EVALUATING PERCENT WITHIN LIMITS (PWL) SPECIFICATIONS

Volume 2: Portland Cement Concrete Pavements

Final Report (DRAFT)

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CHAPTER 1

INTRODUCTION

Problem Statement

The Oklahoma Department of Transportation (ODOT) let four paving projects where "percent within limits" (PWL) specifications were employed. The PWL Specifications are intended to be used as part of the Quality Assessment program to determine the statistical probability of conformance to specified material properties and construction details, and to base the Pay Factor (PF) off of the probability of conformance to specifications. The specifications are relatively new to the ODOT, as are the governing principles. In fact, the four paving jobs are the first to implement the PWL specifications to calculate the probability of conformance and associated pay factors. This project evaluates the performance of the PWL specifications and the suitability of PWL specifications for future jobs.

Objectives

The objectives of this project are to:

1) Assess the accuracy of the PWL specifications in estimating the probabilities and judging the overall quality of the installed pavements and materials employed.
2) Evaluate qualitatively the PWL specifications for their ability to produce cooperation between ODOT and its contractors and to lessen the requirements for sampling and testing by ODOT.
3) Assess the PWL specifications for their ability to properly reward contractors for the quality of their efforts.

Scope

Four paving jobs were let for construction using the proposed PWL specifications, two for hot mix asphalt (HMA) projects and two for Portland Cement Concrete (PCC) paving projects. The results from the HMA projects are included in the Volume 1 report on this project. This report, Volume 2, includes data and discussion from PCC paving projects.

In addition to the normal quality control, acceptance and assurance sampling and testing, the ODOT Materials Division performed more extensive sampling and testing on randomly selected "super-lots." In each PCC super lot, each of six sublots were sampled and tested three times so that there were a total of 18 tests performed for each super lot. The additional sampling and testing included the specified payment based characteristics plus some non payment based characteristics. Fresh PC properties measured included slump, unit weight, air content, concrete temperature and ambient conditions. Contractors were required to perform their normal sampling and testing for each lot and super lot.

Upon completion of the construction projects, the data obtained from the super lots were evaluated. The data were analyzed for their statistical value and estimates for averages, variation were computed. From these calculations, the PWL statistics were developed for the super lots, and these data were then used to determine:

1. Whether the PWL Specifications are working as intended, and to provide some qualitative assessment of the ability of the contractor to meet the specifications.
2. Recommend changes to the PWL specifications if necessary, including possible changes to the methodologies for obtaining samples or the number of tests required for each sub lot.
3. Recommend whether ODOT should continue to pursue the PWL specifications as a matter of policy in their overall QA/QC programs.

CHAPTER 2

TEST PLAN AND TEST DATA

Test Plan

Two PCC pavement projects were let for construction during the 2004 construction season using the proposed PCC PWL Specifications. One project was located on I-40 in Canadian County and the other project was located on I-40 in McIntosh County. Two different contractors were employed. Table 1 shows the super lots sampled and tested from each project. In addition, the data from the two initialization lots were obtained.

Table 2.1. PCC Super Lots

Route	County	Project Number	Contractor	Super Lot No.	Lot No.
I-40	Canadian	IMY-40-4(382)124	Sherwood	Initialization	1
I-40	Canadian	IMY-40-4(382)124	Sherwood	1	2
I-40	Canadian	IMY-40-4(382)124	Sherwood	2	7
I-40	McIntosh	IMY-40-6(286)253	Duit	Initialization	1
I-40	McIntosh	IMY-40-6(286)253	Duit	1	5
I-40	McIntosh	IMY-40-6(286)253	Duit	2	8
I-40	McIntosh	IMY-40-6(286)253	Duit	3	13
I-40	McIntosh	IMY-40-6(286)253	Duit	4	15

Sampling and Testing

In each Super Lot, the Central Office Materials Liaison sampled and tested each of the six sublots a total of three times so that a total of 18 tests were performed and reported for each Super Lot. The contractor performed his regular specified sampling and tests for each Super Lot. Additionally, each project included one "Initialization Lot." Local Resident Offices tested and sampled each initialization lot for comparison with the contractor and central office data. Sampling and testing were performed as prescribed in the *ODOT "Special Provisions for Quality Control and Acceptance Procedures for Portland Cement Concrete Pavements*," also known as the "PWL Specifications." In addition to the testing prescribed in the PWL Specifications, fresh concrete properties were measured in recorded including air content, unit weight, slump, concrete temperature and ambient conditions.

Data Analysis

The data were analyzed to determine the overall sample average, the sample variations and to estimate the statistical probability of compliance with the specification limits set forth in the PWL Specifications. The PWL Specification sets limits for coarse aggregate gradations, fine aggregate gradation, air content and concrete compressive strength at 28 days. The data from the Initialization Lots and Super Lots were analyzed to determine the statistical probability of compliance within the specification limits and also to determine the pay factor for each pay item. PWL statistical computations contained in the tables below were also based on Gaussian probability distributions ("normal" distributions) and Z-tables were used to estimate probabilities. This is a reasonable estimate given the relatively large size (N=18) of each super lot. The cumulative pay factor (CPF) was also computed for each Super Lot. A qualitative analysis is then performed to look at the data to determine what factors provided important influence over the individual pay factors as well as the cumulative pay factor.

The PWL Specification also sets for Target Limits for all of the pay items. No comparisons for pay factors were made relative to the Target Limits. However, some comments are made relative to the Target Limits.

Test Data – Canadian County

The data obtained from sampling and testing for the Canadian County Project are reported in the Table 2.2 through Table 2.9. Each table reports the percent retained on the #200 sieve for both coarse and fine aggregates, the total air content measured in fresh concrete and the compressive strength of concrete cylinders measured at 28 days. For each sample, the compressive strength is obtained from the average compressive strength of three cylinders. All of these items are factors for pay calculations.

The Specification limits for the #200 sieve is 2 percent or less for coarse aggregate and 3 percent or less for fine aggregate. The Specification limit for Total Air Content is 4.5 percent to 7.5 percent, or 6 percent plus or minus 1.5 percent. The specification limit for concrete, Class A is 3800 psi or greater.

Tables 2.2 through 2.4 list data from the Initialization Superlot, Lot #1. Data was collected by the ODOT Central Office, the Contractor and the Residency. The Initialization Superlot was divided into 12 sublots. Each of the three entities collected and measured data for each of the 12 sublots. The materials samples were obtained from split samples.

Tables 2.5 and 2.6 list the data obtained by the ODOT Central Office from Superlot #2 (Lot #3) and Superlot #3 (Lot #7). ODOT Central Office sampled and measured the materials three times from each sublot, so there were a total of 18 individual measurements for each Superlot. The contractor sampled each sublot only once in conformance with the Specification. The contractor data is reported in Tables 2.7 through 2.9.

The specifications also set forth a "*Rejectable Quality Level*" in subsection (m)(3), "*A lot shall be considered of rejectable quality with respect to a particular characteristic if the PWL [for any particular specified item] is lesss than 50 percent.*" Furthermore, the specification states that Lots failing to achieve the rejectable quality level "*shall be subject to removal...*"

Table 2.2. Canadian County Initialization Superlot – Lot #1 – ODOT Central Office

Contractor:	**Sherwood Construction**
P.O.No.:	**IMY-40-4(382)124**
County:	**Canadian**

Initialization Superlot Lot #1					
	Percent Passing #200		**Concrete**	**Concrete**	
			Air Content		
Sample	**Coarse**	**Fine**	**(%)**	**Strength (psi)**	
IS-1	0.97	0.61	1.8%	8950	
IS-2	1.07	0.65	4.9%	7730	
IS-3	1.03	0.84	4.7%	7710	
IS-4	0.88	0.60	6.0%	7670	
IS-5	1.00	0.63	6.2%	7317	
IS-6	0.81	0.83	6.1%	7910	
IS-7	0.99	0.72	5.0%	8420	
IS-8	1.05	0.76	5.0%	8260	
IS-9	0.92	1.91	6.4%	7260	
IS-10	0.99	0.91	6.0%	7480	
IS-11	1.33	0.80	6.8%	6850	
IS-12	1.16	0.76	6.0%	7180	
Average, $\bar{x}$ =	**1.017**	**0.835**	**5.41%**	**7728**	
Std. Deviation, s =	**0.134**	**0.353**	**1.32%**	**589**	
Z-value (s) =	**7.34**	**6.14**	**1.58**	**6.67**	
			0.69		
PWL (z-test) =	**100.0%**	**100.0%**	**69.8%**	**100.0%**	
PF =	**102.0%**	**102.0%**	**86.2%**	**102.0%**	
CPF =					**97.25%**

Table 2.3. Canadian County Initialization Superlot – Lot #1 – Contractor Data

Contractor: Sherwood Construction
P.O.No.: IMY-40-4(382)124
County: Canadian

Initialization Superlot Lot #1

Sample	Percent Passing #200 Coarse	Percent Passing #200 Fine	Concrete Air Content (%)	Concrete Strength (psi)	
IS-1	0.60	1.00	2.2%	8630	
IS-2	0.70	1.10	6.0%	7430	
IS-3	0.80	1.00	5.7%	7750	
IS-4	0.60	1.10	6.4%	7140	
IS-5	0.70	1.30	6.6%	6450	
IS-6	0.50	1.20	6.4%	7510	
IS-7	0.70	1.20	5.5%	8100	
IS-8	0.80	1.20	5.3%	8310	
IS-9	0.40	1.20	6.8%	6630	
IS-10	0.50	1.20	6.0%	7570	
IS-11	0.90	1.10	6.9%	6850	
IS-12	0.80	1.10	6.7%	7330	
Average, $\bar{x}$ =	**0.667**	**1.142**	**5.88%**	**7475**	
Std. Deviation, s =	**0.150**	**0.090**	**1.27%**	**660**	
Z-value =	**8.904**	**20.640**	**1.28** **1.08**	**5.564**	
PWL (z-test) =	**100.0%**	**100.0%**	**76.0%**	**100.0%**	
PF =	**102.0%**	**102.0%**	**91.8%**	**102.0%**	
CPF =					**98.94%**

Table 2.4. Canadian County Initialization Superlot – Lot #1 – ODOT Residency Data

Contractor:	**Sherwood Construction**
P.O.No.:	**IMY-40-4(382)124**
County:	**Canadian**

Initialization Superlot Lot #1					
	Percent Passing #200		**Concrete Air Content**	**Concrete**	
Sample	**Coarse**	**Fine**	**(%)**	**Strength (psi)**	
IS-1	1.10	0.70	1.8%	8950	
IS-2	1.30	0.70	5.5%	7730	
IS-3	1.20	0.70	8.2%	7710	
IS-4	0.80	0.70	6.5%	7670	
IS-5	1.00	0.70	6.6%	7317	
IS-6	0.80	0.80	6.6%	7910	
IS-7	1.00	0.74	5.5%	8420	
IS-8	1.00	0.72	5.2%	8260	
IS-9	0.89	0.71	6.9%	7260	
IS-10	1.28	0.69	6.0%	7480	
IS-11	1.00	0.90	7.0%	6850	
IS-12	0.87	0.75	6.4%	7180	
Average, $\bar{x}$ =	**1.020**	**0.734**	**6.02%**	**7728**	
Std. Deviation, s =	**0.171**	**0.061**	**1.55%**	**589**	
Z-value =	**5.723**	**37.254**	**0.95**	**6.672**	
			0.98		
PWL (z-test) =	**100.0%**	**100.0%**	**66.5%**	**100.0%**	
PF =	**102.0%**	**102.0%**	**82.7%**	**102.0%**	
CPF =					**96.22%**

Table 2.5. Canadian Co. Superlot #1 – Lot #3 - ODOT Central Office

P.O.No.: IMY-40-4(382)124

County: Canadian

Superlot #1 Lot #3	Percent Passing #200		Concrete	Concrete	
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**	
SL1-1	1.64	0.52	6.3%	5690	
SL1-2	1.33	0.28	6.2%	5330	
SL1-3	1.49	0.43	6.0%	5980	
SL1-4	1.19	0.27	5.5%	6390	
SL1-5	1.22	0.53	5.5%	6590	
SL1-6	1.08	0.36	4.6%	7050	
SL1-7	1.27	0.62	5.0%	6770	
SL1-8	1.64	0.41	7.0%	6220	
SL1-9	1.53	0.77	6.2%	6560	
SL1-10	1.47	0.81	6.0%	6650	
SL1-11	1.46	0.5	7.0%	6740	
SL1-12	1.07	0.27	7.0%	5790	
SL1-13	1.43	1.23	6.4%	6250	
SL1-14	1.35	0.45	6.0%	6200	
SL1-15	1.38	0.45	7.2%	6010	
SL1-16	1.65	0.47	7.0%	5700	
SL1-17	1.04	0.56	7.4%	5080	
SL1-18	1.16	0.55	6.8%	5500	
Average, $\bar{x}$ =	**1.356**	**0.527**	**6.28%**	**6139**	
Standard Deviation, s =	**0.199**	**0.231**	**0.78%**	**546**	
PWL (z-test) =	**99.9%**	**100.0%**	**92.9%**	**100.0%**	
PF =	**102.0%**	**102.0%**	**100.9%**	**102.0%**	
CPF =					**101.67%**

Table 2.6. Canadian County, Superlot #2 – Lot #7 – ODOT Central Office

P.O.No.: **IMY-40-4(382)124**

County: **Canadian**

Superlot #2 Lot #7	Percent Passing #200		Concrete Air Content	Concrete
Sample	**Coarse**	**Fine**	**(%)**	**Strength (psi)**
SL2-1	1.00	0.80	4.8%	7558
SL2-2	1.00	0.80	5.5%	7241
SL2-3	1.10	1.00	7.0%	5849
SL2-4	1.10	1.00	6.5%	6006
SL2-5	1.10	0.90	6.4%	6403
SL2-6	1.20	0.80	6.6%	6251
SL2-7	1.10	0.90	4.9%	6965
SL2-8	1.10	0.80	5.5%	6583
SL2-9	0.90	1.10	5.0%	7904
SL2-10	0.80	0.60	6.0%	7095
SL2-11	0.90	0.70	6.0%	6993
SL2-12	1.30	0.70	6.8%	6184
SL2-13	1.10	0.70	5.5%	7220
SL2-14	1.20	0.60	5.0%	7489
SL2-15	1.50	0.80	5.7%	6585
SL2-16	1.40	0.90	5.5%	7174
SL2-17	1.20	0.50	6.4%	6346
SL2-18	1.10	0.80	5.6%	6716
Average, $\bar{x}$ =	**1.117**	**0.800**	**5.82%**	**6809**
Standard Deviation, s =	**0.172**	**0.153**	**0.68%**	**574**
PWL (z-test) =	**100.0%**	**100.0%**	**96.7%**	**100.0%**
PF =	**102.0%**	**102.0%**	**101.7%**	**102.0%**
CPF =				**101.91%**

Table 2.7. Canadian County, Initialization Superlot – Lot #1 – Contractor Data

SHERWOOD

Initialization Superlot Lot #1					
	Percent Passing #200		Concrete Air Content	Concrete	
Sample	Coarse	Fine	(%)	Strength (psi)	
Sublot-1	0.81	0.22	6.4%	6430	
Sublot-2	1.02	0.28	7.1%	5840	
Sublot-3	1.01	0.44	5.6%	6630	
Sublot-4	1.31	0.26	7.5%	6630	
Sublot-5	0.94	0.45	6.8%	6320	
Sublot-6	0.69	0.40	7.0%	6740	
Average, $\bar{x}$ =	**0.963**	**0.342**	**6.73%**	**6432**	
Std. Deviation, s =	**0.212**	**0.100**	**0.66%**	**328**	
Z-value =	**4.89**	**26.56**	**1.16**	**8.04**	
			3.37		
PWL (z-test) =	**100.0%**	**100.0%**	**85.5%**	**100.0%**	
PF =	**102.0%**	**102.0%**	**98.1%**	**102.0%**	
CPF =					**100.82%**

Table 2.8. Canadian County, Superlot #1 - Lot #3 - Contractor Data

SHERWOOD

Superlot #1 Lot #3					
	Percent Passing #200		Concrete Air Content	Concrete	
Sample	Coarse	Fine	(%)	Strength (psi)	
Sublot-1	0.92	0.44	6.0%	6240	
Sublot-2	1.02	0.37	5.5%	6250	
Sublot-3	0.93	0.56	6.0%	7590	
Sublot-4	0.78	0.79	5.5%	7590	
Sublot-5	0.78	0.49	6.0%	6550	
Sublot-6	1.40	0.42	6.8%	6060	
Average, $\bar{x}$ =	**0.972**	**0.512**	**5.97%**	**6713**	
Standard Deviation, s =	**0.230**	**0.151**	**0.48%**	**697**	
Z-value =	**4.478**	**16.488**	**3.22**	**4.180**	
			3.08		
PWL (z-test) =	**99.9%**	**100.0%**	**99.8%**	**100.0%**	
PF =	**102.0%**	**102.0%**	**102.0%**	**102.0%**	
CPF =					**102.00%**

Table 2.9. Canadian County Superlot #3 - Lot #7 - Contractor Data

SHERWOOD

Superlot #2					
Lot #7					
	Percent Passing #200		**Concrete**	**Concrete**	
			Air Content		
Sample	**Coarse**	**Fine**	**(%)**	**Strength (psi)**	
Sublot-1	0.75	0.49	6.1%	7140	
Sublot-2	1.00	0.70	6.0%	6900	
Sublot-3	1.01	0.75	6.8%	6430	
Sublot-4	0.91	0.60	6.1%	8060	
Sublot-5	0.93	0.64	6.4%	7440	
Sublot-6	0.84	0.36	6.1%	6820	
Average, $\bar{x}$ =	**0.907**	**0.590**	**6.25%**	**7132**	
Standard Deviation, s =	**0.099**	**0.144**	**0.30%**	**566**	
Z-value =	**11.05**	**16.77**	**4.14**	**5.89**	
			5.80		
PWL (z-test) =	**100.0%**	**100.0%**	**100.0%**	**100.0%**	
PF =	**102.0%**	**102.0%**	**102.0%**	**102.0%**	
CPF =					**102.00%**

Test Data – McIntosh County

The data obtained from sampling and testing for the McIntosh County Project are reported in the Tables 2.10 through Table 2.xxxxx. Each table reports the percent retained on the #200 sieve for both coarse and fine aggregates, the total air content measured in fresh concrete and the compressive strength of concrete cylinders measured at 28 days. For each sample, the compressive strength is obtained from the average compressive strength of three cylinders. All of these items are factors for pay calculations.

The Specification limits for the #200 sieve is 2 percent or less for coarse aggregate and 3 percent or less for fine aggregate. The Specification limit for Total Air Content is 4.5 percent to 7.5 percent, or 6 percent plus or minus 1.5 percent. The specification limit for concrete, Class A is 3800 psi or greater.

Tables 2.10 through 2.12 list data from the Initialization Superlot, Lot #1. Data was collected by the ODOT Central Office, the Contractor and the Residency. The Initialization Superlot was divided into 12 sublots. Each of the three entities collected and measured data for each of the 12 sublots. The materials samples were obtained from split samples.

Tables 2.13 and 2.16 list the data obtained by the ODOT Central Office from Superlot #1 (Lot #5), Superlot #2 (Lot #8), Superlot #3 (Lot #13) and Superlot #4 (Lot #15). ODOT Central Office sampled and measured the materials three times from each sublot, so there are a total of 18 individual measurements for each Superlot. The contractor sampled each sublot only once in conformance with the Specification. The contractor data is reported in Tables 2.17 through 2.20.

Table 2.10. McIntosh County, Initialization Superlot – Lot #1 – ODOT Central Office

P.O.No.: **IMY-40-6(286)253**
County: **McIntosh**

Superlot #1
Lot #5

Sample	Percent Passing #200 Coarse	Fine	Concrete Air Content (%)	Concrete Strength (psi)	
SL5-1	2.00	0.20	6.0%	5510	
SL5-2	1.80	0.30	6.0%	4760	
SL5-3	2.40	0.10	6.0%	5050	
SL5-4	2.20	0.50	6.1%	5240	
SL5-5	2.00	1.40	5.6%	4970	
SL5-6	2.10	1.30	6.1%	4820	
SL5-7	1.70	0.80	6.2%	4820	
SL5-8	2.00	1.00	5.9%	4960	
SL5-9	1.90	0.70	5.5%	5510	
SL5-10	2.10	0.20	5.8%	4980	
SL5-11	2.40	0.20	5.9%	5010	
SL5-12	2.50	0.20	6.6%	4930	
SL5-13	2.80	0.20	6.8%	4970	
SL5-14	2.10	0.30	6.9%	4870	
SL5-15	2.00	0.20	6.6%	5350	
SL5-16	2.40	0.70	6.6%	4580	
SL5-17	2.20	0.40	5.6%	5330	
SL5-18	2.00	1.20	5.7%	5260	
Average, $\bar{x}$ =	**2.144**	**0.550**	**6.11%**	**5051**	
Standard Deviation, s =	**0.271**	**0.427**	**0.43%**	**261**	
PWL (z-test) =	**29.8%**	**100.0%**	**99.9%**	**100.0%**	
PF =	**20.3%**	**102.0%**	**102.0%**	**102.0%**	
CPF =					**93.82%**

Table 2.11. Canadian County Initialization Superlot – Lot #1 – Contractor Data

DUIT DATA

P.O.No.:	**IMY-40-6(286)253**				
County:	**McIntosh**				
Initialization Superlot Lot #1		**Duit Lots 1A and 1B**			
	Percent Passing #200		**Concrete**	**Concrete**	
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**	
IS-1	2.10	0.98	6.8%	5020	
IS-2	1.98	1.13	7.2%	4750	
IS-3	1.67	1.02	6.8%	4890	
IS-4	1.98	0.40	5.0%	5710	
IS-5	1.75	0.90	4.6%	6320	
IS-6	1.98	1.00	7.4%	4930	
IS-7	1.82	1.26	6.4%	5300	
IS-8	1.82	0.99	6.2%	5340	
IS-9	1.65	0.87	7.4%	5010	
IS-10	1.53	0.50	7.8%	4400	
IS-11	1.62	0.30	7.1%	5160	
IS-12	1.61	0.40	6.6%	4990	
Average, $\bar{x}$ =	**1.793**	**0.813**	**6.61%**	**5152**	
Standard Deviation, s =	**0.184**	**0.323**	**0.96%**	**490**	
Z-value =	**1.13**	**6.76**	**0.93** **2.19**	**2.76**	
PWL (z-test) =	**87.1%**	**100.0%**	**81.0%**	**99.7%**	
PF =	**98.8%**	**102.0%**	**95.4%**	**102.0%**	
CPF =					**99.70%**

Table 2.12. Canadian County Initialization Superlot – Lot #1 – Residency Data

P.O.No.: **IMY-40-6(286)253**

County: **McIntosh**

Initialization Superlot
Lot #1

	Percent Passing #200		**Concrete**	**Concrete**	
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**	
IS-1	2.19	0.43	6.6%	4650	
IS-2	1.96	0.50	6.6%	4970	
IS-3	2.11	0.53	6.4%	4880	
IS-4	2.35	0.21	4.4%	5310	
IS-5	2.53	0.23	4.7%	5860	
IS-6	2.30	0.42	7.2%	6640	
IS-7	2.31	1.10	5.6%	5500	
IS-8	2.67	0.95	6.6%	5260	
IS-9	2.15	0.49	7.4%	5020	
IS-10	1.98	0.48	8.5%	4440	
IS-11	2.28	0.23	7.0%	5260	
IS-12	2.11	0.33	6.5%	5710	
Average, $\bar{x}$ =	**2.245**	**0.492**	**6.46%**	**5292**	
Standard Deviation, s =	**0.209**	**0.275**	**1.13%**	**591**	
Z-value =	**-1.17**	**9.11**	**0.92**	**2.52**	
			1.73		
PWL (z-test) =	**12.1%**	**100.0%**	**77.7%**	**99.4%**	
PF =	**0.0%**	**102.0%**	**93.1%**	**102.0%**	
CPF =					**89.12%**

Table 2.13. McIntosh County, Superlot #1 – Lot #5 - ODOT Central Office Data

P.O.No.: **IMY-40-6(286)253**

County: **McIntosh**

Superlot #1

Lot #5

	Percent Passing #200		Concrete	Concrete	
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**	
SL5-1	2.00	0.20	6.0%	5510	
SL5-2	1.80	0.30	6.0%	4760	
SL5-3	2.40	0.10	6.0%	5050	
SL5-4	2.20	0.50	6.1%	5240	
SL5-5	2.00	1.40	5.6%	4970	
SL5-6	2.10	1.30	6.1%	4820	
SL5-7	1.70	0.80	6.2%	4820	
SL5-8	2.00	1.00	5.9%	4960	
SL5-9	1.90	0.70	5.5%	5510	
SL5-10	2.10	0.20	5.8%	4980	
SL5-11	2.40	0.20	5.9%	5010	
SL5-12	2.50	0.20	6.6%	4930	
SL5-13	2.80	0.20	6.8%	4970	
SL5-14	2.10	0.30	6.9%	4870	
SL5-15	2.00	0.20	6.6%	5350	
SL5-16	2.40	0.70	6.6%	4580	
SL5-17	2.20	0.40	5.6%	5330	
SL5-18	2.00	1.20	5.7%	5260	
Average, $\bar{x}$ =	**2.144**	**0.550**	**6.11%**	**5051**	
Standard Deviation, s =	**0.271**	**0.427**	**0.43%**	**261**	
Z-value =	**-0.53**	**5.73**	**3.26**	**4.80**	
			3.75		
PWL (z-test) =	**29.8%**	**100.0%**	**99.9%**	**100.0%**	
PF =	**20.4%**	**102.0%**	**102.0%**	**102.0%**	
CPF =					**93.84%**

Table 2.14. McIntosh County, Superlot #2 – Lot #8 - ODOT Central Office Data

P.O.No.:	**IMY-40-6(286)253**				
County:	**McIntosh**				
Superlot #2					
Lot #8					
	Percent Passing #200		**Concrete Air Content**	**Concrete**	
Sample	**Coarse**	**Fine**	**(%)**	**Strength (psi)**	
SL5-1	2.48	0.31	5.7%	3030	
SL5-2	1.71	0.36	5.7%	3570	
SL5-3	1.36	0.49	5.7%	3700	
SL5-4	1.55	1.53	5.8%	3980	
SL5-5	2.05	0.37	5.8%	3760	
SL5-6	2.25	0.82	5.8%	3750	
SL5-7	2.34	0.34	5.8%	3590	
SL5-8	1.61	0.41	5.8%	3880	
SL5-9	1.86	0.69	5.9%	3720	
SL5-10	2.13	0.16	5.9%	3900	
SL5-11	2.43	0.21	5.9%	3700	
SL5-12	2.53	0.25	6.0%	3650	
SL5-13	2.80	0.25	6.0%	3680	
SL5-14	2.09	0.26	6.0%	3630	
SL5-15	2.01	0.18	6.0%	3590	
SL5-16	2.36	0.66	6.0%	3630	
SL5-17	2.21	0.38	6.0%	3680	
SL5-18	1.99	1.23	6.0%	3850	
Average, $\bar{x}$ =	**2.098**	**0.494**	**5.88%**	**3683**	
Standard Deviation, s =	**0.377**	**0.373**	**0.12%**	**200**	
PWL (z-test) =	**21.4%**	**100.0%**	**100.0%**	**27.9%**	
PF =	**0.0%**	**102.0%**	**102.0%**	**16.0%**	
CPF =					**50.41%**

Table 2.15. McIntosh County, Superlot #3 – Lot #13 - ODOT Central Office Data

P.O.No.: **IMY-40-6(286)253**

County: **McIntosh**

Superlot #3					
Lot #13					
	Percent Passing #200		**Concrete Air Content**	**Concrete**	
Sample	**Coarse**	**Fine**	**(%)**	**Strength (psi)**	
SL13-1	1.70	0.60	6.4%	5024	
SL13-2	1.60	0.70	6.2%	5585	
SL13-3	1.60	0.50	6.1%	5054	
SL13-4	1.50	0.50	6.2%	4811	
SL13-5	1.90	0.50	6.4%	5135	
SL13-6	1.70	0.70	6.8%	4682	
SL13-7	1.40	0.90	6.4%	4936	
SL13-8	1.60	0.60	6.2%	5147	
SL13-9	1.30	0.30	6.8%	4650	
SL13-10	1.50	0.50	6.0%	5560	
SL13-11	1.60	1.00	5.8%	5270	
SL13-12	1.50	0.70	6.2%	4920	
SL13-13	1.80	0.50	6.6%	4740	
SL13-14	2.50	1.70	6.6%	5103	
SL13-15	2.70	0.50	6.4%	4930	
SL13-16	1.80	0.30	6.8%	4010	
SL13-17	1.80	0.40	6.8%	5290	
SL13-18	1.80	1.10	7.2%	4320	
Average, $\bar{x}$ =	**1.739**	**0.667**	**6.44%**	**4954**	
Standard Deviation, s =	**0.352**	**0.338**	**0.35%**	**392**	
PWL (z-test) =	**77.1%**	**100.0%**	**99.9%**	**99.8%**	
PF =	**92.7%**	**102.0%**	**102.0%**	**102.0%**	
CPF =					**101.99%**

Table 2.16 McIntosh County, Superlot #4 - Lot #15 – ODOT Central Office Data

P.O.No.: IMY-40-6(286)253

County: McIntosh

Superlot #4

Lot #15

	Percent Passing #200		Concrete	Concrete	
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**	
SL15-1	1.50	0.48	8.2%	3951	
SL15-2	1.50	1.45	7.4%	4659	
SL15-3	1.00	1.50	6.6%	4288	
SL15-4	1.60	1.56	6.6%	4980	
SL15-5	1.00	1.03	6.4%	4598	
SL15-6	1.20	1.28	7.2%	4530	
SL15-7	1.70	0.87	6.8%	4835	
SL15-8	1.80	1.40	6.6%	4762	
SL15-9	1.70	1.55	6.6%	5026	
SL15-10	1.50	0.99	6.6%	4848	
SL15-11	1.70	0.74	6.4%	4753	
SL15-12	1.70	1.64	6.3%	4850	
SL15-13	1.90	1.56	6.2%	5011	
SL15-14	1.60	1.55	6.3%	5127	
SL15-15	1.60	0.74	6.0%	4579	
SL15-16	1.60	0.78	6.0%	5138	
SL15-17	1.60	1.48	6.1%	4641	
SL15-18	1.70	0.83	5.9%	4909	
Average, $\bar{x}$ =	**1.550**	**1.191**	**6.57%**	**4749**	
Standard Deviation, s =	**0.248**	**0.377**	**0.57%**	**299**	
Z-value =	**1.82**	**4.81**	**1.65**	**3.18**	
			3.65		
PWL (z-test) =	**96.6%**	**100.0%**	**95.1%**	**99.9%**	
PF =	**101.7%**	**102.0%**	**101.4%**	**102.0%**	
CPF =					**101.82%**

Table 2.17. McIntosh County Superlot #1 - Lot #5 - Contractor Data

DUIT

Superlot #1				
Lot #5				
	Percent Passing #200		**Concrete**	**Concrete**
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**
Sublot 1	1.16	0.19	5.6%	4970
Sublot 2	1.58	0.24	6.1%	5360
Sublot 3	1.72	0.27	5.8%	4820
Sublot 4	1.67	0.33	6.3%	4880
Sublot 5	1.53	0.53	6.1%	4810
Sublot 6	1.81	0.36	6.3%	4590
Average, $\bar{x}$ =	**1.578**	**0.320**	**6.03%**	**4905**
Standard Deviation, s =	**0.228**	**0.120**	**0.28%**	**256**
Z-value =	**1.85**	**22.40**	**5.23**	**4.32**
			5.47	
PWL (z-test) =	**96.8%**	**100.0%**	**100.0%**	**100.0%**
PF =	**101.7%**	**102.0%**	**102.0%**	**102.0%**
CPF =				**101.97%**

Table 2.18. McIntosh County Superlot #2 - Lot #8 - Contractor Data

DUIT

Superlot #2				
Lot #8				
	Percent Passing #200		**Concrete**	**Concrete**
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**
Sublot 1	1.57	0.16	6.5%	3660
Sublot 2	1.67	0.25	6.2%	3590
Sublot 3	1.37	0.71	6.6%	3500
Sublot 4	1.35	0.15	6.4%	3610
Sublot 5	1.54	0.24	6.1%	3740
Sublot 6	0.95	0.36	6.4%	3870
Average, $\bar{x}$ =	**1.408**	**0.312**	**6.37%**	**3662**
Standard Deviation, s =	**0.256**	**0.209**	**0.19%**	**129**
Z-value =	**2.31**	**12.84**	**6.09**	**-1.07**
			10.03	
PWL (z-test) =	**99.0%**	**100.0%**	**100.0%**	**27.9%**
PF =	**101.9%**	**102.0%**	**102.0%**	**16.0%**
CPF =				**50.41%**

Table 1.19. McIntosh County Superlot #3 - Lot #13 - Contractor Data

DUIT

Superlot #3					
Lot #13					
	Percent Passing #200		**Concrete**	**Concrete**	
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**	
Sublot 1	1.88	0.39	6.2%	5170	
Sublot 2	1.54	0.74	6.2%	5200	
Sublot 3	1.59	0.64	6.7%	5640	
Sublot 4	1.65	0.55	6.0%	6230	
Sublot 5	1.52	0.65	6.2%	6180	
Sublot 6	1.41	0.46	6.8%	4520	
Average, $\bar{x}$ =	**1.598**	**0.572**	**6.35%**	**5490**	
Standard Deviation, s =	**0.159**	**0.130**	**0.32%**	**659**	
Z-value =	**2.52**	**18.62**	**3.58**	**2.56**	
			5.76		
PWL (z-test) =	**99.4%**	**100.0%**	**100.0%**	**99.8%**	
PF =	**102.0%**	**102.0%**	**102.0%**	**102.0%**	
CPF =					**102.00%**

Table 2.20. McIntosh County, Superlot #3 – ODOT Central Office Data

Superlot #4					
Lot #15					
	Percent Passing #200		**Concrete**	**Concrete**	
Sample	**Coarse**	**Fine**	**Air Content (%)**	**Strength (psi)**	
Sublot 1	1.19	0.93	7.4%	5290	
Sublot 2	1.22	0.50	7.0%	5440	
Sublot 3	1.27	0.96	6.6%	5080	
Sublot 4	1.22	0.48	6.6%	4880	
Sublot 5	1.63	0.66	6.3%	5260	
Sublot 6	1.31	0.39	6.1%	5171	
Average, $\bar{x}$ =	**1.307**	**0.653**	**6.67%**	**5187**	
Standard Deviation, s =	**0.164**	**0.242**	**0.47%**	**193**	
Z-value =	**4.23**	**9.69**	**1.77**	**7.19**	
			4.59		
PWL (z-test) =	**100.0%**	**100.0%**	**96.2%**	**99.9%**	
PF =	**102.0%**	**102.0%**	**101.6%**	**102.0%**	
CPF =					**101.88%**

CHAPTER 3

CONRETE PAVEMENT ACCEPTANCE - THE STATISTICAL SPECIFICATION ENVIRONMENT

Almost all of the states surrounding Oklahoma have portland cement concrete paving specifications that use some form of statistical evaluation in the administration of the contract requirements. All of the surrounding states require the contractor to perform quality control (QC) testing and post or provide the results to the department. A few of the states use the contractor's QC tests for acceptance in order to lessen the testing burden on the department. This chapter will briefly discuss the highlights of the surrounding states' current specifications for portland cement concrete pavement and some aspects of their statistical procedures.

Arkansas:
The Arkansas DOT concrete paving specification is not a true PWL specification, although it does use some statistical techniques. This specification uses average plastic air content, average compressive strength and thickness of pavement cores, and smoothness as acceptance and payment criteria, however, this discussion will be limited to the discussion of strength and air content determination. The lot size is set at 4,000 cubic yards with 4 sublots of 1,000 cubic yards each. The Department selects the locations for sampling in each sublot and the contractor's QC tests are used for acceptance as long as they show statistical agreement with the states' results. The specification uses single test values and the average of the four contractor's sublot tests and the single department lot sample to determine the acceptability of the pavement lot. There are defined limits on either side of the production target that determine lot and sublot test acceptability. The air content criterion will be used as an example.

As mentioned in the previous paragraph, there are sets of limits that a test result must meet. The inner set of limits are the compliance limits, which in the case of air content are set ±2% away from the 6% air content midpoint of the specification. These limits identify the zone of full pay for the average.

The second set of limits outside of the compliance limits are the price reduction limits, set ±2.5% away from the 6% midpoint. They enclose the area of reduced pay for average values that fall within this zone. The price reduction consists of a 10% reduction in price for an air content deviation of 2.0 to 2.5% away from the target value. A further reduction of 10% occurs when the air content falls 2.6 to 3.0% away from the target. As an example, if the average plastic air content for a lot falls at 3.6% or 8.3%, a 10% reduction in price is applied.

The final two limits are rejection limits. The lot rejection limits are set ±3.0% away from the midpoint of the specification range. If an average lot value falls on or beyond this point, the lot is subject to rejection and replacement. The outer limit is the sublot rejection limit, which is set 4.0% away from the specification midpoint. If a single sublot test value falls outside of this range, it is rejected and subject to replacement.

A shortcoming of the Arkansas specification is there is no strong incentive for the contractor to control the variability of his process. Limited control is exercised through the use of sublot rejection limits, but this is a method with limited effectiveness. While the Arkansas specification is not a PWL specification, an estimate of the PWL values for the specification limits can be calculated. Let's examine a sample population made up of 4 alternating sublot samples just within the upper and lower lot rejection limits, at plastic air contents of 4.0% and 8.0%. This lot population has an average of 6% air content and a sample standard deviation of 2.309. Under the Arkansas specification, this lot would be subject to full pay. However, the actual amount of concrete that falls within the compliance limits of 4.0 and 8.0% air, would only represent 58% of the material produced. This leaves 42% of the paving material that could have air contents below 4.0% or above 8.0%. States, like Oklahoma, with true PWL specifications have the ability to control variability much more effectively and, as a result, will have much more uniform pavement properties than those with a lot-average based specification.

Colorado:

The Colorado concrete paving specification is a true PWL specification with an extraordinarily complex pay factor equation. Acceptance of portland cement concrete pavement is based on compressive or flexural strength, sand equivalent, and pavement thickness. The contractor must choose which strength option he is going to use. The Colorado specification sets the acceptable and rejectable quality limits at 95% and 58% for more than 26 tests (All other surrounding states use an AQL of 90% and an RQL of 50% for statistically based tests). The contractor is required to perform quality control testing, but the Department conducts the acceptance testing.

The contractor conducts process control testing at a frequency of 1 set of tests per day or 1 set of tests for every 2,500 square yards of paving (compressive strength, air content, yield, and sand equivalent). Acceptance tests are conducted every 5,000 square yards. Even though independent samples are used by the Department for acceptance purposes, statistical verification of the contractor's QC program is conducted. Statistical verification can use either a d2s (difference-2-sigma) procedure for check tests (Colorado Procedure 13) or a process verification procedure using the f and t-test (Colorado Procedure 14).

As mentioned previously, the pay factor equation is very complex. The pay factors for each individual specification item are adjusted depending on the number of acceptance samples (Section 105, Colorado DOT Standard Specifications). The pay factor equation is set up to permit bonus pay if the contractor achieves a quality level exceeding 98. A 3% bonus is possible for production projects with total acceptance samples exceeding 26. For a unity pay factor (PF=1.00), with a large number of samples, the quality level is equal to 95. For very small samples (n=3), a unity pay factor corresponds to a quality level of 85.

Kansas:

The Kansas concrete paving specification is a true PWL specification that uses contractor quality control tests for acceptance with statistical process verification (the f and t-test). Process verification for the first two lots uses a comparison of means. The mean and standard deviation is computed for the contractor's process control test results and the 2 standard deviation limits are calculated. If the department's verification test falls within the 2 standard deviation limit, the contractor's and department's tests are judged to be in good agreement. From the third lot on, the f and t-test is used to determine statistical agreement. From the fifth lot onward, a moving average of the last five lots is used as the data for the f and t-test.

The AQL and RQL for the Kansas specification are set at 90 and 50 percent, respectively. Acceptance of portland cement concrete pavements is based compressive strength and slab thickness. The lower specification limit (LSL) for strength is 3900 psi and the LSL for thickness is 0.2 inches less than plan thickness. A unity pay factor for compressive strength and thickness occurs for a PWL = 90. The maximum pay factor available is 1.06.

Missouri:

The Missouri concrete paving specification is also a true PWL specification. The contractor's test results are used for acceptance as long as the Department's quality assurance results fall within the greater of two sample standard deviations or ½ of the specification tolerance from the mean of the contractor's test results. This comparison is not as powerful as those based on the t-test.

Acceptance of Portland cement concrete pavement is a weighted sum of the in-place compressive strength and slab thickness. The weighting factors for the pay equation are

0.5 for all of the pay items. The specification has an AQL set at 90% for 100% pay and the RQL is set at 50% for removal. The maximum pay factor available is 1.05

New Mexico:

The New Mexico portland cement concrete paving specification is a PWL specification that uses a combination of department and contractor quality control tests for acceptance with statistical process verification (the f and t-test). The department's acceptance tests are always used for acceptance determination, and if the contractor's QC test results agree statistically using the f and t-test, they are incorporated into the PWL calculation.

The concrete characteristics used in the pay equation are the entrained air content from plastic tests, the compressive strength from cores, and the slab thickness. The target, upper, and lower specification limits for entrained air are 6.0%, 4.5%, and 7.5%, respectively. The compressive strength specification limits are set at 1,000 psi above and below the target strength from the mix design. The lower specification limit for thickness is 1.0 inches.

The maximum pay factor available to the contractor is 1.05 and is based on the average PWL for strength, thickness, and plastic air content. The AQL for a unity pay factor ranges from 69 for 3 acceptance tests to 92 for more than 67 tests. The RQL ranges from 35 to 65 for the same number of acceptance tests. The minimum acceptable pay factor is 0.75 at the RQL.

Texas:

The Texas portland cement concrete paving specification is not a PWL specification, even though the contractor must have a quality control testing program and the results are verified statistically by the department. Pay is based on measurement of the pavement thickness. If the pavement is deficient in thickness from 0.2 to 0.75 inches, a deduct is applied. If the pavement has a greater deficiency than 0.75 inches, the pavement is rejected. There is no bonus for pavement thicknesses greater than plan.

The above specification review demonstrates the different approaches to portland cement concrete paving statistical quality control that exist in the surrounding states. The Oklahoma DOT specification is very similar to many of the surrounding PWL specifications and appears to be superior in some aspects to those of surrounding states. The superlot quality assurance data from two pilot projects has been used in this analysis to try to determine the power and accuracy of the Oklahoma pilot specification. The results of that analysis are summarized in the succeeding chapters.

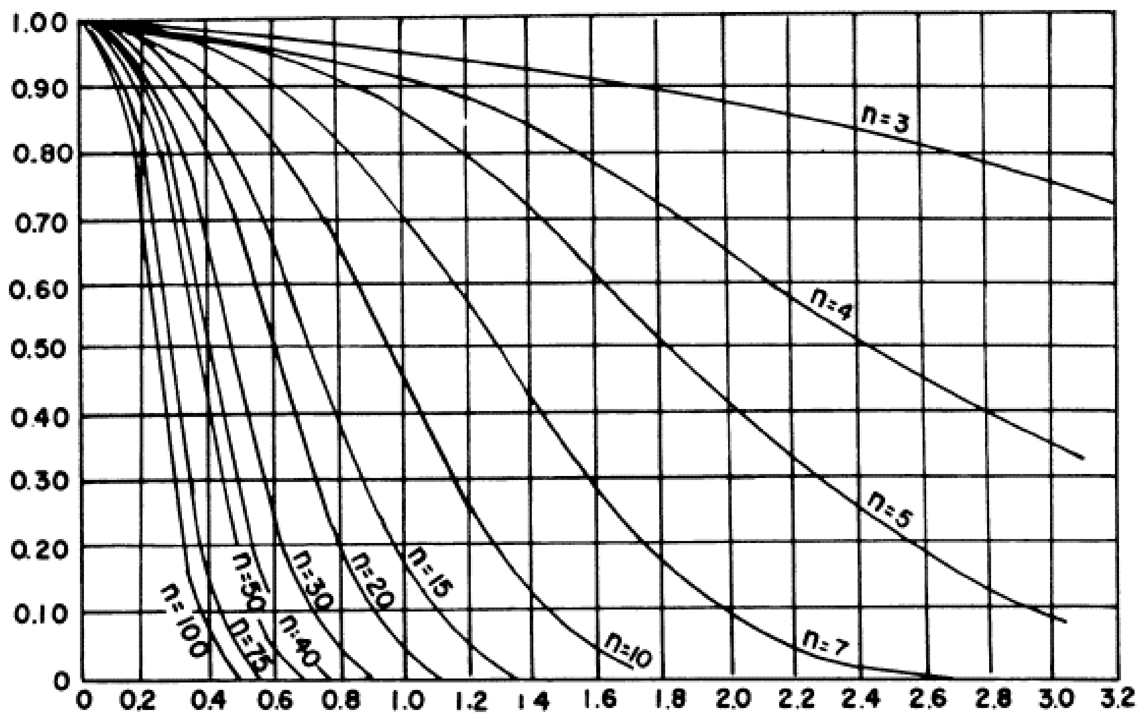
CHAPTER 4

PWL SPECIFICATIONS, ACCURACY AND PRODUCT QUALITY ASSESSEMENT

The Oklahoma pilot specification used standard quality level analysis techniques to estimate the quality of the pavement produced on the basis of a limited number of tests. An assessment of the contractor's quality control testing accuracy can be obtained by several statistical methods such as the difference 2-sigma limit, paired t-test, and the process verification f and t-test. The method chosen in the prototype Oklahoma DOT specification is the paired t-test.

The paired t-test method uses split samples to verify that the contractor's and department's test results come from the same population. The use of split samples reduces the effect of all sources of variance except for the testing variance of the two parties. The assumption underlying this procedure is that the selection of paired random samples will tend to average out the effects of the other sources of variation and the variance of the pairs of data can be pooled. This assumption permits the use of a single statistical test (the t-test) to determine testing bias.

The Oklahoma implementation of the paired t-test requires an initialization lot consisting of 12 sublots. A split sample is taken and tested by both the department and the contractor. The results of the tests are examined using the paired t-test, with the significance level for a two-tailed test set at 0.01. The Operating Characteristic (OC) curve for this test is shown in Figure BB1. The vertical axis on Figure A1 is the probability of not detecting a difference and the horizontal axis is the standardized difference, d.



Standardized Difference, d

Figure 1. OC Curves for a two-sided t-test, α = 0.01 (FHWA, 2003)

If good agreement is obtained in the initialization lot, production proceeds with reduced split sample testing for succeeding lots. The reduced frequency for testing is one paired test per lot (6 sublots of 2,500 cubic yards), but not less than one paired t-test for 10 sublots. As testing continues and data points continue to be accumulated, the $t_{critical}$ value is reduced, increasing the accuracy of the test.

The use of the paired t-test as implemented in the prototype Oklahoma specification is statistically valid and accurate in its current form. This procedure yields good control and is statistically valid. The only drawbacks are that it requires considerable initialization testing and does not measure the overall process variability. The main source of variability in the procedure is from the process of splitting the sample and running the required test, all other sources of variability having been reduced by using a split sample. However, it does require considerable initialization testing which places a considerable burden on contractor QC and department QA personnel.

The amount of department testing could be reduced by adopting the process verification method. This method has the same level of risk associated with it as does the paired-t. Both are equivalent if they are run at the same significance level.

The process verification method consists of having the contractor run quality control tests at the prescribed level of one test per sublot. The department runs one independent sample in each lot. Comparisons of the department's and the contractor's test results are performed by running a two-tailed F-test and the t-test at a significance level $\alpha = 0.01$, using the mean and standard deviation from the contractor's and department's data sets. The F-test, a statistical procedure for comparing variances, provides a way for comparing the variances of the contractor's and department's test data for each lot to determine if they represent the same sample population. If the data sets do have similar variances, the variances may be pooled and a t-test may be performed on the means just as in the paired t-test procedure. However, if the variances show a statistically significant difference, the variances cannot be pooled and the degree of freedom calculation for selecting the $t_{critical}$ value must be modified by computing a weighted average for the degree of freedom value.

A drawback to the process verification system is that the standard deviation is required to perform the comparison, and that requires the department to wait for three lots in order to accumulate sufficient data to perform a comparison. A way around this problem is to use the contractor's data set to develop a measure of the production population. After the first lot, sufficient contractor data exists to develop a measure of the process. Using the mean and standard deviation from the QC data developed by the contractor, the department can compare their first test to the contractor's data by seeing if the department's test result falls within 2 standard deviations of the contractor's mean. If it does, there is reasonable agreement between the tests and production can continue. If the department's result falls outside of the 2σ limit, there is not good agreement, and an investigation into the cause of the difference is launched. This procedure is used for the first three lots, incorporating the succeeding contractor's test results in the computation for the mean and standard deviation. Once three department QA test results are available, the F and t-test can be run. Figure BB-2 presents the OC curves for this Kansas QA method. The OC curves represent a significance level of $\alpha = 0.05$.

This system has been used by the Kansas DOT for the last 10 years with good results. The process verification method eliminates the need for the 12 sublot initialization testing and provides an equally accurate assessment of the QC and QA sample populations as the split t-test, at a reduced testing rate for the Department.

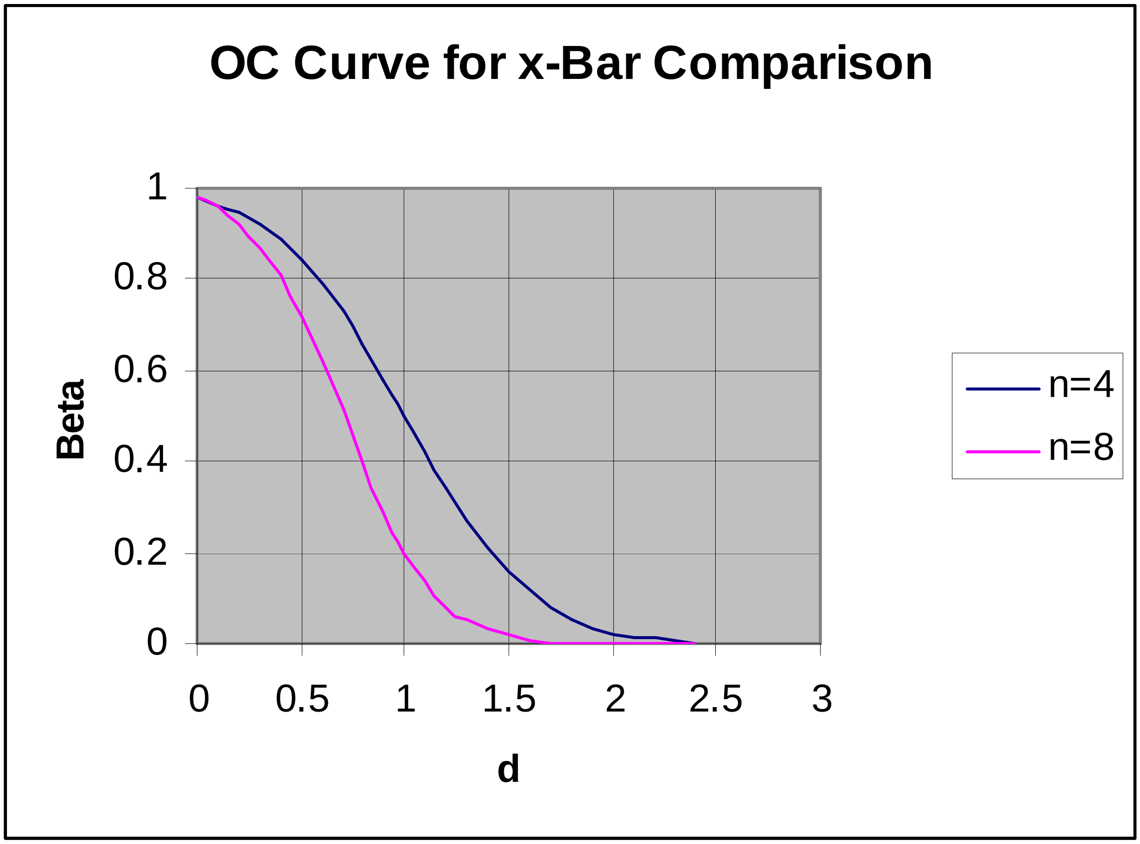


Figure 2. OC Curves for $2s_x$ Comparison of Contractor and Department Test Results

CHAPTER 5

PWL SPECIFICATIONS, PAVEMENT QUALITY-LINKED PAY AND RISK LEVEL

Four mix design characteristics have been selected as pay items in the pilot specification: percent passing the #200 sieve for coarse and fine aggregates, compressive strength, and plastic air content. The most reliable predictors of pavement performance are the compressive strength, and air content of the completed pavement.

An analysis of the pay equation using the FHWA's PWL-Risk program (FHWA, 2004) shows that the contractor has a single lot probability 100 percent pay or greater at the AQL of about 58%, This probability raises to about 61% for a 10 lot project. The pay equation probability for contractor pay compares well with the Kansas DOT specification formula, which has single lot and 10 lot probabilities of 59% and 61%, respectively. A plot of Acceptance Probability versus Quality for the Oklahoma specification is shown in Figure 3. Figure 4 shows the Kansas result. The plots PF1 through PF6 represent single lot pay factors of 103, 100, 95, 90, 80, and 70 percent, respectively.

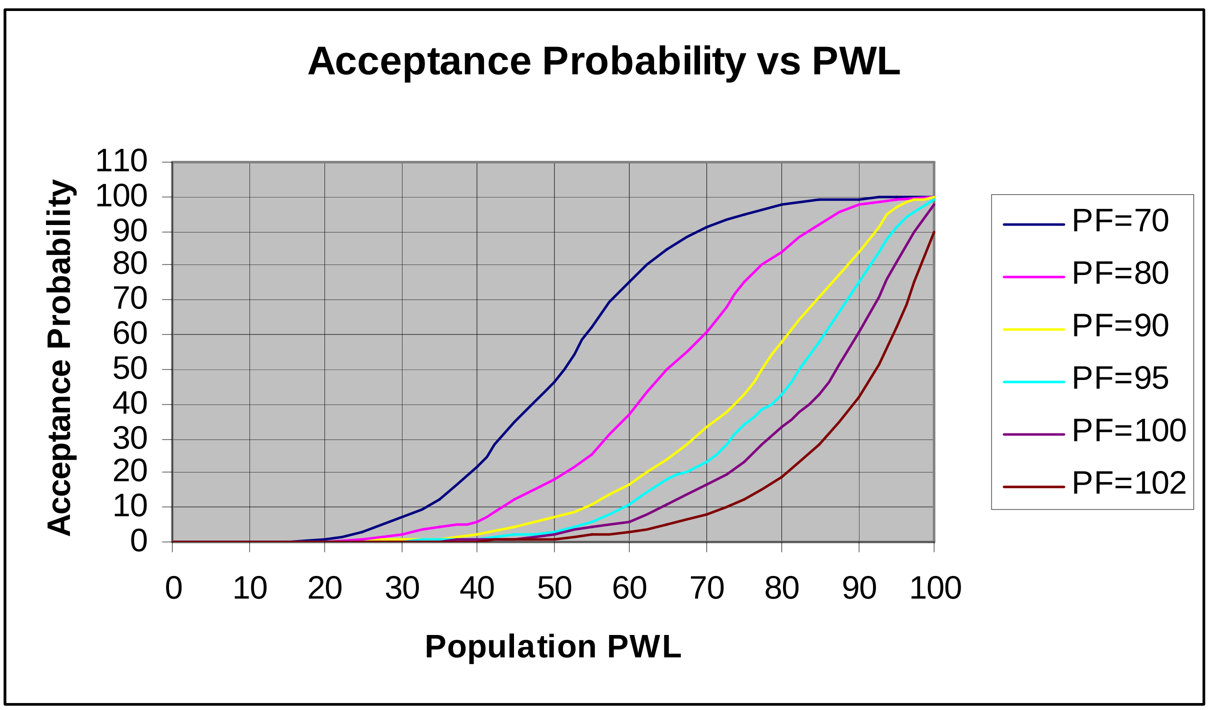


Figure 3. Oklahoma PWL Spec Acceptance Probability vs. Quality

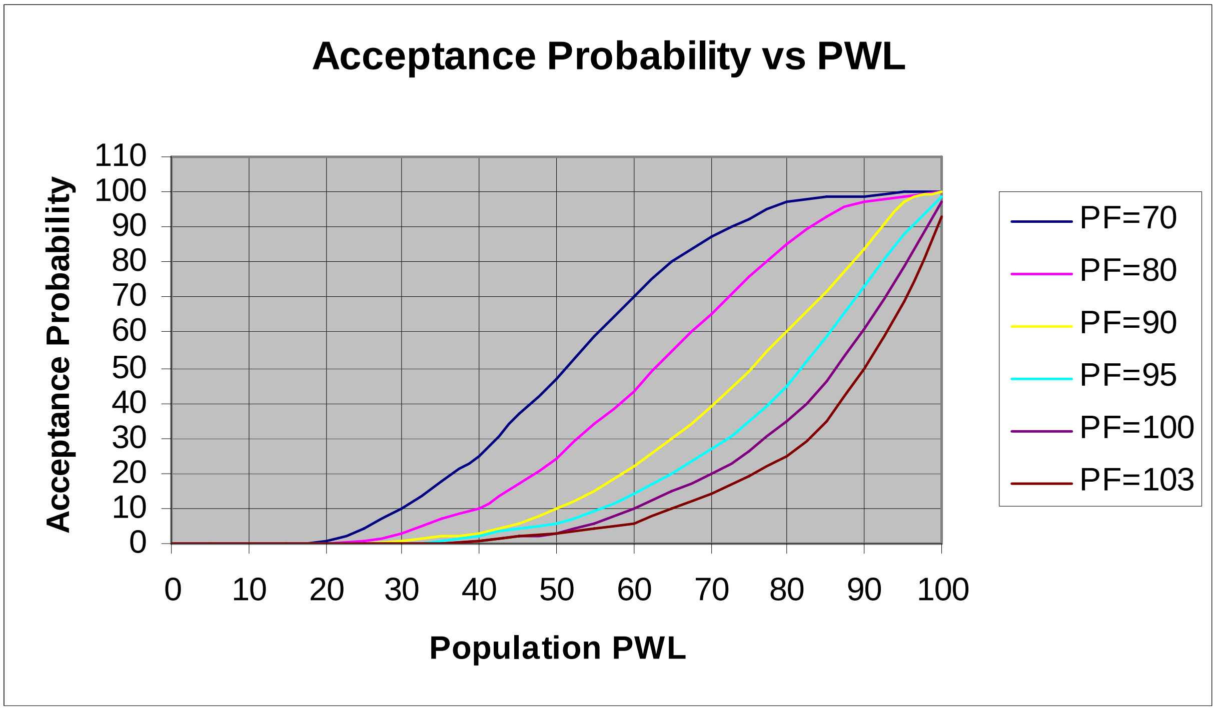


Figure 4. Kansas PWL Spec Acceptance Probability vs. Quality

The pilot specification is a good implementation of the PWL concept. The specification uses compressive strength of the concrete mix, air content, and gradation as pay factor items. Compressive strength and air content are normally the primary items that control long term serviceability of a pavement. These items are featured in the pay factor equations in most of the neighboring states' specifications.

The Percent Within Limits (PWL) portion of the Oklahoma specification essentially follows current thinking in both Federal and State specifications. **The concept of a target limit within the specification limits that is a part of the Oklahoma specification is a controversial addition in the authors' view.** This concept will be discussed further on. However, this addition does not detract from the overall PWL concept as written. The Rejectable and Acceptable Quality Limits (RQL and AQL, respectively) are set at the 50 and 90 percent levels, as is common in other state and federal PWL specifications.

The pay factor equation is made up of a weighted average of mix characteristics. The four mix design characteristics that have been selected as pay items, in general, are those characteristics that predict pavement performance. The most reliable predictors of pavement performance are the air content of the concrete and the compressive strength of the in-place mix. The -#200 gradation seems to be the least important measure of the four in prediction of pavement performance. The relative weighting in the pay factor equation places 60% of the weight on compressive strength and 30% of the weight on percent on air content in the mix. The -#200 gradation is given a 10% weight. The relative weights seem reasonable in light of the relative impact of the various factors on pavement performance.

If a change in the pay factor equation is desired, the -#200 gradation component could be given serious consideration for elimination. The fines passing the # 200 sieve have a minor impact on the overall pay factor. However, if the Department has local data that shows that gradation has a significant impact on pavement performance in Oklahoma, it should be retained in the pay factor equation.

The inclusion of a Target Limit within the Specification Limits, coupled with a target-adjusted standard deviation appears to be an attempt to 1) achieve tighter control over the product than required by the specification limits, or 2) push the mean of the measured characteristics to the center of the specification band. The term "target limit" is not a commonly used quality assurance term in the highway industry and is not mentioned in the Transportation Research Circular Glossary of Highway Quality Assurance Terms. The setting of target limits for production is a quality control decision that should be made by the producer, not dictated by the buyer. It is the Department's right to set the specification limits, and if tighter control is desired the specification limits should be narrowed to achieve the level of performance desired. The use of target limits and adjusted standard deviation values appears to be an attempt to impose tighter specification limits on the contractor without saying so. This practice can place the unwary contractor at a greater risk for unwarranted loss.

CHAPTER 6

DISCUSSION OF THE SUPER LOT DATA AND PWL SPECIFICATIONS

Four concrete parameters have been selected as pay items in the pilot specification:

1) Percent passing the #200 sieve for coarse aggregate;
2) Percent passing the #200 sieive for fine aggregate;
3) Compressive strength of concrete, and;
4) Total air content.

The most reliable predictors of pavement performance are the compressive strength and air content of the completed pavement.

With regard to the first two pay items prescribed requirements for gradation are common; however, it is the author's opinion that is unusual to establish the percent passing the #200 has a pay item. It is usually sufficient to prescribe a particular gradation for a coarse aggregate, for example, the ASTM designation for #57 prescribes specific gradation requirements for the coarse aggregate. Furthermore, ASTM C 33 limits fine contents (percent passing #200) to 3% in fine aggregate and 1% in coarse aggregate. It is noted that the PWL Specification limit for coarse aggregate is 2% passing the #200 sieve.

To be sure, a heavy fine content in aggregates can have deleterious affect on pavement performance. Too many fines increase water demand, thereby encouraging the ready mix producer to add more water to the mixture, increasing the water to cement ratio (w/c) and possibly hurting strength and durability as a result. Also, too many fines can decrease the abrasion resistance of concrete, so it may be suitable to continue to use the percent passing #200 as a pay item.

It is curious, however, that the specification limit in the PWL specification is 2% for coarse aggregate whereas the ASTM C 33 limits the percent passing #200 sieve to 1%. The PWL specification is further complicated by incorporating within the Cumulative Pay Factor whichever aggregate (coarse or fine) which is worst with respect to its compliance with the fineness specification.

The data from the McIntosh County project highlight how problematic this specification limit can be for the contractor. If one looks at the data from Super Lots #1 and #2, one can see that the coarse aggregate has less than 50% compliance with this specification. Based on these test results, the entire Super Lots could be rejected outright based solely on the coarse aggregate gradation requirements. Further, the entire pavement sections represented by these Super Lots could be subject to removal. This represents an incredible risk to the contractor who may simply raise prices to account for that risk. A review of that aggregate source needs to be done to make sure that the aggregate stockpiles were not improperly sampled. It is possible that the aggregate supplier needs to provide an aggregate where the fine materials are more aggressively washed from the aggregate.

For the same Super Lots, the sand gradations indicate that the sand does not have any trouble meeting the requirements for percent passing the #200 sieve. Given this result, it is interesting that the ASTM C 33 allows for increase in the amount of fine materials carried by the coarse aggregate if the sand aggregate falls short of its allowable limit. Essentially, the ASTM C 33 makes a calculation for the total amount of aggregate materials that would pass the #200 sieve and limits the total amount of fines to an equivalent amount as if both the sand and the coarse aggregate were at their specification limit. **The author believes that if the gradation limits are retained as part of the specification, the two limits be combined as a single pay factor which will allow acceptance of this particular aggregate while not harming the pay factor too much.**

Review of the super lot data also indicate that the prescribed range for total air content is more difficult to achieve than the prescribed compression strength. This is an expected result, and air content can be a difficult parameter to control. Total air content is affected by a large number of factors, many of which are very difficult to control. Mixing time, time in transit, concrete slump, concrete temperature and ambient temperature all affect total air content, plus the various parameters are interactive. It should also be noted that the test for total air content requires a careful and methodical approach by the technician performing the test. And even with careful attention to the testing protocols, the test can produce results with fairly high variability. **Therefore, the author is considering a recommendation where two measurements for air content are taken for each sublot, and the results of those two measurements then averaged together to obtain one air content value for the sub lot. If that is recommended, it is also necessary to consider a change to the specification limits.**

Of the various pay factors, compressive strength is perhaps the easiest to control. Increases in concrete strength can be brought about by decreasing the w/c – usually accomplished by adding cement to the mixture rather than reducing water. However, one adverse affect of this approach is that the increase is cement content will dramatically increase the shrinkage of concrete. So oftentimes, improvements in concrete quality come about by leaving the cement content at a relatively low level and then further reducing water content. In only one Super Lot did it appear that concrete strength was not achieved. The author has no explanation, except perhaps confusion regarding the specification requirement.

In addition to the parameters specified as Pay Factors in the PWL specifications, one might also consider the addition of unit weight. Like total air content, however, proper unit weight measurement requires careful observance of the testing protocols. On the other hand, if unit weight measurements are properly made, then the unit weight measurement can be the most powerful and informative quality assurance test performed on fresh concrete. This item is worthy of continued review and consideration.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This review of the "Special Provisions" or the PWL Specifications and analysis of the Super Lot data indicate that the concept for PWL Specification is sound. Furthermore, the concepts of the PWL Specifications if not the specifications themselves can be implemented into a wider scope of projects with relatively little additional work.

The PWL Specification uses split samples and paired t-testing for initialization testing. This process for initialization is sound, and can be continued. However, for ongoing testing and as a check on Contractor vs. Owner agreement, paired t-testing from split samples should not be used. Instead, each lot or sublot that is being used to determine agreement should be independently sampled. The statistics prepared from each Lot if sampled independently by both the contractor and owner will reveal whether there is adequate agreement between the two parties.

The gradation of coarse aggregate apparently caused the potential rejection of large segments of paving. The specification should be reviewed to determine if this outcome is appropriate.

Recommendations

1. The authors recommend the implementation of a PWL Specification for concrete paving.
2. The PWL Specification should be modified in one or more of the following ways:
   (a) Remove gradation as a pay item, OR
   (b) Combine the fineness of sand and coarse aggregate to make the total amount of fines a single pay item and allow greater flexibility in selection of aggregate source. Use the same language as the ASTM C 33 specification where the total amount of fines for the whole amount of aggregates does not exceed the equivalent of 1% for coarse aggregate and 3% for fine aggregate.

(c) Incorporate unit weight into the specification, and include it as a pay item. Unit weight is the best available quality assurance parameter that we currently possess for concrete in the fresh state.

(d) For each sub lot and for each sample of fresh concrete, increase the number of air content measurements from one to two. The tests must be performed independently. This will help avoid the pratfall from a single data point that may not be taken carefully by the trained technician.

(e) Consider writing specifications that will encourage the use of lower shrinkage concretes.

3. Proper training and certification of all technicians is imperative.

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