BMD and Field Validation

Thomas Harman

Senior Research Engineer

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY


IT'SUGAR
Youngest Child
THE RULES DON'T APPLY TO ME
Premium Milk Chocolate
NET WT 3 OZ (85g)
IT'SUGAR
Middle Child
I'M THE REASON WE
AVE RULES
Premium Milk Chocolate
NET WT 3 OZ (85g)
IT'SUGAR
Oldest Child
I MAKE THE RULES

RUTTING
BALANCED DESIGN
024 OAPC ASPHALT
HNICAL SYMPOSIU
2024
Scarborough Convention Center
20 Torham Pl, Scarborough, ON M1X 0B3

Innovation is Disruptive

What do these systems have in common?

Hu

A PERFORMANCE TEST

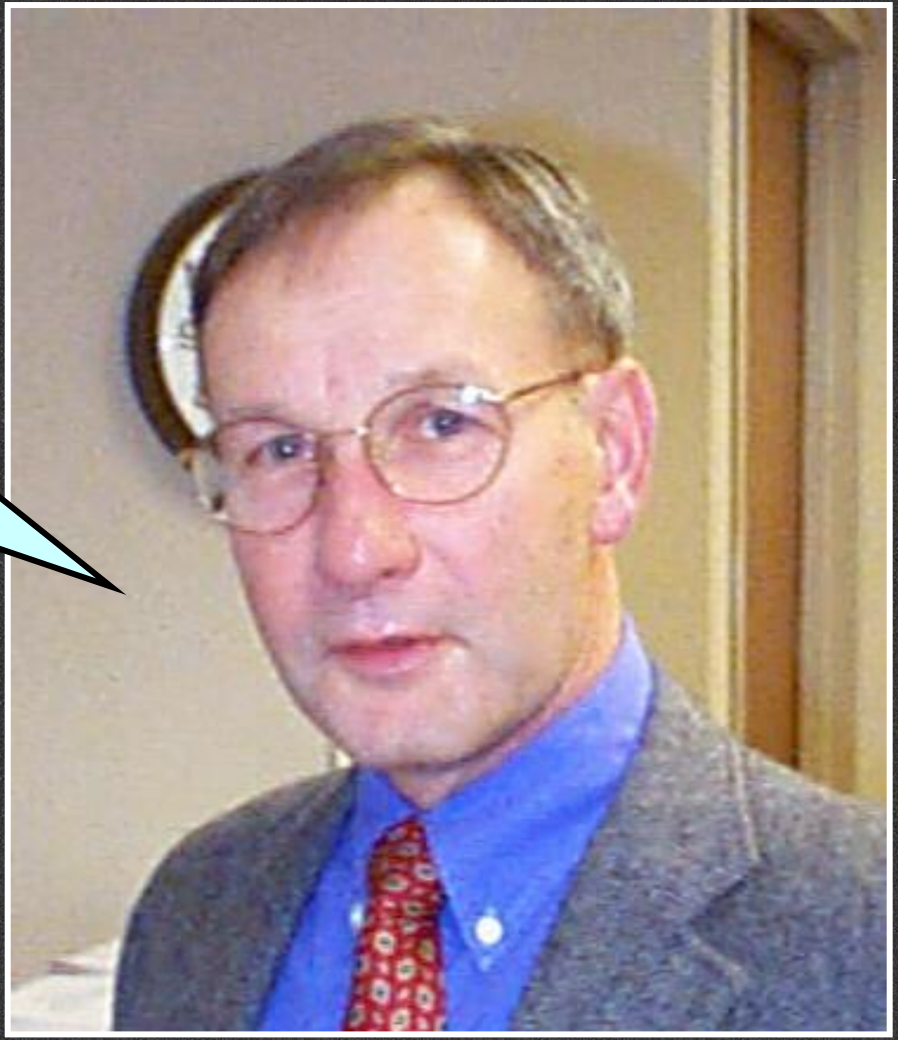
0s

Imperfection should never stall implementation.

You can still drink from a chipped cup.

AASHTO FHWA INDUSTRY

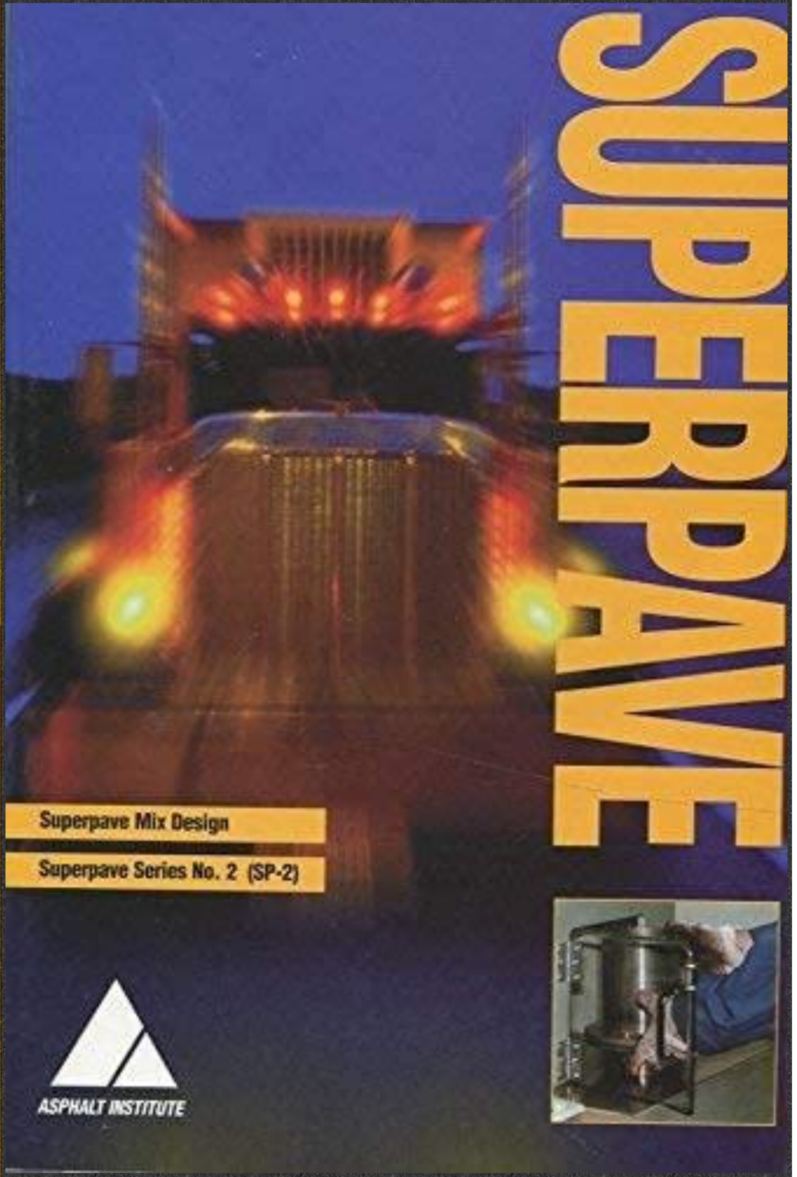
SUPERPAVE 2000



Paul Mack

New York State - Retired

6



- Performance-based Binder Purchase Specification
- Consensus Aggregate Properties
- Design Aggregate Structure
- Volumetric-based Design Binder Content
- Evaluation of Moisture Sensitivity
- A Simple Performance Test

"Asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure."

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

Balanced Mixed Design BMD

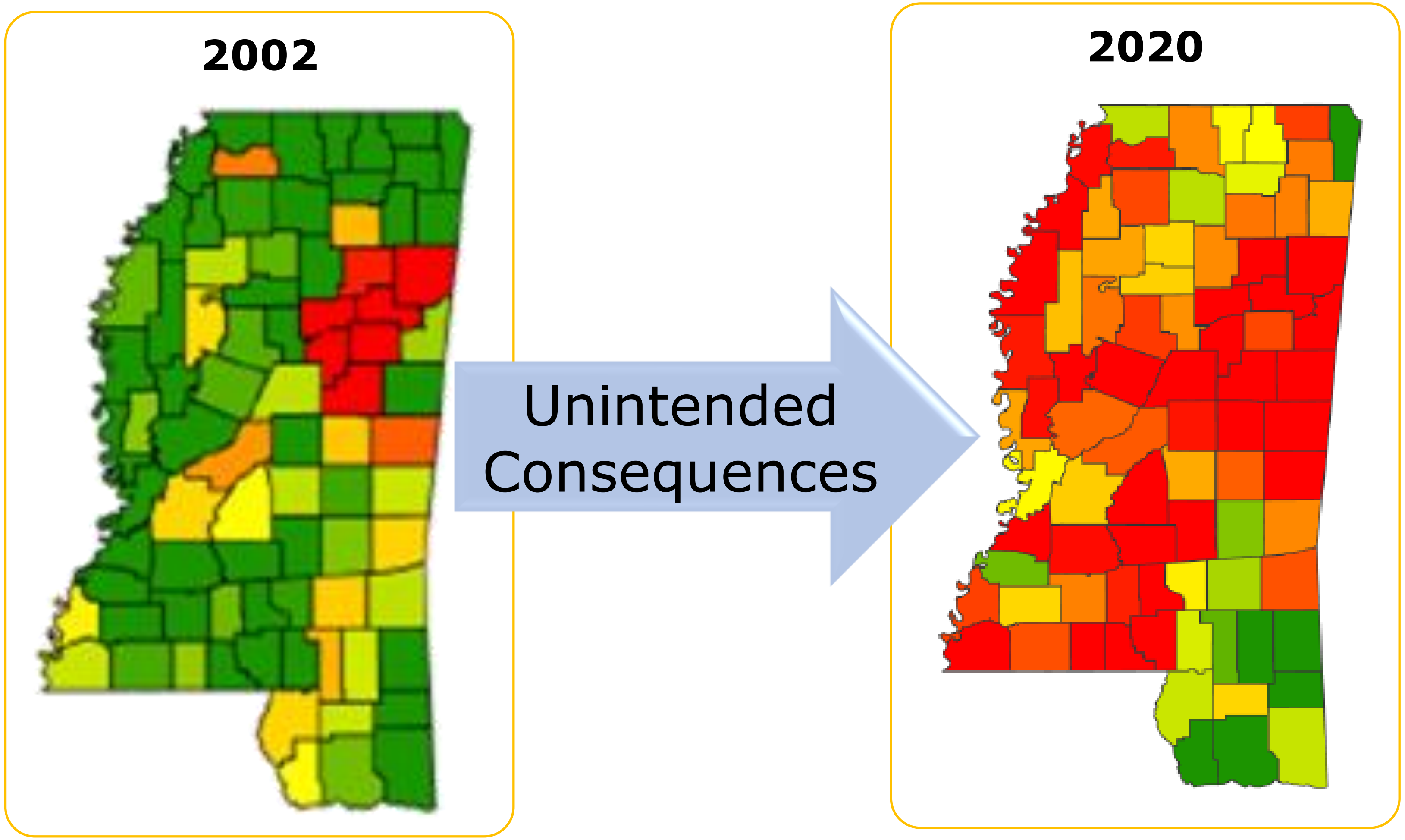
(circa 2015)

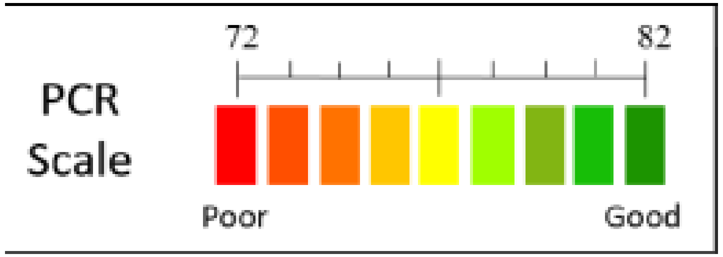
The Tenants of Balance Mix Philosophy

- The Goal is to design, produce, and place an **economical**, *resource-responsible*, **long-life** **asphalt pavement** that balances risk between agency-buyer and contractor-seller.
- We understand the various distress mechanisms in asphalt pavements.
- We believe laboratory performance tests can effectively assess binder and mix resistance to the various distresses.
- There can be a juxtaposition between designing mix resistance to two or more distresses, necessitating a balanced approach.

MDOT
MISSISSIPPI DEPARTMENT OF TRANSPORTATION

Volumetric-only mix design is not fully capable of dealing with present-day mixes





Pavement Condition Rating

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER
US Army Corps of Engineers


NOW LEAVING
SUPERPAVE
WELCOME TO
BALANCED DESIGN

Original BMD Approaches (circa 2015)

National Center for Asphalt Technology NCAT AT AUBURN UNIVERSITY

APPROACH A	• Volumetric Design with Performance Verification
APPROACH B	• Volumetric Design with Performance Optimization
APPROACH C	• Performance-Modified Volumetric Design
APPROACH D	• Performance Design

Approaches

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

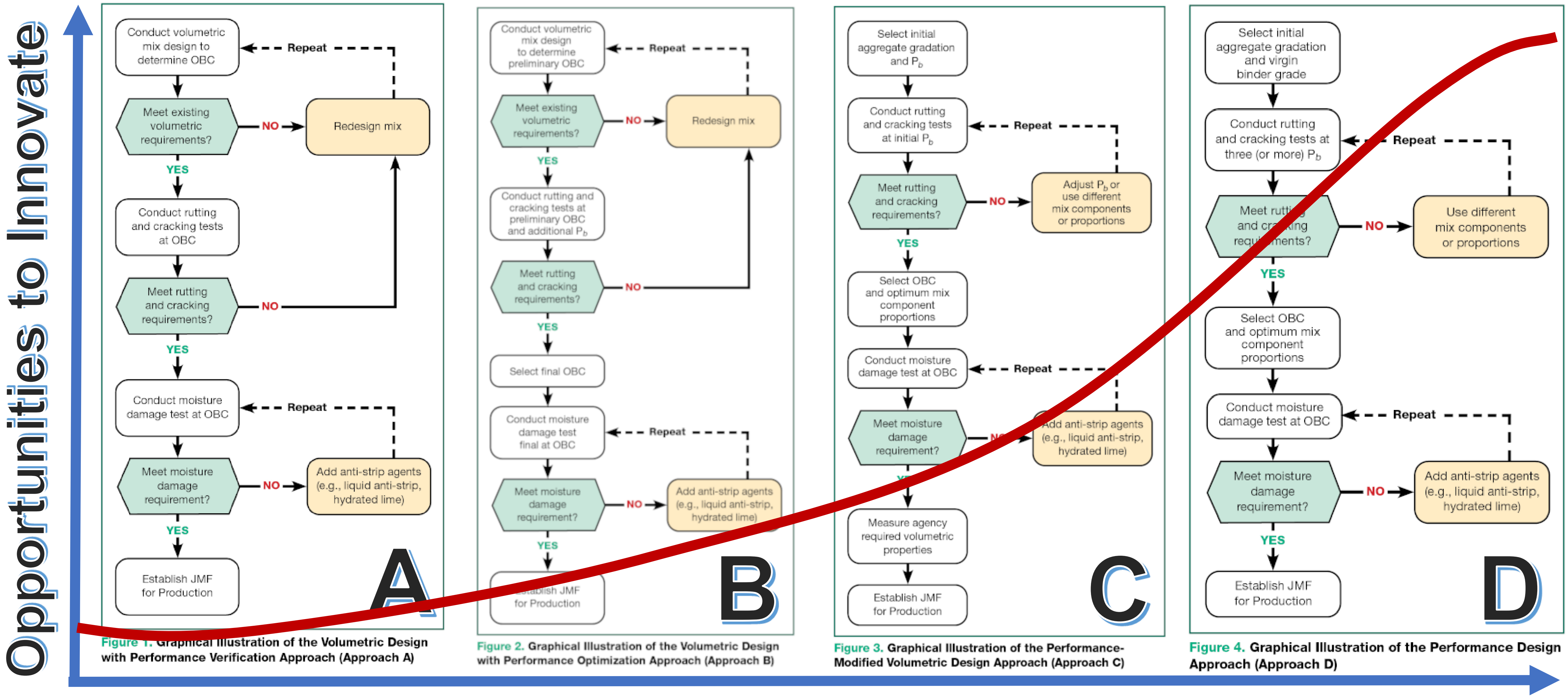


Figure 1. Graphical Illustration of the Volumetric Design with Performance Verification Approach (Approach A)

Figure 2. Graphical Illustration of the Volumetric Design with Performance Optimization Approach (Approach B)

Figure 3. Graphical Illustration of the Performance-Modified Volumetric Design Approach (Approach C)

Figure 4. Graphical Illustration of the Performance Design Approach (Approach D)


Are you a Chef or a Cook?

With the current volumetric mix design system…

BALANCED APPROACH


Quantity
Quality
BMD

BMD Candidate Performance Tests

6

Rutting (Permanent Deformation)

- 6 Candidate Performance Tests
- Equipment $20k to $120k

10

Fatigue Cracking

- 10 Candidate Performance Tests
- Equipment $10k to $180k

1

Moisture Damage

- AASHTO T 283, Modified Lottman
- Equipment ~$10k

1

Other Performance Considerations

- AASHTO TP 108, Toughness – Cantabro
- Equipment ~$10k

How valid is the field validation?

How sensitive?

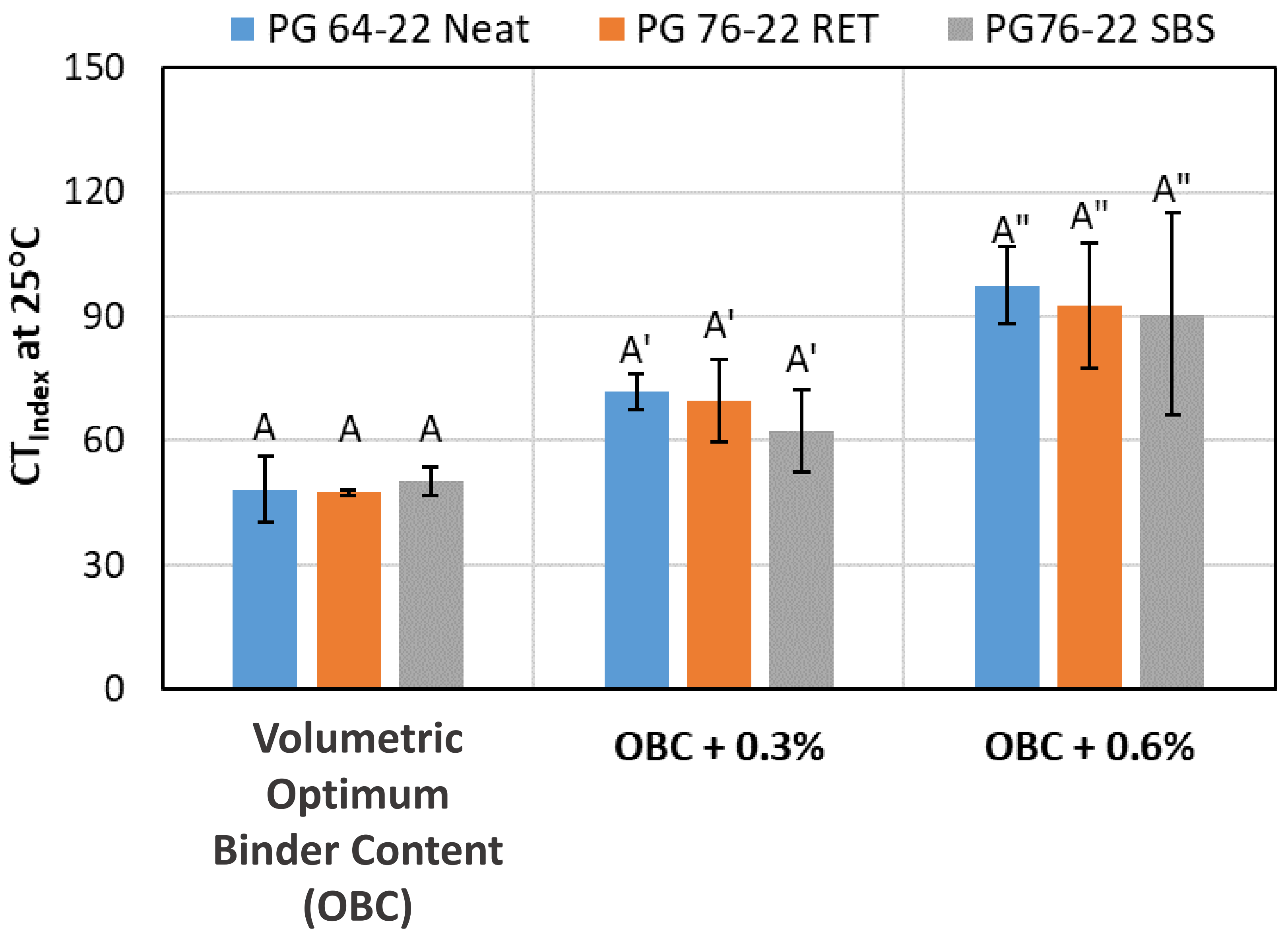
Does it pick up on modifiers/fibers?

Cracking

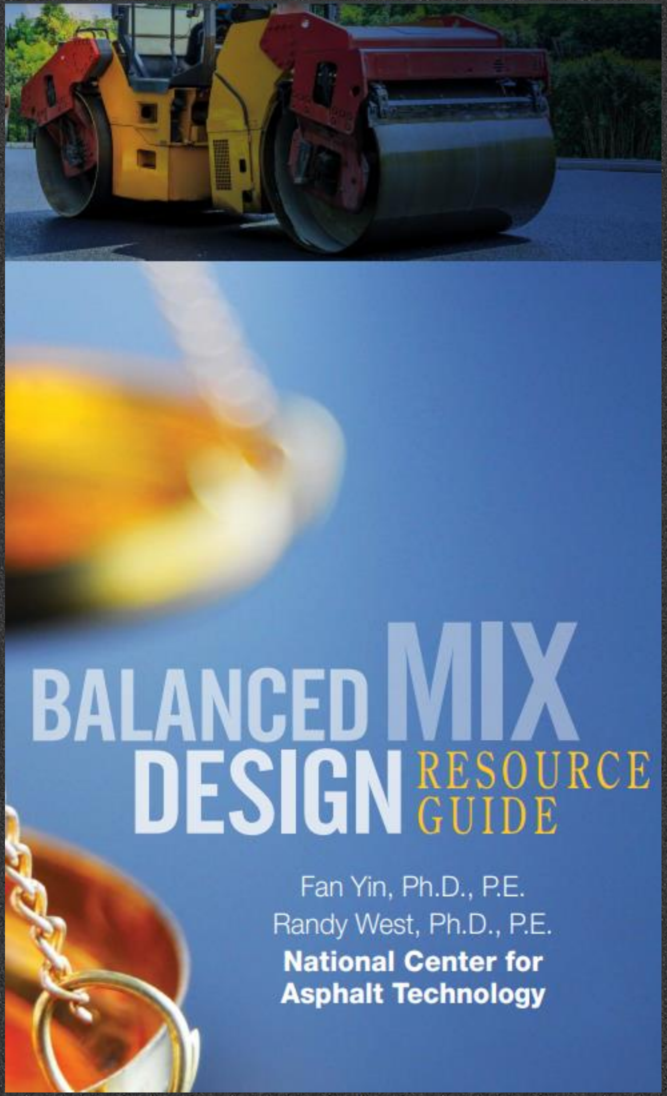
National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

CT_{Index} appears insensitive to polymer modification

IDEAL-CT Results of Alabama Mixtures at 25°C



National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY



Establishing Criterion

- ✓ Easy to Set Up
- ✓ Easy to Run
- PASS / FAIL — Easy to Analyze

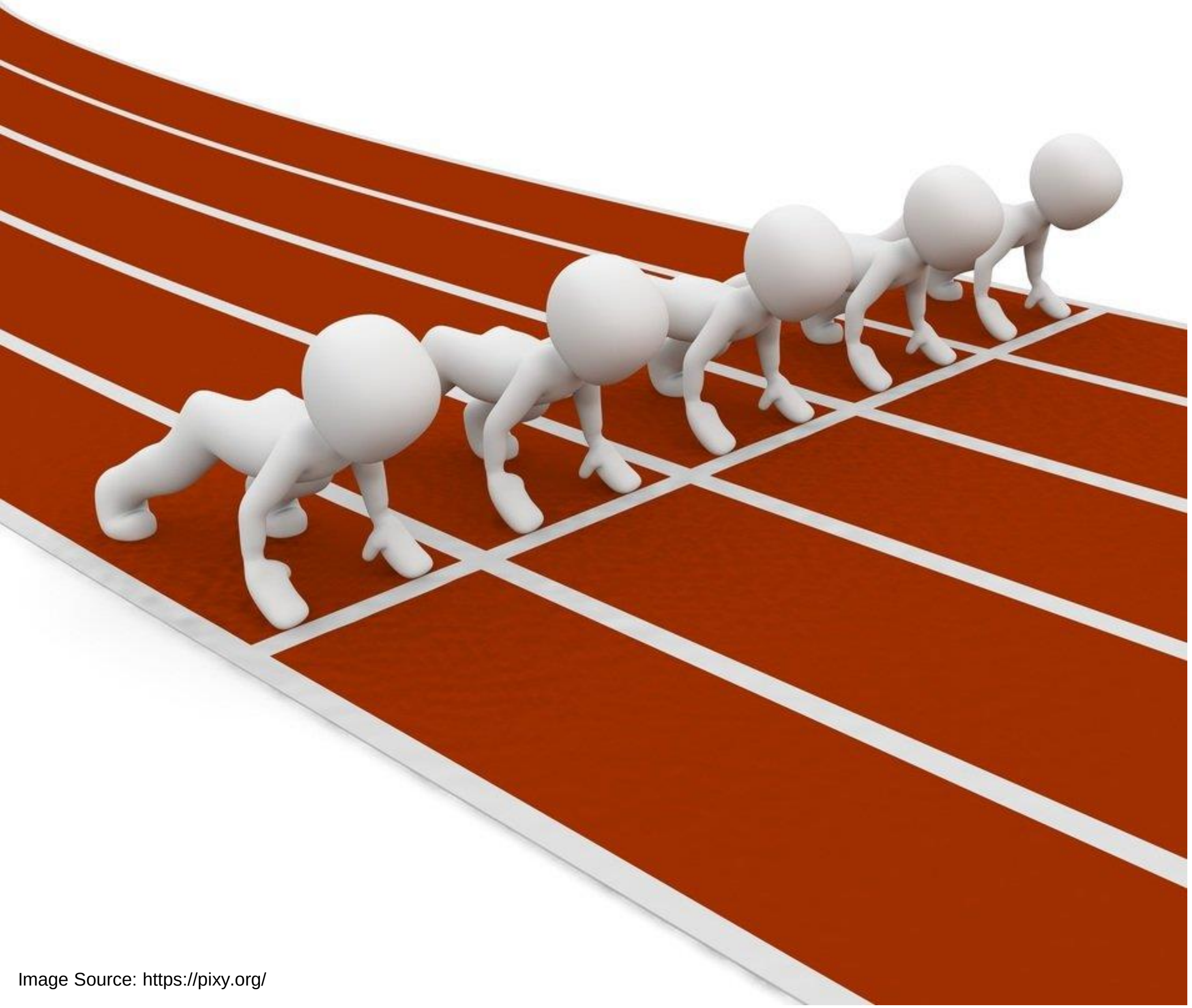


Image Source: https://pixy.org/

A few of the proposed tests are pulling ahead…

BMD Performance Direction...

1


Rutting

- APA or HWT | IDEAL-RT
- Equipment $46k to $120k



1


Fatigue Cracking

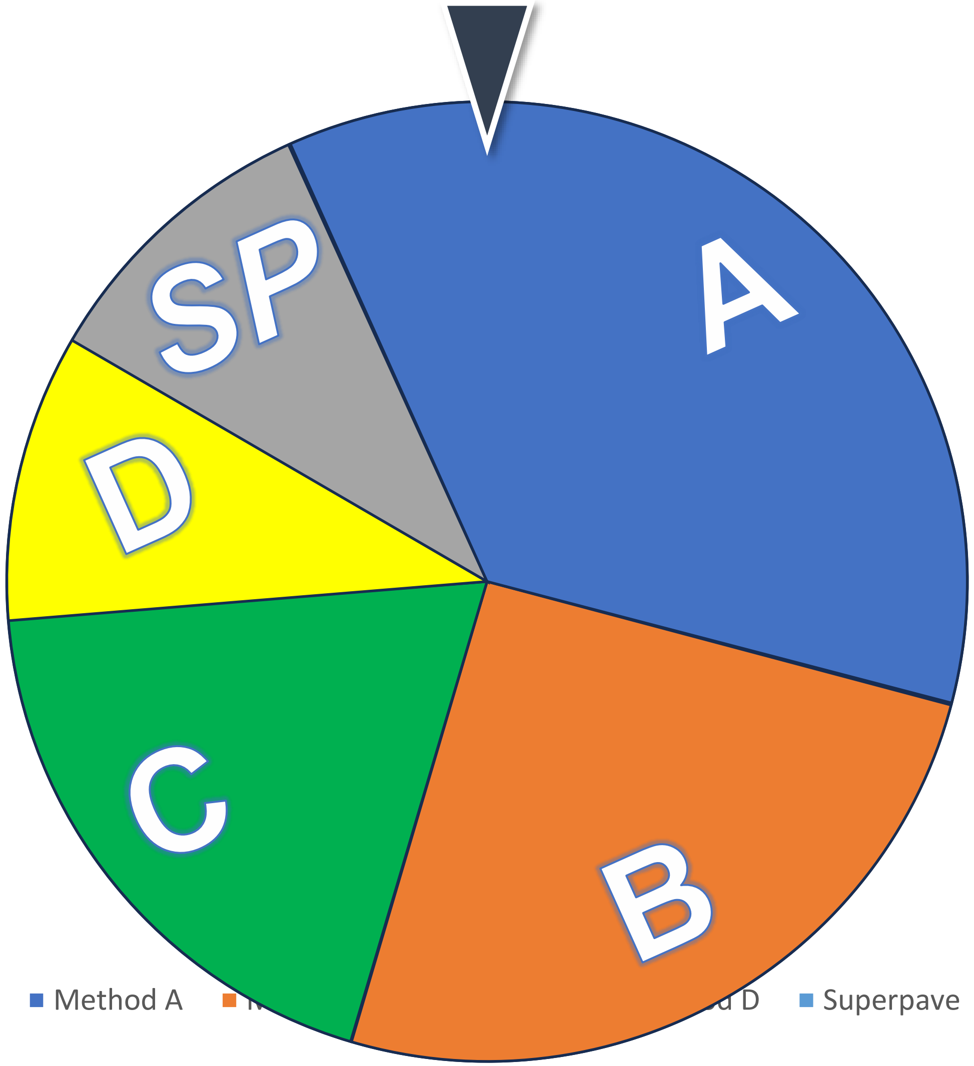
- IDEAL-CT or I-FIT
- Equipment $14k to $24k


1?


Moisture Damage (HWTT)

- AASHTO T 283, Modified Lottman
- Equipment ~$10k

Where are we today with BMD Method?



National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

Why BMD Method A?

- ✓ Appears the easiest from an Agency perspective.
- ✓ Just adds performance testing to Superpave.
- ✓ Superpave volumetrics are still required.
- ✓ No reduction in consensus properties.
- ✓ Allows current AQCs for QA.

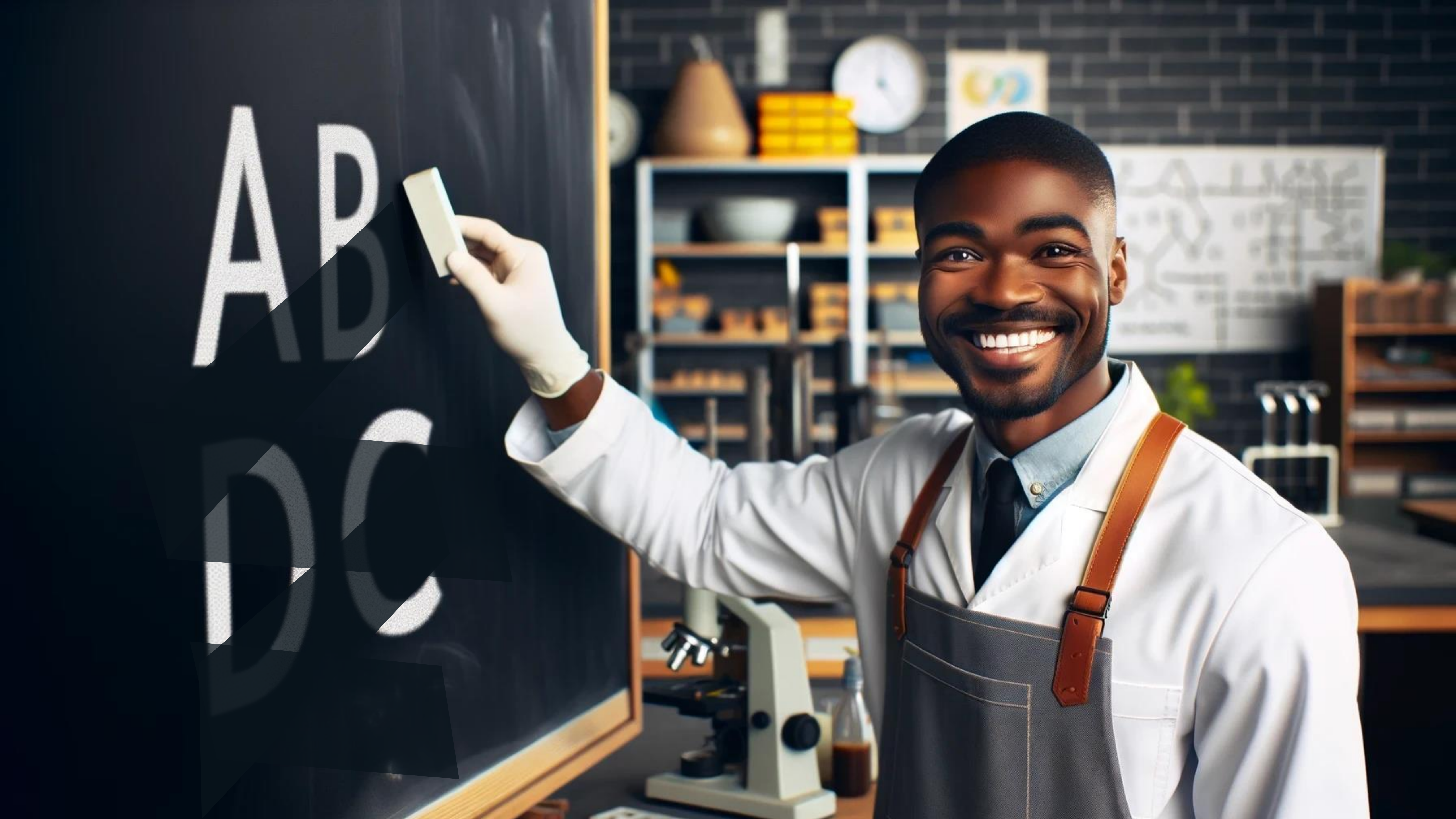
National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

National Center for Asphalt Technology NCAT AT AUBURN UNIVERSITY

Other Considerations

Method A

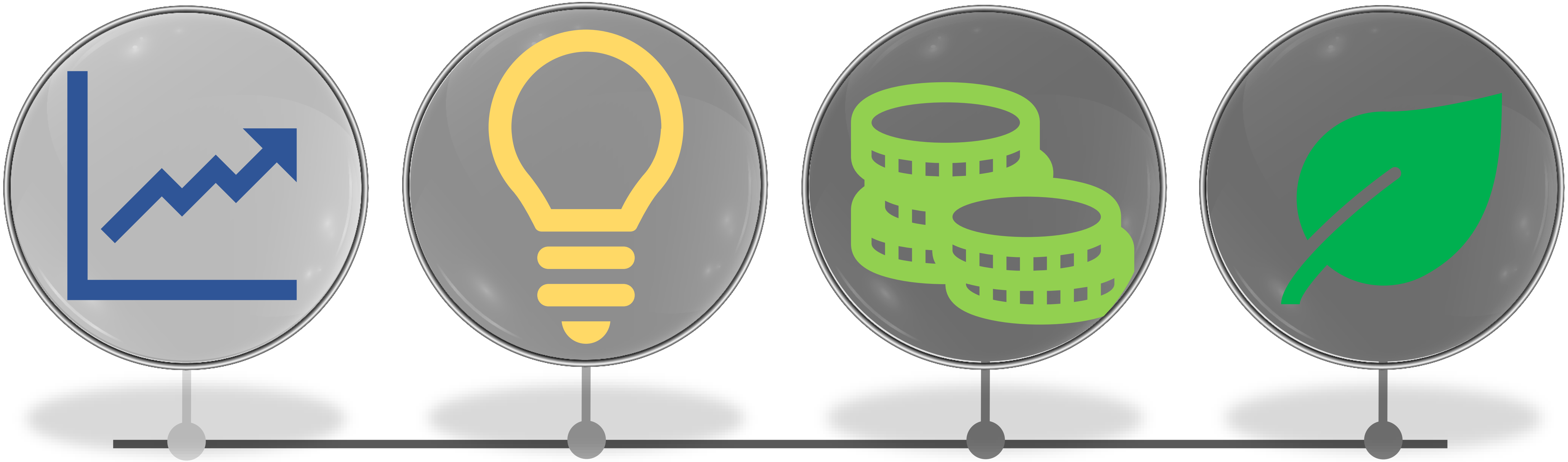
- Increased Cost and Time
- Iterative Mix Design with limited flexibility
- Restricts innovation
- Sustainability:
  - Limits local aggregate
  - Limits RAP and other recycled materials
  - Increases GWP of EPDs


AB
DC


BMD
Balanced Design
Performance Tests
Est. Binder Content
Trial Gradations
Additional Materials
RAP
Aggregate
PG-Binder
Mix Type
Sustainable
Economical
Long-Life Asphalt

Anticipated Benefits

National Center for Asphalt Technology NCAT AT AUBURN UNIVERSITY



Improve Performance

Enable Innovation

Optimize Cost

Sustainable

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

The Who –
The Critical Role of Champions

- 80/20 Rule
- 10% more is only 4 hours a week
- Have a Plan
- S.M.A.R.T. Goals
- Use your Resources
- You are not alone

Challenge

"Whenever enemies have the ability to attack the innovator, they do so with the passion of partisans, while the others defend them sluggishly so that the innovator and their party alike are vulnerable."

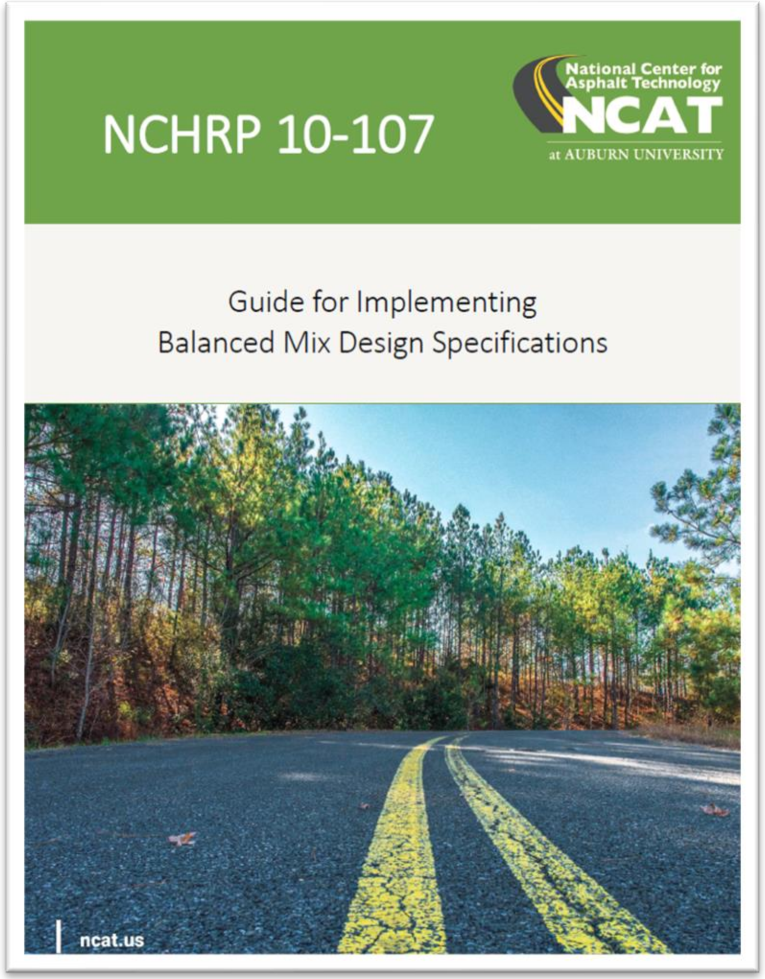
-Niccolȯ Machiavelli, The Prince (1513)

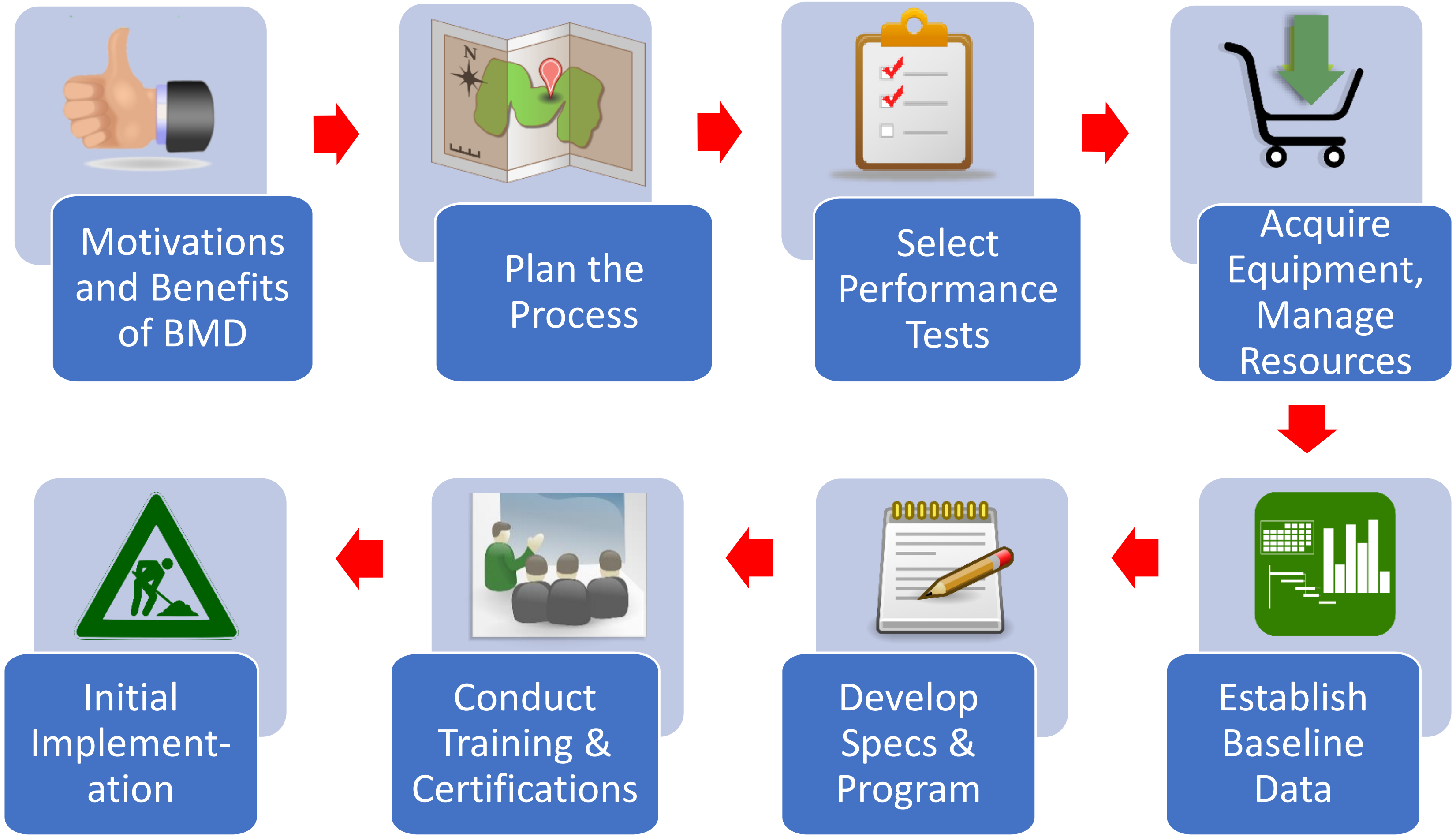
CAPRI – What are you waiting for?

- The Consortium for Asphalt Pavement Research & Implementation

Guide for Implementing BMD Spec's

- Guide & 1-day Workshop





National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

Field Validation

Objective

- Develop guidelines and recommendations that Agencies can follow to build test sections for establishing valid relationships between BMD test results and field performance and to ensure that appropriate specification criteria are developed.

Research Team

Tom Harman

Fan Yin

Carolina Rodezno

Nam Tran

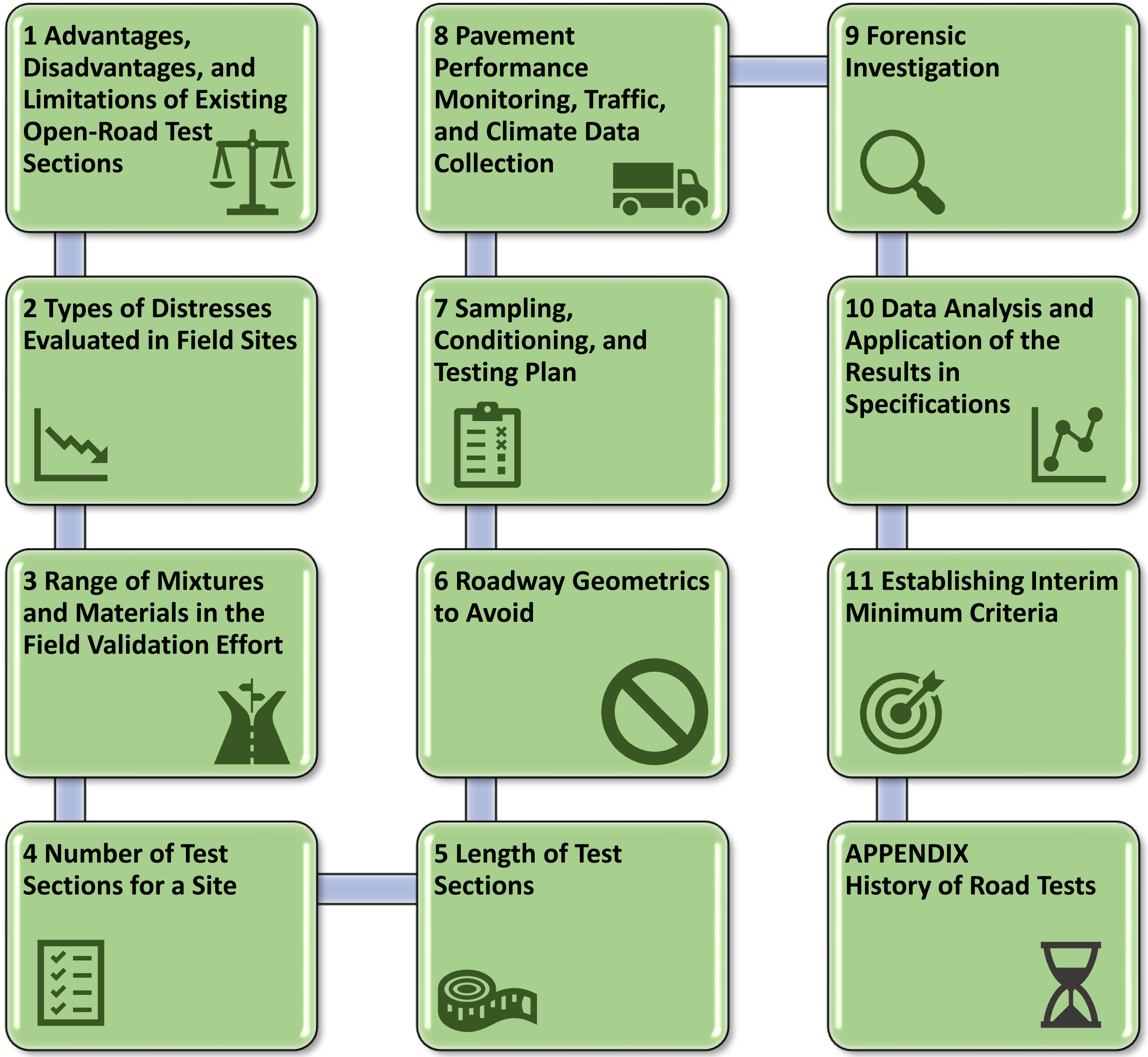
Randy West

Project Oversight Group

CAPRI
CONSORTIUM FOR ASPHALT PAVEMENT RESEARCH AND IMPLEMENTATION

- Jason Blomberg, Missouri DOT
- Andrew Brooks, C.W. Matthews
- Jeff Kern, Champaign Asphalt
- Zane Hartzog, Alabama DOT
- Tyler Wollmuth, North Dakota DOT

The Flow of the Guide



1 Advantages, Disadvantages, and Limitations of Test Section Approaches

Advantages	Open-Road Test Section	Closed Test Track	Accelerated Loading Simulator	Agency Pavement Management Data
Real-world Traffic	✓			✓
Real-world Environmental Conditions	✓			✓
Long-Term Data Collection	✓			✓
Cost Effectiveness	✓	✓		✓
Accelerated Testing		✓	✓	
Controlled Environment		✓	✓	
Controlled and Repeatable Testing			✓	
Comprehensive Data	✓	✓	✓	
Disadvantages				
Slow Data Accumulation	✗			✗
Limited Control	✗	✗	✗	✗
Spatial Variability	✗			✗
Limited Representation of Real-World Conditions		✗	✗	
Limited Flexibility		✗	✗	✗
Complexity and Cost			✗	
Granularity of Data				✗
Data Accuracy				✗

2 Types of Distresses Evaluated in Field Sites

← Rutting

← Cracking

Type	Mode
Load-related	○ Top-down cracking ○ Bottom-up fatigue cracking
Environmental	○ Thermal cracking (Transverse) ○ Block cracking
Reflection	○ Asphalt over concrete ○ Asphalt over asphalt

← Moisture Damage

2 Types of Distresses Evaluated in Field Sites

Table 3. Summary of Recommended Approaches

Type of Distress	Targeted Layer	Construction	Design Considerations	Additional Items
Rutting	Surface Layer	Overlay, or Mill & Fill	Lower Layers have High Rut Resistance	Avoid intersections
Top-down Cracking	Surface Layer (e.g., 1.5-inches)	New or Reconstruction with a fatigue-resistance intermediate layer	Consider designing for a short design life	Resource: NCAT 2015-2020 Test Track
Bottom-up Cracking	Sufficient tensile strains in the bottom layer	New or Reconstruction	Considerably thinner than needed	Resource: NCAT Additive Group 2021
Thermal Cracking	Surface Layer	Overlay, or Mill & Fill		Resource: MnROAD-NCAT Cracking Group 2016-2022
Reflective Cracking	Surface Layer	Artificial Cracks (sand / no sand options)		Resource: MnROAD-NCAT Reflective Cracking Challenge
Moisture Susceptibility	Surface layer	APT Facility	AASHTO T283 or HWTT	Resource: List of six proposed research tasks

NCAT Test Track Reports

MnROAD

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

3 Range of Mixtures and Materials in the Field Validation Effort

Table 4. Common Mix Design Strategies to Improve Performance

Rutting Resistance

- Adjust aggregate gradation
- Use a stiffer asphalt binder
- Polymer modification
- Lower asphalt binder content
- Increase recycled materials content
- Add fiber additives

Cracking Resistance

- Increase asphalt binder content
- Lower recycled materials content (*)
- Use a softer (better quality) asphalt binder
- Polymer modification (in most cases)
- Add a rejuvenator

Moisture Resistance

- Add an anti-strip agent
- Change binder source
- Change aggregate type

(*) – Crack-resistant mixes can be developed with high recycled material content.

3 Range of Mixtures and Materials in the Field Validation Effort

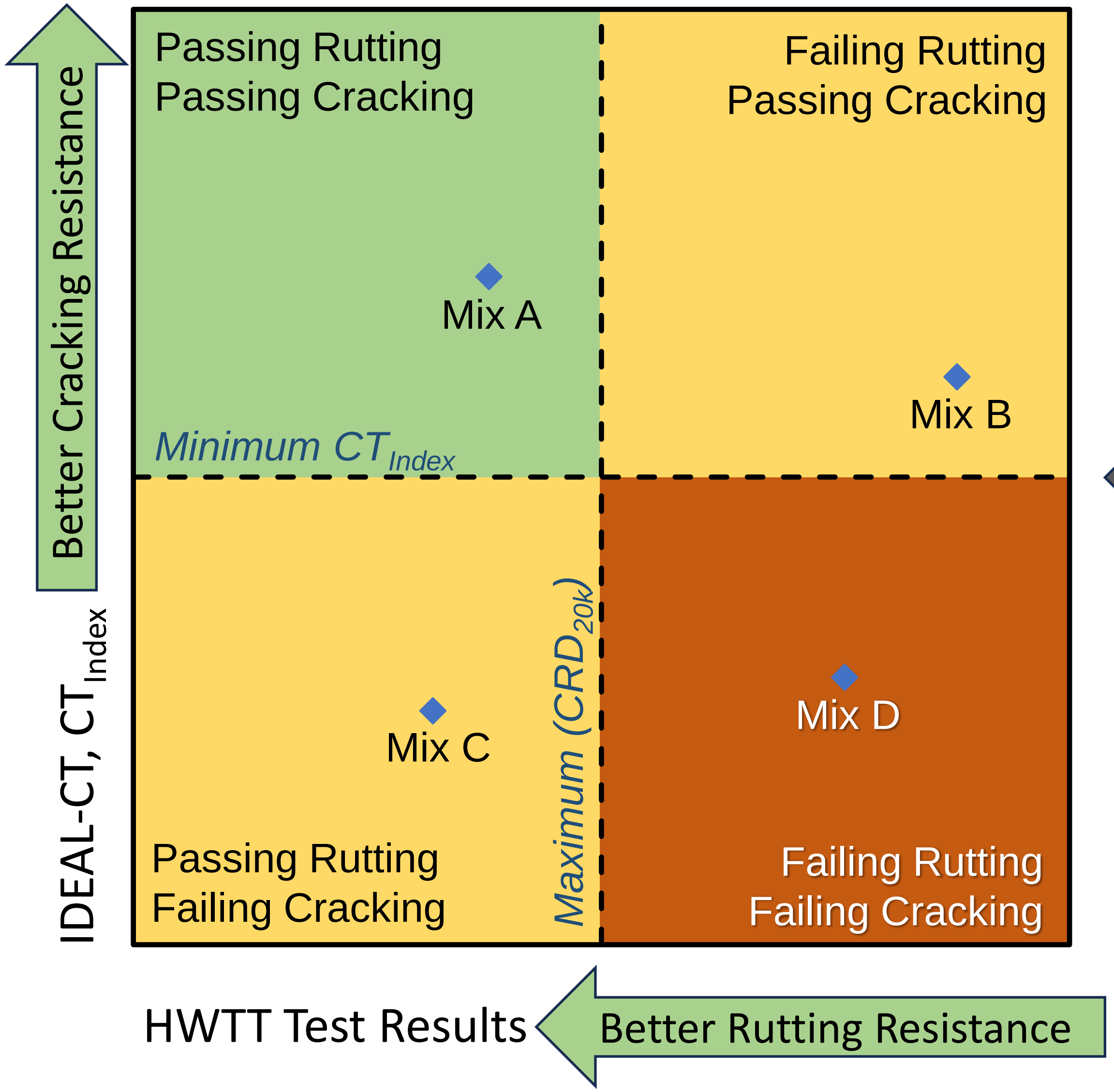


Figure 8. Example of Performance Diagram to Select Asphalt Mixtures for Field Validation Experiment.

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

4 Number of Test Sections for a Site

Table 5. Example Field Validation Experimental Matrix with 6 Test Sections

Rutting Resistance	Cracking Resistance		
	Low	Medium	High
Low		①	②
Medium	③		④
High	⑤	⑥	

Figure 9. Hypothetical Laboratory-to-field Correlation Results from a Validation Experiment; (a) Rutting Correlation Results, (b) Cracking Correlation Results

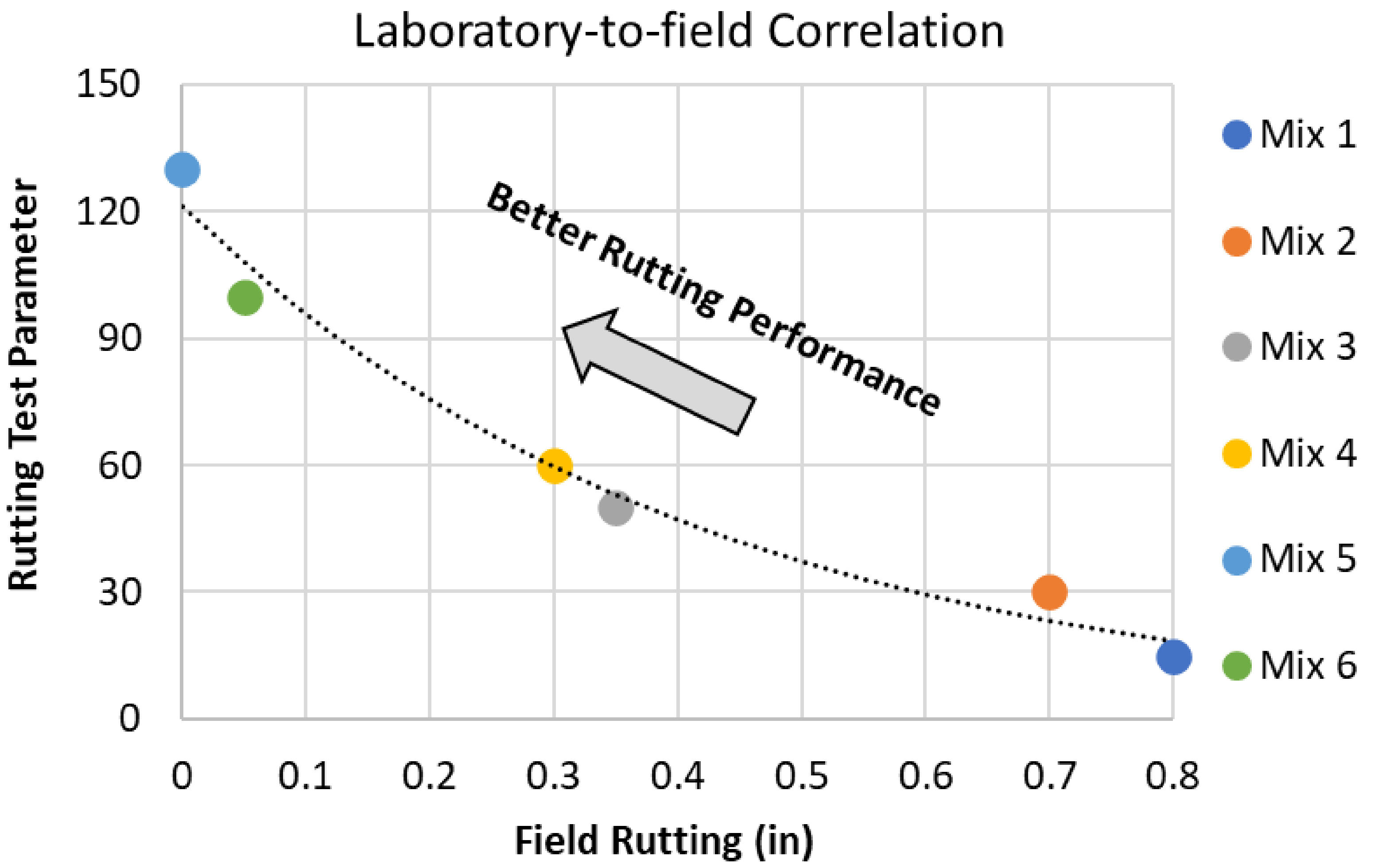
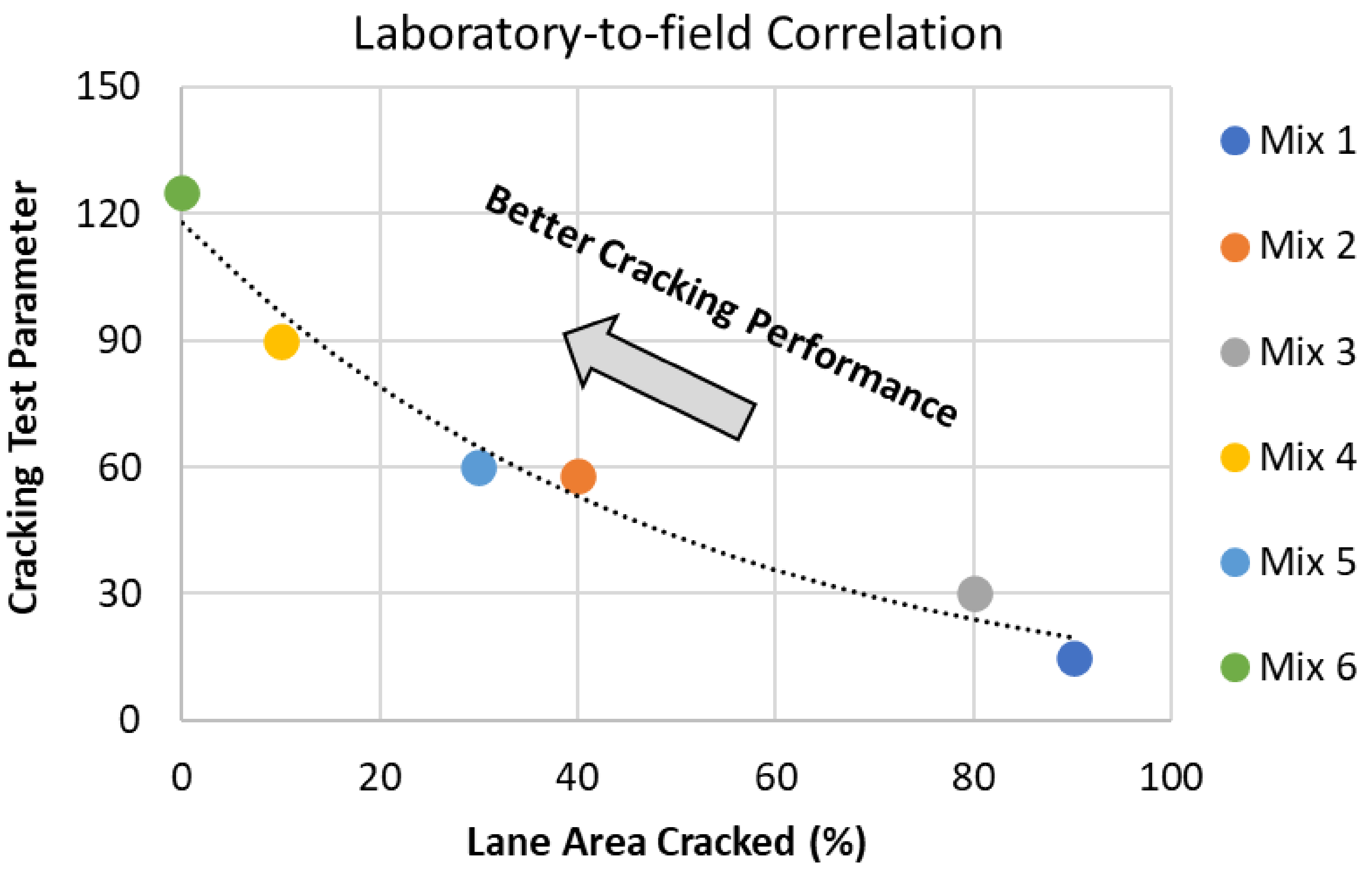


Figure 9. Hypothetical Laboratory-to-field Correlation Results from a Validation Experiment; (a) Rutting Correlation Results, (b) <u>Cracking Correlation Results</u>

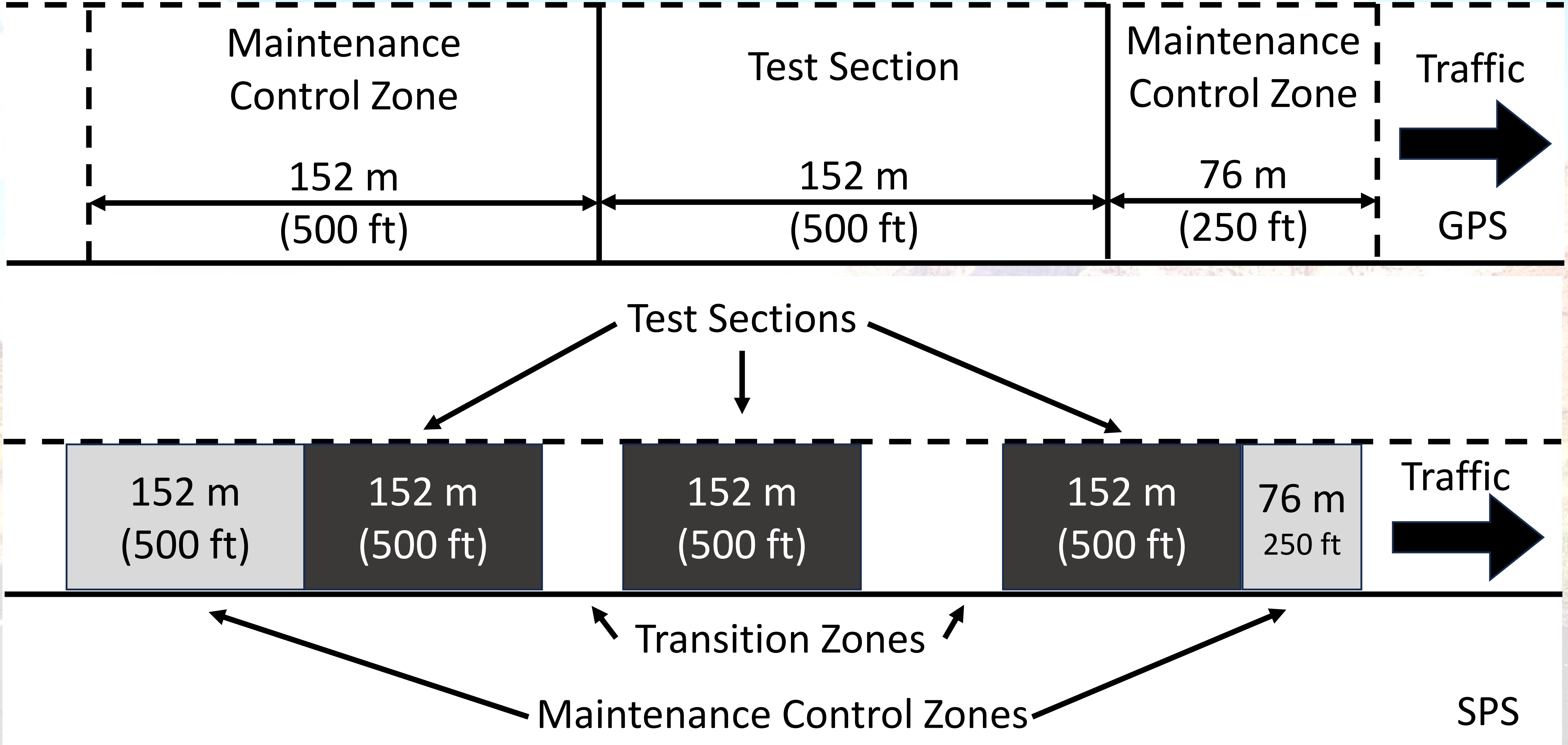


5 Length of Test Sections

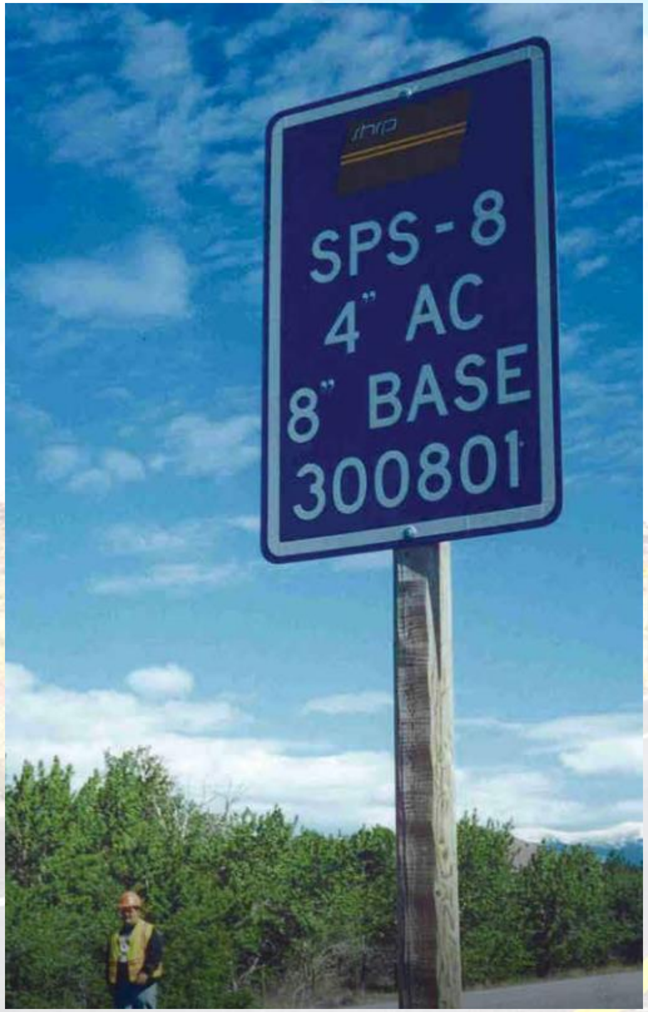
Considerations

- ✓ Type of Test Section
- ✓ Meaningful Pavement Condition Monitoring
- ✓ Transition/Buffer Zone between sections
- ✓ Sampling of Materials
- ✓ Number of BMD Replicates
- ✓ Variability Reduction
- ✓ Traffic and Load Considerations
- ✓ Budget and Resource Constraints
- ✓ Statistical Significance

5 Length of Test Sections
Figures 10. LTPP GPS and 11. LTPP SPS



5 Length of Test Sections
Labeling | GPS Coordinates



5 Length of Test Sections
Sampling of Materials, Tables 6 & 7

	COV (3 Replicates)		
Sample Size, n	10%	15%	20%
3	16%	20%	24%
4	12%	14%	15%
5	9%	10%	11%
6	7%	8%	9%
7	6%	7%	7%
8	5%	6%	6%
9	5%	5%	5%

	No. Replicates (Pop. COV 15%)		
Sample Size, n	3	4	5
3	20%	7%	6%
4	14%	6%	4%
5	10%	5%	3%
6	8%	4%	2%
7	7%	3%	2%
8	6%	3%	1%
9	5%	3%	1%

Where: The |Mean – Ave|/SEM yields the likelihood of accepting a result statistically outside the true mean of the field test section.

5 Length of Test Sections
EXAMPLE

a. State DOT identifies *top-down cracking* and *rutting* as key performance challenges

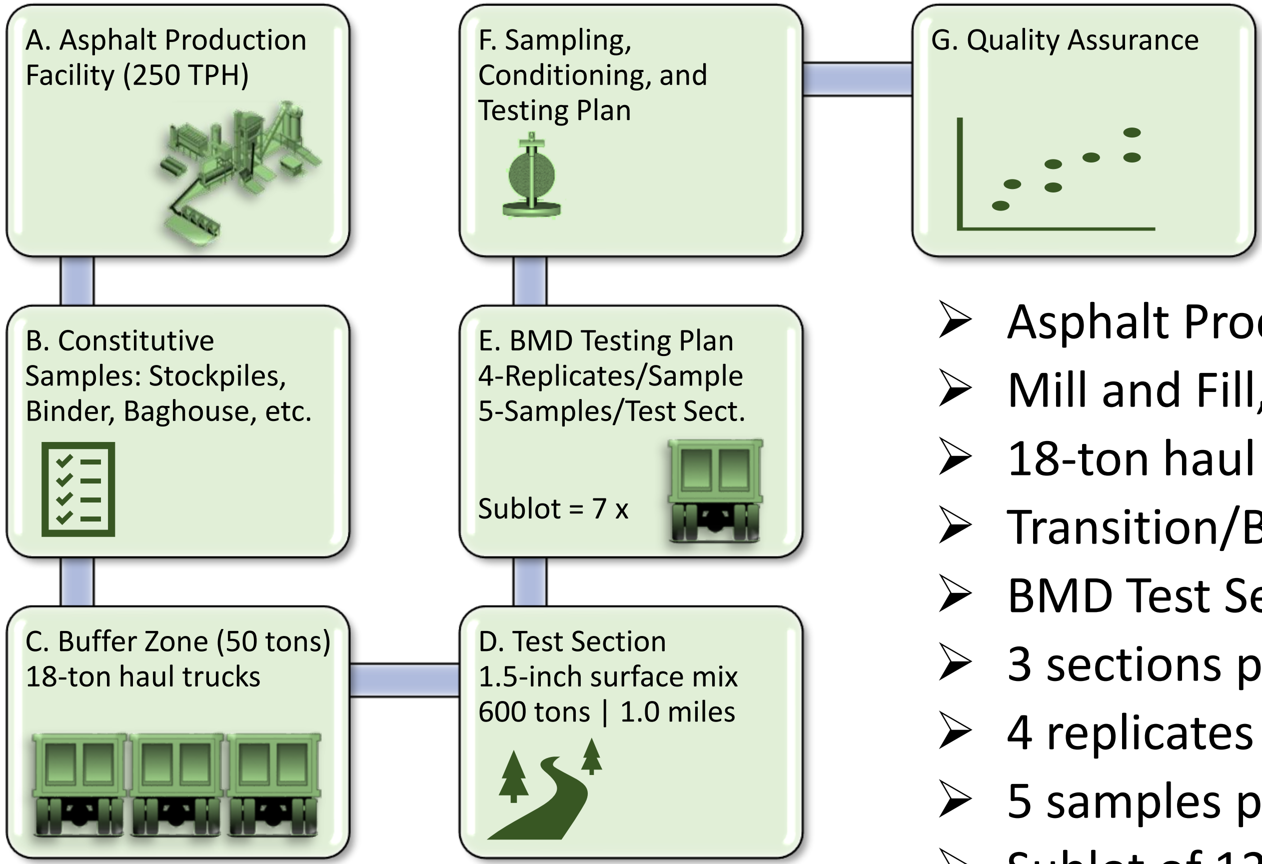
b. Laboratory assessment of several of the BMD tests
   - ✓ Selected the IDEAL-CT and the HWTT

c. Shadow testing of Superpave mixes provides a range of typical test results

d. Based on the Guidelines and Recommendations for Field Validation of Test Criteria for Balanced Mixture Design (BMD) Implementation, they have adopted Table 4.1 Field Validation Experimental Matrix with 6 Test Sections to design their open-road experiment

e. The state DOT has established an Agency-Industry taskforce to identify challenges and address concerns in constructing the sections
   - ✓ NCAT provided a 1-day BMD workshop to kick off the taskforce

5 Length of Test Sections



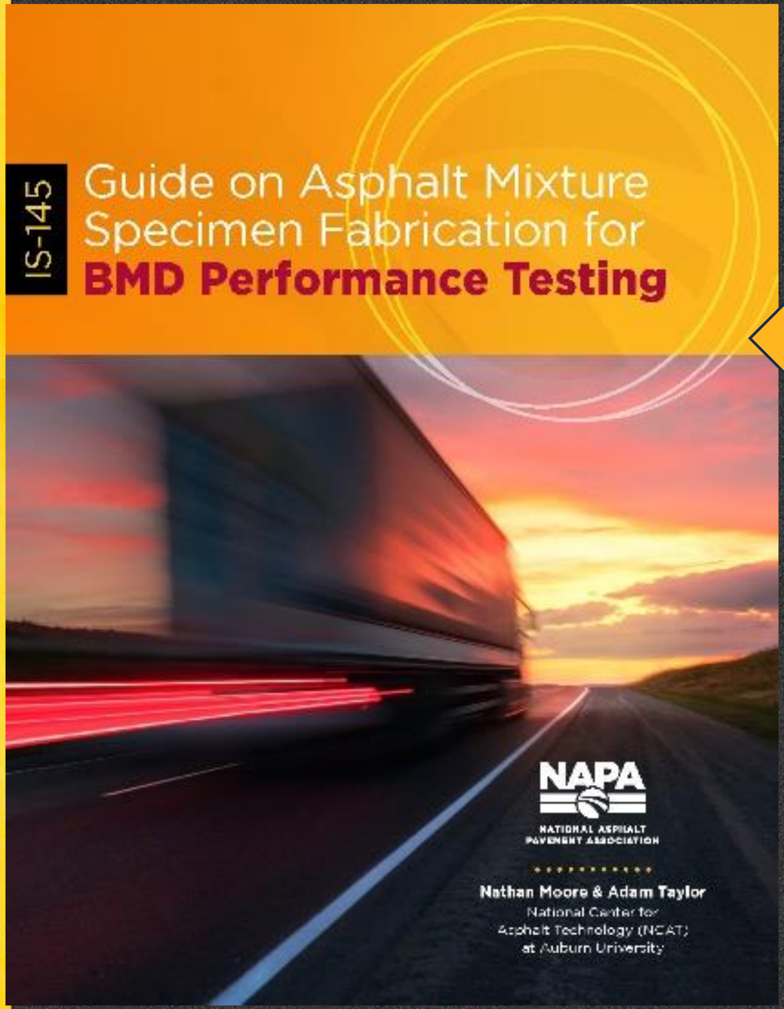
- Asphalt Production Facility, 250 TPH
- Mill and Fill, 1.5-inch surface mix (6 JMF)
- 18-ton haul trucks
- Transition/Buffer Zone = 3 trucks / 54 tons
- BMD Test Section = 600 tons / 1.0 miles
- 3 sections per day over 2 days
- 4 replicates for each BMD test
- 5 samples per test section
- Sublot of 126 tons (600 tons / 5 samples) or 7 trucks

National Center for Asphalt Technology NCAT AT AUBURN UNIVERSITY

6 Roadway Geometrics to Avoid

- Intersections
- Horizontal Grades
- Curves
- Variable Traffic Speeds

7 Sampling, Conditioning, and Testing Plan

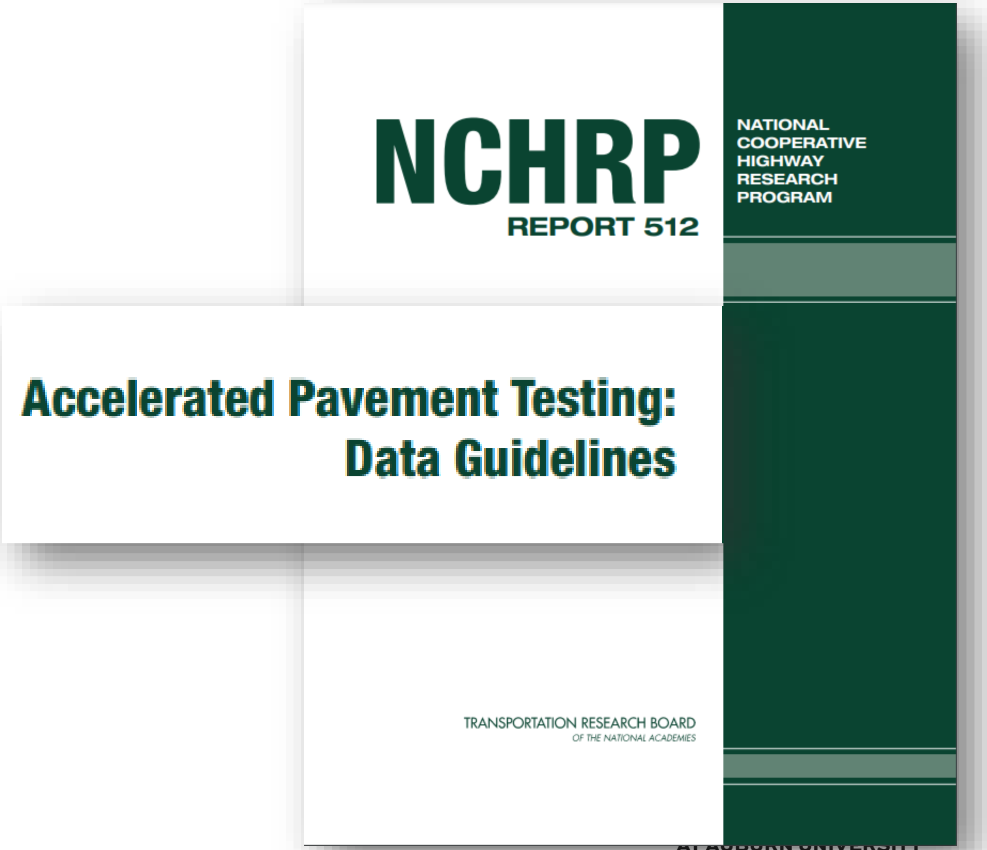


1. Sampling Methods
2. Representativeness
3. Sample Storage & Reheating (Lag-/Dwell-Time)
4. **Fabrication Resource**
5. Sample Conditioning
6. Test Procedures
7. In-place Density
8. Additional Information
9. Conventional Testing
10. QA
11. Split Samples

8 Pavement Performance Monitoring, Traffic, and Climate Data Collection

- Pavement Performance, Traffic, and Climate Data Collection

- Protocols
  - Training and Certification
  - Equipment and Tools
  - Data Collection Procedures
  - Data Management and Storage
  - Data Quality Control

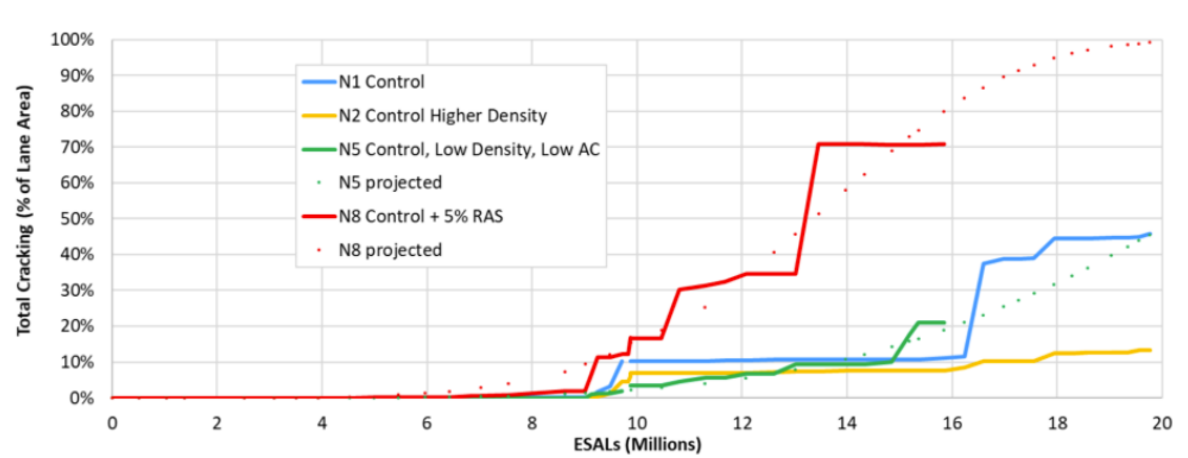


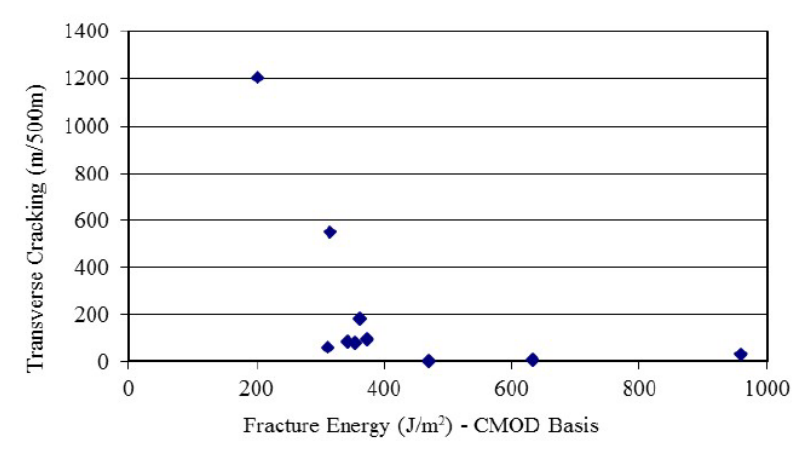
9 Forensic Investigation

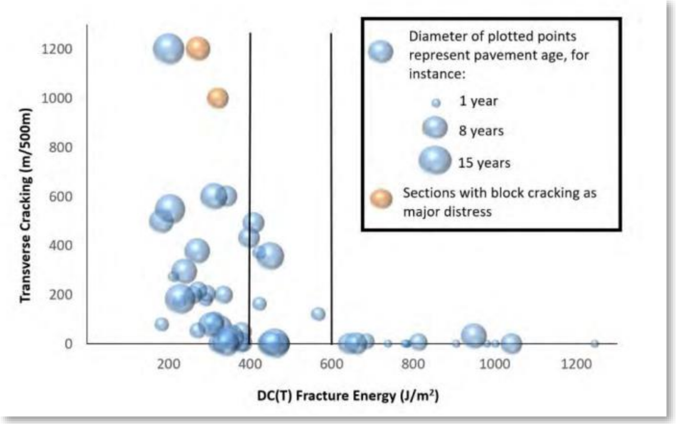
- Defining the Problem
- Conducting Visual Inspections
- Formulating Possible Hypotheses (H0)
- Conducting Tests for Evaluating H0
- Analyzing Results
- Developing Conclusions

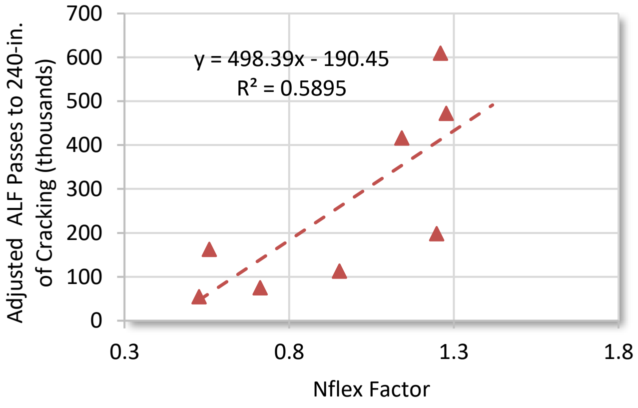
10 Data Analysis and Application of the Results in Specification

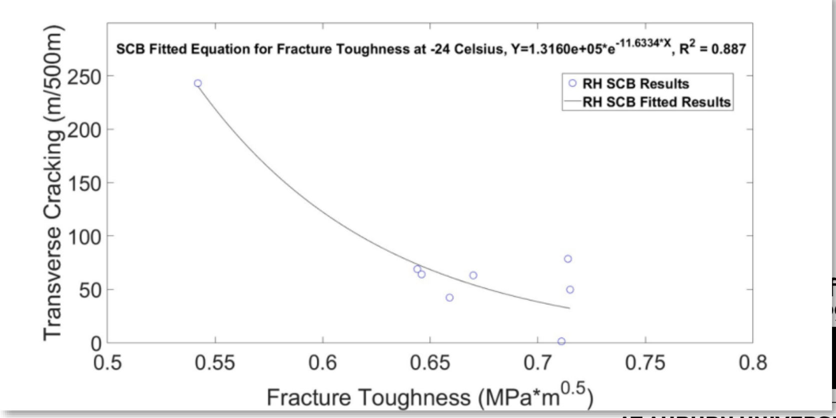
✓ Detailed Examples from Numerous Studies…







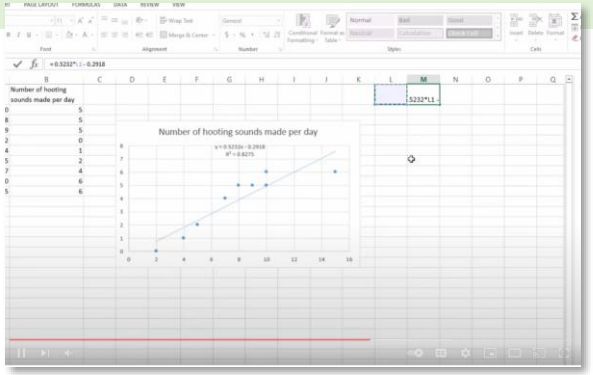




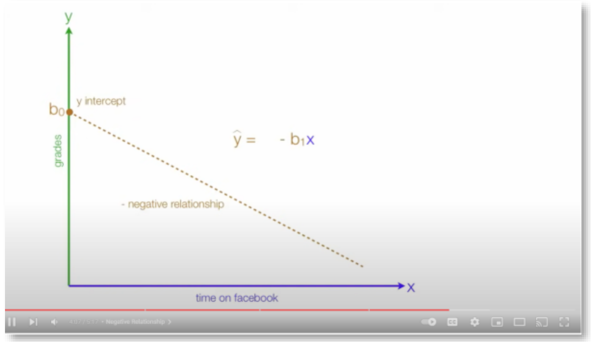
AT AUBURN UNIVERSITY

10 Data Analysis and Application of the Results in Specification

- *Useful Tools for Analysis:*
  - ✓ Video of constructing a scatterplot is a simple process in Microsoft Excel



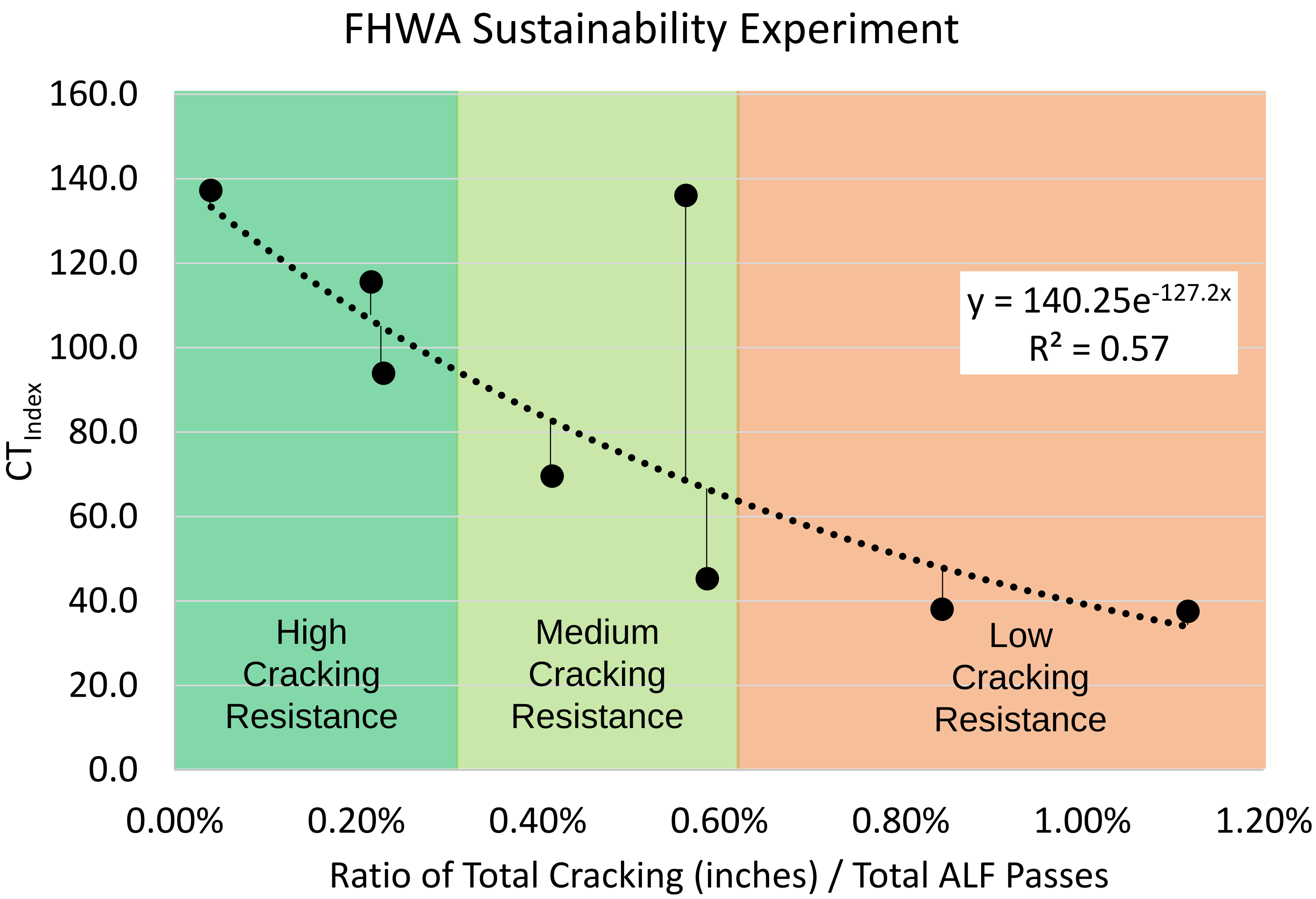
  - ✓ Video on linear regressions and R^2



  - ✓ Video of R^2 and *its limitations* Includes RSE

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

Example of Setting BMD Criteria CT_{Index}



Example of Setting BMD Criteria CT_{Index}

- In general, R^2 of 0.60 or higher
  - $Y = 140.25\, e^{-127.2x}$, $R^2 = 0.57$

- In addition, assess:
  - Residual Standard Error (RSE)
    - RSE = 28.0

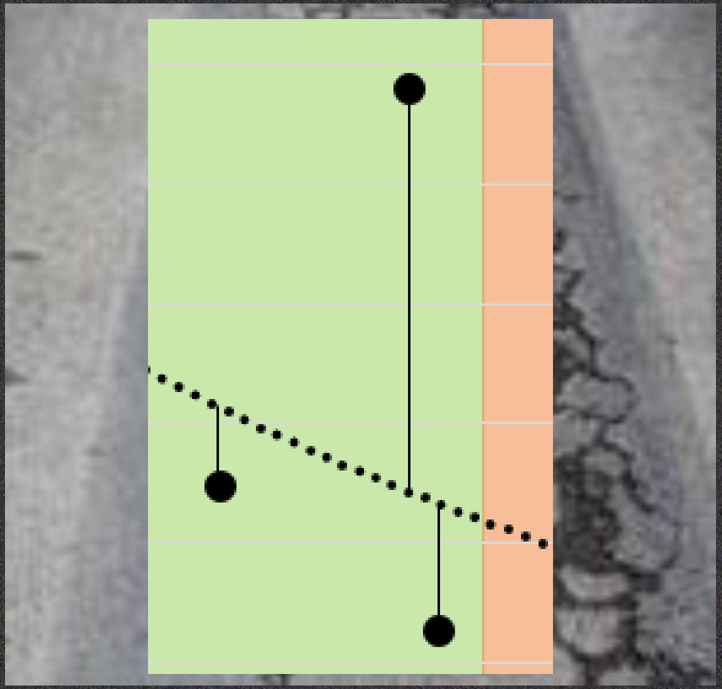
Example of Setting BMD Criteria CT_{Index}

- Note: Data point with high-residual (x=0.56, y=136.0)

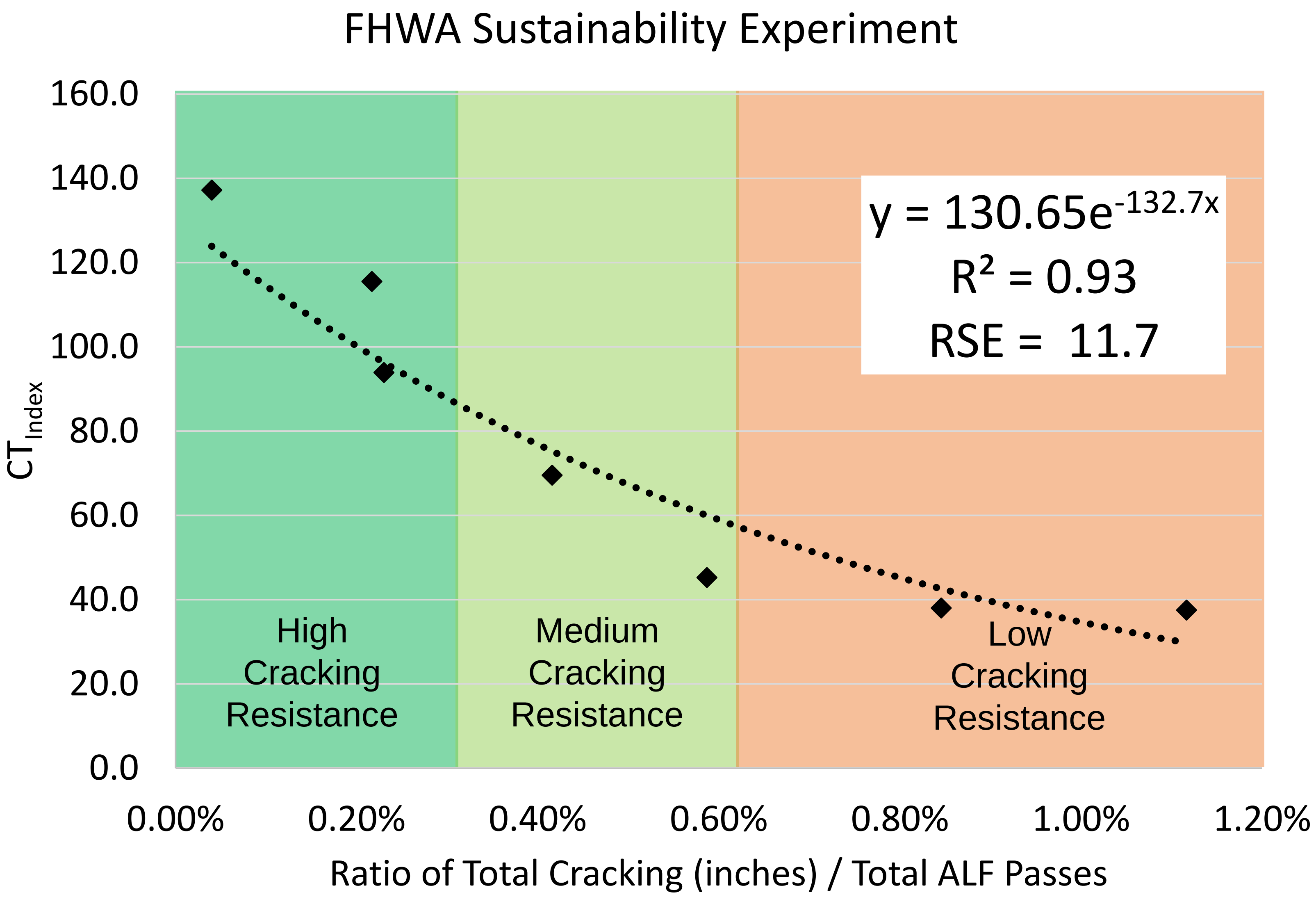
- Several potential or combination of reasons for this point to have a high residual:

  a) Variable subgrade support under the ALF sections
  b) Age of section at time of loading
  c) Sampling bias
  d) Relationship between CT_{Index} & measured performance

- For illustrative purposes, let's assume we determine this data point to be suspect and remove it from the analysis as such:



Example of Setting BMD Criteria CT_{Index}



11 Establishing Criteria

1. Benchmarking
2. Shadow Projects
3. Data Analysis
4. Consistency
5. Risk Assessment
6. Adaptability
7. Communication with Contractors
8. Documentation
9. Sharing *Regionally & Nationally*

E.g., A Journey to Performance

Sandy, the State DOT Bituminous Engineer, has taken on the challenge to implement BMD to address performance issues and provide a sustainable pathway forward.

PCI Score	Condition	Interstate	State Route	Region/District	Low-Volume
96 – 100	Very Good	13%	13%	5%	2%
76 – 95	Good	53%	44%	50%	59%
46 – 75	Fair	32%	31%	28%	27%
21 – 45	Poor	2%	12%	16%	9%
0 – 20	Very Poor	0%	0%	1%	3%

Ten years ago
66% rated
Good or better

Today
58% rate
Good or better

PCI Calculations

PCI Indexes	Statewide Average	Minimum Value	
RUT	91.1	52	Rutting Resistance
FAT	73.7	40	Fatigue Cracking Resistance
RAV	92.7	72	Related to Moisture Susceptibility

$150M State Paving Program

Breakdown:

- 10% reconstruction
- 41% asphalt overlays
- 49% pavement preservation

Last year's surface mixes by traffic level:

- 10% Low
- 60% Medium
- 30% High

Traffic	NMAS	Gradation	N_{design}	VMA	VFA	$P_{0.075}/P_{be}$	Allowable RAP
Low	9.5mm	Fine	50	15.0	70 to 80	0.6 to 1.2	25 to 40%
Medium	12.5mm	Fine	75	14.0	65 to 78	0.6 to 1.2	20 to 30%
High	12.5mm	Coarse	100	14.0	65 to 75	0.8 to 1.6	15 to 25%

Sandy's review of the information, along with conversations with the contractor community, provides the following insights:

- Lower PCI's are being driven *by fatigue cracking*.
- The state *does not have a rutting issue*.
- The majority of the paving program uses *12.5mm fine-graded mixes*.
- Contractors typically design mixes on the *lower allowable RAP range*, citing challenges meeting all the Superpave volumetric criteria.
- The State DOT would like to *increase the RAP* content for a more sustainable product.
- The Contractors are also interested in *higher-RAP* as they explore developing environmental product declarations (*EPD*).
- Sandy is developing a BMD field validation experiment to establish criteria.

Benchmarking

Traffic	Parameter	HWTT-SIP	HWTT Rut Depth 10k passes	IDEAL-CT (CT_{Index})	DCT Fracture Energy (J/M^2)
Medium	Mixes, *n*	22			
	Average, $\bar{y}$	13,700	5mm	66.5	481.3
	COV	23%	19%	18%	22%
High	Mixes, *n*	13			
	Average, $\bar{y}$	16,200	4mm	59.5	422.7
	COV	15%	17%	19%	21%

APPENDIX
Full-scale Road Test Sections & APTs

- 1920 Bates Road, IL
- 1952 WASHO Test Road, ID
- 1958 AASHO Road Test, IL
- 1990 LTPP, USA-Canada
- 1993 MnROAD
- 1995 WesTrack, NV
- 2000 NCAT Test Track, AL
- 2012 NCAT Pavement Preservation Studies, AL
- 2015 MnROAD PP Studies
- Accelerated Pavement Test Facilities

Asphalt AI Tool

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

HeyNAPA.com

- Built with the GPT4 software
- Only draws from vetted asphalt research and publications
    - NAPA
    - FHWA
    - NCAT
- Gives citations with responses

NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

National Center for Asphalt Technology
NCAT
AT AUBURN UNIVERSITY

CAPRI
CONSORTIUM FOR ASPHALT PAVEMENT RESEARCH AND IMPLEMENTATION

Questions?

FOR ANY INQUIRIES ABOUT OAPC, PLEASE E-MAIL:
INFO@ONASPHALT.ORG

VISIT OUR REFRESHED WEBSITE TO LEARN MORE:
WWW.ONASPHALT.ORG