U.S. Department of Transportation
Federal Highway Administration

2019 Asphalt Institute Conference

We spread in the summer, and we laid it nice hot
Two million yards or more of it, we had to roll the lot
The sun was blazing down; until I thought me back would melt
Working on the Motor highway, laying hot asphalt

When you're speeding in your motor car and tearing through the shires
And the only thing you're hearing is the humming of your tires
You'll be riding soft and easy, with a road as smooth as felt
Then don't forget the boys, who lay the hot asphalt

The Pogues – Hot Asphalt

U.S. Department of Transportation
Federal Highway Administration

2019 Construction and Project Development Conference

March 6, 2019
Bismarck, ND

NDDOT
North Dakota Department of Transportation

Robert Conway, P.E., CCM
FHWA-Resource Center

U.S. Department of Transportation
Federal Highway Administration

Migration Toward Percent Within Limits (PWL)

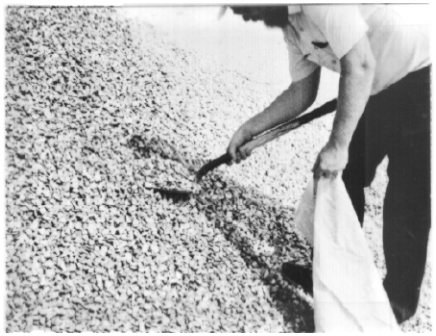
- General Discussion of PWL Benefits
- Overview of How PWL Works
- Comparison of PWL to Average
- How to Implement

Sources of Variability

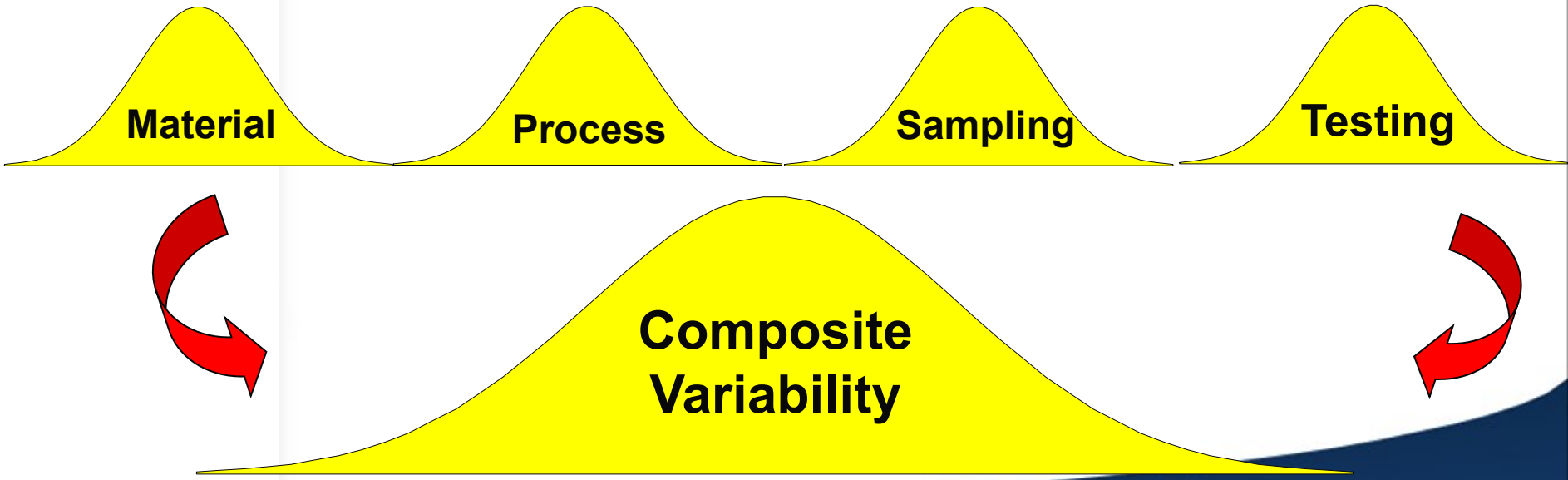
Material

Process

Sampling

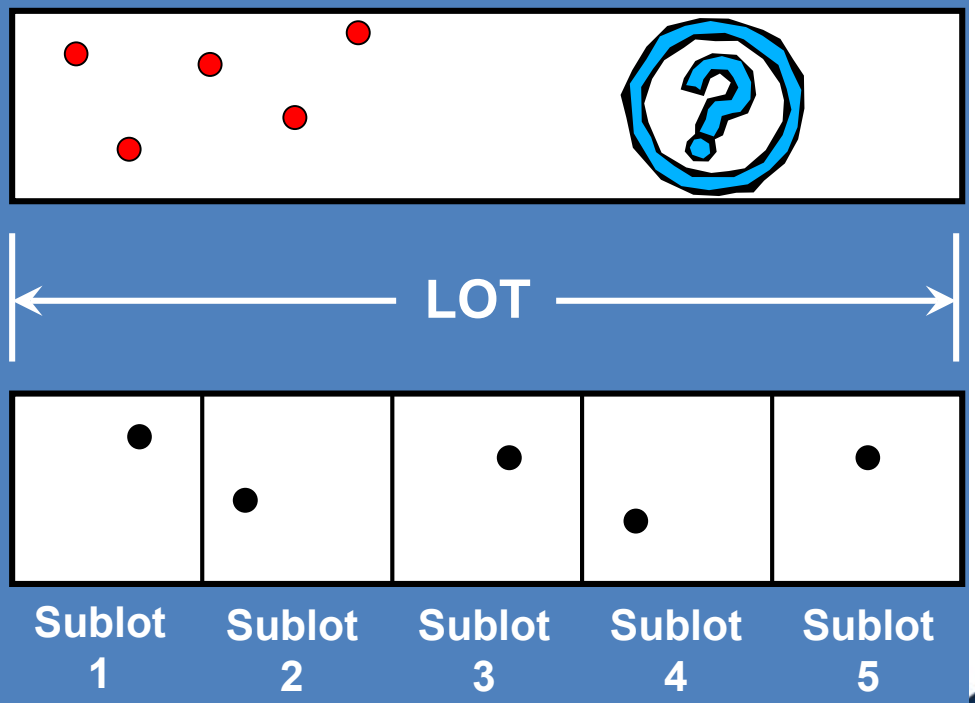


Testing



Random Sampling

- Simple Random Sampling
- Stratified Random Sampling
  - Ensures all material will be sampled
  - No extra cost
  - Reduces fraud



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100 Asphalt Contents (%)

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Arrange Low to High

Low

5.45	5.75	5.83	5.90	5.95	6.01	6.05	6.11	6.17	6.26
5.57	5.76	5.85	5.90	5.96	6.01	6.06	6.11	6.18	6.28
5.62	5.77	5.85	5.91	5.96	6.01	6.06	6.12	6.19	6.29
5.63	5.78	5.85	5.92	5.97	6.02	6.07	6.13	6.19	6.30
5.65	5.79	5.86	5.92	5.97	6.02	6.07	6.13	6.20	6.33
5.67	5.80	5.87	5.93	5.98	6.03	6.08	6.14	6.22	6.33
5.69	5.81	5.87	5.93	5.98	6.03	6.08	6.15	6.23	6.37
5.72	5.81	5.88	5.94	5.99	6.04	6.09	6.15	6.23	6.39
5.73	5.82	5.88	5.94	5.99	6.04	6.10	6.16	6.24	6.42
5.74	5.83	5.89	5.95	5.99	6.05	6.10	6.16	6.25	6.47

High

Minimum and Maximum

Range = Max-Min

= 6.47 – 5.45

= 1.02

Mean or "Average"

Mean = Sum / Total Count

= 599.85 / 100

= 6.00

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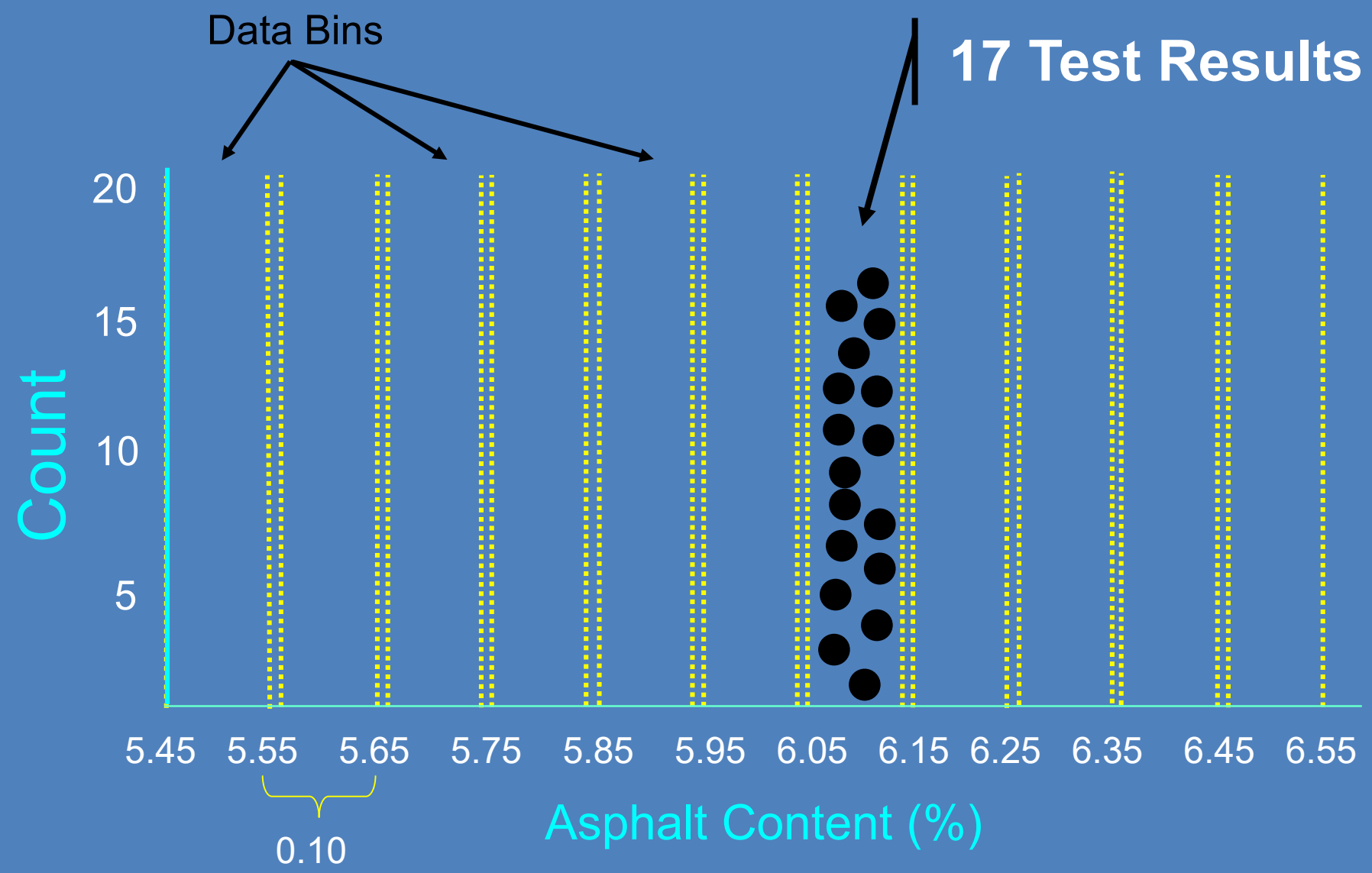
Median: Halfway point of dataset

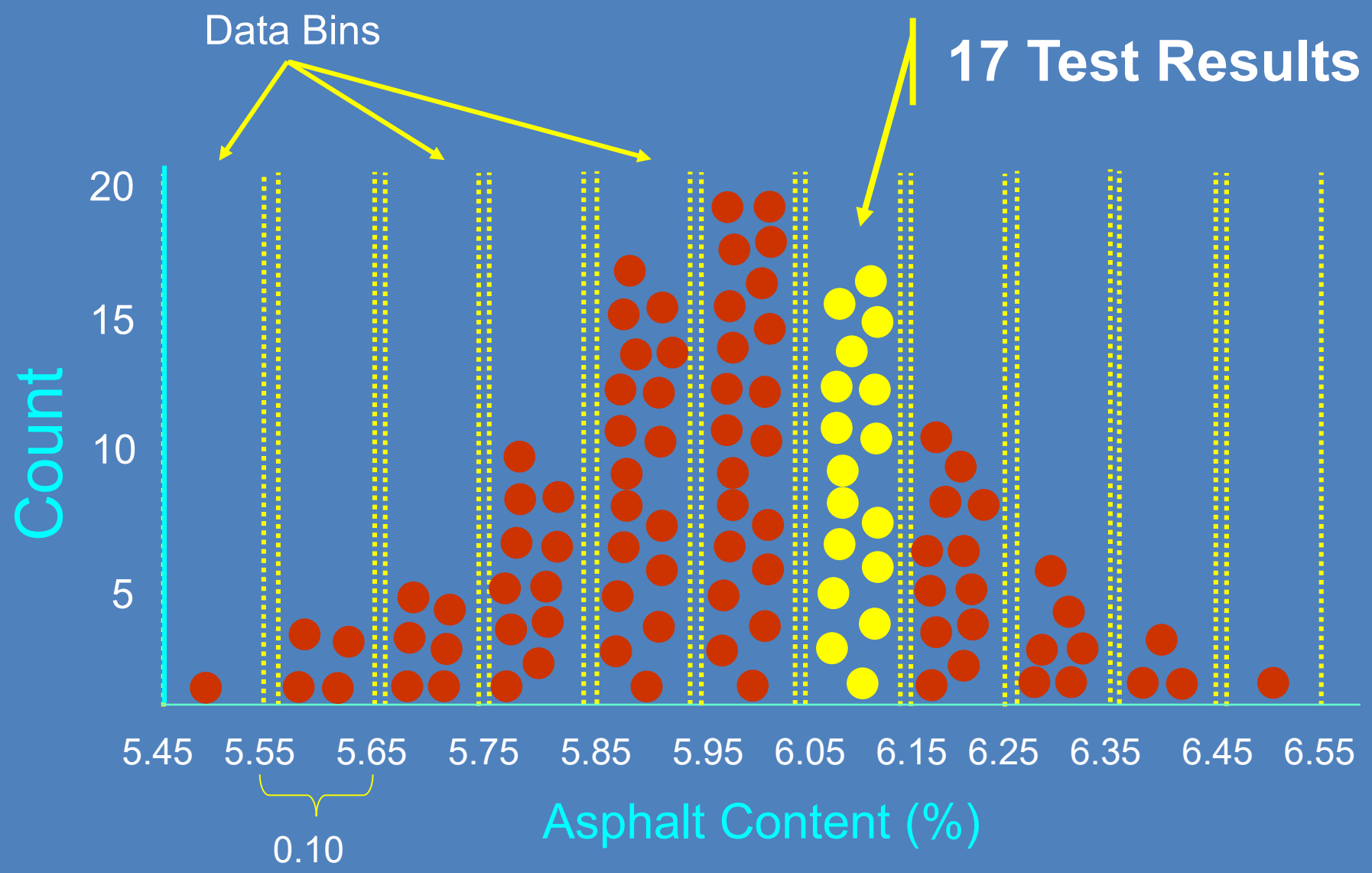
Low

5.45	5.75	5.83	5.90	5.95	6.01	6.05	6.11	6.17	6.26
5.57	5.76	5.85	5.90	5.96	6.01	6.06	6.11	6.18	6.28
5.62	5.77	5.85	5.91	5.96	6.01	6.06	6.12	6.19	6.29
5.63	5.78	5.85	5.92	5.97	6.02	6.07	6.13	6.19	6.30
5.65	5.79	5.86	5.92	5.97	6.02	6.07	6.13	6.20	6.33
5.67	5.80	5.87	5.93	5.98	6.03	6.08	6.14	6.22	6.33
5.69	5.81	5.87	5.93	5.98	6.03	6.08	6.15	6.23	6.37
5.72	5.81	5.88	5.94	5.99	6.04	6.09	6.15	6.23	6.39
5.73	5.82	5.88	5.94	5.99	6.04	6.10	6.16	6.24	6.42
5.74	5.83	5.89	5.95	5.99	6.05	6.10	6.16	6.25	6.47

High

Median = (5.99+6.01)/2 = 6.00


Data Bins
17 Test Results
Count
20
15
10
5
5.45
5.55
5.65
5.75
5.85
5.95
6.05
6.15
6.25
6.35
6.45
6.55
0.10
Asphalt Content (%)


Data Bins
17 Test Results
Count
20
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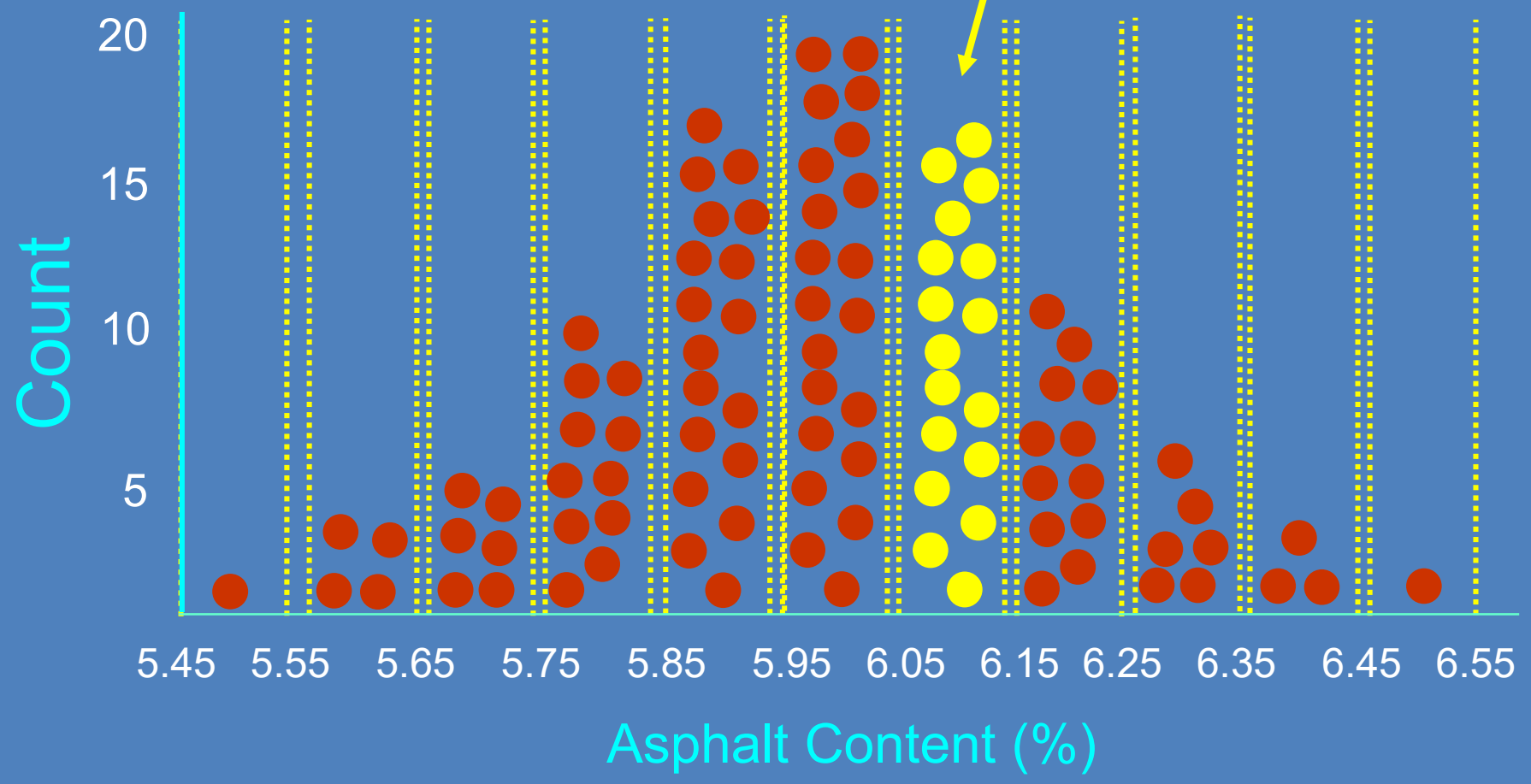
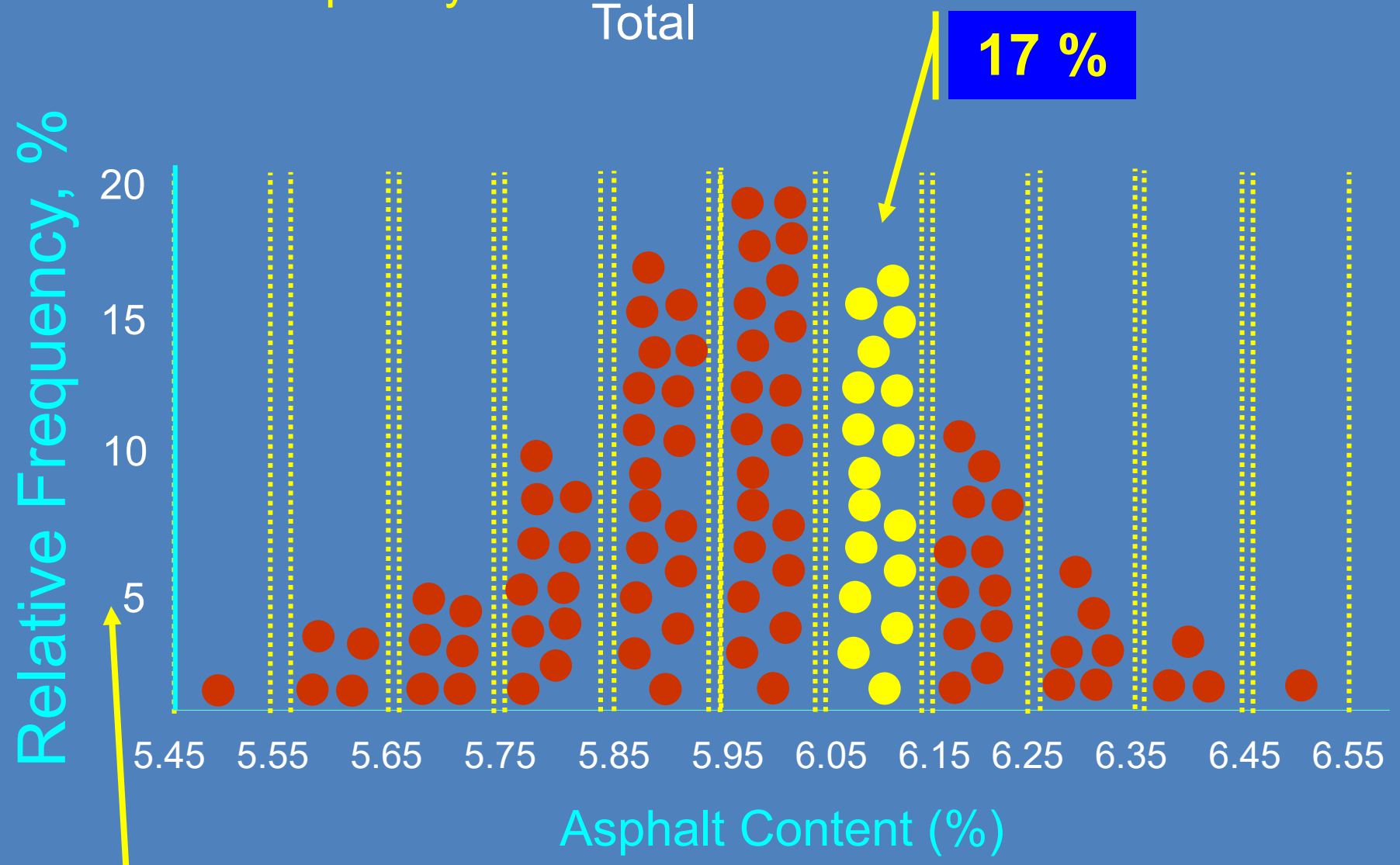
5.45
5.55
5.65
5.75
5.85
5.95
6.05
6.15
6.25
6.35
6.45
6.55
0.10
Asphalt Content (%)

$$\text{Relative Frequency} = \frac{\text{Bin Count}}{\text{Total}}$$

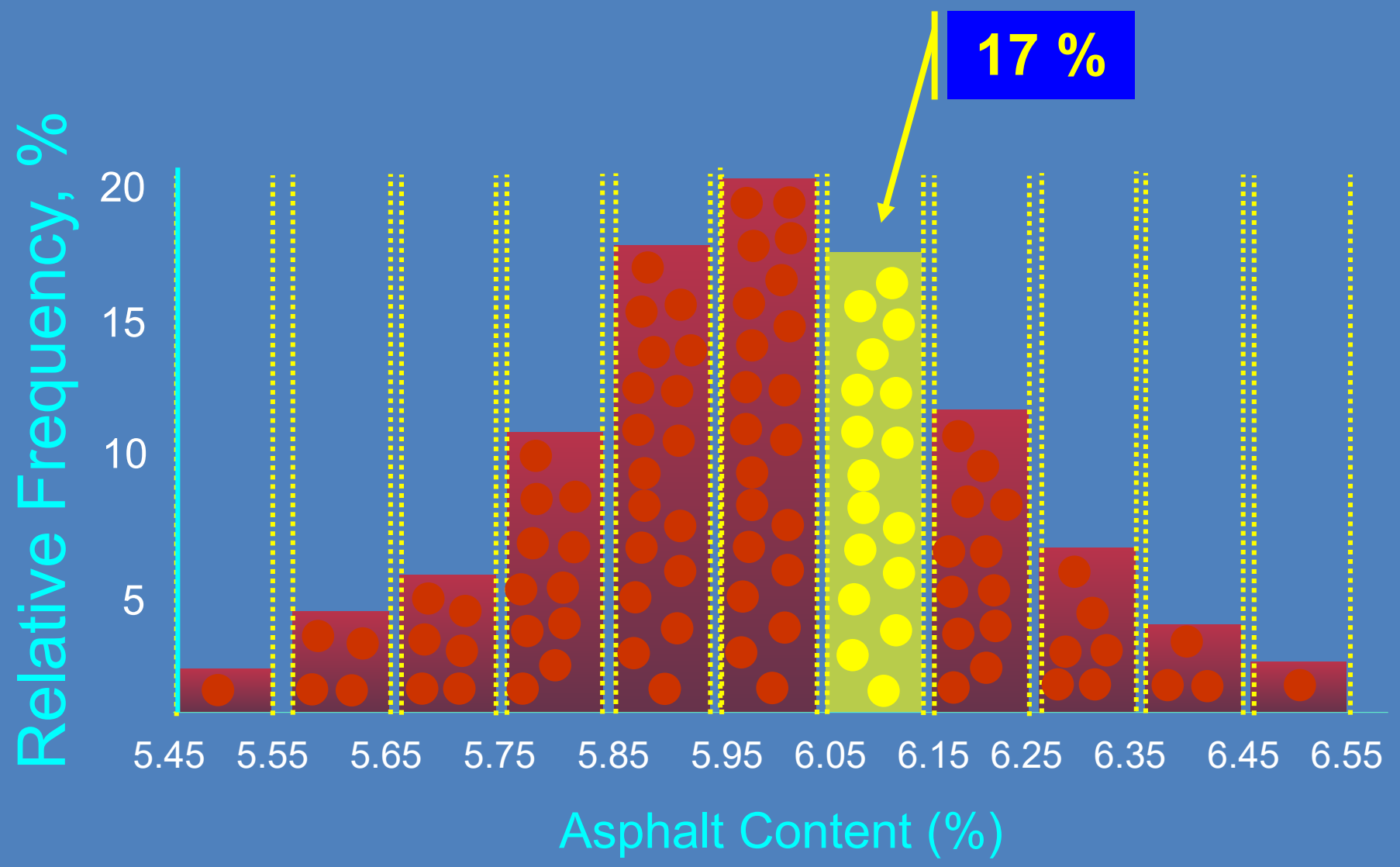
17 Test Results



$$\text{Relative Frequency} = \frac{\text{Bin Count}}{\text{Total}}$$



Axis did not change because we had "100" test results


17 %
Relative Frequency, %
20
15
10
5
5.45
5.55
5.65
5.75
5.85
5.95
6.05
6.15
6.25
6.35
6.45
6.55
Asphalt Content (%)

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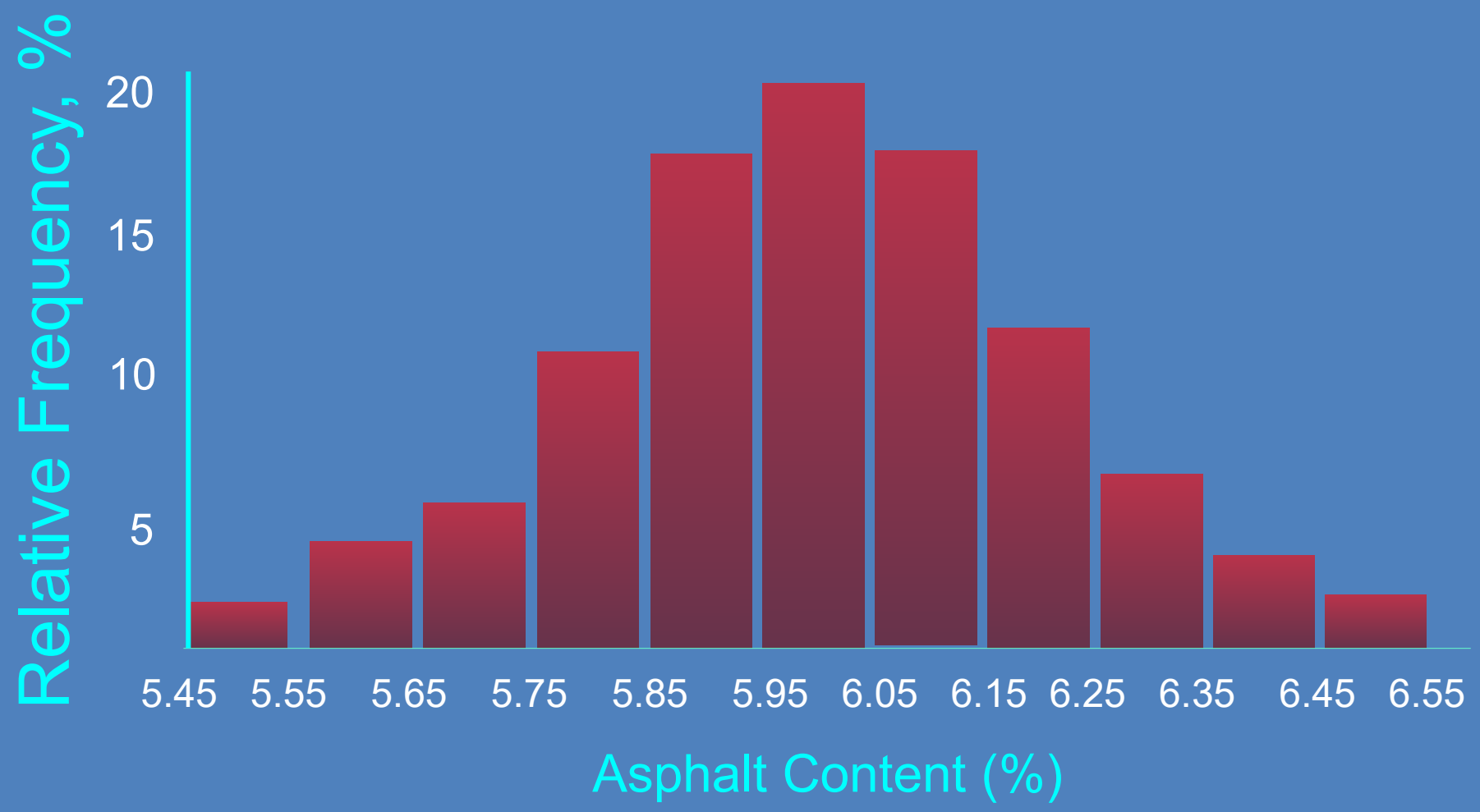
Histogram



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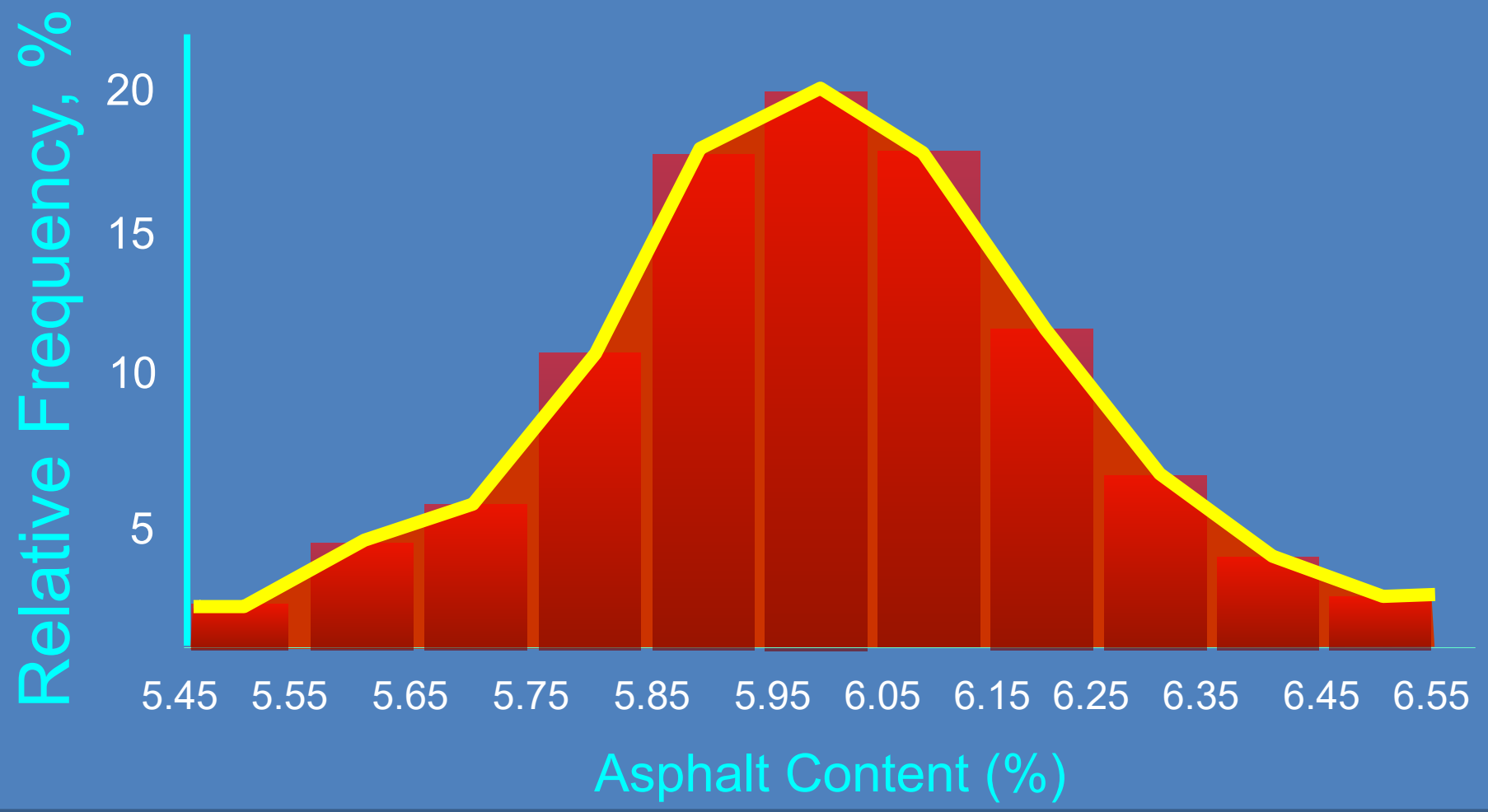
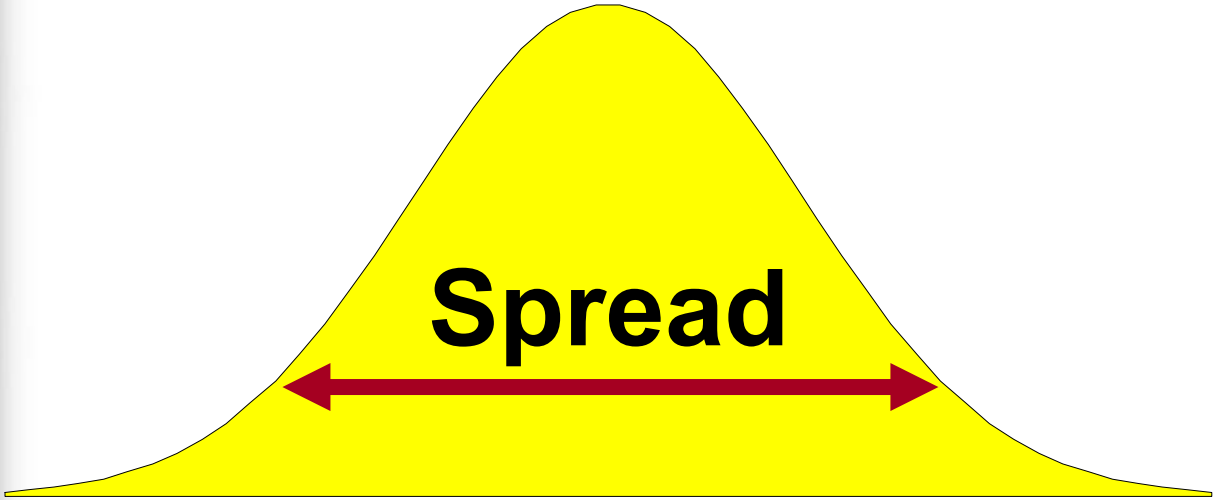
Bell Shaped Curve

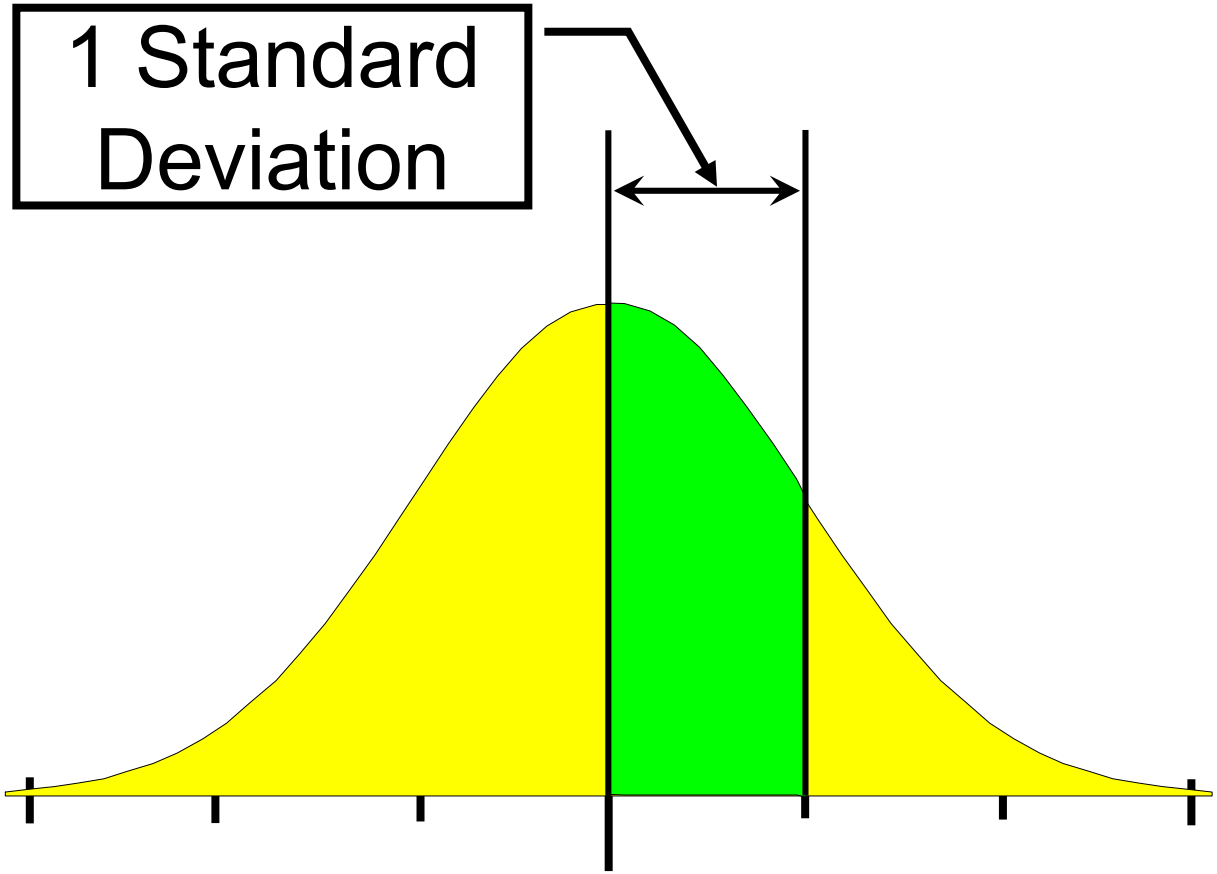


Standard Deviation

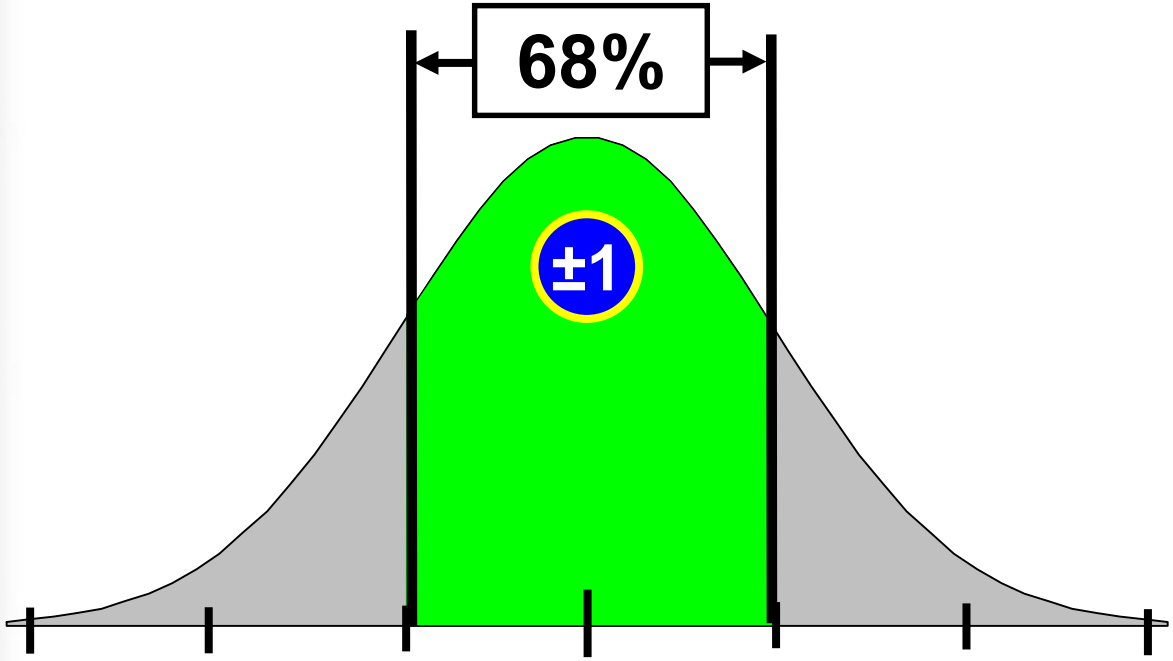
- A measure of the variability (i.e. spread) of data



Standard Deviation



Data within ± 1 Standard Deviation



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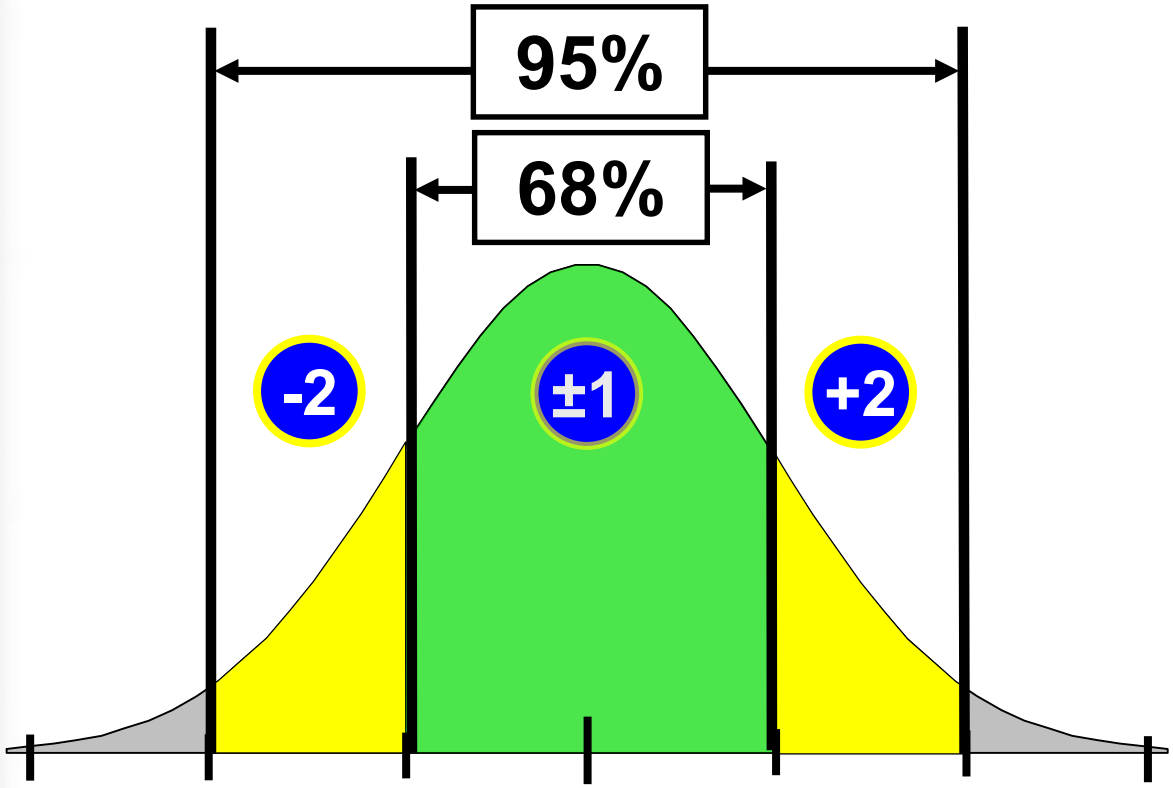
± 1 Standard Deviation ≈ 68%

Data

5.45	5.75	5.83	5.90	5.95	6.01	6.05	6.11	6.17	6.26
5.57	5.76	5.85	5.90	5.96	6.01	6.06	6.11	6.18	6.28
5.62	5.77	5.85	5.91	5.96	6.01	6.06	6.12	6.19	6.29
5.63	5.78	5.85	5.92	5.97	6.02	6.07	6.13	6.19	6.30
5.65	5.79	5.86	5.9[illegible]	5.97	6.02	6.07	6.13	6.20	6.33
5.67	5.80	5.87	5.9[illegible]	5.98	6.03	6.08	6.14	6.22	6.33
5.69	5.81	5.87	5.93	5.98	6.03	6.08	6.15	6.23	6.37
5.72	5.81	5.88	5.94	5.99	6.04	6.09	6.15	6.23	6.39
5.73	5.82	5.88	5.94	5.99	6.04	6.10	6.16	6.24	6.42
5.74	5.83	5.89	5.95	5.99	6.05	6.10	6.16	6.25	6.47

68%

Data within
± 2 Standard Deviations



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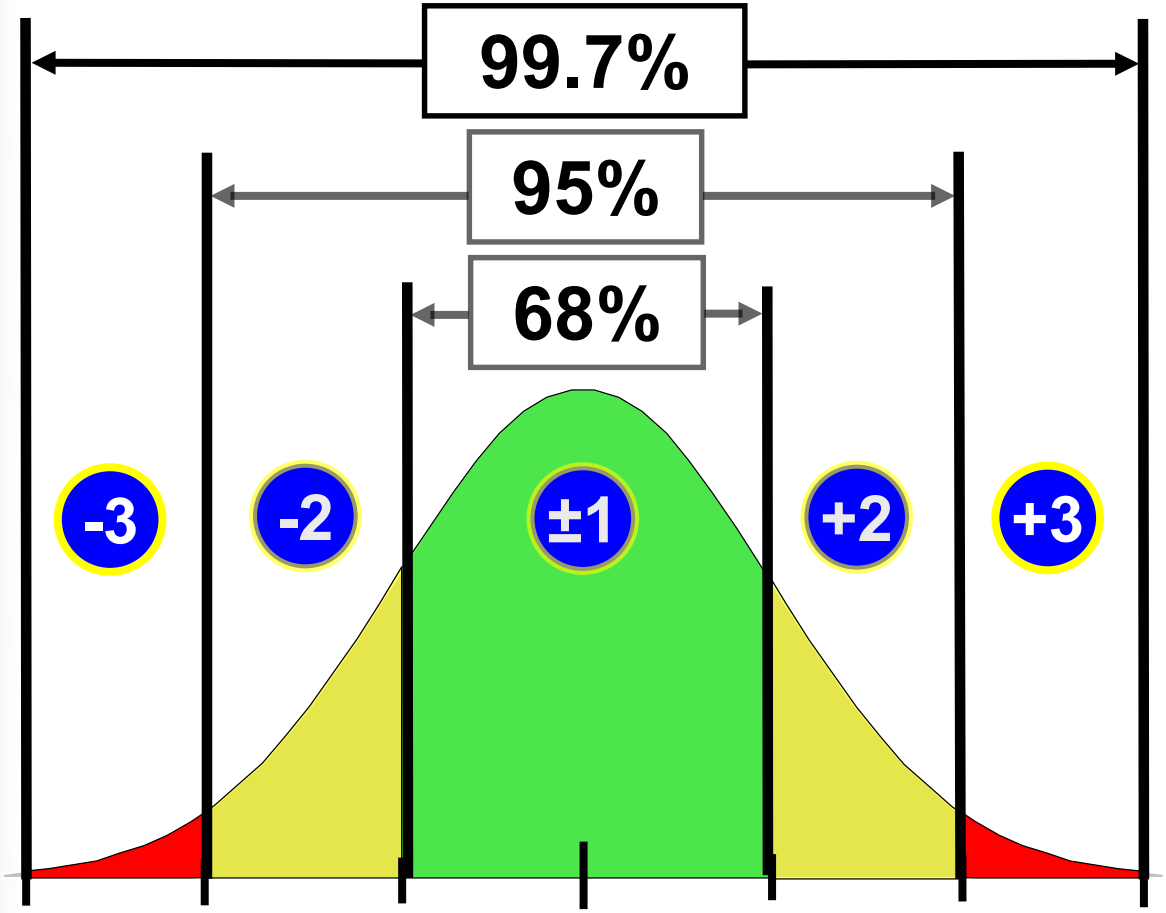
± 2 Standard Deviations
≈ 95% Data

5.45	5.75	5.83	5.90	5.95	6.01	6.05	6.11	6.17	6.26
5.57	5.76	5.85	5.90	5.96	6.01	6.06	6.11	6.18	6.28
5.62	5.77	5.85	5.91	5.96	6.01	6.06	6.12	6.19	6.29
5.63	5.78	5.85	5.9[illegible]	[illegible].97	6.[illegible]2	6.[illegible]7	6.13	6.19	6.30
5.65	5.79	5.86	5.[illegible]	5.97	6.02	[illegible].07	6.13	6.20	6.33
5.67	5.80	5.87	5.9[illegible]	5.98	6.03	6.0[illegible]	6.14	6.22	6.33
5.69	5.81	5.87	5.93	5.98	6.03	6.08	6.15	6.23	6.37
5.72	5.81	5.88	5.94	5.99	6.04	6.09	6.15	6.23	6.39
5.73	5.82	5.88	5.94	5.99	6.04	6.10	6.16	6.24	6.42
5.74	5.83	5.89	5.95	5.99	6.05	6.10	6.16	6.25	6.47

95%

Data within
± 3 Standard Deviations



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± 3 Standard Deviations
≈ 99.7% Data

5.45	5.75	5.83	5.90	5.95	6.01	6.05	6.11	6.17	6.26
5.57	5.76	5.85	5.90	5.96	6.01	6.06	6.11	6.18	6.28
5.62	5.77	5.85	5.91	5.96	6.01	6.06	6.12	6.19	6.29
5.63	5.78	5.8[illegible]	[illegible].92	5.97	6.02	6.[illegible]7	6.[illegible]3	6.19	6.30
5.65	5.79	5.8[illegible]	[illegible].92	5.97	6.[illegible]2	6.07	6.13	6.20	6.33
5.67	5.80	5.8[illegible]	5.93	5.98	6.03	6.08	6.1[illegible]	6.22	6.33
5.69	5.81	5.87	5.93	5.98	6.03	6.08	6.15	6.23	6.37
5.72	5.81	5.88	5.94	5.99	6.04	6.09	6.15	6.23	6.39
5.73	5.82	5.88	5.94	5.99	6.04	6.10	6.16	6.24	6.42
5.74	5.83	5.89	5.95	5.99	6.05	6.10	6.16	6.25	6.47

99.7%

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Standard Deviation: Equations

- Sample standard deviation (s)

$$s = \sqrt{\frac{\sum(X_i - \bar{X})^2}{n - 1}}$$

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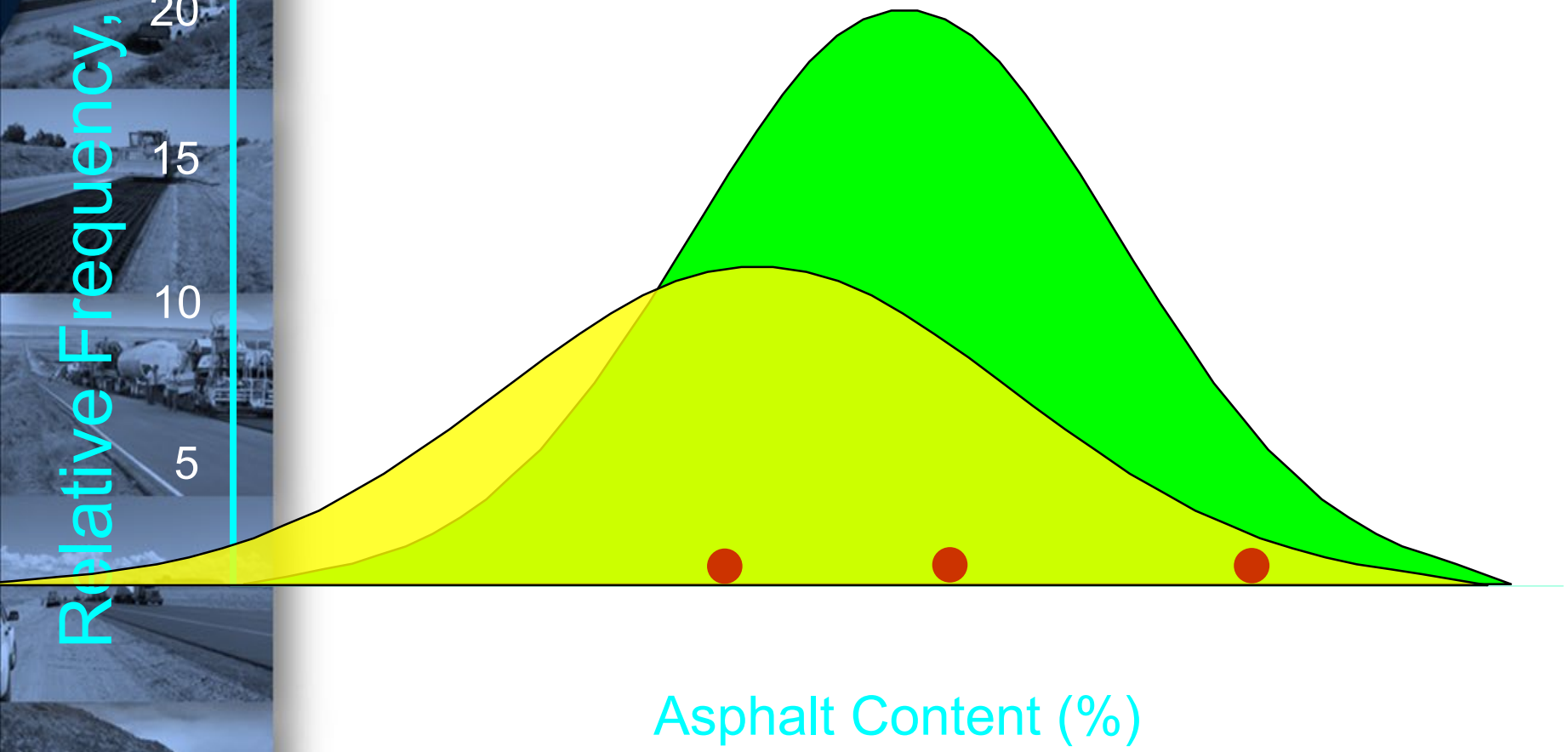
3 Samples, Different Populations



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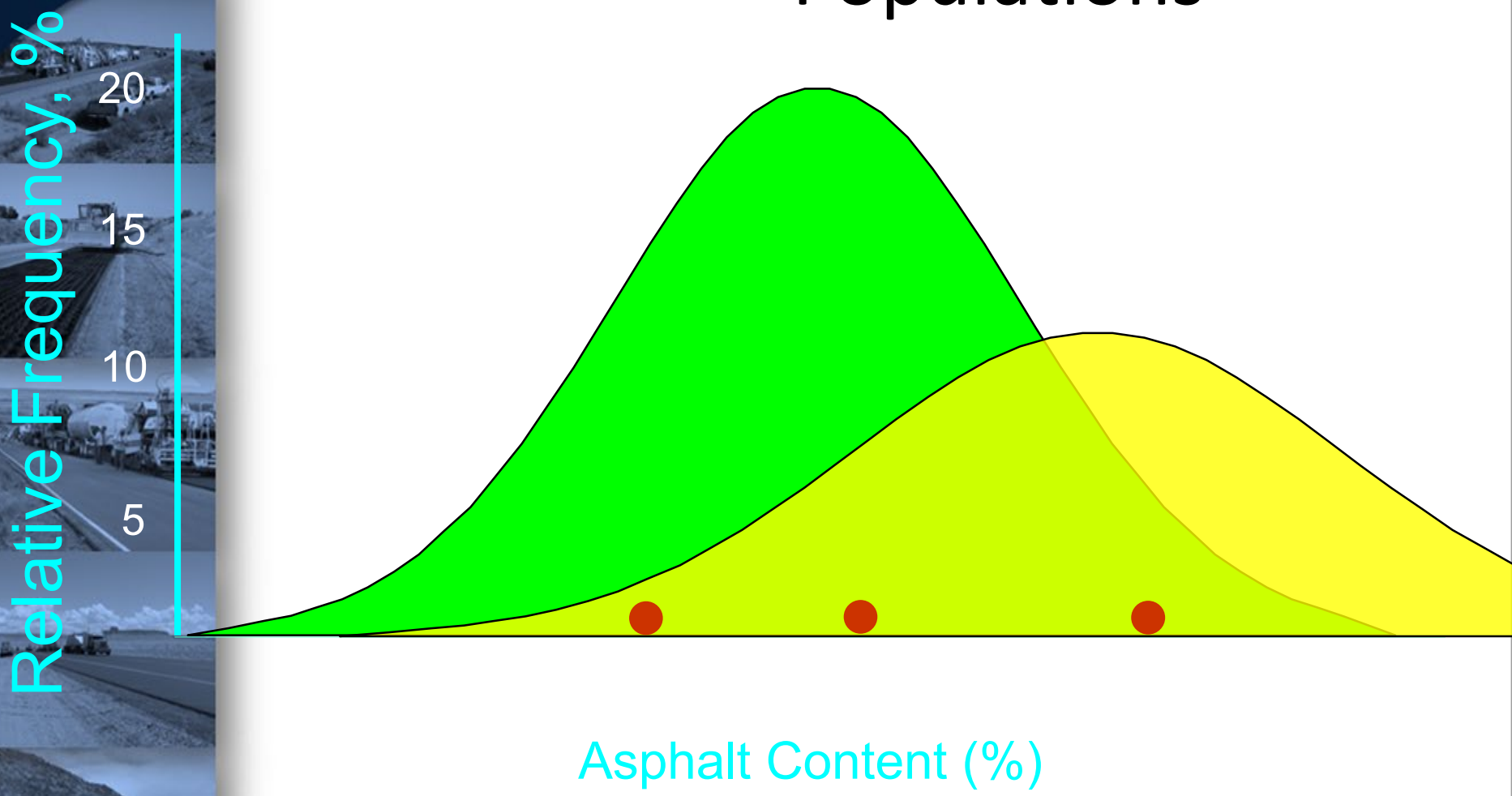
3 Samples, Different Populations



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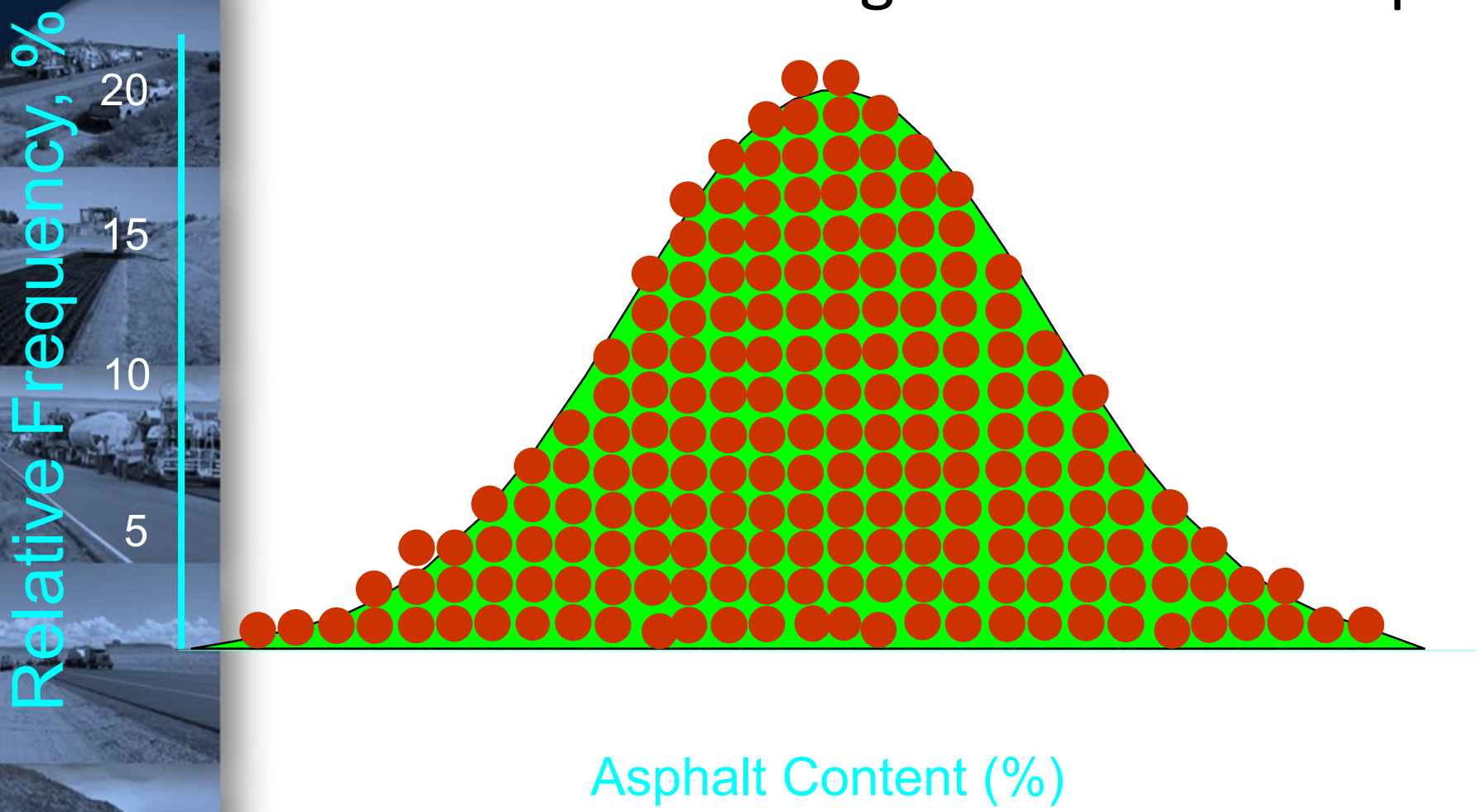
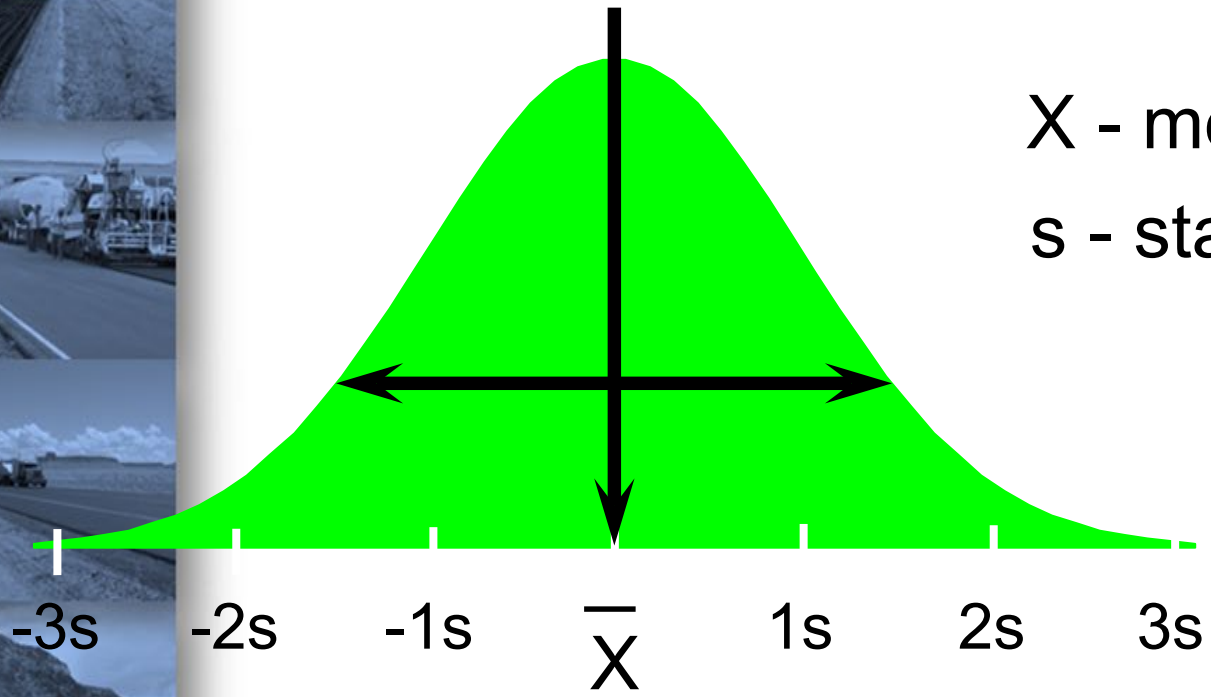
Estimate of Population Improves with Increasing Number of Samples



PWL

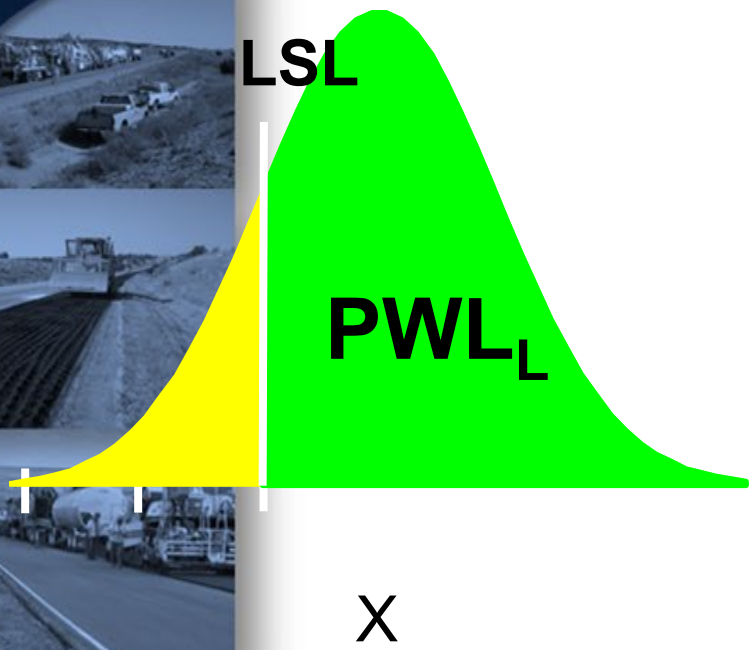
- Efficiently captures mean and standard deviation in one quality measure



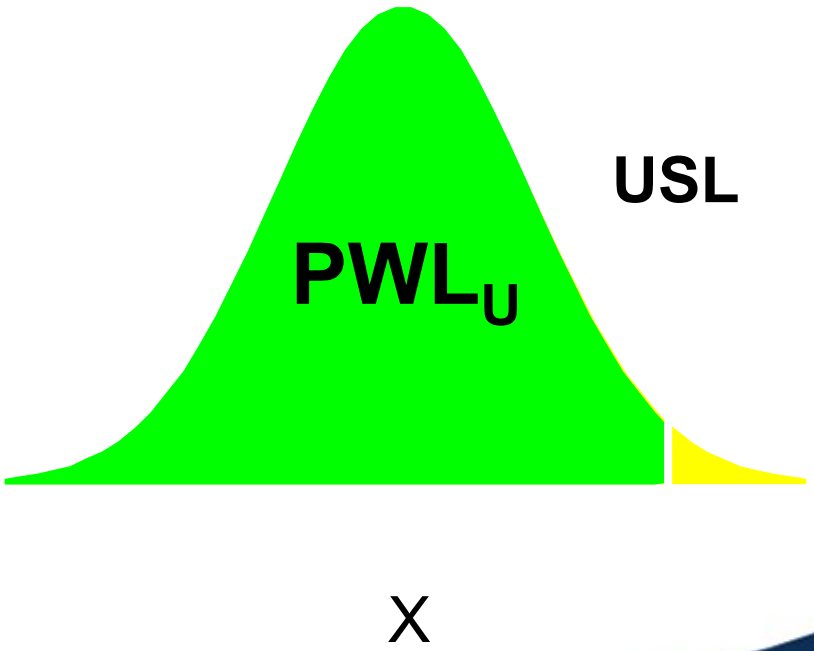
X - mean

s - standard deviation

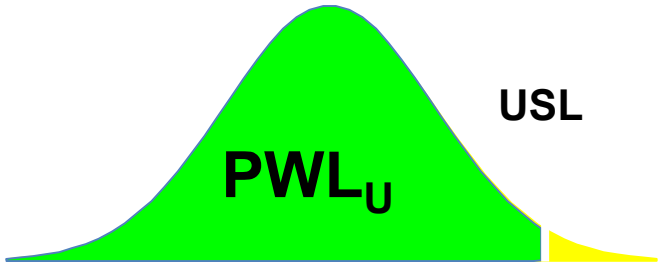
Single Specification PWL

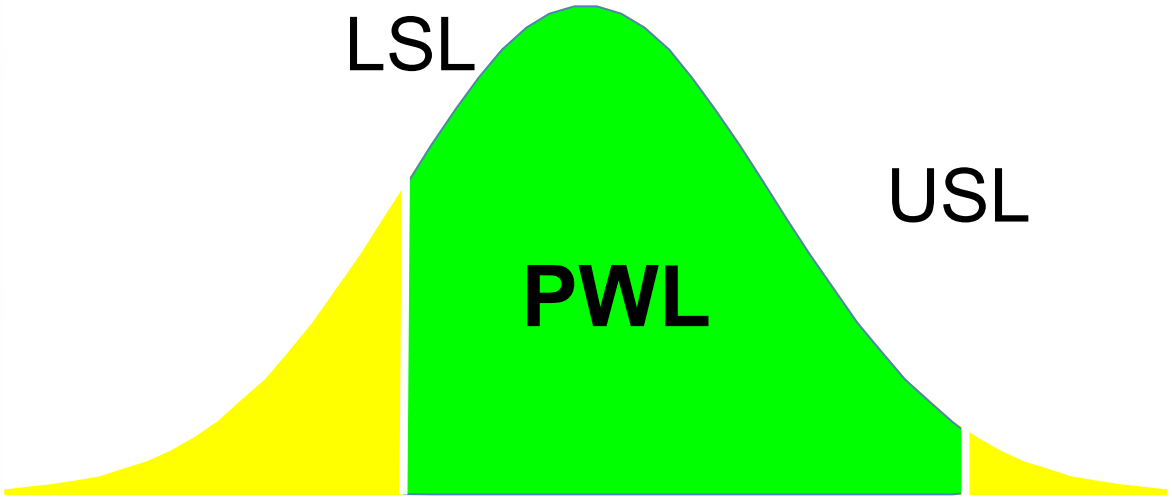


or



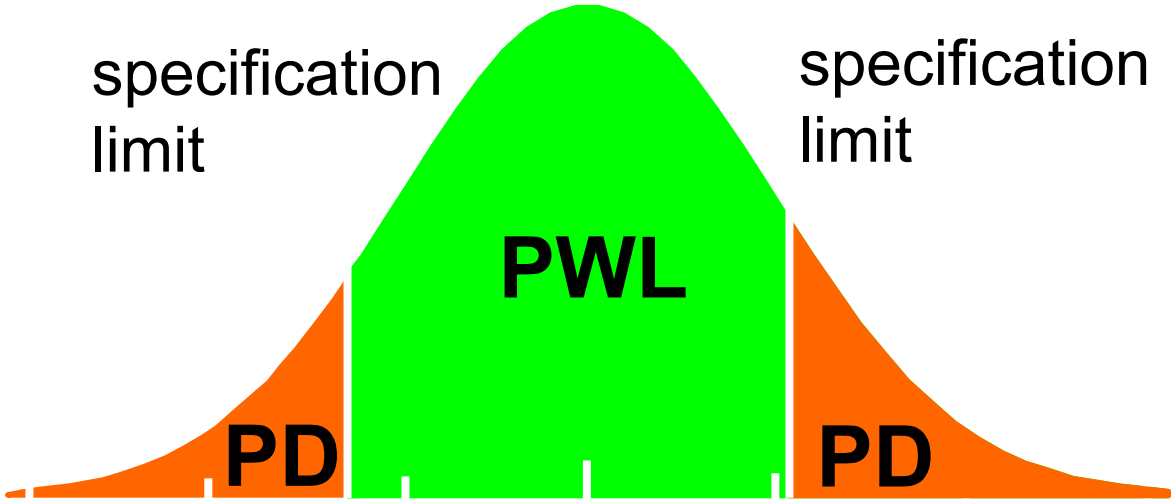
Double Specification PWL





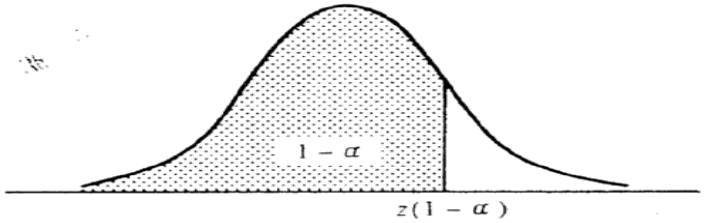
Recommended Quality Measure

- Percent within Limits (PWL)
- Percent Defective (PD)



Cumulative Probabilities of the Standard Normal Distribution

Entry is area $1 - \alpha$ under the standard normal curve from $-\infty$ to $z(1 - \alpha)$

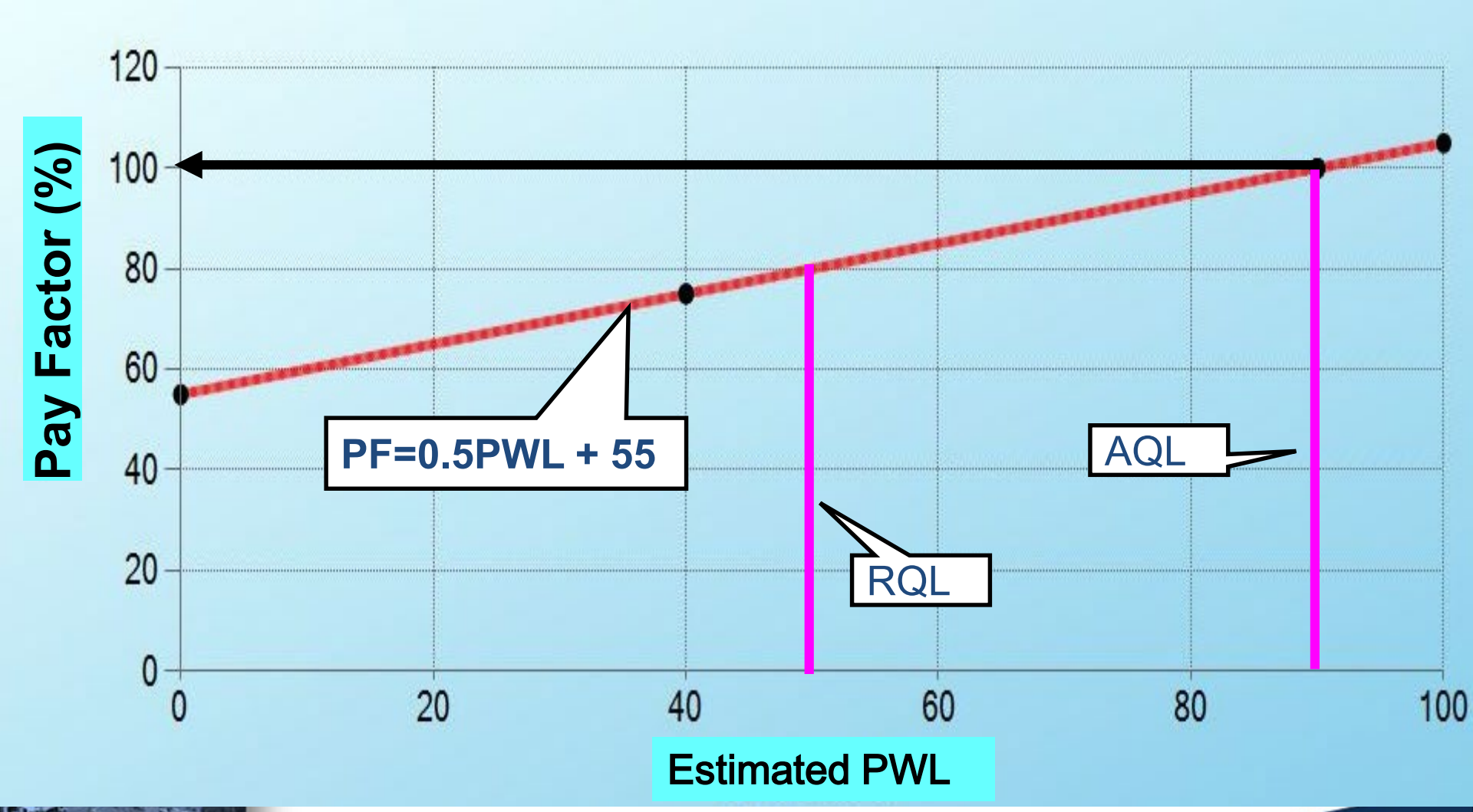


z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767

PWL Benefits

- Quantifies how much of the material received was within contract
- Average and Spread of test data in a single quality measure
- More Accurately Characterizes the Quality of each Lot or Population of Data
- Methodology to Adjust Price Based on Quality Received

Payment Plan with 5% Incentive



Comparing PWL

Density Lower Spec. Limit: 93.0

92.4	93.3	94.7
93.7	93.4	95.6
91.7	92.8	93.8
94.4	92.5	94.9
	92.6	95.0
Mean: 93.05	Mean: 92.92	Mean: 94.80
Range: 2.7	Range: 0.9	Range: 1.8
St. Dev: 1.22	St. Dev: 0.41	St. Dev: 0.65
P-Value: 11.7	P-Value: 4.52	P-Value: -14.5
PWL: 51.4	PWL: 43.0	PWL: 100
PF: 80.7%	PF: 76.5%	PF: 105%

Implementing PWL

- Contractor is successful if they can control variability and target within limits
- Quality Measures
- Population of Test Data
- PWL Training
- Specification Development
- Individual PWL Training/Meeting
- Calibration

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There's Help Available

PWL Training

- FHWA PWL 1.5 day workshop
  - Dennis Dvorak, FHWA
  - Robert Conway, FHWA
- NHI Course # 134064 Transportation Construction Quality Assurance

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Thank You – Questions?

Robert Conway, P.E. CCM

- robert.conway@dot.gov
- FHWA – Resource Center
  - 202-906-0536