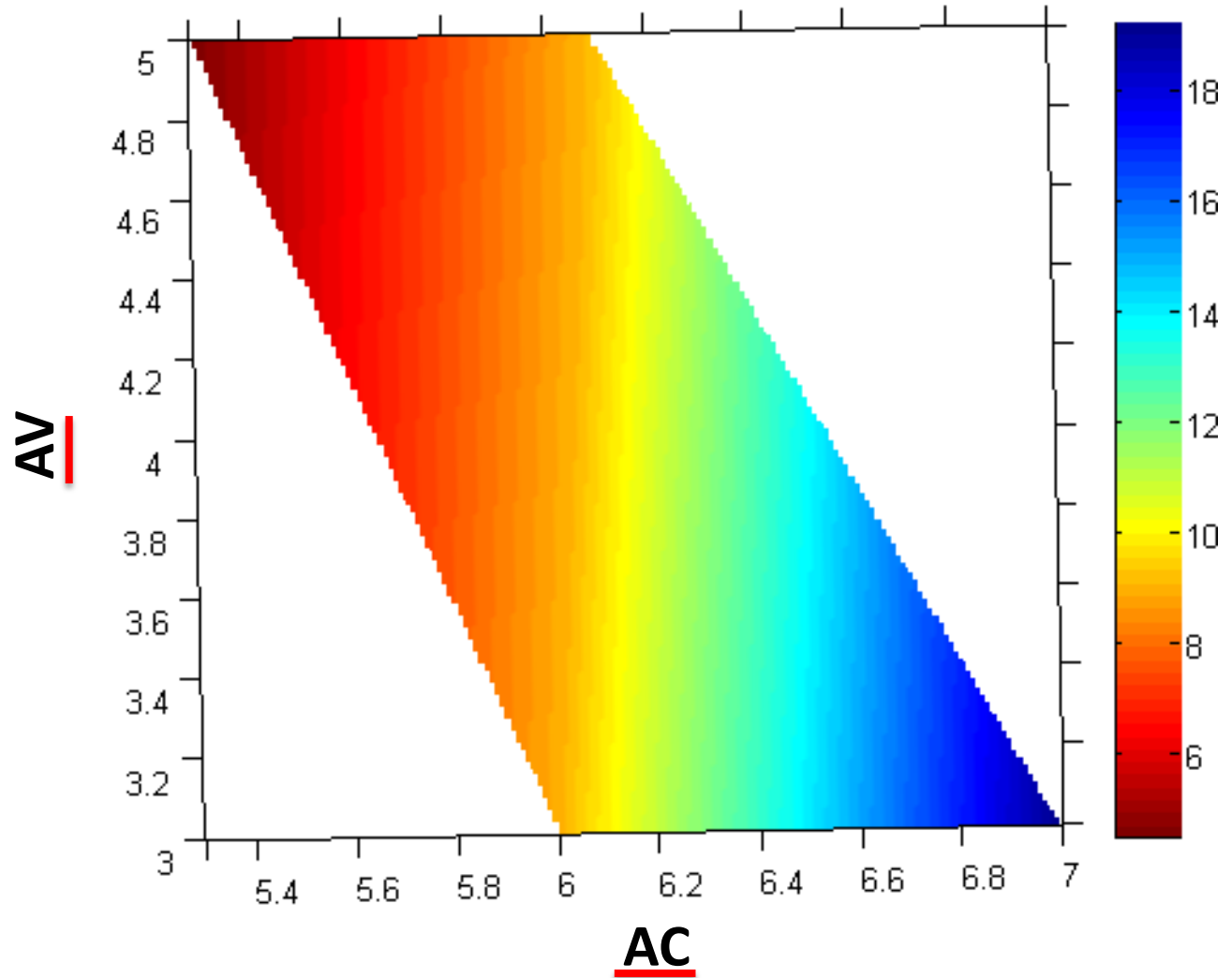
Example, Finding Mixture Design

Minimum of
Rutting and Fatigue



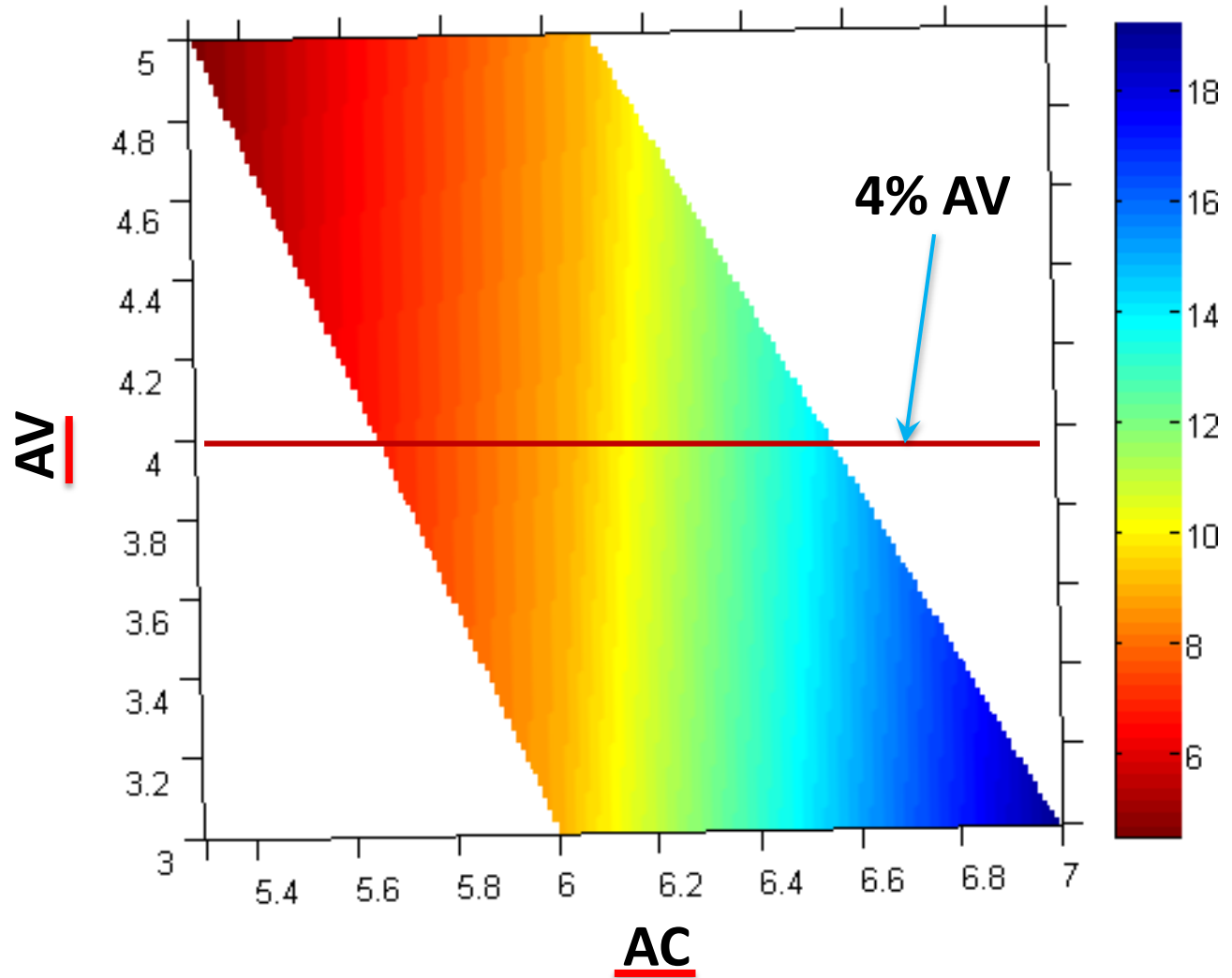
Predictive PEMD

Example, Finding Mixture Design



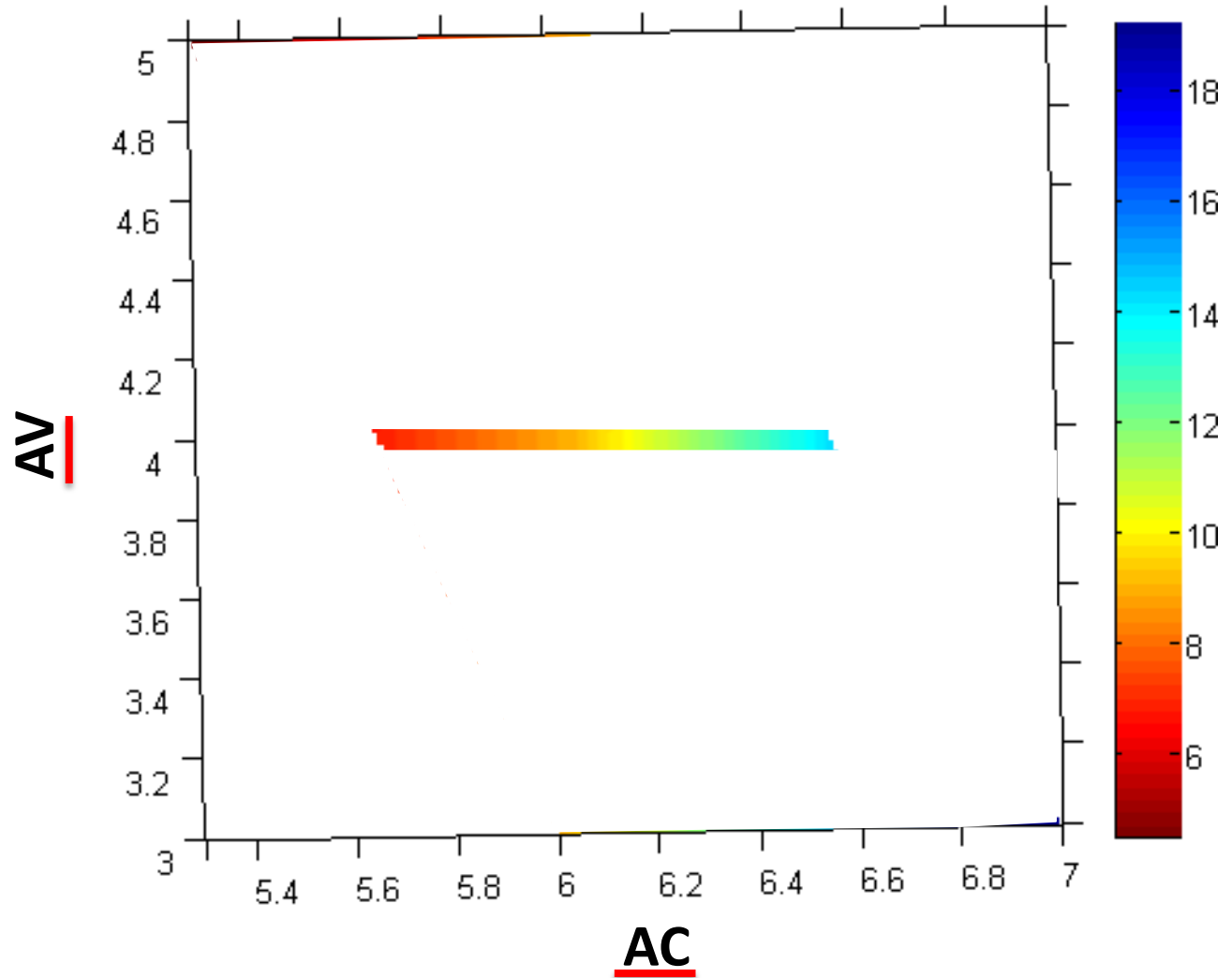
Predictive PEMD

Example, Finding Mixture Design



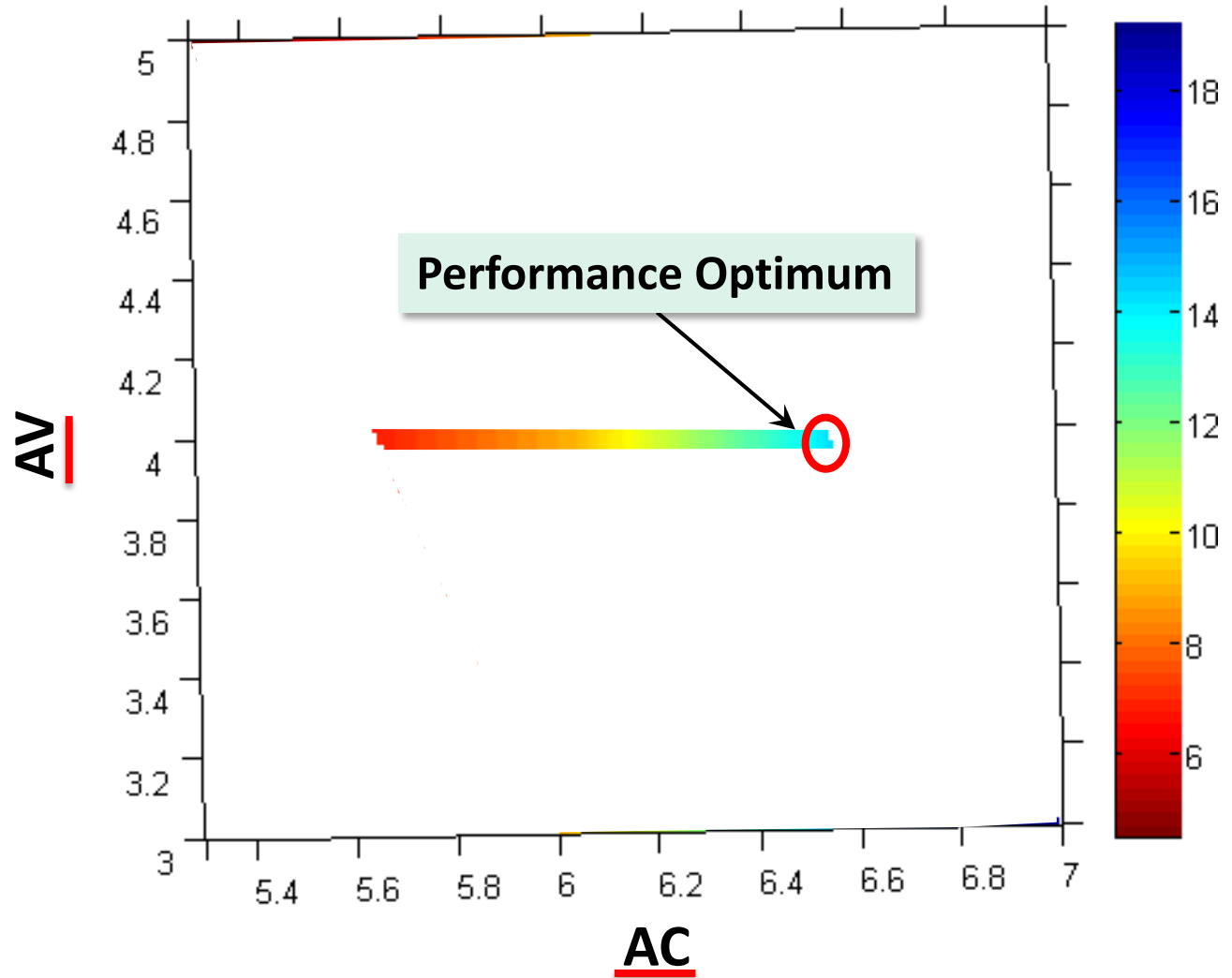
Predictive PEMD

Example, Finding Mixture Design



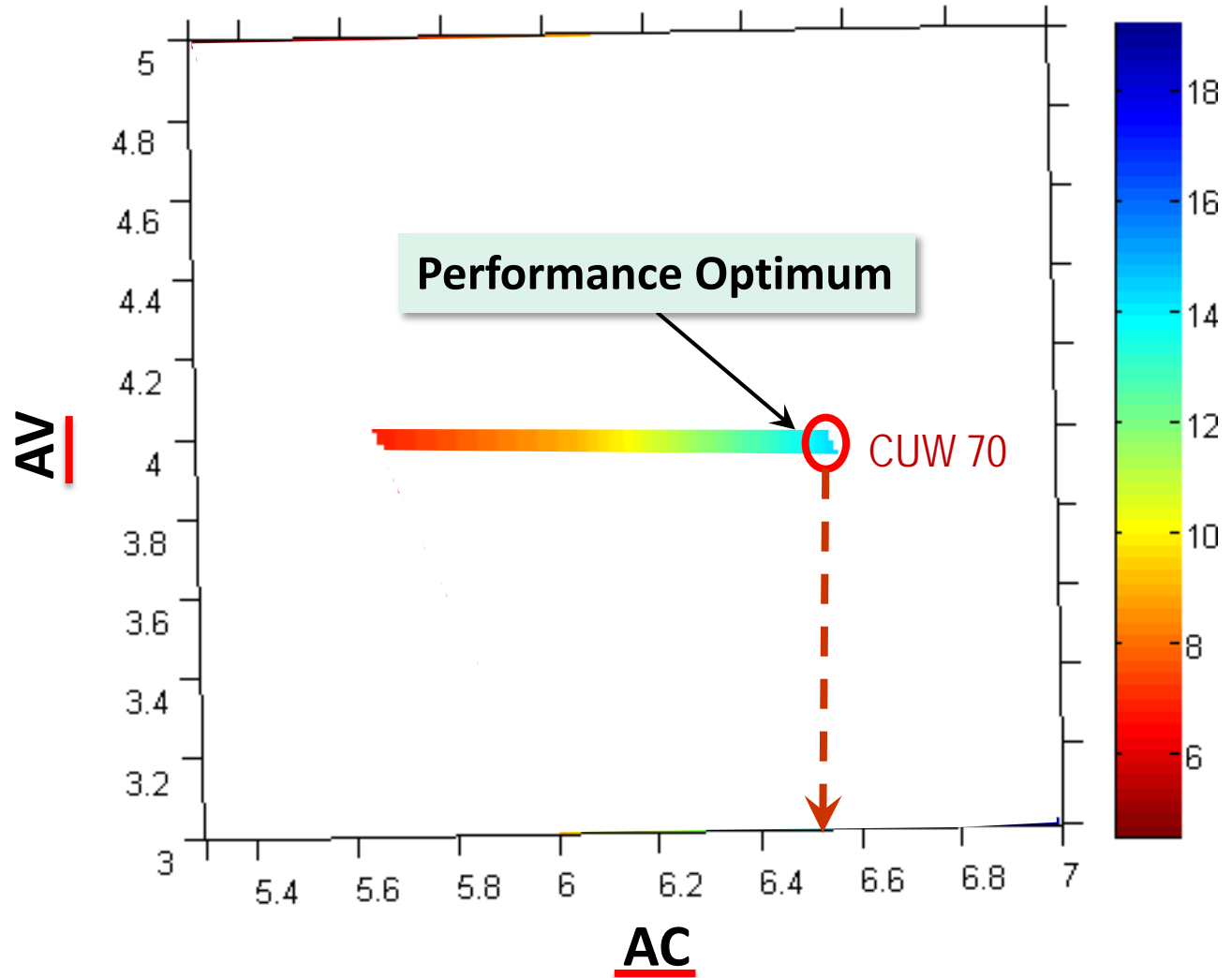
Predictive PEMD

Example, Finding Mixture Design



Predictive PEMD

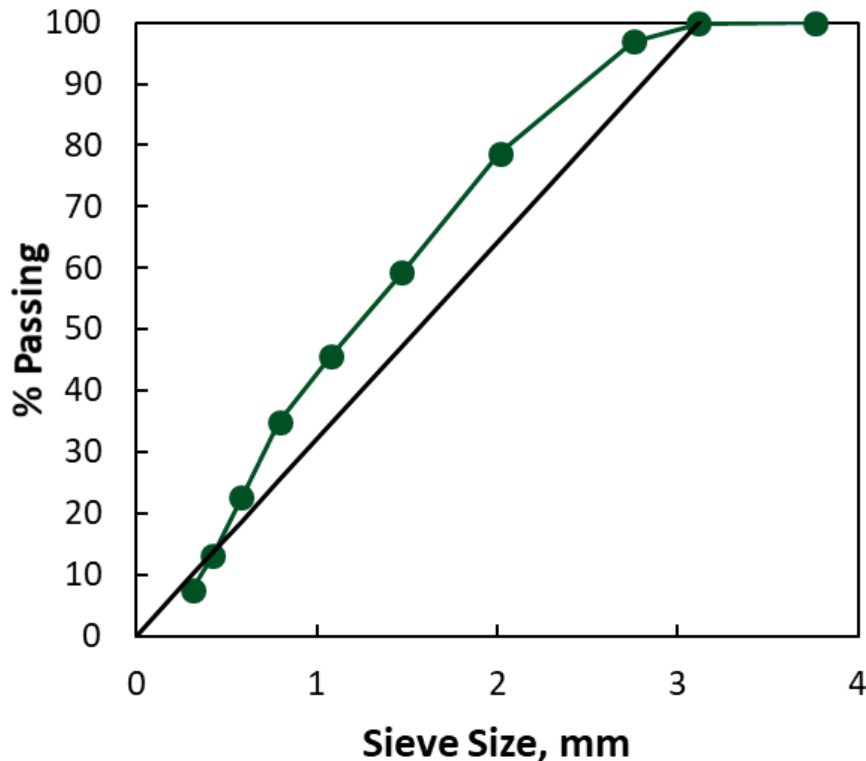
Example, Finding Mixture Design



Predictive PEMD

Example, Final Mixture Design

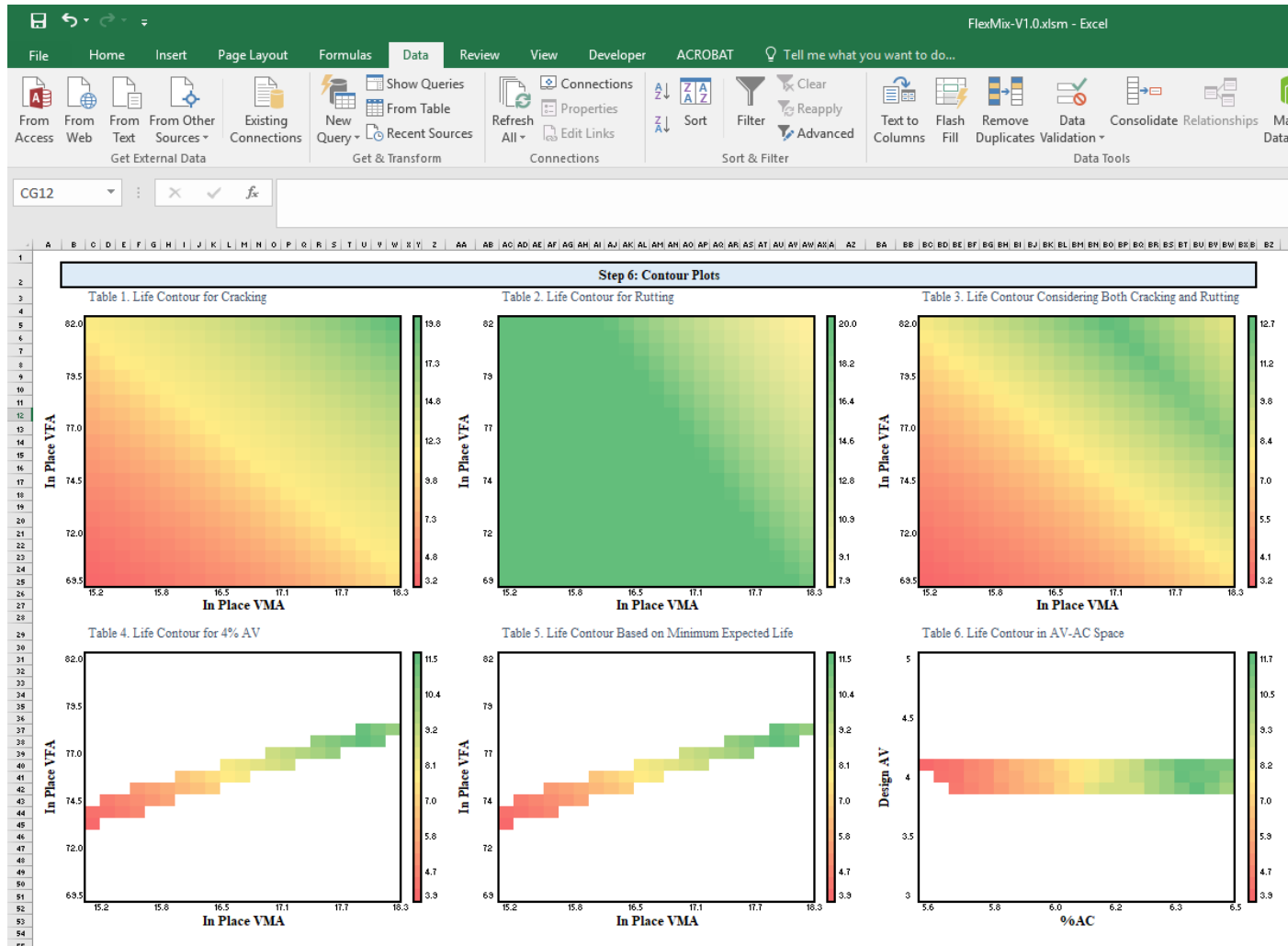
Gradation



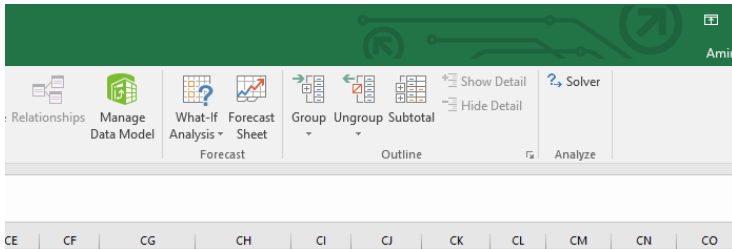
Asphalt Content and
Stockpile Percentages

CUW	AC	Stockpile Contribution			
		#78	DS	WS	RAP
70	6.5	44	13	43	30

FlexMIX for PVR Analysis

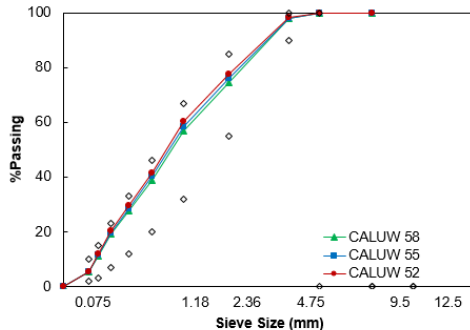


Automatic Determination of Optimal Gradation and Binder Content



Step 7: Candidate for Optimum Design

Minimum Expected Life (Year): 8.0	
%CALW:	58 - 52
Pb:	6.0 - 6.4
	%AC Life
CALW 52	6.4 11.5
CALW 55	6.2 9.8
CALW 58	6.0 8.1
AV @ Ndes:	4.0 - 4.1
VMA @ Ndes:	18.0 - 17.2
VFA @ Ndes:	77.6 - 76.4
Design Airvoid	Tolerance
4	0.1



Sieve Size (mm)	Size ^ 0.45	%Passing		
		CALW 52	CALW 55	CALW 58
19.0	3.76	100.0	100.0	100.0
12.5	3.12	100.0	100.0	100.0
9.5	2.75	98.2	98.1	97.9
4.75	2.02	77.5	76	74.6
2.36	1.47	60.4	58.5	56.8
1.18	1.08	41.6	40.3	39
0.600	0.79	29.5	28.5	27.7
0.300	0.58	20.5	19.8	19.2
0.150	0.43	11.8	11.4	11.1
0.075	0.31	5.6	5.4	5.3

	#78	DS	WS
CALW 52	32.2	26.7	41.1
CALW 55	34.4	25.8	39.8
CALW 58	36.5	25.0	38.5

Example Pay Tables in PRS

Pay Factor		QA VMA @ Ndes = 13%				
		QA Vbe @ Ndes				
		11	10	9	8	7
In-Place A.V.	4	101.5	100.0	100.0	93.9	67.3
	5	100.3	100.0	100.0	84.9	60.0
	6	100.0	100.0	96.3	73.7	0.0
	7	100.0	100.0	88.2	60.0	0.0
	8	100.0	97.1	78.3	0.0	0.0
	9	100.0	89.8	65.9	0.0	0.0
	10	96.1	80.8	60.0	0.0	0.0
	11	89.3	69.7	0.0	0.0	0.0
	12	81.1	60.0	0.0	0.0	0.0

Pay Factor		QA VMA @ Ndes = 14%				
		QA Vbe @ Ndes				
		11	10	9	8	7
In-Place A.V.	4	102.3	102.1	101.0	100.0	100.0
	5	101.4	101.1	100.0	100.0	95.5
	6	100.4	100.0	100.0	100.0	87.1
	7	100.0	100.0	100.0	97.3	76.6
	8	100.0	100.0	100.0	89.7	63.5
	9	100.0	100.0	97.5	80.3	60.0
	10	100.0	100.0	90.5	68.6	0.0
	11	100.0	95.8	81.9	60.0	0.0
	12	97.3	89.2	71.4	0.0	0.0

Pay Factor		QA VMA @ Ndes = 15%				
		QA Vbe @ Ndes				
		11	10	9	8	7
In-Place A.V.	4	101.6	102.4	102.6	102.0	100.2
	5	100.8	101.6	101.7	100.8	100.0
	6	100.0	100.7	100.6	100.0	100.0
	7	100.0	100.0	100.0	100.0	100.0
	8	100.0	100.0	100.0	100.0	98.1
	9	100.0	100.0	100.0	100.0	90.9
	10	100.0	100.0	100.0	97.6	82.0
	11	100.0	100.0	100.0	90.9	70.9
	12	100.0	100.0	95.1	82.7	60.0

Pay Factor		QA VMA @ Ndes = 16%				
		QA Vbe @ Ndes				
		11	10	9	8	7
In-Place A.V.	4	100.0	101.4	102.4	102.9	102.6
	5	100.0	100.6	101.6	102.0	101.6
	6	100.0	100.0	100.8	101.1	100.5
	7	100.0	100.0	100.0	100.0	100.0
	8	100.0	100.0	100.0	100.0	100.0
	9	100.0	100.0	100.0	100.0	100.0
	10	100.0	100.0	100.0	100.0	100.0
	11	100.0	100.0	100.0	100.0	97.4
	12	98.0	100.0	100.0	99.3	90.9

Shadow Project

- ❑ Two-day AMPT hands-on training workshop at NCSU
- ❑ On-site training at the shadow agency's lab
- ❑ Proficiency testing
- ❑ Mix design using PEMD
- ❑ Development of life tables using PVR
- ❑ Collection of construction mix samples
- ❑ Comparison of PEMD-based PVR and PVR developed from construction samples
- ❑ Shadow PRS application

Concluding Remarks

- ❑ PASSFlex is a system of test methods, mechanistic models, and software programs.
- ❑ PASSFlex allows the integration of mix design, pavement design, and PRS.
- ❑ FlexMAT™, FlexPAVE™, and FlexMIX are available upon request.
- ❑ Southeastern states are welcome to participate in the shadow project!

Slide by Prof. Kevin Hall

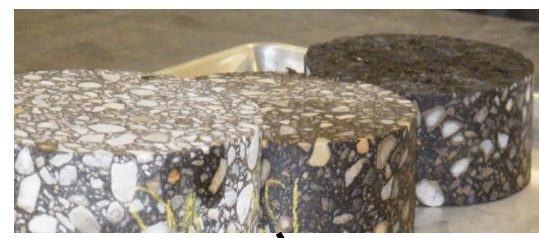
PASSFlex

Structural Design
(materials/thickness)



Richard Kim

Mixture Design
Material Characterization



Rutting

Cracking

gecan.ca

Pay Factor = $f(\Delta\text{life})$

Construction
(QA; QC)



fhwa.gov

Thank you!