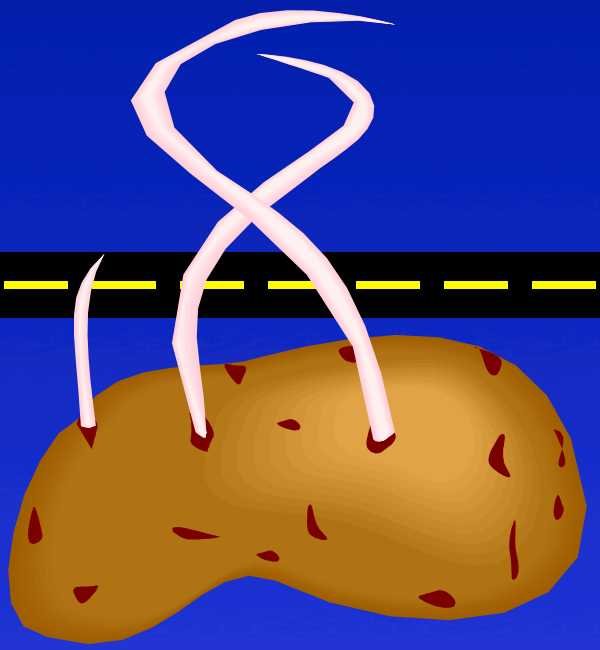
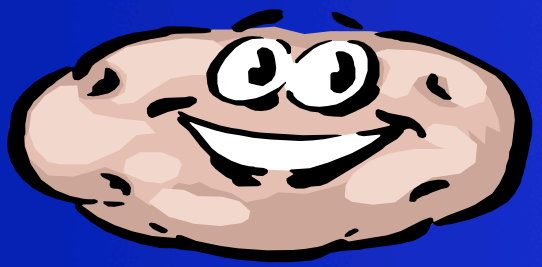
Redneck Olympics - FreeStyle Mudding

Variability in Pavement Construction

Baked Potatoes by a College Student



- Take two potatoes
- Cook one until it explodes
- Cook the second one slightly less



Method Specification

- Used routinely in past
- Contractor is told what to produce, what equipment to use, and how to place the material

Then penalized when it doesn't work!

Warranty

Performance Specification

- Significant leeway to contractor as long as performance guidelines are met
- Significant risk for product services to contractor

What are causes of variability?

Almost Everything!!

No two tests are ever run under exactly same conditions.

Statistics as a Tool

Test Method Variability

- Is test method precise?
- Which of several methods is most precise?
- What is quality of lab work?
- Has material become contaminated?
- What are appropriate manufacturing targets?

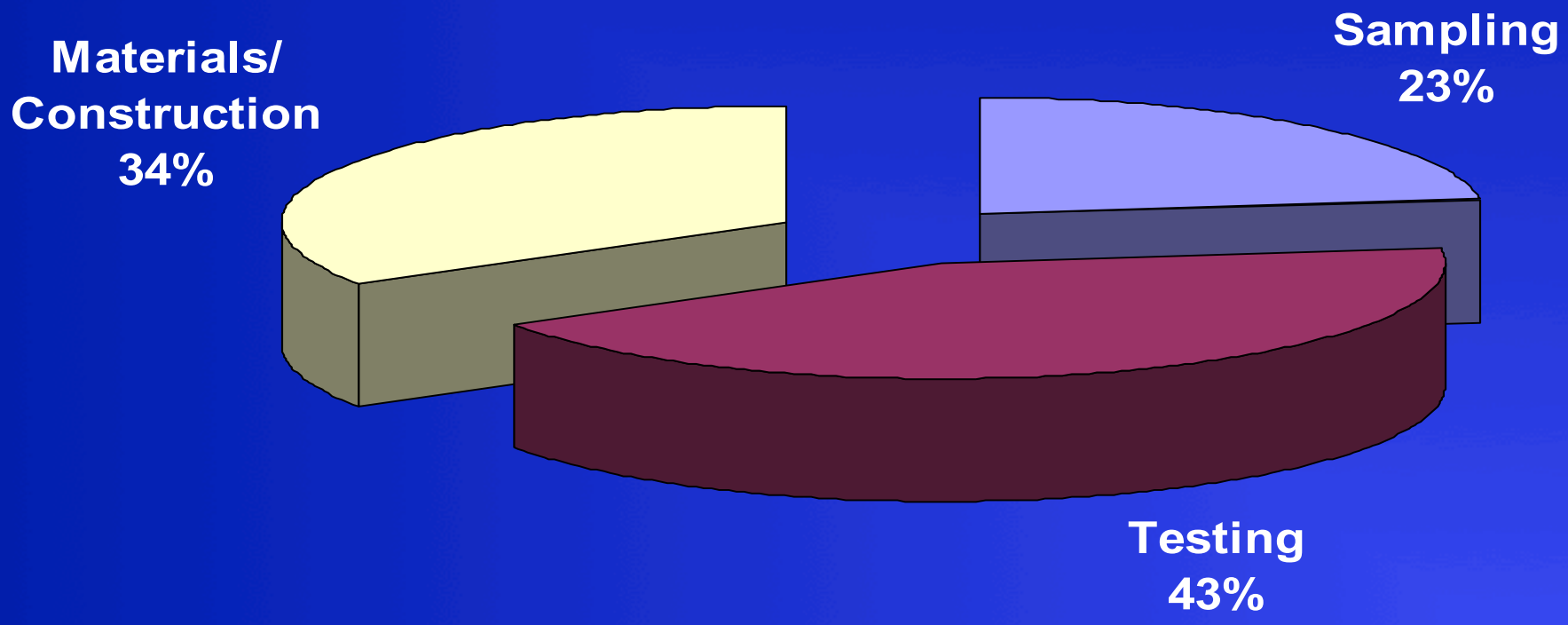
Variability Example

- Average adult male in U.S. is 5’9”
- Info not very helpful to determine how tall to make doorways

Sources of Variability

- Within Lab
  - Comparison of test results for same tech in same lab performing test at different times
- Between Lab
  - Comparison of test results for two techs in different labs

Variability



Examples of Variability

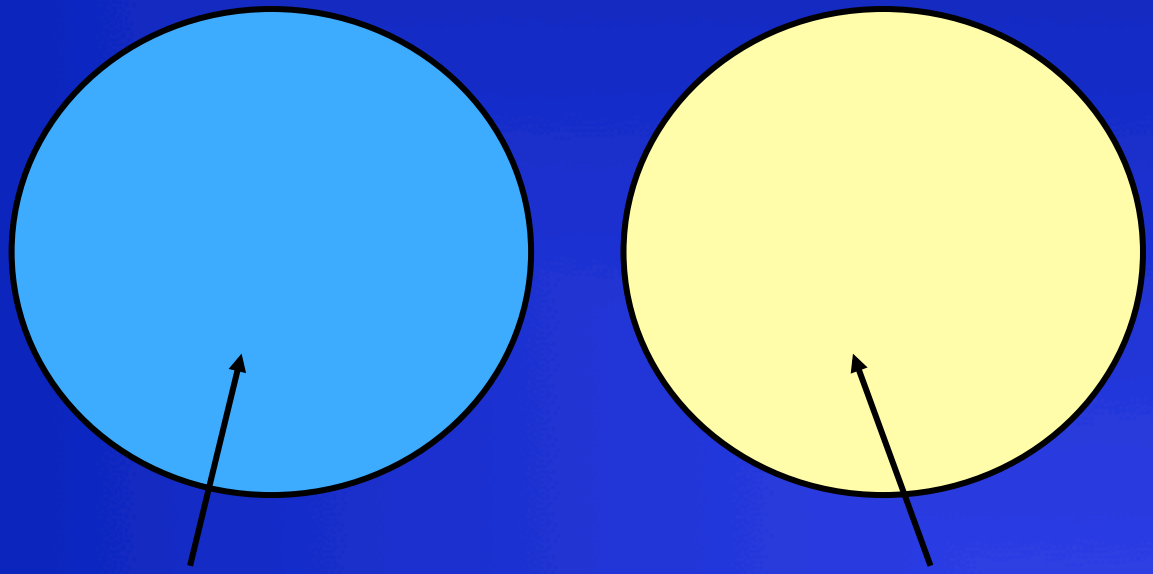
- Aggregate sampled consistently from one side of a stockpile
  - Gradation may be influenced by wind blown particles
- Mix consistently sampled from edge of paved lane
  - Segregation can influence test methods

Test Variation

When result outside range

Re-evaluate test results before applying any penalty

Independent Variables



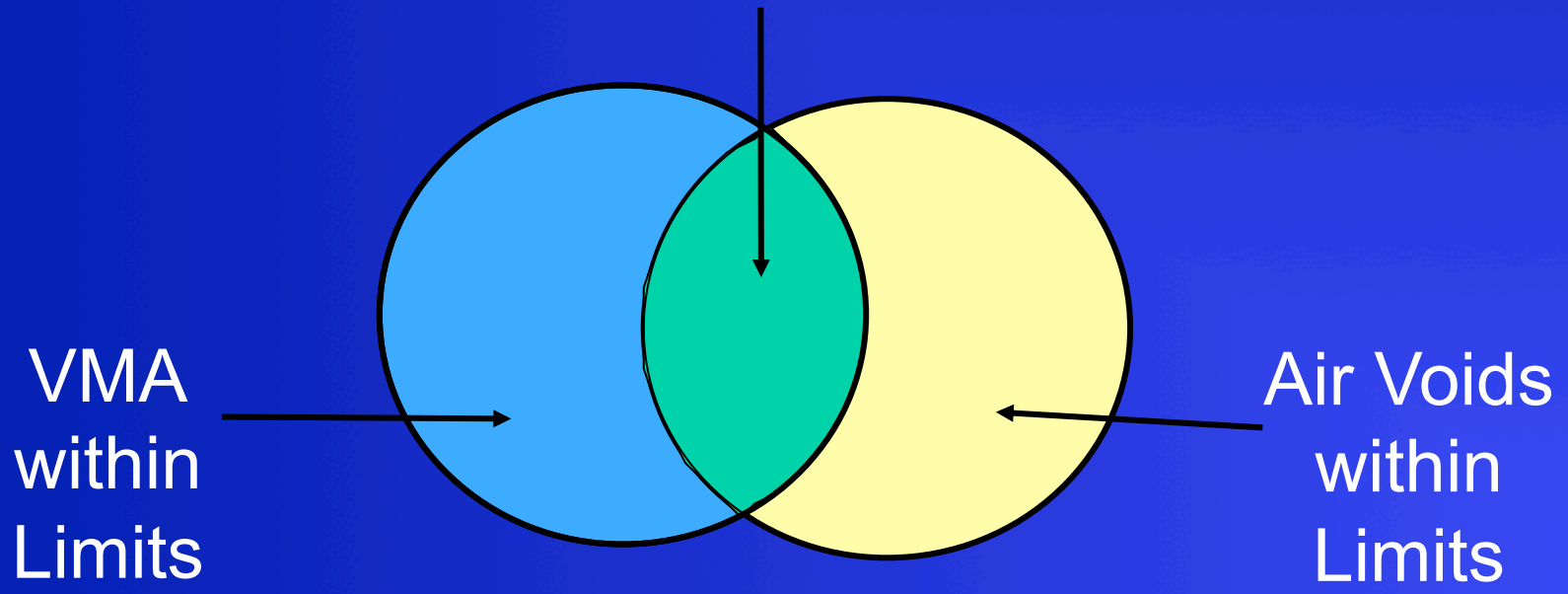
Layer Thickness in Specified Limits

Asphalt Content in Specified Limits

Dependent Variables

Both Air Voids and

VMA within Limits

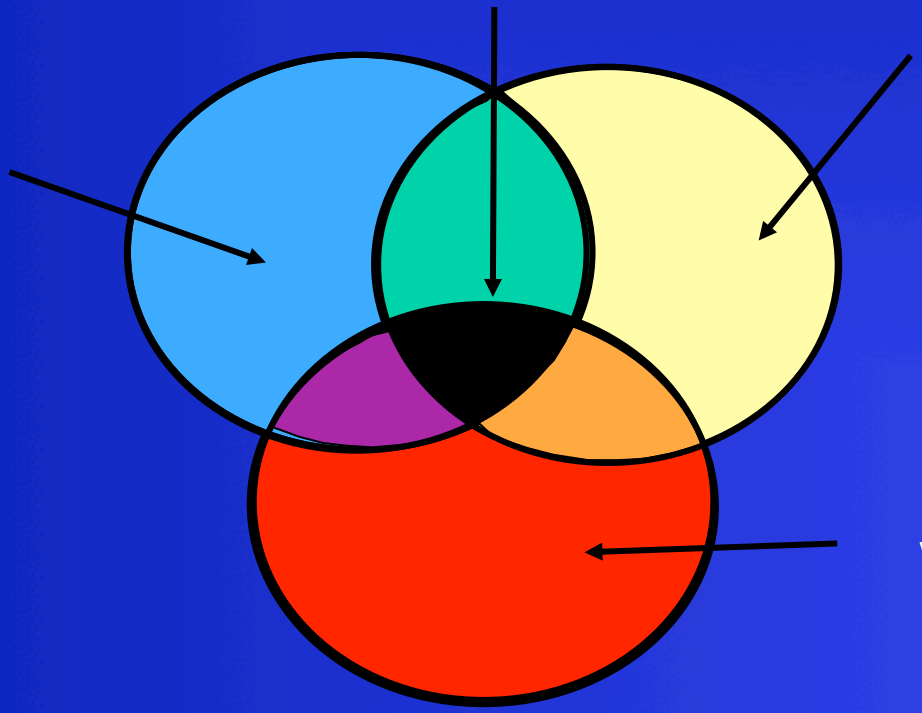


Dependent Variables

Air Voids, VMA and VFA all within Limits

VMA within Limits

Air Voids within Limits

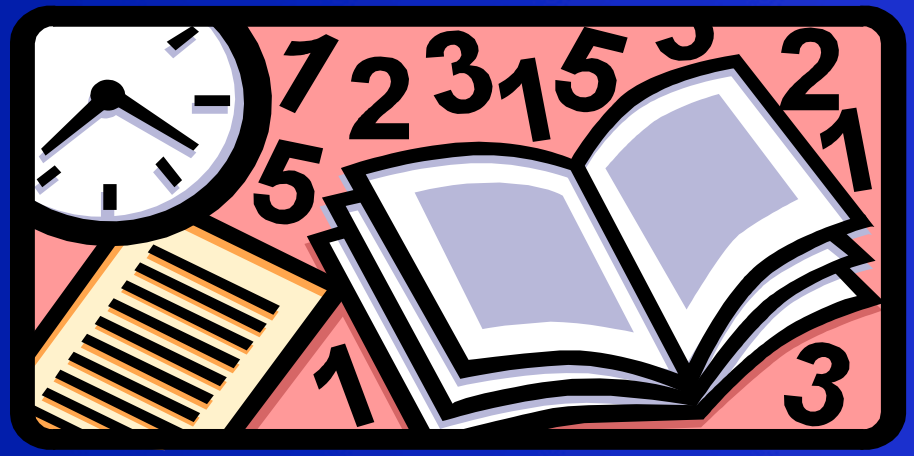


VFA within Limits

Statistics in Pavement Construction

Statistics

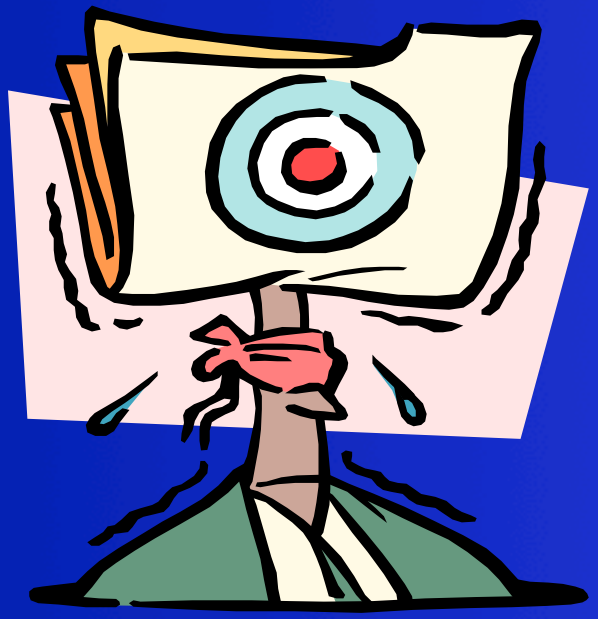
The mathematics of the collection, organization, and interpretation of numerical data



American Heritage Dictionary

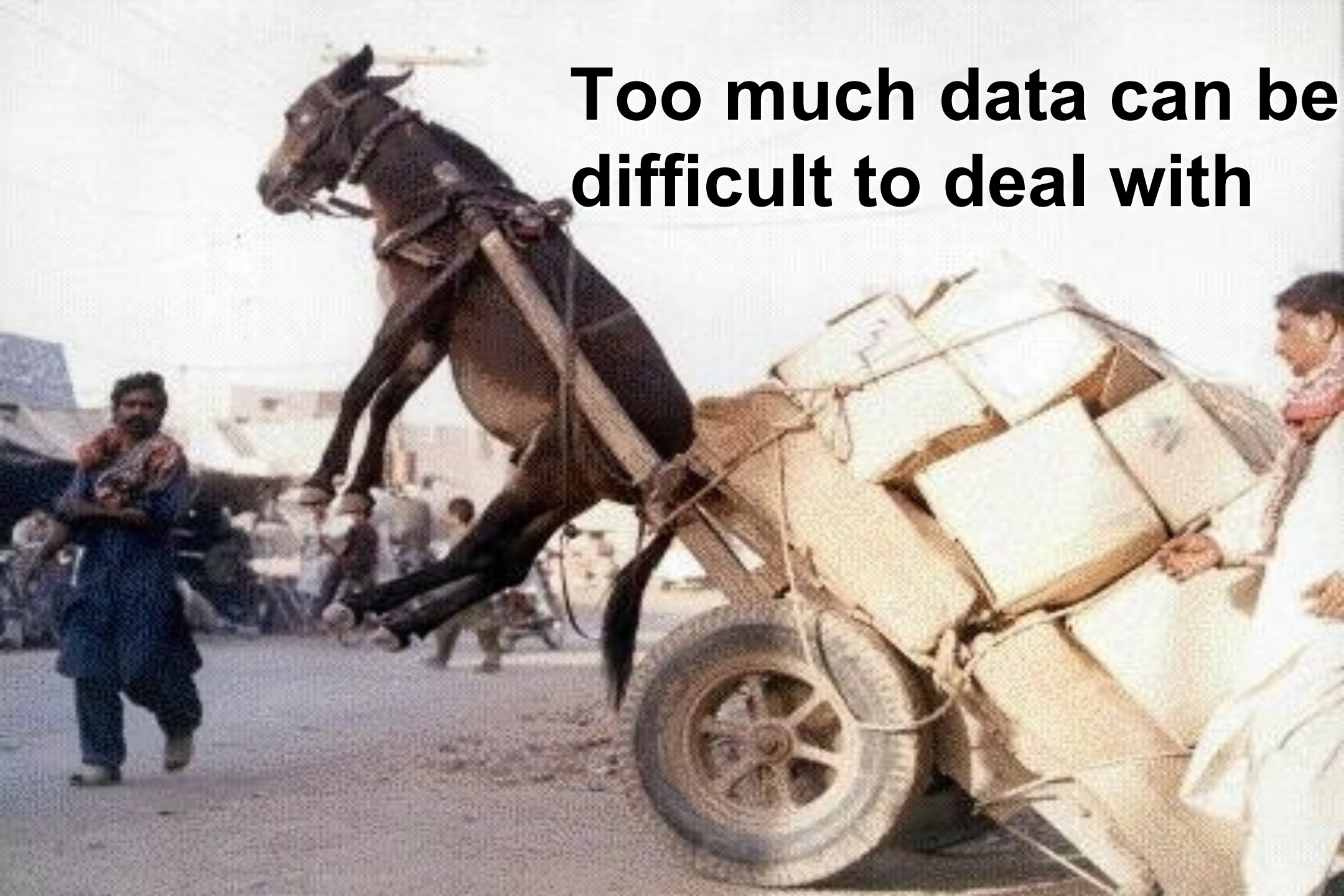
Statistics

The science that scares the hell out of normal people.



Dale Decker

	3/8"	5/16"	1/4"	#4	1/8"	#8	#20	Sample Type	Tested By
September 21, 1999	100.0	100.0	89.6	48.7	9.2	2.9	2.3	Belt	Mike
September 23, 1999	100.0	100.0	91.2	53.0	12.3	4.3	3.0	Belt	Mike
September 24, 1999	100.0	100.0	92.5	52.4	12.1	3.8	2.4	Belt	Mike
September 27, 1999	100.0	100.0	93.2	54.7	15.1	6.0	3.7	Belt	Mike
September 28, 1999	100.0	100.0	92.5	56.4	16.0	8.2	5.3	Plant #22	Mike
September 28, 1999	100.0	100.0	90.3	46.1	8.5	2.6	2.4	Belt	Mike
September 29, 1999	100.0	100.0	92.3	48.4	7.6	1.6	0.8	Belt	Mike
October 1, 1999	100.0	100.0	91.8	52.5	10.3	2.7	1.6	Belt	Mike
October 6, 1999	100.0	100.0	89.6	47.9	8.4	2.6	1.7	Belt	pills
October 6, 1999	100.0	100.0	94.7	57.5	11.3	3.5	1.9	Belt	mike
October 8, 1999	100.0	100.0	91.5	49.7	11.4	3.6	1.2	Belt	mike
October 12, 1999	100.0	100.0	90.1	47.8	9.0	3.1	2.1	Plant #22	mike
October 12, 1999	100.0	100.0	91.7	50.3	8.8	2.9	1.7	Plant #22	mike
October 12, 1999	100.0	100.0	91.9	51.5	10.3	3.2	1.8	Belt	mike
October 13, 1999	100.0	100.0	90.9	52.7	10.0	3.2	1.9	Belt	mike
October 26, 1999	100.0	100.0	86.3	44.5	8.2	3.7	2.7	Belt	mike
October 26, 1999	100.0	100.0	93.5	48.2	8.9	4.0	3.0	Belt	mike
October 27, 1999	100.0	100.0	93.3	48.6	7.7	1.6	0.3	Belt	mike
November 2, 1999	100.0	100.0	91.8	50.6	12.5	1.3	0.3	Plant #22	mike
November 2, 1999	100.0	100.0	91.6	49.3	9.1	2.0	0.7	Plant #22	mike
November 2, 1999	100.0	100.0	84.5	35.5	4.3	1.4	1.1	Plant #22	mike
November 2, 1999	100.0	100.0	87.7	40.0	3.9	1.0	0.6	Plant #22	mike
November 3, 1999	100.0	100.0	87.7	43.3	5.9	1.4	0.9	Belt	mike
November 8, 1999	100.0	100.0	89.0	45.0	7.3	2.2	1.5	Belt	mike
November 8, 1999	100.0	100.0	88.0	48.4	8.4	1.8	0.8	Belt	mike
November 10, 1999	100.0	100.0	89.1	43.2	5.4	1.2	1.0	Belt	mike
November 12, 1999	100.0	100.0	89.3	52.4	7.7	0.9	0.7	Belt	mike
November 15, 1999	100.0	100.0	89.3	45.3	6.2	1.3	0.9	Belt	mike
November 19, 1999	100.0	100.0	87.7	44.3	5.6	1.3	1.0	Belt	mike


Too much data can be
difficult to deal with

Statistics

- Average
- Normal distribution
- Standard deviation

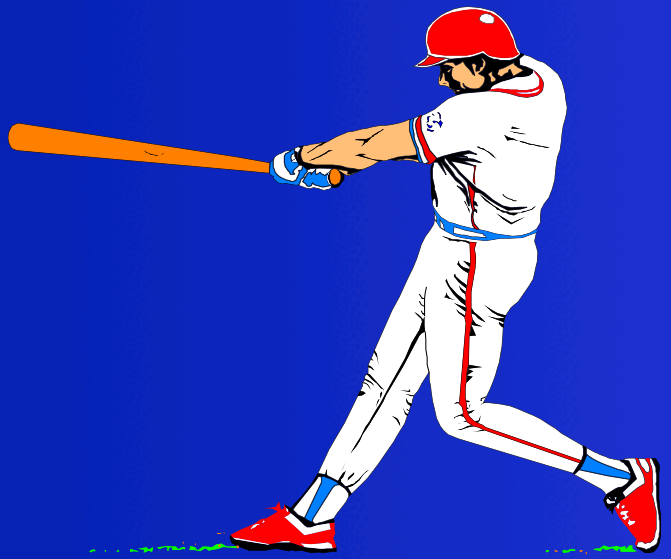
Average

$$\overline{X} = \frac{X_1 + X_2 + \ldots + X_n}{n} = \frac{\Sigma_1^n x}{n}$$

Statisticians call this the mean.

Average (Simplified)

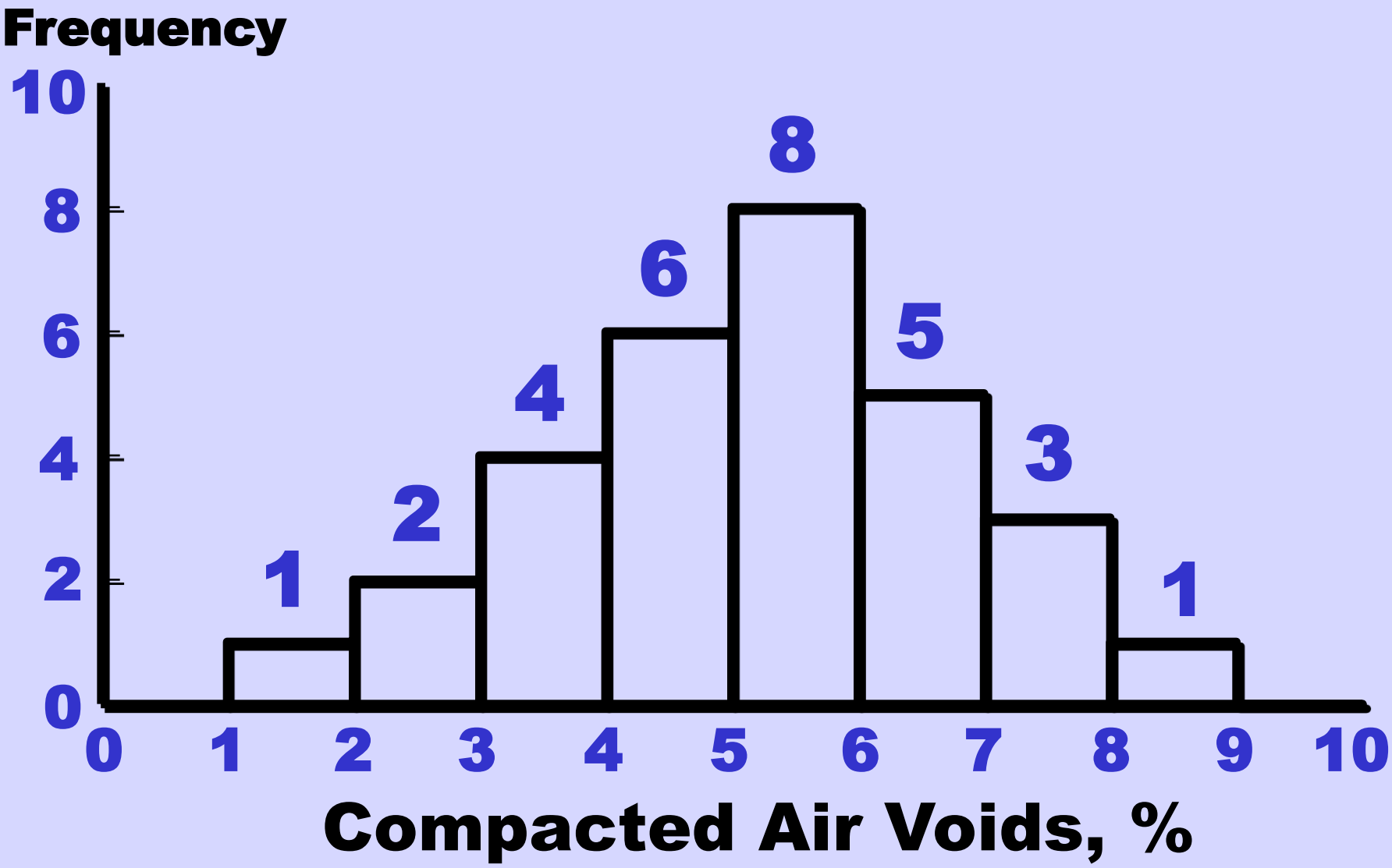
$$\text{Batting Avg} = \frac{\text{\# Hits}}{\text{\# Times at Bat}}$$



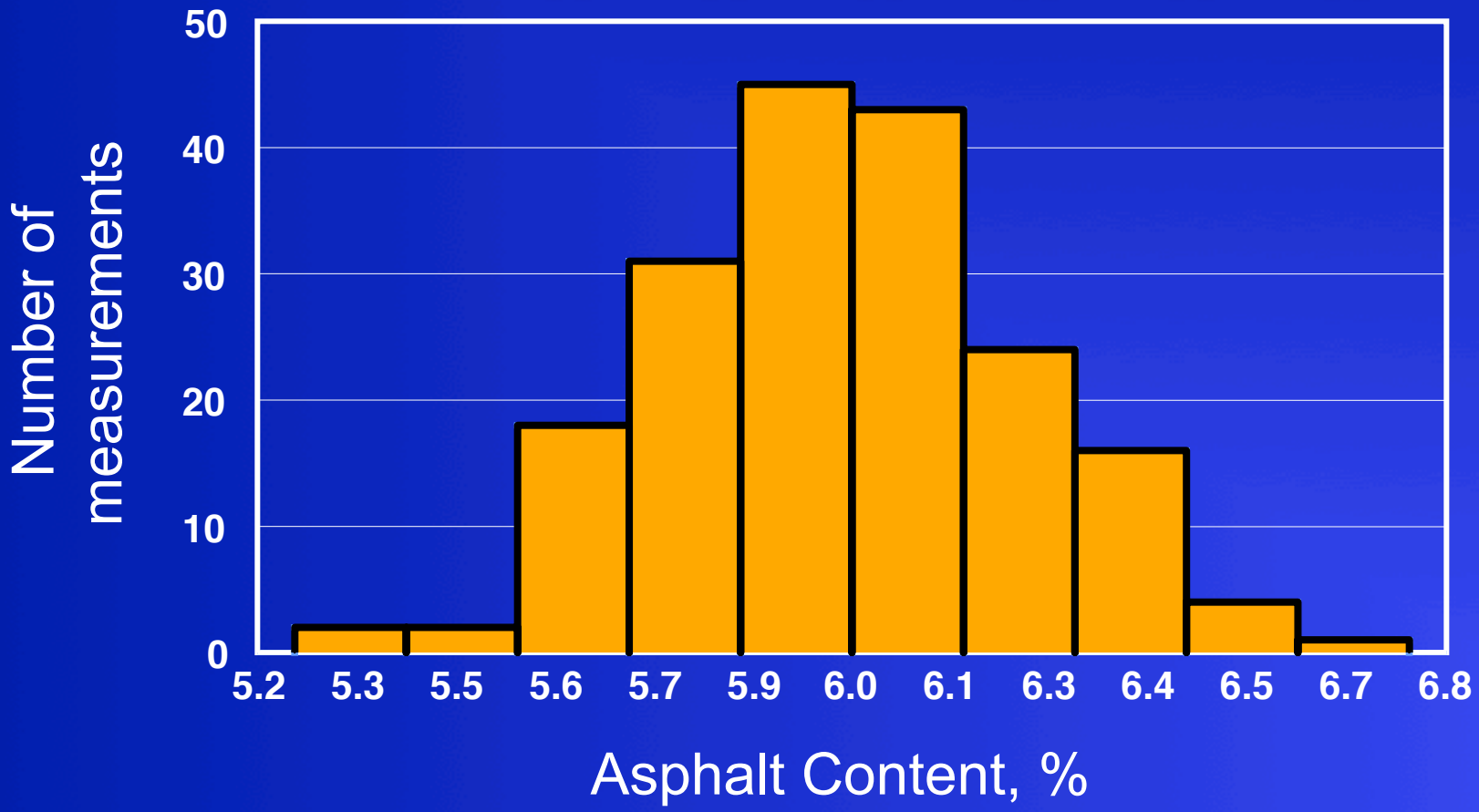
Remember that if you are "Average", about half are above you and half below!

	3/8"	5/16"	1/4"	#4	1/8"	#8	#20	Sample Type	Tested By
September 21, 1999	100.0	100.0	89.6	48.7	9.2	2.9	2.3	Belt	Mike
September 23, 1999	100.0	100.0	91.2	53.0	12.3	4.3	3.0	Belt	Mike
September 24, 1999	100.0	100.0	92.5	52.4	12.1	3.8	2.4	Belt	Mike
September 27, 1999	100.0	100.0	93.2	54.7	15.1	6.0	3.7	Belt	Mike
September 28, 1999	100.0	100.0	92.5	56.4	16.0	8.2	5.3	Plant #22	Mike
September 28, 1999	100.0	100.0	90.3	46.1	8.5	2.6	2.4	Belt	Mike
September 29, 1999	100.0	100.0	92.3	48.4	7.6	1.6	0.8	Belt	Mike
October 1, 1999	100.0	100.0	91.8	52.5	10.3	2.7	1.6	Belt	Mike
October 6, 1999	100.0	100.0	89.6	47.9	8.4	2.6	1.7	Belt	pills
October 6, 1999	100.0	100.0	94.7	57.5	11.3	3.5	1.9	Belt	mike
October 8, 1999	100.0	100.0	91.5	49.7	11.4	3.6	1.2	Belt	mike
October 12, 1999	100.0	100.0	90.1	47.8	9.0	3.1	2.1	Plant #22	mike
October 12, 1999	100.0	100.0	91.7	50.3	8.8	2.9	1.7	Plant #22	mike
October 12, 1999	100.0	100.0	91.9	51.5	10.3	3.2	1.8	Belt	mike
October 13, 1999	100.0	100.0	90.9	52.7	10.0	3.2	1.9	Belt	mike
October 26, 1999	100.0	100.0	86.3	44.5	8.2	3.7	2.7	Belt	mike
October 26, 1999	100.0	100.0	93.5	48.2	8.9	4.0	3.0	Belt	mike
October 27, 1999	100.0	100.0	93.3	48.6	7.7	1.6	0.3	Belt	mike
November 2, 1999	100.0	100.0	91.8	50.6	12.5	1.3	0.3	Plant #22	mike
November 2, 1999	100.0	100.0	91.6	49.3	9.1	2.0	0.7	Plant #22	mike
November 2, 1999	100.0	100.0	84.5	35.5	4.3	1.4	1.1	Plant #22	mike
November 2, 1999	100.0	100.0	87.7	40.0	3.9	1.0	0.6	Plant #22	mike
November 3, 1999	100.0	100.0	87.7	43.3	5.9	1.4	0.9	Belt	mike
November 8, 1999	100.0	100.0	89.0	45.0	7.3	2.2	1.5	Belt	mike
November 8, 1999	100.0	100.0	88.0	48.4	8.4	1.8	0.8	Belt	mike
November 10, 1999	100.0	100.0	89.1	43.2	5.4	1.2	1.0	Belt	mike
November 12, 1999	100.0	100.0	89.3	52.4	7.7	0.9	0.7	Belt	mike
November 15, 1999	100.0	100.0	89.3	45.3	6.2	1.3	0.9	Belt	mike
November 19, 1999	100.0	100.0	87.7	44.3	5.6	1.3	1.0	Belt	mike

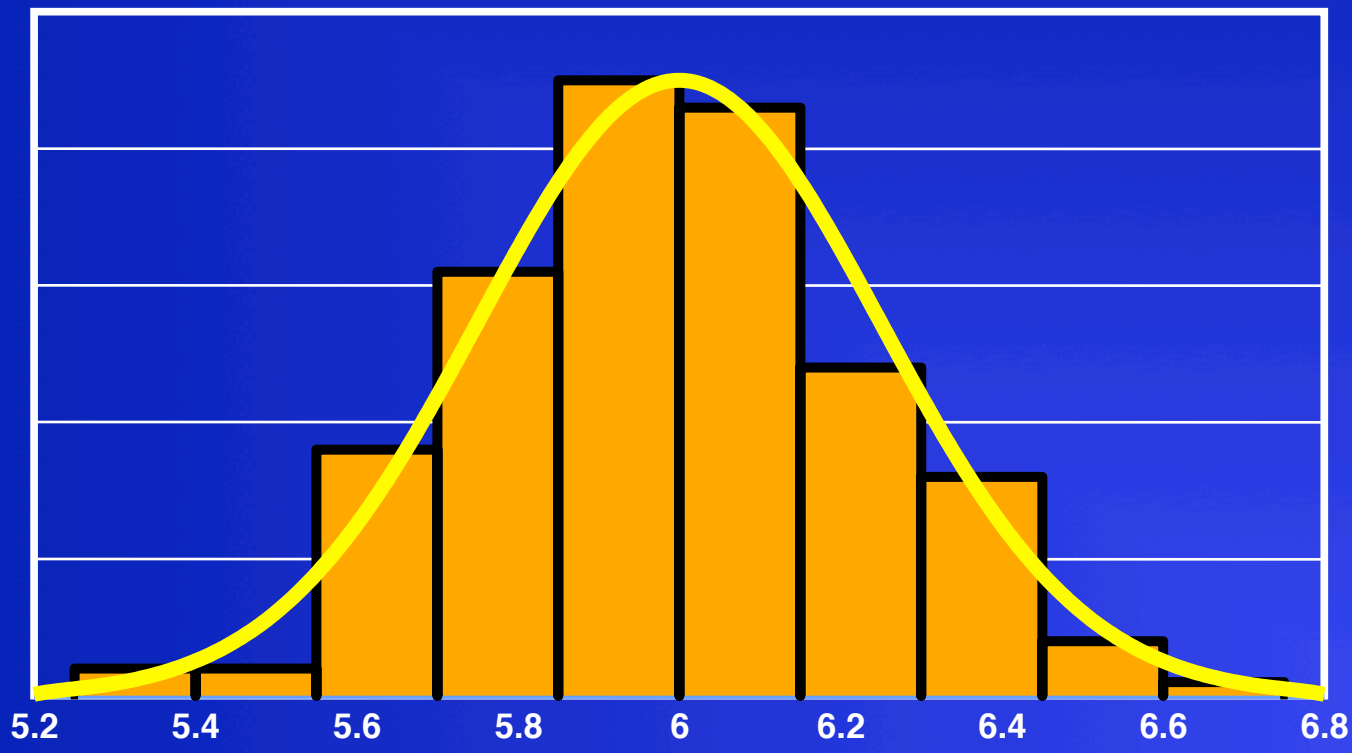
Frequency Bar Chart



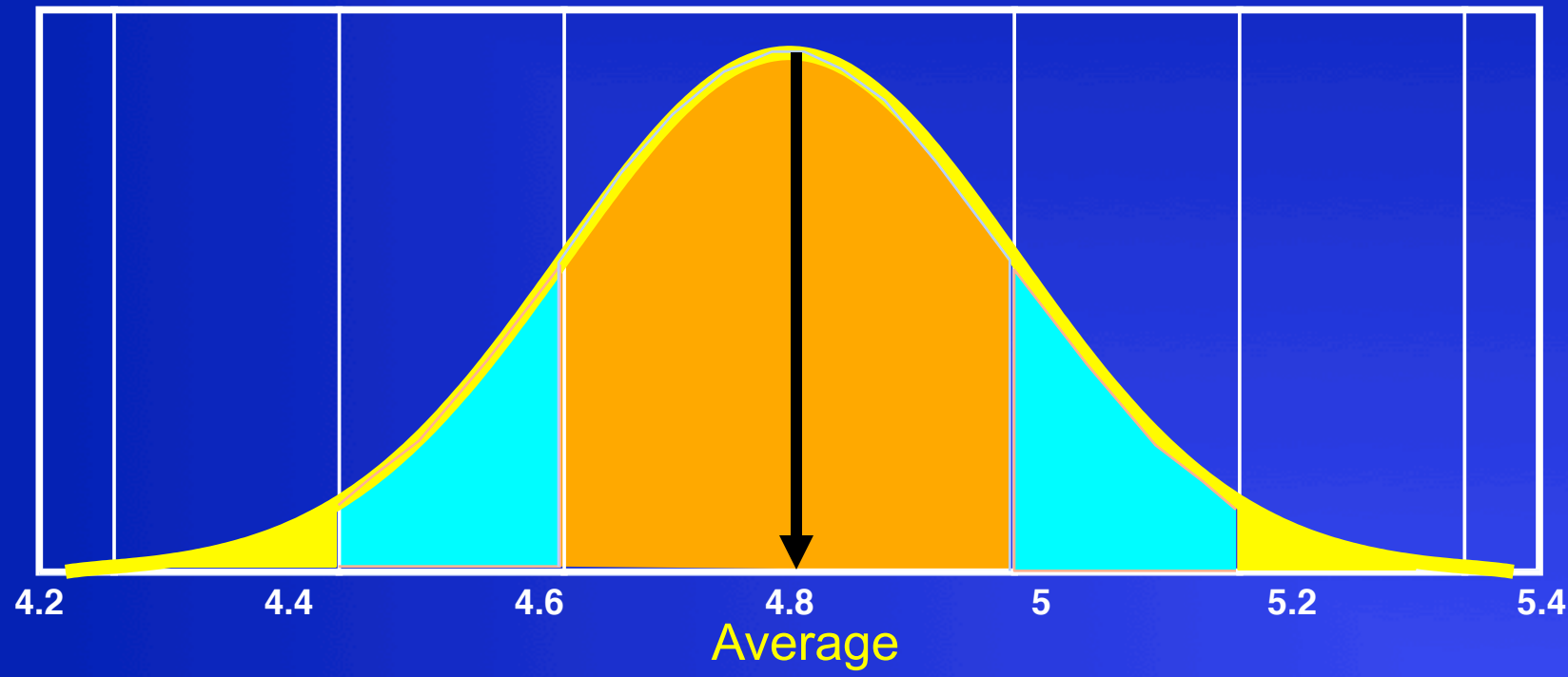
Bar Chart


Number of measurements
50
40
30
20
10
0
5.2
5.3
5.5
5.6
5.7
5.9
6.0
6.1
6.3
6.4
6.5
6.7
6.8
Asphalt Content, %

Bar Chart with Normal Distribution

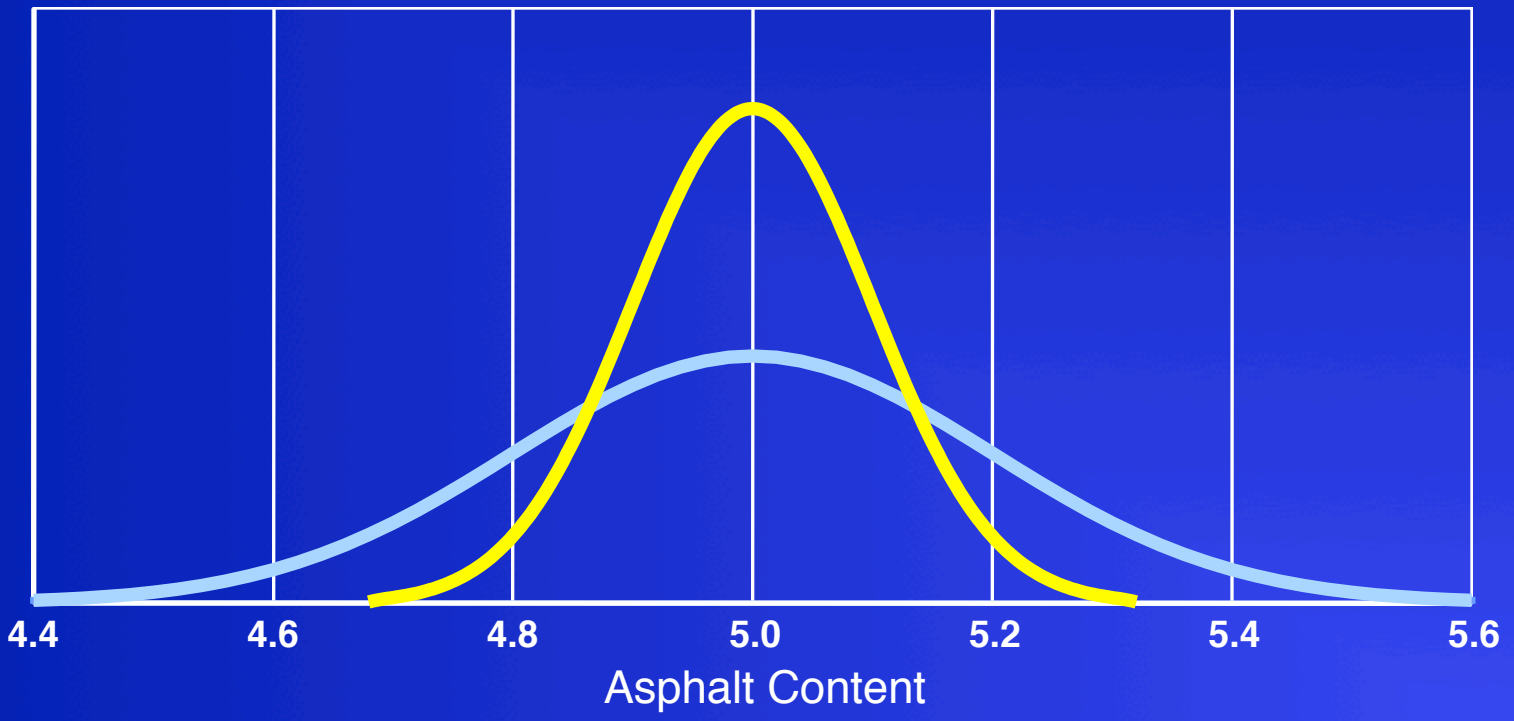


Normal Distribution

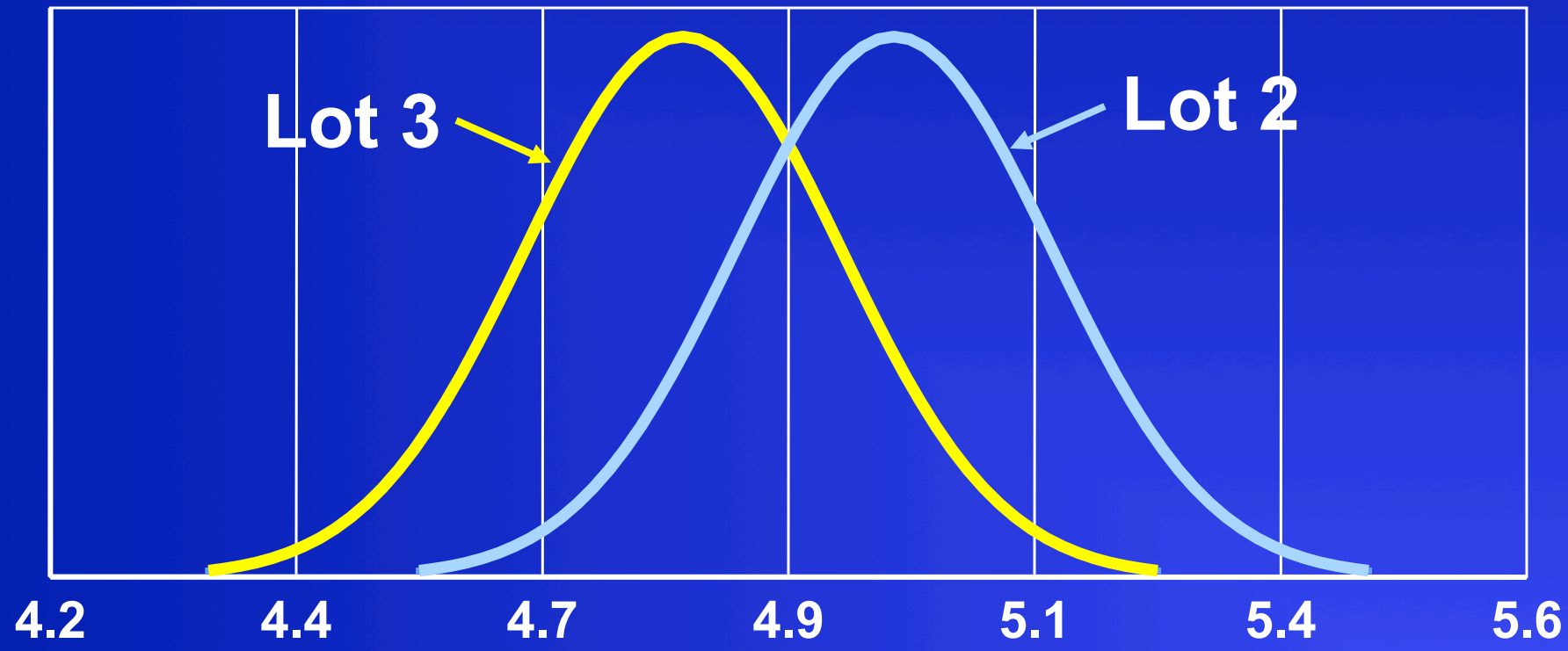


Asphalt Content, %

Variable Normal Distributions

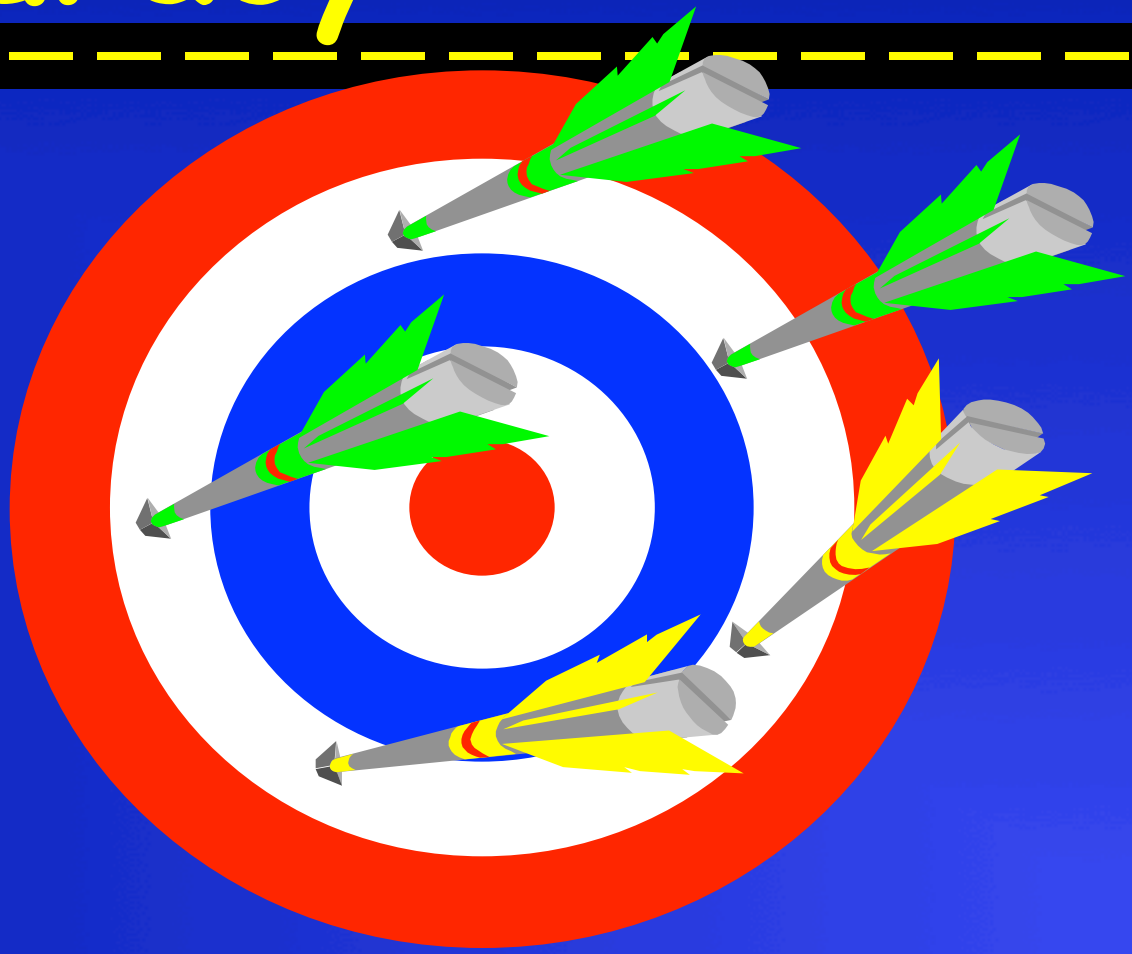


Normal Distribution Shift



Accuracy Versus Precision

Accuracy



Poor Precision

Good Accuracy (unbiased)

Precision

Good Precision

Poor Accuracy (biased)

Accuracy & Precision

Good Precision

Good Accuracy (unbiased)

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September 27, 1999	100.0	100.0	93.2	54.7	15.1	6.0	3.7	Belt	Mike
September 28, 1999	100.0	100.0	92.5	56.4	16.0	8.2	5.3	Plant #22	Mike
September 28, 1999	100.0	100.0	90.3	46.1	8.5	2.6	2.4	Belt	Mike
September 29, 1999	100.0	100.0	92.3	48.4	7.6	1.6	0.8	Belt	Mike
October 1, 1999	100.0	100.0	91.8	52.5	10.3	2.7	1.6	Belt	Mike
October 6, 1999	100.0	100.0	89.6	47.9	8.4	2.6	1.7	Belt	pills
October 6, 1999	100.0	100.0	94.7	57.5	11.3	3.5	1.9	Belt	mike
October 8, 1999	100.0	100.0	91.5	49.7	11.4	3.6	1.2	Belt	mike
October 12, 1999	100.0	100.0	90.1	47.8	9.0	3.1	2.1	Plant #22	mike
October 12, 1999	100.0	100.0	91.7	50.3	8.8	2.9	1.7	Plant #22	mike
October 12, 1999	100.0	100.0	91.9	51.5	10.3	3.2	1.8	Belt	mike
October 13, 1999	100.0	100.0	90.9	52.7	10.0	3.2	1.9	Belt	mike
October 26, 1999	100.0	100.0	86.3	44.5	8.2	3.7	2.7	Belt	mike
October 26, 1999	100.0	100.0	93.5	48.2	8.9	4.0	3.0	Belt	mike
October 27, 1999	100.0	100.0	93.3	48.6	7.7	1.6	0.3	Belt	mike
November 2, 1999	100.0	100.0	91.8	50.6	12.5	1.3	0.3	Plant #22	mike
November 2, 1999	100.0	100.0	91.6	49.3	9.1	2.0	0.7	Plant #22	mike
November 2, 1999	100.0	100.0	84.5	35.5	4.3	1.4	1.1	Plant #22	mike
November 2, 1999	100.0	100.0	87.7	40.0	3.9	1.0	0.6	Plant #22	mike
November 3, 1999	100.0	100.0	87.7	43.3	5.9	1.4	0.9	Belt	mike
November 8, 1999	100.0	100.0	89.0	45.0	7.3	2.2	1.5	Belt	mike
November 8, 1999	100.0	100.0	88.0	48.4	8.4	1.8	0.8	Belt	mike
November 10, 1999	100.0	100.0	89.1	43.2	5.4	1.2	1.0	Belt	mike
November 12, 1999	100.0	100.0	89.3	52.4	7.7	0.9	0.7	Belt	mike
November 15, 1999	100.0	100.0	89.3	45.3	6.2	1.3	0.9	Belt	mike
November 19, 1999	100.0	100.0	87.7	44.3	5.6	1.3	1.0	Belt	mike

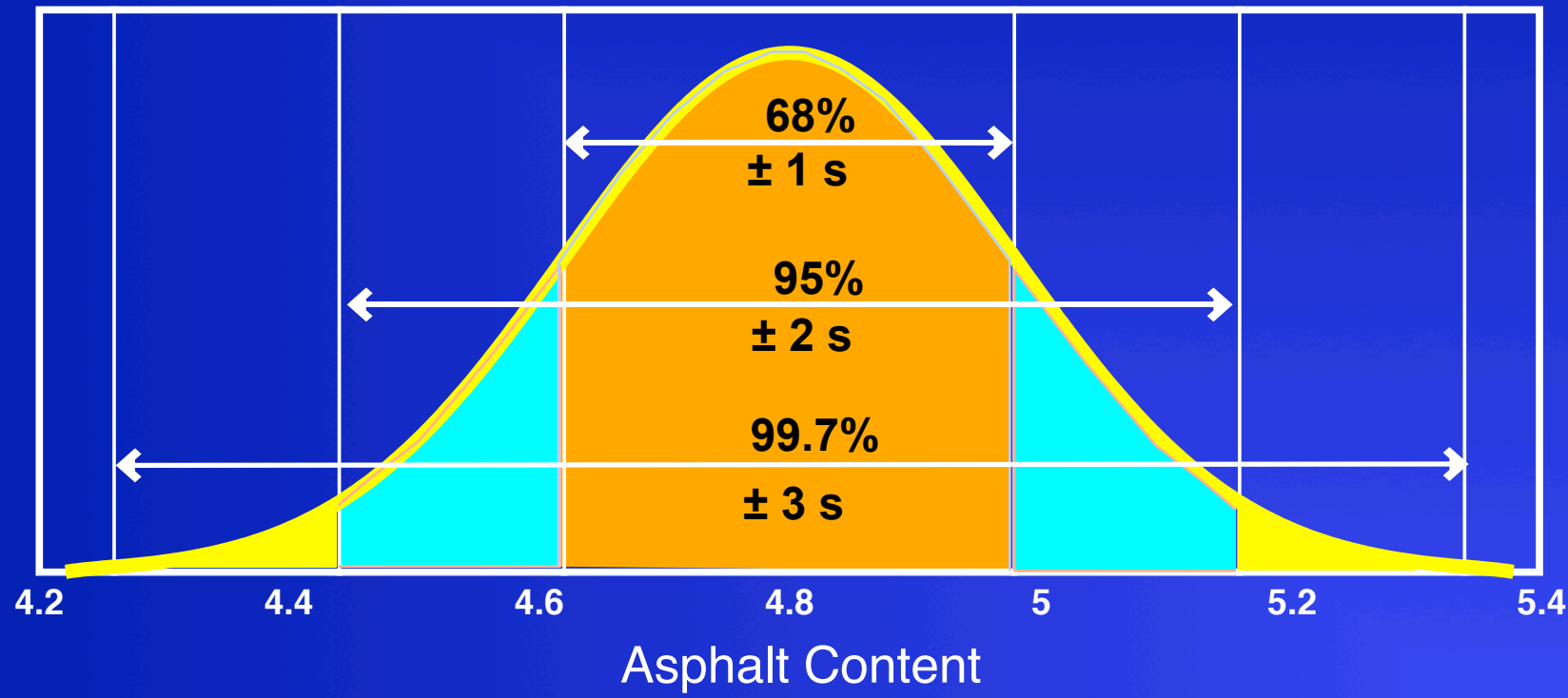
Measure of Variability

- How “good” are the data?
- How much variability can be expected for a given test?
- How much confidence can be placed in a test?

Standard Deviation

- A measure of variability
- Don’t need equations
- Value is generated from calculator

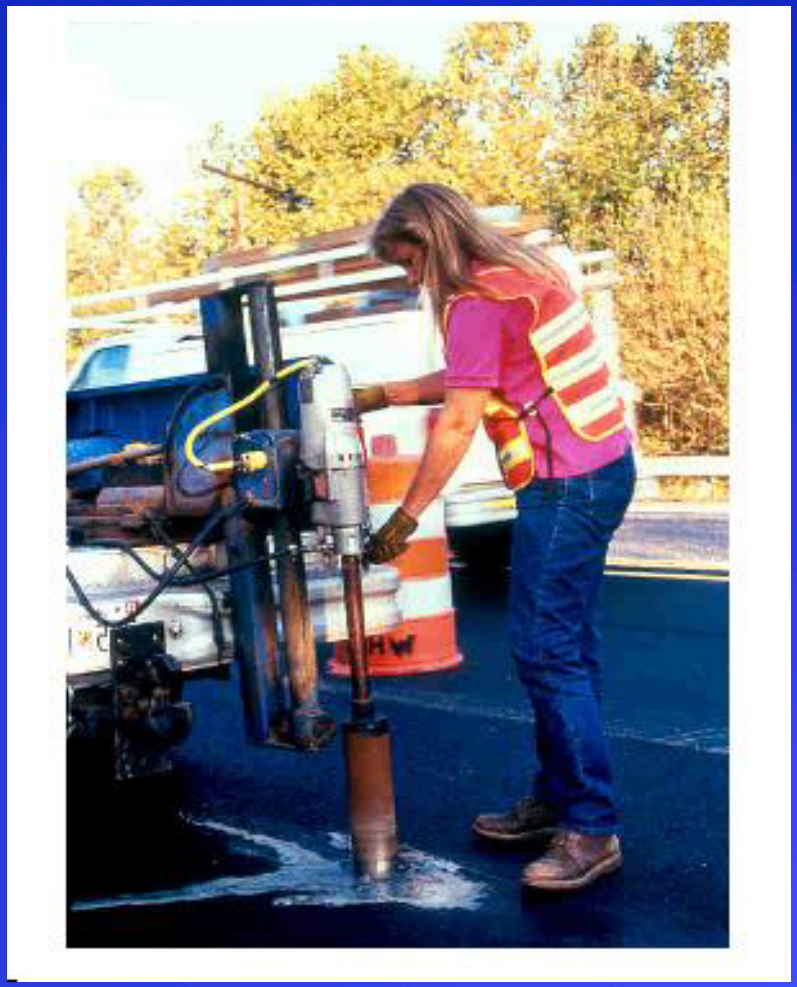
Normal Distribution & Probability




Only God can make
a random selection.

Random Sampling

- Every section should have equal opportunity of being tested
- Enough samples should be taken to understand material properties.

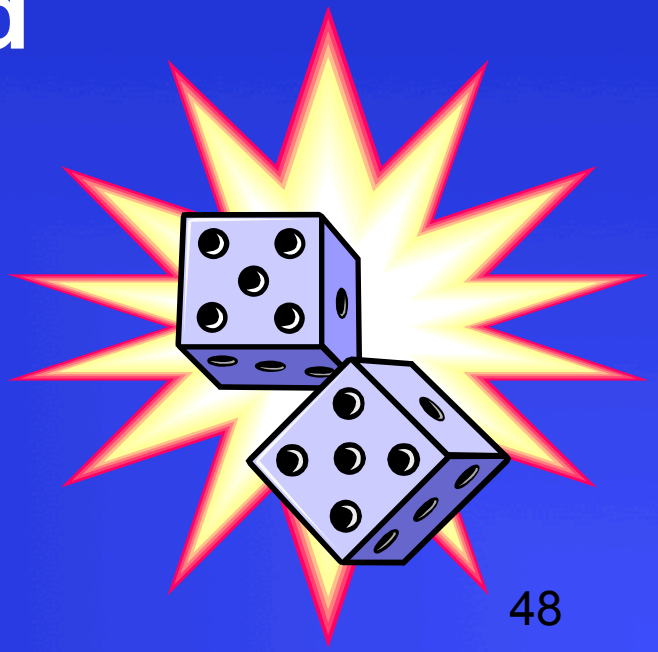


Seller's Risk

- Risk that material of acceptable quality will be rejected

Buyer's Risk

- Risk that material which should be rejected will be accepted



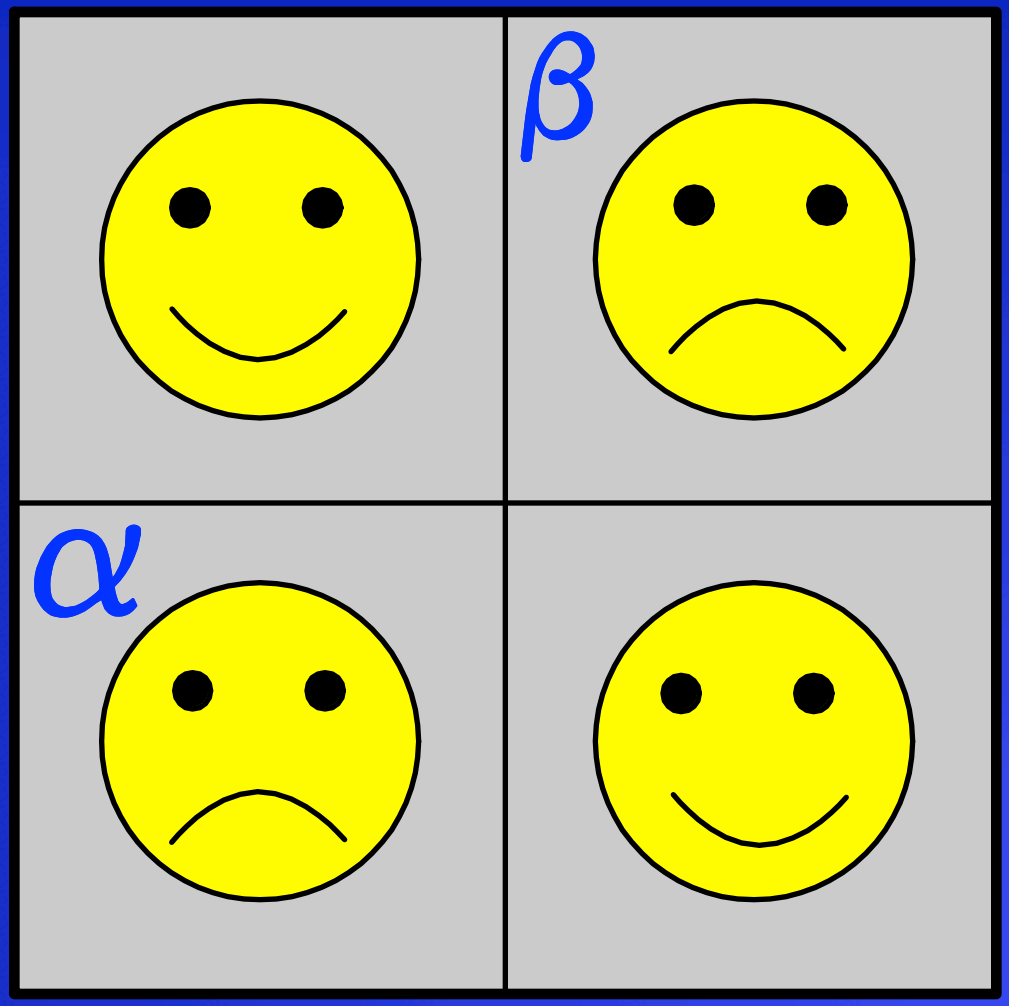
Large Buyer's Risk

- High probability of accepting poor (RQL) work
- Encourages low bid prices
- Greatly increases likelihood for premature failures and higher maintenance costs

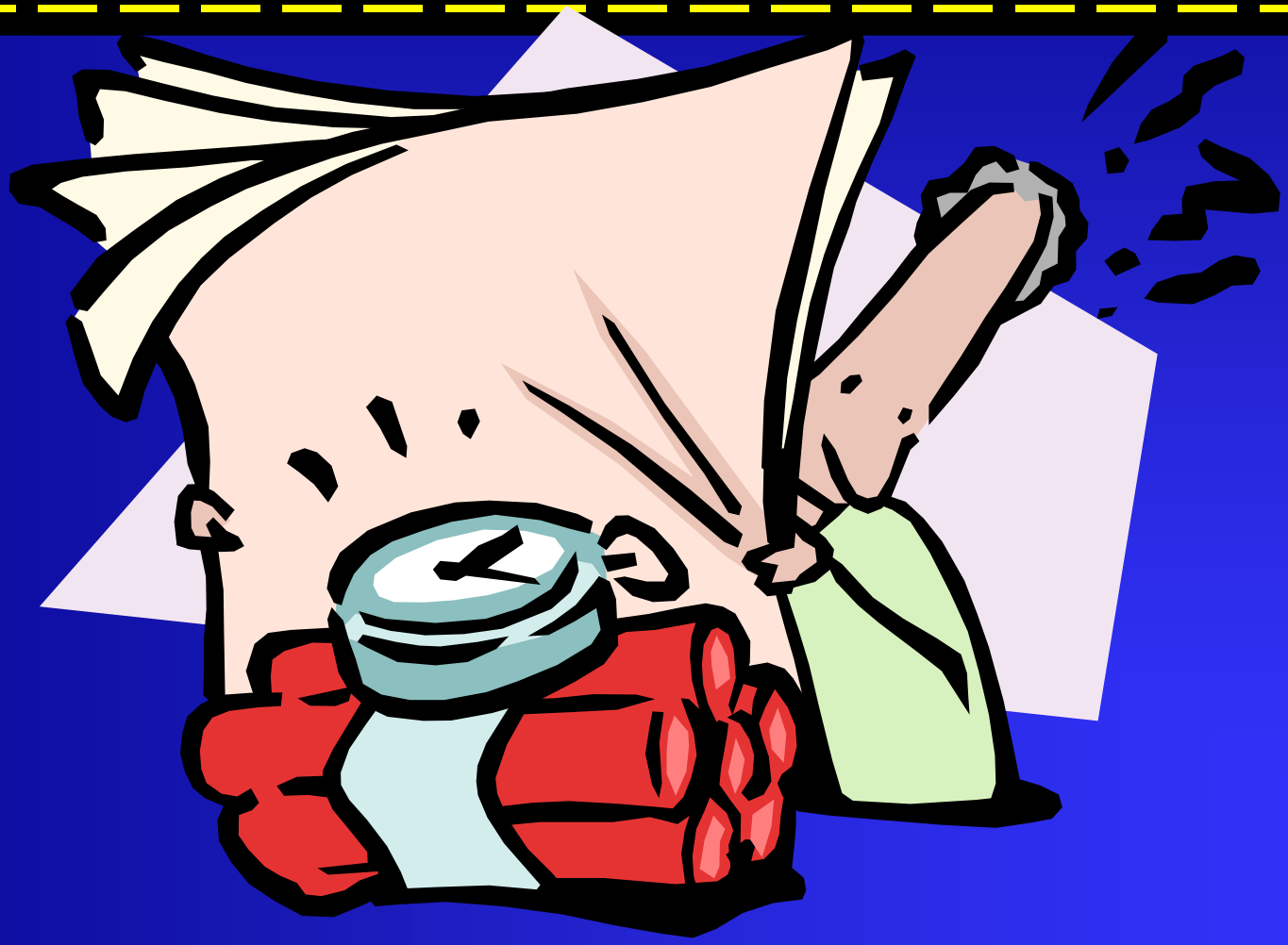
Large Seller's Risk

- Unnecessary rejection of satisfactory (AQL) work
- Drives up prices
- Quality level may be unnecessarily high

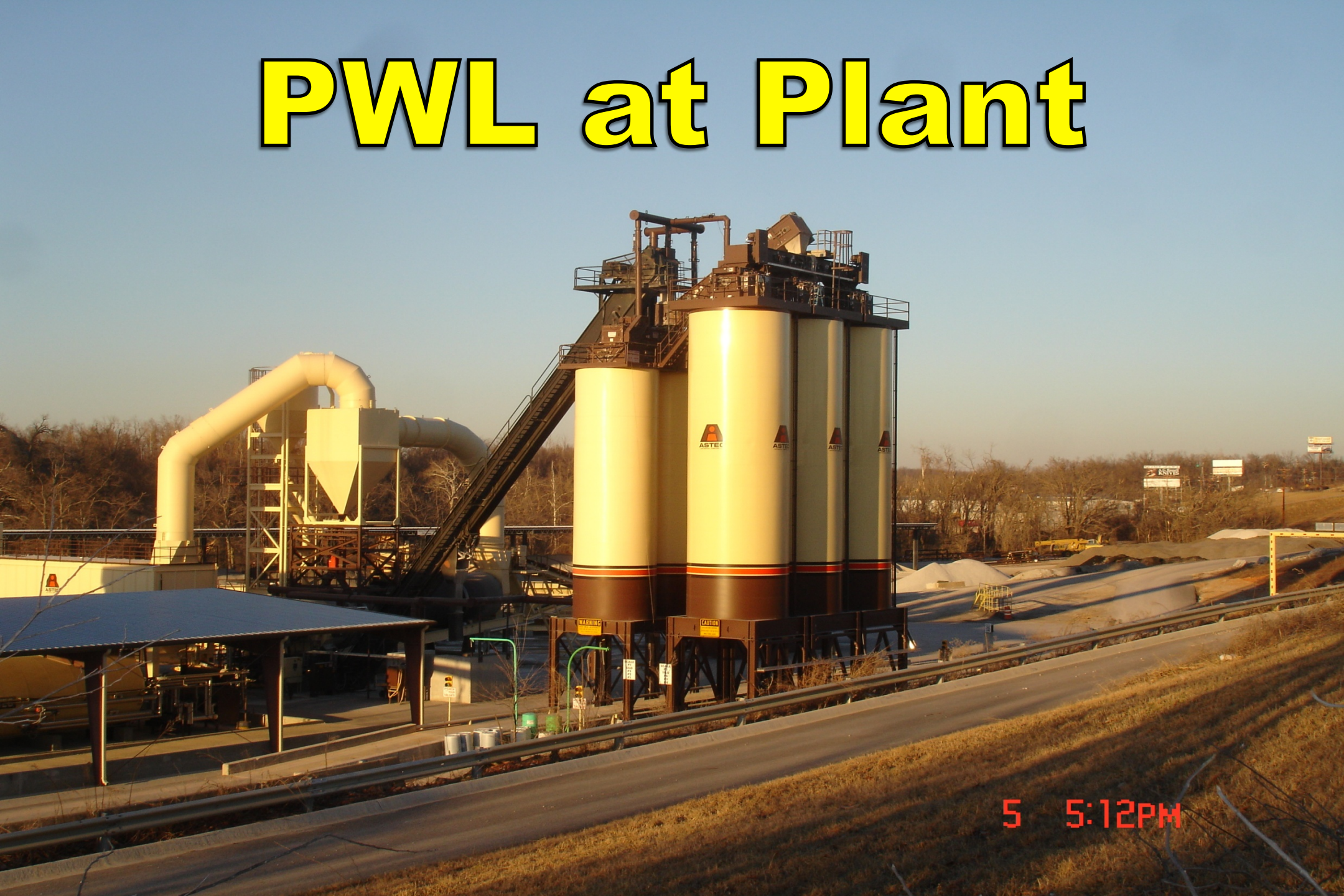
Risk Analysis



Contracting = Risk Management



PWL at Plant



Example Determination of PWL

% Passing # 40 Sieve	
25.5	24.1
28.0	23.7
29.5	26.4
22.9	25.3

PWL and Pay Factor

Average = 25.68

Standard Deviation = 2.23

PWL = 71.1

PF = 87.5

% Passing # 40 Sieve	
25.5	24.1
28.0	23.7
29.5	26.4
22.9	25.3


PWL in Field

Example Determination of PWL

% MTD
92.1
92.0
94.1
92.0
92.0

Density Pay Factor

Average = 92.4

Standard Deviation = 0.930

PWL = 65

PF = 0.93

% MTD
92.1
92.0
94.1
92.0
92.0

Example Determination of PWL

% MTD	
91.8	92.0
92.4	91.9
92.0	91.9
91.2	

Density Pay Factor

Average = 91.9

Standard Deviation = 0.358

PWL = 39

PF = 0.0.67 (<0.75)

% MTD	
91.8	92.0
92.4	91.9
92.0	91.9
91.2	

Control of HMA

Factor: AC – Variation from JMF

Status	Action Point	Action
Green	± 0.15%	Normal Ops
Yellow	± 0.16 to 0.25%	QC ↔ Tower
Red	± 0.26 to 0.39%	QC ↔ Tower Resample Tower ↔Mgmt
Shutdown	± 0.40%	Same as Red

Control of HMA

Factor: # 8 – Variation from JMF

Status	Action Point	Action
Green	± 2%	Normal Ops
Yellow	± 3 to 4%	QC ↔ Tower
Red	± 5%	QC ↔ Tower Resample Tower ↔Mgmt
Shutdown	± 6%	Same as Red

Control of HMA

Factor: #200 – Variation from JMF

Status	Action Point	Action
Green	± 1.5%	Normal Ops
Yellow	± 1.6 to 2.0%	QC ↔ Tower
Red	± 2.1 to 3.0%	QC ↔ Tower Resample Tower ↔Mgmt
Shutdown	± 3.1%	Same as Red


Thank You!
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