WEST VIRGINIA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
MATERIALS CONTROL, SOILS AND TESTING DIVISION

MATERIALS PROCEDURE

GUIDE TO STATISTICAL ANALYSIS OF MATERIAL USING QUALITY LEVEL ANALYSIS-PERCENT WITHIN LIMITS

1. PURPOSE

1.1 The procedure described herein was developed in order to evaluate a set of test results and determine the Percent Within Limits (PWL) of the test results in accordance with Specification requirements.

2. SCOPE

2.1 This procedure is directly applicable to the WVDOH Standard Specifications Section 410, and the intent is to help determine pay factors for Asphaltic Pavement material as per the Special Provision. Please note that the resulting values for PWL determined with this procedure are affected by shifts in the arithmetic mean and by the sample standard deviation.

2.2 The resulting PWL values determined using this procedure are to be used to calculate pay factors as per the corresponding parts within WVDOH Standard Specifications 410.13, Basis of Payment.

3. PROCEDURE

3.1 All sampling and testing shall be performed as specified in the appropriate AASHTO, ASTM, and Division Material Procedures as required. The PWL can be calculated when evaluating test results within a specification containing both upper and lower target values, or when evaluating test results within a specification containing a single target value. Calculations will done in accordance with the procedures outlined within AASHTO R-9, *Standard Practice for Acceptance Sampling Plans for Highway Construction* using Excel workbooks prepared by MCS&T and used for laboratory analysis and documentation of test results.

4. CALCULATIONS

All rounding is to occur in the final PL and PU calculations. Sample rounding precision is listed in the table below.

4.1 Determine the arithmetic mean ($\overline{X}$) of the test results

$$\overline{X} = \frac{\Sigma x}{n}$$

Where:

$\overline{X}$ = arithmetic mean of test results
Σx = sum of test results
x = individual test value, and
n = total number of test values.

4.2 Compute the sample standard deviation(s):

$$s = \sqrt{\frac{n\Sigma(x^2)-(\Sigma x)^2}{n(n-1)}}$$

$$s = ((n\Sigma(x^2) - (\Sigma x)^2)/(n(n-1)))^{1/2}$$

Where:

s = sample standard deviation

4.3 Compute the upper quality index (Qu):

$$Q_u = \frac{USL - \overline{X}}{s}$$

Where:

Q_u = upper quality index, and
USL = upper specification limit

Mix or Pavement Criteria	Rounding Precision	Upper Specification Limit (USL)
Mat Density (%)	0.00	97.0
Asphalt Binder Content (%) - *mixes with NMAS 19 mm (3/4") or less*	0.00	Mix design target value + 0.4
Asphalt Binder Content (%) - *mixes with NMAS 25 mm (1") or greater.*	0.00	Mix design target value + 0.5
Gradation Minus #200 (%)	0.0	Mix design target + 2.0.
Bond Strength (psi)	0.	Min 100. psi

4.4 Compute the lower quality index (QL):

$$Q_L = \frac{\overline{X} - LSL}{s}$$

Where:

Q_L = lower quality index, and
LSL = lower specification limit = target value[1] minus allowable deviation on a low side.

Mix or Pavement Criteria	Lower Specification Limit (LSL)
Mat Density (%)	91.5
Joint Density (%)	89.0
Bond Strength (psi)	100
Asphalt Binder Content (%) - *mixes with NMAS 19 mm (3/4") or less*	Mix design target value - 0.4
Asphalt Binder Content (%) - *mixes with NMAS 25 mm (1") or greater.*	Mix design target value - 0.5
Gradation Minus #200 (%)	Mix design target - 2.0.

4.5 Compute the quality level:

$$PWL = (P_u + P_L) - 100$$

Round PWL to whole number

Where:

PWL = Percent Within Limit.
P_u = percent within the upper specification limit which corresponds to a given Q_u from Table 1.
P_L = percent within the lower specification limit which corresponds to a given Q_L from Table 1.

[1] *When a USL is not specified, P_u shall be 100, and when a LSL is not specified, P_L shall be 100.*

TABLE 1
QUALITY LEVEL ANALYSIS BY THE STANDARD DEVIATION METHOD

PU or PL % *	Upper Quality Index (QU) or lower Quality Index (QL)														
	N=3	n=4	n=5	n=6	n=7	n=8	N=9	n=10 To n=11	n=12 to n=14	n=15 To n=18	n=19 to n=25	n=26 To n=37	n=38 to n=69	N=70 To N=200	n=201 to n=x
100	1.16	1.50	1.79	2.03	2.23	2.39	2.53	2.65	2.83	3.03	3.20	3.38	3.54	3.70	3.83
99		1.47	1.67	1.80	1.89	1.95	2.00	2.04	2.09	2.14	2.18	2.22	2.26	2.29	2.31
98	1.15	1.44	1.60	1.70	1.76	1.81	1.84	1.86	1.91	1.93	1.96	1.99	2.01	2.03	2.05
97		1.41	1.54	1.62	1.67	1.70	1.72	1.74	1.77	1.79	1.81	1.83	1.85	1.86	1.87
96	1.14	1.38	1.49	1.55	1.59	1.61	1.63	1.65	1.67	1.68	1.70	1.71	1.73	1.74	1.75
95		1.35	1.44	1.49	1.52	1.54	1.55	1.56	1.58	1.59	1.61	1.62	1.63	1.63	1.64
94	1.13	1.32	1.39	1.43	1.46	1.47	1.48	1.49	1.50	1.51	1.52	1.53	1.54	1.55	1.55
93		1.29	1.35	1.38	1.40	1.41	1.42	1.43	1.44	1.44	1.45	1.46	1.46	1.47	1.47
92	1.12	1.26	1.31	1.33	1.35	1.36	1.36	1.37	1.37	1.38	1.39	1.39	1.40	1.40	1.40
91	1.11	1.23	1.27	1.29	1.30	1.30	1.31	1.31	1.32	1.32	1.33	1.33	1.33	1.34	1.34
90	1.10	1.20	1.23	1.24	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.28	1.28	1.28
89	1.09	1.17	1.19	1.20	1.20	1.21	1.21	1.21	1.21	1.22	1.22	1.22	1.22	1.22	1.23
88	1.07	1.14	1.15	1.16	1.16	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
87	1.06	1.11	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.13	1.13
86	1.04	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
85	1.03	1.05	1.05	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
84	1.01	1.02	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99
83	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.95	0.95	0.95
82	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
81	0.96	0.93	0.91	0.90	0.90	0.89	0.89	0.89	0.89	0.88	0.88	0.88	0.88	0.88	0.88
80	0.93	0.90	0.88	0.87	0.86	0.86	0.86	0.85	0.85	0.85	0.85	0.84	0.84	0.84	0.84
79	0.91	0.87	0.85	0.84	0.83	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.81
78	0.89	0.84	0.82	0.80	0.80	0.79	0.79	0.79	0.78	0.78	0.78	0.78	0.77	0.77	0.77
77	0.87	0.81	0.78	0.77	0.76	0.76	0.76	0.75	0.75	0.75	0.75	0.74	0.74	0.74	0.74
76	0.84	0.78	0.75	0.74	0.73	0.73	0.72	0.72	0.72	0.71	0.71	0.71	0.71	0.71	0.71
75	0.82	0.75	0.72	0.71	0.70	0.70	0.69	0.69	0.69	0.68	0.68	0.68	0.68	0.68	0.67
74	0.79	0.72	0.69	0.68	0.67	0.66	0.66	0.66	0.66	0.65	0.65	0.65	0.65	0.64	0.64
73	0.76	0.69	0.66	0.65	0.64	0.63	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.61	0.61
72	0.74	0.66	0.63	0.62	0.61	0.60	0.60	0.60	0.59	0.59	0.59	0.59	0.59	0.58	0.58
71	0.71	0.63	0.60	0.59	0.58	0.57	0.57	0.57	0.57	0.56	0.56	0.56	0.56	0.55	0.55
70	0.68	0.60	0.57	0.56	0.55	0.55	0.54	0.54	0.54	0.53	0.53	0.53	0.53	0.53	0.52
69	0.65	0.57	0.54	0.53	0.52	0.52	0.51	0.51	0.51	0.50	0.50	0.50	0.50	0.50	0.50
68	0.62	0.54	0.51	0.50	0.49	0.49	0.48	0.48	0.48	0.48	0.47	0.47	0.47	0.47	0.47
67	0.59	0.51	0.47	0.47	0.46	0.46	0.46	0.45	0.45	0.45	0.45	0.44	0.44	0.44	0.44
66	0.56	0.48	0.45	0.44	0.44	0.43	0.43	0.43	0.42	0.42	0.42	0.42	0.41	0.41	0.41
65	0.52	0.45	0.43	0.41	0.41	0.40	0.40	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.39
64	0.49	0.42	0.40	0.39	0.38	0.38	0.37	0.37	0.37	0.37	0.36	0.36	0.36	0.36	0.36
63	0.46	0.39	0.37	0.36	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.33	0.33	0.33
62	0.43	0.36	0.34	0.33	0.32	0.32	0.32	0.32	0.31	0.31	0.31	0.31	0.31	0.31	0.31
61	0.39	0.33	0.31	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28	0.28
60	0.36	0.30	0.28	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25
59	0.32	0.27	0.25	0.25	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.23
58	0.29	0.24	0.23	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20
57	0.25	0.21	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
56	0.22	0.18	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15
55	0.18	0.15	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
54	0.14	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
53	0.11	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
52	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
51	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NOTE: For negative values of QU or QL, PU or PL is equal to 100 minus the table value for PU or PL. If the value of QU or QL does not correspond exactly to a figure in the table, use the next higher figure.

* Within limits for positive values of QU or QL.

5. EXAMPLE CALCULATIONS

5.1 The following examples are shown for illustrative purposes only. All rounding shown below will not apply to formal calculations for project pay factors.

EXAMPLE 1 – Mat Density Evaluation

2,500 tons of asphaltic pavement are placed, and five equal sublots of material have been laid out in the field as per MP 401.07.21. A core for density analysis is removed from locations determined randomly and the resulting compaction percentage is determined for each individual sample. The individual values are shown below.

$X_1 = 91.10$
$X_2 = 92.00$
$X_3 = 92.80$
$X_4 = 95.20$
$X_5 = 96.00$

- *The sample average for the lot and the standard deviation are calculated as follows:*

  $\mathbf{X_{avg}} = (91.10 + 92.00 + 92.80 + 95.20 + 96.00)/5 =$ **93.40**

  Sample size, n = 5

  ***S* = 2.10**

- *Calculate the Quality Index values:*

  For mat density, USL = 97.00 and LSL = 91.50

  $\mathbf{Q_U} = (97 – 93.4)/2.10 =$ **1.71**
  $\mathbf{P_U} =$ **100** (From Table 1)

  $\mathbf{Q_L} = (93.4 – 91.5)/2.10 =$ **0.91**
  $\mathbf{P_L} =$ **81** (From Table 1)

- *Calculate PWL:*

  $PWL = (P_u + P_l) – 100$ ➡ **PWL** $= (100 + 81) – 100 =$ **81**

- *Pay Factor :* As per Table 401.13.3.1, Pay factor = 0.5(PWL)+55

  Pay Factor = 0.5(81)+55 = **95.5%**

EXAMPLE 2 – Joint Density Evaluation

10,000' of longitudinal joint was constructed between the fast lane and slow lane on an interstate paving project. This constructed joint was laid out prior to construction and divided into five equal sublots of 2,000' per each sublot in the field as per MP 401.07.21. A core for density analysis is removed from locations determined randomly within each sublot and the resulting compaction percentage is determined for each individual sample.

$X_1 = 88.30$
$X_2 = 89.60$
$X_3 = 88.50$
$X_4 = 89.20$
$X_5 = 89.50$

- *The sample average for the lot and the standard deviation are calculated with the following results:*

  X_{avg} = 89.00

  ***S* = 0.59**

- *Calculate the Quality Index values:*

  For joint density, LSL = 89.00

  Q_L = (89.00 – 89.00)/0.59 = **0.00**
  P_L = 50 (From Table 1)

- *Calculate PWL:*

  PWL = (P_U + P_L) – 100 (For single tolerance, use 100 for the other value)

  PWL = (100 + 50) – 100 = **50**

- *Pay Factor :* As per 401.13.4, PWL is less than 60

  Negative Adjustment = [(60 – PWL)/60] x $12,500

  Negative Adjustment = [(60 – 50)/60] x $12,500

  Negative Adjustment = [0.166666] x $12,500 = **$2,083.33**

EXAMPLE 3 – Asphalt Content

2,500 tons of asphaltic pavement are placed, and five equal sublots of material have been laid out in the field as per MP 401.07.20. The mix being placed is a Superpave 9.5 mm mix with a design target of 6.5% AC. A loose sample for determination of asphalt binder content is removed from locations within each sublot and the resulting asphalt binder content is determined for each individual sample. The individual values are shown below.

$X_1 = 6.70$
$X_2 = 6.90$
$X_3 = 6.70$
$X_4 = 6.90$
$X_5 = 7.00$

- *The sample average for the lot and the standard deviation are calculated as follows:*

  $\mathbf{X_{avg} = 6.84}$

  Sample size, n = 5

  $\boldsymbol{S = 0.13}$

- *Calculate the Quality Index values:*

  For AC, USL = 6.9 and LSL = 6.1

  $\mathbf{Q_U}$ = (6.9 – 6.84)/0.13 = **0.46**
  $\mathbf{P_U = 67}$ (From Table 1)

  $\mathbf{Q_L}$ = (6.84 – 6.1)/0.13 = **5.69**
  $\mathbf{P_L = 100}$ (From Table 1)

- *Calculate PWL:*

  PWL = $(P_u + P_l) - 100$ ➡ **PWL** = (67 + 100) – 100 = **67**

- *Pay Factor :* As per Table 401.13.3.2

  Pay Factor = 55%

EXAMPLE 4 - Gradation

2,500 tons of asphaltic pavement are placed, and five equal sublots of material have been laid out in the field as per MP 401.07.20. The mix being placed is a Superpave 9.5 mm mix with a design target of 6.4% on the #200 sieve. A loose sample for gradation is removed from locations within each sublot and the results for material finer than the #200 sieve are shown below.

$X_1 = 4.4$
$X_2 = 5.3$
$X_3 = 5.6$
$X_4 = 5.9$
$X_5 = 6.4$

- *The sample average for the lot and the standard deviation are calculated as follows:*

  $\mathbf{X_{avg}} = \mathbf{5.52}$

  Sample size, n = 5

  $\boldsymbol{S} = \mathbf{0.75}$

- *Calculate the Quality Index values:*

  For #200 sieve, USL = 8.4 and LSL = 4.4

  $\mathbf{Q_U}$ = (8.4 – 5.52)/0.75 = **3.84**
  $\mathbf{P_U}$ = **100** (From Table 1)

  $\mathbf{Q_L}$ = (5.52 – 4.4)/0.75 = **1.49**
  $\mathbf{P_L}$ = **96** (From Table 1)

- *Calculate PWL:*

  PWL = $(P_u + P_l) - 100$ ➡ **PWL** = (100 + 96) – 100 = **96**

- *Pay Factor :* As per Table 401.13.3.2

  Pay Factor = 96%

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