Acceptance Testing and Variability Impacts on Construction Operation

ISAP

June 4, 2014

Raleigh, North Carolina

Jon Epps

Texas A&M Transportation Institute

Texas A&M University

- **Introduction**
- Areas of Concern
- Use of Tests
- Economics
- Variability
- Sampling
- Testing
- Materials/Construction Variability
- Fabrication of Samples
- Summary

What We Need

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Performance Related/Based Test

- Simple Concept
- Difficult to Accomplish
- Difficult to Implement
- Considerable Impact on Industry

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History of Test Method Development

- Use Test from Another Industry
- We Have Used This Test for Years
- Develop Performance Indicator Tests
- Develop Tests that Measure "Fundamental" Properties

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Ideal Test Attributes

- Measure Fundamental Property
- Related to Performance
- Duplicates
  - Stress/Strain
  - Time/Rate of Loading
  - Temperature

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Ideal Test Attributes

- Equipment Costs – Low
- Qualification of Technicians – Minimal
- Quick Results
  - Sampling
  - Fabrication
- Testing
- Precision & Bias

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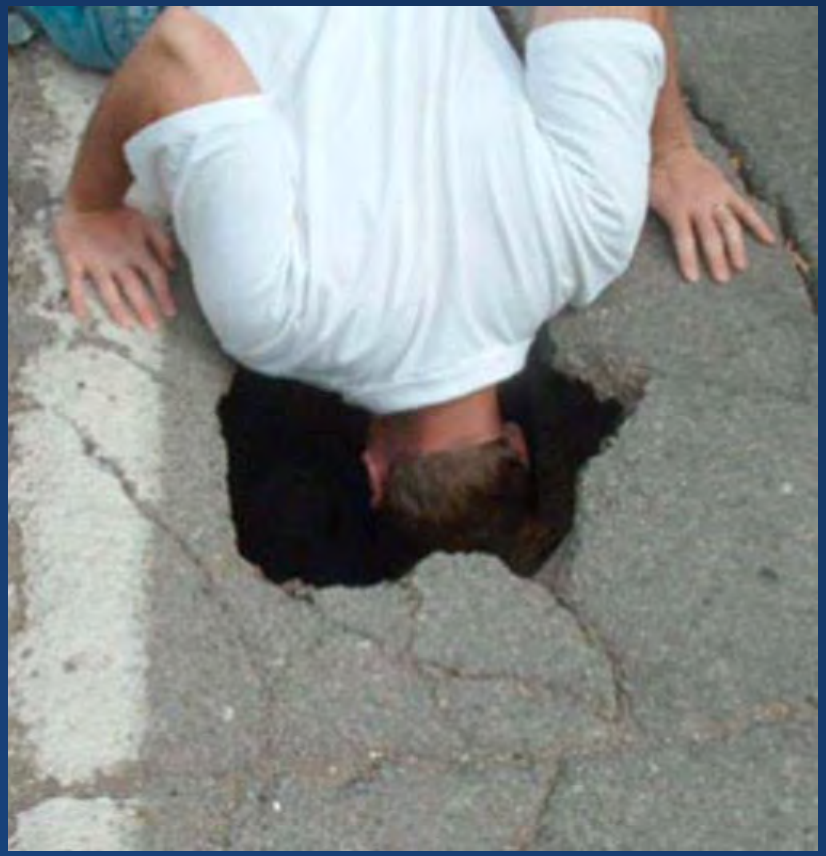

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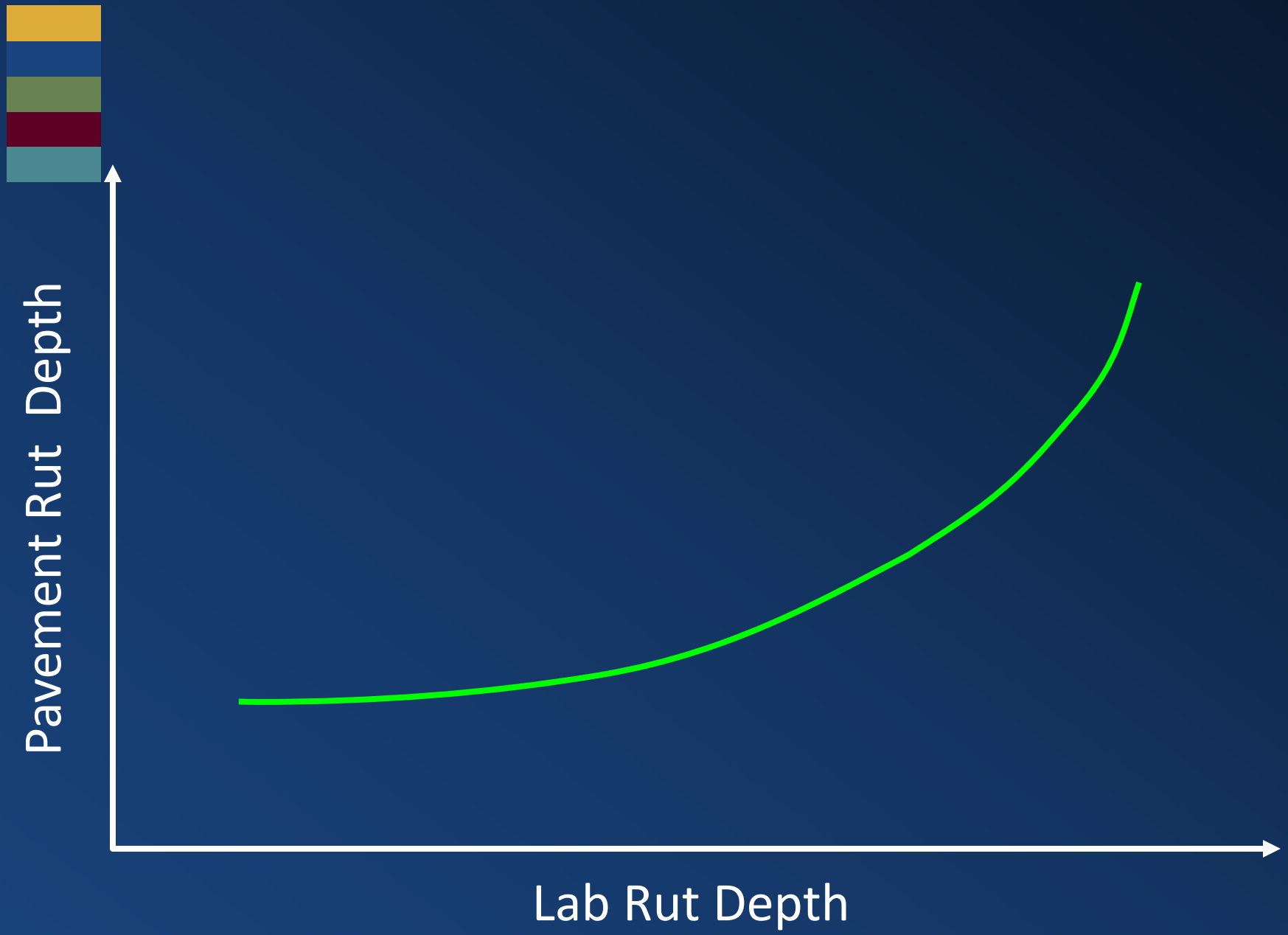

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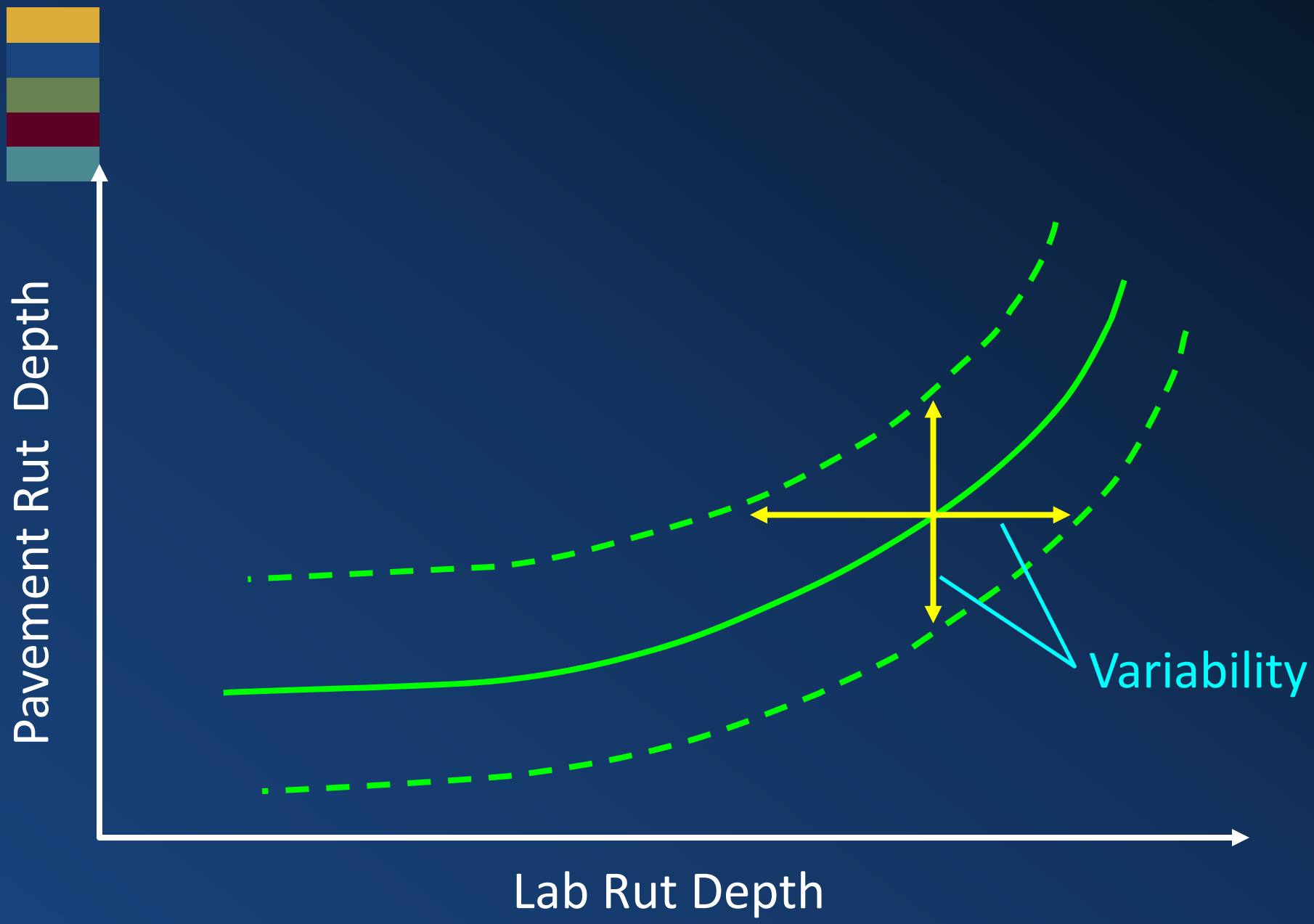

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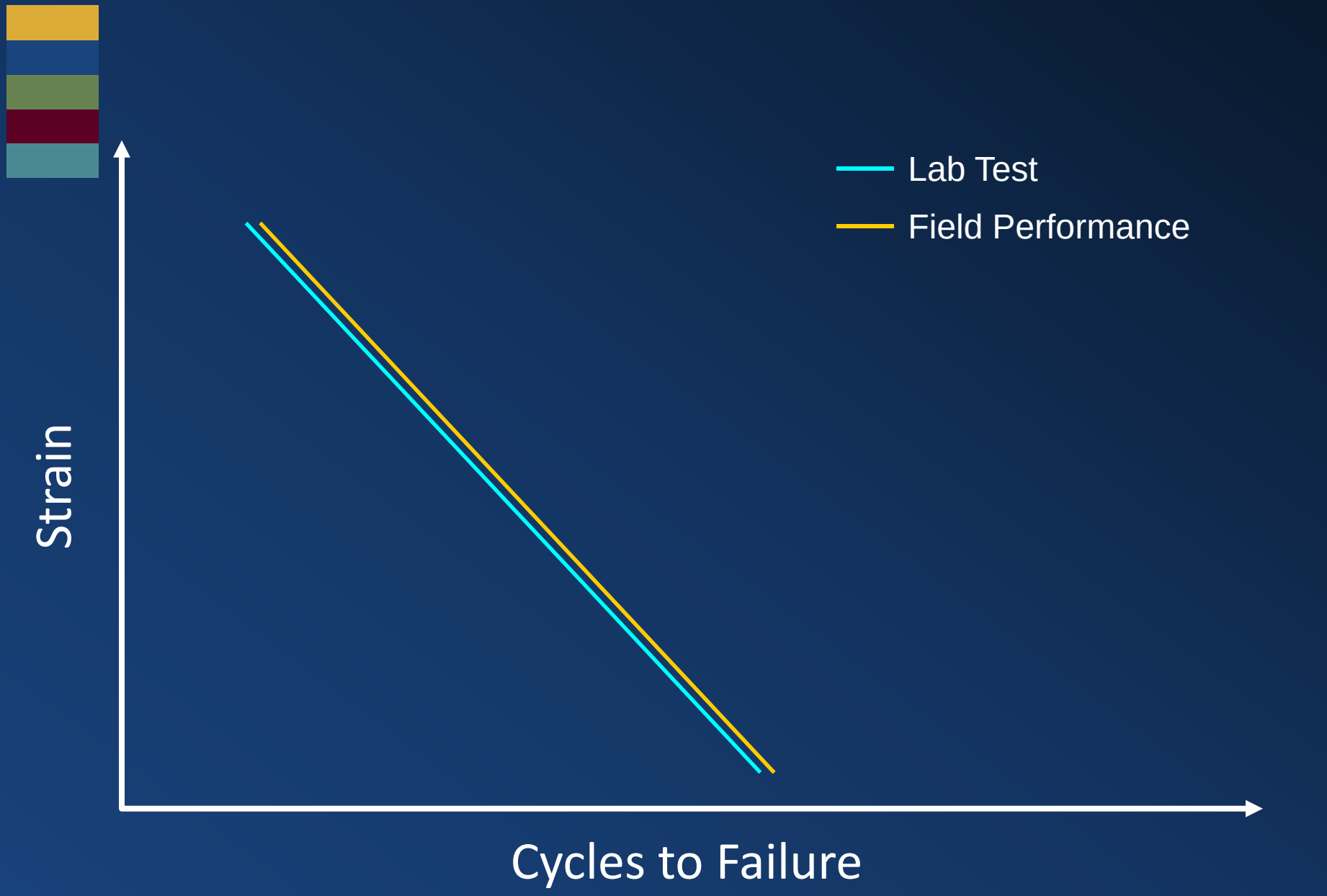

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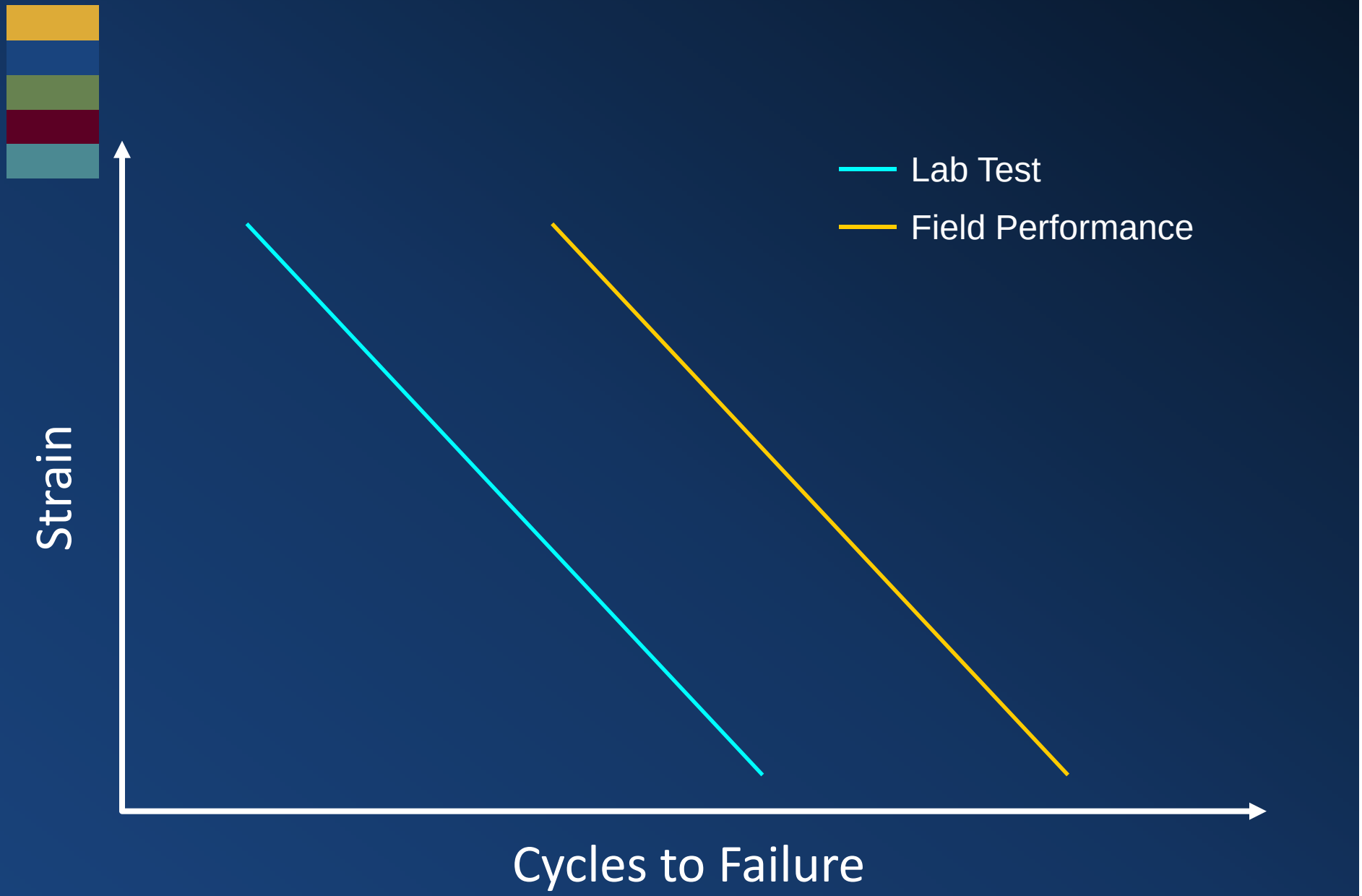

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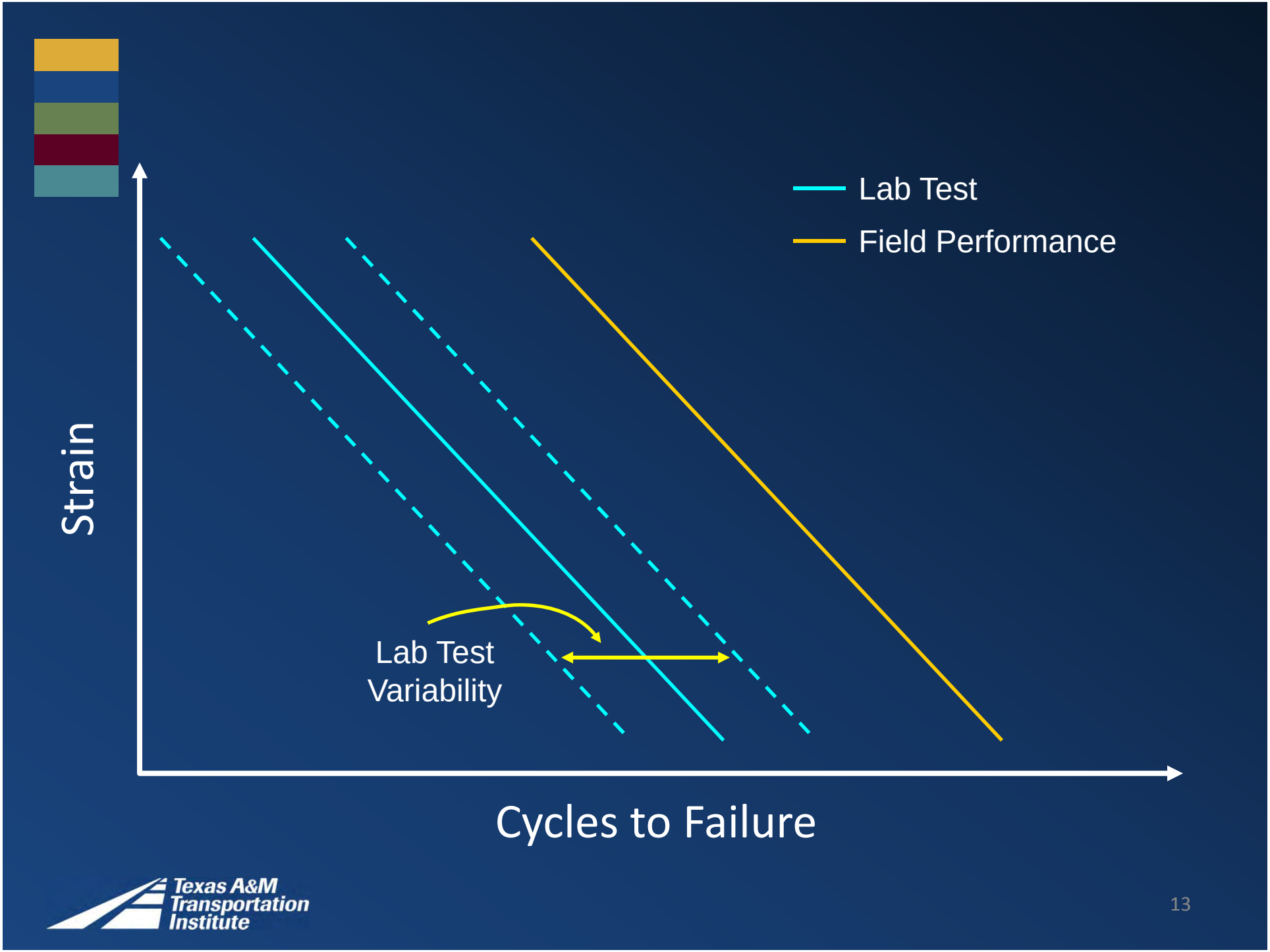

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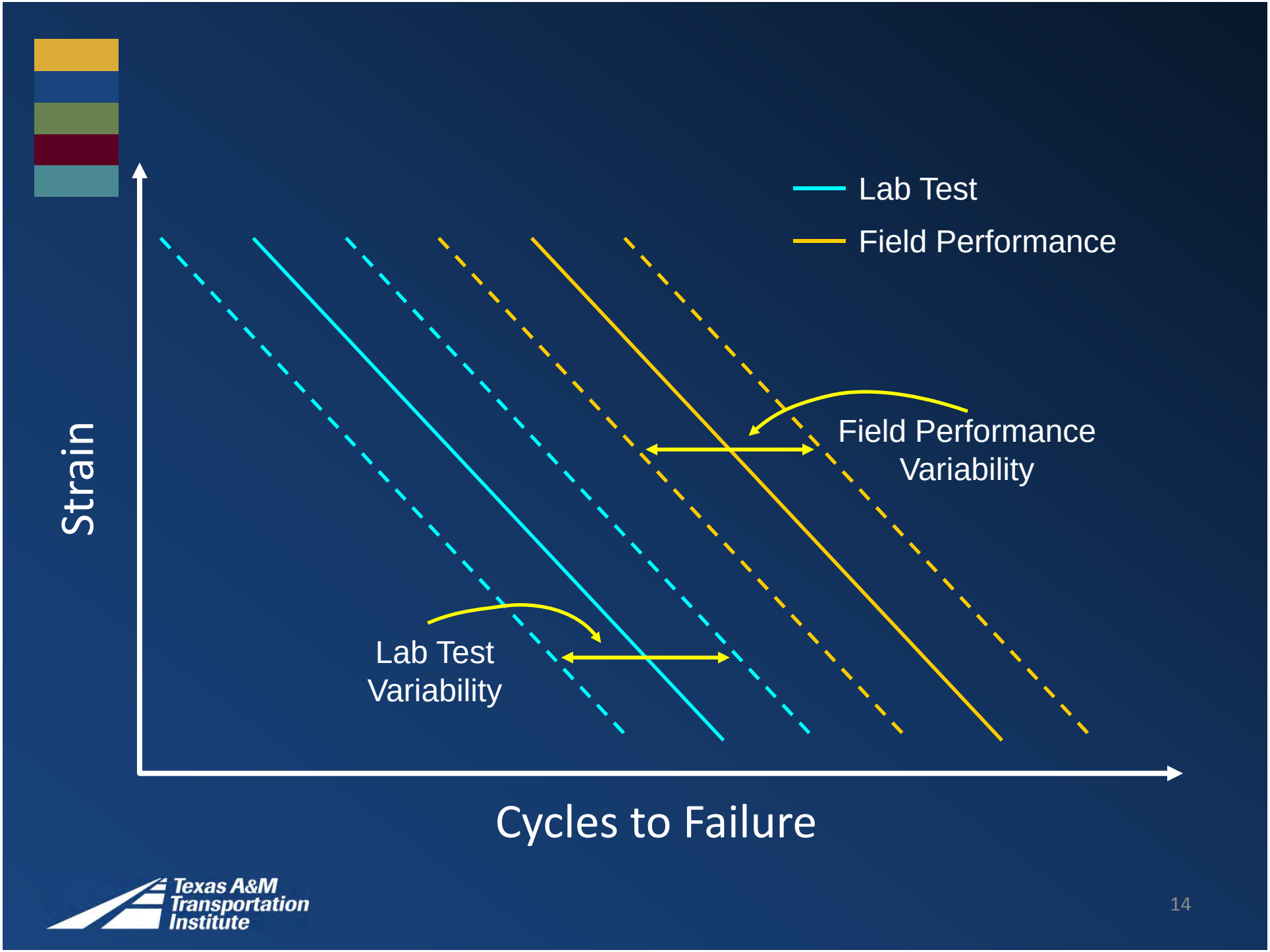

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How Test(s) Will Be Used

- Structural Design
- Mixture Design
- Acceptance (Quality)/Pay
- Economics

Who Will Use Test

- Owner (Public Agency)
- Contractor/Materials Supplier
- Research Community
- Forensics/Legal

Why Owner Interested

- Quality Pavement (Performance)
- Quality Mixture (Performance)
- Economics
- Material Production Quality
- Mixture/Placement Quality
- Acceptance
- Pay

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Why Contractor Interested

- Select Materials
- Mixture Design
- Structural Design
- Process Control/ Quality Control
- Acceptance
- Pay
- Economics (Bid/Profit)

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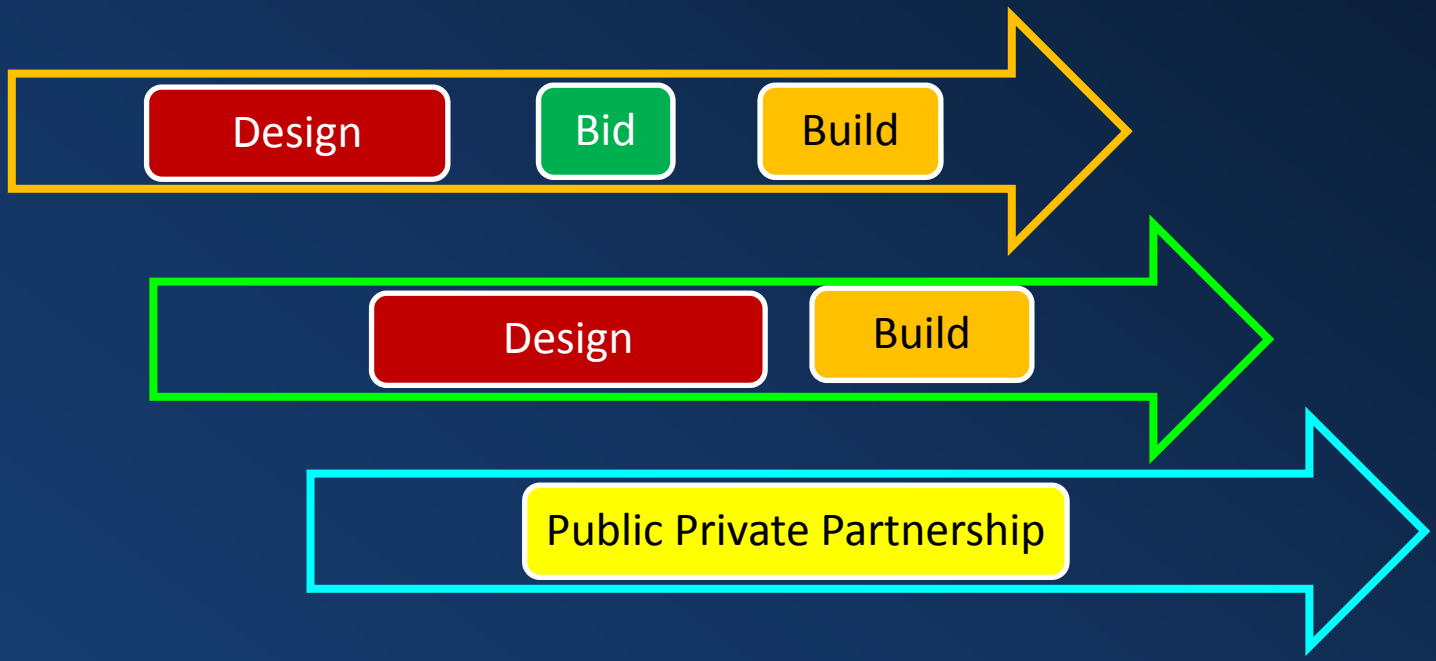
Type of Contract



Contractor Interest

Type of Contract	Select Materials	Mix Design	Structural Design	Acceptance/ Pay	Bid/Profit	Performance
D – B – B	X			X	X	
D/B	X	X	X	X	X	
PPP	X	X	X	X	X	X

Material Supplier

- Raw Material Selection
- Manufacturing Process
- Process Control
- Quality Control
- Acceptance/Pay

Consultants

- Material Selection
- Structural Design
- Process Control/ Quality Control
- Acceptance

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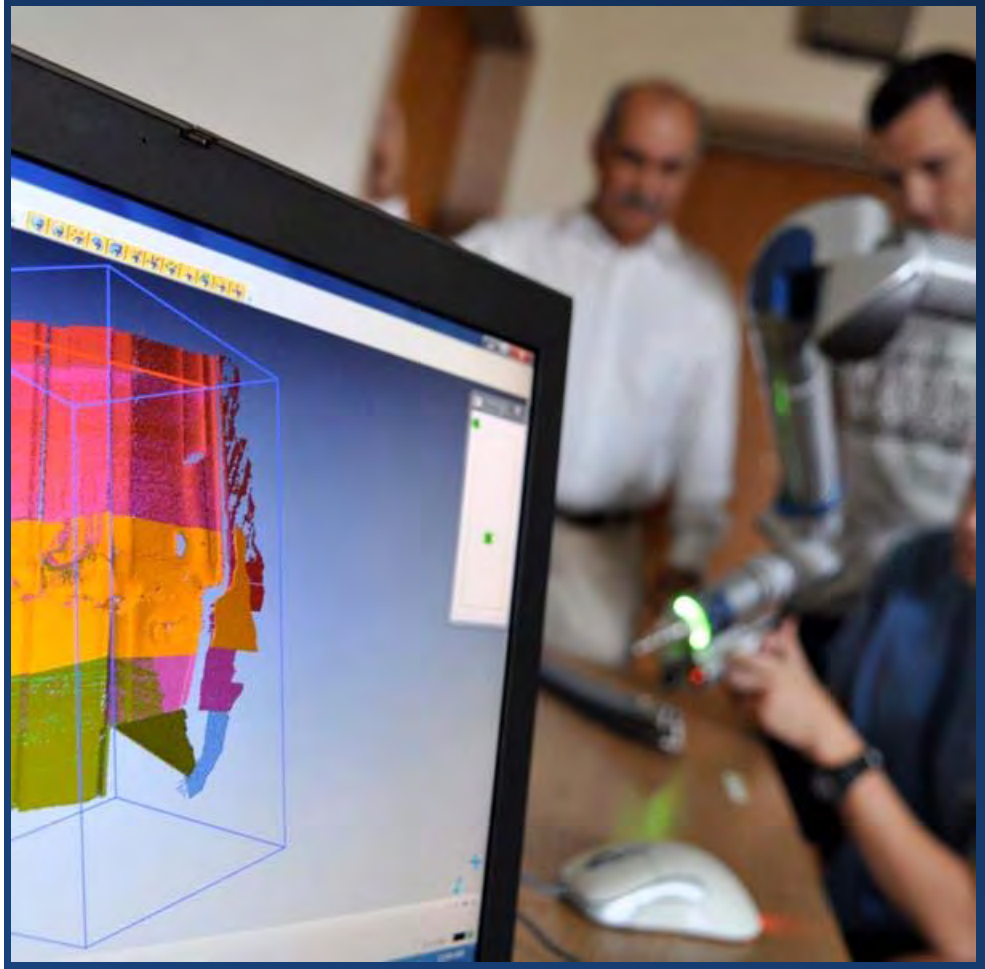
Research Community



- Improved Performance Production
  - Materials
  - Mixtures
  - Structural Design
- Publications/ Promotion/Tenure

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Forensics/Legal

- Engineering Analysis
- Remove/Replace/
  Pay Reduction
- Responsible Party

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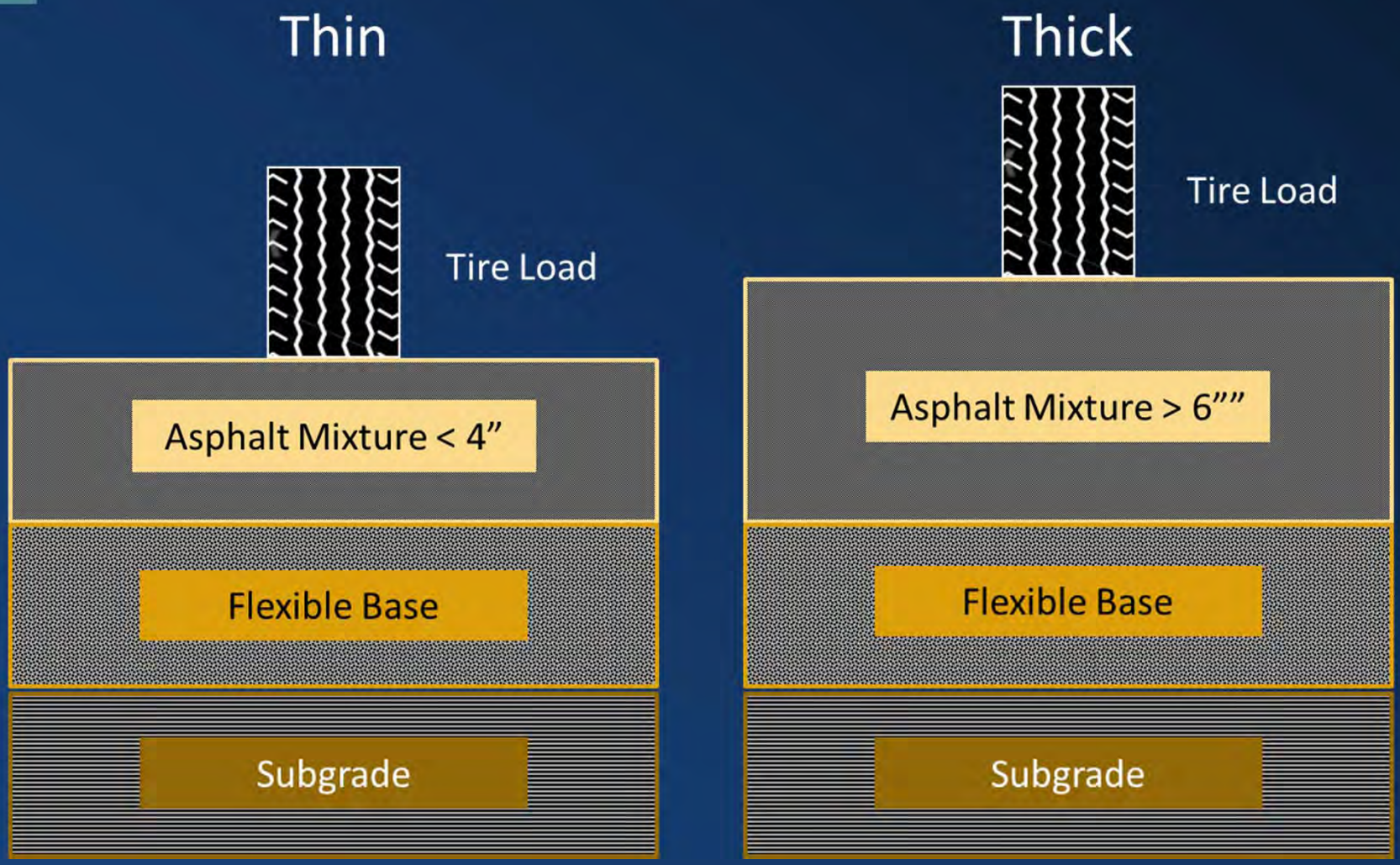
Structural Design



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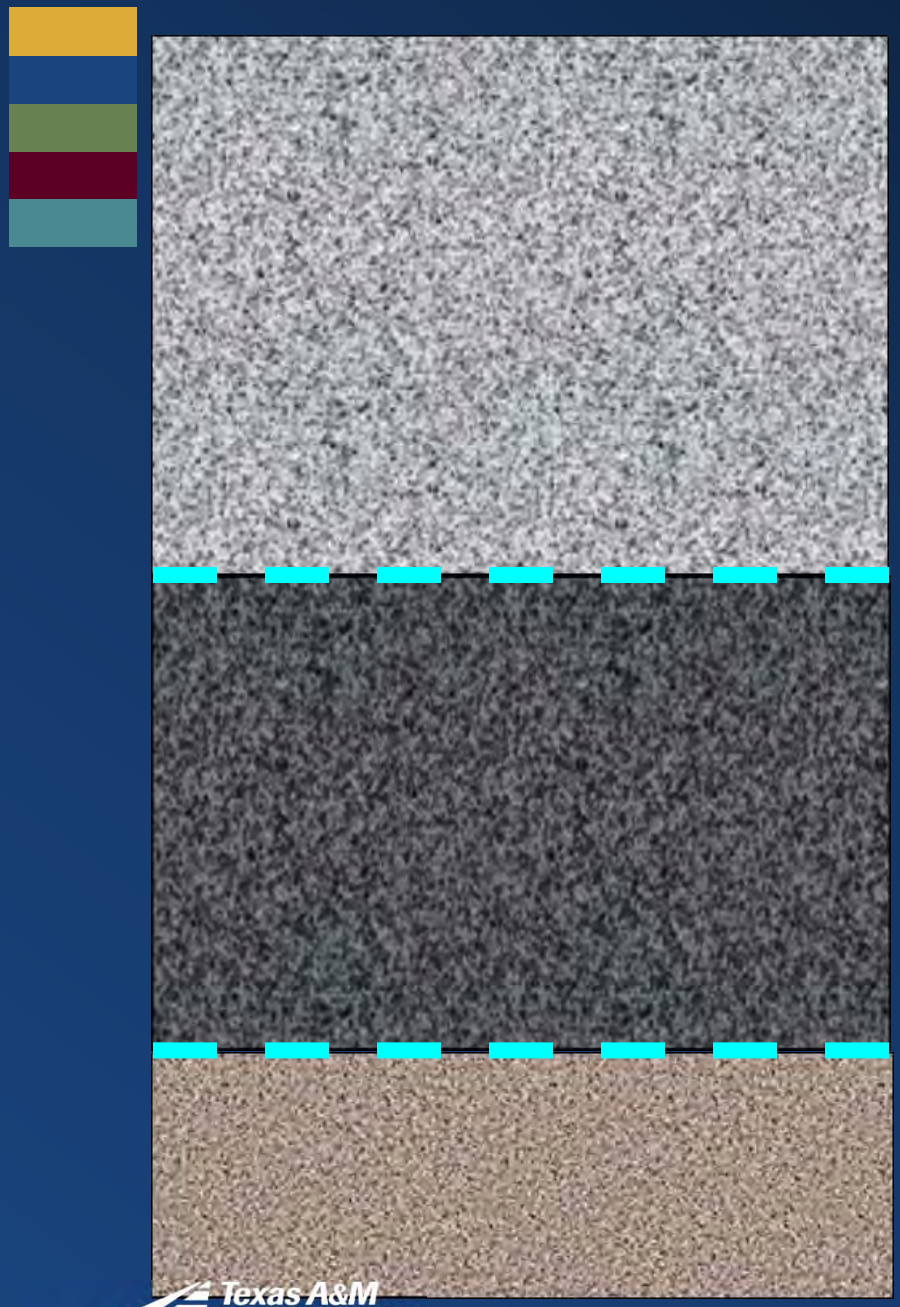

- Friction/Splash/Spray /Noise
- Permanent deformation
- Thermal cracking
- Water Susceptibility

- Stiffness
- High RAP/RAS
- Permanent deformation

- Fatigue resistance
- Water susceptibility

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Mixture Design

- Material Selection
- Mixture Volumetric
- Mixture Properties

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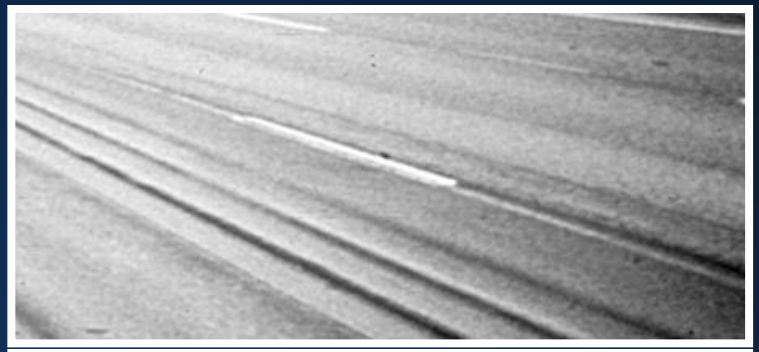
Mixture

- Stiffness
- Rutting
- Fatigue
- Thermal cracking
- Water susceptibility
- Aging



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RAP/RAS/WMA Concern

Pavement Distress	RAP	RAS	WMA
Raveling	X	X	
Bleeding			X
Rutting			X
Transverse Cracks	X	X	
Longitudinal Cracks	X	X	
Fatigue Cracks	X	X	
Reflection Cracks	X	X	
Water Sensitivity			X
Aging	X	X	

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Acceptance (Quality)

- Material Properties
- Process Control
- Quality Control
- Quality Assurance
- Quality Management
- Pay

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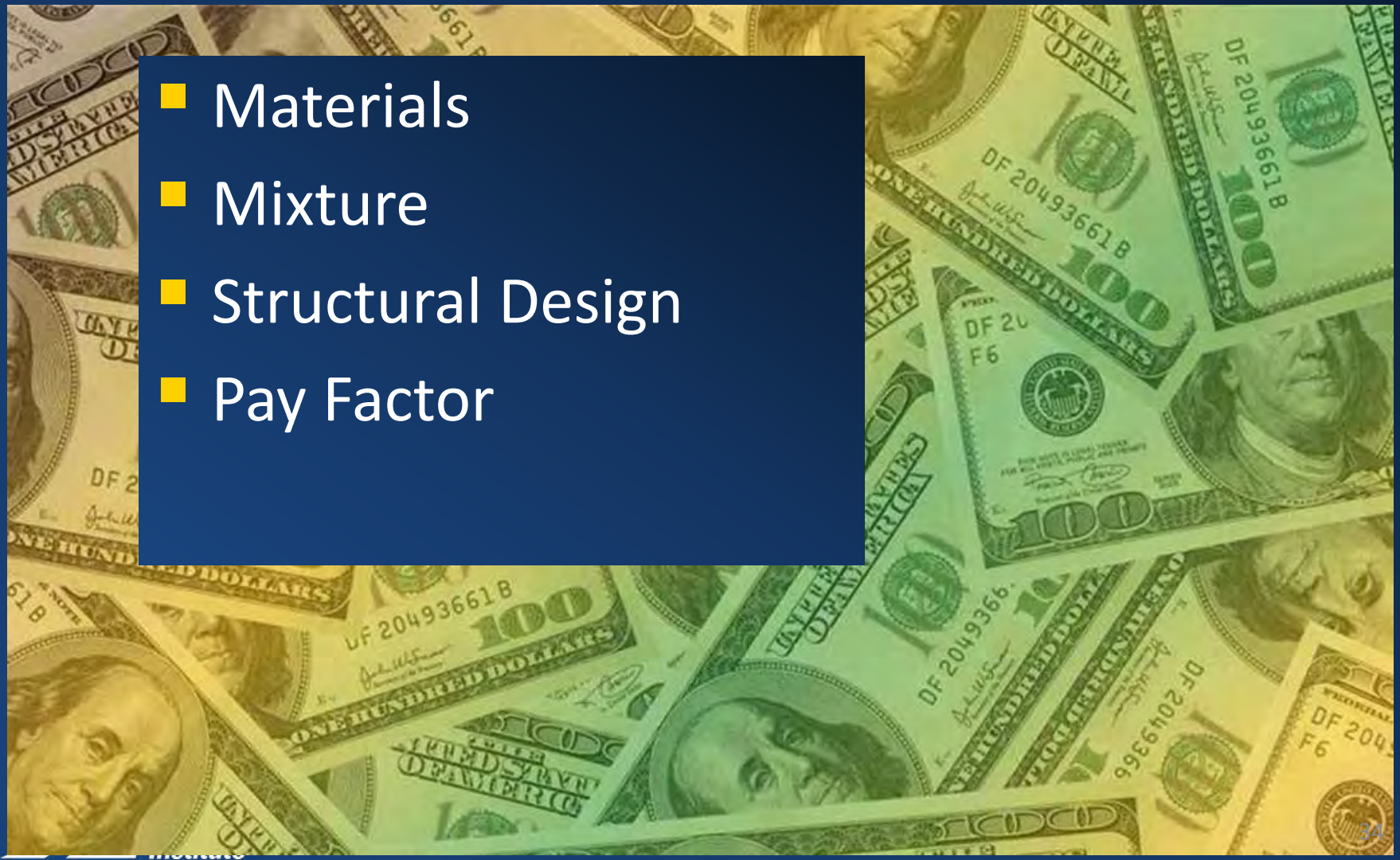
Economics



- Materials
- Mixture
- Structural Design
- Pay Factor

Materials

Material	50 Miles	100 Miles
Asphalt Binder	0.40	0.80
Aggregate	7.00	14.00

$/Ton of Mix

Mixture Design

Price of Asphalt Binder $/Ton	Percent Asphalt Binder Saved		
	0.1	0.3	0.5
400	0.40	1.20	2.00
500	0.50	1.50	2.50
600	0.60	1.80	3.00

$/Ton of Mix

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Structural Design

Reduce Thickness Inches (mm)	Lane Miles		
	10	20	30
1 (25)	275	550	1,375
2 (50)	550	1,100	2,750
3 (75)	825	1,650	4,125

Dollars - Thousands

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Remove and Replace

Tons	Costs, Dollars
1,000	110,000
2,000	220,000
3,000	330,000

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QC/QA and Variability

Variability = variability + variability + variability

(QC/QA) (sampling) (test method) (mat./const.)

$$S^2_{QC/QA} = S^2_s + S^2_t + S^2_{m/c}$$

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Sources of Variability

- Sampling - random variation in sampling methods or procedures
- Testing - random variation in testing performance and equipment

Sampling + testing variability = about 50% of the variation in test results

- Material - random natural variation
- Construction - variation inherent in production and construction methods

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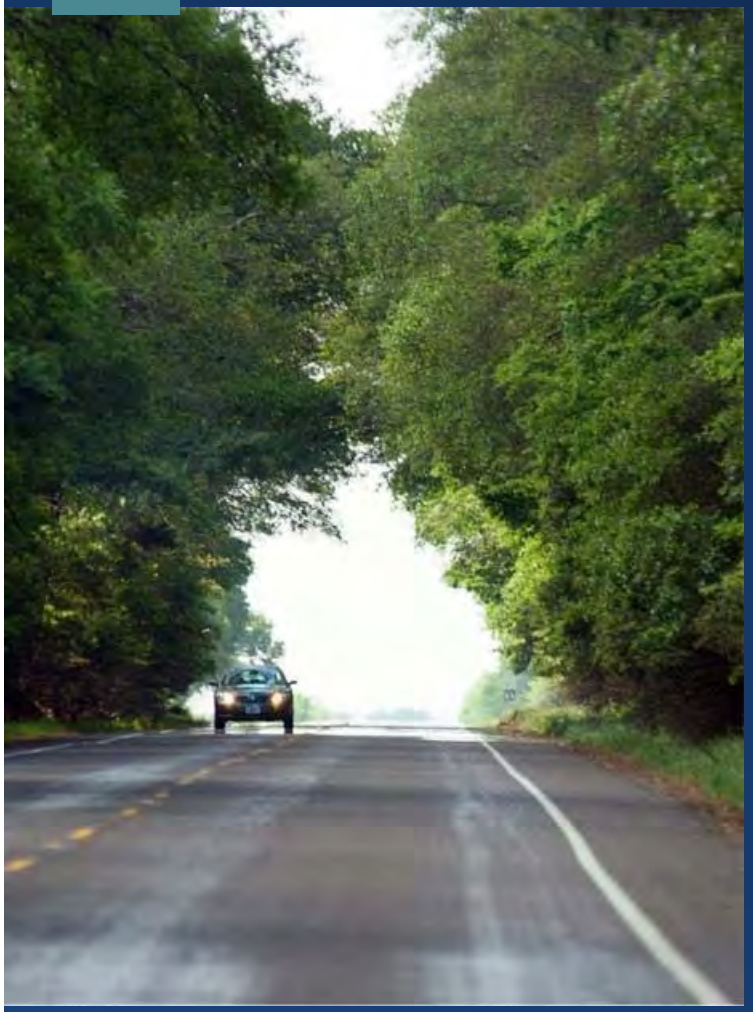

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Effect of Number of Samples and Associated Risk

Number of Samples (n)	Contractor's Risk (α)	Owner's Risk (β)
1	0%	84%
1	5%	50%
4	0%	16%
4	5%	2.5%

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Reported Test Result

- Single sample/size test result
- Single sample/multiple test result
- Multiple samples/multiple test result
- $s_n = \frac{s}{\sqrt{n}}$

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Number and Size of Samples ASTM Standards

- D3665 - Random Sampling of Construction Materials
- E105 - Probability Sampling of Materials
- E122 - Choice of Sample Size to Estimate the Average Quality of a Lot or Process
- E141 - Acceptance of Evidence Based on the Result of Probability Sampling

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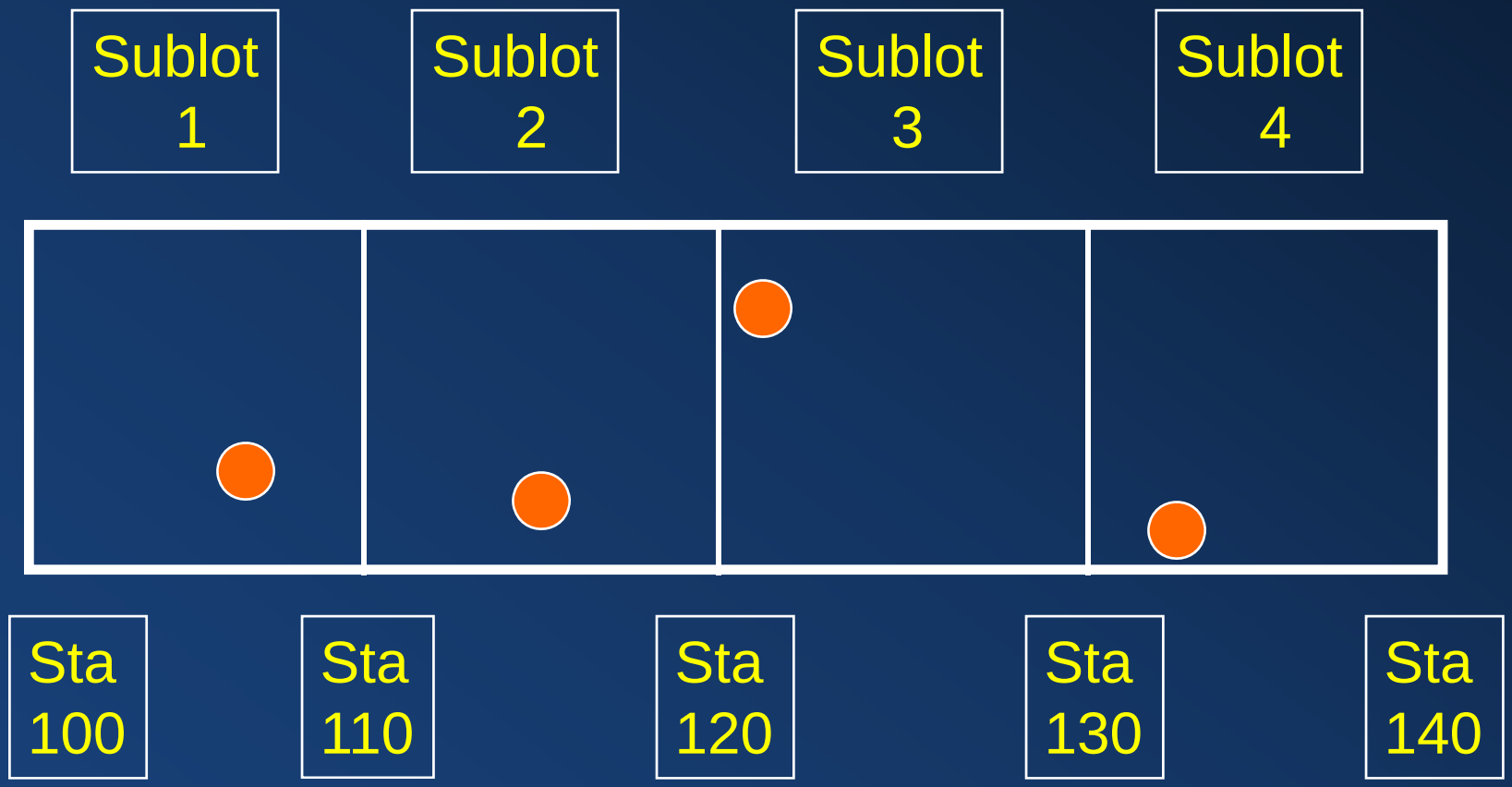
Stratified Random Sampling



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Point of Sampling

- Asphalt
  - Plant Tank or Middle 1/3 of Truck Load
  - Bleed off & Discard Prior to Sampling
  - Sample & Seal

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Point of Sampling

- Asphalt Content
  - Loose Plant, Truck, Mat (entire lift), Windrow, or Paver (auger) Samples, Cores
- Aggregate Gradation
  - Coldfeeds or hot bins
  - Extracted from HMA (loose samples or cores)
- Lab Compacted Volumetrics
  - Loose Plant, Truck, Mat (entire lift), Windrow, or Paver (auger) Samples

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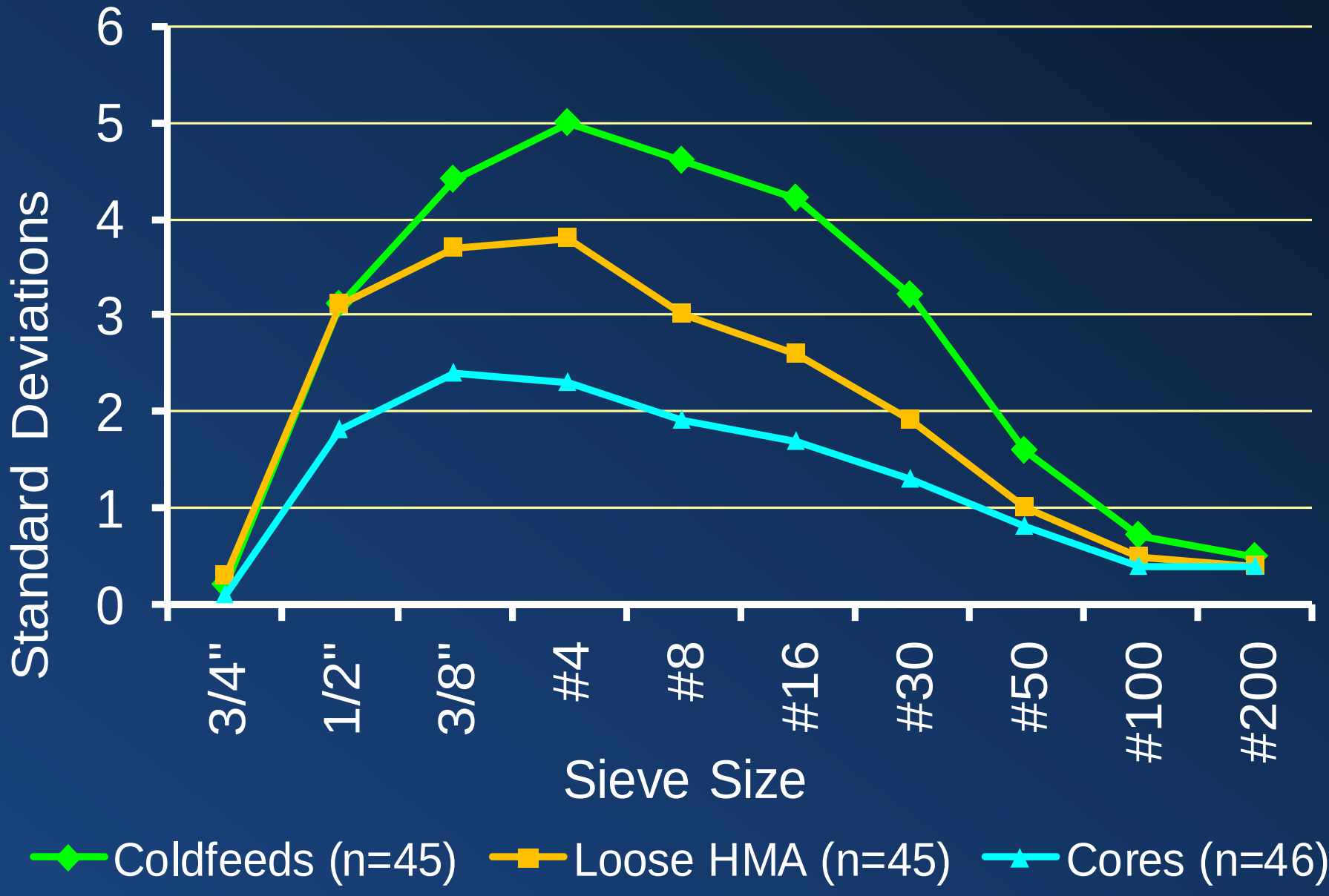
Effect of Sampling Location on Gradation Variability



Sample Splitting to Avoid Segregation

Coarse @ 3.79%ac
Fine @ 5.21%ac

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Mix Design Volumetric Criteria

- Superpave
  - $Gmm_{i,\ d,\ m}$, AV, VMA, VFA, DP
- Marshall
  - AV, VMA, VFA

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Mixture Volumetrics

- All Specified Volumetric Properties Calculated from Measured Material Properties (AASHTO or ASTM Test Methods):
  - Asphalt Content (AC)
  - Asphalt Cement Specific Gravity (G_b)
  - Combined Aggregate Specific Gravity (G_{sb})
  - Bulk Specific Gravity of Compacted Mixture (G_{mb})
  - Theoretical Maximum Specific Gravity (G_{mm})
  - Amount of Material Passing the #200 Sieve (p200)

Question ?

What are the <u>combined</u> effects of variability in material and mixture property measurements on calculated volumetric properties and optimum asphalt content selection?

Answer

Perform an analysis to find out

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Analysis

- Show the effect of what is considered acceptable variability in G_b, G_{sb}, G_{mb}, G_{mm} measurements on mixture volumetrics for both within and between laboratory conditions

- 19mm Superpave mix design data
- ASTM single-operator and multilaboratory precision
- Monte Carlo Simulations
- Generate range of volumetric properties due to test method variability

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Test Method Precision and Bias

- Precision Statements Account for Inherent Test Method Variability (uncontrollable random error)
- Single-operator, within lab, repeatability
- Multilaboratory, between lab, reproducability
- One-Sigma Limits (standard deviation, σ, 1S)
- Difference Two-Sigma Limits $\{(2\sqrt{2}\}\sigma$, D2S$\}$

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Within Laboratory Precision

(Single Operator Precision)

Designations		Description	Single Operator Precision			
AASHTO Method	ASTM Method		Standard Deviation (1S)		Acceptable Range of Two Results (D2S)	
			AASHTO	ASTM	AASHTO	ASTM
T228	D70	Asphalt Cement Specific Gravity	0.0008	0.0008	0.0023	0.0023
T85	C127	Coarse Aggregate Specific Gravity	0.009	0.009	0.025	0.025
T84	C128	Fine Aggregate Specific Gravity	0.011	0.011	0.032	0.032
T166	D2726	Bulk Specific Gravity of Compacted Bituminous Specimens	*	0.0124	*	0.035
T209	D2041	Theoretical Maximum Specific Gravity of Bituminous Mixture	0.0040 (0.0064)	0.0040 (0.0064)	0.011 (0.018)	0.011 (0.018)

*** - "Duplicate specific gravity results by the same operator should not be considered suspect unless they differ more than 0.02."**

( ) - supplemental procedure for mixtures containing porous aggregate conditions ("dryback procedure").

Between Laboratory Precision
(Multilaboratory Precision)

Designations		Description	Multilaboratory Precision			
AASHTO Method	ASTM Method		Standard Deviation (1S)		Acceptable Range of Two Results (D2S)	
			AASHTO	ASTM	AASHTO	ASTM
T228	D70	Asphalt Cement Specific Gravity	0.0024	0.0024	0.0068	0.0068
T85	C127	Coarse Aggregate Specific Gravity	0.013	0.013	0.038	0.038
T84	C128	Fine Aggregate Specific Gravity	0.023	0.023	0.066	0.066
T166	D2726	Bulk Specific Gravity of Compacted Bituminous Specimens	*	0.0269	*	0.076
T209	D2041	Theoretical Maximum Specific Gravity of Bituminous Mixture	0.0064 (0.0193)	0.0064 (0.0193)	0.019 (0.055)	0.019 (0.055)

*** - "Duplicate specific gravity results by the same operator should not be considered suspect unless they differ more than 0.02."**

( ) - supplemental procedure for mixtures containing porous aggregate conditions ("dryback procedure").

Monte Carlo Simulation Process

- Develop Probability Distributions from Mix Design Property Means and ASTM One-Sigma Limits for *Each* Input Variable
  - eg.: G_{mb} and G_{mm}
- Repeatedly Sample the Input Distributions (G_{mb} and G_{mm}) and Calculate the Output Variable to Generate an Output Distribution
  - eg.: %AV
- 1000's of iterations

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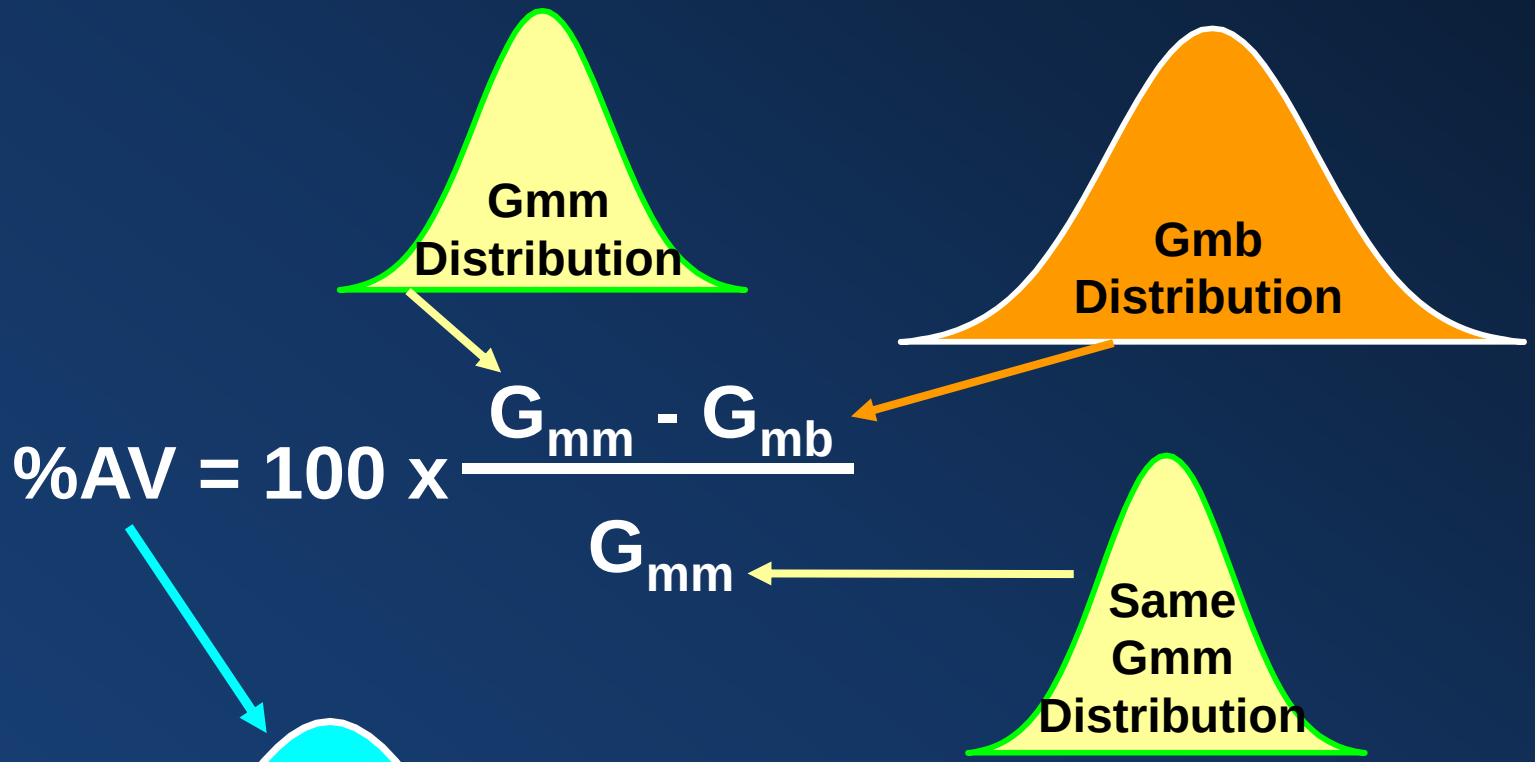
Monte Carlo Simulation



G_{mm} and G_{mb} =inputs

%AV = output

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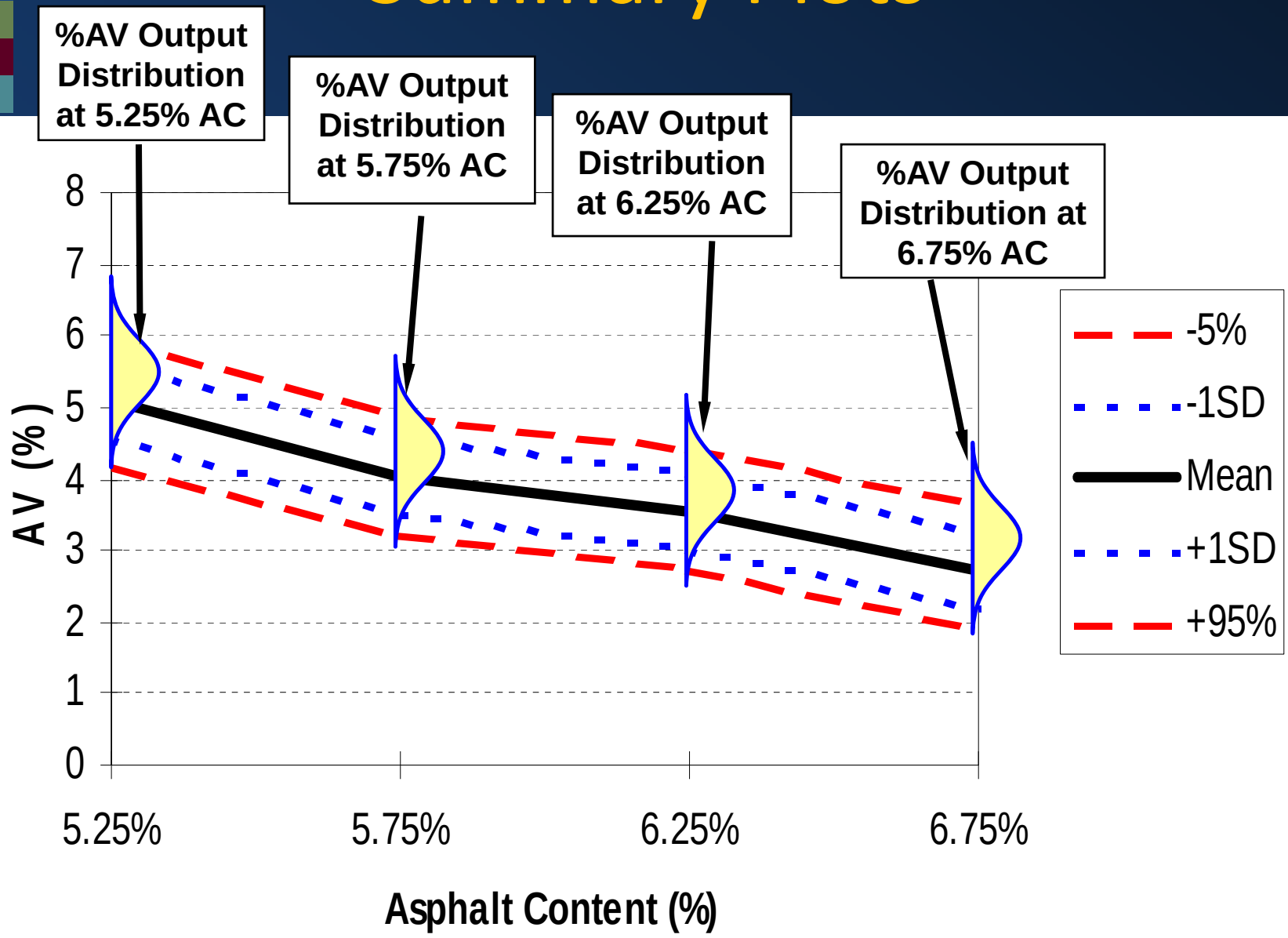
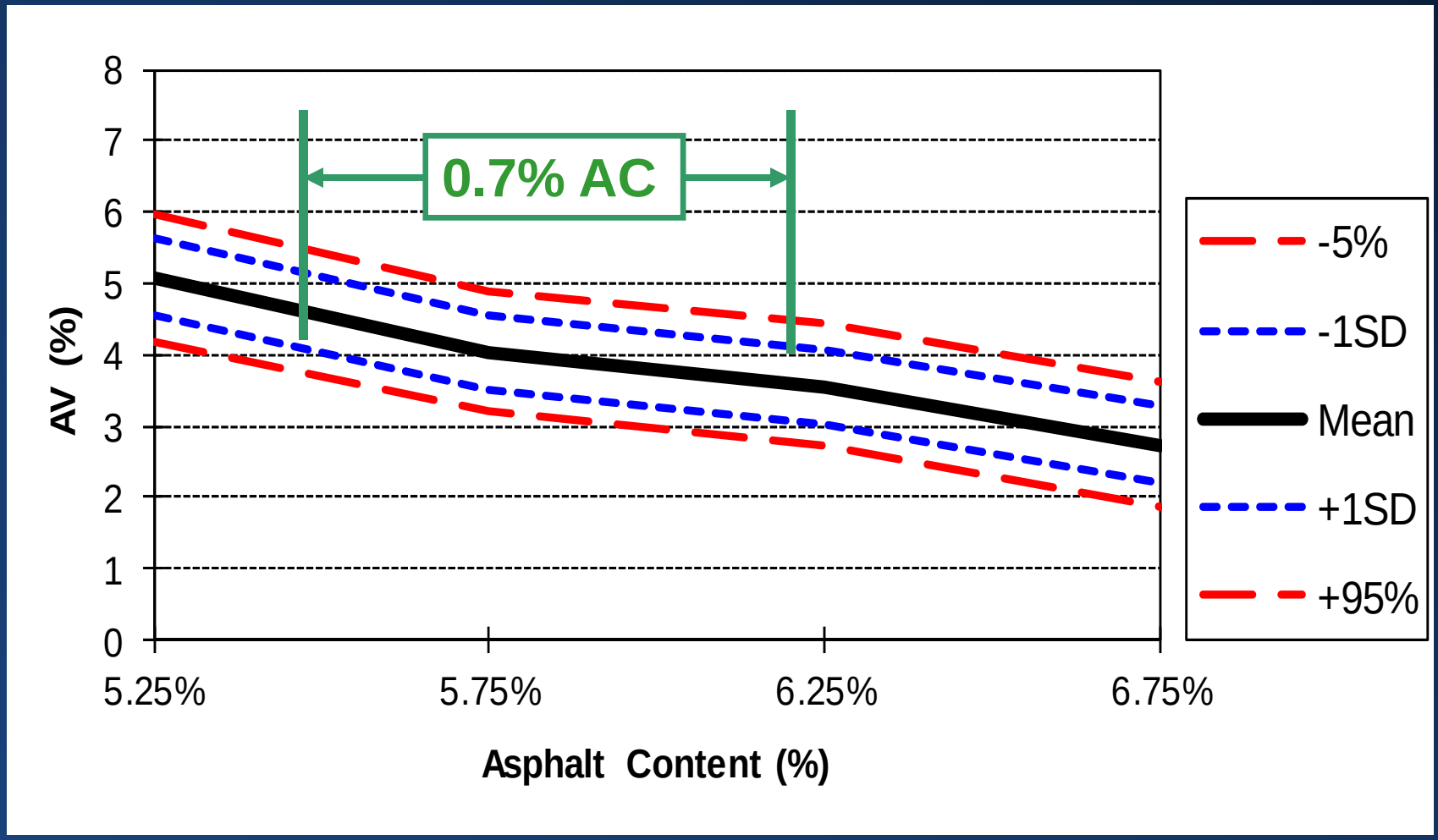
Summary Plots



Within Laboratory Air Voids



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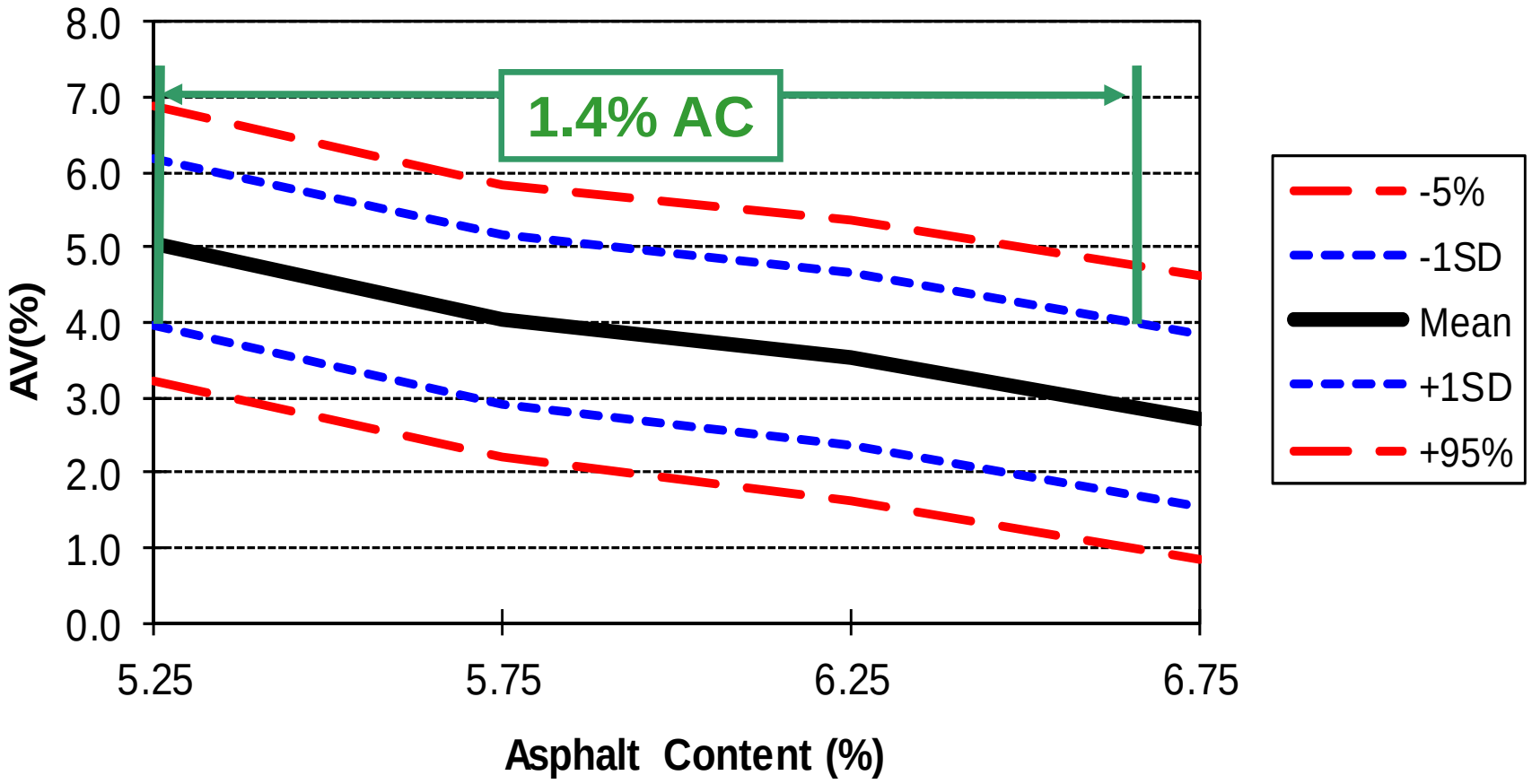
Between Laboratory Air Voids



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Summary and Conclusions

- "Acceptable" Variability Associated with the Measurement of the Properties Required to Determine HMA Volumetrics can Have a Significant Impact on Calculated Volumetric Properties

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Summary and Conclusions

- Within Laboratory Test Method Variability May Lead to Differences in AV and VMA of 1.0^{+}% for Any Given Mix Design

- These Differences Translate into Potential Differences of 0.7% in Optimum Asphalt Content Selection

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Summary and Conclusions

- Between Laboratory Test Method Variability May Lead to Differences in AV and VMA of over 2.0% for Any Given Mix Design
- These Differences Translate into Potential Differences of Over 1.0% in Optimum Asphalt Content Selection

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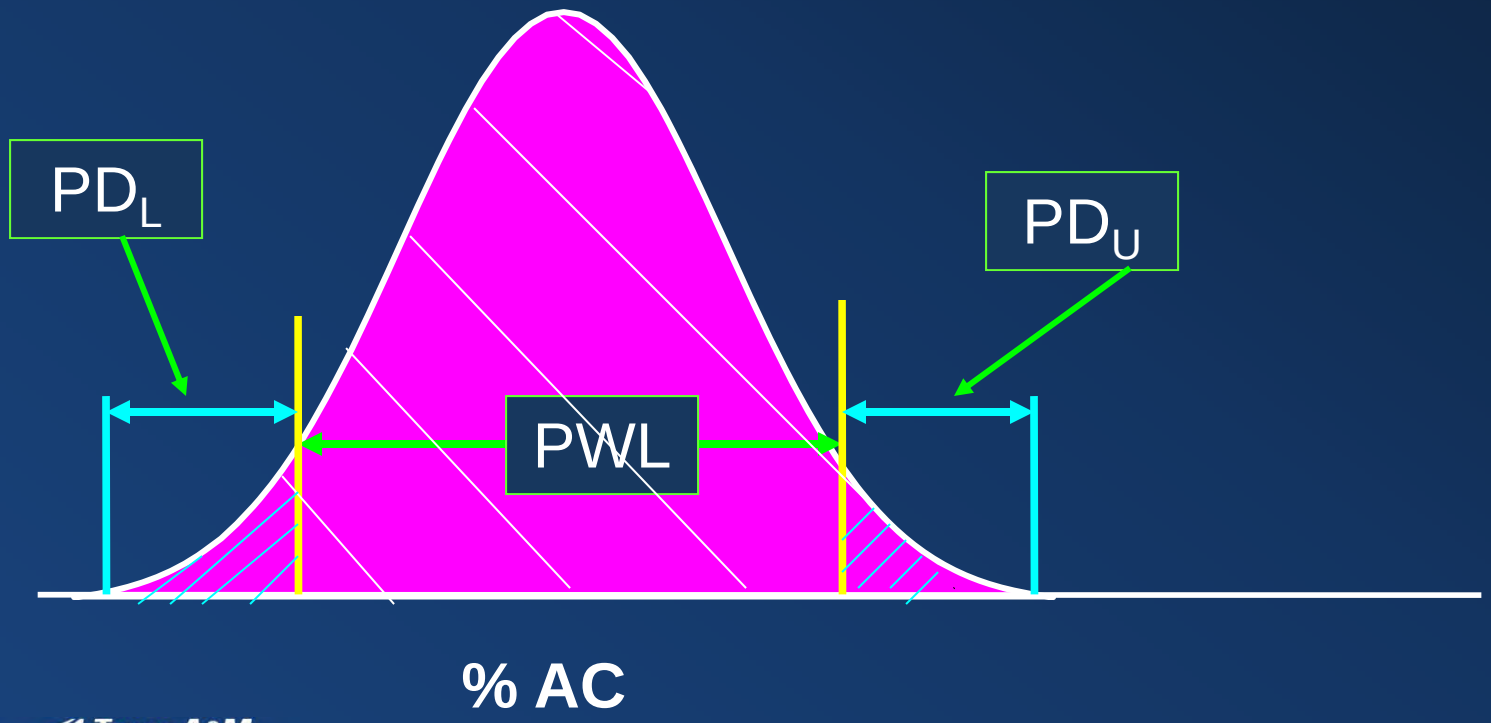
HYPAC

PWL and PD Concept

$$PWL = 100 - (PD_U + PD_L)$$

In Terms of Area of the Distribution



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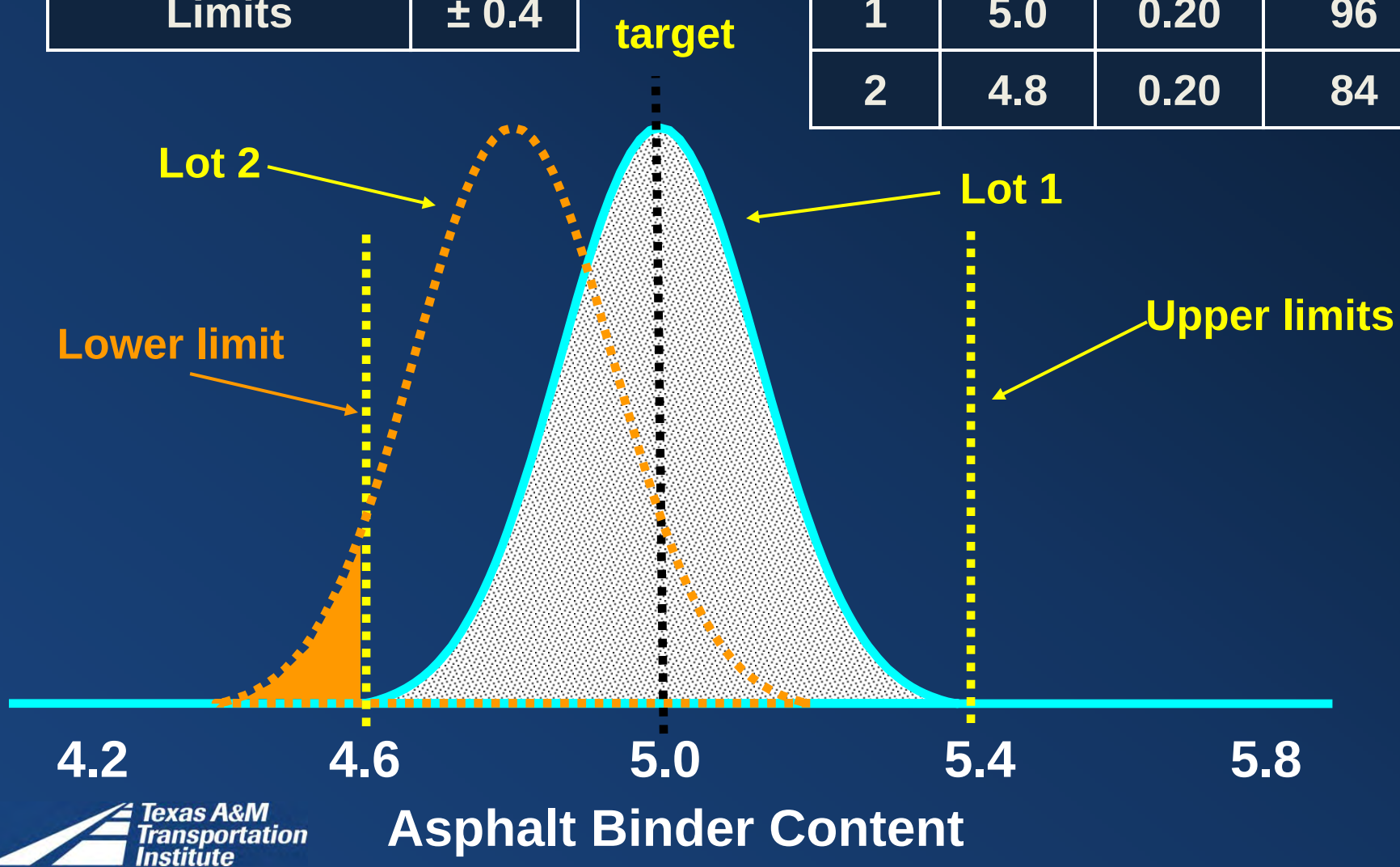
Percent within Limits

Target Value	5.0
Limits	± 0.4

Lot	X	s	PWL
1	5.0	0.20	96
2	4.8	0.20	84



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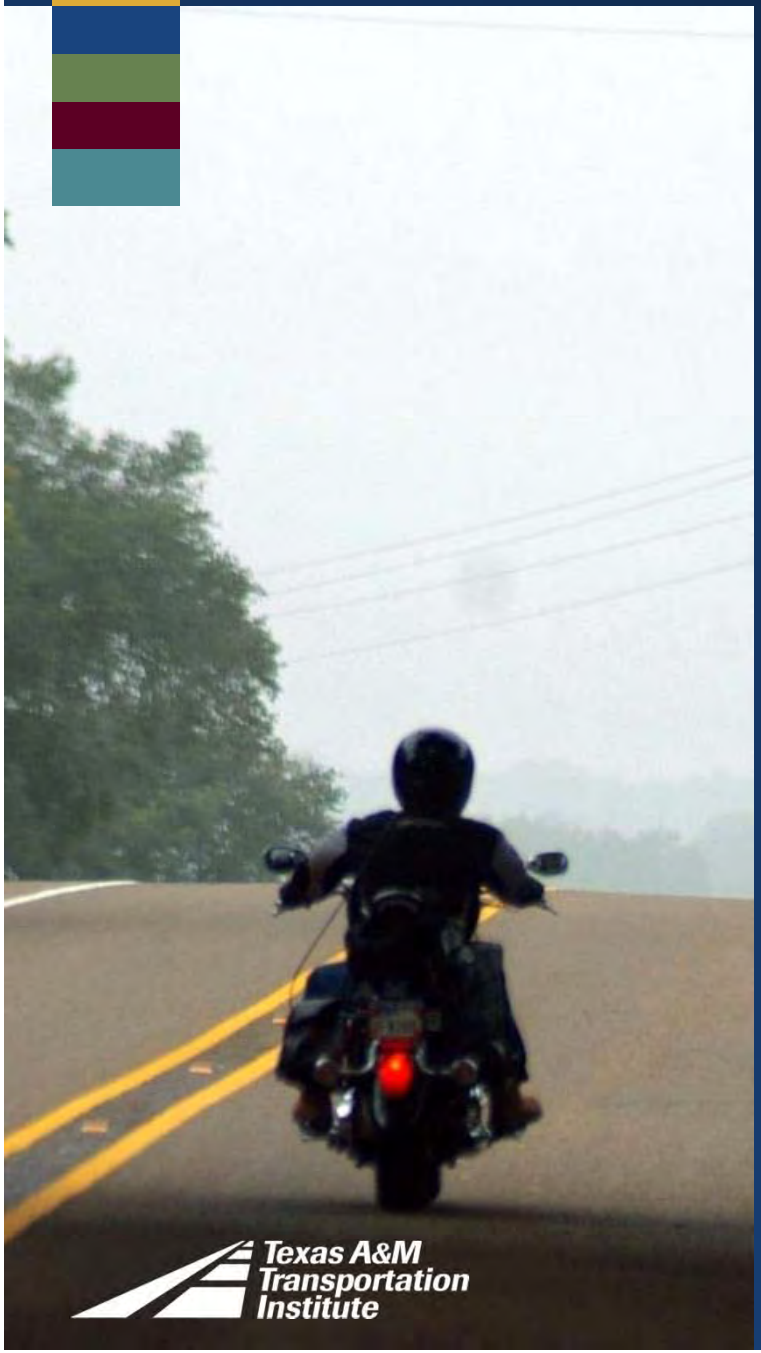
Typical Variability

Property	Standard Deviation(s)
Asphalt Content, %	0.25
% pass 4.75 mm, %	3.0
% pass 2.36 mm to 0.15 mm, %	2.0
% pass 0.075 mm, %	0.7
Air Voids, %	1.0
VMA, %	1.5
VFA, %	5.0



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Fabrication of Samples

- Lab Mixed-Lab Compacted
  - Mixture Design
  - Structural Design
  - Predict Performance
- Field Mixed – Lab Compacted
  - Structural Design?
  - Predict Performance?
- Field Mixed-Field Compacted
  - Acceptance/Pay
  - Structural Design
  - Predict Performance

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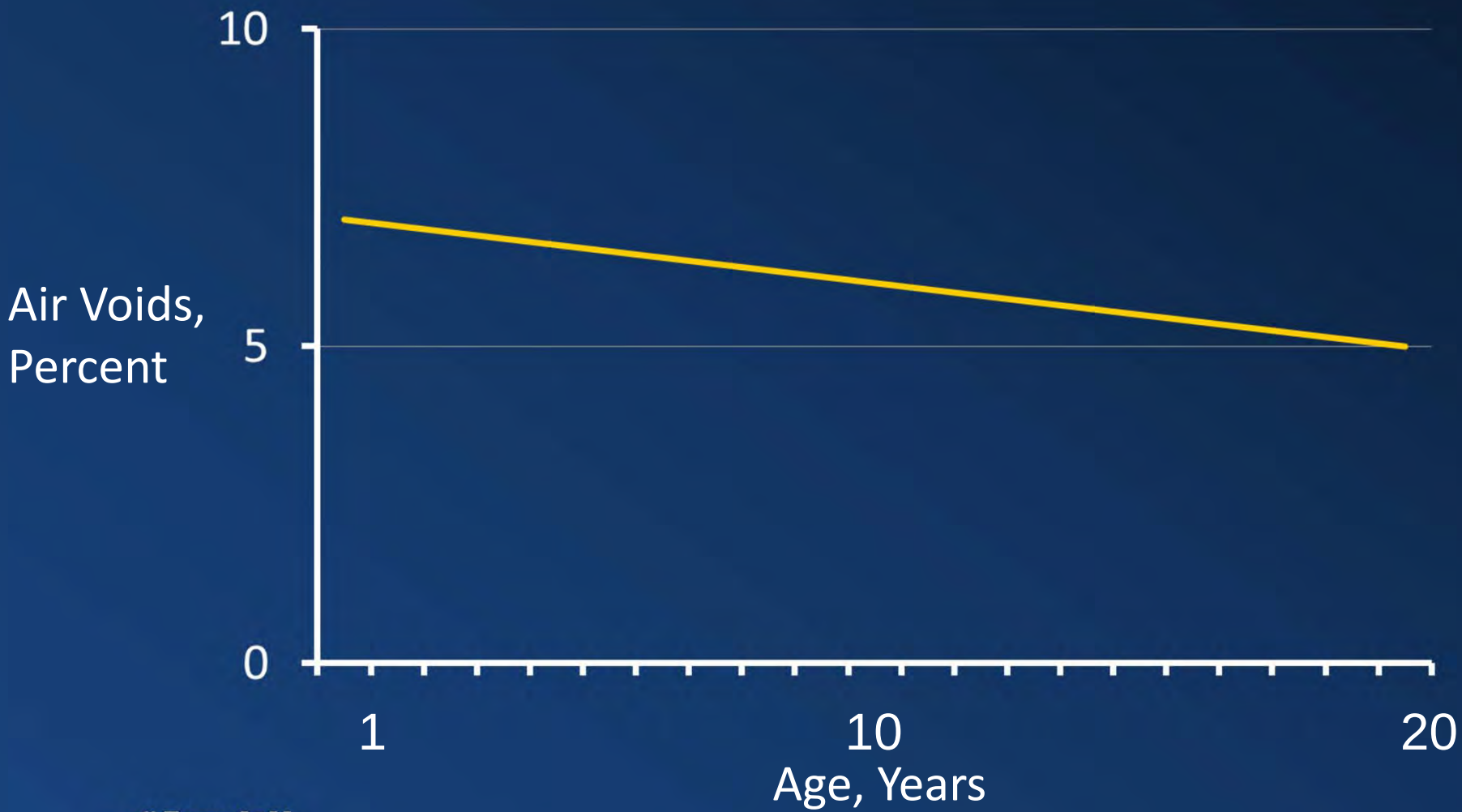
Compaction



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Laboratory

- Plunger
- Impact
- Kneading
- Gyratory
- Slab

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Conditioning

- Construction Hardening
- Short Term
- Long Term

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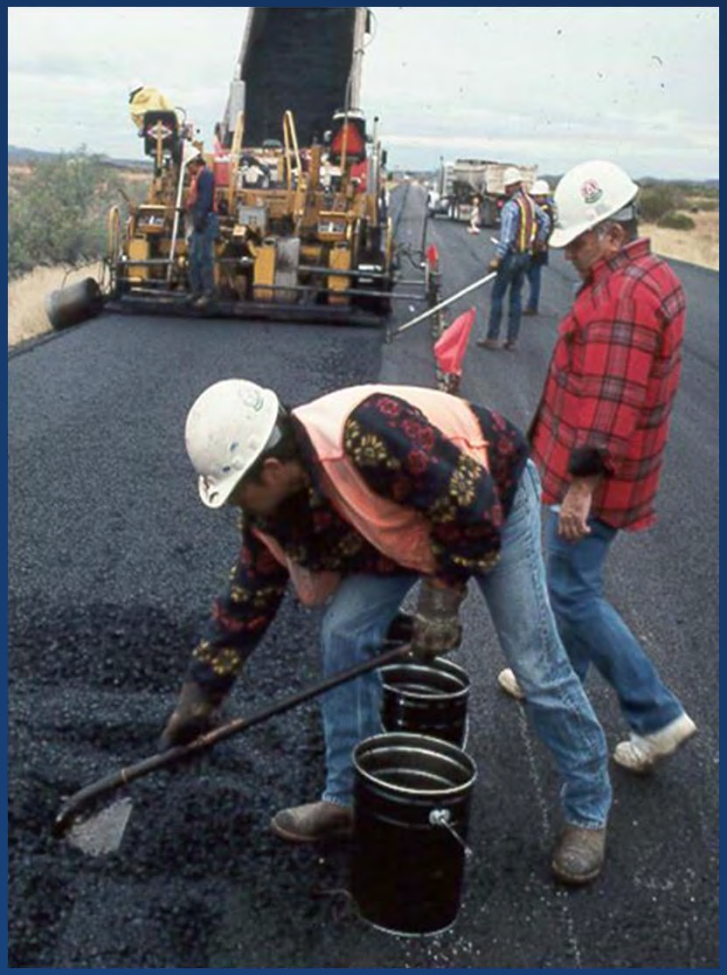

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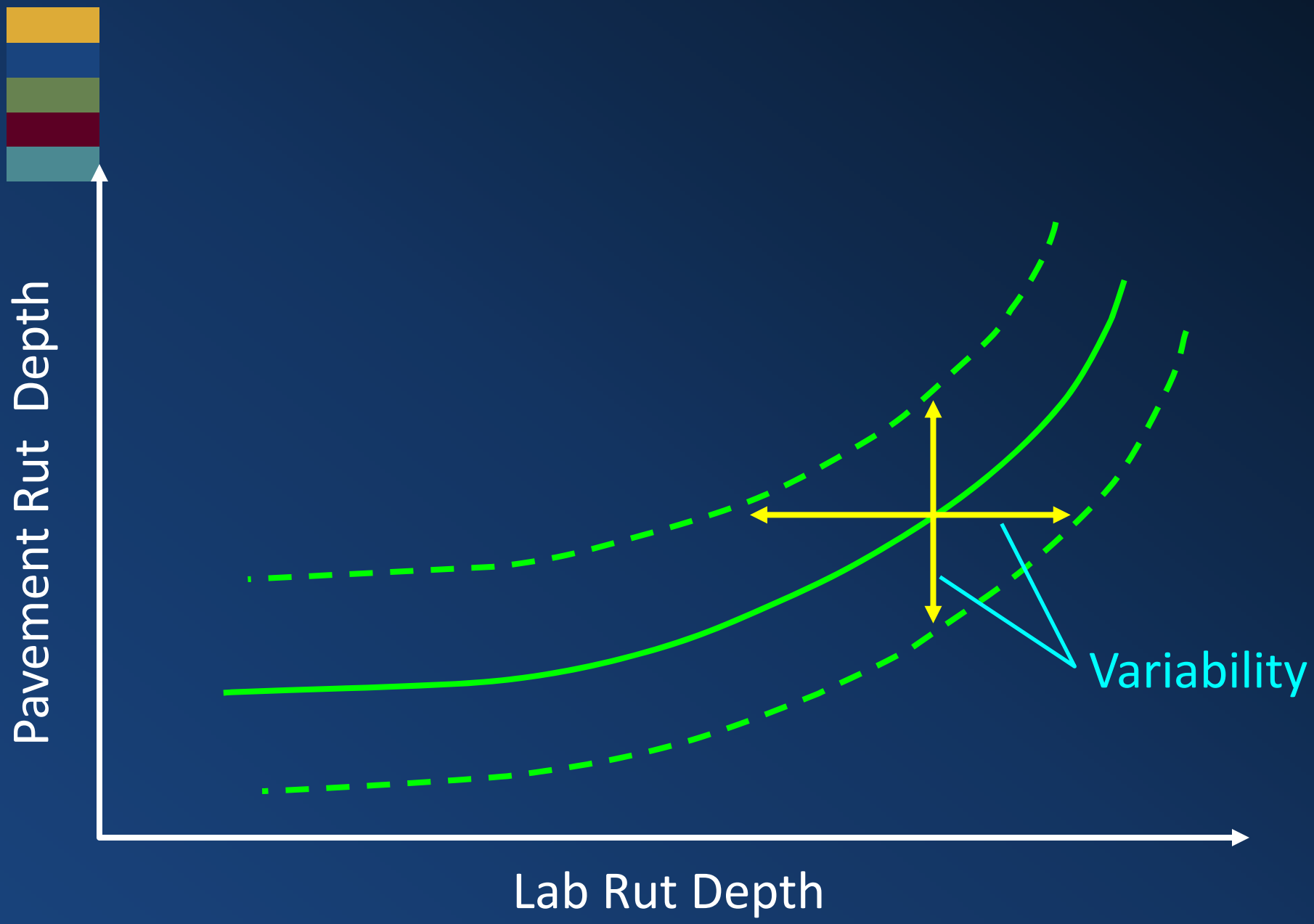

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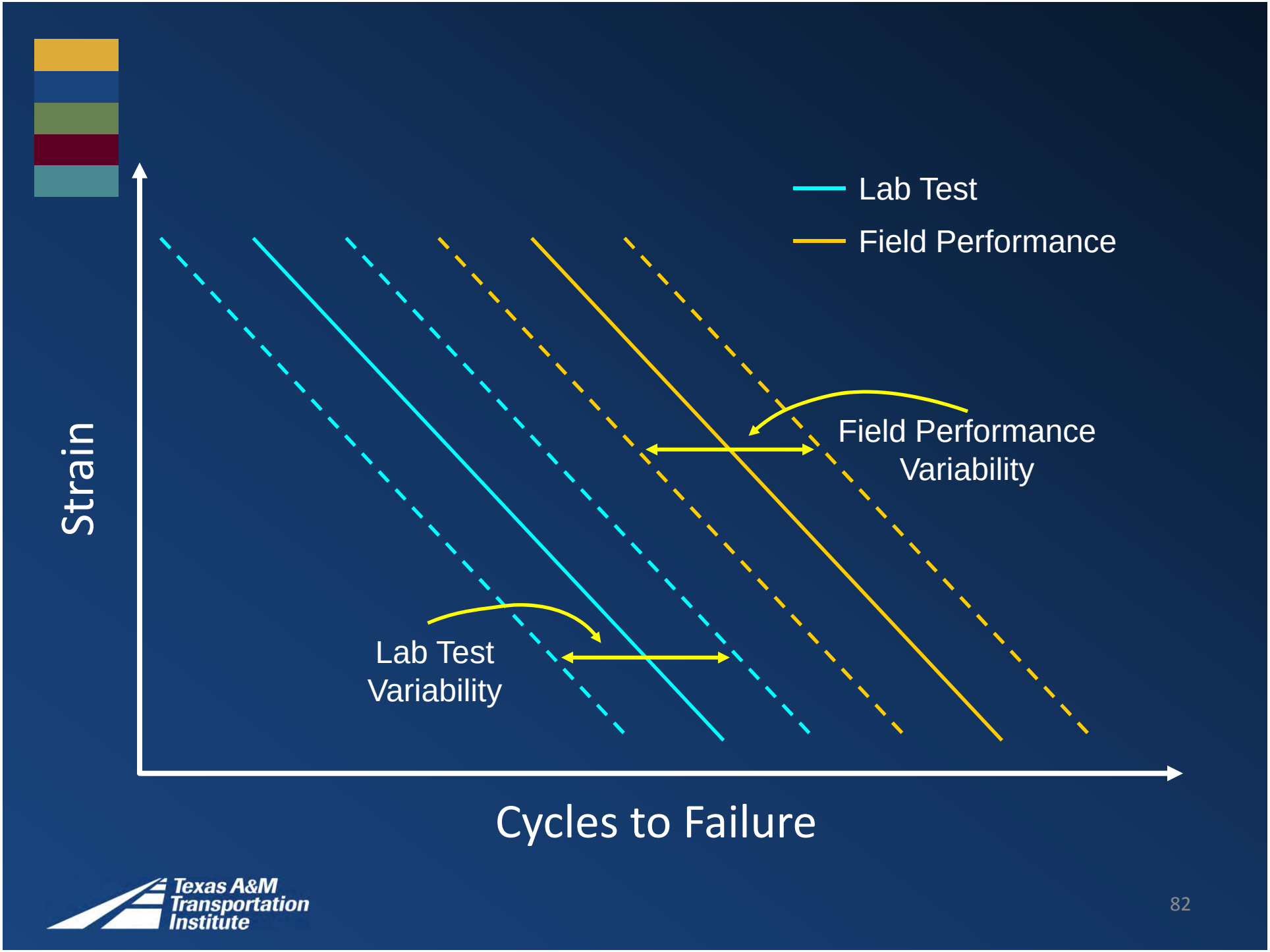

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- Forensics/Legal

Contractor Interest

Type of Contract	Select Materials	Mix Design	Structural Design	Acceptance/ Pay	Bid/Profit	Performance
D – B – B	X			X	X	
D/B	X	X	X	X	X	
PPP	X	X	X	X	X	X

Mixture Design

Price of Asphalt Binder $/Ton	Percent Asphalt Binder Saved		
	0.1	0.3	0.5
400	0.40	1.20	2.00
500	0.50	1.50	2.50
6000	0.60	1.80	3.00

$/Ton of Mix

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Structural Design

Reduce Thickness Inches (mm)	Lane Miles		
	10	20	30
1 (25)	275	550	1,375
2 (50)	550	1,100	2,750
3 (75)	825	1,650	4,125

Dollars - Thousands

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Remove and Replace

Tons	Costs, Dollars
1,000	110,000
2,000	220,000
3,000	330,000

QC/QA and Variability

Variability = variability + variability + variability

(QC/QA) (sampling) (test method) (mat./const.)

$$S^2_{QC/QA} = S^2_s + S^2_t + S^2_{m/c}$$

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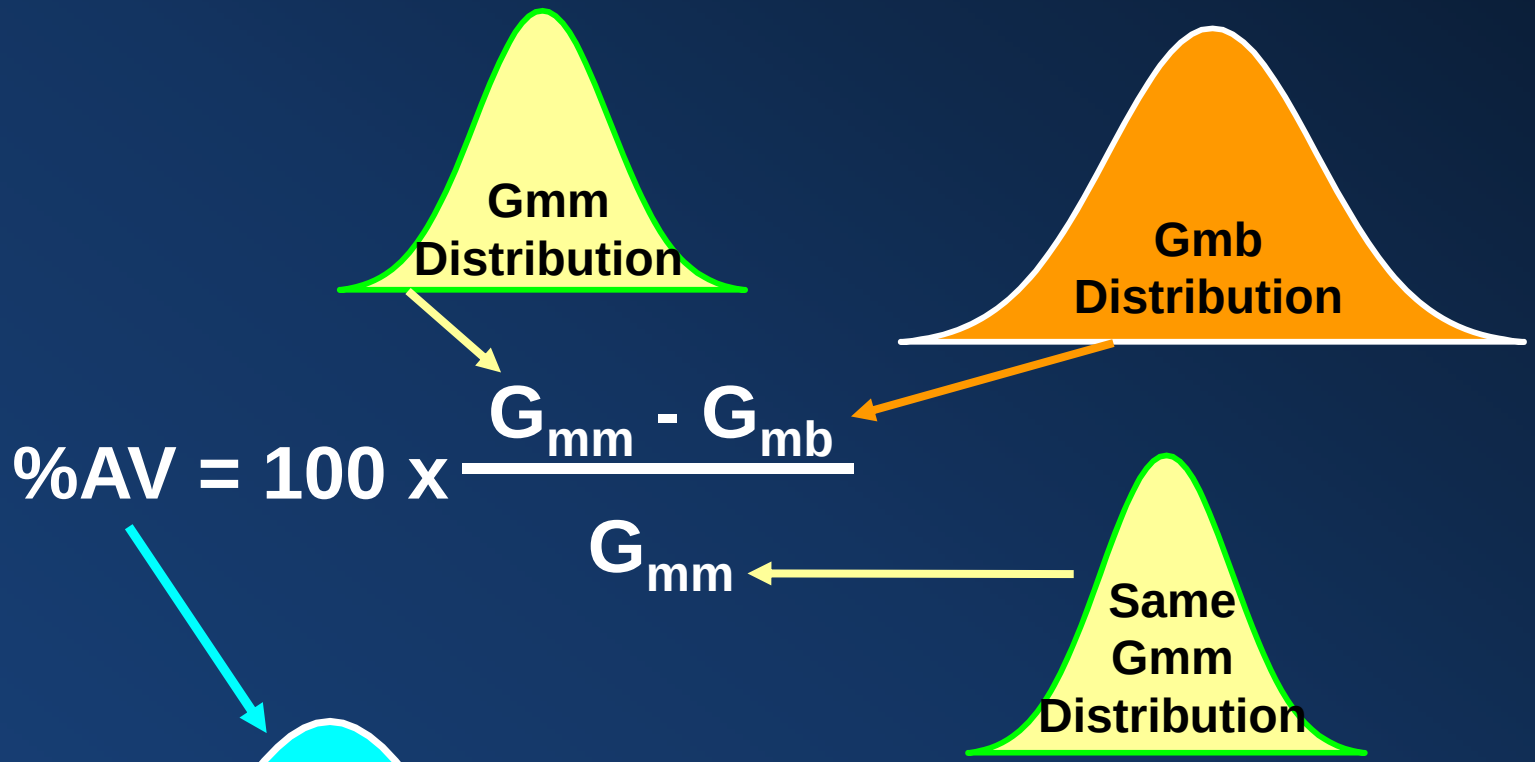
Monte Carlo Simulation



G_{mm} and G_{mb} =inputs

%AV = output

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Within Laboratory Precision

(Single Operator Precision)

Designations		Description	Single Operator Precision			
AASHTO Method	ASTM Method		Standard Deviation (1S)		Acceptable Range of Two Results (D2S)	
			AASHTO	ASTM	AASHTO	ASTM
T228	D70	Asphalt Cement Specific Gravity	0.0008	0.0008	0.0023	0.0023
T85	C127	Coarse Aggregate Specific Gravity	0.009	0.009	0.025	0.025
T84	C128	Fine Aggregate Specific Gravity	0.011	0.011	0.032	0.032
T166	D2726	Bulk Specific Gravity of Compacted Bituminous Specimens	*	0.0124	*	0.035
T209	D2041	Theoretical Maximum Specific Gravity of Bituminous Mixture	0.0040 (0.0064)	0.0040 (0.0064)	0.011 (0.018)	0.011 (0.018)

*** - "Duplicate specific gravity results by the same operator should not be considered suspect unless they differ more than 0.02."**

( ) - supplemental procedure for mixtures containing porous aggregate conditions ("dryback procedure").


Questions?