Percent Within Limits

A Comprehensive Review

Wisconsin's PWL for HMA

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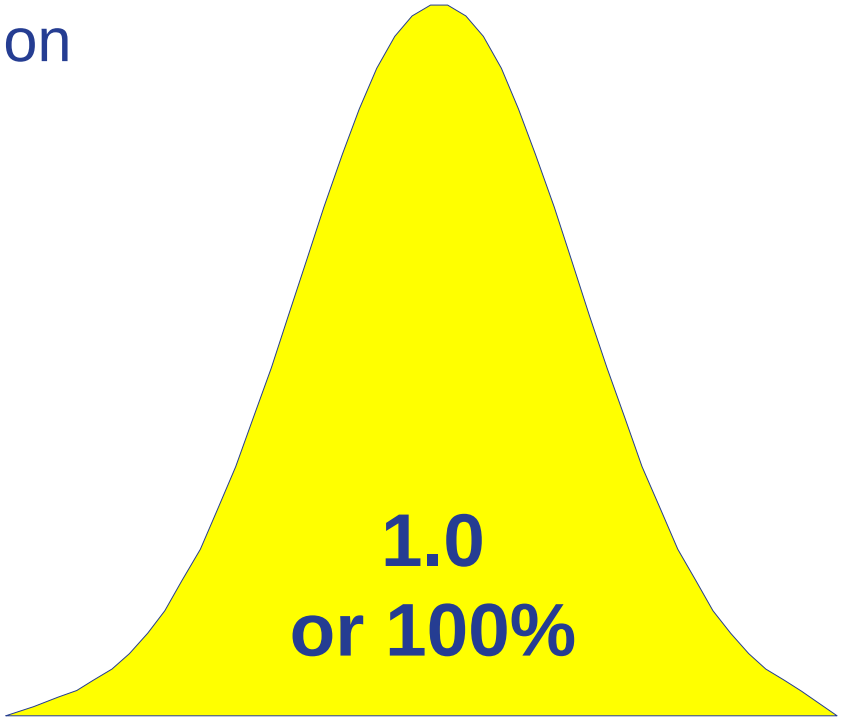
What's in the Pipeline?

- WisDOT is implementing statistical acceptance on HMA paving projects
- The chosen measure of acceptance is Percent Within Limits (PWL)
- Changing to the PWL system encourages the material to be produced and placed on target and with consistency
- PWL measures mean (average) and standard deviation (variance)

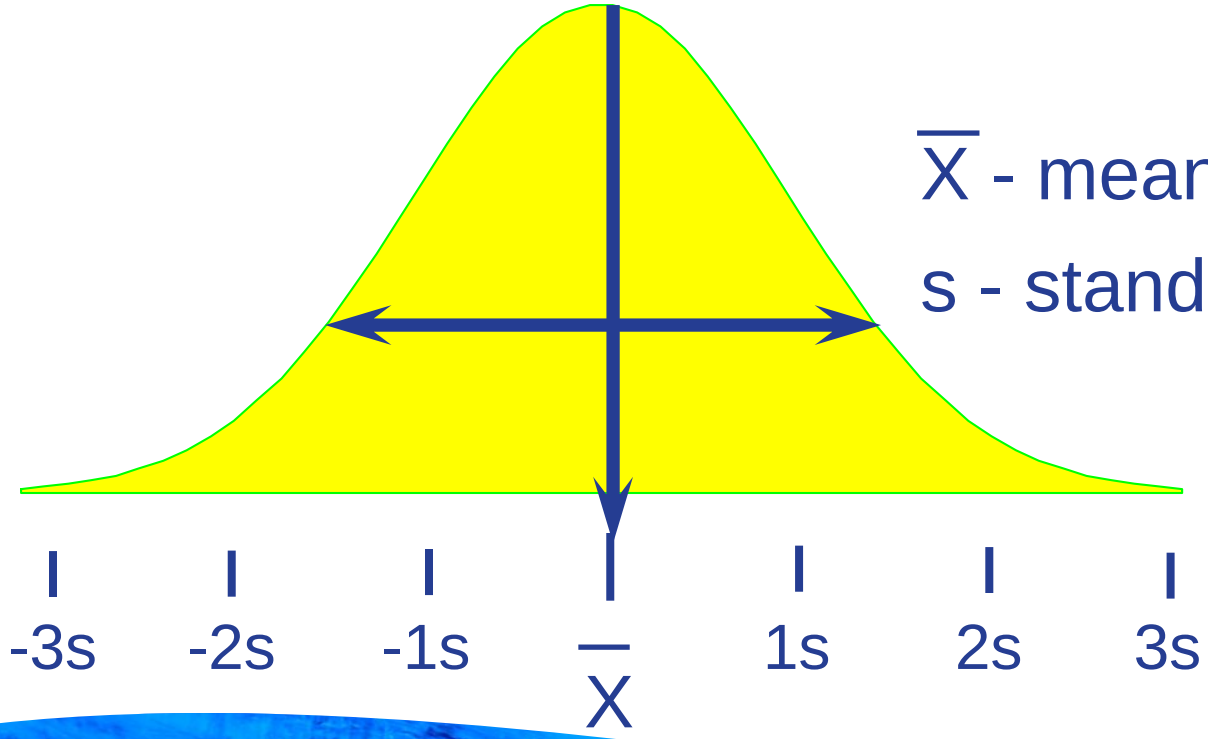
PWL

- Estimates the percentage of material within specification limits
  - Assumes normal distribution



PWL

- Efficiently captures mean and standard deviation in one quality measure



$\overline{X}$ - mean

s - standard deviation

Benefits of PWL

- More discerning than other quality measures
- Efficiently captures the mean and standard deviation into one measure of quality
- Encourages Uniformity
  - Controls both the average level and variability of the product in a statistically efficient way
  - Variability is a predictor of performance

Why would you pay more than 100% for a pavement product?

- Incentives give the bidding advantage to the better contractor
  - They know they can meet the incentive requirements
  - They can reduce the bid price by some portion of the incentive
- Reduces inspection time and cost
  - No time spent on rework
- Reduce delays due to rework
  - Open to the public sooner

PWL is an acronym for *PERCENT Within Limits*

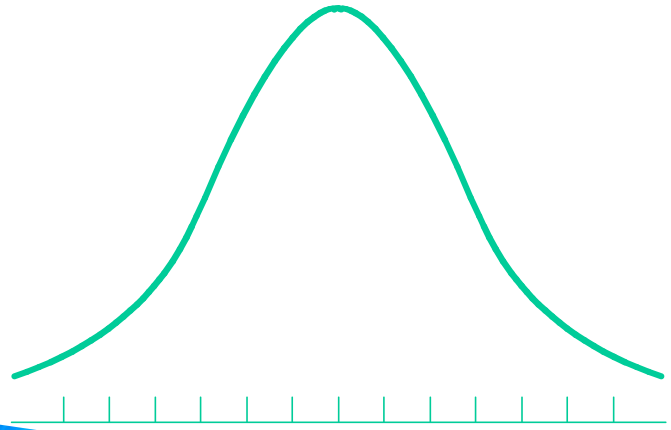
Because it is impractical to test 100% of the material produced, PWL uses *statistical analysis* to evaluate material tested at a lesser frequency and extrapolates to estimate results as if ALL material was tested. It allows for estimating the *percentage* of material that is most likely to fall *within acceptable limits*, based on this “extrapolation.”

Definitions/Terminology

- Normal Distribution
- Average, Mean
- Standard Deviation
- Variance

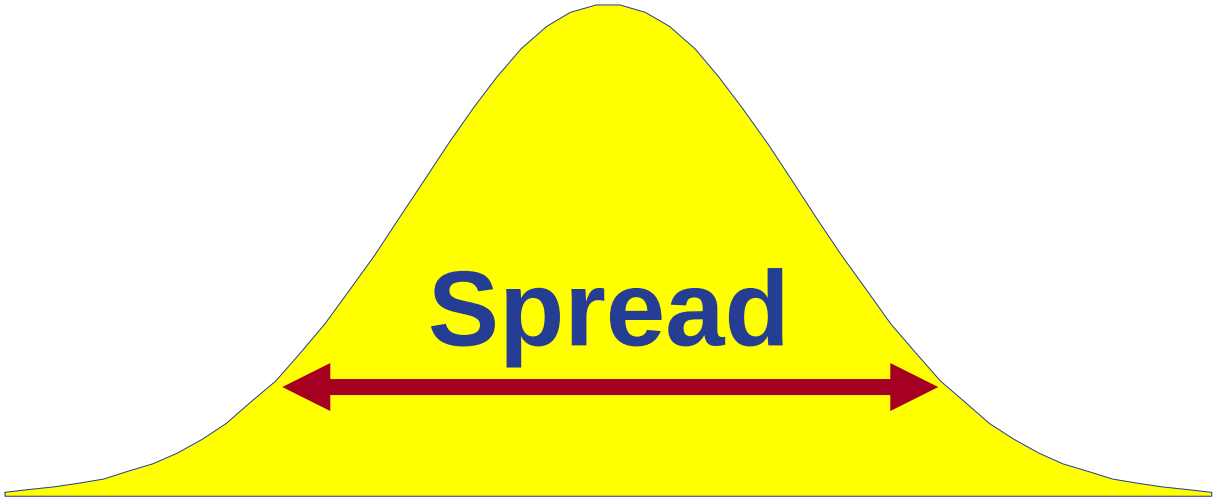
Normal Distribution

- Pattern formed is referred to as **Normal Distribution**
- Properly obtained statistical sample for an entire lot of most construction material will form a **Normal Distribution Curve**



Standard Deviation

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

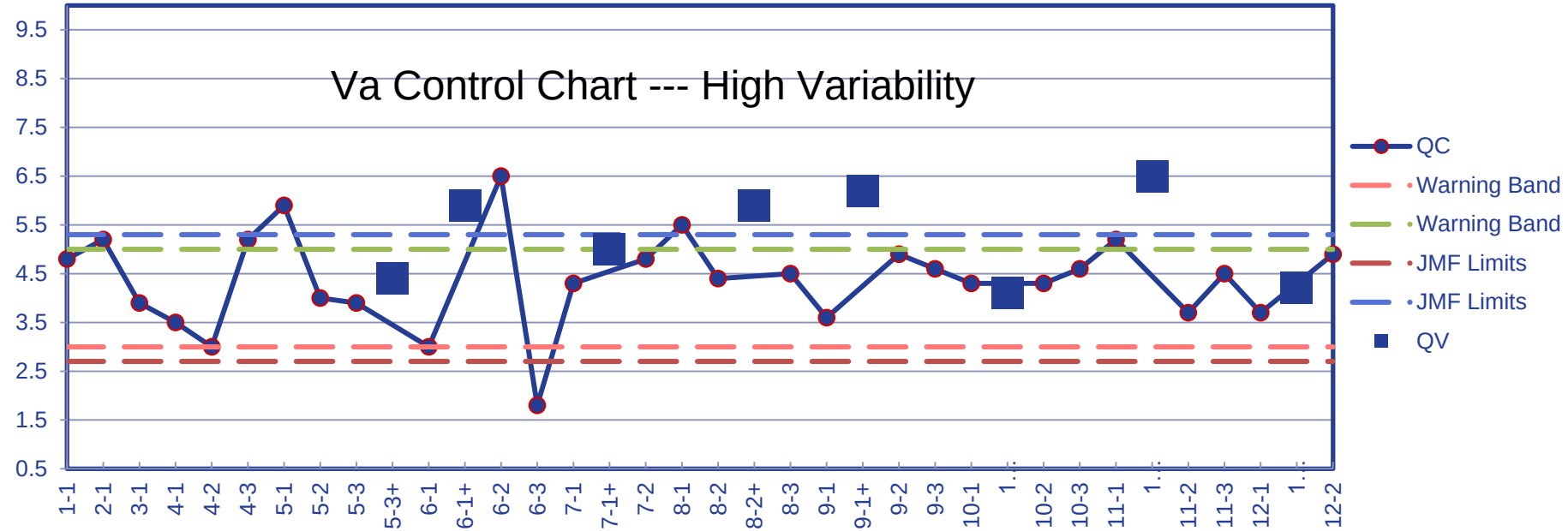


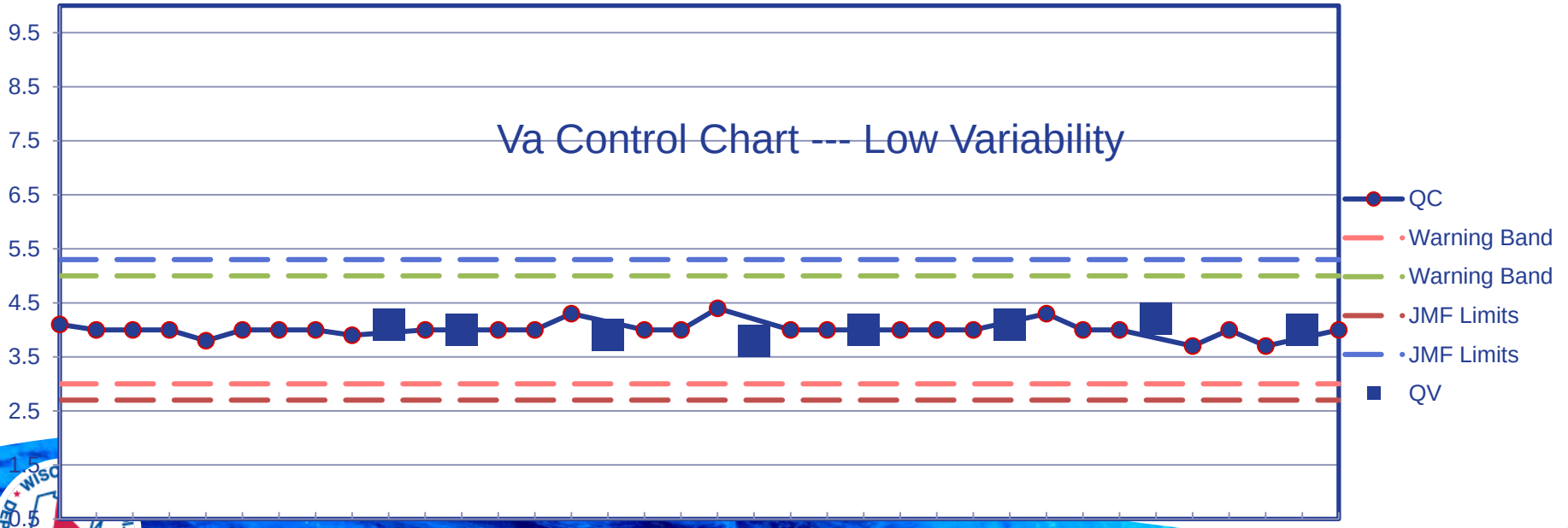
Standard Deviation

- Sample standard deviation (s)

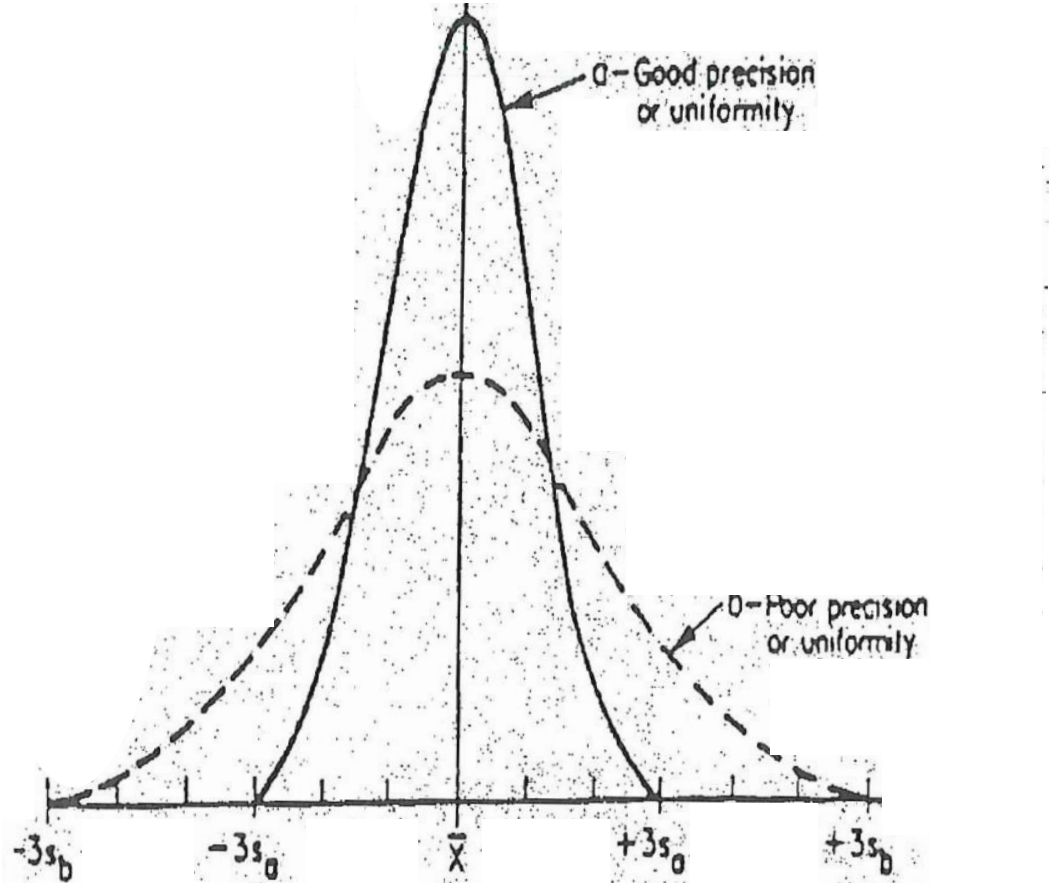
$$s = \sqrt{\frac{\sum(X_i - \overline{X})^2}{n - 1}}$$

Computes the difference from the average, $(X_i - \overline{X})$

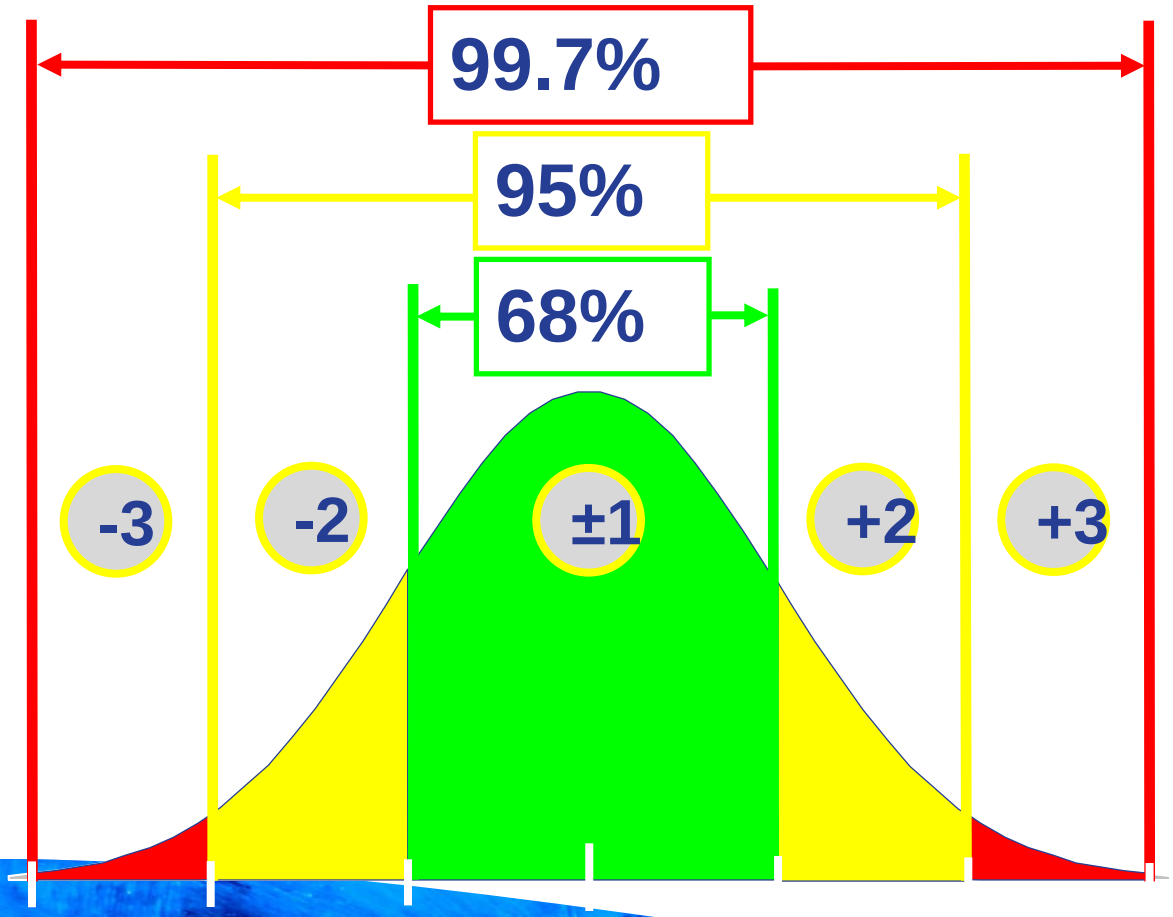

Va Control Chart --- High Variability
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
1-1
2-1
3-1
4-1
4-2
4-3
5-1
5-2
5-3
5-3+
6-1
6-1+
6-2
6-3
7-1
7-1+
7-2
8-1
8-2
8-2+
8-3
9-1
9-1+
9-2
9-3
10-1
10-2
10-3
11-1
11-2
11-3
12-1
12-2
QC
Warning Band
Warning Band
JMF Limits
JMF Limits
QV


Va Control Chart --- Low Variability
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
QC
Warning Band
Warning Band
JMF Limits
JMF Limits
QV

PWL (Percent Within Limits)

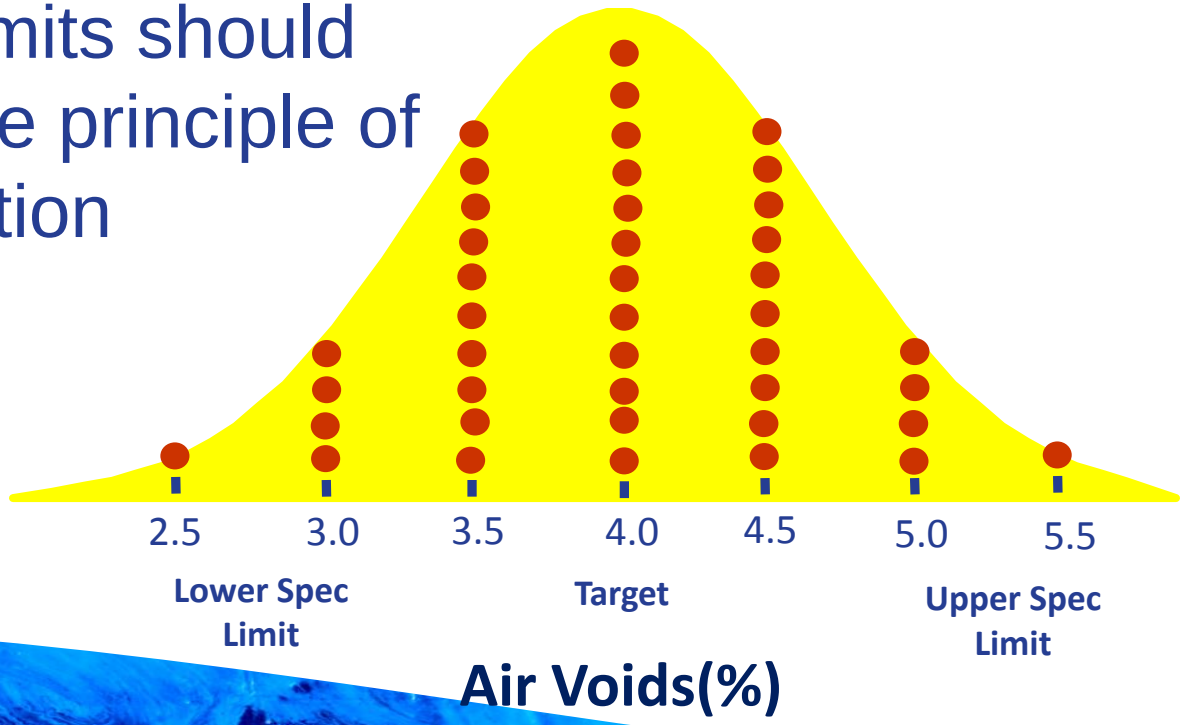


Data within ± Standard Deviation



Testing Targets and Limits Based on Normal Distribution

- Specifications normally identify targets and/or limits for individual quality characteristics
- Specification limits should be based on the principle of normal distribution

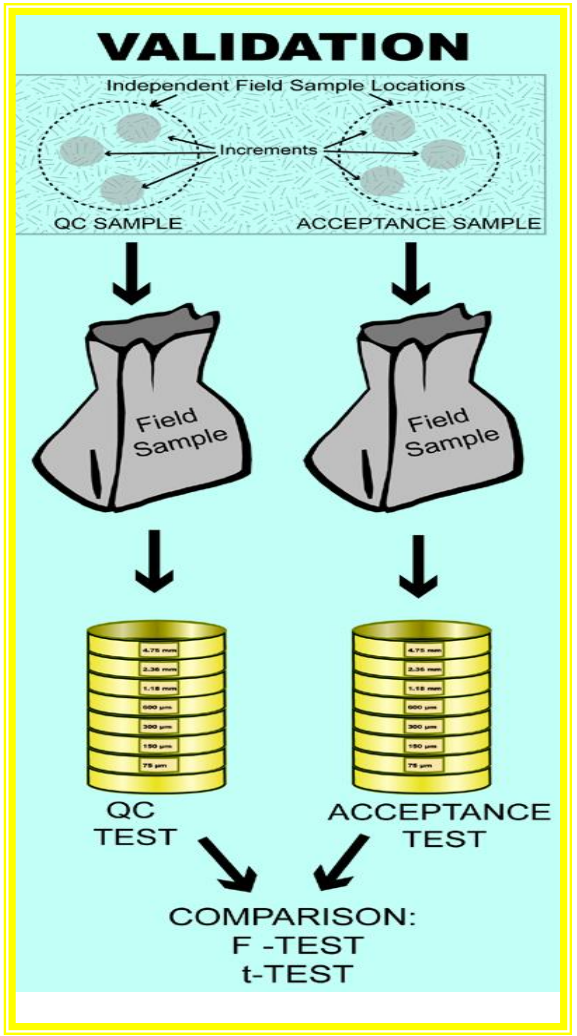


Validation

The mathematical comparison of two independently obtained sets of data to determine whether it can be assumed they came from the same population

Validation

- When comparing the two data sets for validation:
  - It is important to compare both the means and the variances
  - A different test is used for each of these properties
- Can identify differences in test results that can result in significant difference in payment



Statistical test used for Validation

- Two Tests
  - F-test compares variances
  - T-tests compare means

Statistical analysis

F- and t-tests:

- Statistical tools to determine if two data sets are from the same population (do they compare to each other)
- Compares the variance (F-test) and the mean (t-test)
- Requires a minimum of 3 tests to run
  - 3 lots (15 QC tests and 3 QV tests)

- Statistical tests are conducted at a selected level of significance, alpha (α)
  - Recommended range is between .01 and .05

If 0.025 is used and the two sets of data do not compare, then there is only 1 chance in 40 that they actually do compare and was rejected in error ("false alarm") 1/40 = 0.025

Conducting the F- and t-tests

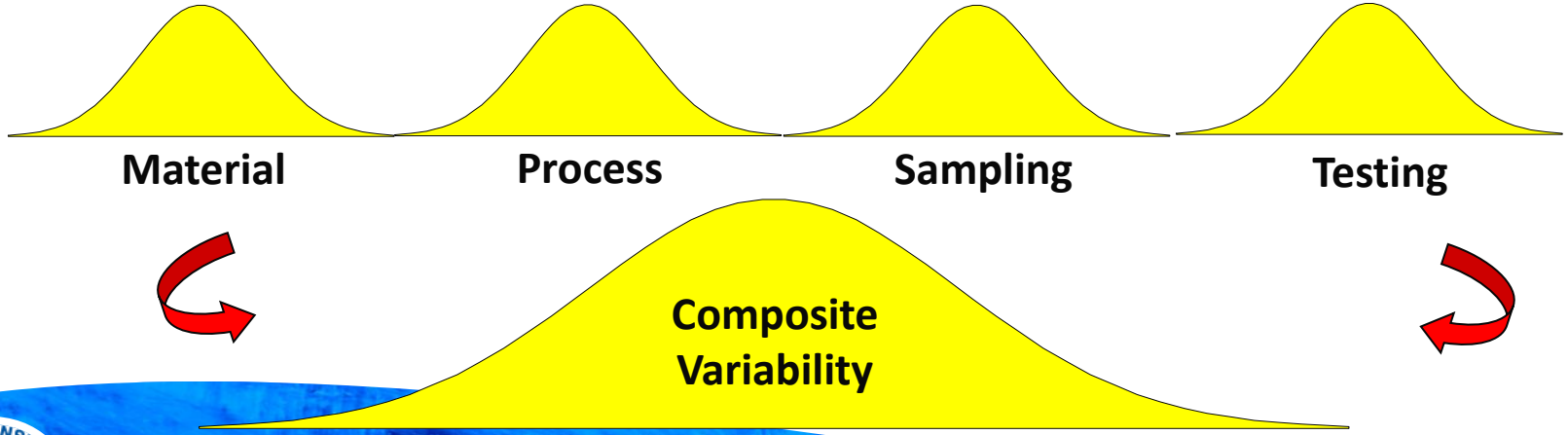
These tests can identify a *difference*…

but not a *cause*

Sources of Variability

Material Process Sampling Testing



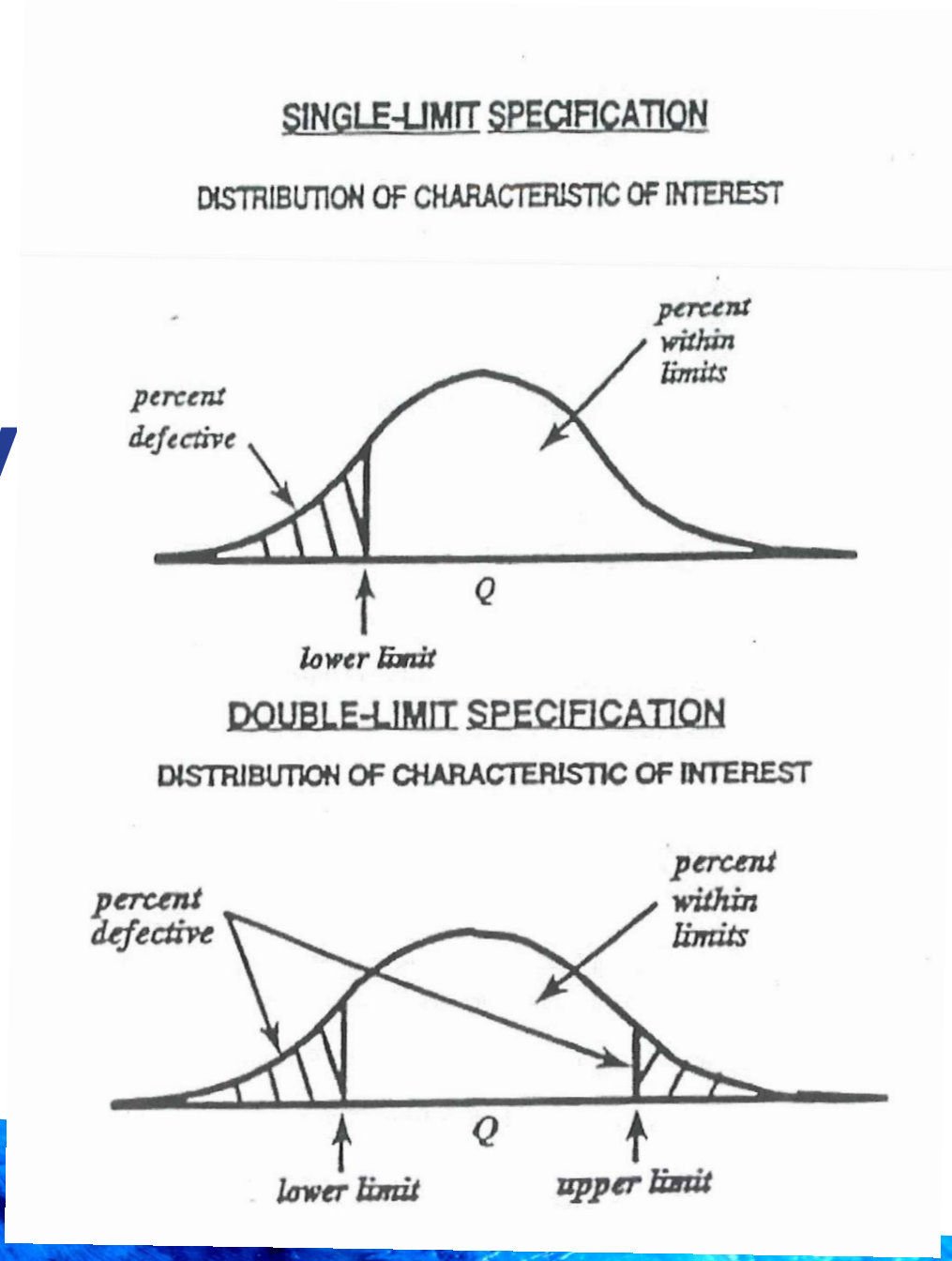



“This all seems a bit complicated. How does this change my job?”

~Most of the People in this Room

Density

Air Voids



When will it be used?

- Pilot projects in 2016 construction season
  - Goal is 1 pilot project per Region

- Implementation beginning 2017
  - Will evaluate Pilot Project data
    - Adjustments may be needed before full implementation
  - Round 1: projects with > 11,250 tons per mix type
  - Round 2: lower threshold to use PWL with smaller tonnage projects

PWL specification attempted to keep as much of the current practices in place.

- Here are some major changes:
  - Density gauges will be correlated to cores during a test strip
  - Volumetric testing between QC & QV will need to match each other
  - QC team will test same material as QV team

What's New?

Current QMP

- 4 point running average
- Volumetrics
  - Lot size, currently variable
    (600, 900, 1200, 1500, etc)
- Densities
  - Lot sizes will not change with PWL
- Nuclear Gauges are not correlated to specific mix

PWL

- Statistically based (Individual tests)
- Volumetrics:
  - Lot size = 3750 ton
  - Sublot size = 750 ton
- Densities
  - Lot sizes will not change with PWL
  - QV tests become more statistically meaningful in new system
- Nuclear Gauges will be correlated to specific mix for each layer (cores)

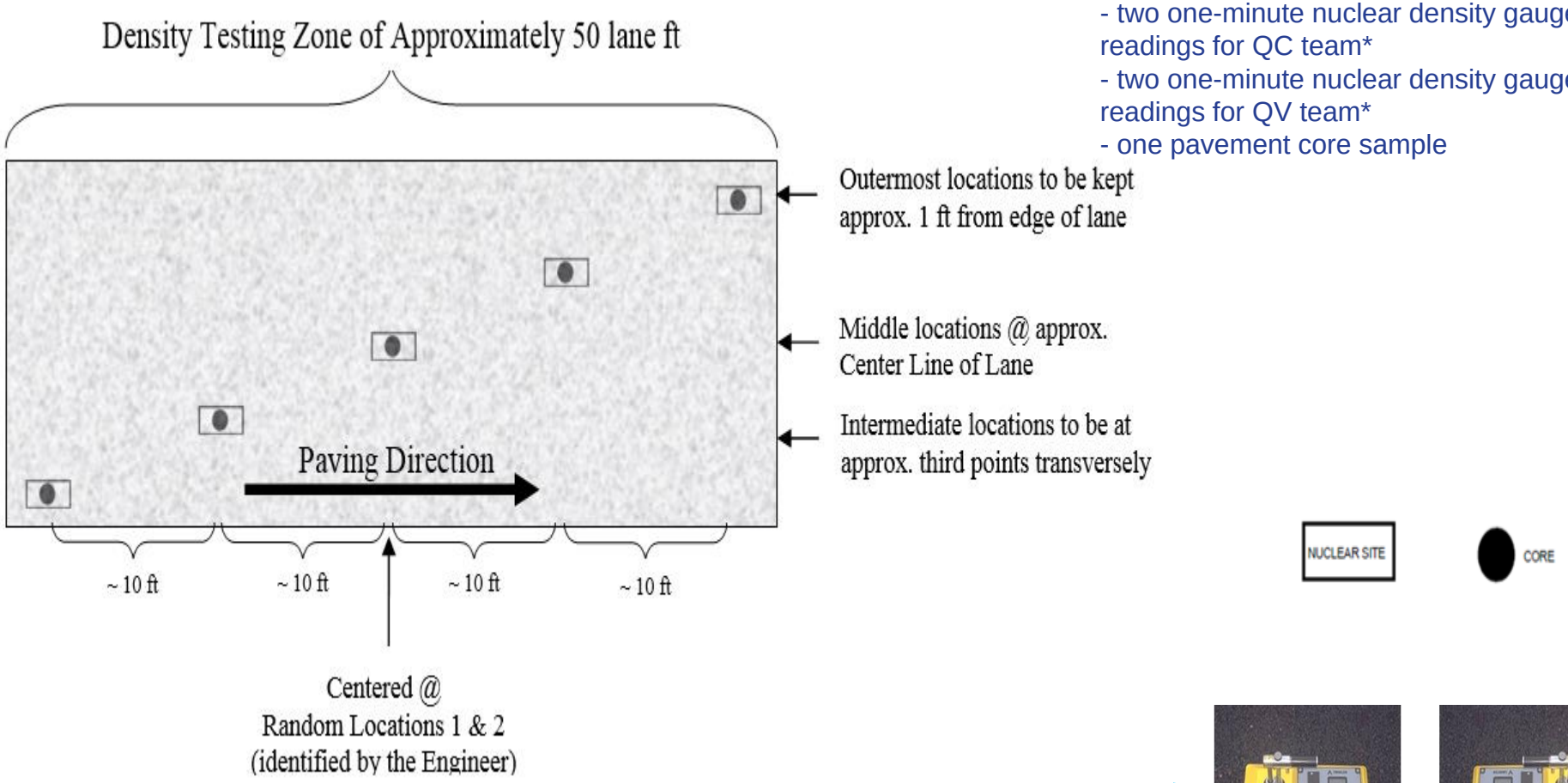
Details of PWL

- Test Strip
  - Approx. 750 tons
    - Volumetrics: 3 samples @ 50-250, 251-500, and 501-750 tons
      - 4-way split: QC, QV, QC retained, & QV retained
    - Density: used for correlation with cores @ time of Test Strip
    - Core/Gauge Correlation: 2 zones @ 50-400 and 401-750 tons

Test Strip – A Closer Look

The following shall be determined at each of the five locations within both zones:

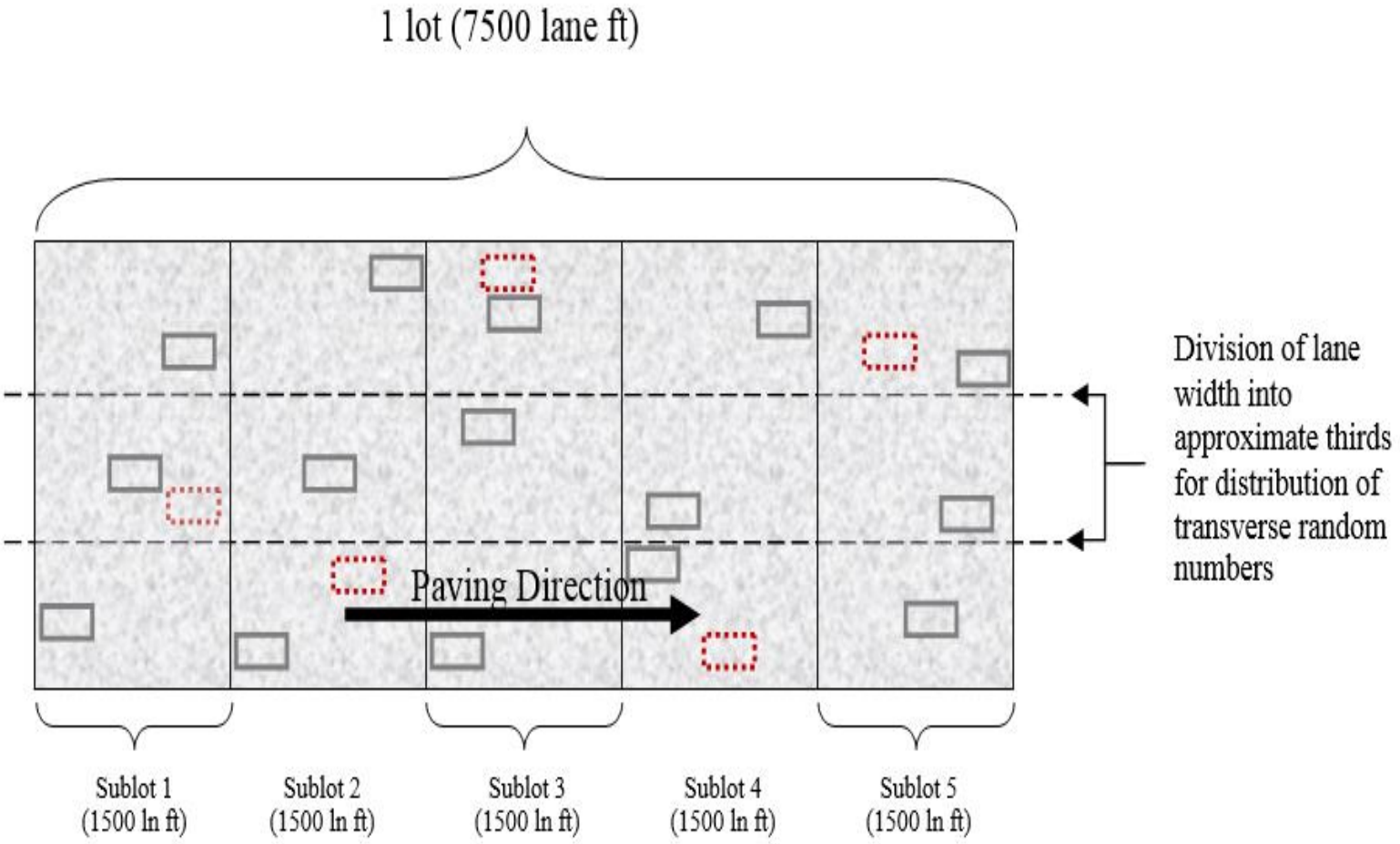
- two one-minute nuclear density gauge readings for QC team*
- two one-minute nuclear density gauge readings for QV team*
- one pavement core sample



Details of Wisconsin's PWL

- Main Production
  - Defined as any material beyond test strip
    - Density
      - Sublots @ 1500 LF, Lots @ 7500 LF (5 sublots per lot)
      - 15 QC, 5 QV locations per lot
      - Incentive will only be for the travel lane (12 feet)
      - Shoulders, intersections, ramps, etc. will be accepted by department testing

Main Production – Density



Lot		Date	QC Tests	Verification Test	F-Test Result	t-Test Result
3	1A	9/04/2014	94.75			
3	1B	9/04/2014	95.96	94.90		
3	1C	9/04/2014	93.91			
3	2A	9/04/2014	95.00	94.20		
3	2B	9/04/2014	93.27			
3	2C	9/04/2014	94.17			
3	3A	9/05/2014	91.47			
3	3B	9/05/2014	92.88			
3	3C	9/05/2014	93.33	91.90		
3	4A	9/10/2014	95.70	95.63		
3	4B	9/10/2014	95.47			
3	4C	9/10/2014	95.06			
3	5	9/10/2014	92.83	93.27		
3	5B	9/10/2014	94.29			
3	5C	9/10/2014	93.39		Pass	Pass

													Layer Thickness (inches)	Average Unit Price
						Density								
Lot		Date	Contractor QC Test	DOT Verification Test	Standard Deviation	Mean	Number of Tests in Lot	Quality Index	PWL_D	PF_D	Lot Size (Ton)	Density Pay Adjustment	2.00	$80.00
3	1A	9/4/2014	94.75											
3	1B	9/4/2014	95.96	94.90										
3	1C	9/4/2014	93.91											
3	2A	9/4/2014	95.00	94.20										
3	2B	9/4/2014	93.27											
3	2C	9/4/2014	94.17											
3	3A	9/5/2014	91.47											
3	3B	9/5/2014	92.88											
3	3C	9/5/2014	93.33	91.90										
3	4A	9/10/2014	95.70	95.63										
3	4B	9/10/2014	95.47											
3	4C	9/10/2014	95.06											
3	5A	9/10/2014	92.83	93.27										
3	5B	9/10/2014	94.29											
3	5C	9/10/2014	93.39		1.25093	94.10083	15	2.0791	98.7558	103.50	1120.00	$1,569.04		

Dispute Resolution - Density

Statistical analysis performed on QC & QV nuclear gauge data:

1. If data compares, QC data used in subsequent calculations

2. If data does not compare, QV data used in subsequent calculations

Details of Wisconsin's PWL

- Main Production
  - Any material beyond test strip
    - Volumetrics
      - 3-way splits for QC, QV, & retained
      - Sublots @ 750 tons, Lots @ 3750 tons (5 sublots per lot)
      - 5 QC, 1 QV test per lot

Air Voids											α
Lot	Date	QC Tests	Verification Test	QC Tests	QV Test	Number of QC Tests	Number of QA Tests	Variances Compare?	Means Compare?		0.025
1A	6/01/2014		2.475		2.475						
1B	6/02/2014	2.469		2.469							
1C	6/03/2014	2.477		2.477							
1D	6/04/2014	2.466		2.466							
1E	6/07/2014	2.467		2.467							
2A	6/01/2014	2.464		2.464							
2B	6/02/2014		2.482		2.482						
2C	6/03/2014	2.471		2.471							
2D	6/04/2014	2.473		2.473							
2E	6/07/2014	2.470		2.470							
3A	6/01/2014	2.474		2.474							
3B	6/02/2014	2.469		2.469							
3C	6/03/2014		2.472		2.472						
3D	6/04/2014	2.470		2.470							
3E	6/07/2014	2.476		2.476		12	3	Yes	Yes		
4A	6/01/2014	2.467		2.467							
4B	6/02/2014	2.470		2.470							
4C	6/03/2014	2.468		2.468							
4D	6/04/2014		2.471		2.471						
4E	6/07/2014	2.477		2.477		16	4	Yes	Yes		
5A	6/01/2014	2.468		2.468							
5B	6/02/2014	2.483		2.483							
5C	6/03/2014	2.481		2.481							
5D	6/04/2014		2.479		2.479						
5E	6/07/2014	2.473		2.473		20	5	Yes	Yes		

PWL Air void payment calculated from Gmm & Gmb data

Project1234

				Air Voids					
Lot	Date	Contractor QC Test	Department QV Test	PWL	PF_{AV}	Lot Size (Ton)	Air Voids Pay Adjustment	Use Contractors Test?	
1A	6/1/2014	2.83	2.86						
1B	6/2/2014	2.87							
1C	6/3/2014	3.36							
1D	6/4/2014	4.14							
1E	6/7/2014	4.80		72.93	91.47	3750.00	($12,795.00)	Yes	Y
2A	6/8/2014	3.05							
2B	6/9/2014	3.47	2.97						
2C	6/10/2014	3.68							
2D	6/11/2014	3.86							
2E	6/12/2014	3.66		99.89	103.96	3750.00	$5,940.00	Yes	Y
3A	6/13/2014	3.79							
3B	6/14/2014	3.66							
3C	6/15/2014	4.17	2.30						
3D	6/16/2014	4.20							
3E	6/17/2014	3.82		100.00	104.00	3750.00	$6,000.00	Yes	Y
4A	6/18/2014	3.55							
4B	6/19/2014	3.43							
4C	6/20/2014	3.60							
4D	6/21/2014	3.89	3.25						
4E	6/22/2014	3.65		100.00	104.00	3750.00	$6,000.00	Yes	Y
5A	6/23/2014	3.01							
5B	6/24/2014	4.51							
5C	6/25/2014	4.55							
5D	6/26/2014	4.04	2.99						
5E	6/27/2014	3.77		95.38	102.15	3750.00	$3,225.00	Yes	Y
						Total	$8,370.00		

Dispute Resolution - Volumetrics

Statistical analysis performed on Gmm & Gmb. If F- or t-test do not compare, proceed as follows:

1. Bureau referee tests retained portion of split sample
   - Run secondary statistical analysis
   - If data compare, QC data is reliable
   - If data does not compare, QC or QV data is suspect. Proceed to #2
2. QV tests run on remaining 4 sublots
   - 4 QV and 1 referee test results used in subsequent calculations

- For volumetrics, contractor will be able to dispute a lot. Bureau will test the material
  - If incentive increases, department will cover costs
  - If incentive decreases, contractor will pay $2000 per lot

Lot	Date	QC Tests	QV Test	Variances Compare?	Means Compare?
1A	6/01/2014		2.475		
1B	6/02/2014	2.469			
1C	6/03/2014	2.477			
1D	6/04/2014	2.466			
1E	6/07/2014	2.467			
2A	6/09/2014	2.464			
2B	6/10/2014		2.482		
2C	6/11/2014	2.471			
2D	6/11/2014	2.473			
2E	6/11/2014	2.470			
3A	6/11/2014	2.474			
3B	6/12/2014	2.469			
3C	6/12/2014		2.472		
3D	6/13/2014	2.470			
3E	6/13/2014	2.476		Yes	Yes
4A	6/14/2014	2.467			
4B	6/15/2014	2.470			
4C	6/15/2014	2.468			
4D	6/15/2014		2.471		
4E	6/16/2014	2.477		Yes	Yes
5A	6/17/2014	2.468			
5B	6/17/2014	2.483			
5C	6/17/2014	2.481			
5D	6/18/2014		2.443		
5E	6/18/2014	2.473		NO	Yes

= Testing performed by the Region
= Testing performed by the Referee third party (BTS)
= QC random production sample
= data to be used in pay determination for the lot

WISCONSIN DEPARTMENT OF TRANSPORTATION

Lot	Date	QC Tests	QV Test	Variances Compare?	Means Compare?
1A	6/01/2014		2.475		
1B	6/02/2014	2.469			
1C	6/03/2014	2.477			
1D	6/04/2014	2.466			
1E	6/07/2014	2.467			
2A	6/09/2014	2.464			
2B	6/10/2014		2.482		
2C	6/11/2014	2.471			
2D	6/11/2014	2.473			
2E	6/11/2014	2.470			
3A	6/11/2014	2.474			
3B	6/12/2014	2.469			
3C	6/12/2014		2.472		
3D	6/13/2014	2.470			
3E	6/13/2014	2.476		Yes	Yes
4A	6/14/2014	2.467			
4B	6/15/2014	2.470			
4C	6/15/2014	2.468			
4D	6/15/2014		2.471		
4E	6/16/2014	2.477		Yes	Yes
5A	6/17/2014	2.468			
5B	6/17/2014	2.483			
5C	6/17/2014	2.481			
5D	6/18/2014		2.479		
5E	6/18/2014	2.473		Yes	Yes

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WISCONSIN DEPARTMENT OF TRANSPORTATION

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1D	6/04/2014	2.466			
1E	6/07/2014	2.467			
2A	6/09/2014	2.464			
2B	6/10/2014		2.482		
2C	6/11/2014	2.471			
2D	6/11/2014	2.473			
2E	6/11/2014	2.470			
3A	6/11/2014	2.474			
3B	6/12/2014	2.469			
3C	6/12/2014		2.472		
3D	6/13/2014	2.470			
3E	6/13/2014	2.476		Yes	Yes
4A	6/14/2014	2.467			
4B	6/15/2014	2.470			
4C	6/15/2014	2.468			
4D	6/15/2014		2.471		
4E	6/16/2014	2.477		Yes	Yes
5A	6/17/2014	2.468			
5B	6/17/2014	2.483			
5C	6/17/2014	2.481			
5D	6/18/2014		2.451		
5E	6/18/2014	2.473		NO	Yes

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WISCONSIN DEPARTMENT OF TRANSPORTATION

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1B	6/02/2014	2.469	
1C	6/03/2014	2.477	
1D	6/04/2014	2.466	
1E	6/07/2014	2.467	
2A	6/09/2014	2.464	
2B	6/10/2014		2.482
2C	6/11/2014	2.471	
2D	6/11/2014	2.473	
2E	6/11/2014	2.470	
3A	6/11/2014	2.474	
3B	6/12/2014	2.469	
3C	6/12/2014		2.472
3D	6/13/2014	2.470	
3E	6/13/2014	2.476	
4A	6/14/2014	2.467	
4B	6/15/2014	2.470	
4C	6/15/2014	2.468	
4D	6/15/2014		2.471
4E	6/16/2014	2.477	
5A	6/17/2014	2.468	2.448
5B	6/17/2014	2.483	2.454
5C	6/17/2014	2.481	2.443
5D	6/18/2014		2.451
5E	6/18/2014	2.473	2.442

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WISCONSIN DEPARTMENT OF TRANSPORTATION

PAY FACTOR FOR HMA PAVEMENT AIR VOIDS & DENSITY

PERCENT WITHIN LIMITS (PWL)	*PAYMENT FACTOR, PF (percent of contract price)*
> 90 to 100	PF = ((PWL – 90) * 0.4) + 100
≥ 50 to 90	(PWL * 0.5) + 55
<50	50%[1]

where,

PF is calculated per air voids and density, denoted $PF_{air\ voids}$ & $PF_{density}$

[1] Any material resulting in PWL value of 50 or less shall be removed and replaced, unless the engineer allows for such material to remain in place. In the event the material remains in place, it will be paid at 50% of the contract unit price.

Pay Adjustment = (PF-100) x (WP) x (tonnage) x (unit price)

The following weighted percentage (WP) values shall be used for the corresponding parameter:

Parameter	WP
Air Voids	0.5
Density	0.5

Example of Incentives

At the maximum 4% incentive:

- ½ of 4% assigned to Air Voids
  - $6,000 per lot incentive (3750 tons)
    (Assuming $80/ton unit price)
- ½ of 4% assigned to Density
  - $1,790 per lot incentive (1120 tons)
    (Assuming two inch thickness)

The future:

- Contractors across the state receive the maximum 4% incentive, $$$$$$

- This would mean that Wisconsin pavements will last a significant amount longer which will more than pay for the cost of the incentive

Questions/Comments