Guidelines and Recommendations for Field Validation of Test Criteria for Balanced Mixture Design (BMD) Implementation

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CONSORTIUM FOR ASPHALT PAVEMENT RESEARCH AND IMPLEMENTATION

August 2023

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Background

- BMD tests are intended to be an indicator of a mixture's performance in the field…

- Critical step – ensure BMD test results have a strong relationship to field performance

  ✓ Support the development of specification criteria

  ✓ Relationships are also necessary when developing criteria for mixture design approval

Challenge

- Limited studies exist that establish the relationship between test results and performance
- Some studies are based on field sites that did not adequately characterize the underlying pavement structures
- Some studies compared pavements of different ages or loading conditions
- Ideally, when laboratory-to-field relationships are developed, they should be specific not only to an agency's traffic, climate, materials, and existing pavement structures but also to the types of distress typically encountered in that state

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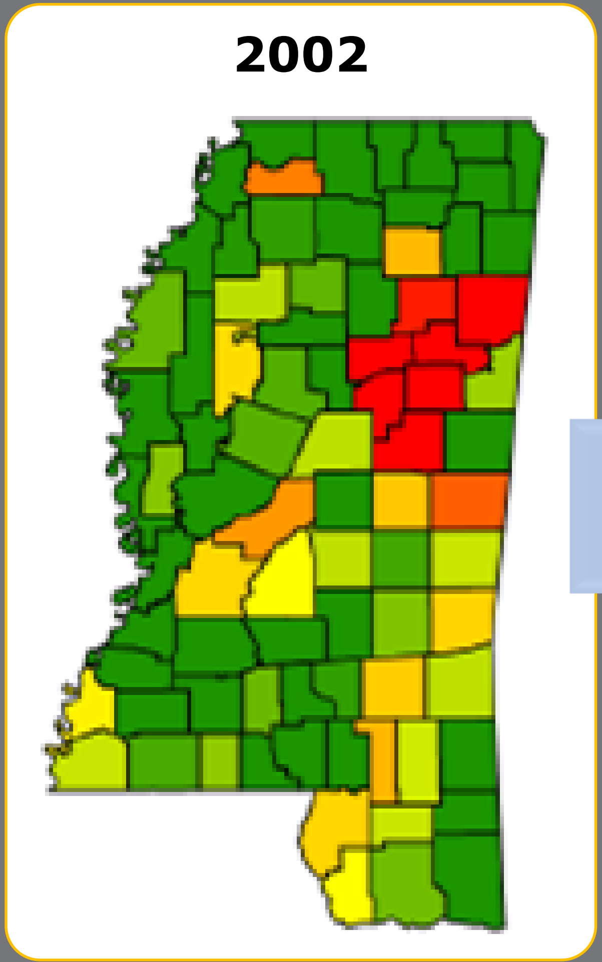
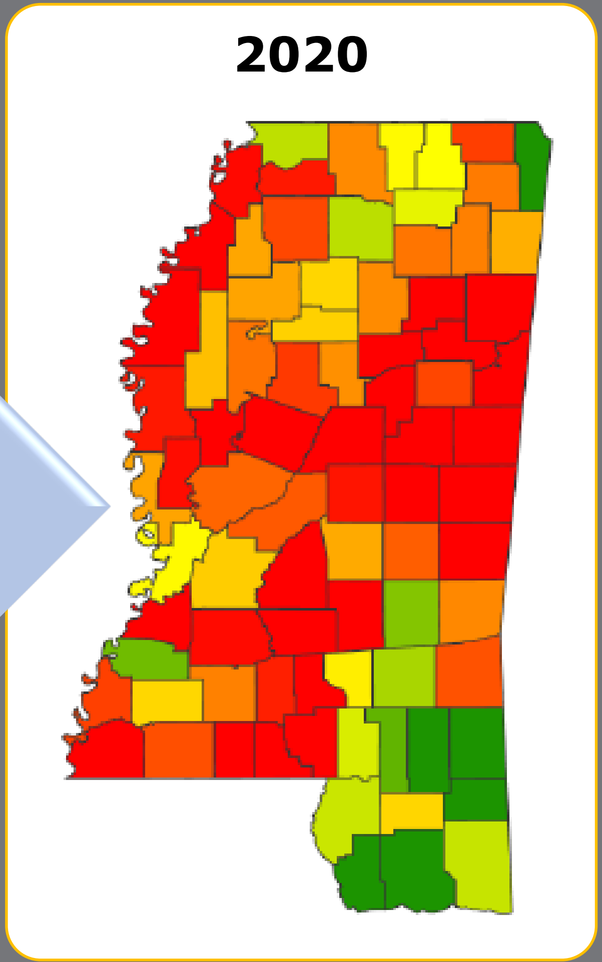
MISSISSIPPI DEPARTMENT OF TRANSPORTATION

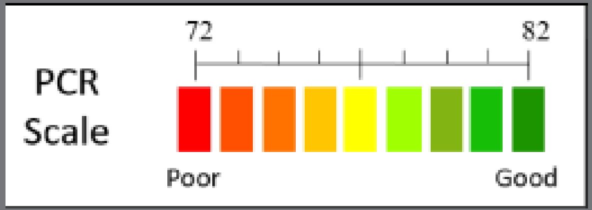
Volumetric-only mix design is not fully capable of dealing with present-day mixes



Unintended Consequences



Pavement Condition Rating



US Army Corps of Engineers

ERDC ENGINEER RESEARCH & DEVELOPMENT CENTER

TRB ANNUAL MEETING

January 8–12, 2023 ▲ Washington, DC

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Research Tasks

- Task 1 - Literature Review
- Task 2 - Develop Guidelines and Recommendations
- Task 3 - Final Report
- Task 4 - Presentation

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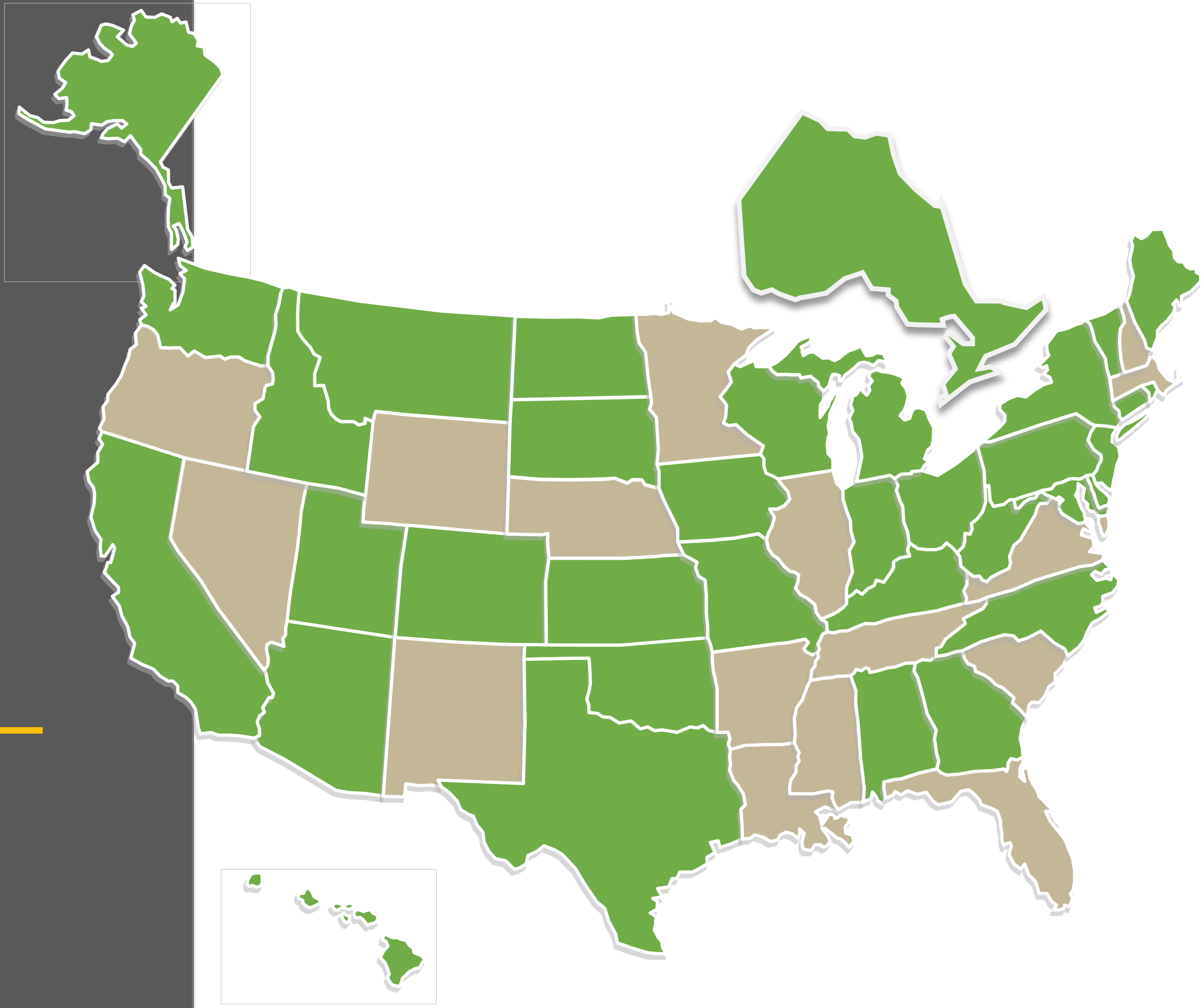
Objective

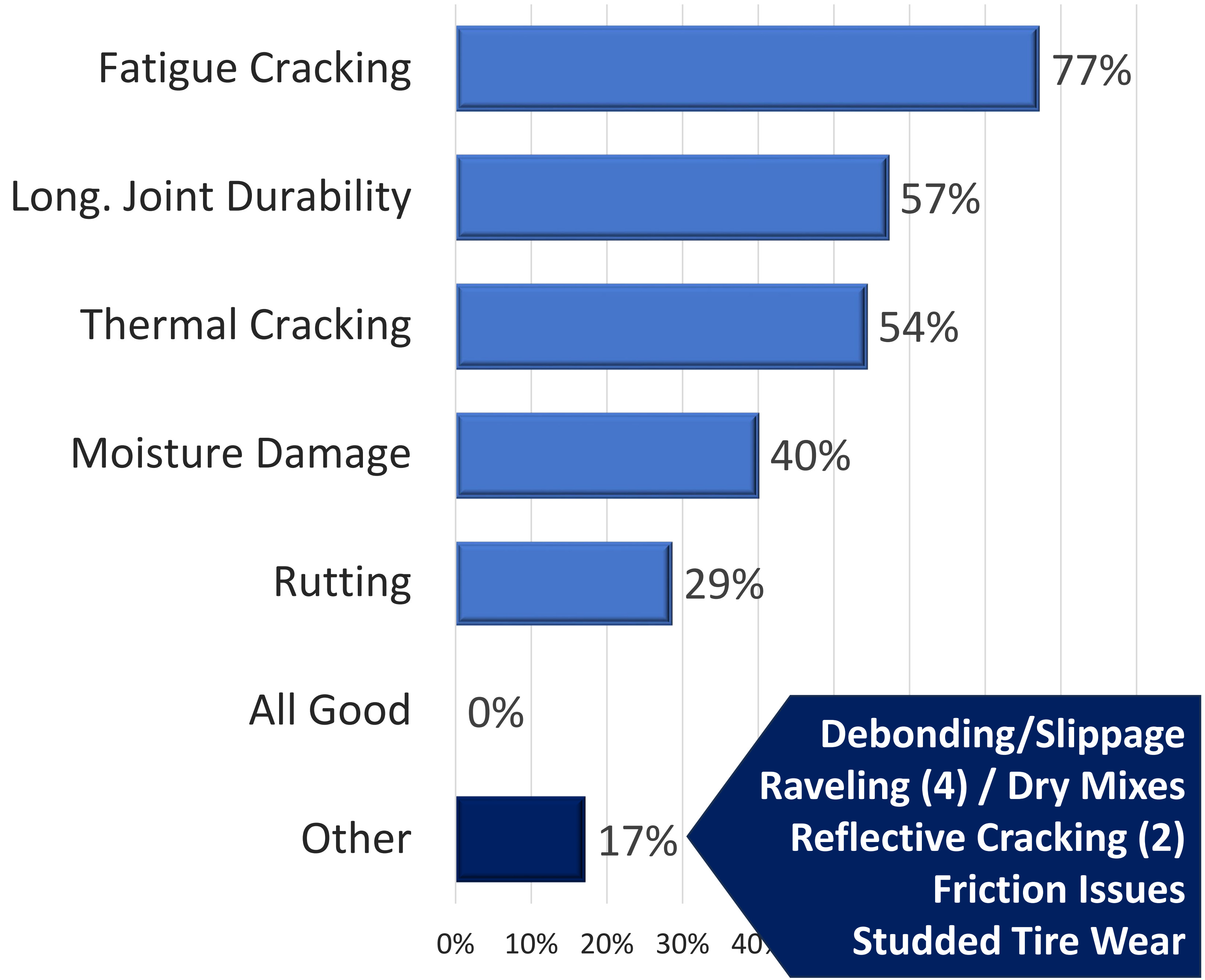
- Develop guidelines and recommendations that agencies can follow to build test sections for establishing valid relationships between BMD test results and field performance and to ensure that appropriate specification criteria are developed.

35 Respondents
34 State Agencies
1 Ontario

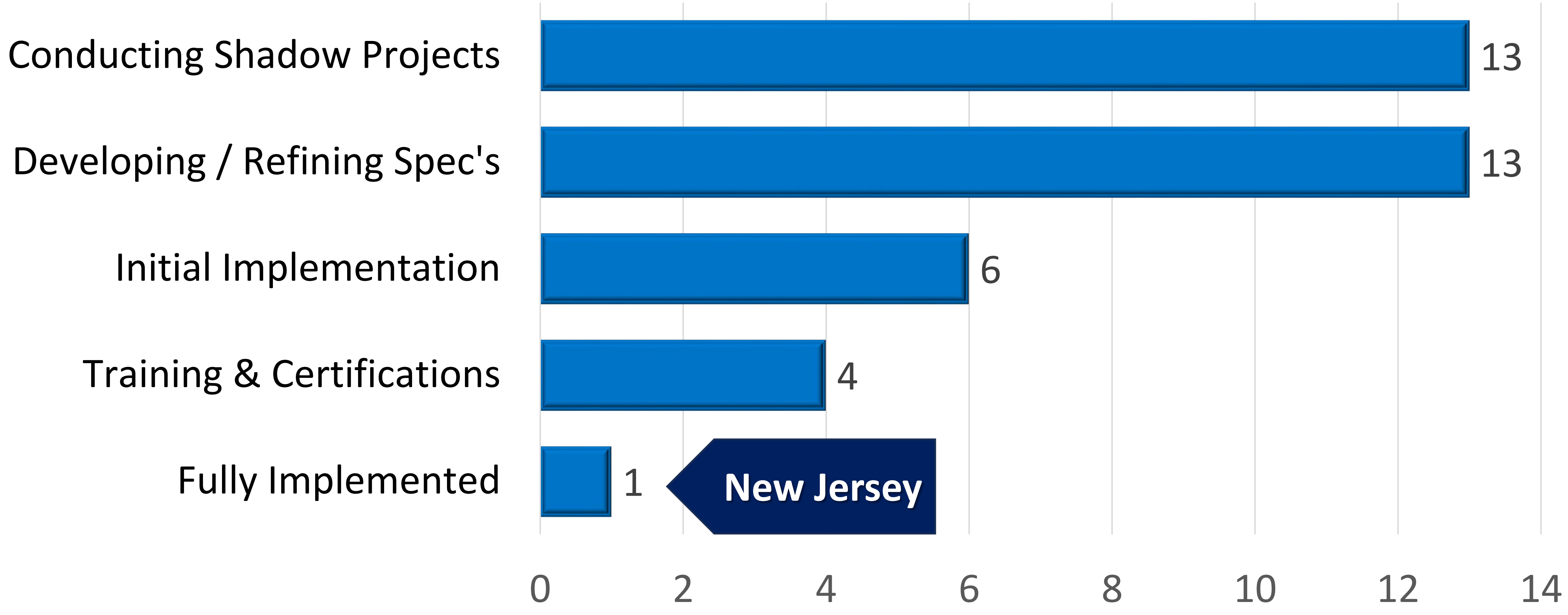
NAPA Website for
16 State Agencies



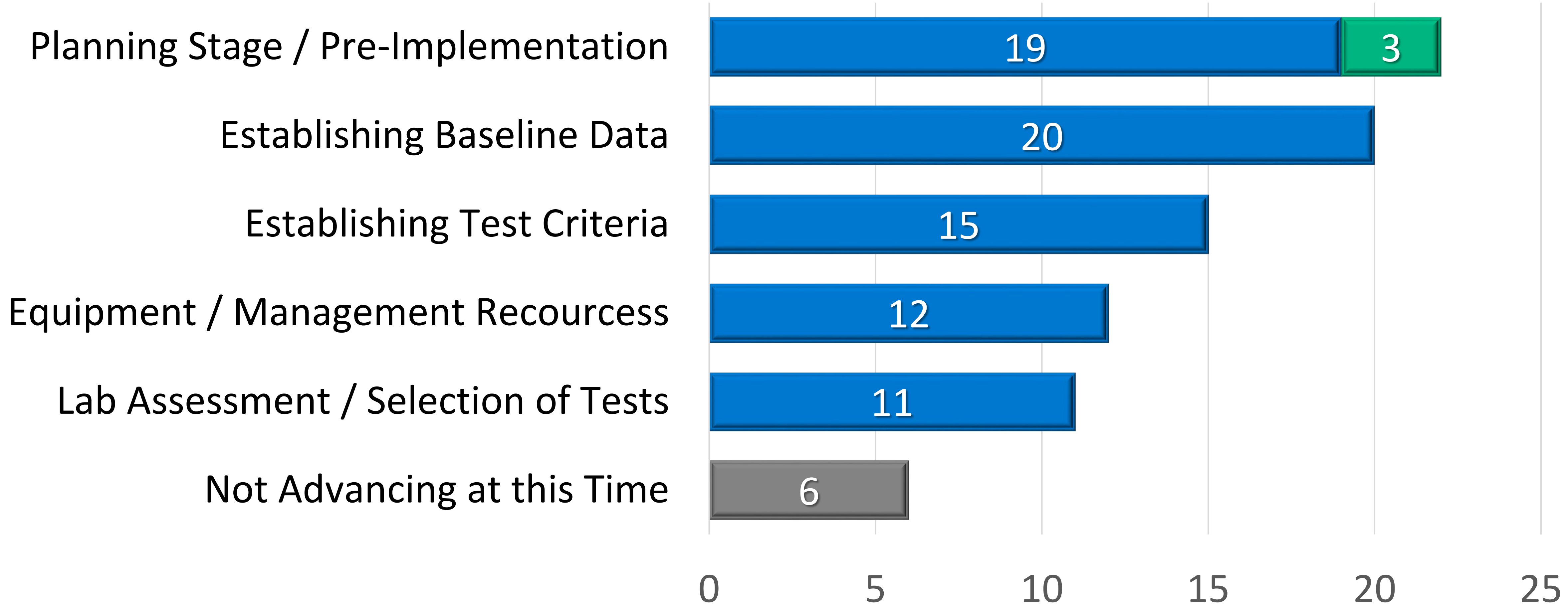
Performance Challenges



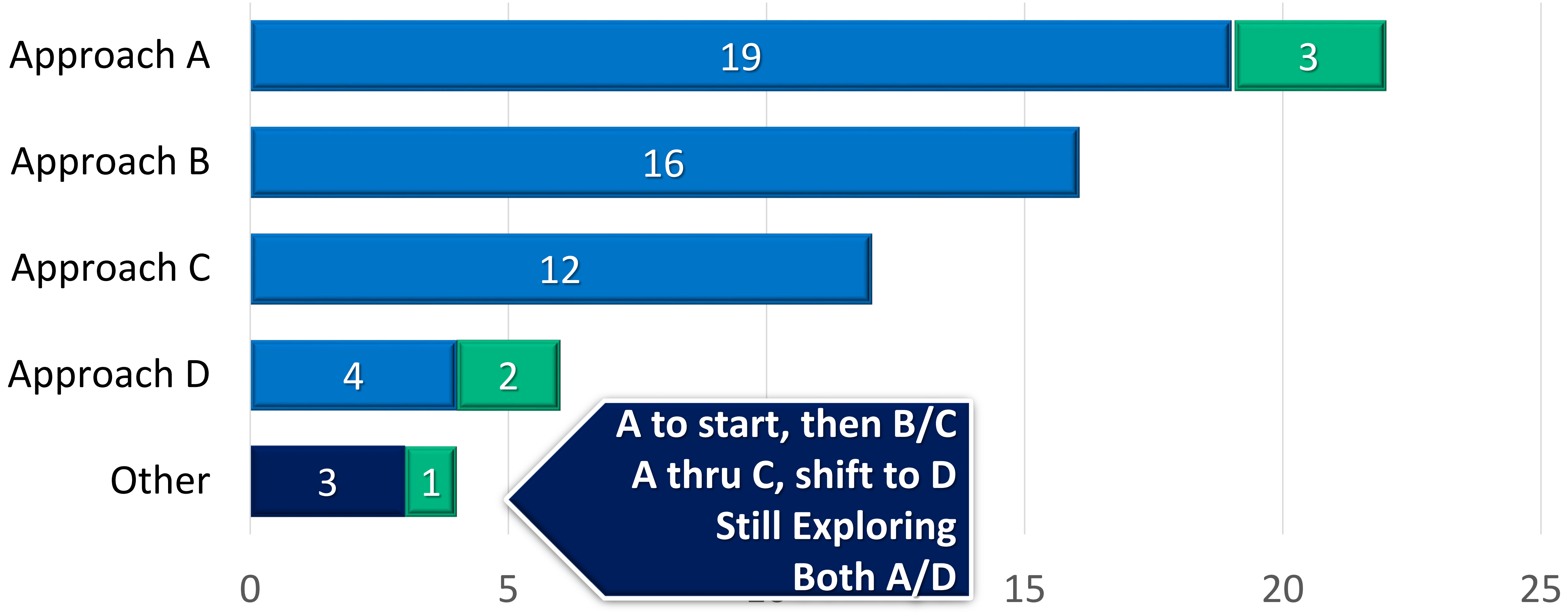
BMD Implementation (1 of 2)



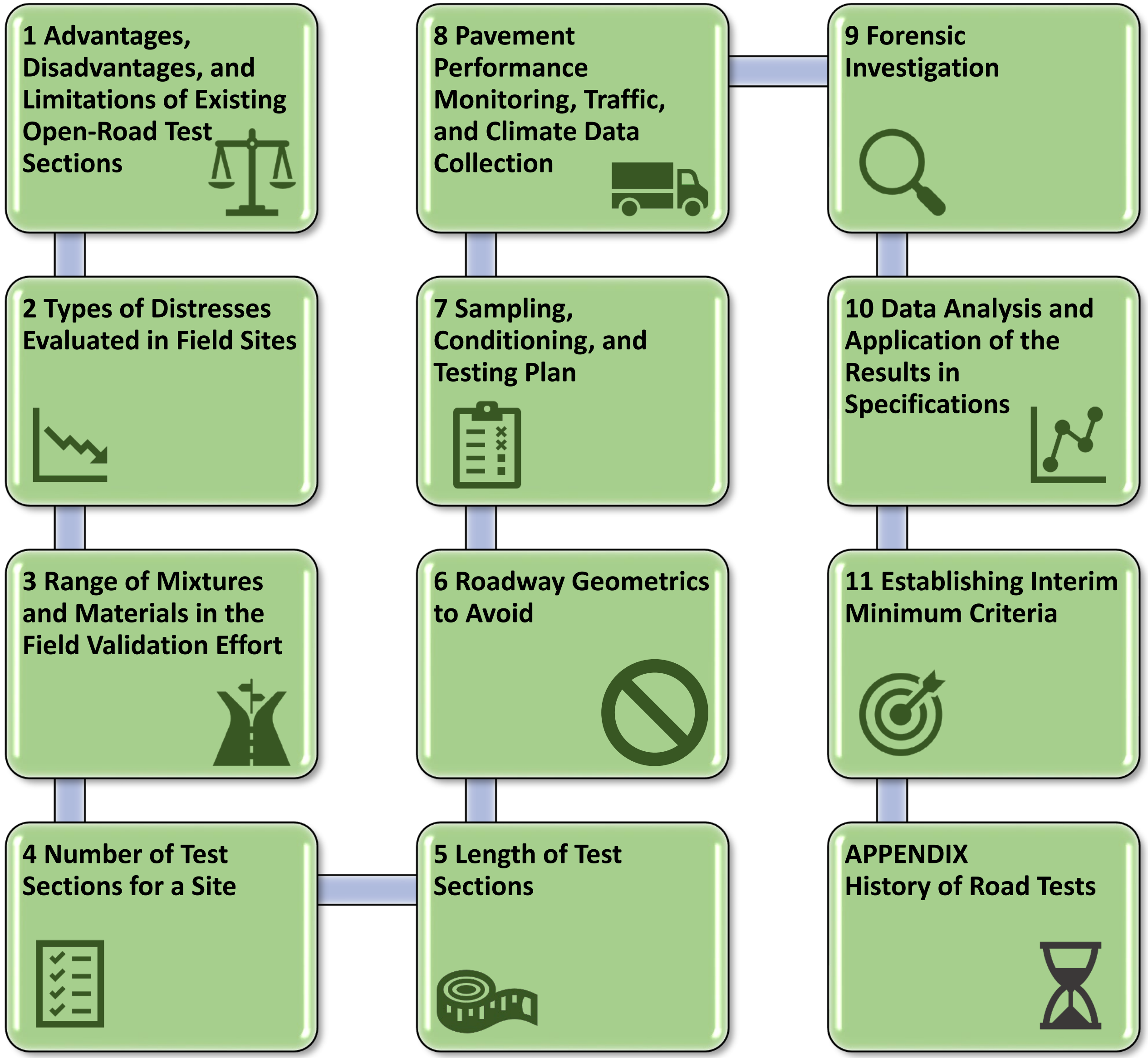
BMD Implementation (2 of 2)



Survey Implementation Status +



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				✗

2 Types of Distresses Evaluated in Field Sites

← Rutting

← Cracking

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

← Moisture Damage

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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 trains 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

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3 Range of Mixtures and Materials in the Field Validation Effort

Table 4. Common Mix Design Strategies to Improve Performance

Rutting Resistance	Cracking Resistance	Moisture Resistance
• Adjust aggregate gradation • Use a stiffer asphalt binder • Polymer modification • Lower asphalt content • Increase recycled materials content • Add fiber additives	• Increase asphalt content • Lower recycled materials content • Use a softer (better quality) asphalt binder • Polymer modification (in most cases) • Add a rejuvenator	• Add an anti-strip agent • Change binder source • Change aggregate type

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3 Range of Mixtures and Materials in the Field Validation Effort

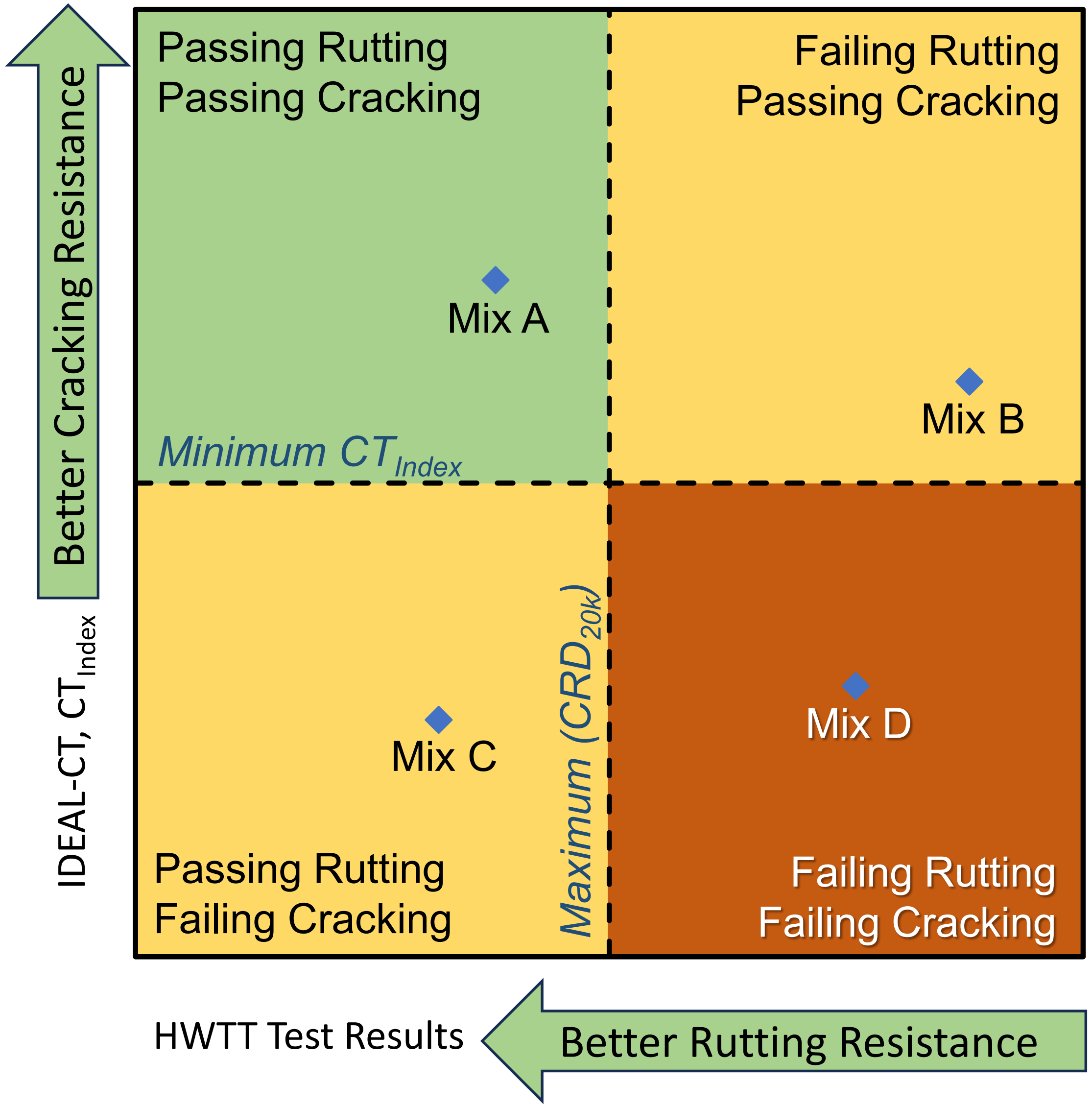


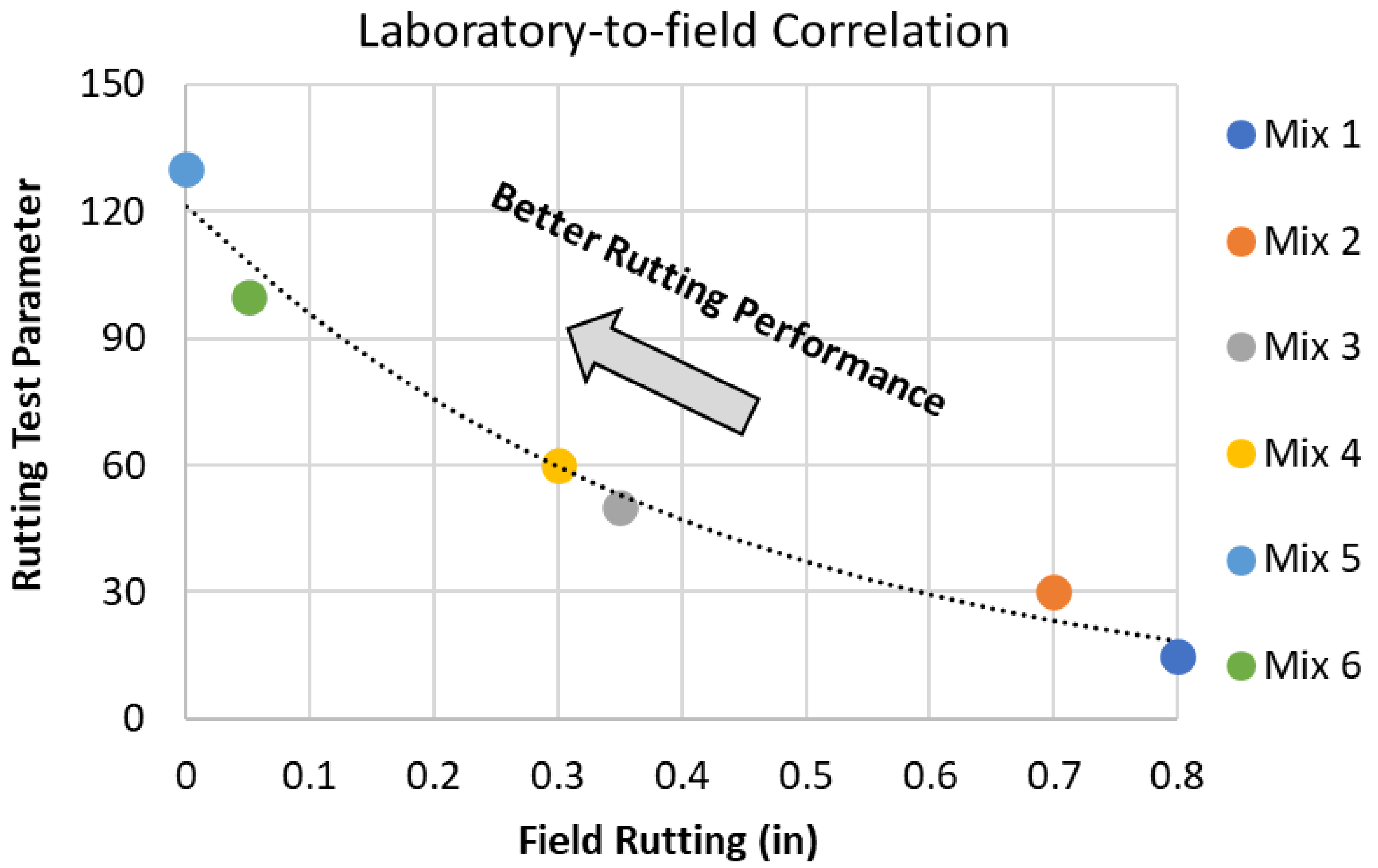
Figure 8. Example of Performance Diagram to Select Asphalt Mixtures for Field Validation Experiment.

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



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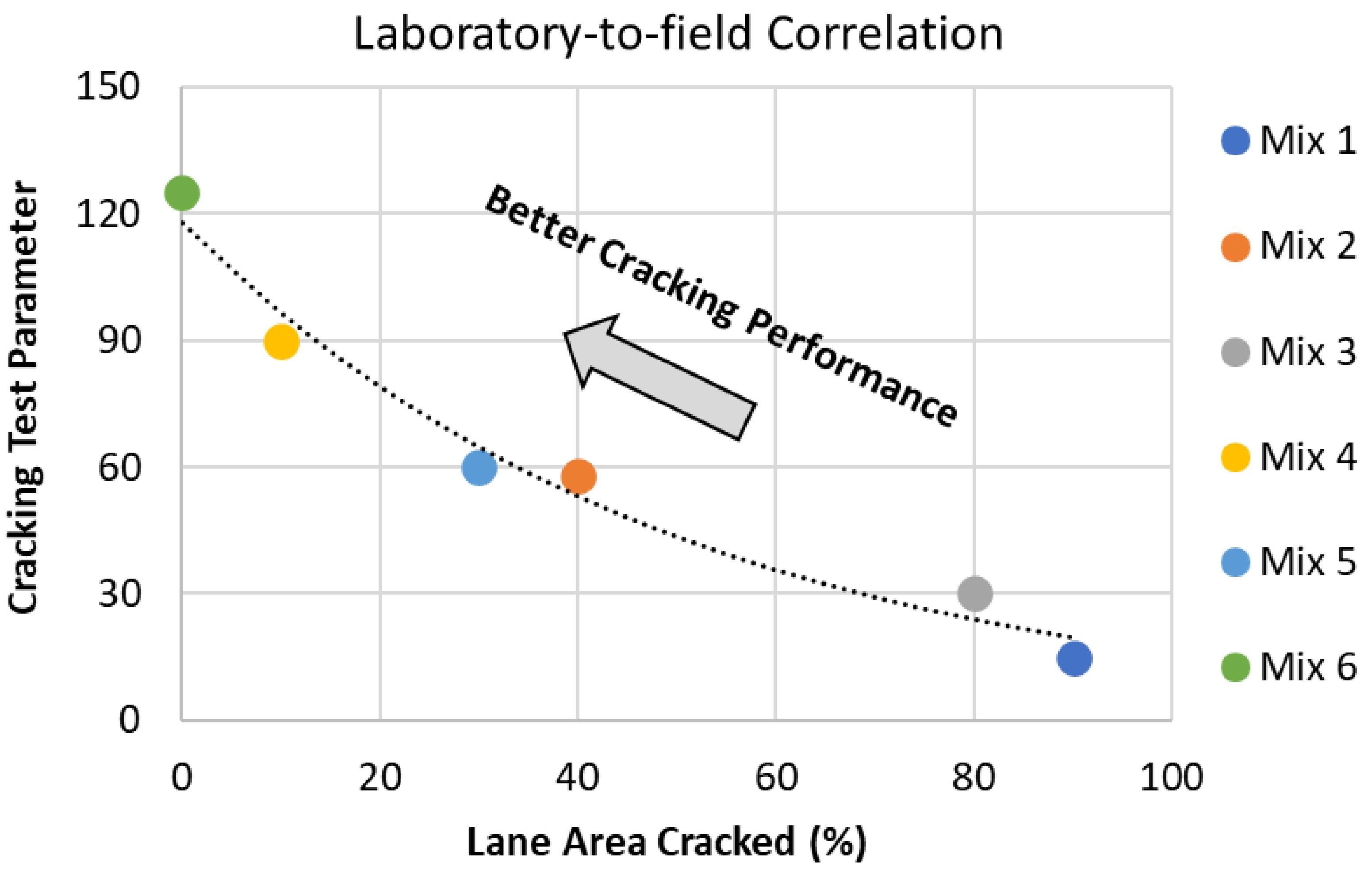
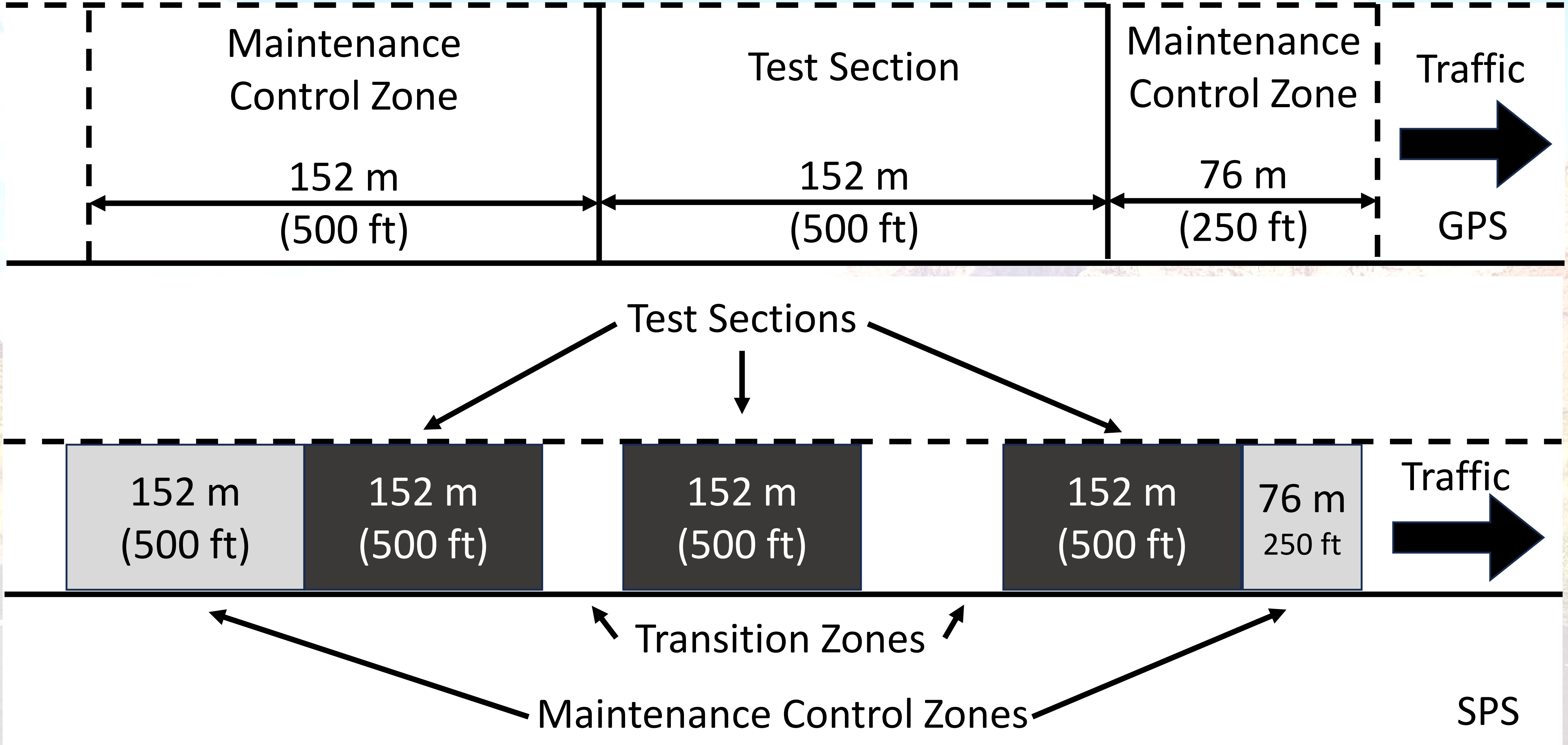


5 Length of Test Sections

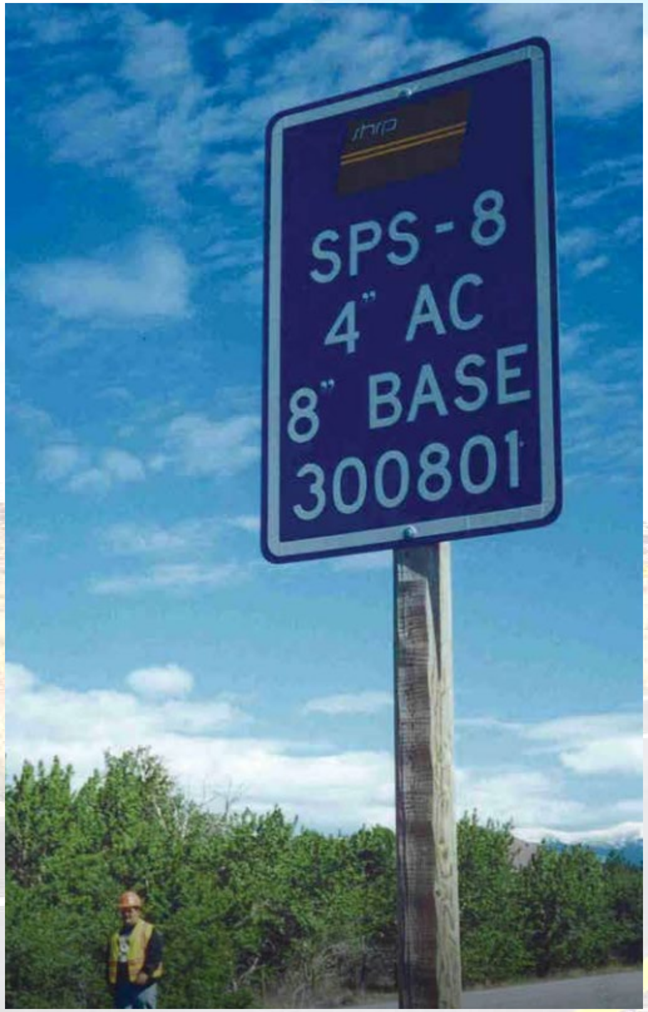
Considerations

- ✓ 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



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%
10	4%	4%	4%
12	3%	3%	3%

	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%
10	4%	2%	1%
12	3%	2%	1%

Where: The 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

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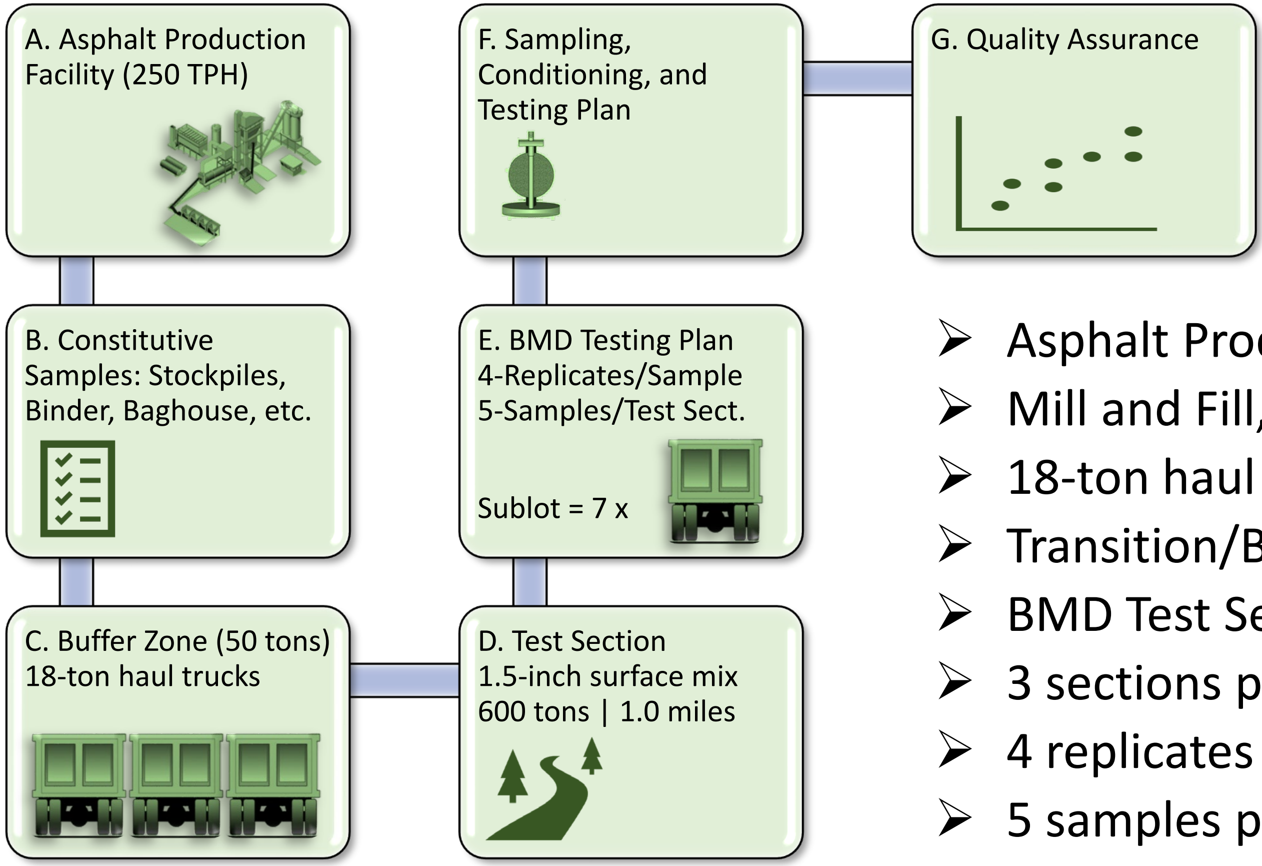
5 Length of Test Sections



- 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

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6 Roadway Geometrics to Avoid

- Intersections
- Horizontal Grades
- Curves
- Variable Traffic Speeds

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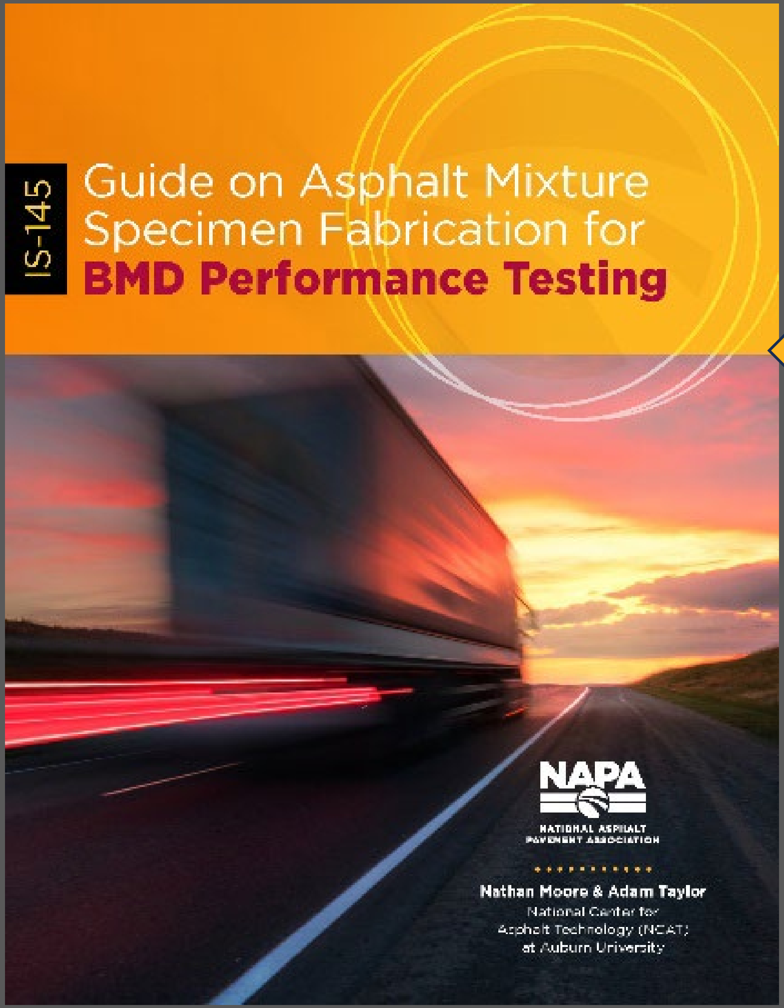


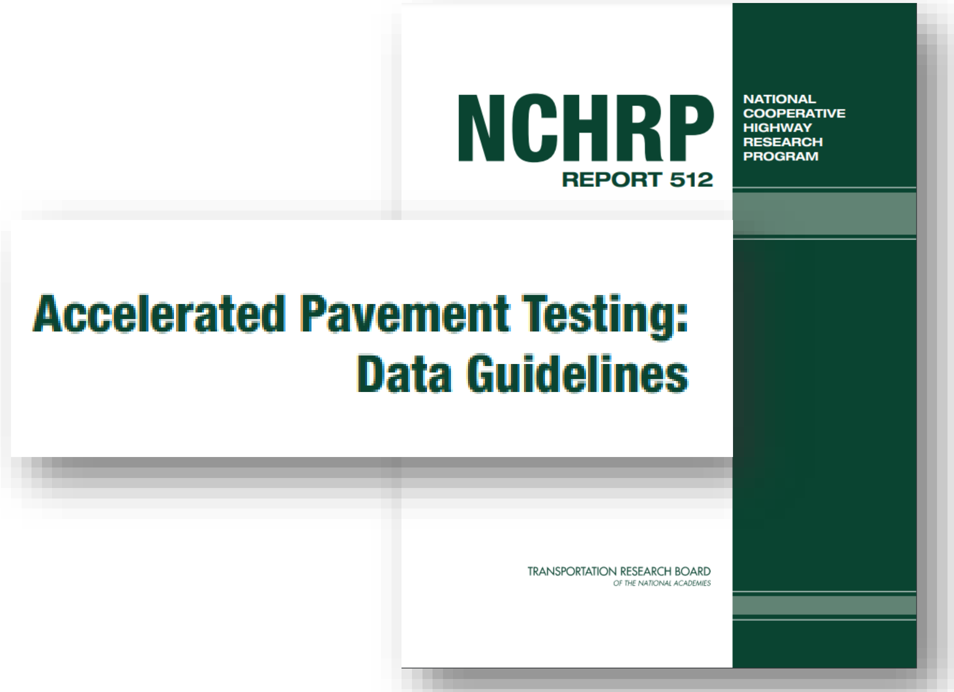
7 Sampling, Conditioning, and Testing Plan

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

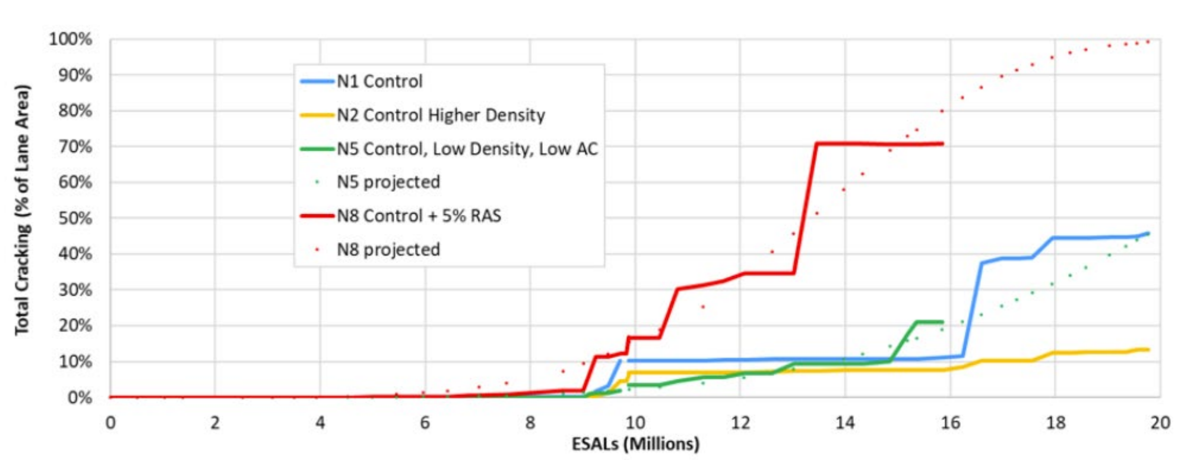


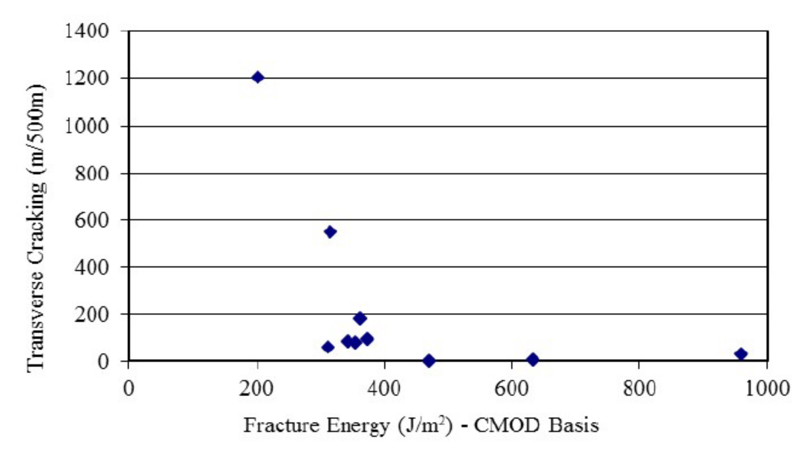
9 Forensic Investigation

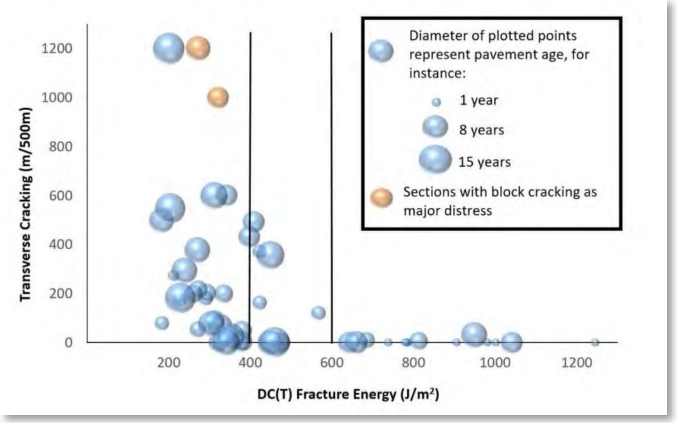
- Defining the Problem
- Conducting Visual Inspections
- Formulating Possible Hypotheses (H0)
- Conducting Tests for Evaluating H0
- Analyzing Results
- Developing Conclusions

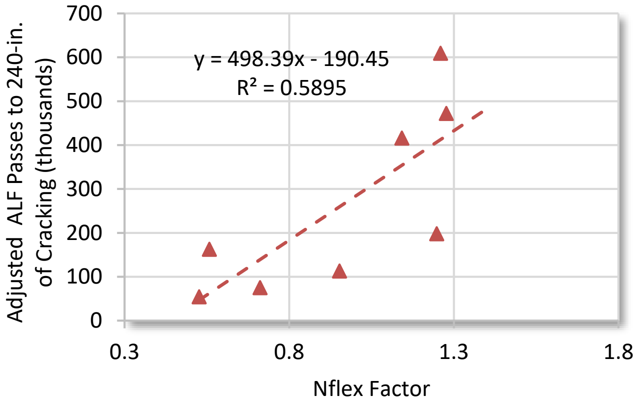
10 Data Analysis and Application of the Results in Specification

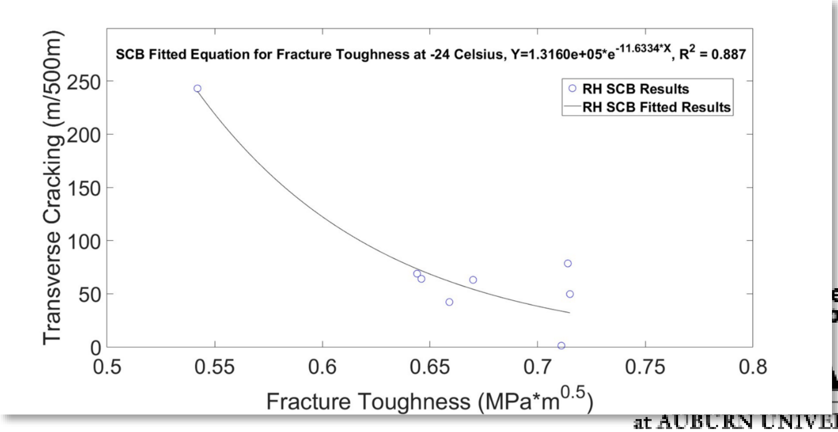
✓ Detailed Examples from Numerous Studies…





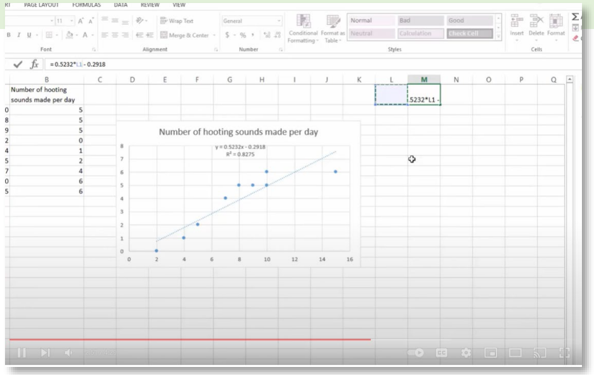




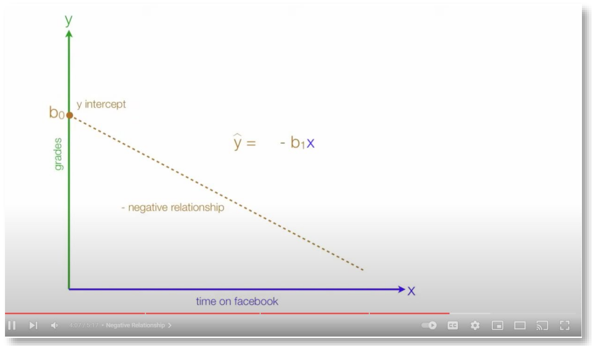


10 Data Analysis and Application of the Results in Specification

- *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

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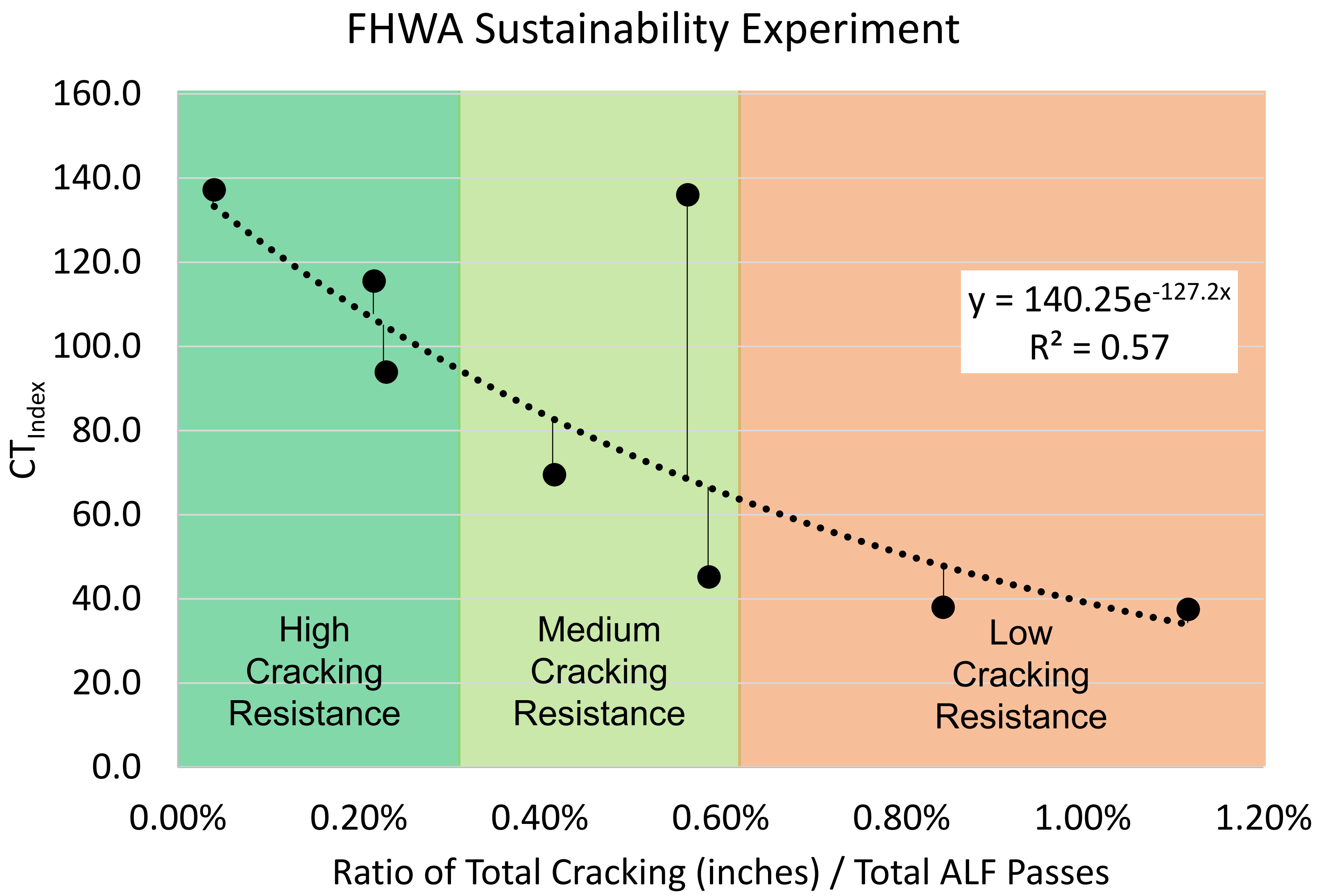
Example of Setting BMD Criteria CT_{Index}



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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

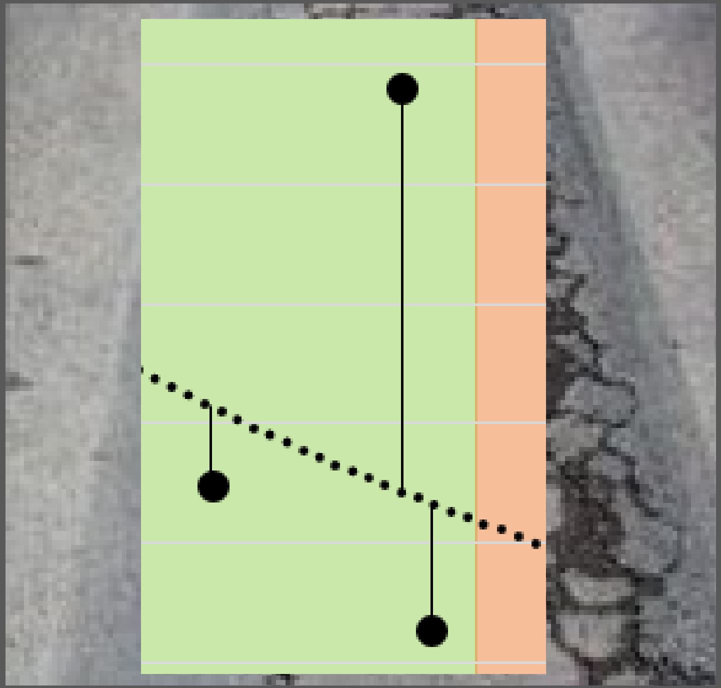
Example of Setting BMD Criteria CT_{Index}

- 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:



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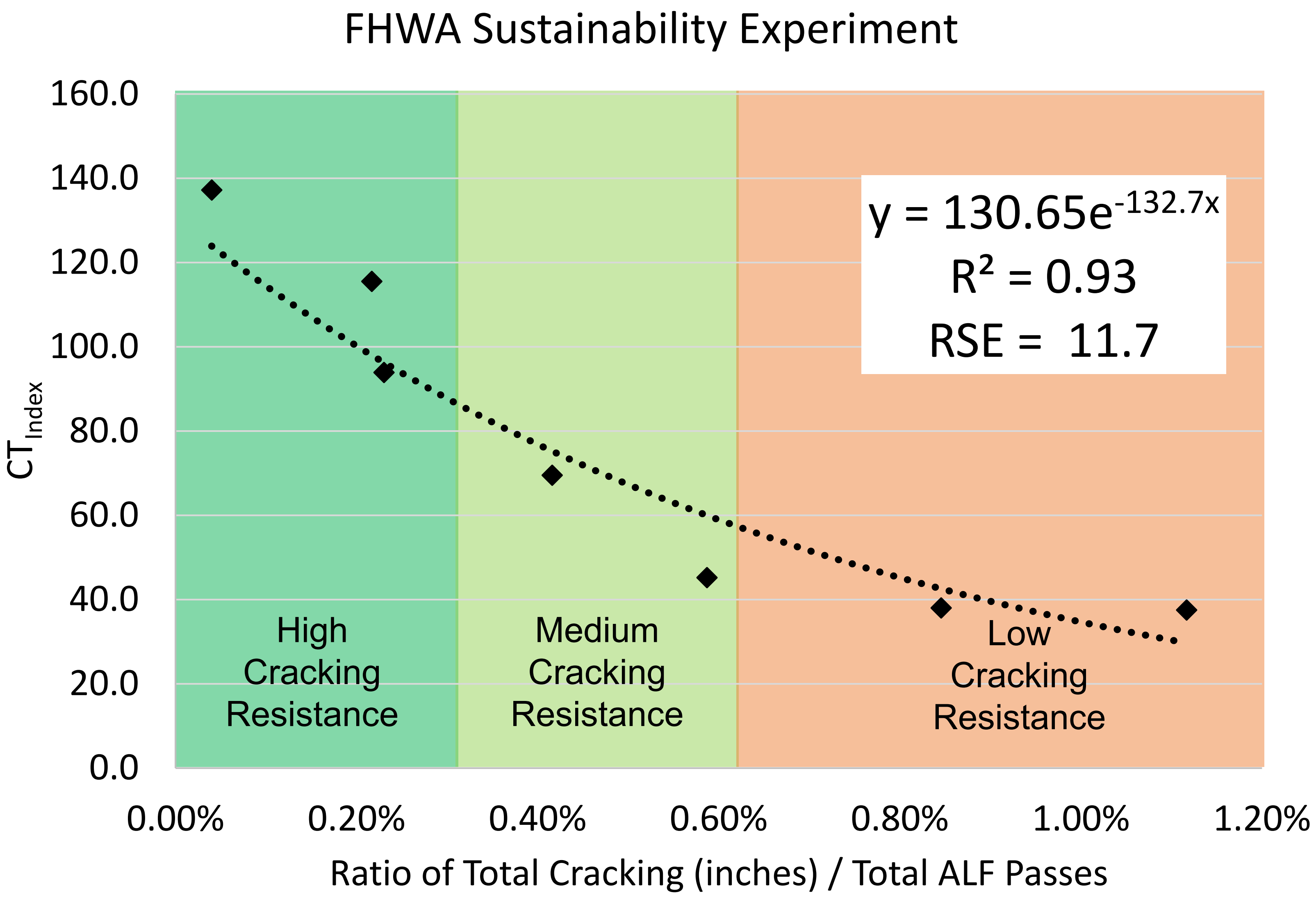

11 Establishing Criteria

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

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$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%

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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.

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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

Thanks Jim!

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Proposed Next Steps

- Incorporate CAPRI Feedback into the Document
- Develop a 1-day Workshop
- Discuss and promote the Guide at upcoming BMD peer exchanges
- Work with State DOT to develop Case Studies

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Questions?