How To Measure Quality

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Objectives

- Define quality
- Describe quality measures historically used in highway construction
  - Uses
  - Advantages
  - Disadvantages
  - Identify best quality measure
- Federal Lands Specification
  - Why use the entire project as a lot?

Definitions: Quality

- TRB E-C074 & AASHTO R 10:

(1) The degree of excellence of a product or service;

(2) the degree to which a product or service satisfies the needs of a specific customer;

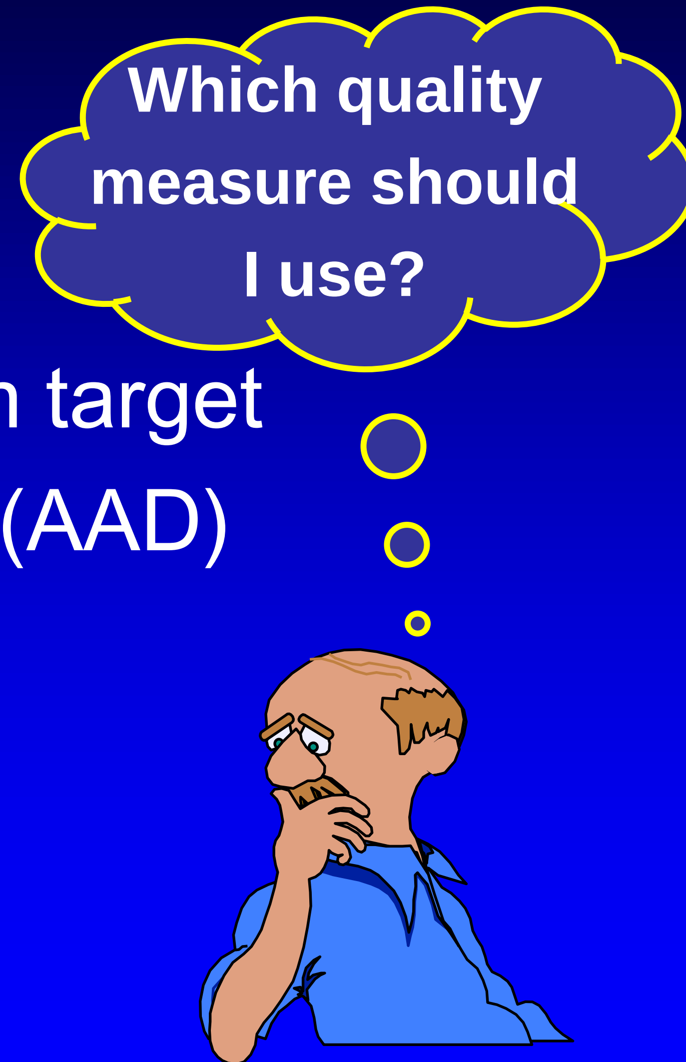
(3) the degree to which a product or service conforms with a given requirement.

Why Measure Quality and What do we want from a Quality Measure?

- Owner needs to know product quality
- Pay for what you get
- Fairness issues
- Reward contractors for quality
- Obtain a more uniform product
- Increase service life

Examples of Quality Measures

- Average
- Moving average
- Average deviation (AD) from target
- Average absolute deviation (AAD)
- Conformal index (CI)
- Percent defective (PD)
- Percent within limits (PWL)



Quality Measure Rating System

Elements of a Quality Measure						
Element	Average	Moving Average	AD	AAD	CI	PWL PD
Applies to…	*Target Value, Specification Limit, N/A*					
Simplicity	G F P	G F P	G F P	G F P	G F P	G F P
Capture center	G F P	G F P	G F P	G F P	G F P	G F P
Capture spread	G F P	G F P	G F P	G F P	G F P	G F P
Describe quality	Yes No	Yes No	Yes No	Yes No	Yes No	Yes No
Encourages uniformity	Yes No	Yes No	Yes No	Yes No	Yes No	Yes No
Single spec	Yes No	Yes No	Yes No	Yes No	Yes No	Yes No
Double spec	Yes No	Yes No	Yes No	Yes No	Yes No	Yes No
Encourages manipulation	Yes No	Yes No	Yes No	Yes No	Yes No	Yes No

Quality Measure: Average

- OK for monitoring trends for quality control

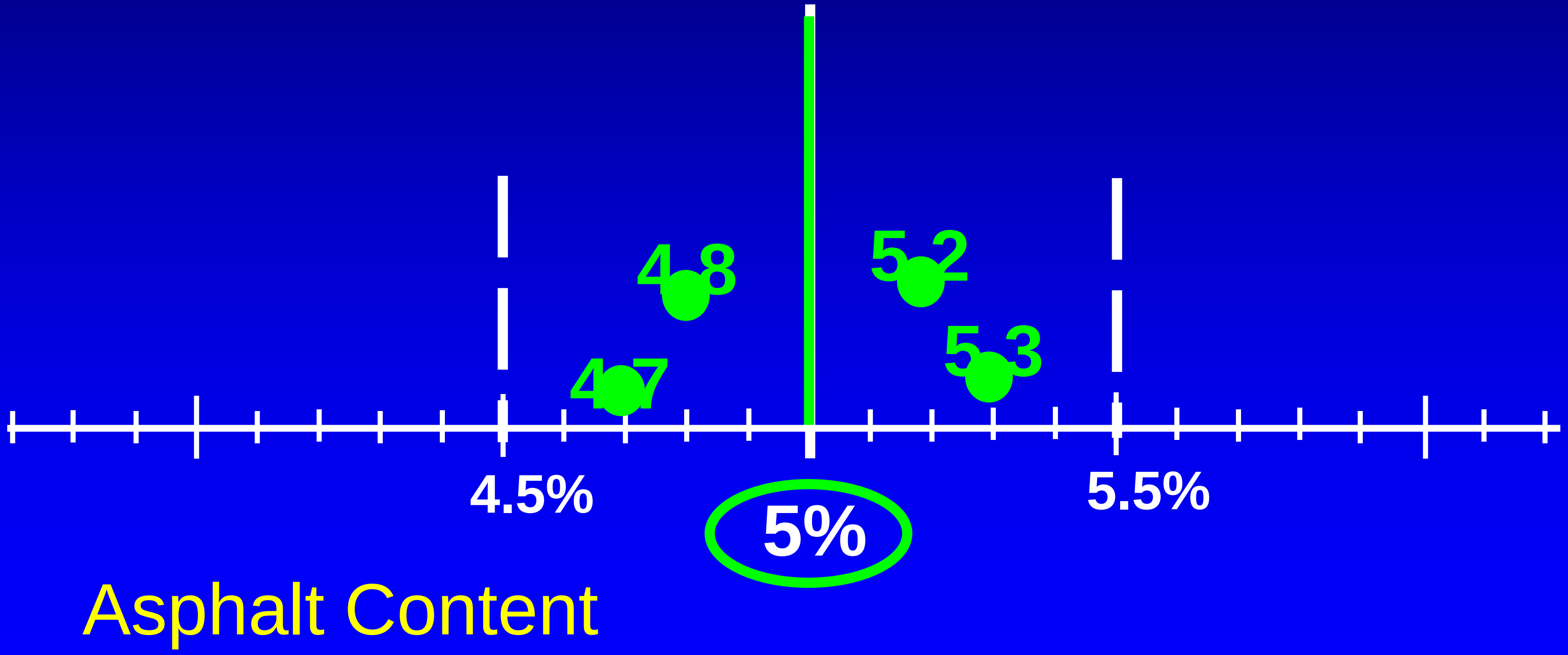
$$\bar{X} = \frac{\sum X_i}{n}$$

X_i = individual test value

n = total number of test values

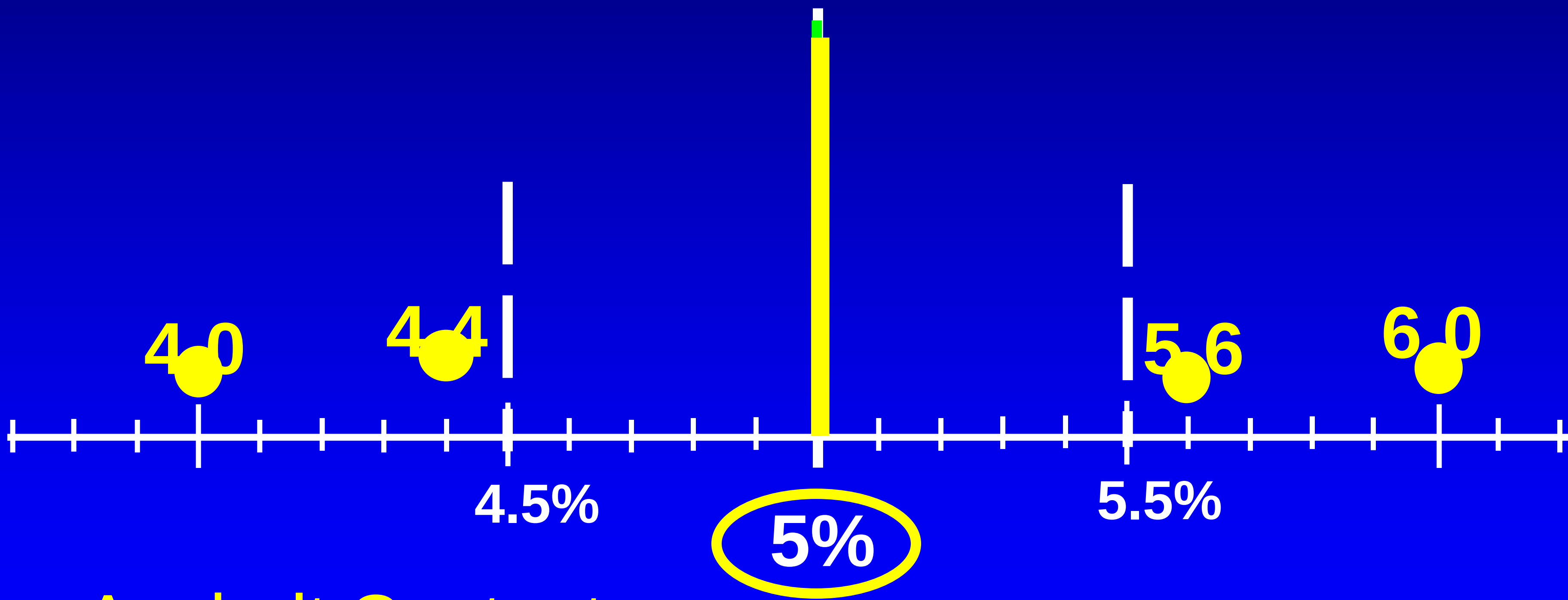
Example of Using Average

$$\frac{4.7 + 4.8 + 5.2 + 5.3}{4} = 5.0$$



Disadvantage of Using Average

$$\frac{4.7 + 4.8 + 5.2 + 5.3}{4} = 5 \qquad \frac{4 + 4.4 + 5.6 + 6}{4} = 5$$



Asphalt Content

Summary: Average

- OK for monitoring trends for quality control
- NOT recommended for payment
  - Does not measure variability
  - Encourages increased variability
  - Encourages game playing to maximize the pay factor

Quality Measure: Moving Average

- OK for monitoring trends for quality control

$$\bar{\mathbf{X}}_{\mathbf{m}} = \frac{\sum X_i}{n}$$

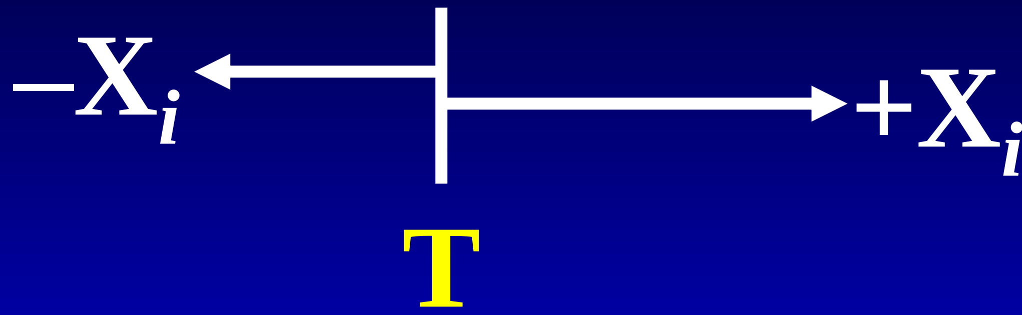
X_i = individual test value

n = total number of test values

Summary: Moving Average

- OK for monitoring trends for quality control
- NOT recommended for payment
  - Not consistent with lot-by-lot acceptance
  - Could result in production shut downs and plant adjustments
  - Encourages manipulation of the data and increases variability
  - Impacts pay factor determination due to having inter related moving averages

Quality Measure:
Average Deviation (AD)

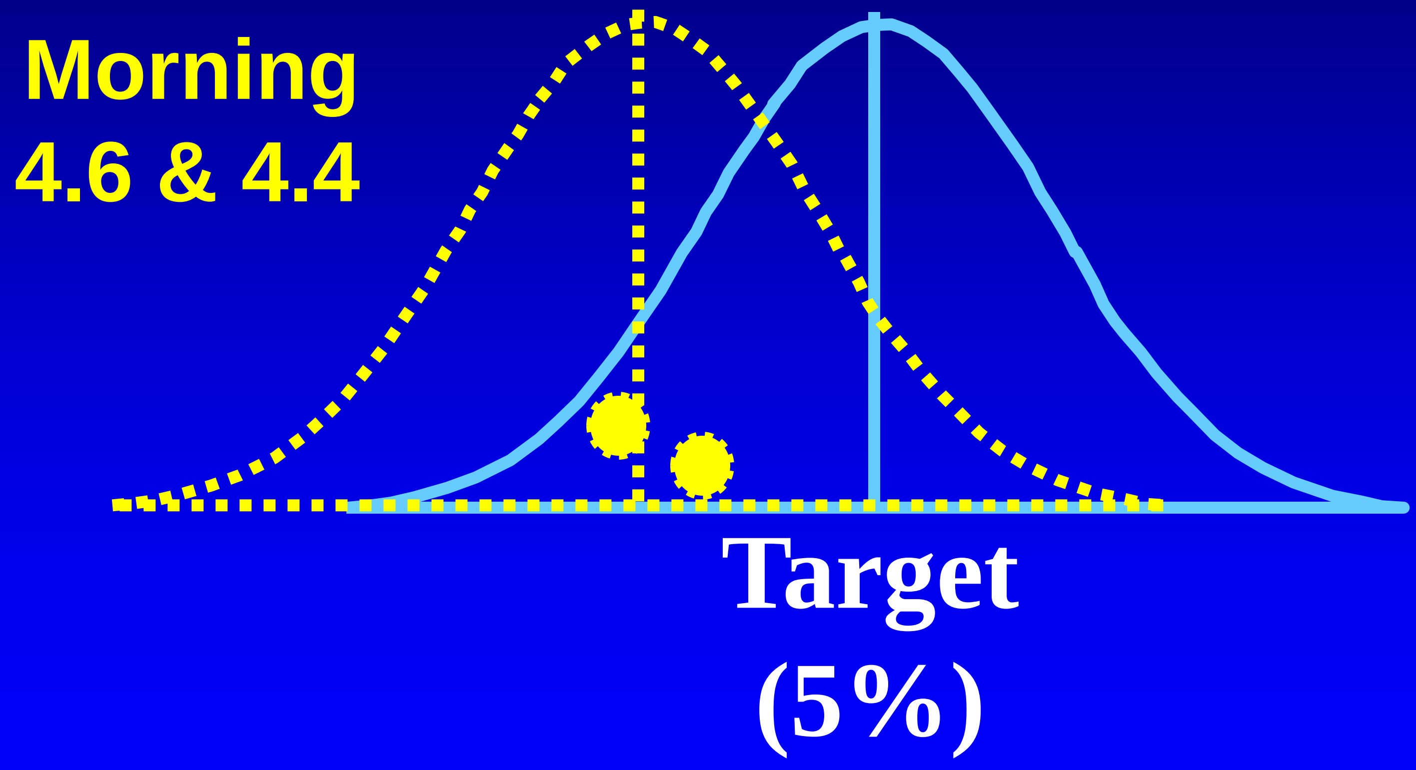


- Measures deviation from the target

$$AD = \frac{\sum X_i - T}{n}$$

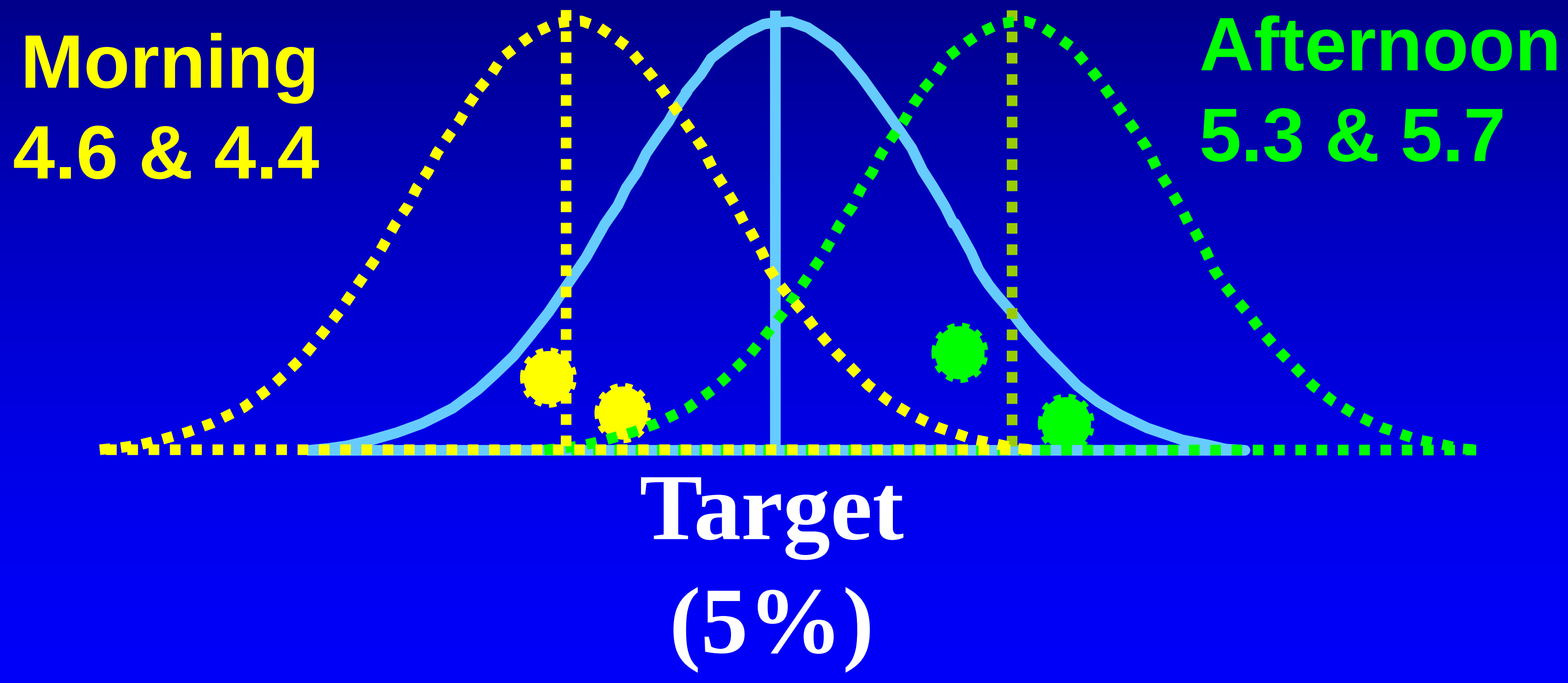
Example of Using AD

Asphalt Content



Example of Using AD

Asphalt Content

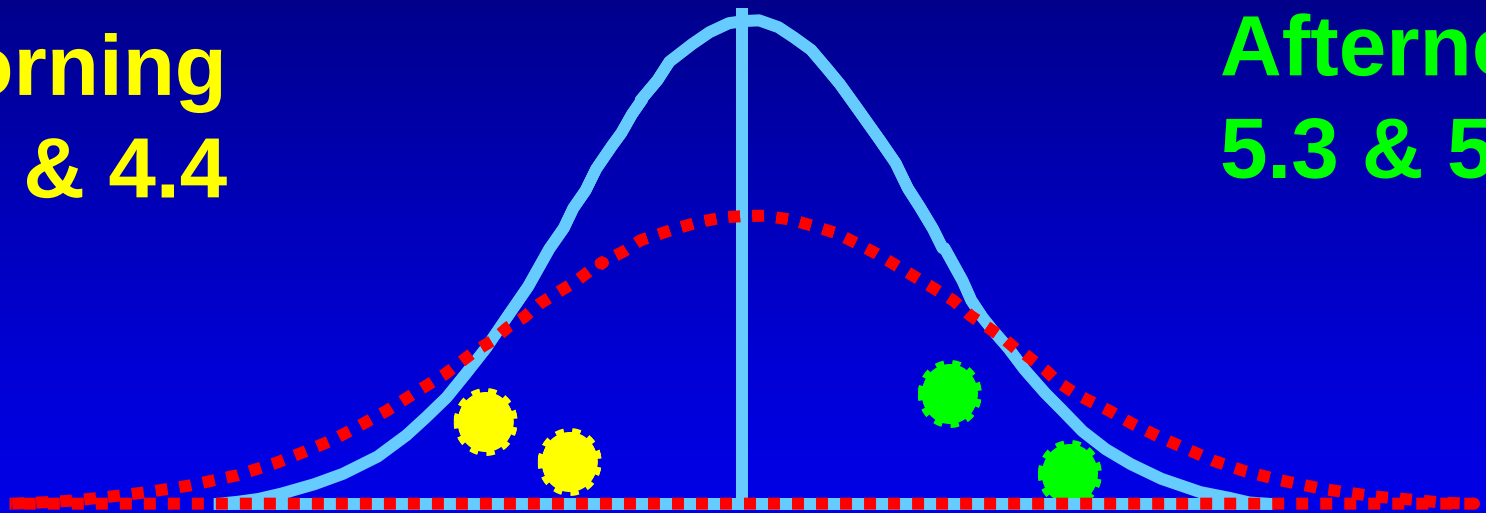


Example of Using AD

Asphalt Content

Morning
4.6 & 4.4

Afternoon
5.3 & 5.7



Target
(5%)

Example of Using AD (cont'd)

Test
4.6%
4.4%
5.3%
5.7%

Target
5%

Average Deviation
-0.4%
-0.6%
0.3%
0.7%

$$AD = \frac{-0.4 - 0.6 + 0.3 + 0.7}{4} = 0.0$$

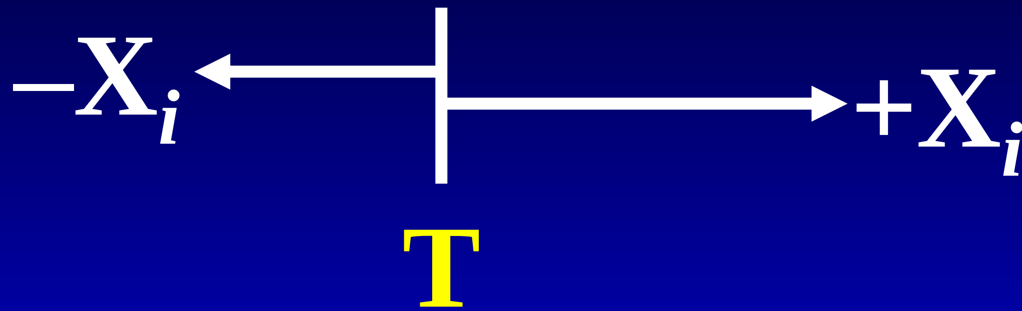
Summary: Average Deviation (AD)

- Simple measure
- NOT recommended for payment
  - Encourages manipulation of the process during production
    - Increases process variability
    - Potential for non-uniform material
    - Requires a target – not applicable to single limit specifications

Quality Measure: Average Absolute Deviation (AAD)

- Improvement on AD
  - Measures absolute deviation from target
  - A low AAD implies data is centered (close to target) and has low variability

Average Absolute Deviation (AAD)

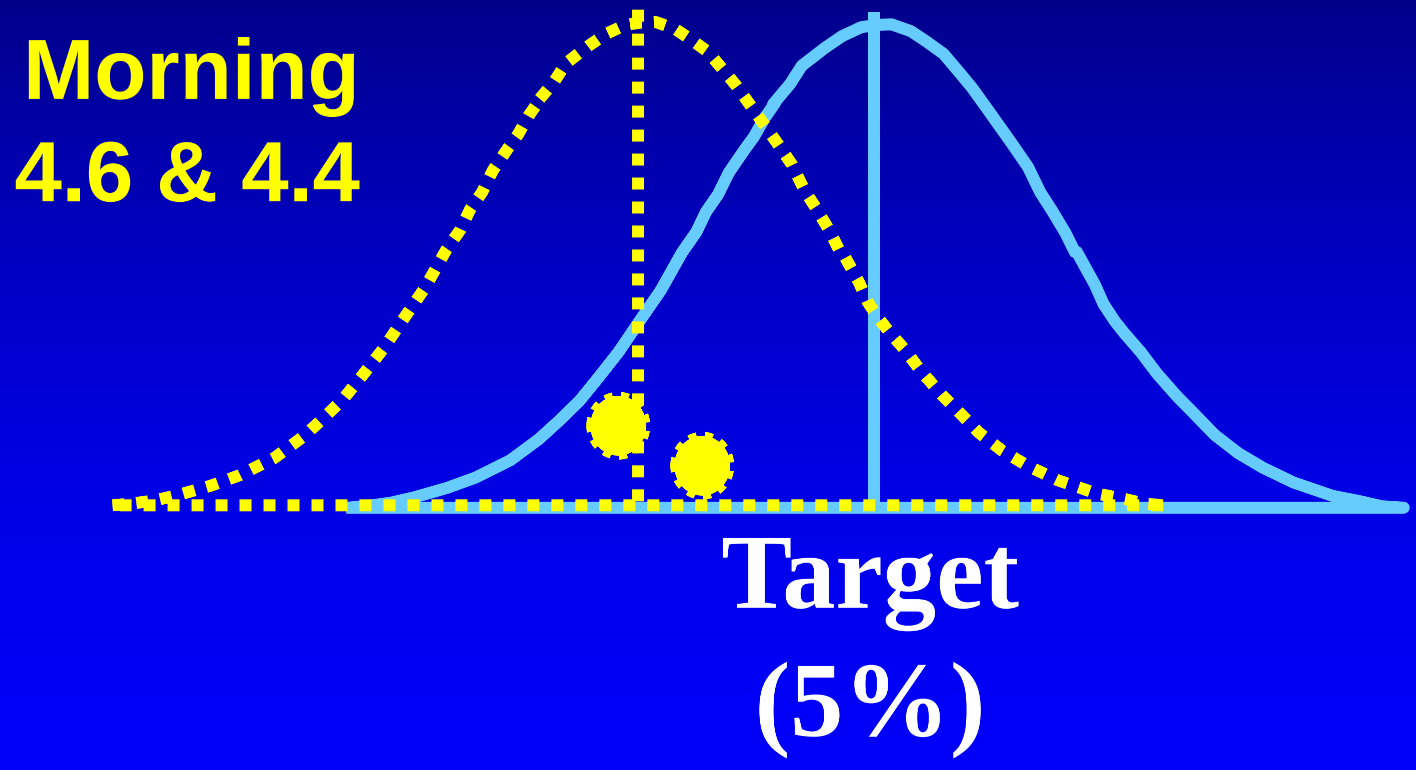


- Measures <u>absolute</u> deviation from target

$$AAD = \frac{\sum \left| X_i - T \right|}{n}$$

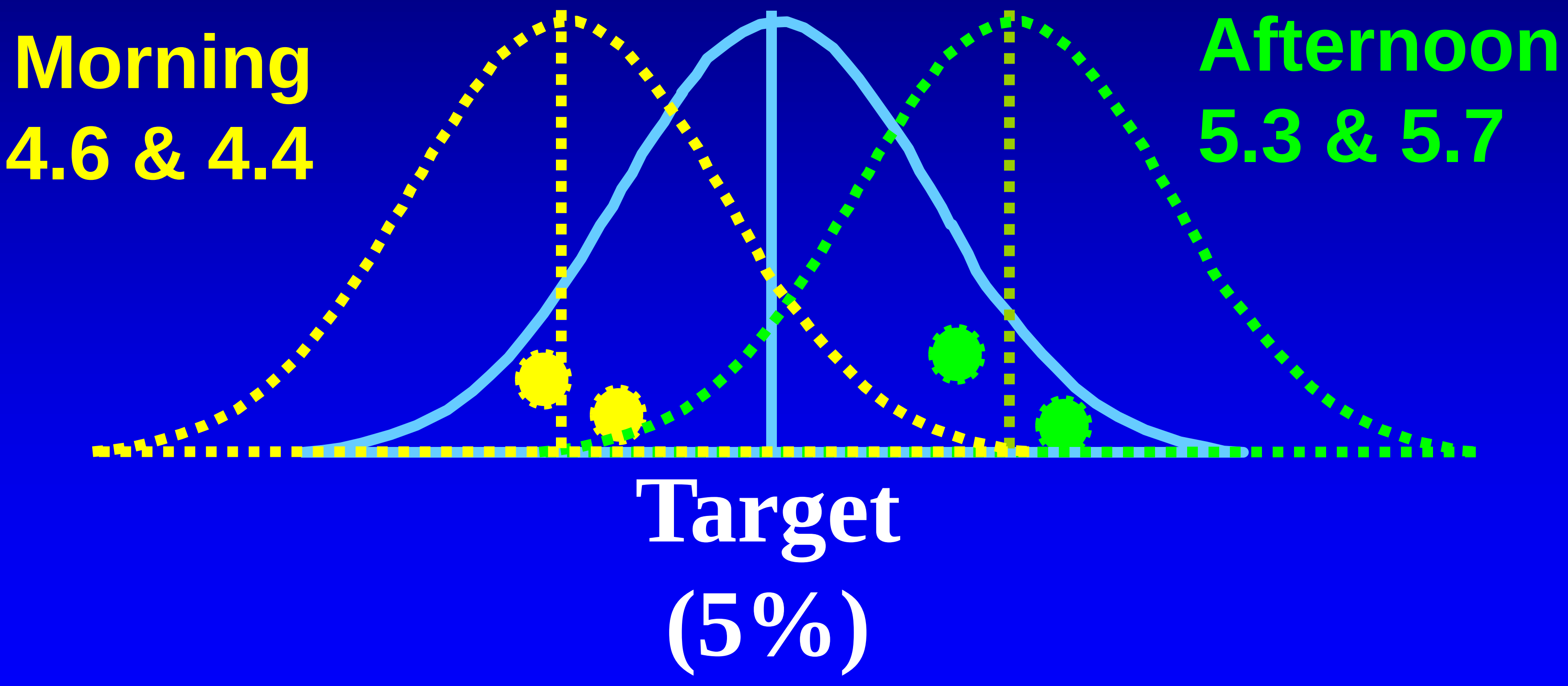
Example of Using AAD

Asphalt Content



Example of Using AAD

Asphalt Content



Example of Using AAD (cont'd)

Test	Average Deviation (AD)
4.6%	-0.4%
4.4%	-0.6%
5.3%	0.3%
5.7%	0.7%

AAD
0.4%
0.6%
0.3%
0.7%

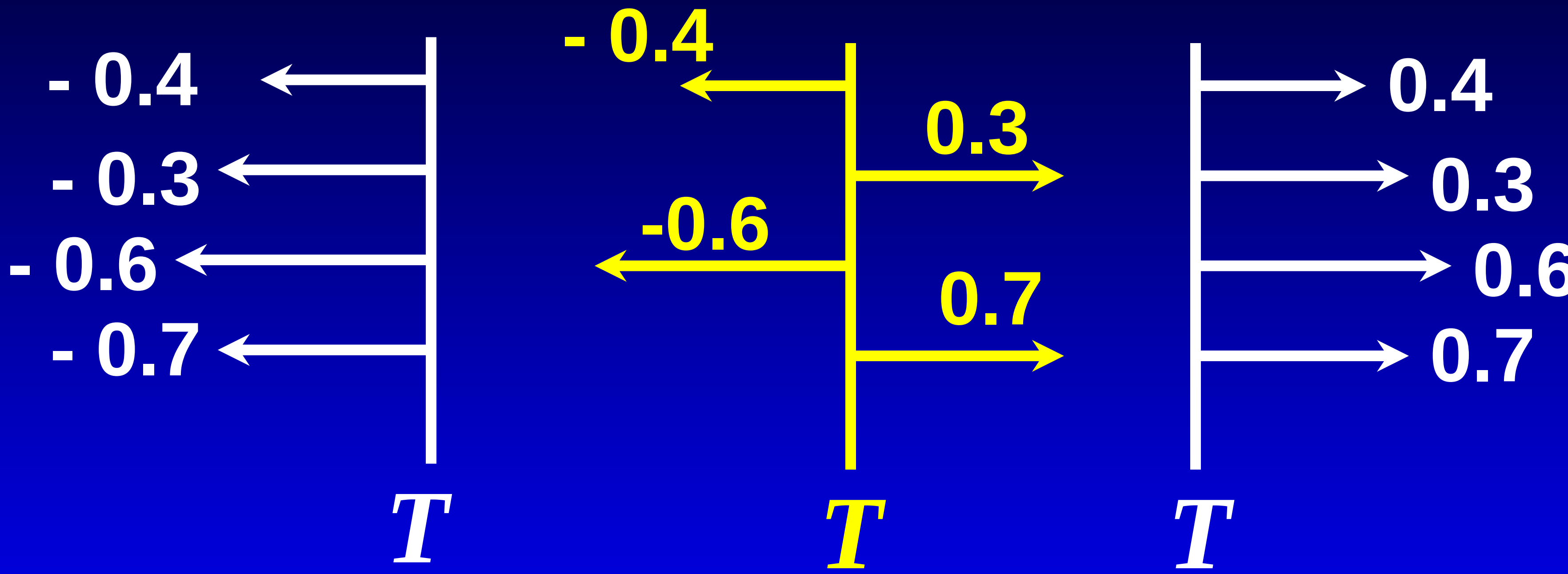
Example of Using AAD (cont'd)

$$AAD = \frac{|-0.4| + |-0.6| + |+0.3| + |+0.7|}{4} = 0.5$$

Recall calculation for AD:

$$AD = \frac{-0.4 - 0.6 + 0.3 + 0.7}{4} = 0$$

AAD: Disadvantage



AAD = 0.5	AAD = 0.5	AAD = 0.5
$\overline{X}$ = - 0.5	$\overline{X}$ = 0.0	$\overline{X}$ = 0.5
s = 0.18	s = 0.61	s = 0.18

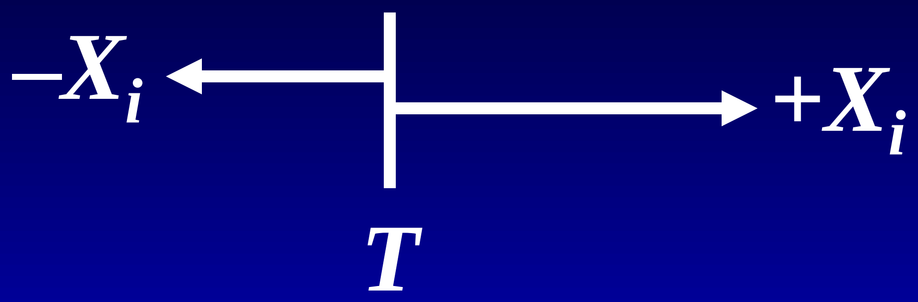
Summary:
Average Absolute Deviation (AAD)

- Improvement on AD
  - Measures absolute deviation from target
  - A low AAD implies both good center and good spread of data (low variability)
- NOT recommended for payment
  - A high AAD does not necessarily imply both poor center and poor spread of data (high variability)
  - AAD does not differentiate quality
  - Variability not adequately measured

Quality Measure: Conformal Index (CI)

- Improvement on AAD
  - A measure of the dispersion of a series of results around a target value
  - Similar in concept to standard deviation

Conformal Index (CI)



- **Measures <u>squared</u> deviation from the target**

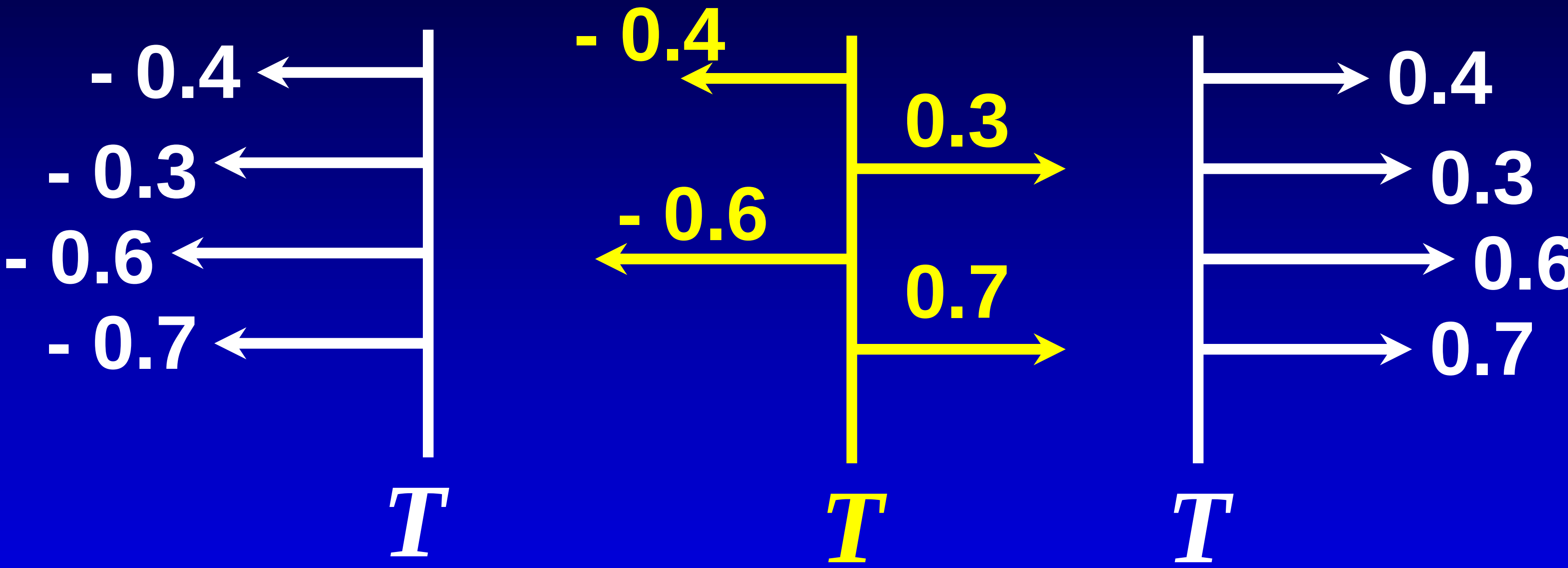
CI:

$$\sqrt{\frac{\sum (X_i - T)^2}{n}}$$

Population Std. Dev. (σ):

$$\sqrt{\frac{\sum (X_i - \mu)^2}{n}}$$

CI: Disadvantages



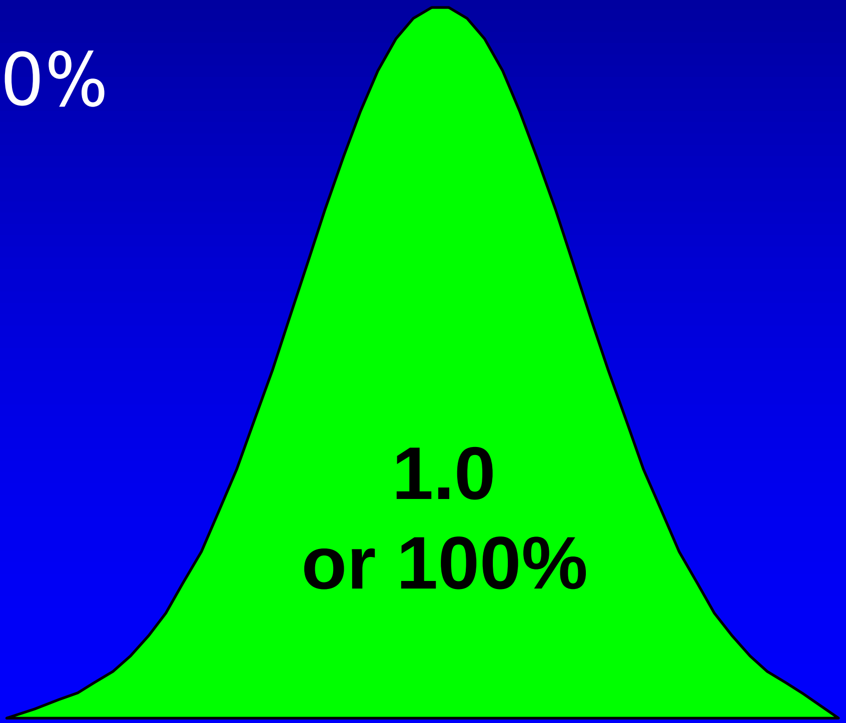
CI = 0.52	CI = 0.52	CI = 0.52
$\bar{X}$ = - 0.5	$\bar{X}$ = 0.0	$\bar{X}$ = 0.5
s = 0.18	s = 0.61	s = 0.18

Summary: Conformal Index (CI)

- Improvement on AAD
  - A measure of the dispersion of a series of results around a target value
  - Similar in concept to standard deviation
- NOT recommended for payment
  - Same deficiencies as AAD
    - Different test results can give identical CI values

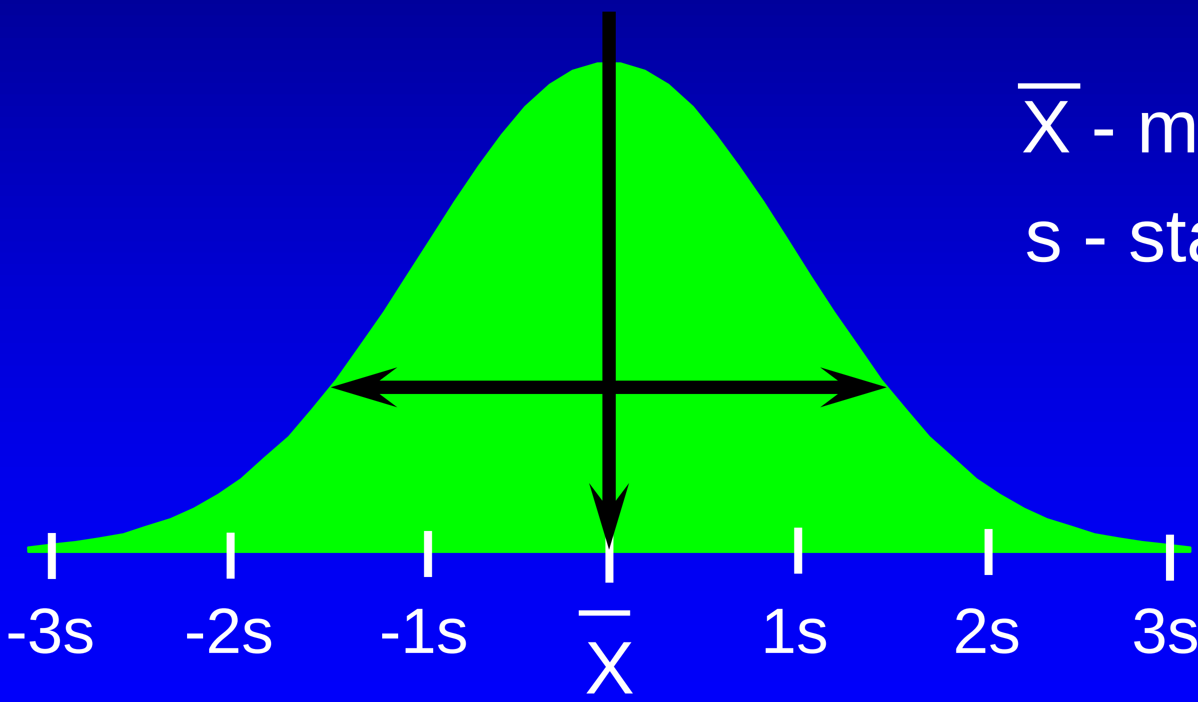
Quality Measure: Percent Within Limits (PWL)

- Estimates the percentage of material within specification limits
  - Assumes normal distribution
  - Area equals 1.0 or 100%



PWL

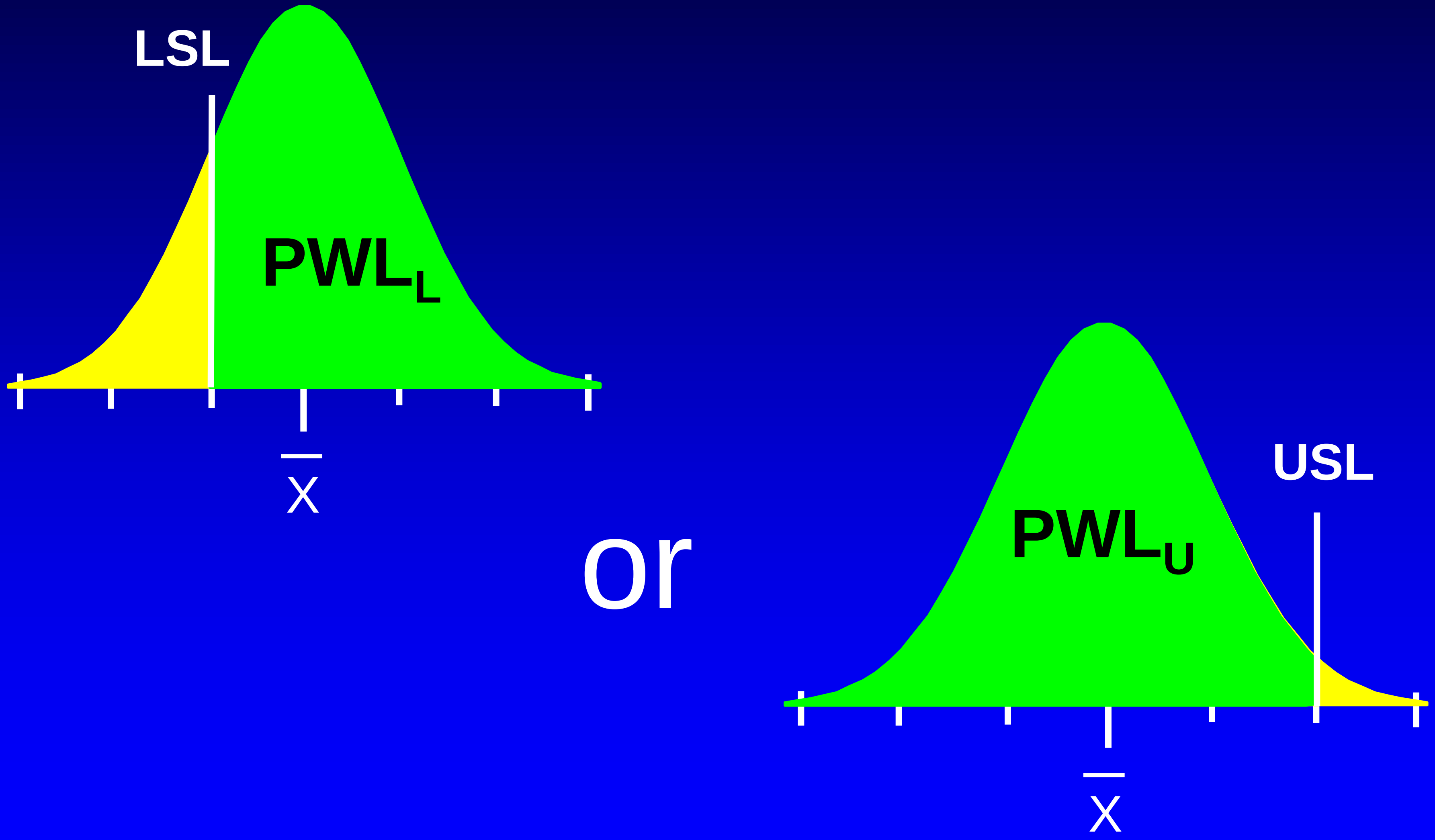
- Efficiently captures mean and standard deviation in one quality measure



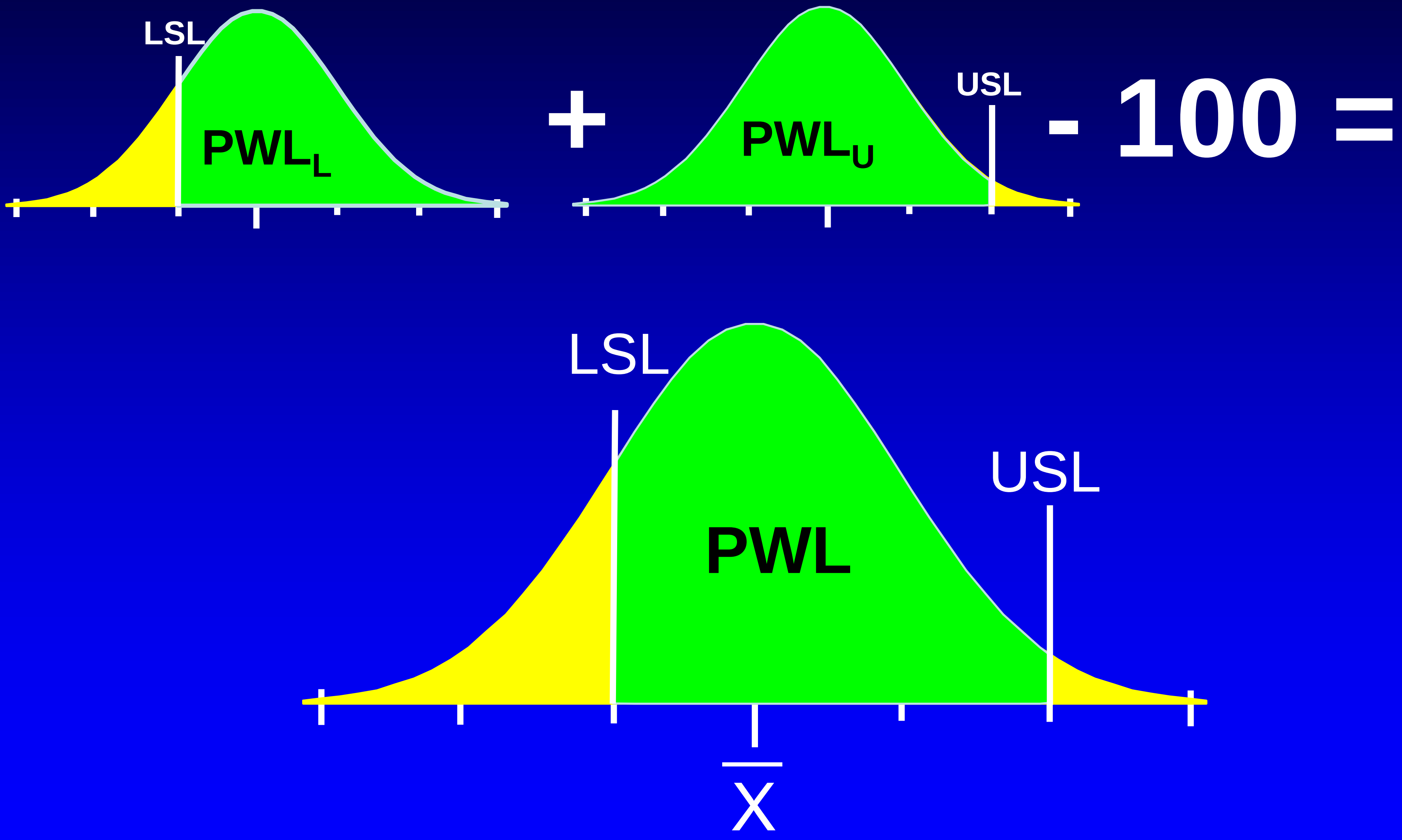
X̄ - mean

s - standard deviation

Single Specification PWL

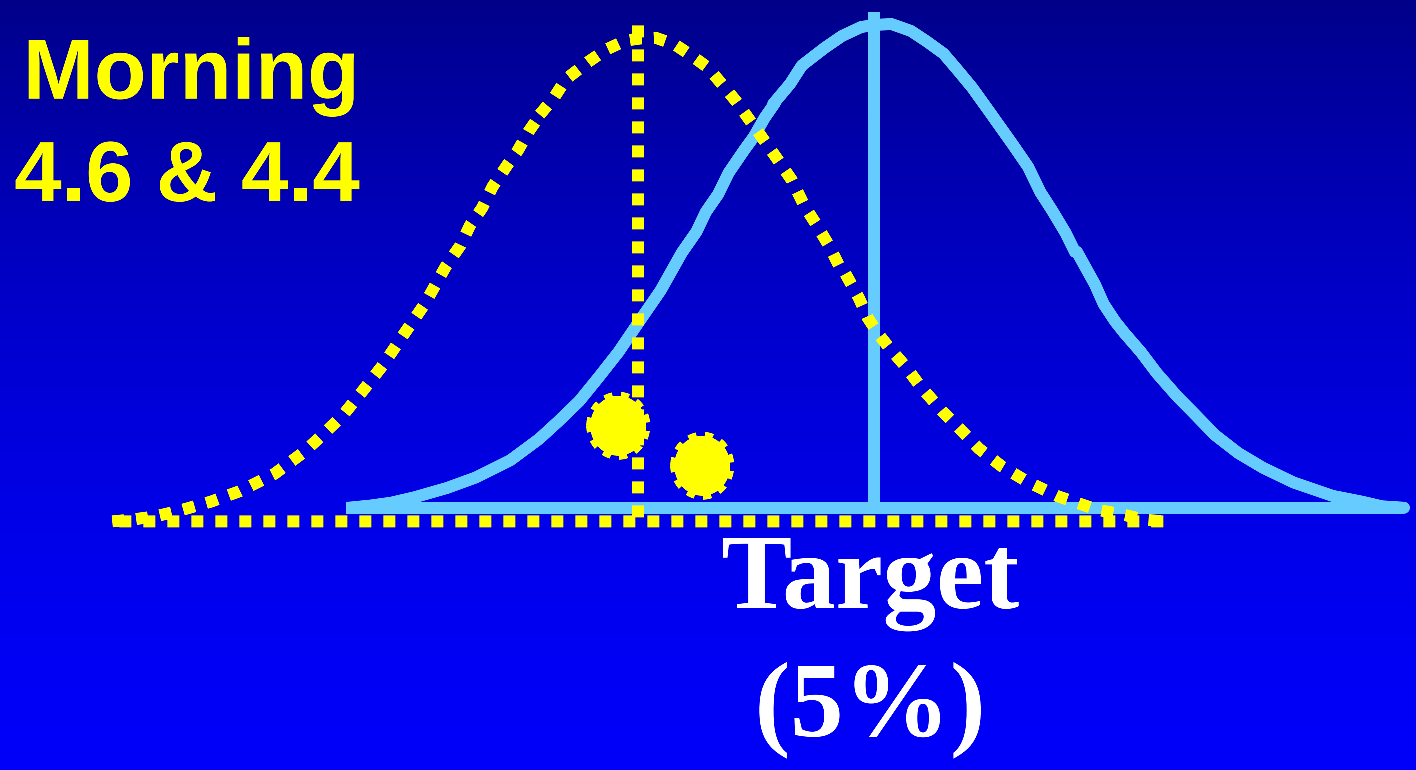


Double Specification PWL



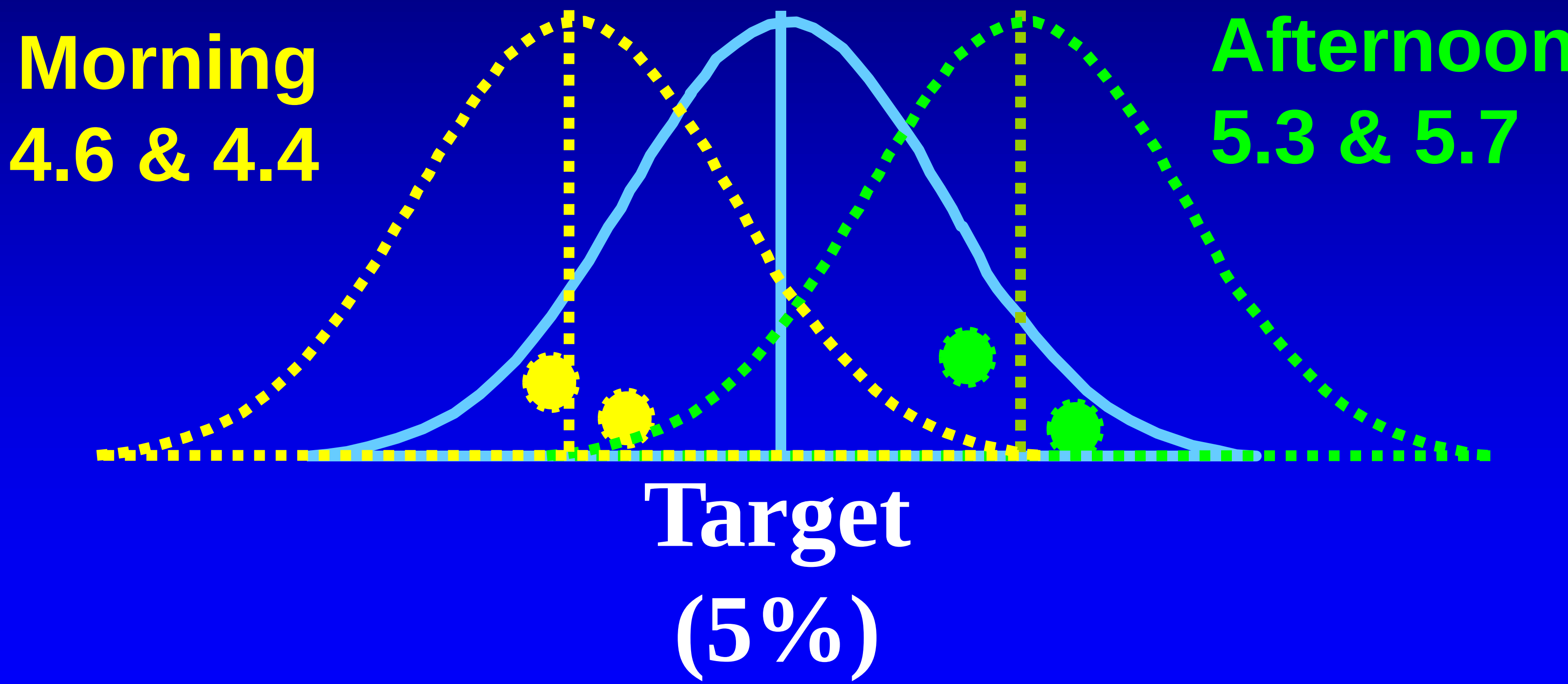
Example of Using PWL

Asphalt Content



Example of Using PWL

Asphalt Content

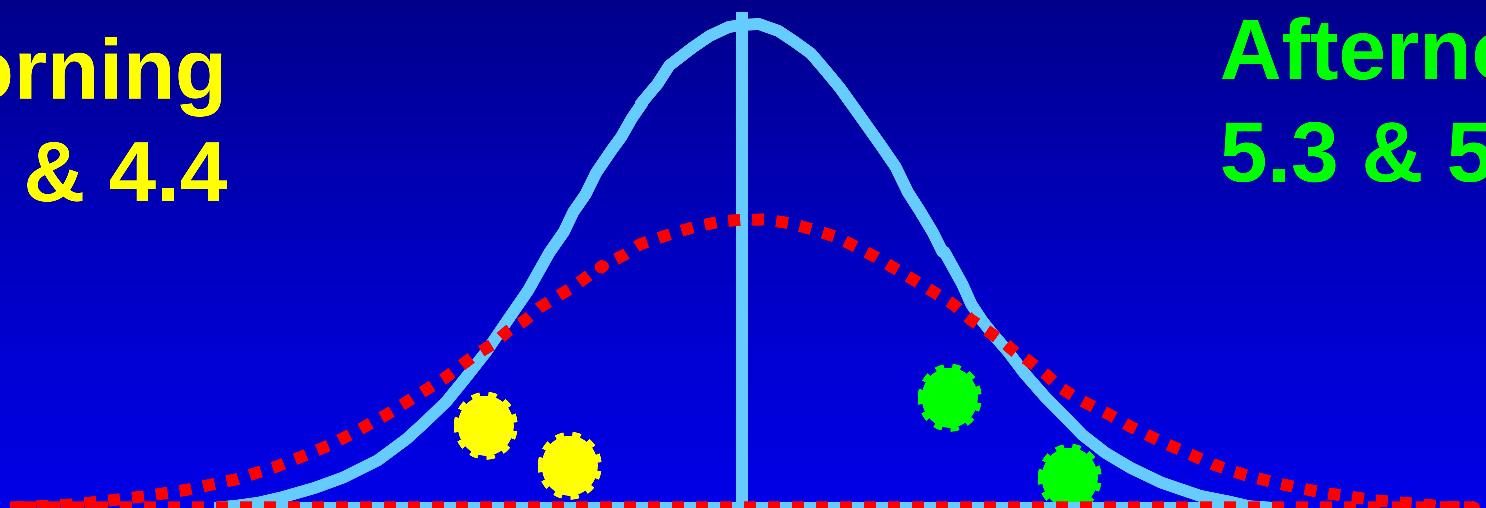


Example of Using PWL

Asphalt Content

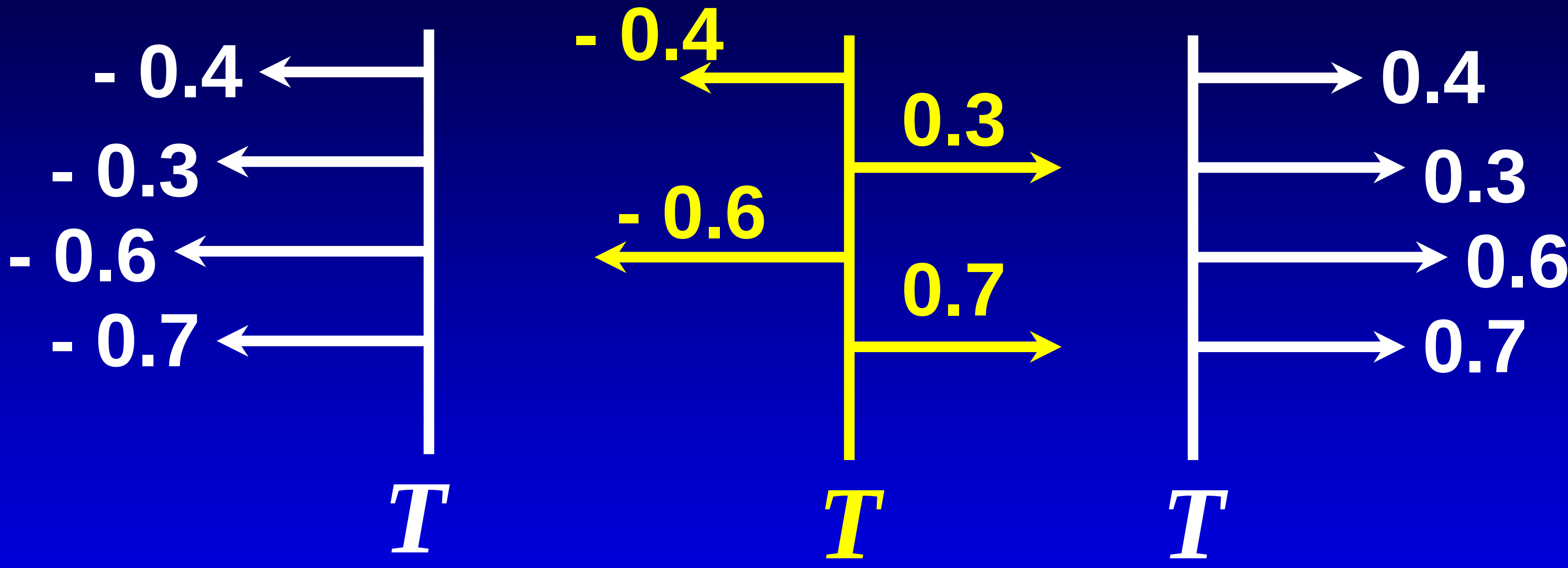
Morning
4.6 & 4.4

Afternoon
5.3 & 5.7



Target
(5%)

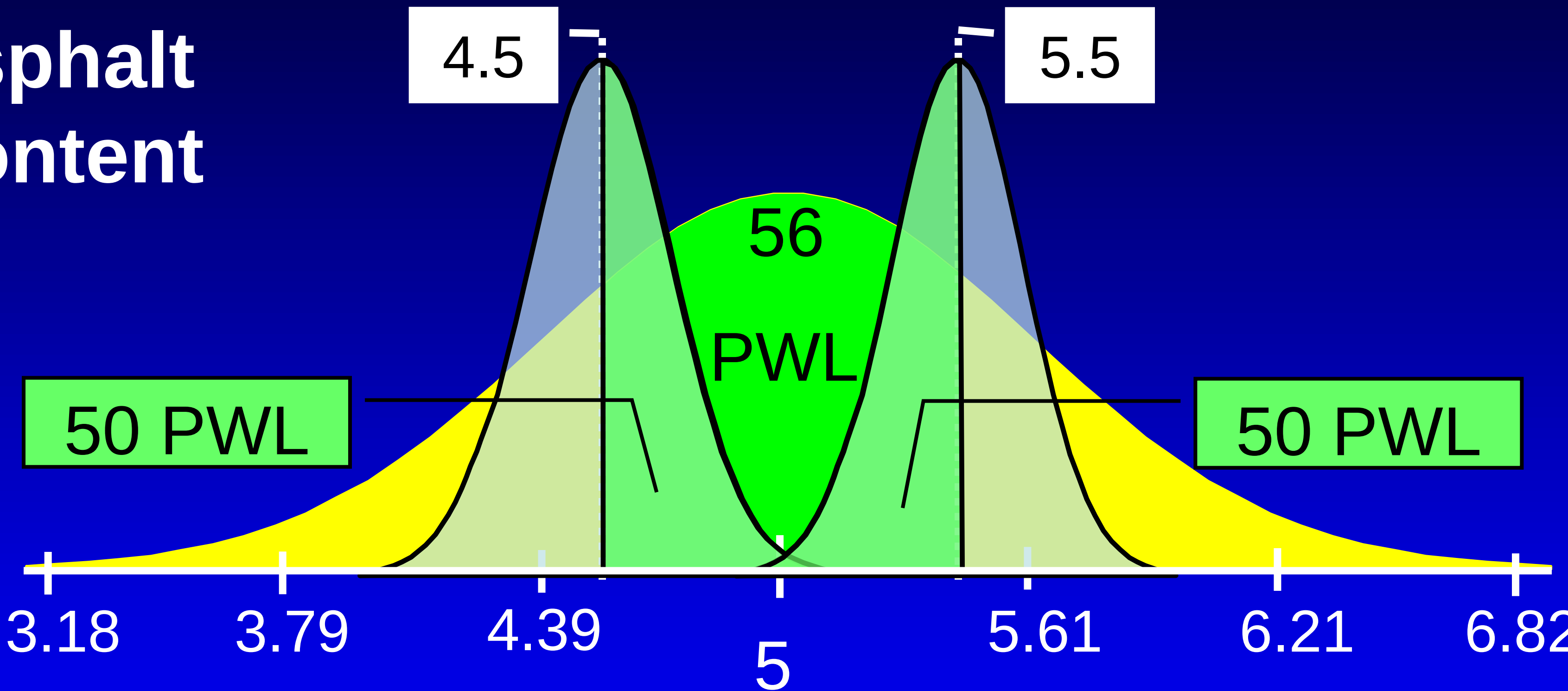
Example of Using PWL (cont'd)



PWL=?	PWL=?	PWL=?
$\bar{X} = -0.5$	$\bar{X} = 0.0$	$\bar{X} = 0.5$
$s = 0.18$	$s = 0.61$	$s = 0.18$

Example of Using PWL (cont'd)

Asphalt Content



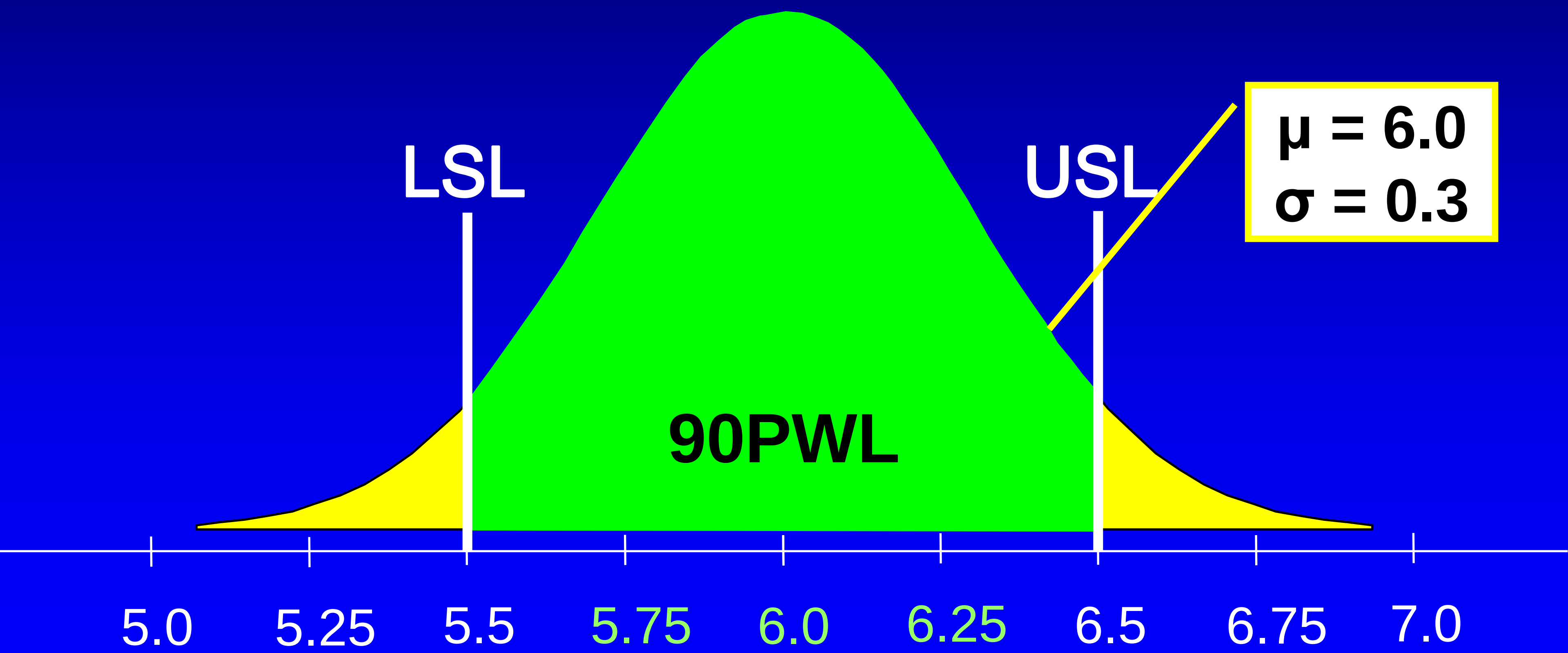
$\bar{X}$ = **4.5**
s = **0.18**

$\bar{X}$ = **5.0**
s = **0.61**

$\bar{X}$ = **5.5**
s = **0.18**

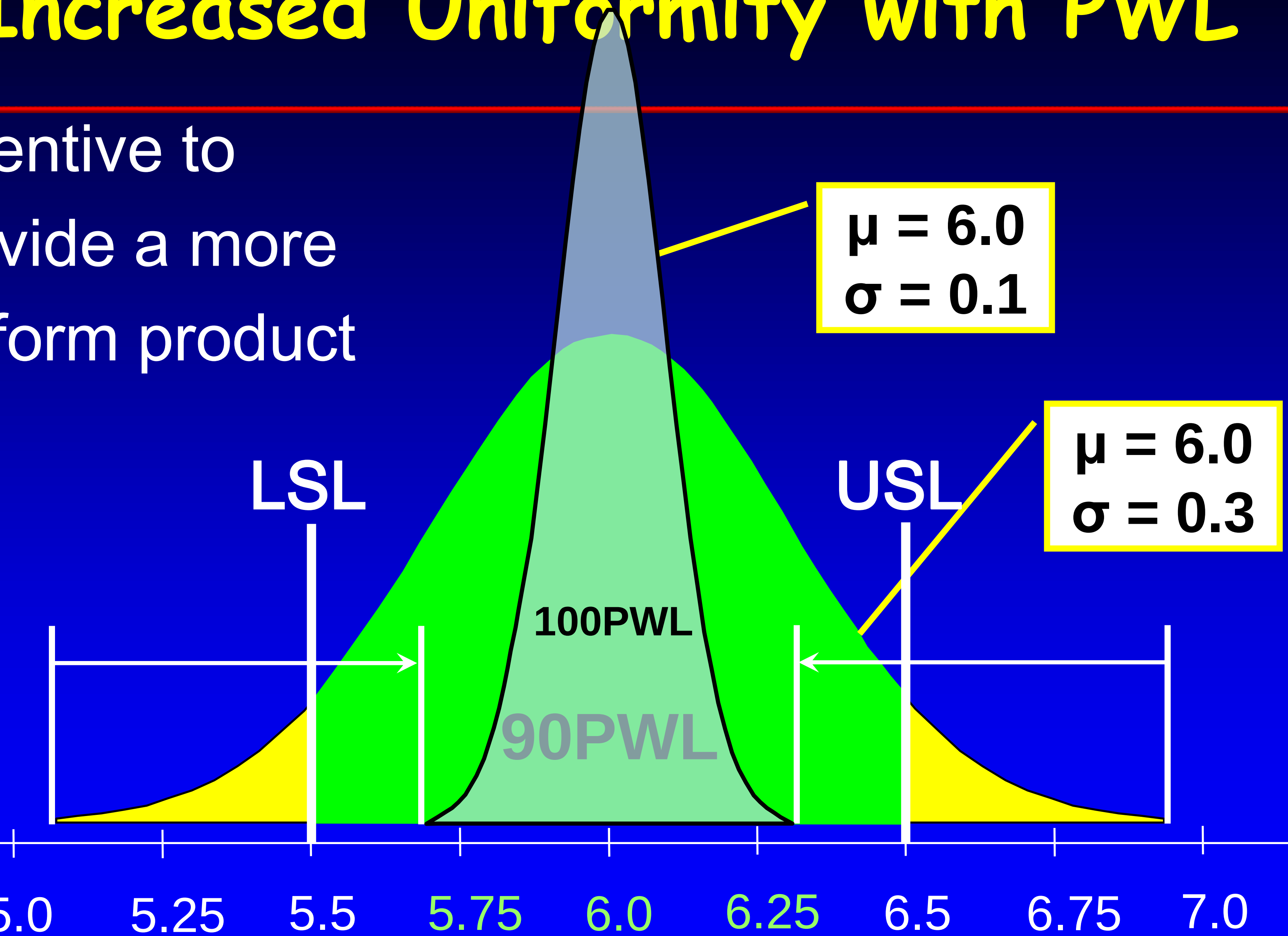
Increased Uniformity with PWL

Asphalt Content



Increased Uniformity with PWL

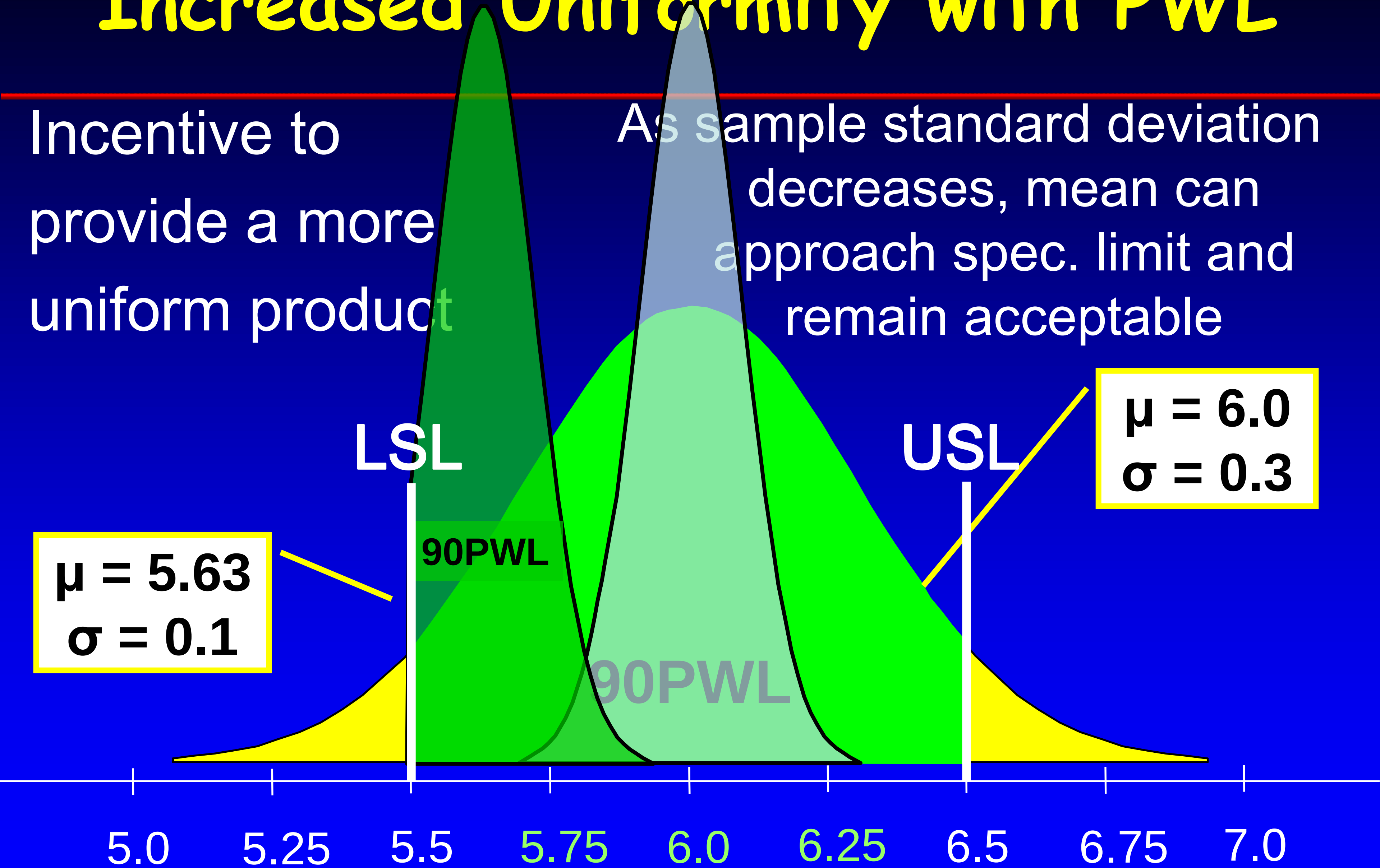
Incentive to provide a more uniform product



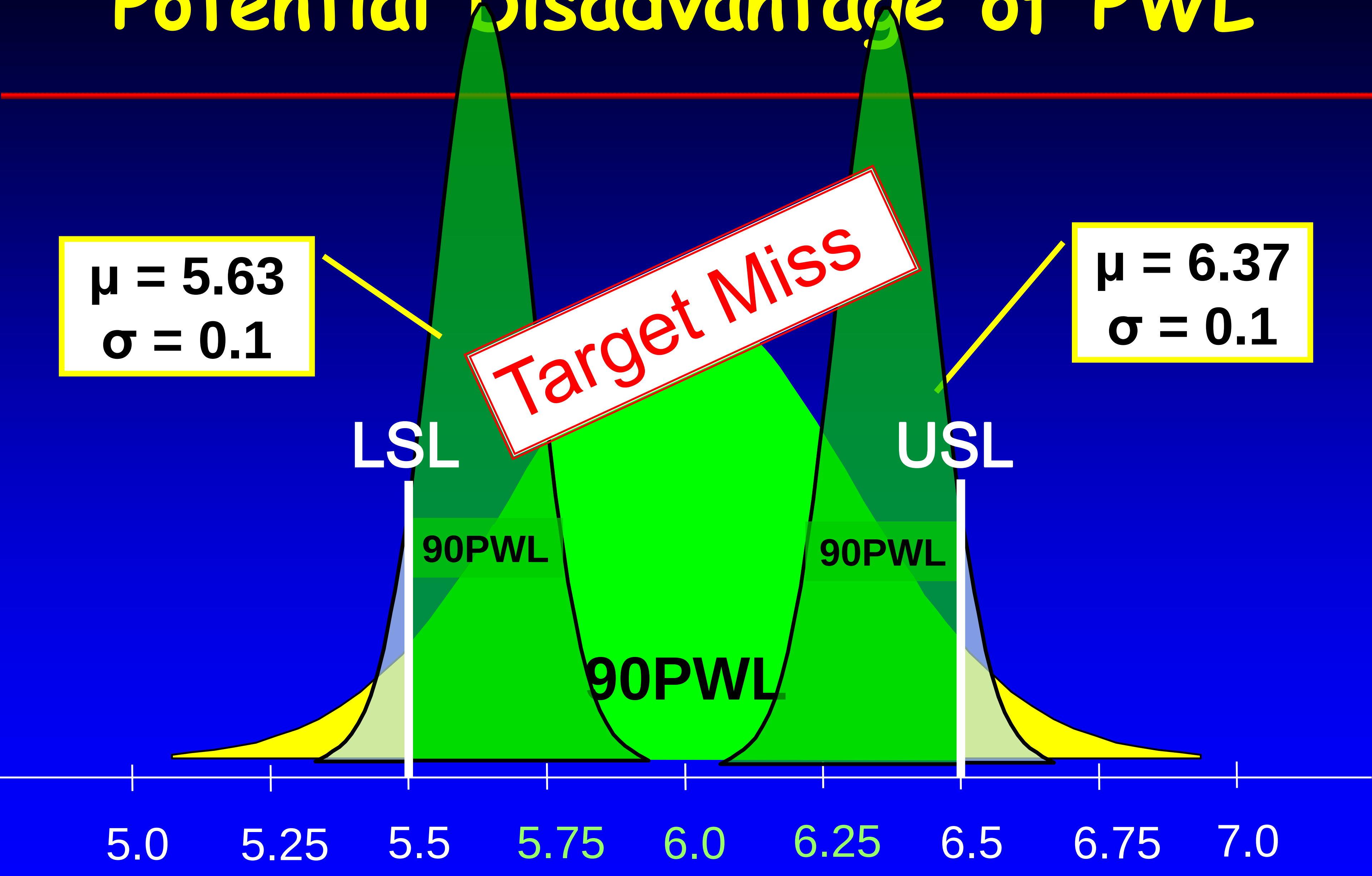
Increased Uniformity with PWL

Incentive to provide a more uniform product

As sample standard deviation decreases, mean can approach spec. limit and remain acceptable

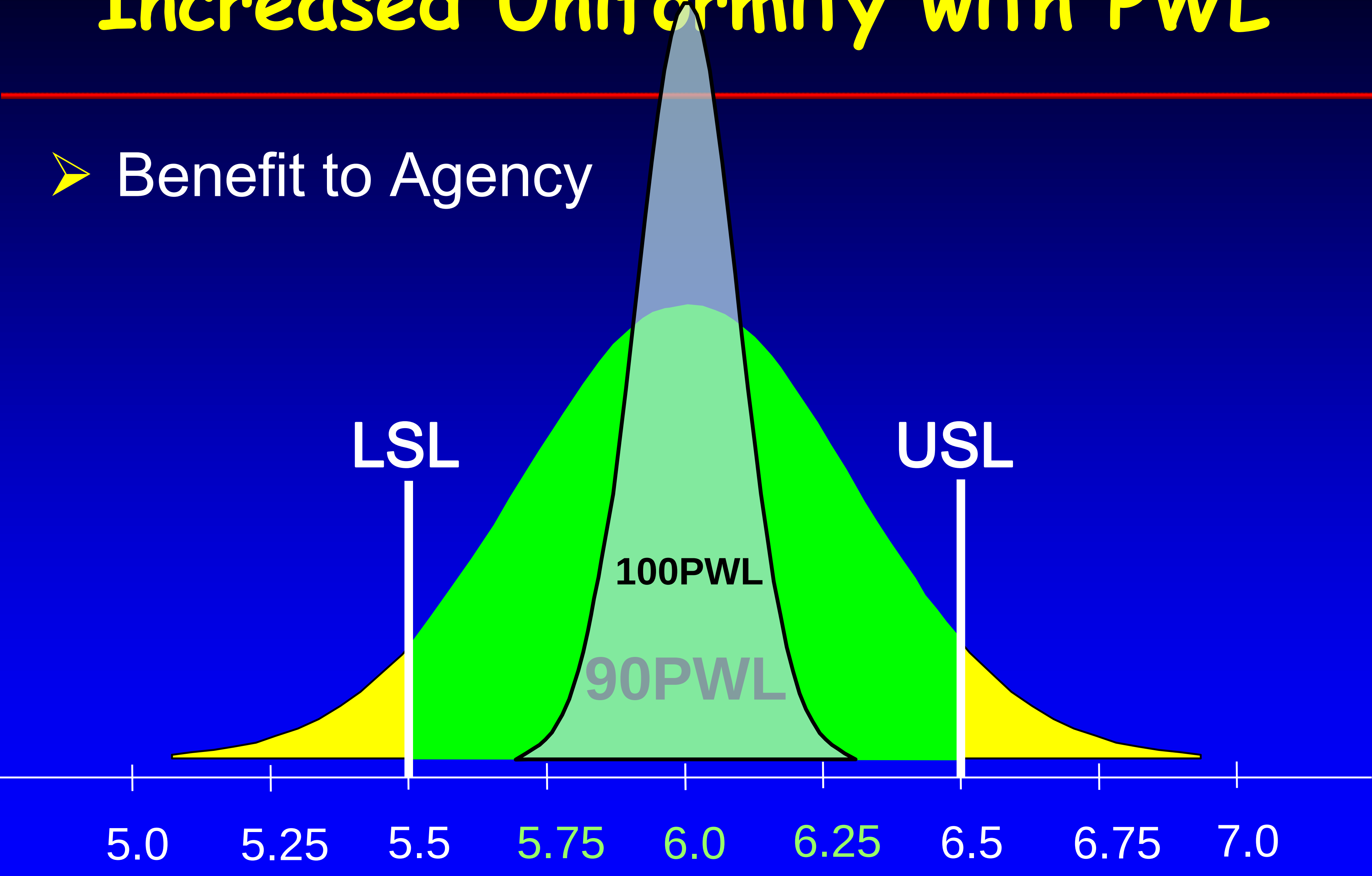


Potential Disadvantage of PWL



Increased Uniformity with PWL

- Benefit to Agency

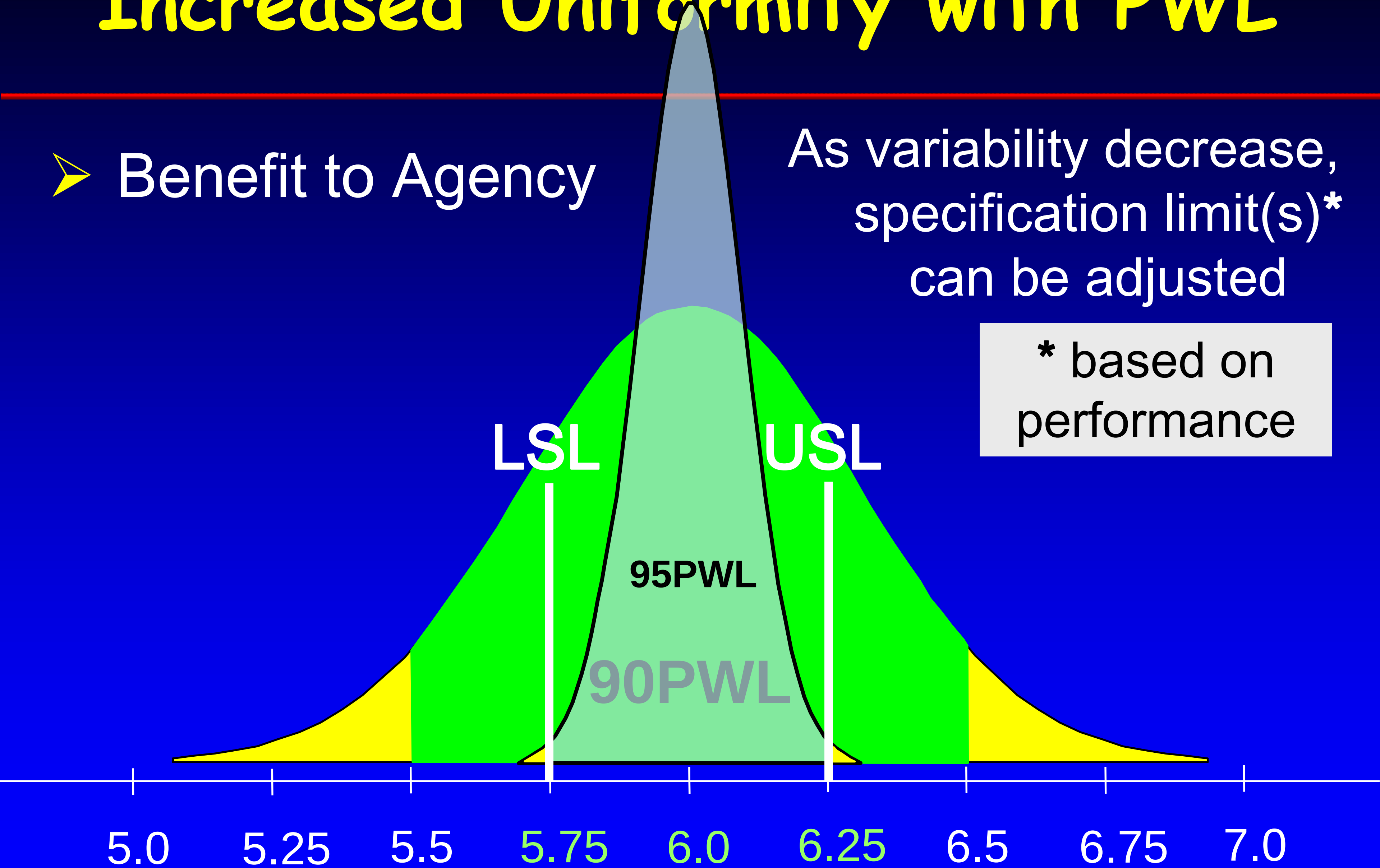


Increased Uniformity with PWL

- Benefit to Agency

As variability decrease, specification limit(s)* can be adjusted

* based on performance



Quality Measure Rating System

Elements of a Quality Measure						
Element	**Average**	**Moving Average**	**AD**	**AAD**	**CI**	**PWL PD**
Applies to…	*NA*	*NA*	*Target*	*Target*	*Target*	*SL*
Simplicity	Good	Good	Fair	Fair	Poor	Poor
Capture center	Good	Good	Good	Poor	Poor	Good
Capture spread	Poor	Poor	Poor	Fair	Fair	Good
Describe quality	No	No	No	No	No	Yes
Encourages uniformity	No	No	No	Yes	Yes	Yes
Single spec	Yes	Yes	No	No	No	Yes
Double spec	Yes	Yes	Yes	Yes	Yes	Yes
Encourages manipulation	Yes	Yes	Yes	No	No	No

Federal Lands Specification

- PWL
- Lot Size – The Entire Project
- Sampling Rate
  - HMA – 1 sample per 750 tons
  - Crushed Aggregate – 1 sample per 1,000 tons
  - PCC – 1 sample per 30 cubic yards

Federal Lands Specification

- Lot size – The Entire Project --- WHY???
- Risk Considerations: AQL & RQL

Sample Size (N)	Contractor's Risk	Agency's Risk
3	0.05	0.48
5	0.05	0.32
10	0.05	0.12
22	0.05	0.01

Is there an Optimal Sample Size?

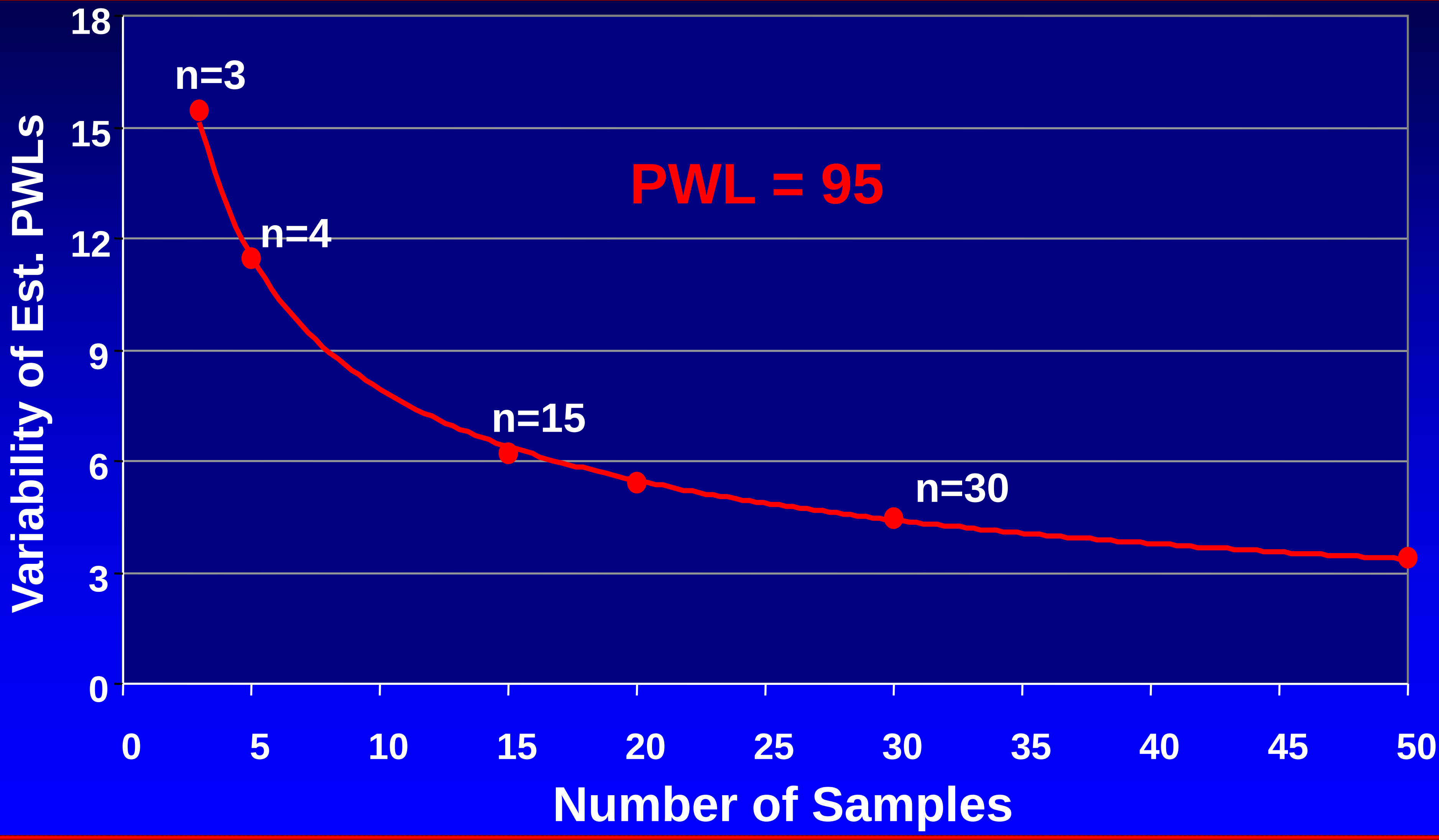
Well, there is a range…

Determining Optimal Sample Size

Std. Normal Dist. Mean = 0 Std. Dev. = 1	USL & LSL => 95 PWL		
	n = 3		Estimated PWL
Count	Mean	Std	
1	-0.1616	0.9751	87.49
2	-0.5032	1.6670	66.87
3	-0.0977	1.2920	81.39
4 …	0.1579	0.4718	100.00
5,000	0.1226	0.7908	98.08

Std. Dev. = 15.6

Optimal Sample Size

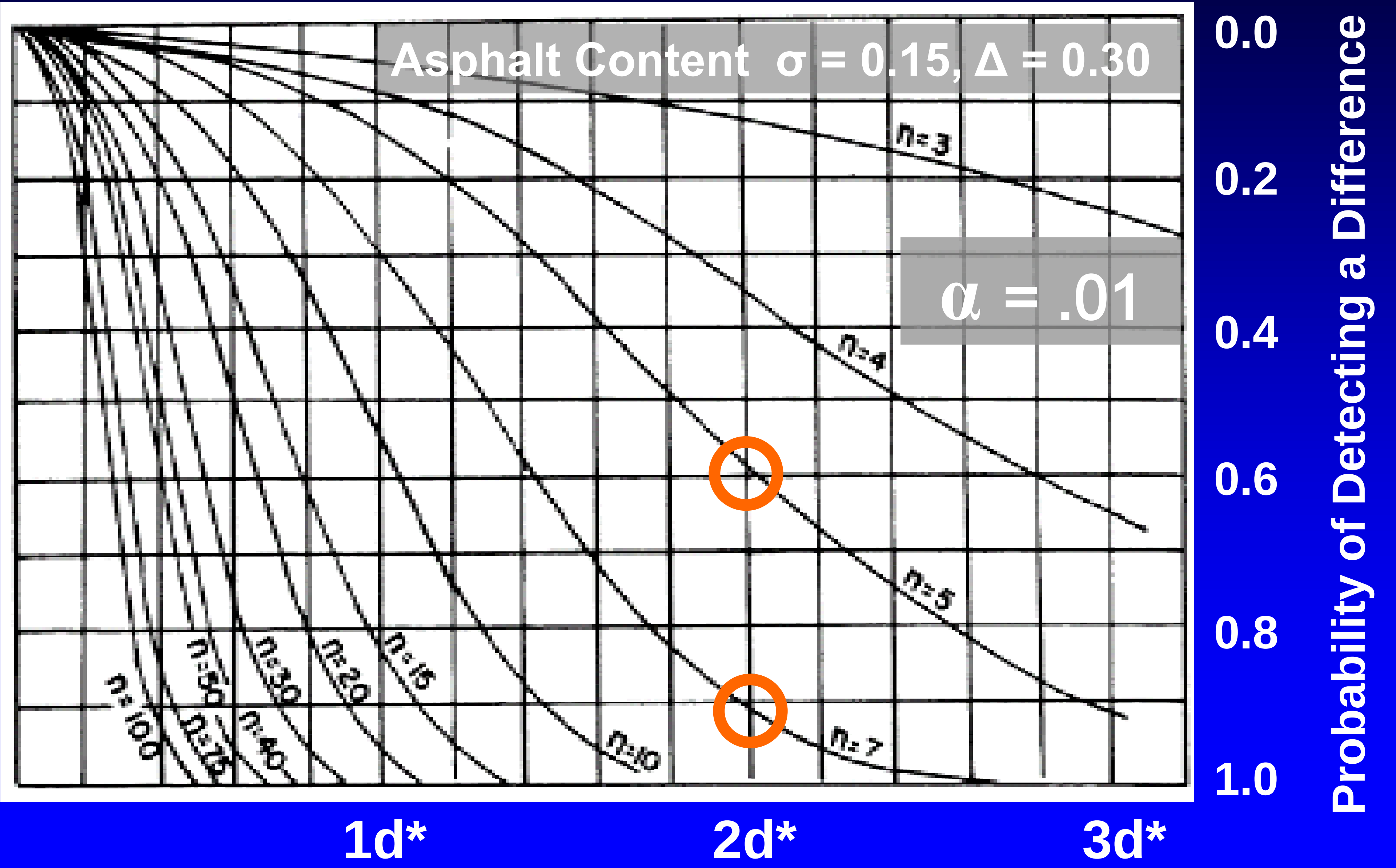


Contractor Testing Verification

AASHTO Multi Lab Limits (D2S)

- If asphalt content has a standard deviation of 0.12
- You will be able to detect a difference of 0.18 between contractor and agency results about 30 percent of the time.

Hypothesis Test for: Paired Samples



Hypothesis Test for: Independent Samples

N_c, N_a	Probability of Detecting a Difference
9, 2	0.35
19, 2	0.50
18, 3	0.64
16, 5	0.88
28, 3	0.76
25, 6	0.95

Asphalt Content $\sigma = 0.15$, $\Delta = 0.30$, $\alpha = 0.01$

The Bottom Line

- Statistical Acceptance Plans and Verification procedures are complicated.
- They can easily be computerized.
- A Large number of tests are typically required to find statistically–valid differences.
- With Properly designed Acceptance Plans and Verification Procedures it is possible to manage the risk (Agency & Contractor).

The End