Statistical Analysis

Determining payment

NEC/AAAE 2017 Annual Airport Conference

Hershey, PA

Content of Presentation

- Explain concept behind Percentage Within Limits (PWL)
- Demonstrate importance of process control on PWL
- Testing results as outliers
- Resampling
- Present ERLPM PWL calculation sheet and FAA Spreadsheet

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FAA Acceptable Quality

- Item P-401--FAA assumes process control parameters that are "not unreasonable" for mat density, joint density, and air voids.
- All acceptance criteria is based on processes with variation in quality conforming to a normal distribution "bell" curve.
- Each day's production is evaluated and pay is based on daily evaluation of 4 random samples.

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Basic Concept

- Contractor quality control
- Random samples of a small fraction of production material
- Acceptance: decision to accept or reject lot for payment based upon random samples of a small fraction from the lot

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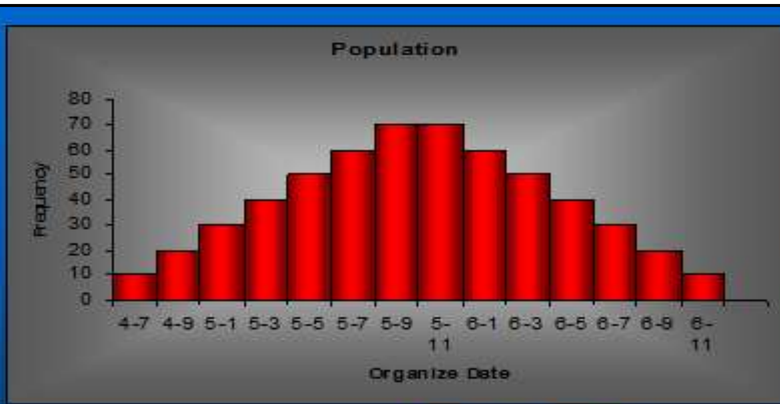

Analysis
% Taller than 5'-6"
% between 5'-6" and 6'-6"
Average Height

Limit # of samples
→ Statistical Analysis
→ Estimate average and % within limits

Overview

P 401 Test Results

↓

Statistical Analysis; PWL Estimate

↓

Verify Production Process: Payment

Theory

1. Assumptions
2. Normal Distribution
3. Tools: Average and Standard Deviation
4. Percent Within Limits (PWL) Concept

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Assumptions

1. Limited # of test results — Statistical Analysis —Quality characteristics of large amount of material
2. Test result variability
   Components:
   - materials
   - sampling
   - testing-
3. Same Process
4. Random sampling-Lot, Sublot
5. Normal Distribution

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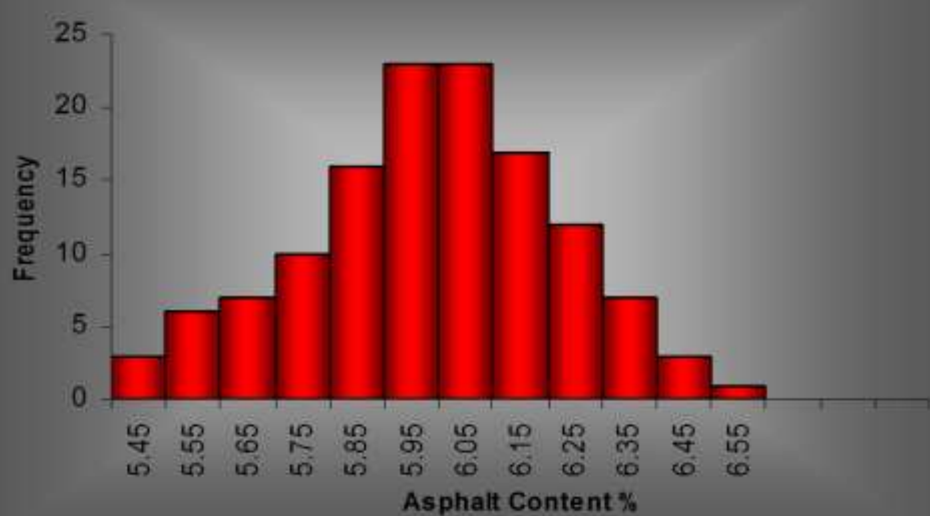
Specific Procedures

1. Sublots, Lots, Partial Lots
2. Calculations
3. Retesting
4. Outliers

Figure 1



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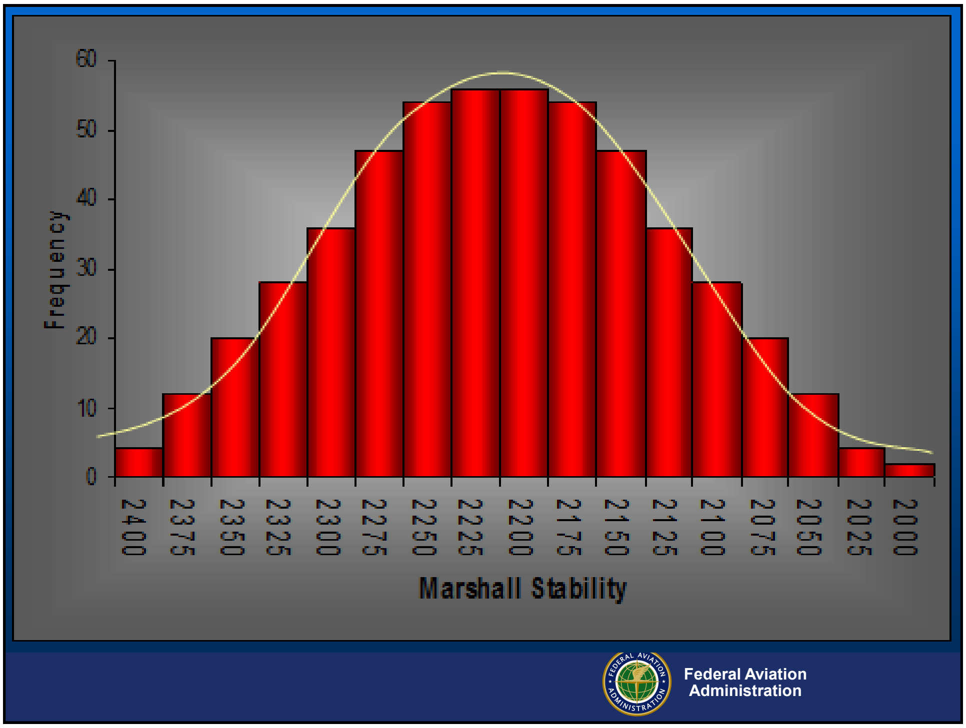
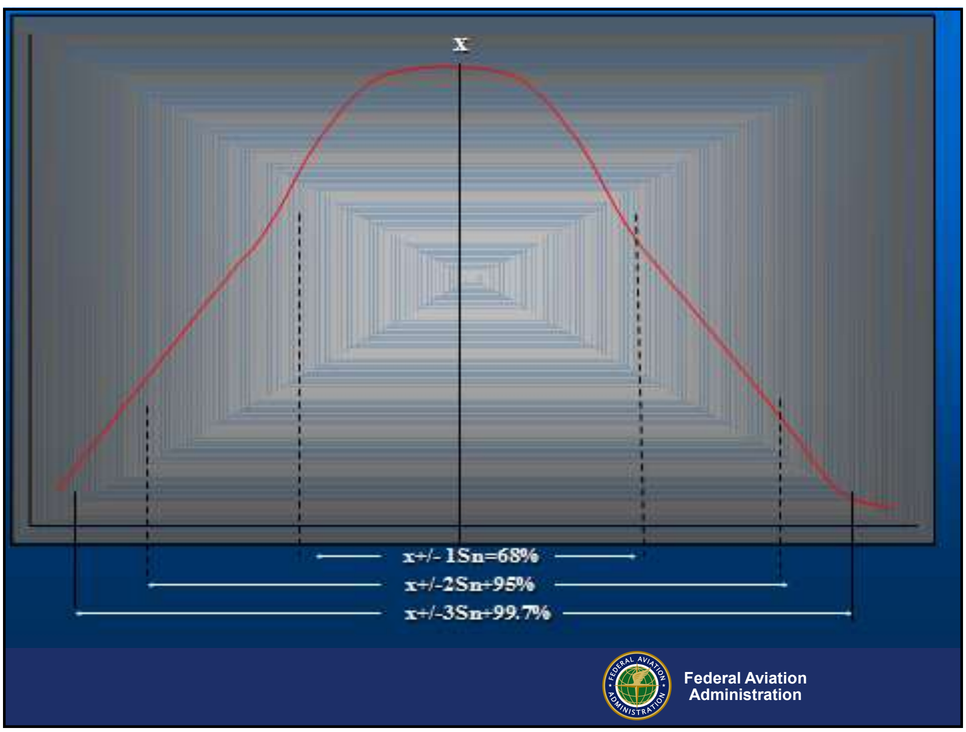

60
50
40
30
20
10
0
Frequency
2400
2375
2350
2325
2300
2275
2250
2225
2200
2175
2150
2125
2100
2075
2050
2025
2000
Marshall Stability
Federal Aviation Administration


x
x+/- 1Sn=68%
x+/-2Sn=95%
x+/-3Sn=99.7%
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PWL Calculation Procedures

ERLPM-page 48

Section 110-AC 150/5370-10G.

Method for Computing PWL and Examples

Section 110-02

Spec. P401 Table 5: L and U Spec. Limits pages 37 and 38

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Table 5: Marshall Acceptance Limits

TEST PROPERTY	Pavements Designed for Aircraft Gross Weights of 60,000 Lbs. or More or Tire Pressures of 100 Psi or More		Pavements Designed for Aircraft Gross Weights Less Than 60,000 Lbs. or Tire Pressures Less Than 100 Psi	
Number of Blows	75		50	
	Specification Tolerance Limits		Specification Tolerance Limits	
	L	U	L	U
Stability, minimum, pounds	1800	--	1000	--
Flow, 0.01-inch	8	16	8	20
*Air Voids Total Mix, percent	2	5	2	5
*Surface Course Mat Density, percent	96.3	[101.3]	96.3	[101.3]
*Base Course Mat Density, percent	95.5	101.3]--	95.5	[101.3]
*Joint density, percent	93.3	--	93.*3	--

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Given

$x_1=2$

$x_2=4$

$x_3=6$

$x_4=8$

$$X = \frac{2+4+6+8}{4} = 5$$

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$X=5$

$d_1=2-5=-3$	$d_1^2=9$
$d_2=4-5=-1$	$d_2^2=1$
$d_3=6-5=1$	$d_3^2=1$
$d_4=8-5=3$	$d_4^2=9$

$$Sn = \sqrt{\frac{d_1^2+d_2^2+d_3^2=d_4^2}{n-1}}$$

$$Sn = \sqrt{\frac{9+1+1+9}{4-1}} = \sqrt{\frac{20}{3}}$$

$Sn = 2.58$

(calculator n-1)

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Roundout Rules

ERLPM-page 48

Example-last digit to be kept-nearest 10th

4.61
4.62
4.64
4.6500
4.66
4.67
4.68
4.69

4.66–4.69 becomes 4.7

4.6500:

Even Digit-same
Odd Digit-increase by 1
This case becomes 4.6
If it was 4.7500 it would become 4.8

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MAT Density –One side density acceptance (Manual Appendix E, page 4)

Sublot

1. = 96.0
2. = 97.0
3. = 99.0
4. = 100.0

$\bar{x}=98.0$

$S_n=1.8$

$Q_L = \frac{\bar{x} - L}{S_n}$ — Quality Index. See Section 110-02f and Section 8 page 49 of ERLPM par 8.4.1

$Q_L = \frac{98.0 - 96.3}{1.8} = .9444$ — Spec Tables 5, page 37

Section 110-Table 1, N=4

$P_L=82$ — ERLPM Table 4, pages 51 and 52

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Percent Within Limits (P_L and P_U)	Positive Values of Q (Q_L and Q_U)							
	n=3	n=4	n=5	n=6	n=7	n=8	n=9	N=10
99	1.1541	1.4700	1.6714	1.8008	1.8888	1.9520	1.9994	2.0362
98	1.1524	1.4400	1.6016	1.6982	1.7612	1.8053	1.8379	1.8630
97	1.1496	1.4100	1.5427	1.6181	1.6661	1.6993	1.7235	1.7420
96	1.1456	1.3800	1.4897	1.5497	1.5871	1.6127	1.6313	1.6454
95	1.1405	1.3500	1.4407	1.4887	1.5181	1.5381	1.5525	1.5635
94	1.1342	1.3200	1.3946	1.4329	1.4561	1.4717	1.4829	1.4914
93	1.1269	1.2900	1.3508	1.3810	1.3991	1.4112	1.4199	1.4265
92	1.1184	1.2600	1.3088	1.3323	1.3461	1.3554	1.3620	1.3670
91	1.1089	1.2300	1.2683	1.2860	1.2964	1.3032	1.3081	1.3118
90	1.0983	1.2000	1.2290	1.2419	1.2492	1.2541	1.2576	1.2602
89	1.0864	1.1700	1.1909	1.1995	1.2043	1.2075	1.2098	1.2115
88	1.0736	1.1400	1.1537	1.1587	1.1613	1.1630	1.1643	1.1653
87	1.0597	1.1100	1.1173	1.1192	1.1199	1.1204	1.1208	1.1212
86	1.0448	1.0800	1.0817	1.0808	1.0800	1.0794	1.0791	1.0789
85	1.0288	1.0500	1.0467	1.0435	1.0413	1.0399	1.0389	1.0382
84	1.0119	1.0200	1.0124	1.0071	1.0037	1.0015	1.0000	0.9990
83	0.9939	0.9900	0.9785	0.9715	0.9671	0.9643	0.9624	0.9610
82	0.9749	0.9600	0.9452	0.9367	0.9315	0.9281	0.9258	0.9241
81	0.9550	0.9300	0.9123	0.9025	0.8966	0.8928	0.8901	0.8882
80	0.9342	0.9000	0.8799	0.8690	0.8625	0.8583	0.8554	0.8533
79	0.9124	0.8700	0.8478	0.8360	0.8291	0.8245	0.8214	0.8192
78	0.8897	0.8400	0.8160	0.8036	0.7962	0.7915	0.7882	0.7858
77	0.8662	0.8100	0.7846	0.7716	0.7640	0.7590	0.7556	0.7531
76	0.8417	0.7800	0.7535	0.7401	0.7322	0.7271	0.7236	0.7211
75	0.8165	0.7500	0.7226	0.7089	0.7009	0.6958	0.6922	0.6896
74	0.7904	0.7200	0.6921	0.6781	0.6701	0.6649	0.6613	0.6587
73	0.7636	0.6900	0.6617	0.6477	0.6396	0.6344	0.6308	0.6282
72	0.7360	0.6600	0.6316	0.6176	0.6095	0.6044	0.6008	0.5982
71	0.7077	0.6300	0.6016	0.5878	0.5798	0.5747	0.5712	0.5686
70	0.6787	0.6000	0.5719	0.5582	0.5504	0.5454	0.5419	0.5394
69	0.6490	0.5700	0.5423	0.5290	0.5213	0.5164	0.5130	0.5105
68	0.6187	0.5400	0.5129	0.4999	0.4924	0.4877	0.4844	0.4820
67	0.5878	0.5100	0.4836	0.4710	0.4638	0.4592	0.4560	0.4537
66	0.5563	0.4800	0.4545	0.4424	0.4355	0.4310	0.4280	0.4257
65	0.5242	0.4500	0.4255	0.4139	0.4073	0.4030	0.4001	0.3980
64	0.4916	0.4200	0.3967	0.3856	0.3793	0.3753	0.3725	0.3705
63	0.4586	0.3900	0.3679	0.3575	0.3515	0.3477	0.3451	0.3432
62	0.4251	0.3600	0.3392	0.3295	0.3239	0.3203	0.3179	0.3161
61	0.3911	0.3300	0.3107	0.3016	0.2964	0.2931	0.2908	0.2892
60	0.3568	0.3000	0.2822	0.2738	0.2691	0.2660	0.2639	0.2624
59	0.3222	0.2700	0.2537	0.2461	0.2418	0.2391	0.2372	0.2358
58	0.2872	0.2400	0.2254	0.2186	0.2147	0.2122	0.2105	0.2093
57	0.2519	0.2100	0.1971	0.1911	0.1877	0.1855	0.1840	0.1829
56	0.2164	0.1800	0.1688	0.1636	0.1607	0.1588	0.1575	0.1566
55	0.1806	0.1500	0.1406	0.1363	0.1338	0.1322	0.1312	0.1304
54	0.1447	0.1200	0.1125	0.1090	0.1070	0.1057	0.1049	0.1042
53	0.1087	0.0900	0.0843	0.0817	0.0802	0.0793	0.0786	0.0781
52	0.0725	0.0600	0.0562	0.0544	0.0534	0.0528	0.0524	0.0521
51	0.0363	0.0300	0.0281	0.0272	0.0267	0.0264	0.0262	0.0260
50	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

MAT DENSITY – PERCENT COMPACTION	
PERCENT WITHIN LIMITS (PWL)	
SUBLOT 1 (%)	RESAMPLE 1 (%) *
SUBLOT 2 (%)	RESAMPLE 2 (%) *
SUBLOT 3 (%)	RESAMPLE 3 (%) *
SUBLOT 4 (%)	RESAMPLE 4 (%) *
X (AVERAGE) *	
S_n (STANDARD DEVIATION) *	
L (LOWER LIMIT) = 96.3	
$Q_L = (X-L)/S_n =$	
PWL (% TABLE 4, SECTION 8)	
* TO THE NEAREST HUNDRETH (TWO DECIMAL PLACES)	
CALCULATED BY:	DATE
AFILIATION	

APPENDIX E PAGE 4 OF 4

Mat Density -Two sided acceptance for density

x=98.0

Sn=1.8

$Q_u = \frac{U - x}{Sn}$ (ERLPM page 50)

$Q_u = \frac{101.3 - 98.0}{1.8} = 1.833$ (101.3 found in spec Table 5)

Determine PWL using ERLPM table 4. In column n=4 look up the P_L value which corresponds to Qu=1.833

Read P_L= 100

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PWL calculation for two sided specification

PWL= PL + PU-100
(ERLPM page 50 par 8.5.2)

PWL= 82 + 100 – 100 = 82

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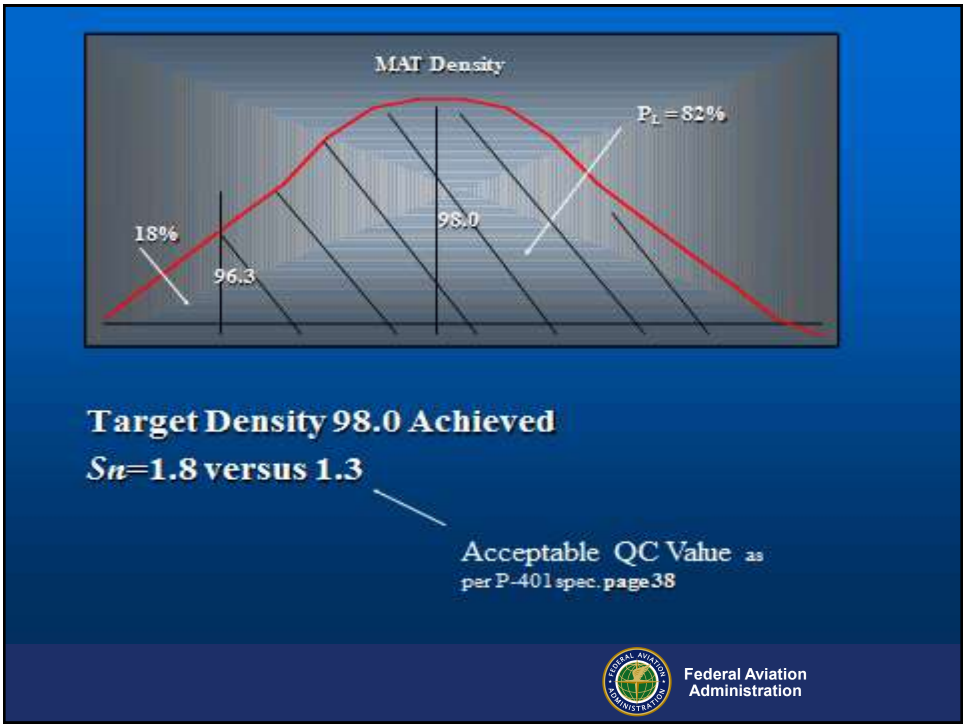
MAT Density
P_L = 82%
18%
96.3
98.0
Target Density 98.0 Achieved
Sn=1.8 versus 1.3
Acceptable QC Value as per P-401 spec. page 38
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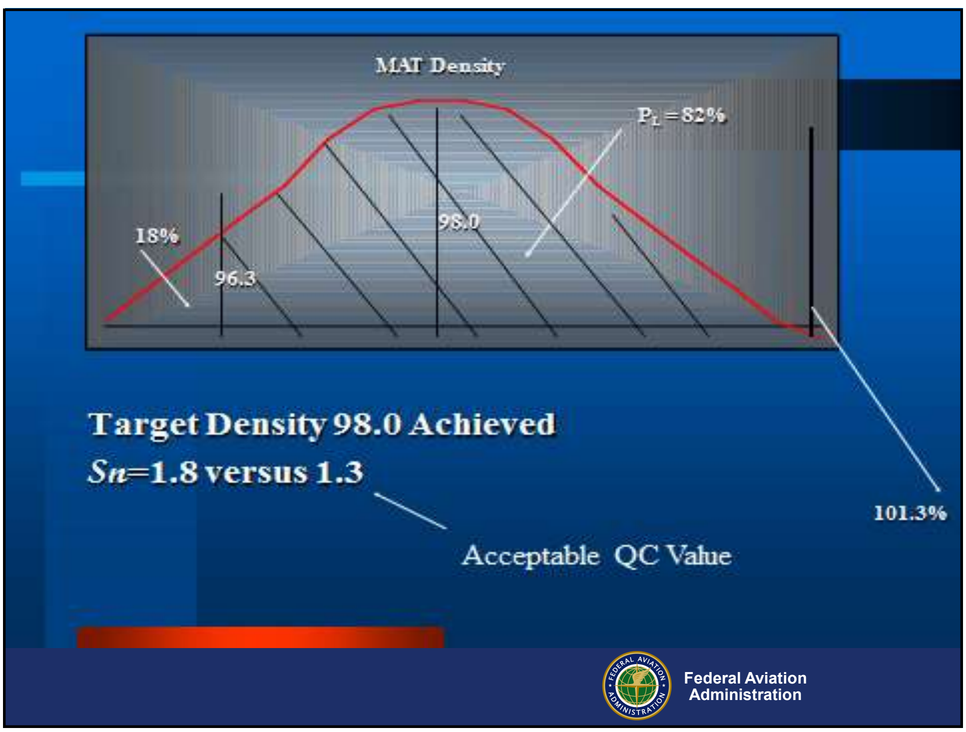
MAT Density
P_L = 82%
18%
96.3
98.0
101.3%
Target Density 98.0 Achieved
Sn=1.8 versus 1.3
Acceptable QC Value
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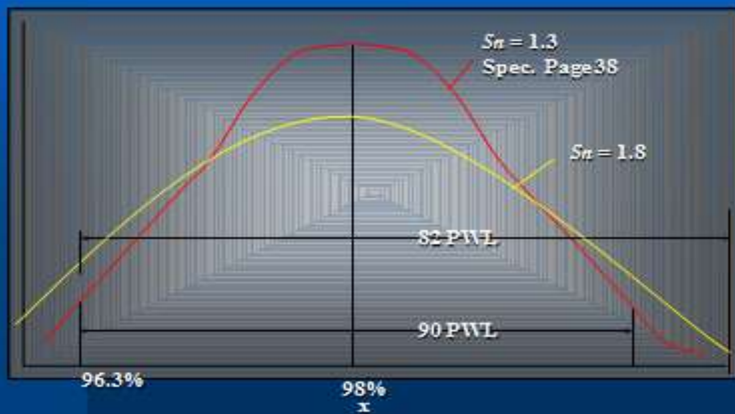
Effect of Quality Control



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Air Voids

App. D, page 3

Sublot

1= 2.1

2= 3.2

3=2.5

4=6.0

X= 3.4

S_n= 1.76

Spec. paragraph 401-3.2 - 0.65 page 7

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For L and U values see P-401 Table 5

page 51,52 of ERLPM

$$Q_L = \frac{\underline{x}-L}{Sn} = \frac{3.4-2.0}{1.76} = .7955$$

P_L(table 4) = 77%

n=4

$$Q_U = \frac{U-\underline{x}}{Sn} = \frac{5-3.4}{1.76} = .909$$

P_U(table 4) = 81%

n=4

$PWL = P_L + P_U - 100$

$PWL = 77+81-100 = 58$

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AIR VOIDS (VTM) ACCEPTANCE CALCULATION	
(LABORATORY MARSHALL SPECIMENS)	
PERCENT WITHIN LIMIT (PWL)	
SUBLOT 1 (AVERAGE) = *	
SUBLOT 2 (AVERAGE) = *	
SUBLOT 3 (AVERAGE) = *	
SUBLOT 4 (AVERAGE) = *	
X (AVERAGE) = *	
S_N (STANDARD DEVIATION) = **	
L (LOWER LIMIT) = 2.0	U (UPPER LIMIT) = 5.0
Q_L = (X − L)/S_N =	Q_U = (U − X)/S_N =
P_L = (% TABLE 1, SECTION 8) =	P_U = (% TABLE 1, SECTION 8) =
PWL = (P_L + P_U) − 100 PWL =	
* TO THE NEAREST TENTH (ONE DECIMAL PLACE) ** TO THE NEAREST HUNDREDTH (TWO DECIMAL PLACES)	
CALCULATION BY:	DATE
AFFILIATION	

APPENDIX D, PAGE 3

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Air Voids

$PWL = P_L + P_U - 100$

$PWL = 77 + 81 - 100 = 58$

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Payment – One side for density

TABLE 6. PRICE ADJUSTMENT SCHEDULE [1] (page 44)

Percentage of Material Within Specification Limits (PWL)	Lot Pay Factor (Percent of Contract Unit Price)
96 – 100	106
90 – 95	PWL + 10
75 – 89	0.5 PWL + 55
55 – 74	1.4PWL – 12
Below 55	Reject [2]

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Payment – two sided for density

TABLE 6. PRICE ADJUSTMENT SCHEDULE [1] (page 45)

Percentage of Material Within Specification Limits (PWL)	Lot Pay Factor (Percent of Contract Unit Price)
93 – 100	103
90 – 93	PWL + 10
70 – 89	0.125PWL + 88.75
40 – 69	0.75PWL+45
Below 40	Reject [2]

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Payment

Spec-par 401-8.1 page 43

MAT Density PWL=82

Air Voids PWL= 58 ➡ Lower value

Lot Pay Factor – Table 6

Air Voids- 1.4 x 58-12= 69.2%

Mat Density- 0.5 x 82+55= 96%

Use lower of 2 values- 69.2%

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FAA Pay Adjustment Schedule

Percentage of Material Within Specification Limits (PWL)	Lot Pay Factor (Percent of Contract Unit Price)
96-100	106
90 - 95	PWL + 10
75 - 90	0.5 PWL + 55
55 - 74	1.4 PWL - 12
Below 55	Reject

Full Pay 90 PWL or Greater

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Joint Density

Appendix E, page 5

93.3
95.0
97.0
96.0
X= 95.3
Sn= 1.58

Table 5 pages 37 and 38

$Q_L = \frac{(95.3-93.3)}{1.58} = 1.2658$

$P_L = 93$

Spec. par. 401-5.2(b)(3) if < 71% there is a 5% penalty –page 32

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Partial Lots

Section P-401-5.1c page 30

Sample Problem

Flow-Appendix D, page 5

Partial lot situation-6 sublots

8.0, 8.2, 8.5, 8.2, 8.9, 9.1

X= 8.5

***Sn*= 0.44**

$$QL = \frac{x - L}{Sn} = \frac{8.5 - 8.0}{0.44} = 1.1364; \; PL = 88$$ (table 4 ERLPM n=6)

$$QU = \frac{U - X}{Sn} = \frac{16 - 8.5}{0.44} = 18.75; \; PL = 100$$

PWL= 88 + 100-100= 88<90

Corrective Action! 401-5.2(b)(2) –page 32

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Outliers

Spec 401-5.2d page 38

401-5.3c page 39

MAT Density and Air Voids

Federal Aviation Administration

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change of measuring instrument, or even change of time of measurements, etc.), then the observed value of the sample criterion used would exceed the "critical value" based on random-sampling theory. Tables of critical values are usually given for several different significance levels, for example, 5 %, 1 %. For statistical tests of outlying observations, it is generally recommended that a low significance level, such as 0.5 %, be used and that significance levels greater than 5 % should not be common practice.

NOTE 1—In this practice, we will usually illustrate the use of the 5 % significance level. Proper choice of level in probability depends on the particular problem and just what may be involved, along with the risk that one is willing to take in rejecting a good observation, that is, if the null-hypothesis stating "all observations in the sample come from the same normal population" may be assumed correct.

3.2 It should be pointed out that almost all criteria for outliers are based on an assumed underlying normal (Gaussian) population or distribution. When the data are not normally or approximately normally distributed, the probabilities associated with these tests will be different. Until such time as criteria not sensitive to the normality assumption are developed, the experimenter is cautioned against interpreting the probabilities too literally.

3.3 Although our primary interest here is that of detecting outlying observations, we remark that some of the statistical criteria presented may also be used to test the hypothesis of normality or that the random sample taken did come from a normal or Gaussian population. The end result is for all practical purposes the same, that is, we really wish to know whether we ought to proceed as if we have in hand a sample of homogeneous normal observations.

Recommended Criteria for Single Samples

4.1 Let the sample of n observations be denoted in order of increasing magnitude by $x_1 \leq x_2 \leq x_3 \leq \ldots \leq x_n$. Let x_n be the doubtful value, that is the largest value. The test criterion, T_n, recommended here for a single outlier is as follows:

LARGEST VALUE

$$T_n = (x_n - \bar{x})/s$$

where:

$\bar{x}$ = arithmetic average of all n values, and

s = estimate of the population standard deviation based on the sample data, calculated as follows:

$$s = \left\{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{(n-1)}\right\}^{1/2} = \left\{\frac{n\Sigma x_i^2 - (\Sigma x_i)^2}{n(n-1)}\right\}^{1/2}$$

If x_1 rather than x_n is the doubtful value, the criterion is as follows:

SMALLEST VALUE

$$T_1 = (\bar{x} - x_1)/s$$

The critical values for either case, for the 1 and 5 % levels of significance, are given in Table 1. Table 1 and the following tables give the "one-sided" significance levels. In the previous tentative recommended practice (1961), the tables listed values of significance levels double those in the present practice, since it was considered that the experimenter would test either the lowest or the highest observation (or both) for statistical significance. However, to be consistent with actual practice and in an attempt to avoid further misunderstanding, single-sided significance levels are tabulated here so that both viewpoints can be represented.

4.2 The hypothesis that we are testing in every case is that all observations in the sample come from the same normal population. Let us adopt, for example, a significance level of 0.05. If we are interested *only* in outliers that occur on the *high side*, we should always use the statistic $T_n = (x_n - \bar{x})/s$ and take as critical value the 0.05 point of Table 1. On the other hand, if we are interested *only* in outliers occurring on the *low side*, we would always use the statistic $T_1 = (\bar{x} - x_1)/s$ and again take as a critical value the 0.05 point of Table 1. Suppose, however, that we are interested in outliers occurring on *either side*, but do not believe that outliers can occur on both sides simultaneously. We might, for example, believe that at some time during the experiment something possibly happened to cause an extraneous variation on the high side or on the low side, but that it was very unlikely that two or more such events could have occurred, one being an extraneous variation on the high side *and* the other an extraneous variation on the low side. With this point of view we should use the statistic $T_n = (x_n - \bar{x})/s$ or the statistic $T_1 = (\bar{x} - x_1)/s$ whichever is larger. If in this instance we use the 0.05 point of Table 1 as our critical value, the true significance level would be twice 0.05 or 0.10. If we wish a significance level of 0.05 and not 0.10, we must in this case use as a critical value the 0.025 point of Table 1. Similar considerations apply to the other tests given below.

4.2.1 *Example 1*—As an illustration of the use of T_n and Table 1, consider the following ten observations on breaking strength (in pounds) of 0.104-in. hard-drawn copper wire: 568, 570, 570, 570, 572, 572, 572, 578, 584, 596. The doubtful observation is the high value, $x_{10} = 596$. Is the value of 596 significantly high? The mean is $\bar{x} = 575.2$ and the estimated standard deviation is $s = 8.70$. We compute

$$T_{10} = (596 - 575.2)/8.70 = 2.39$$

From Table 1, for $n = 10$, note that a T_{10} as large as 2.39 would occur by chance with probability less than 0.05. In fact, so large a value would occur by chance not much more often than 1 % of the time. Thus, the weight of the evidence is against the doubtful value having come from the same population as the others (assuming the population is normally distributed). Investigation of the doubtful value is therefore indicated.

4.3 An alternative system, the Dixon criteria, based entirely on ratios of differences between the observations is described in the literature (**1**)[3] and may be used in cases where it is desirable to avoid calculation of s or where quick judgment is called for. For the Dixon test, the sample criterion or statistic changes with sample size. Table 2 gives the appropriate statistic to calculate and also gives the critical values of the statistic for the 1, 5, and 10 % levels of significance.

4.3.1 *Example 2*—As an illustration of the use of Dixon's test, consider again the observations on breaking strength given in Example 1, and suppose that a large number of such samples had to be screened quickly for outliers and it was judged too time-consuming to compute s. Table 2 indicates use of

[3] The boldface numbers in parentheses refer to the list of references at the end of this practice.

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standard deviation is $s = 8.70$. We compute

$$T_{10} = (596 - 573.2)/8.70 = 2.39 \quad (3)$$

From Table 1, for $n = 10$, note that a T_{10} as large as 2.39 would occur by chance with probability less than 0.05. In fact, so large a value would occur by chance not much more often than 1 % of the time. Thus, the weight of the evidence is against the doubtful value having come from the same population as the others (assuming the population is normally distributed). Investigation of the doubtful value is therefore indicated.

TABLE 1 Critical Values for T (One-Sided Test) When Standard Deviation is Calculated from the Same Sample[A]

Number of Observations, n	Upper 0.1 % Significance Level	Upper 0.5 % Significance Level	Upper 1 % Significance Level	Upper 2.5 % Significance Level	Upper 5 % Significance Level	Upper 10 % Significance Level
3	1.155	1.155	1.155	1.155	1.153	1.148
4	1.499	1.496	1.492	1.481	1.463	1.425
5	1.780	1.764	1.749	1.715	1.672	1.602
6	2.011	1.973	1.944	1.887	1.822	1.729
7	2.201	2.139	2.097	2.020	1.938	1.828
8	2.358	2.274	2.221	2.126	2.032	1.909
9	2.492	2.387	2.323	2.215	2.110	1.977
10	2.606	2.482	2.410	2.290	2.176	2.036
11	2.705	2.564	2.485	2.355	2.234	2.088
12	2.791	2.636	2.550	2.412	2.285	2.134
13	2.867	2.699	2.607	2.462	2.331	2.175
14	2.935	2.755	2.659	2.507	2.371	2.213
15	2.997	2.806	2.705	2.549	2.409	2.247
16	3.052	2.852	2.747	2.585	2.443	2.279
17	3.103	2.894	2.785	2.620	2.475	2.309
18	3.149	2.932	2.821	2.651	2.504	2.335
19	3.191	2.968	2.854	2.681	2.532	2.361
20	3.230	3.001	2.884	2.709	2.557	2.385
21	3.266	3.031	2.912	2.733	2.580	2.408
22	3.300	3.060	2.939	2.758	2.603	2.429
23	3.332	3.087	2.963	2.781	2.624	2.448
24	3.362	3.112	2.987	2.802	2.644	2.467
25	3.389	3.135	3.009	2.822	2.663	2.486
26	3.415	3.157	3.029	2.841	2.681	2.502
27	3.440	3.178	3.049	2.859	2.698	2.519
28	3.464	3.199	3.068	2.876	2.714	2.534
29	3.486	3.218	3.085	2.893	2.730	2.549
30	3.507	3.236	3.103	2.908	2.745	2.563
31	3.528	3.253	3.119	2.924	2.759	2.577
32	3.546	3.270	3.135	2.938	2.773	2.591
33	3.565	3.286	3.150	2.952	2.786	2.604
34	3.582	3.301	3.164	2.965	2.799	2.616
35	3.599	3.316	3.178	2.979	2.811	2.628
36	3.616	3.330	3.191	2.991	2.823	2.639
37	3.631	3.343	3.204	3.003	2.835	2.650
38	3.646	3.356	3.216	3.014	2.846	2.661
39	3.660	3.369	3.228	3.025	2.857	2.671
40	3.673	3.381	3.240	3.036	2.866	2.682
41	3.687	3.393	3.251	3.046	2.877	2.692
42	3.700	3.404	3.261	3.057	2.887	2.700
43	3.712	3.415	3.271	3.067	2.896	2.710
44	3.724	3.425	3.282	3.075	2.905	2.719
45	3.736	3.435	3.292	3.085	2.914	2.727
46	3.747	3.445	3.302	3.094	2.923	2.736
47	3.757	3.455	3.310	3.103	2.931	2.744
48	3.768	3.464	3.319	3.111	2.940	2.753
49	3.779	3.474	3.329	3.120	2.948	2.760
50	3.789	3.483	3.336	3.128	2.956	2.768
51	3.798	3.491	3.345	3.136	2.964	2.775
52	3.808	3.500	3.353	3.143	2.971	2.783
53	3.816	3.507	3.361	3.151	2.978	2.790
54	3.825	3.516	3.368	3.158	2.986	2.798

3

Test for Outliers

MAT Density

94.0

96.0

97.0

98.0

x= 96.2

Sn= 1.71

QL= 96.2-96.3 = -.0585

1.71

PL= <50%

ASTM E 178, par. 4

$T_1 = (x - x_1)/Sn$

$T_1 = \frac{96.2 - 94}{1.71} = 1.286$

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- Table 1-ASTM E 178
- N=4
- Upper 5% significance level 1.463
- Since 1.286<1.463 the 94.0 test value is not considered an outlier and is retained!

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Sample Problem-Outliers

Air Voids
2.0, 4.8, 4.9, 5.0
X=4.2
Sn=1.45

$Q_L = \frac{4.2-2.0}{1.45} = 1.5172$; PL= 100

$Q_U = \frac{5-4.2}{1.45} = 0.5517$; PU= 69

PWL= (100+69)-100=69

ASTM E 178 par. 4

$Tn = (x-x_1)/Sn = \frac{4.2-2.0}{1.45} = 1.517$

Table 1, ASTM E 178, N=4, 5% significance

T= 1.463<1.517

therefore 2.0 is the outlier and it is discarded

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Another Outlier Example

Outlier Determination for Mat Density.

Density of four random cores taken from Lot

98.9	Average = 97.65
98.5	Sample s = 1.79
98.2	n = 4
95.0	PWL = 76 (93% lot pay factor)

$$Q = \frac{\text{Lot Average} - \text{Lower Spec. Limit}}{\text{Lot Standard Deviation}}$$

Outlier

Outlier Determination for Mat Density.

E-78 with n=4, 5 percent significance level, critical value for test criterion = 1.463

Compare

Max (98.9 - 97.65) / 1.79 = 0.70 < 1.463 No

Min (97.65 – 95.0) / 1.79 = 1.48 > 1.463 Yes

Outlier

Recalculate PWL after eliminating outlier

Density of 3 random cores taken from Lot A.

98.9	Average = 98.53
98.5	Sample s = 0.351
98.2	n = 3
	PWL = 100 (106% lot pay factor)

NOTE: Outliers exist if:

Density greater than (97.65+1.463x1.79), or

Density less than (97.65-1.463x1.79)

Lot Average +/- Test Criterion*Lot Standard Deviation are Critical Values

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Resampling

401-5.3 page 38

<u>MAT Density ONLY</u>

(Appendix E-pg 4)

Prior MAT Density- 96, 97, 99, 100

PWL 82

4 new cores 96, 96, 97, 98

AVG-all 8, 97.4

Sn= 1.51

$$Q_L = \frac{x - L}{Sn} = \frac{97.4 - 96.3}{1.51} = .7337$$

Table 4, N= 8

PWL= 77

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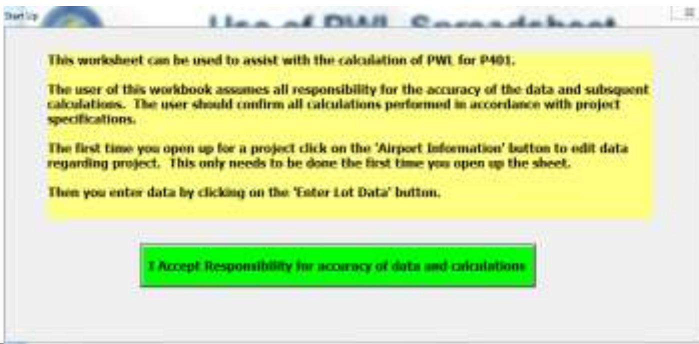
Use of PWL Spreadsheet

- Asphaltic Concrete Payment Adjustments for Densities and Air Voids, Item P401
- https://www.faa.gov/airports/engineering/design_software/
- Latest version: AC1000-P401-PWL-5370-10G-9-13-16.xlsm
- Check for updates



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PWL Spreadsheet

- Step 1: Enter Airport Information

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PWL Spreadsheet

- **Step 1a: Project Specifications**
  - Need to set option to one or two sided \
  - Need to set max pay for project
  - Note individual lots may still be used to offset low lots within the restrictions of specification

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PWL Spreadsheet

- **Step 2: Enter Lot Data**
  - Sampling & Testing per 401-5.1
  - 4 sublots / lot
  - Air Voids / 1 per sublot (Rice / Lab BSG)
  - Mat & Joint Density 1 core per sublot (Lab / Field)
- **Remember since calculating standard deviation need at least 3 samples**

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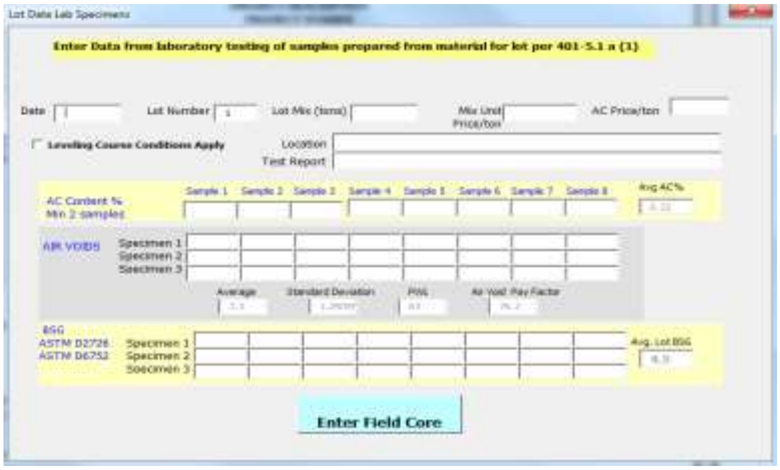
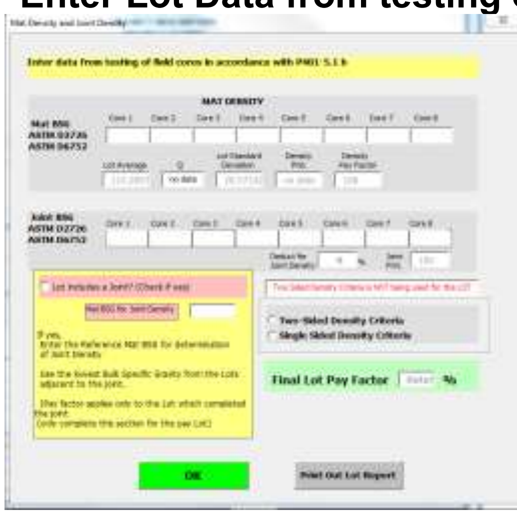
PWL Spreadsheet

- **Step 2: Enter Lot Data from laboratory tests**



PWL Spreadsheet

- **Step 3: Enter Lot Data from testing of field cores**



PWL Spreadsheet

- **3 spreadsheets in the workbook**
- **If you ever turn on sheet tabs to look at the worksheets do not run formulas from sheet 1**
- **2 most common problems with spreadsheet**
  - Trying to run with only 2 samples
  - Formulas corrupted because ran from sheet 1
- **If outlier check results in data being eliminated, be sure to check the E178 button (Spreadsheet is not set up to cycle through multiple outlier tests)**

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Questions

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