Understanding Testing Variability

Rocky Mountain Asphalt Conference & Equipment Show

February 19-21, 2014
Denver, Colorado

Jon Epps

Texas Transportation Institute

Understanding Testing Variability

Rocky Mountain Asphalt Conference & Equipment Show

February 19-21, 2014
Denver, Colorado

Jon Epps

Texas Transportation Institute

Outline

- Introduction
- Variability
- Sampling Variability
- Testing Variability
- Materials/Construction Variability
- Percent within Limit
- Typical Variability
- Summary

Texas A&M Transportation Institute

Why Understand Testing Variability

- Provide quality product to our customer
- Remain in business
- Establish specification limits
- Predict pay factors

Texas A&M Transportation Institute

“Quality”

- Customer
- Engineer

Texas A&M Transportation Institute

Quality – Customer

- Product Meets or Exceeds Customer's Expectation
  - Short Term
  - Long Term (Durability)
- Appearance

Texas A&M Transportation Institute

Quality – Pavements

- Looks Good
- Rides Smoothly
- No Splash and Spray
- Quiet
- Provide Friction

Texas A&M Transportation Institute

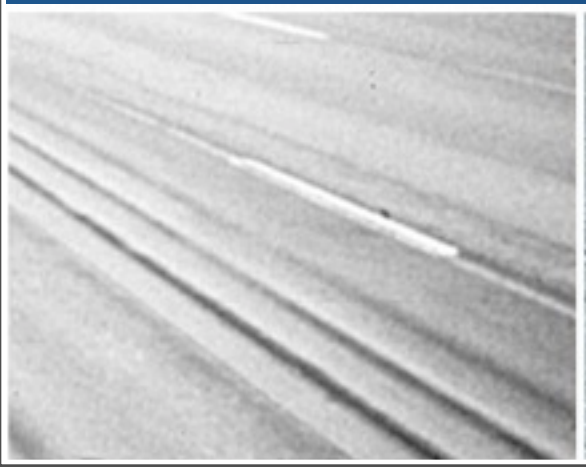
Quality – Engineer

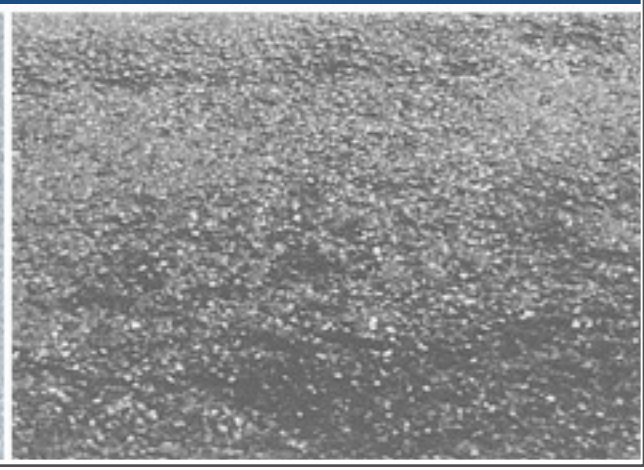
- Meets or Exceeds Expectation (Performance)
  - Short Term
  - Long Term
- Meets or Exceeds Specifications
- Uniform Product

Texas A&M Transportation Institute

Quality–Pavements (Engineer)

- Meets or Exceeds Specification
- Satisfies Customer
- Short & Long Term Performance
  - Rutting
  - Bleeding
  - Patching
  - Raveling
  - Cracking





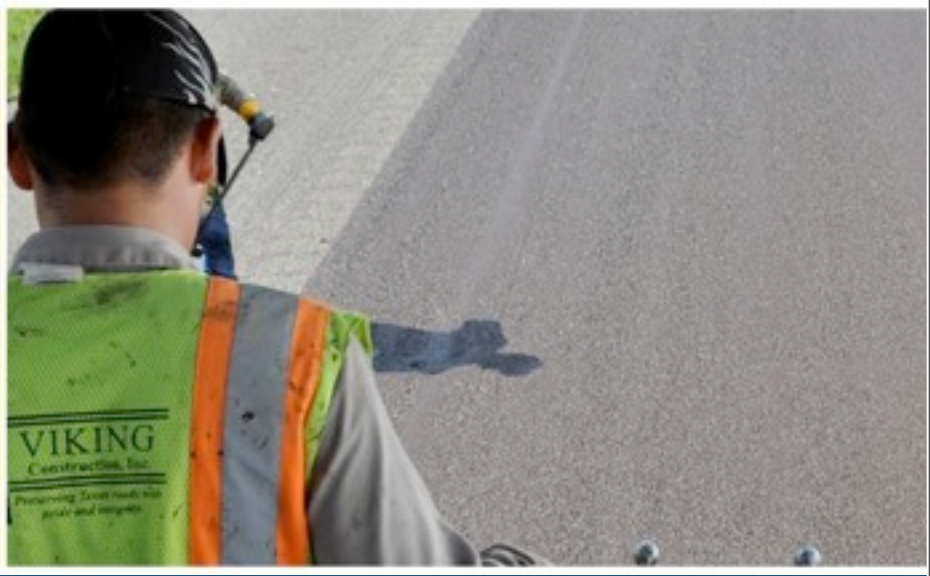
Quality Pavements

- Mixture/ Materials Designs
- Thickness of Pavement
- Specifications
- Construction

Texas A&M Transportation Institute

Who Is Responsible for Quality?

- Owner (Public Agency)
- Contractor/Material Supplier
- All Levels of the Organization



Texas A&M Transportation Institute

Role of Specifications

- Contractors/Material Supplier (Control Quality)
- Owner (Public Agencies) (Specify Quality)

Referee

Contractor/
Material Supplier

- Process Control
  Quality Control

Owner
(Pubic Agency)

- Quality
  Assurance

Independent
Assurance

Texas A&M Transportation Institute

Types of Specifications

Proprietary
Method
QC/QA
End Result

- Performance Related
- Performance Based
- Statistically Based
- Warranty/Guarantee

Specifications – Quality Control/Quality Assurance

- Lot/Sublot
- Process Control /Quality Control
- Quality Assurance
- Acceptance
- Measurement
- Pay Adjustment
- Certification/Accreditation

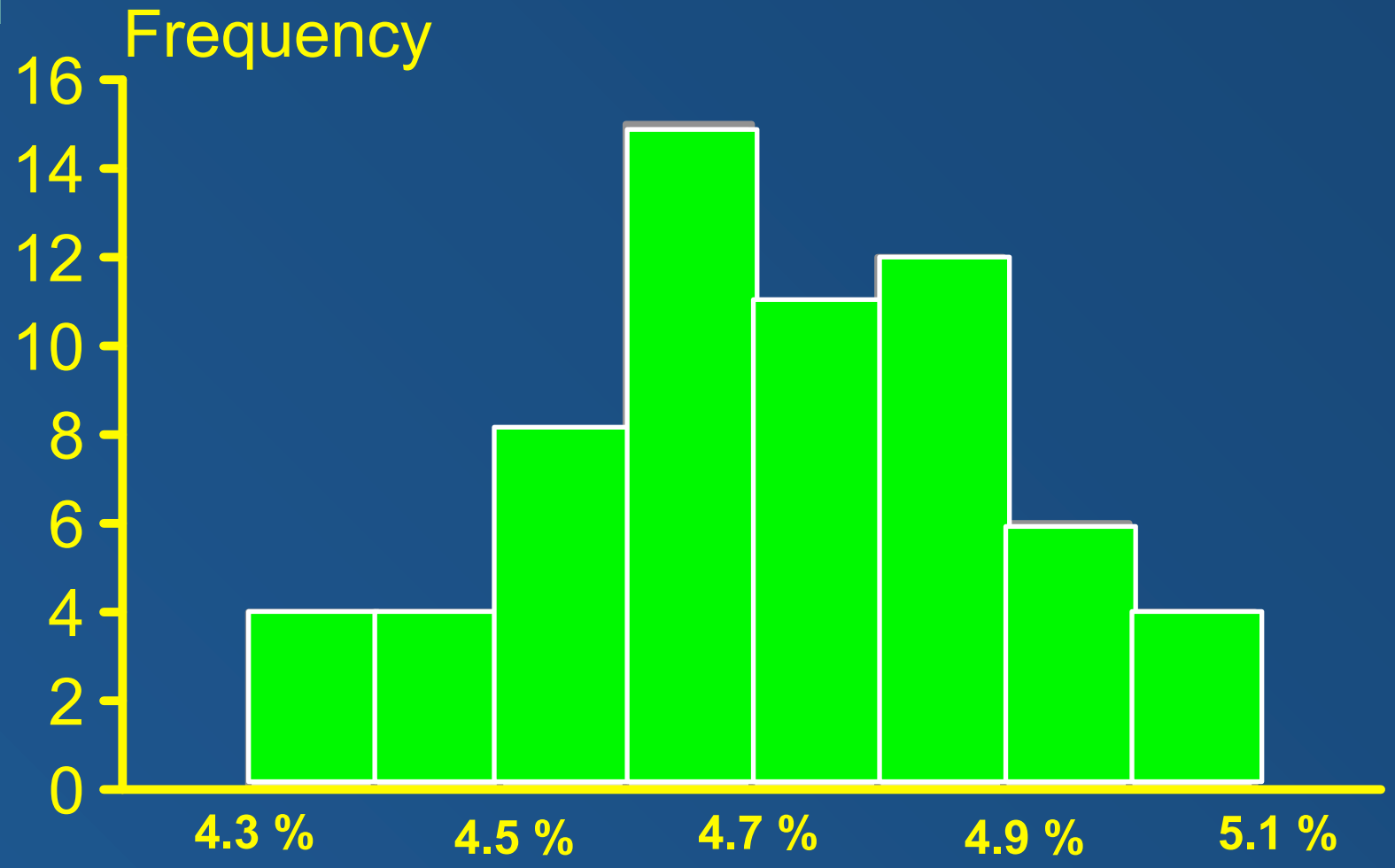
Texas A&M Transportation Institute

Outline

- Introduction
- **Variability**
- Sampling Variability
- Testing Variability
- Materials/Construction Variability
- Percent within Limit
- Typical Variability

Texas A&M Transportation Institute

60 Asphalt Binder Contents

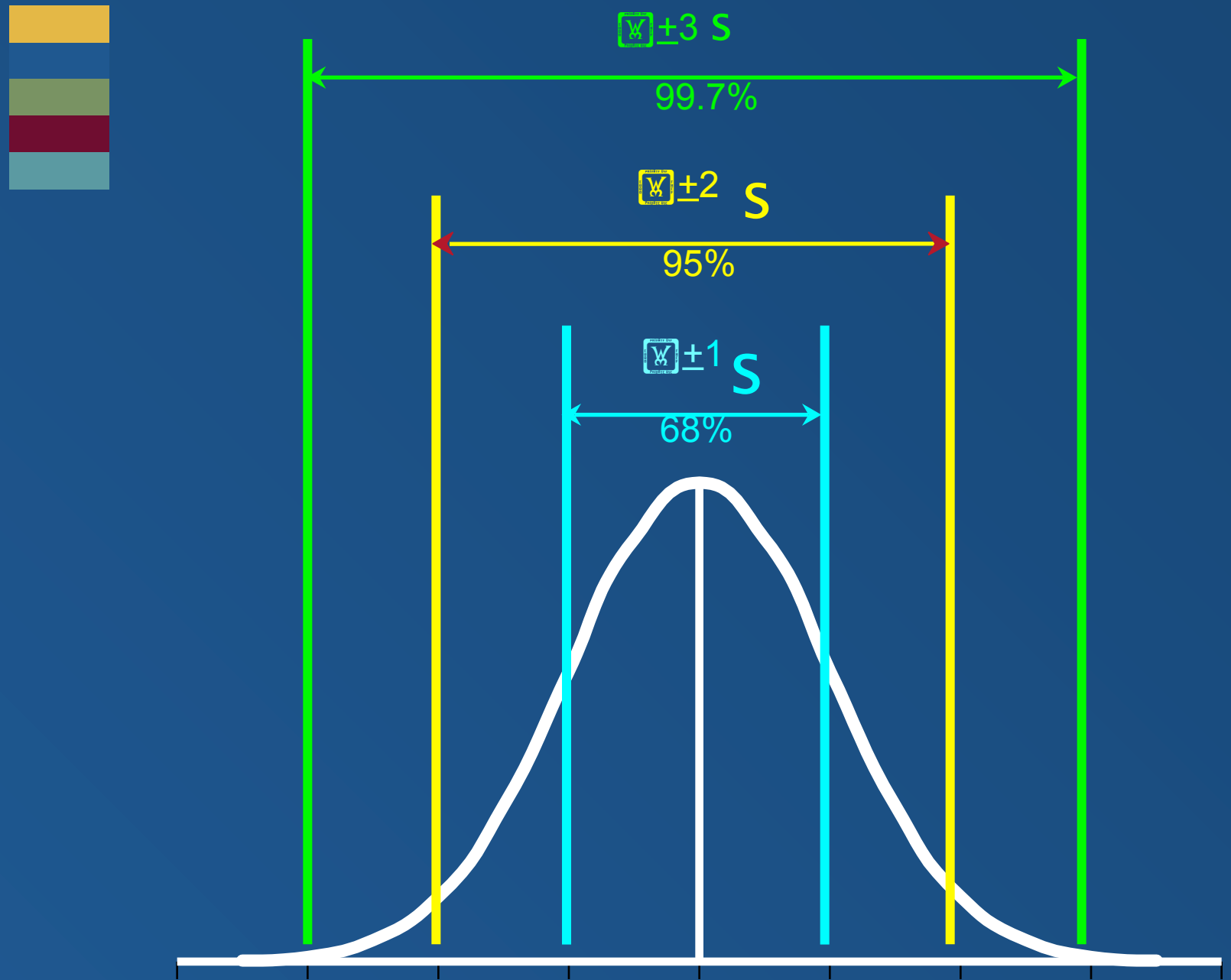


Texas A&M Transportation Institute

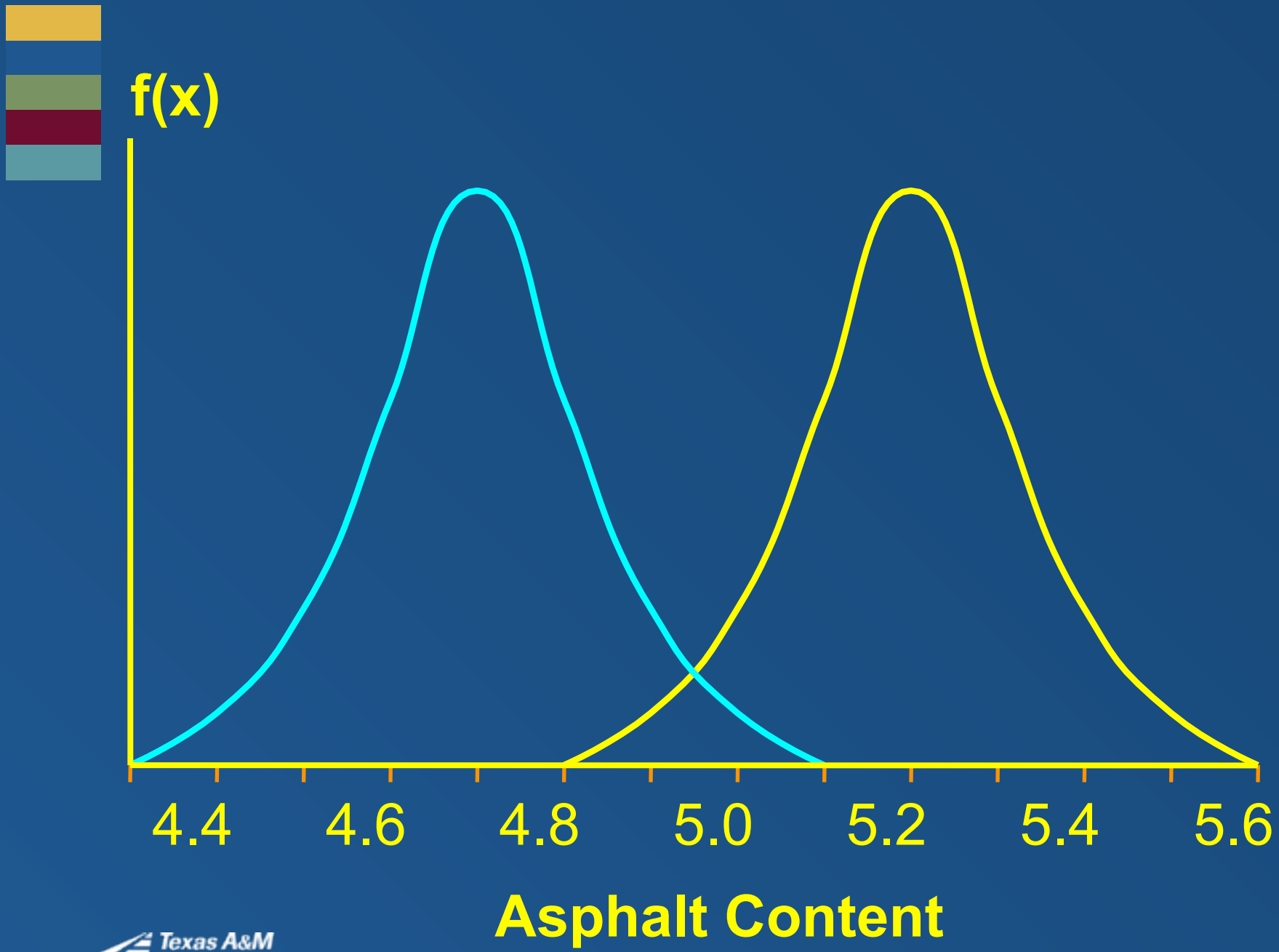
Statistical Representation of Variability

- Mean – $\bar{x}$
- Standard Deviation – s
- Coefficient of Variation - $\frac{s}{\bar{x}}$

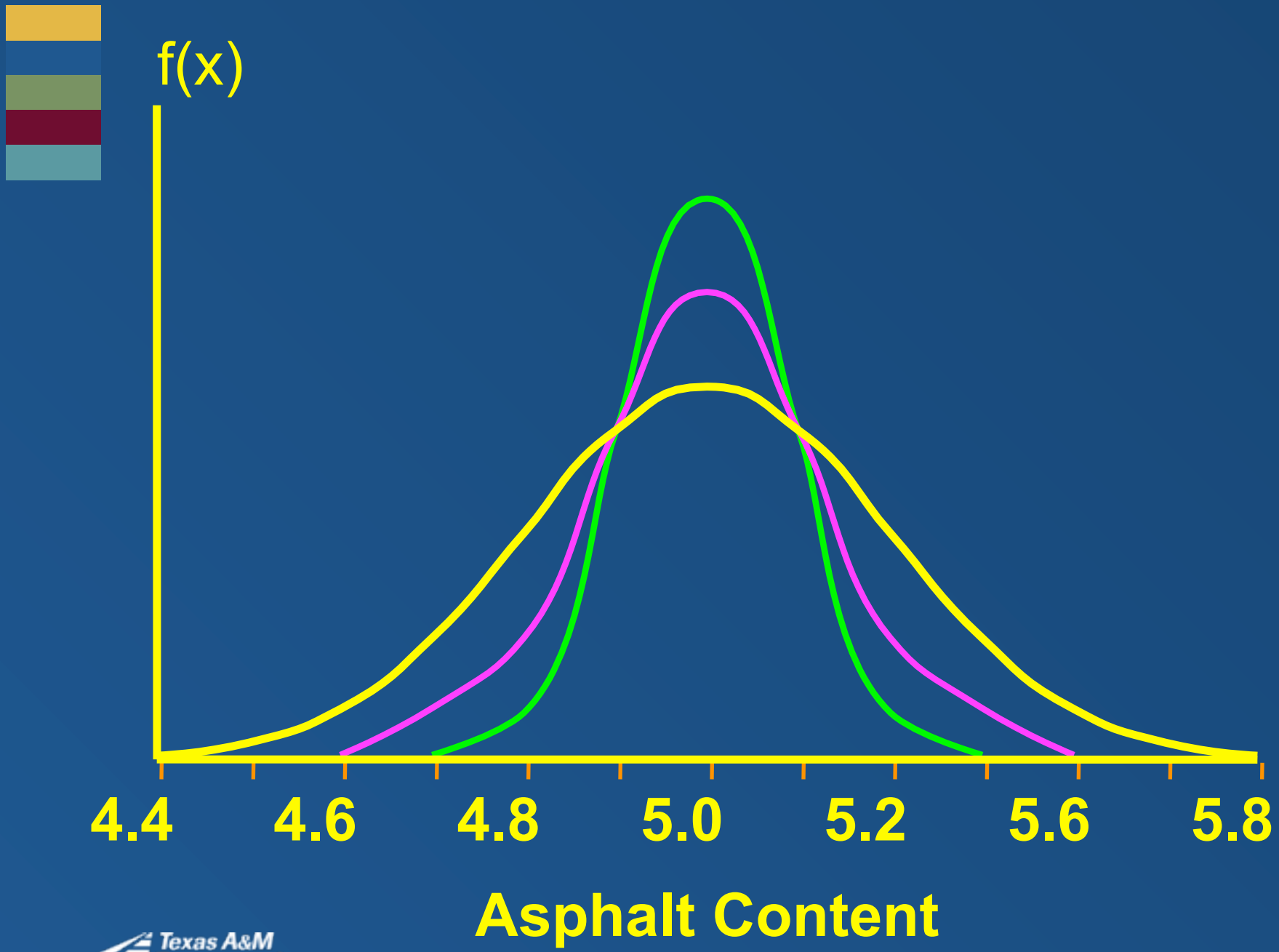
Texas A&M Transportation Institute



Texas A&M Transportation Institute



Texas A&M Transportation Institute



Texas A&M Transportation Institute

QC/QA and Variability

Variability = variability + variability + variability

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

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

Texas A&M Transportation Institute

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

Texas A&M Transportation Institute

Outline

- Introduction
- Variability
- **Sampling Variability**
- Testing Variability
- Materials/Construction Variability
- Percent within Limit
- Typical Variability

Texas A&M Transportation Institute

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%

Texas A&M Transportation Institute

Reported Test Result

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

Texas A&M Transportation Institute

Sample Size & Frequency

- Increase Sample Size & Increase Frequency (#)
  - Large Nom Max Agg Size
  - Large Mixture Variability
  - High Reliability
  - Large Effect on Performance
  - New Materials or Production
  - Non-Compliance w/Specifications

Texas A&M Transportation Institute

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

Texas A&M Transportation Institute

Lot/Sublots/ #Tests

- Lot
  - Amount of material being evaluated for payment purposes
  - Commonly defined by length of roadway or material mass
- Sublots/Lot
  - Sampling divisions within given lot
  - Commonly 4 or 5 with 1 test/sublot
- Tests/Sublot
  - Number of material tests or measurements per lot or sublot
  - Typically 1 to 5 depending on lot and sublot

Texas A&M Transportation Institute

Random Sampling

With simple random Sampling, All samples could end Up in one section of a Roadway lot

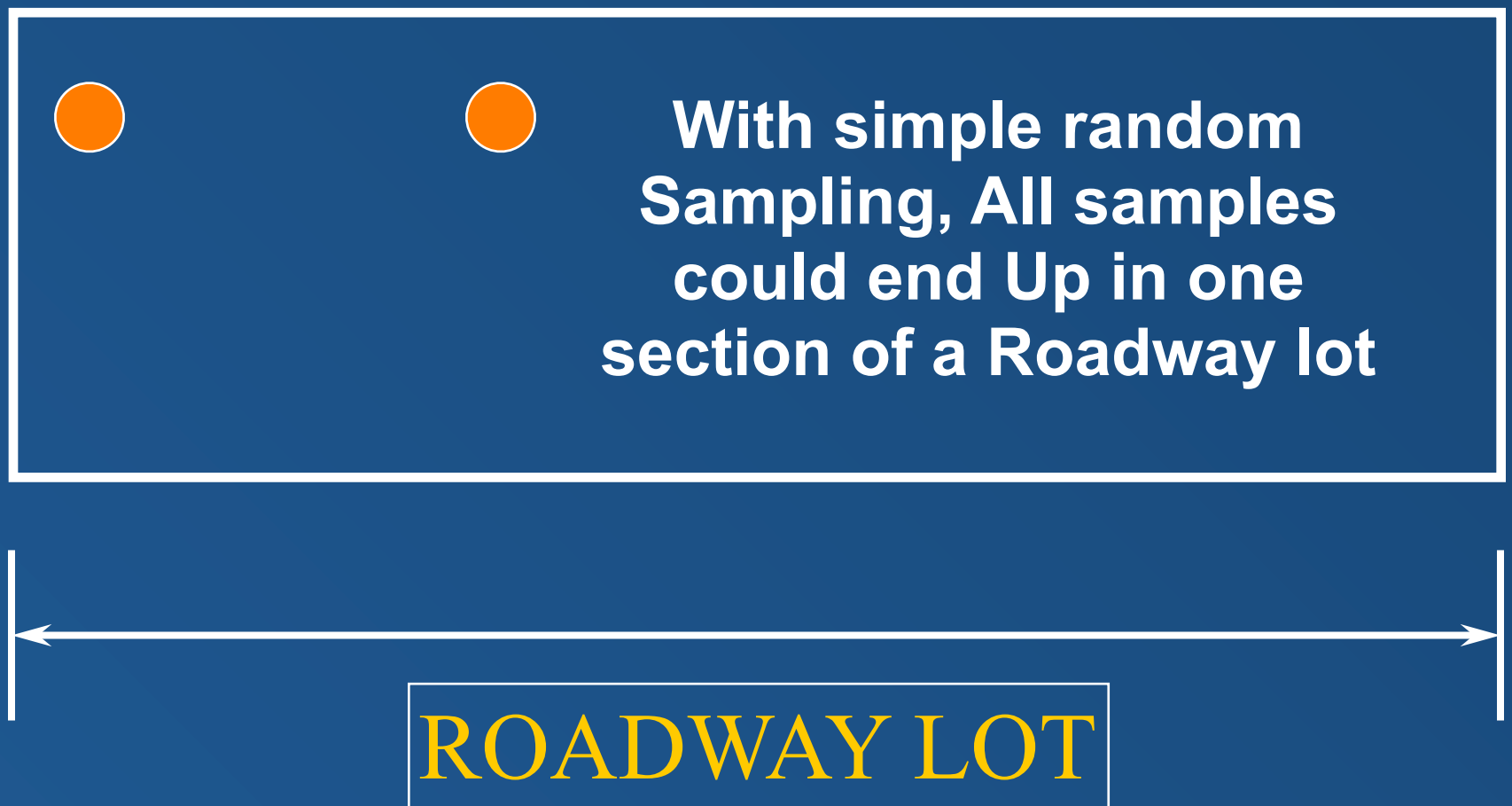
Texas A&M Transportation Institute

Random Sampling

With simple random Sampling, All samples could end Up in one section of a Roadway lot

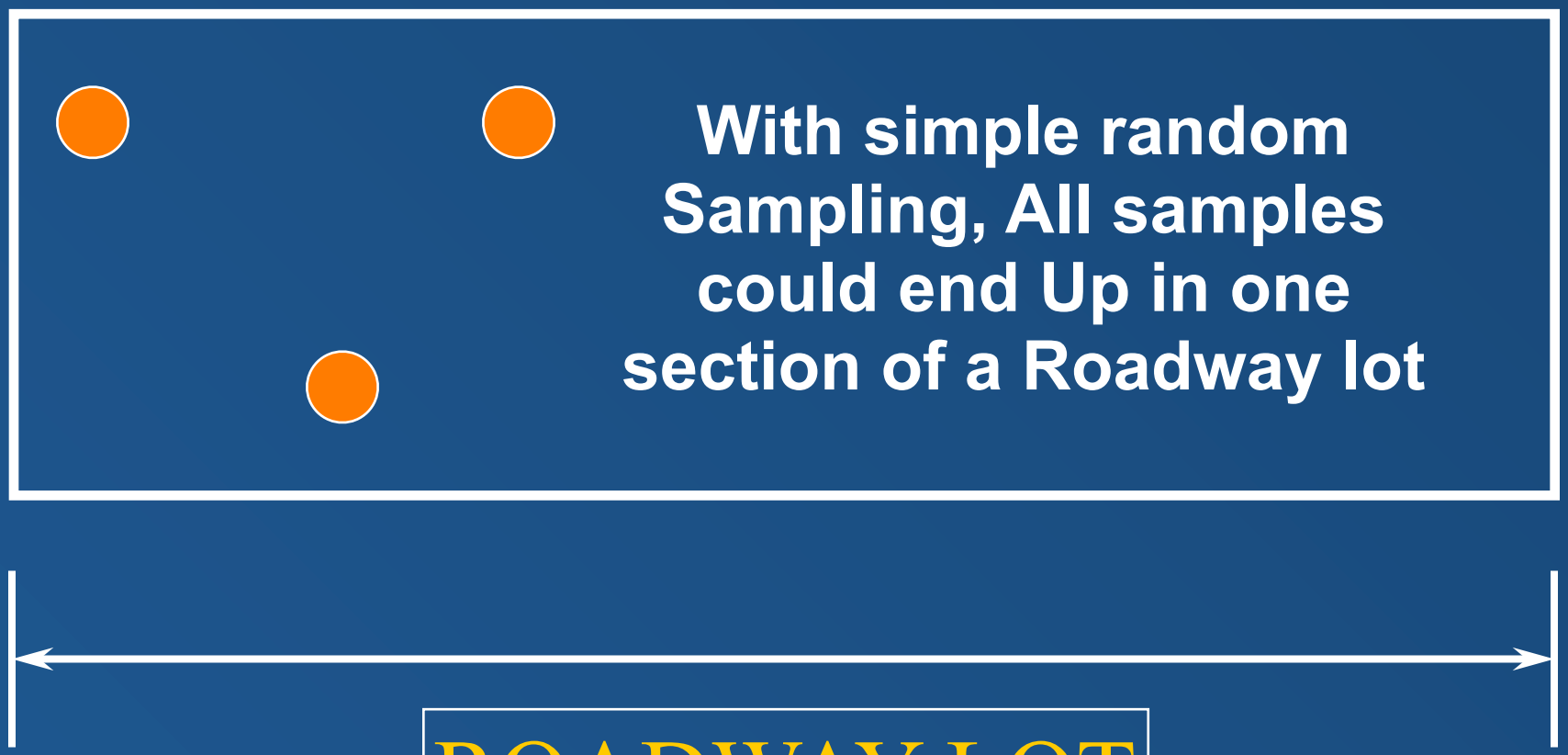
Texas A&M Transportation Institute

Random Sampling



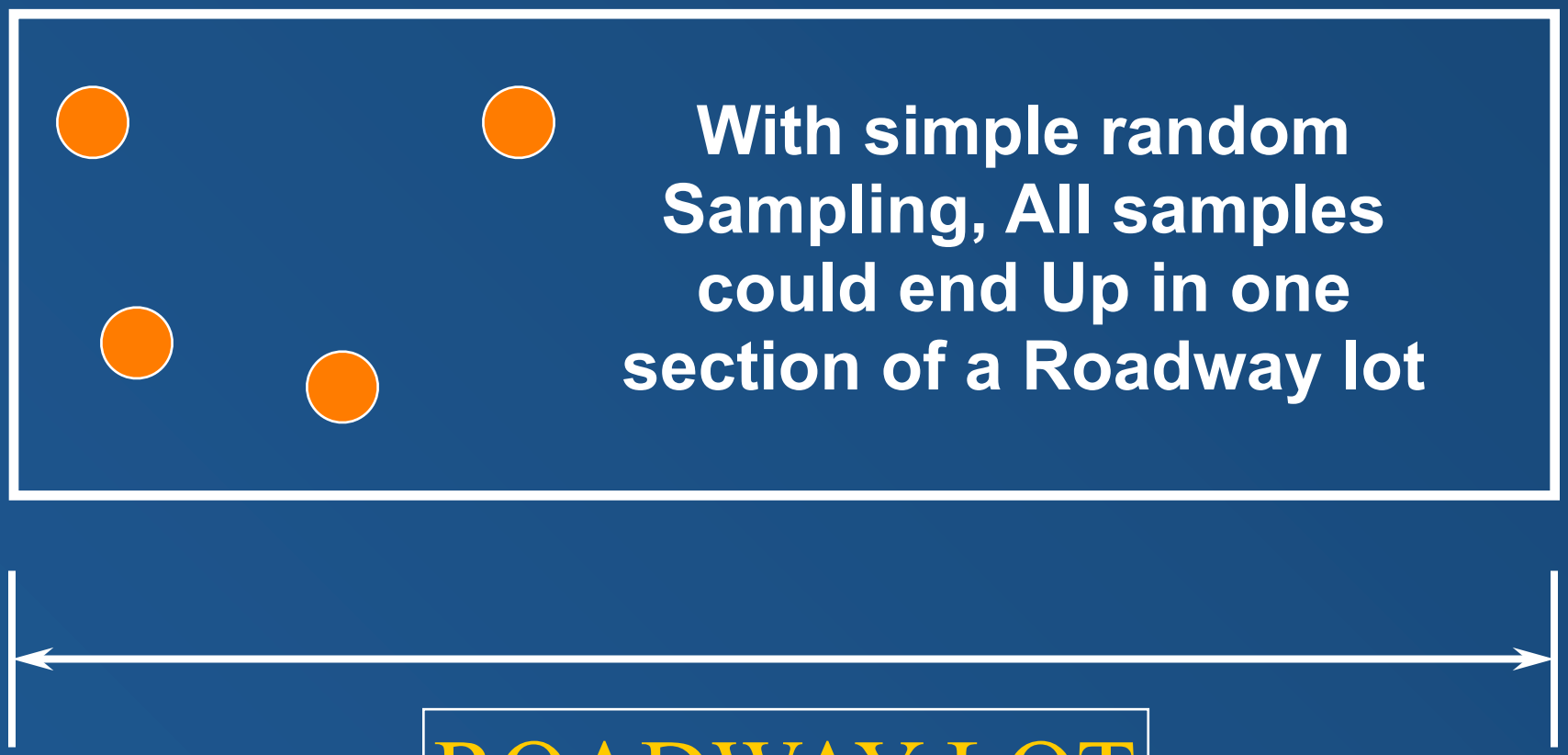
Texas A&M Transportation Institute

Random Sampling



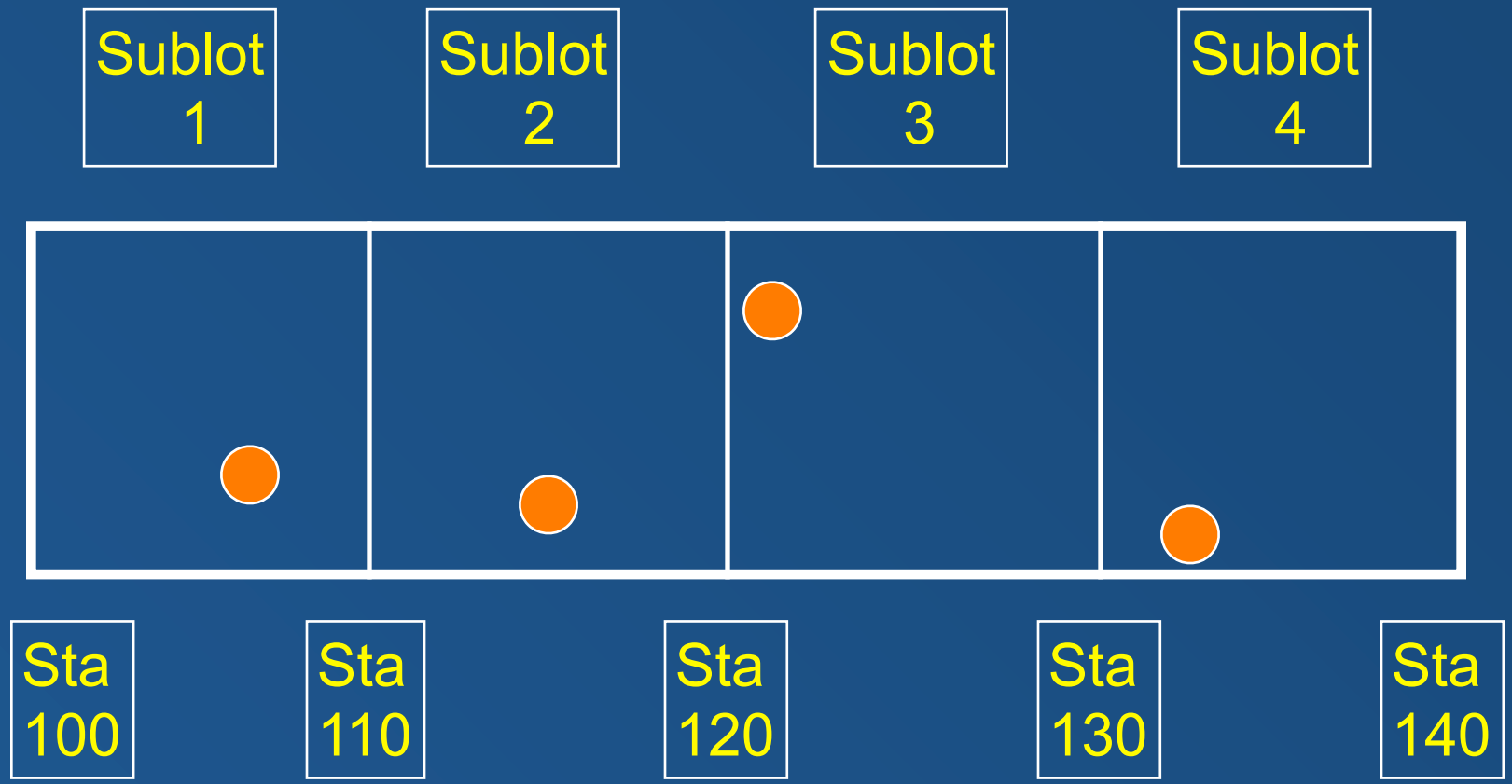
Texas A&M Transportation Institute

Random Sampling



Texas A&M Transportation Institute

Stratified Random Sampling



Texas A&M Transportation Institute

Point of Sampling

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

Texas A&M Transportation Institute

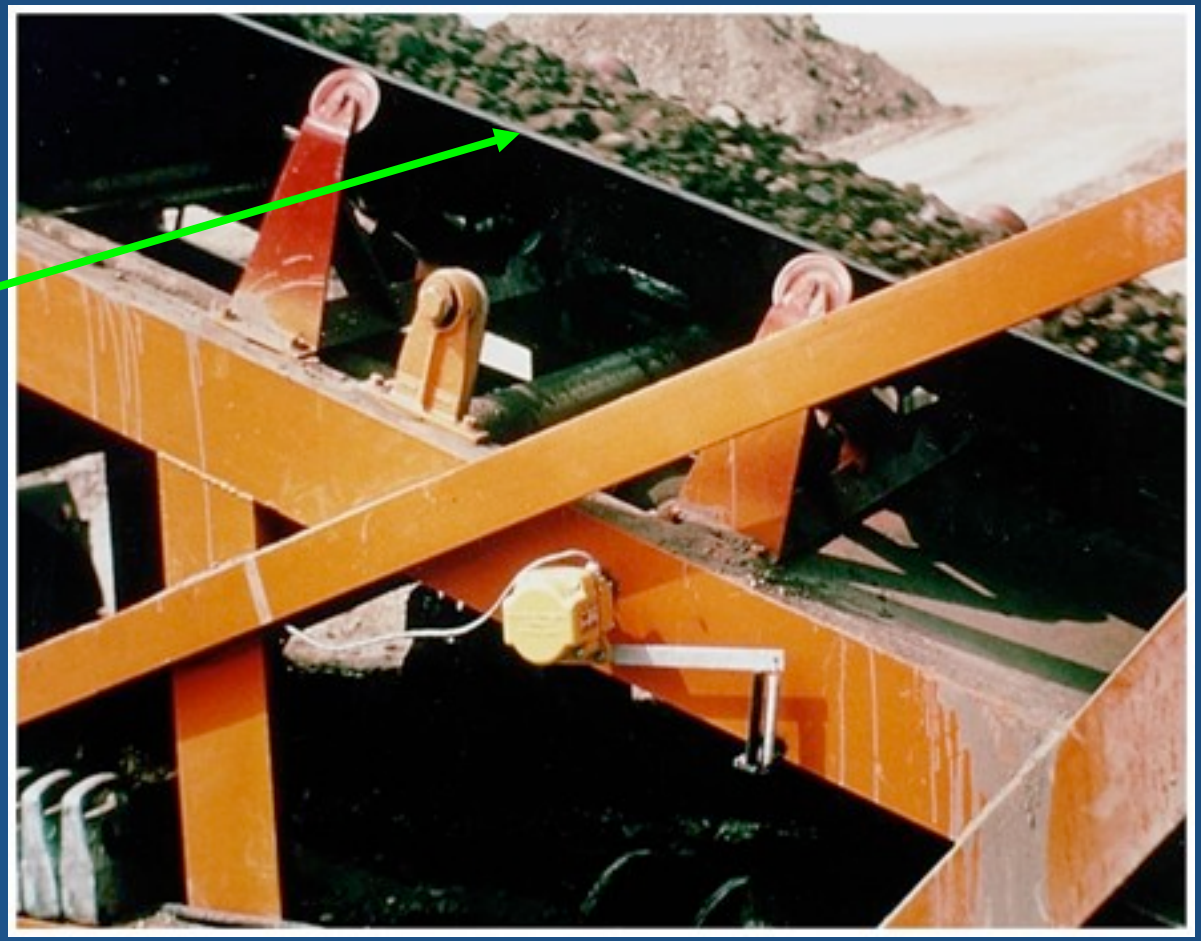
Point of Sampling

- 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),

Texas A&M Transportation Institute

Cold Feed Sampling

Cold Feed "Belt Cuts" are taken from the collector belt enroute to the dryer drum



Texas A&M Transportation Institute

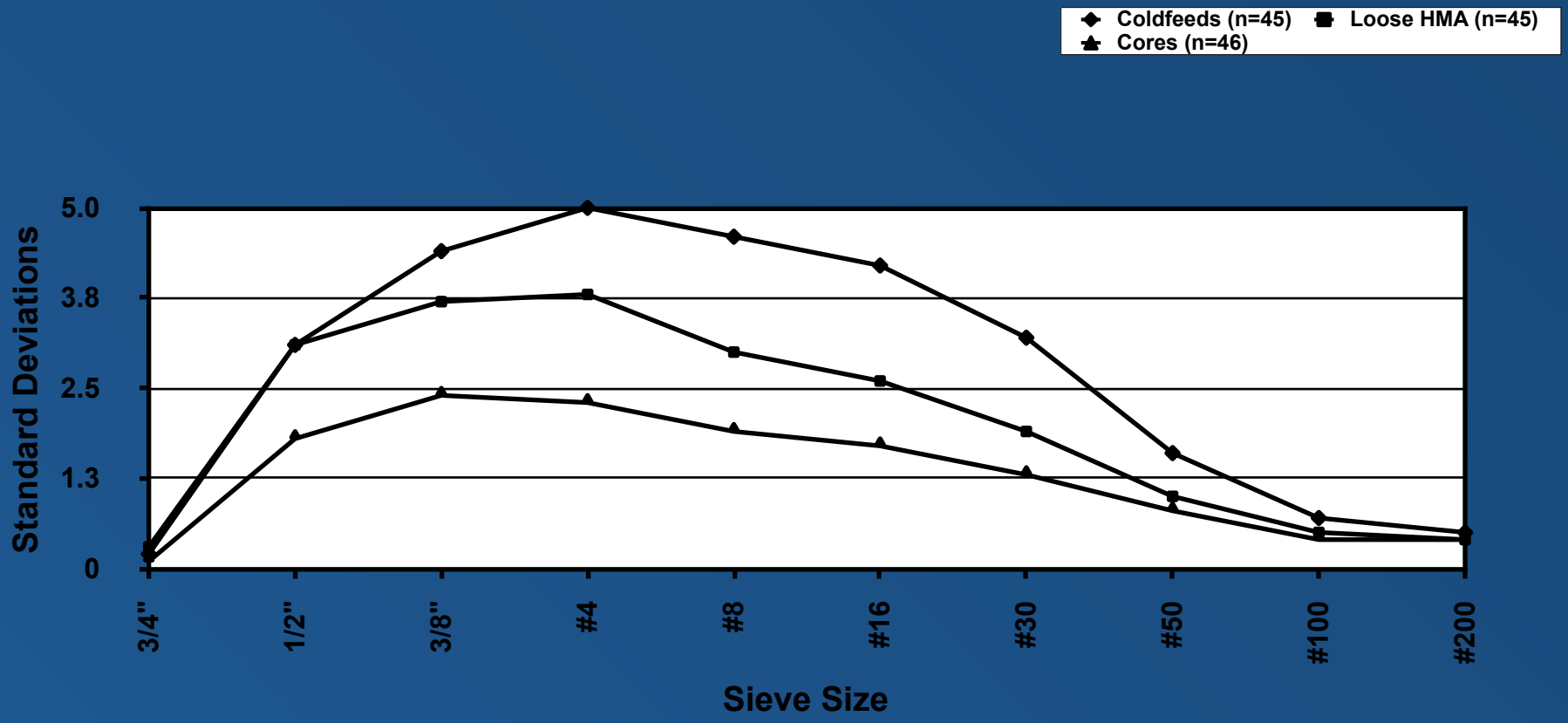
Truck

Texas A&M Transportation Institute

Loose Mat Sampling

Texas A&M Transportation Institute

Effect of Sampling Location on Gradation Variability



Texas A&M Transportation Institute

Point of Sampling

- In-Place Density
  - Compacted Mat
- Thickness
  - Compacted Mat
- Smoothness
  - Longitudinal Profile or Index

Texas A&M Transportation Institute

Sample Splitting

Coarse @ 3.79%ac Fine
@ 5.21%ac

Texas A&M Transportation Institute

Outline

- Introduction
- Variability
- Sampling Variability
- **Testing Variability**
- Materials/Construction Variability
- Percent within Limit
- Typical Variability

Texas A&M Transportation Institute

Test or Measurement Method

- Must be suitable for Field Applications
  - Inexpensive, easy set-up (mobile), relative insensitive to environment, easy to analyze data
- Understand Associated Variability!
- Specification Tolerances = f(Variability)

Texas A&M Transportation Institute

Mix Design Volumetric

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

Texas A&M Transportation Institute

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

Texas A&M Transportation Institute

Properties Calculated Mixture Properties are Function of

Calculated Property	Variables the Property is a Function of
Gsb	P, Gsb
Gse	Pmm, Pb, Gmm, Gb
Gmm	Pmm, Ps, Gse, Pb
Pba	Gb, Gse, Gsb
Pbe	Pb, Pba, Ps
AV	Gmb, Gmm
VMA	Gmb, Gsb, Ps
VFA	VMA, AV
$\%Gmm_i$	Gmb, Gmm
$\%Gmm_m$	Gmb, Gmm
DP	p0.075, Pbe

Texas A&M Transportation Institute

Question ?

What are the combined 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

Texas A&M Transportation Institute

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

Texas A&M Transportation Institute

Test Method Precision and

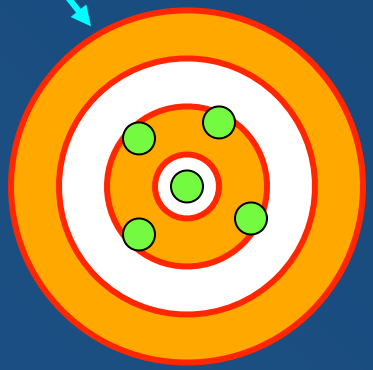
- Precision Statements Account for Inherent Test Method Variability (uncontrollable random error)
- Single-operator, within lab, repeatability
- Multilaboratory, between lab, reproducibility
- One-Sigma Limits (standard deviation, σ, 1S)

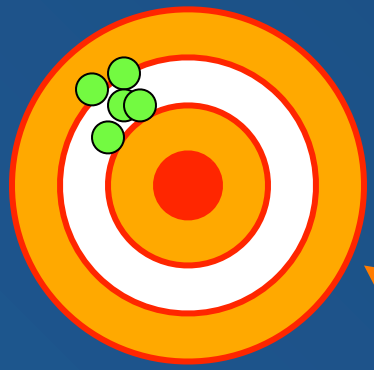
Texas A&M Transportation Institute

Precision and Bias

Precise
Not Bias

Not Precise
Not Bias

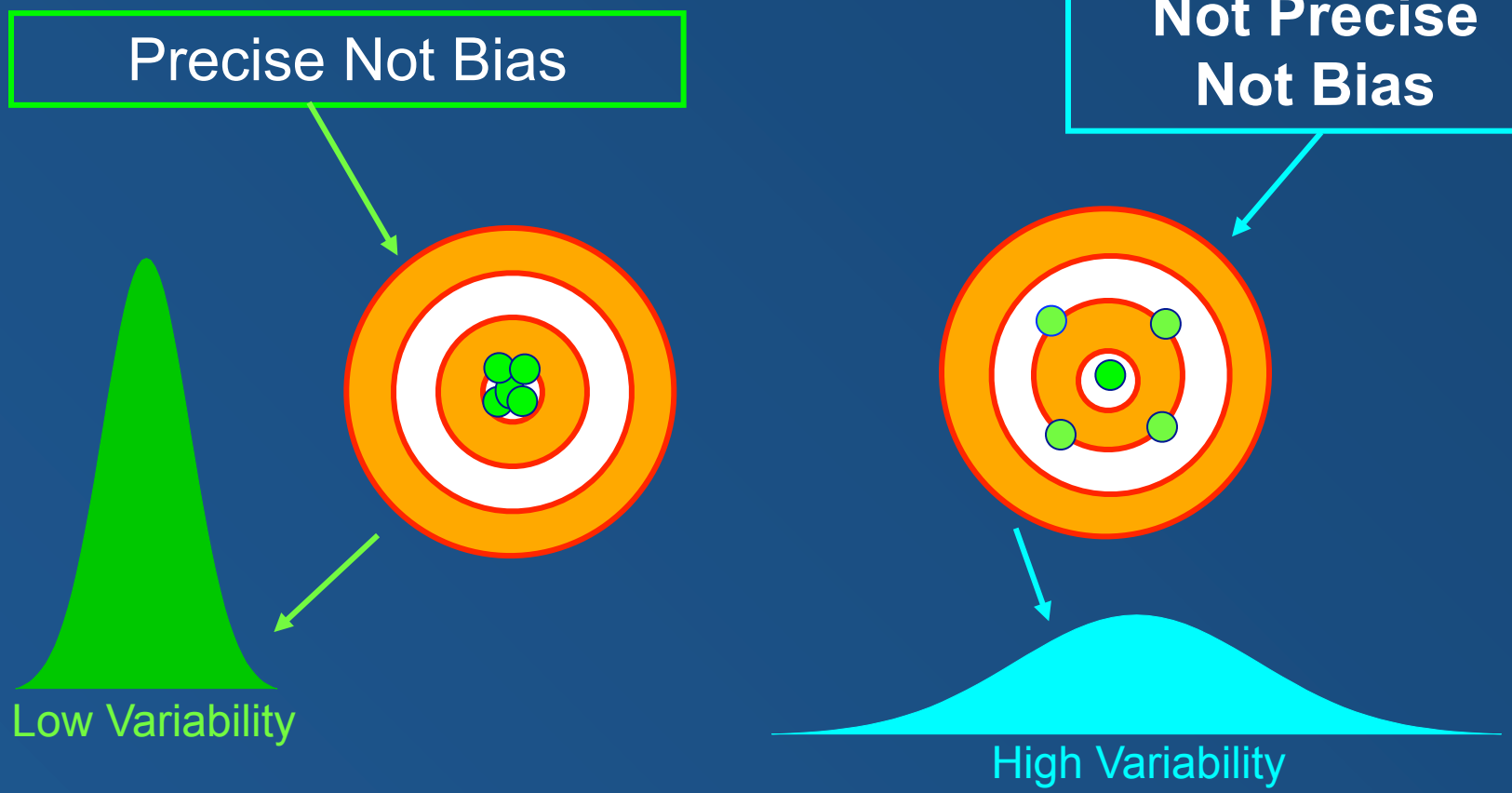




Precise, Biased

Texas A&M Transportation Institute

Precision and Bias



Precision Statements are Based on Interlaboratory Studies

Texas A&M Transportation Institute

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			
			Standard Deviation (1S)		Acceptable Range of Two Results (D2S)	
AASHTO Method	ASTM Method		AASHTO	ASTM	AASHTO	ASTM
T228	D70	Asphalt Cement Specific	0.0024	0.0024	0.0068	0.0068
T85	C127	Coarse Aggregate Specific	0.013	0.013	0.038	0.038
T84	C128	Fine Aggregate Specific	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.”

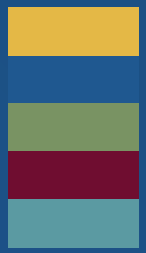
( ) - supplemental procedure for mixtures containing porous aggregate conditions (“dryback procedure”).

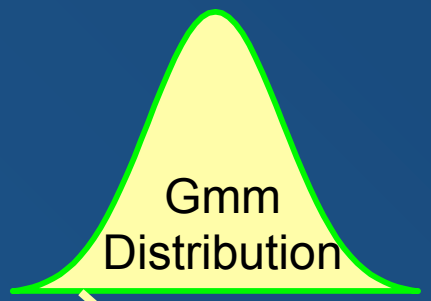
Monte Carlo Simulation Process

- 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

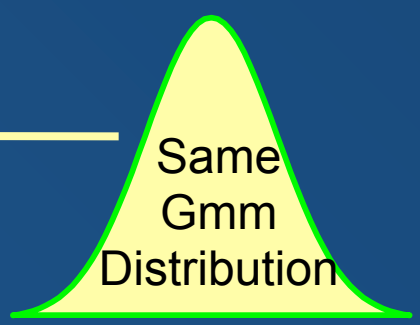
Texas A&M Transportation Institute

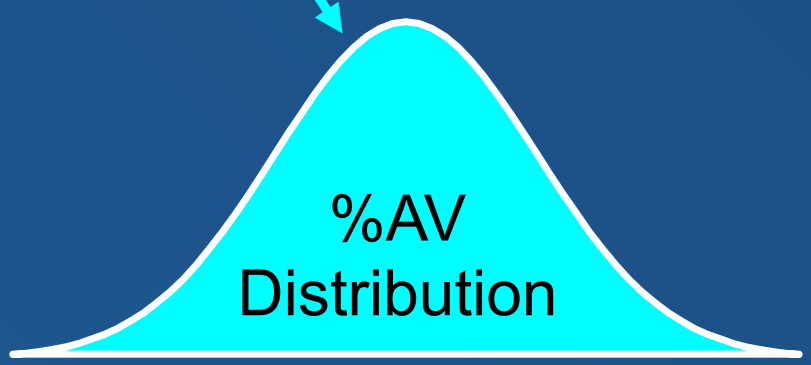
Monte Carlo Simulation





$$\%AV = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}}$$



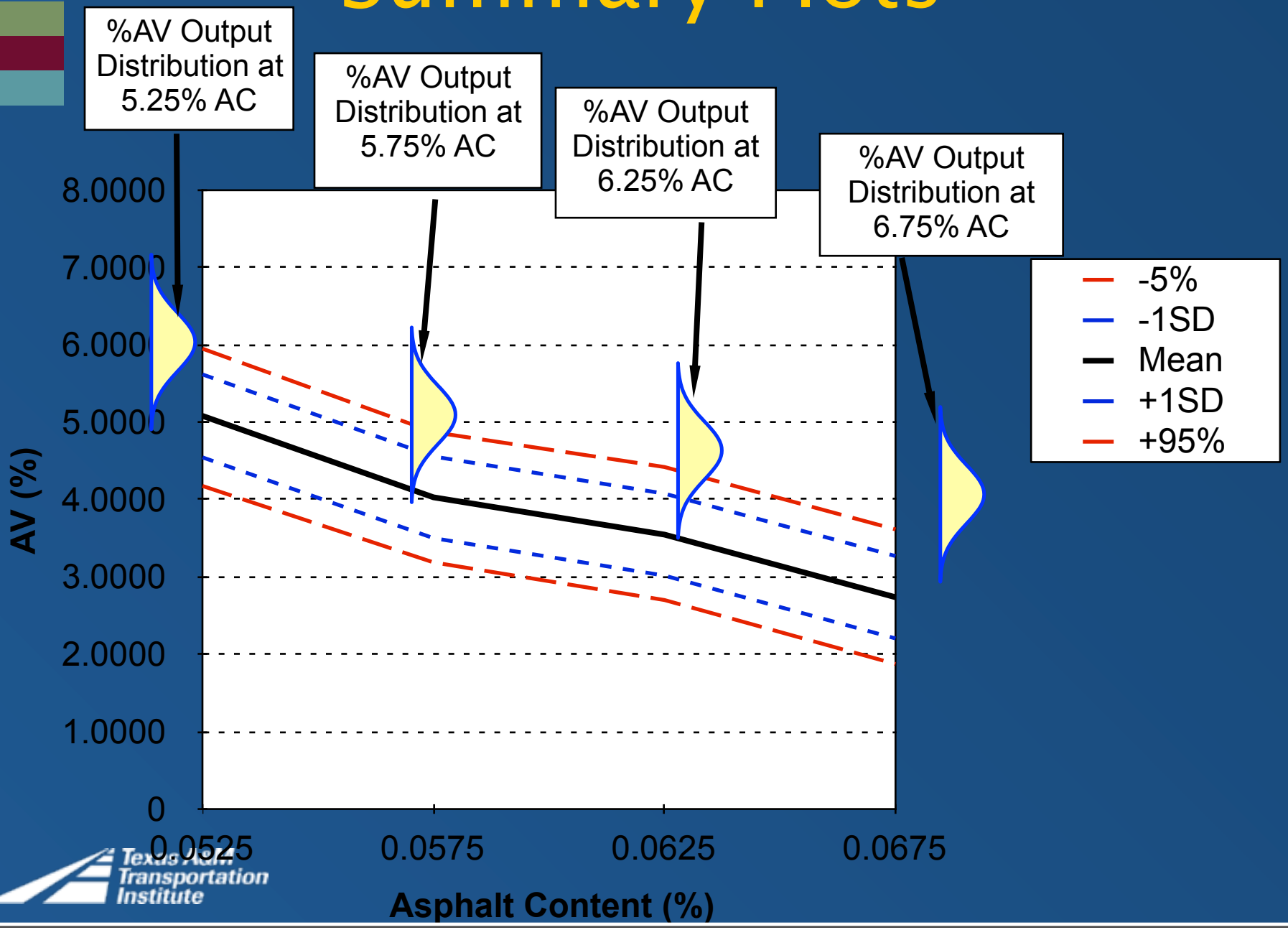


G_{mm} and G_{mb} =inputs

%AV = output

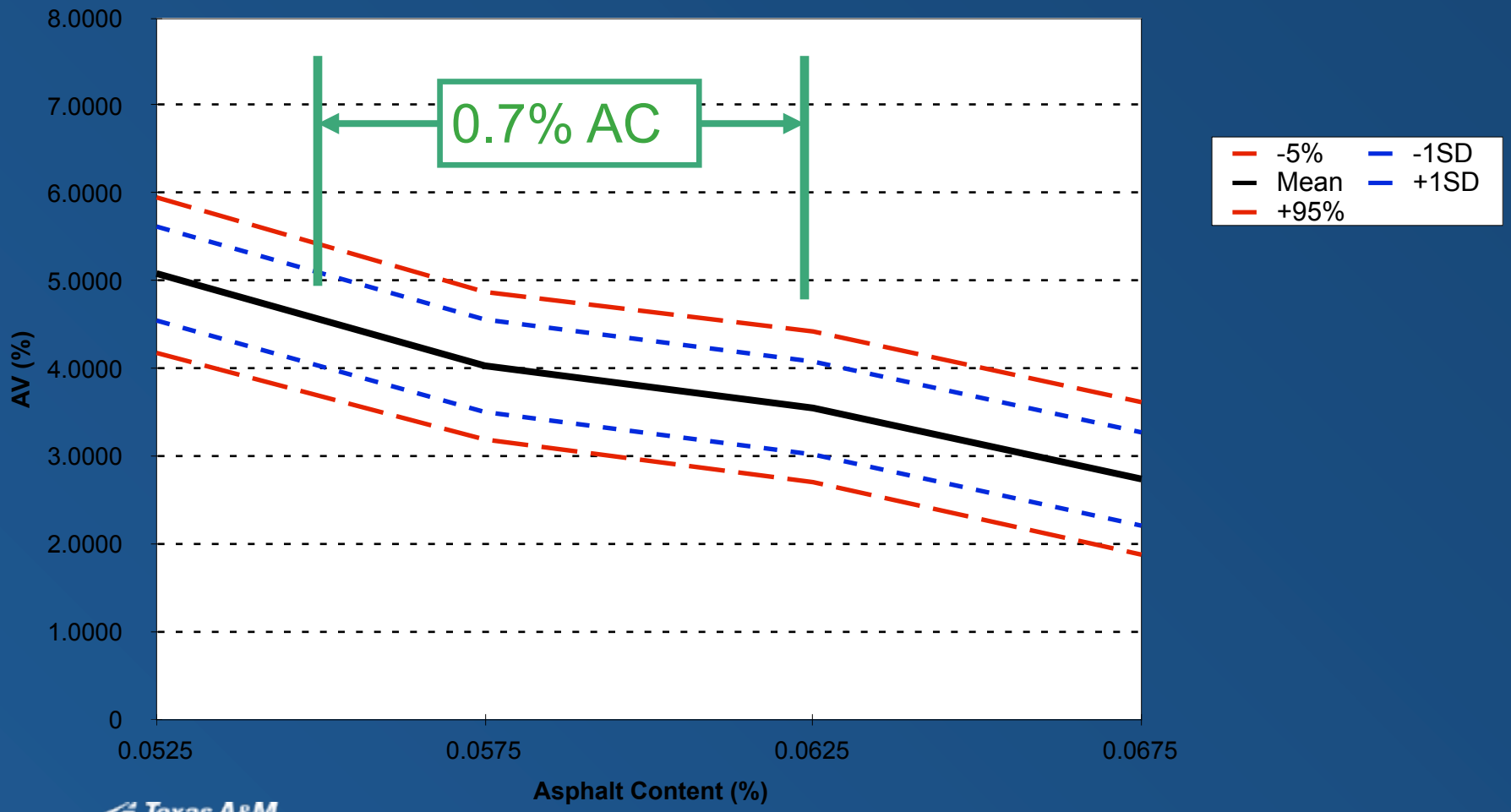
Texas A&M Transportation Institute

Summary Plots



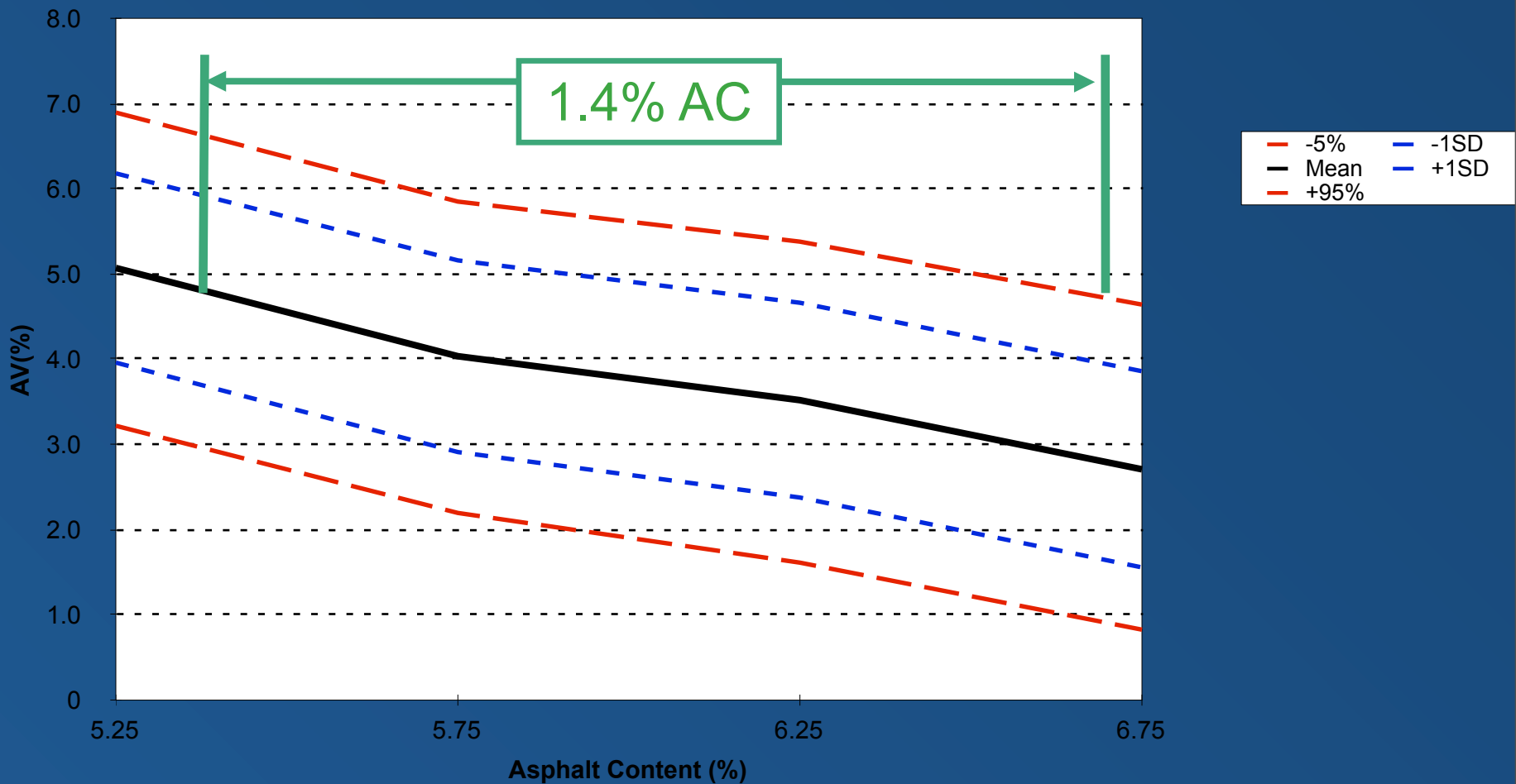
Texas A&M Transportation Institute

Within Laboratory Air Voids



Texas A&M Transportation Institute

Between Laboratory Air Voids



Texas A&M Transportation Institute

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

Texas A&M Transportation Institute

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

Texas A&M Transportation Institute

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

Texas A&M Transportation Institute

Outline

- Introduction
- Variability
- Sampling Variability
- Testing Variability
- **Materials/Construction Variability**
- Percent within Limit

Texas A&M Transportation Institute


HYPAC

Outline

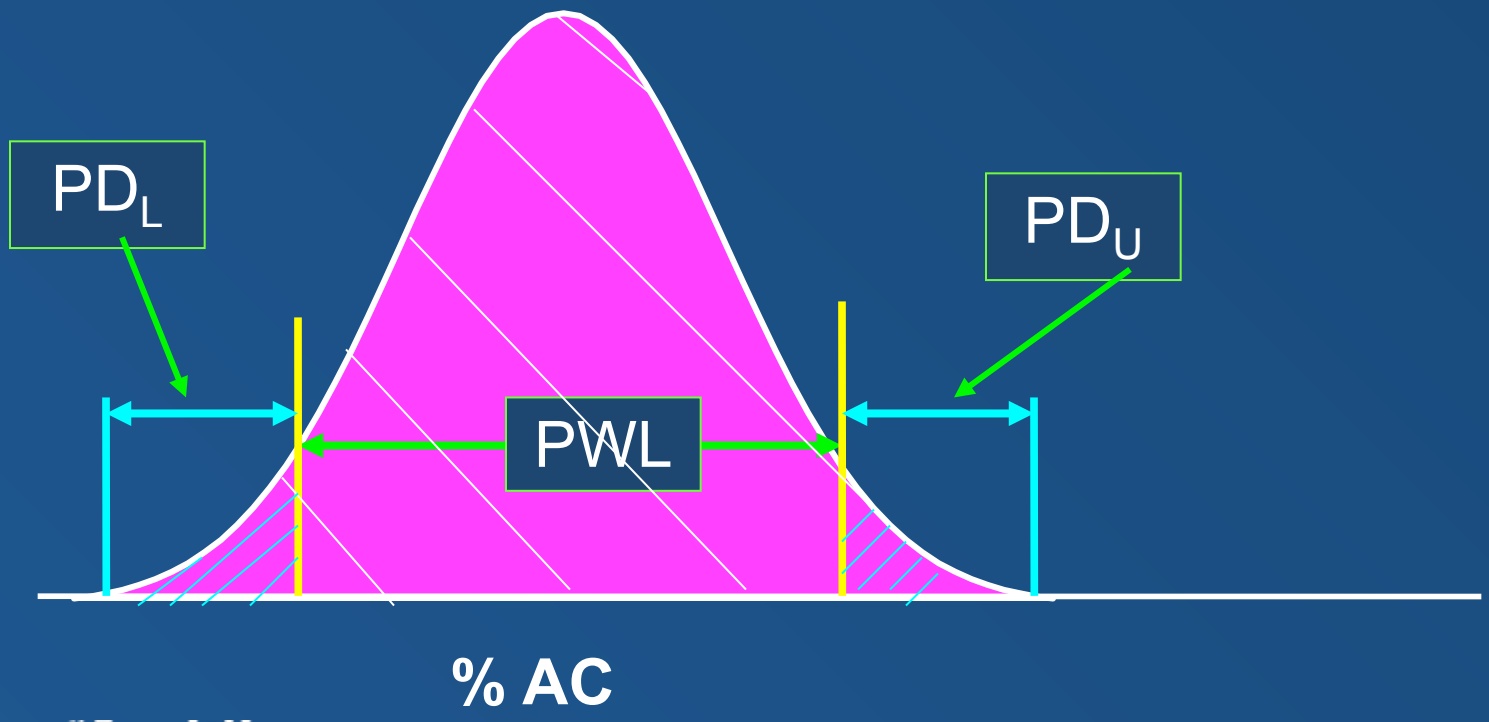
- Introduction
- Variability
- Sampling Variability
- Testing Variability
- Materials/Construction Variability
- **Percent within Limit**
- Typical Variability

Texas A&M Transportation Institute

PWL and PD Concept

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

In Terms of Area of the Distribution

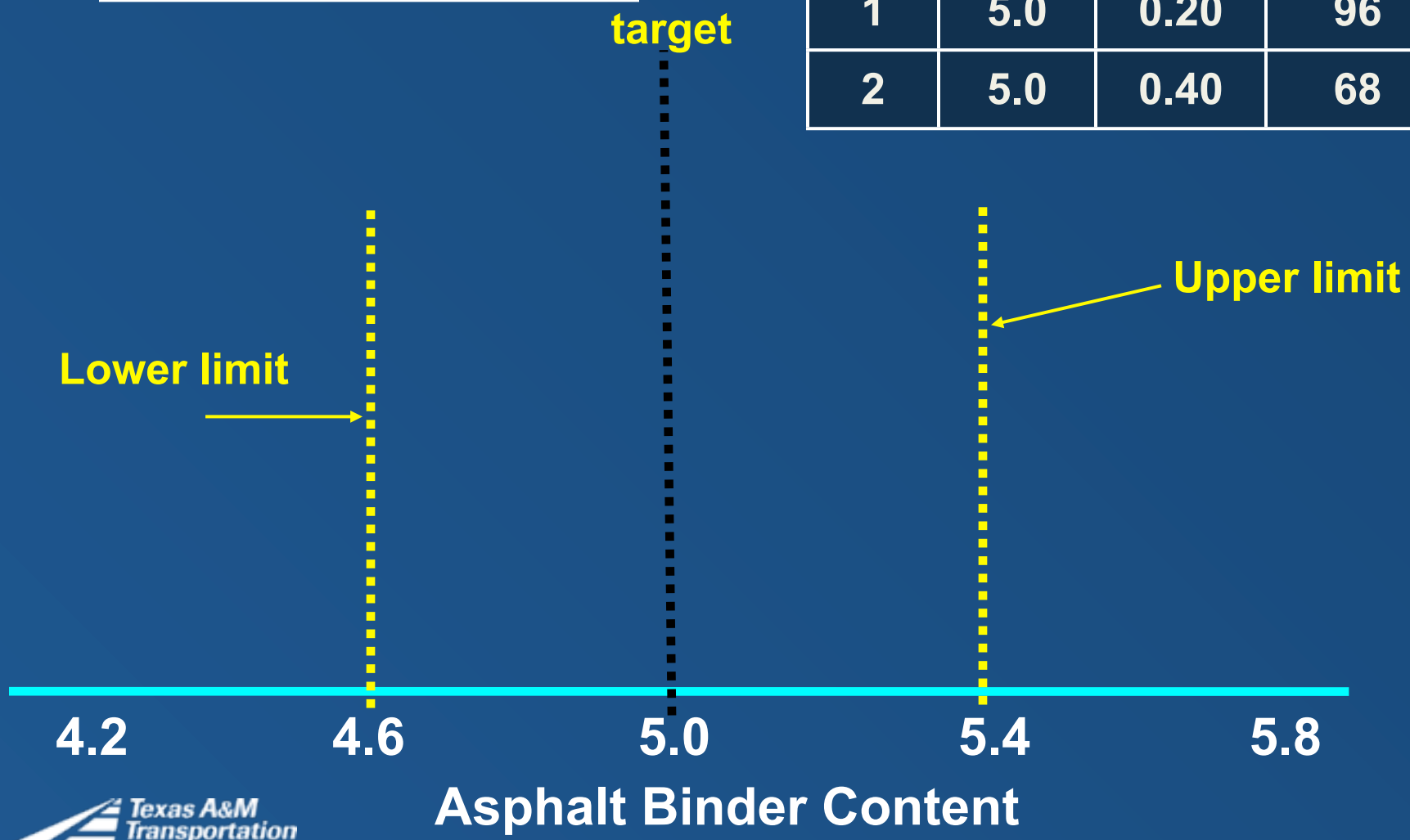


Texas A&M Transportation Institute

Percent Within Limits

Spec	
Target Value	5.0
Limits	± 0.4

	Data		
Lot	X	s	PWL
1	5.0	0.20	96
2	5.0	0.40	68

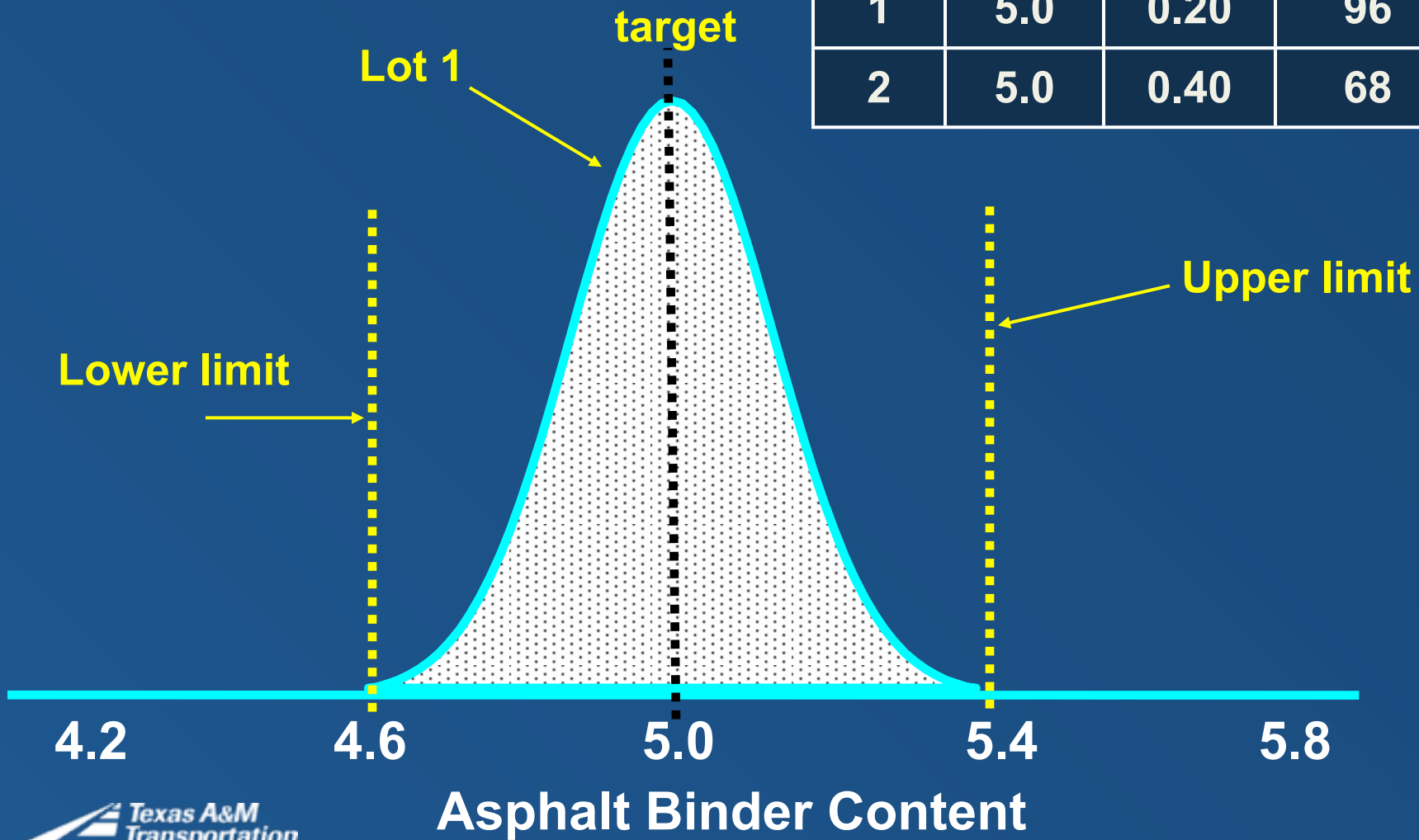


Texas A&M Transportation Institute

Percent Within Limits

Spec	
Target Value	5.0
Limits	± 0.4

Data			
Lot	X	s	PWL
1	5.0	0.20	96
2	5.0	0.40	68

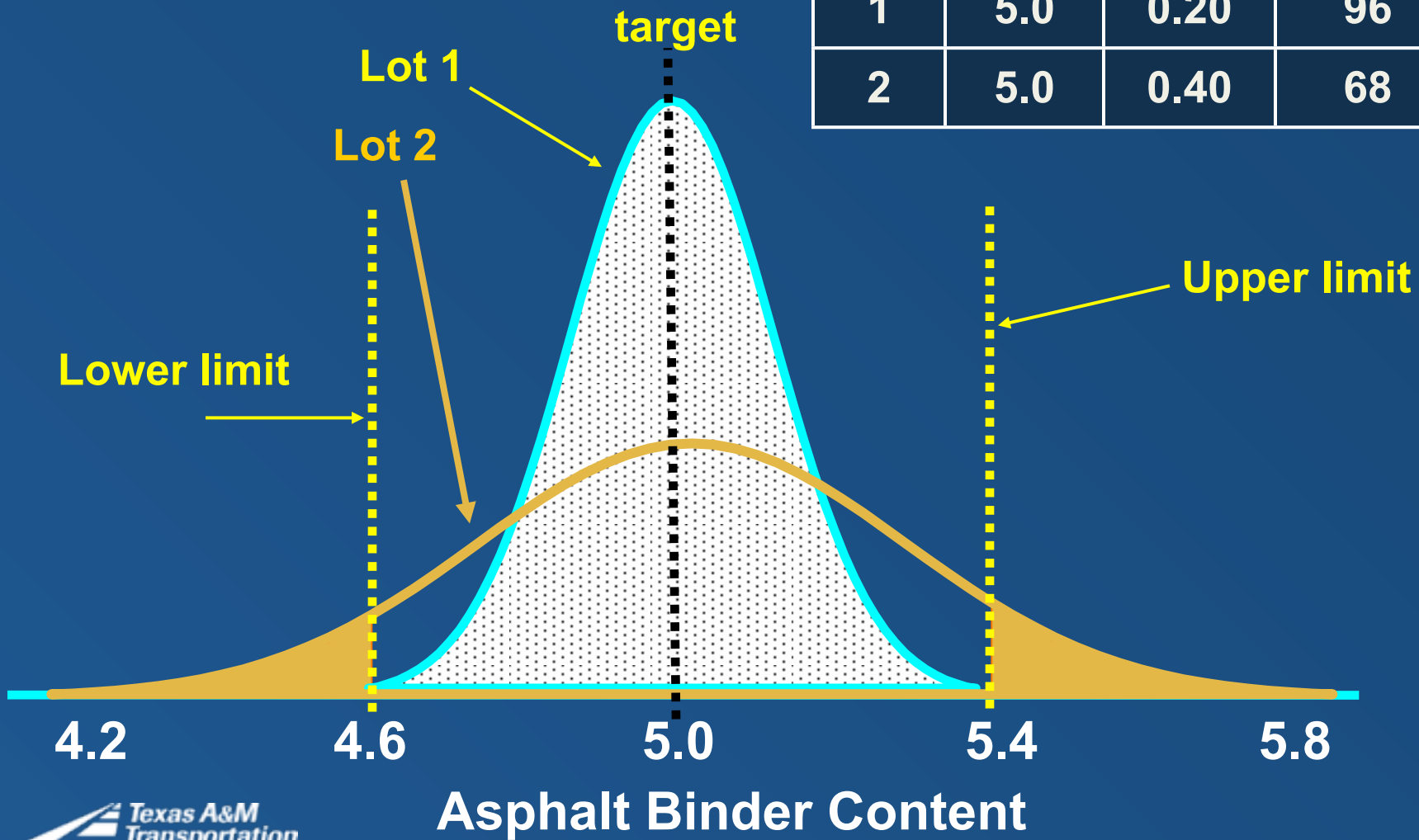


Texas A&M Transportation Institute

Percent Within Limits

Spec	
Target Value	5.0
Limits	± 0.4

	Data		
Lot	X	s	PWL
1	5.0	0.20	96
2	5.0	0.40	68

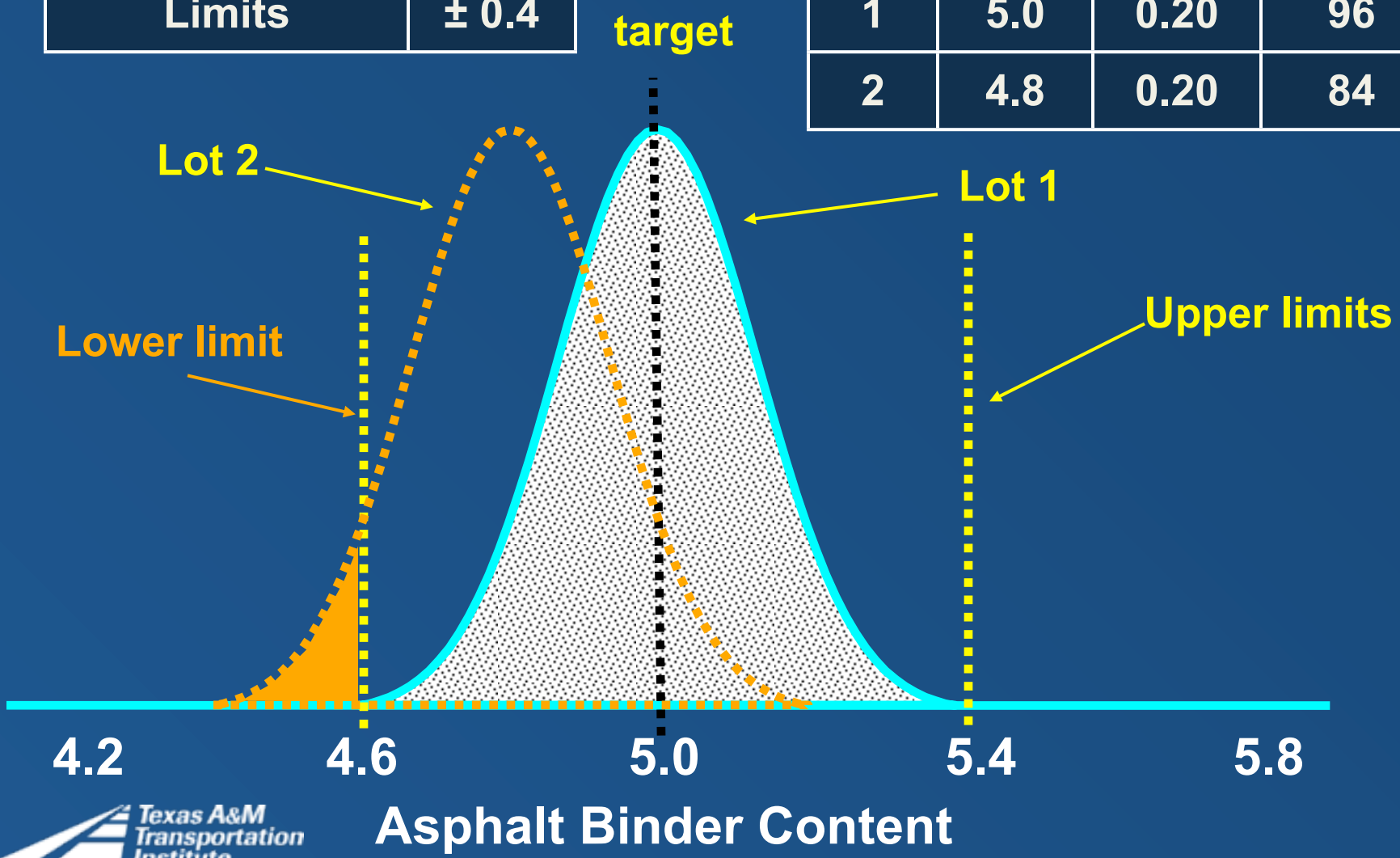


Texas A&M Transportation Institute

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



Texas A&M Transportation Institute

Outline

- Introduction
- Variability
- Sampling Variability
- Testing Variability
- Materials/Construction Variability
- Percent within Limit
- **Typical Variability**

Texas A&M Transportation Institute

Typical Variability

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

Texas A&M Transportation Institute

Outline

- Introduction
- Variability
- Sampling Variability
- Testing Variability
- Materials/Construction Variability
- Percent within Limit
- Typical Variability
- **Summary**

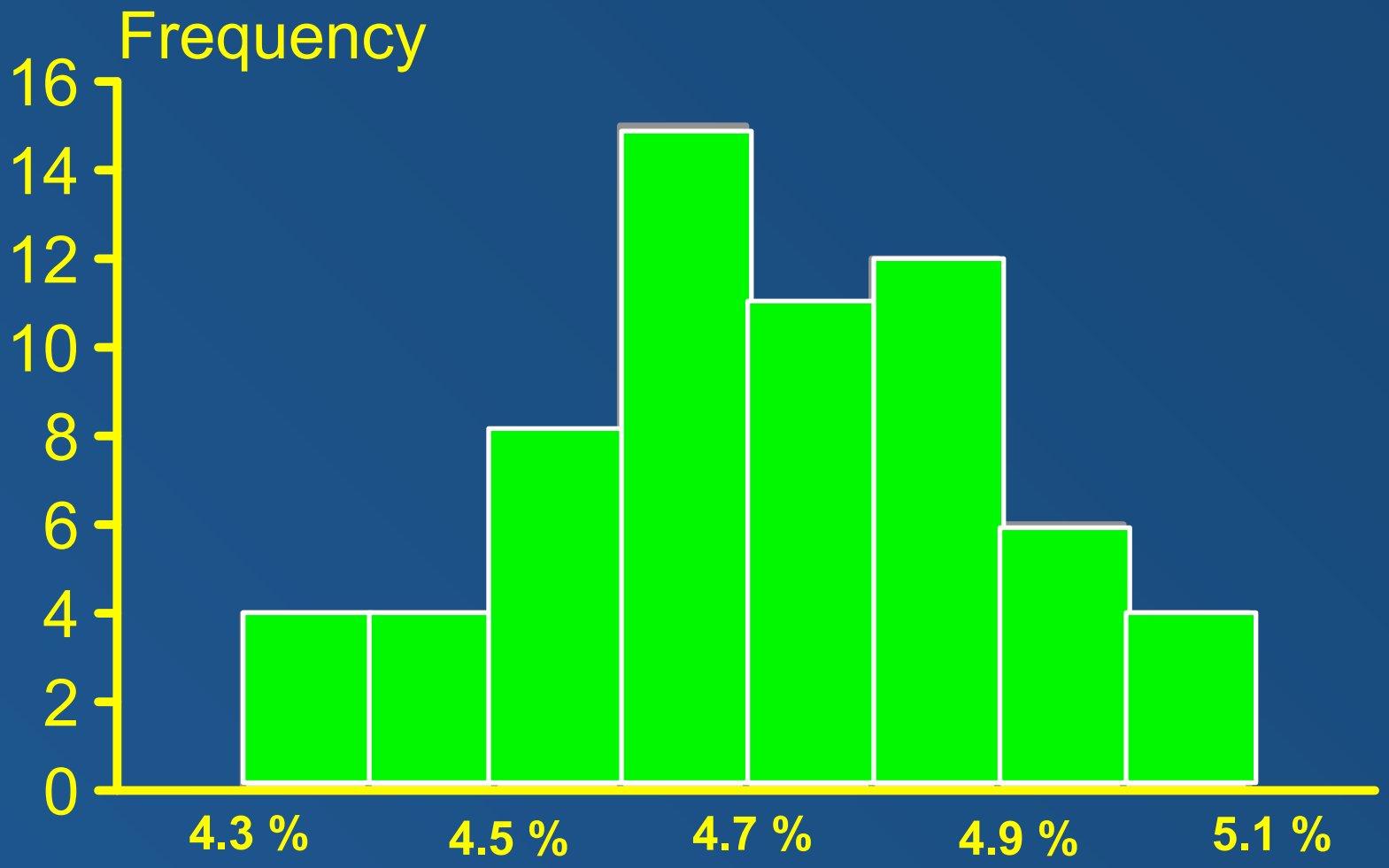
Texas A&M Transportation Institute

Why Understand Testing Variability

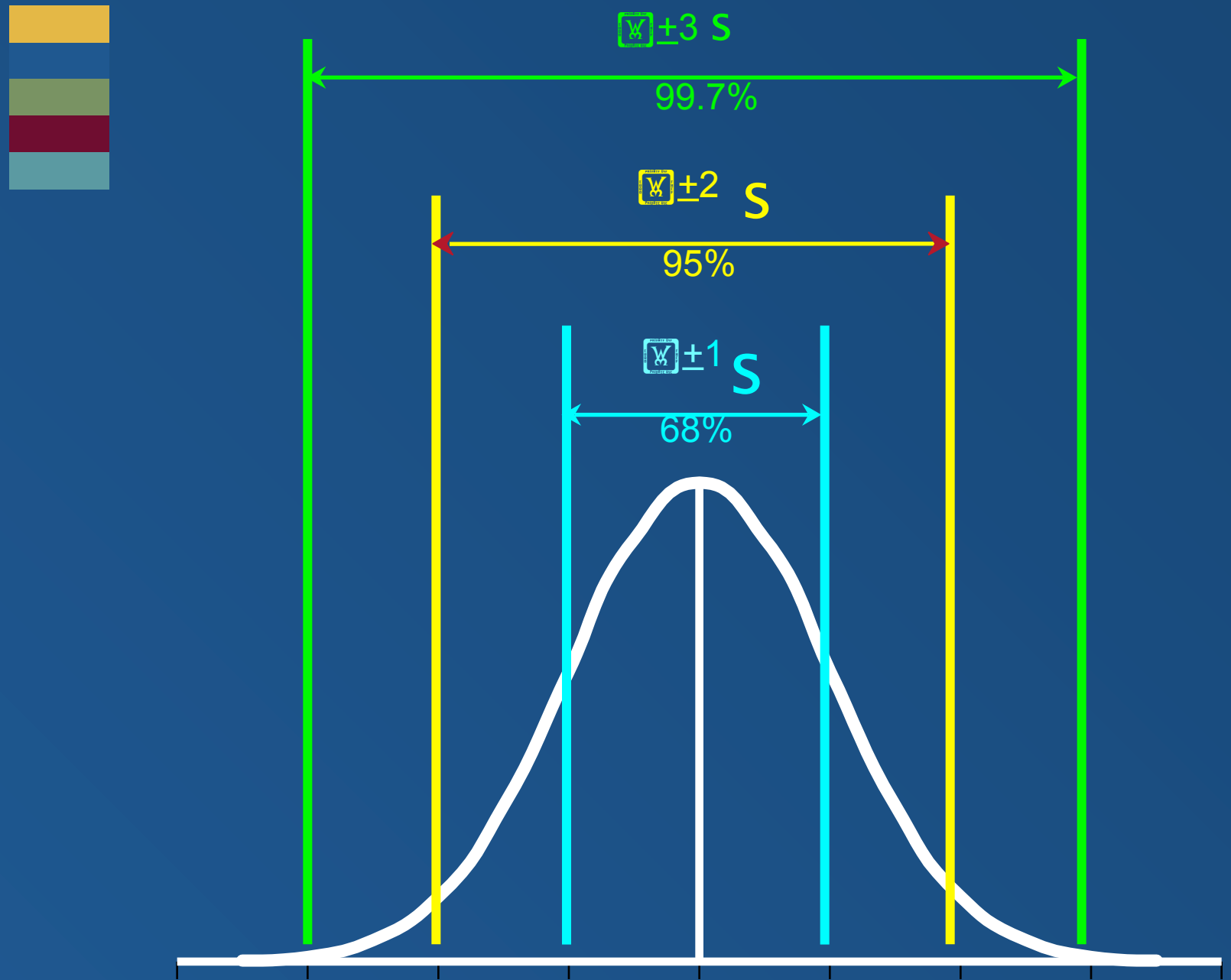
- Provide quality product to our customer
- Remain in business
- Establish specification limits
- Predict pay factors

Texas A&M Transportation Institute

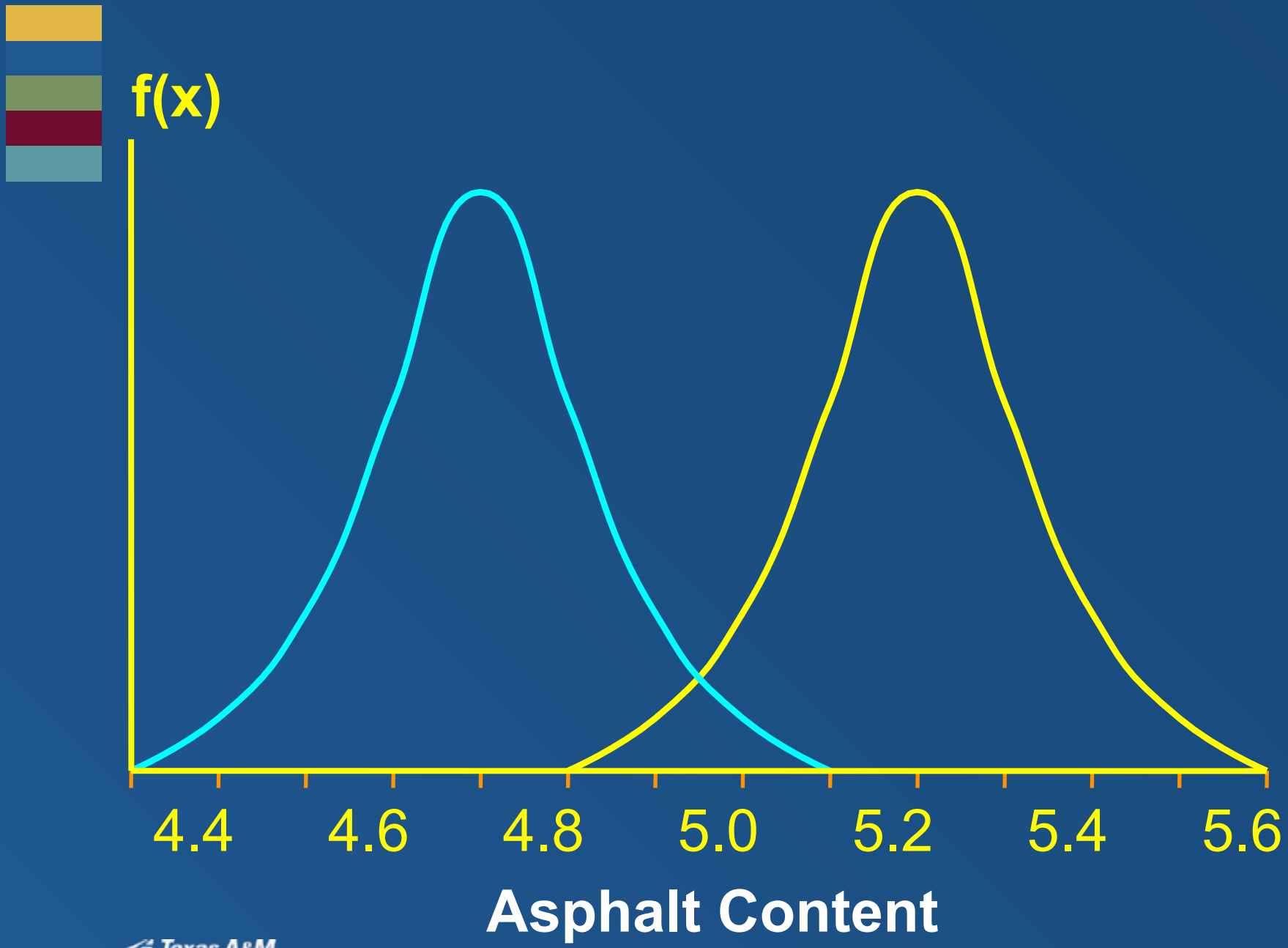
60 Asphalt Binder Contents



Texas A&M Transportation Institute



Texas A&M Transportation Institute



Texas A&M Transportation Institute

QC/QA and Variability

Variability = variability + variability + variability

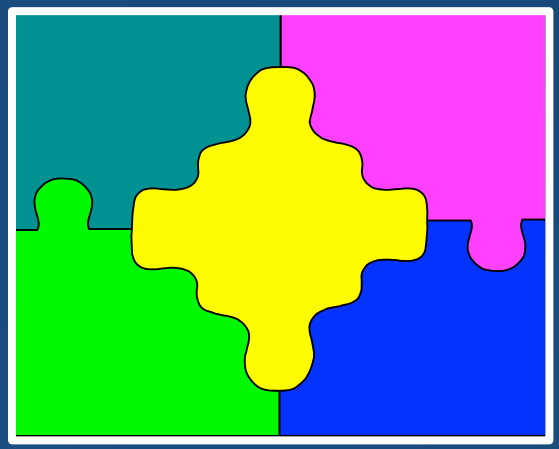
(QC/QA) (sampling) (test method) (mat./const.)

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

Texas A&M Transportation Institute

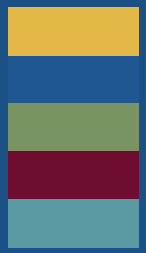
Sampling

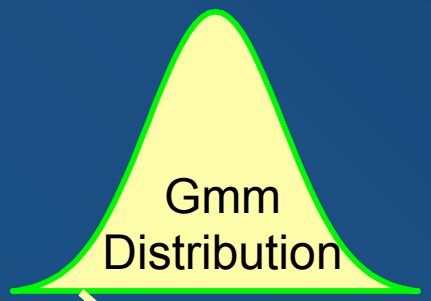
- Number of Samples and Size
- Sampling Location
  - Random
  - *Stratified Random
  - Systematic – uniform interval
  - Quota – @ change in process
  - Judgment
- Sampling Method
- Acceptance OR Source Approval OR QC OR Independent Assurance/Verification of Test Procedures



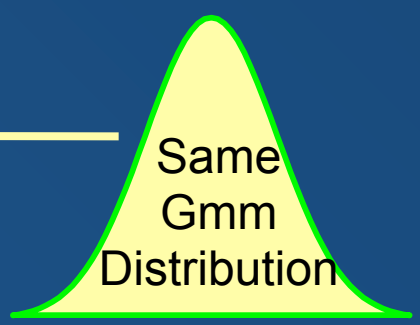
Texas A&M Transportation Institute

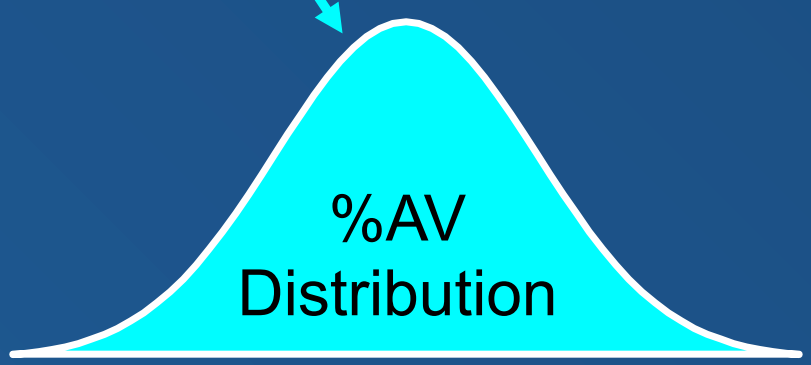
Monte Carlo Simulation





$$\%AV = 100 \times \frac{G_{mm} - G_{mb}}{G_{mm}}$$





G_{mm} and G_{mb} =inputs

%AV = output

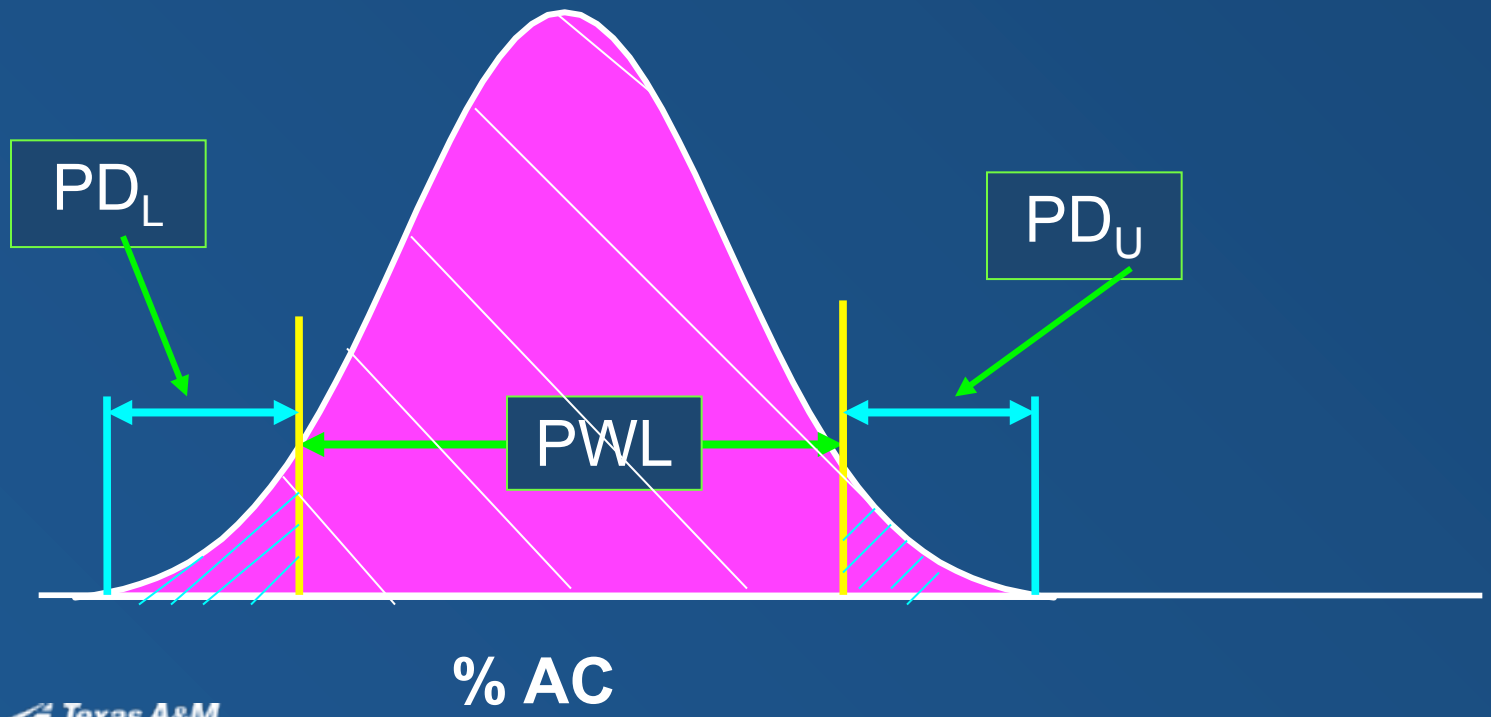
Texas A&M Transportation Institute


HYPAC

PWL and PD Concept

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

In Terms of Area of the Distribution



Texas A&M Transportation Institute

Typical Variability

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

Texas A&M Transportation Institute


Questions?