EVALUATING PERCENT WITHIN LIMITS (PWL) SPECIFICATIONS

Volume 1: HMA Specifications

Final Report

by

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16. Abstract

The Oklahoma Department of Transportation (ODOT) has let four paving jobs for construction 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 the probability of conformance to the specifications. There is a need to evaluate the performance of the PWL specifications and assess the suitability of the PWL specifications for future jobs.

Two hot mix asphalt (HMA) projects were let for construction using the proposed HMA PWL specifications. 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 lots from each pavement which were designated "super lots."

The data obtained were to analyzed 1) to determine whether the PWL specifications are working as intended, 2) to recommend changes to the PWL specification if necessary, including possible changes to the limits and ranges contained within the specifications, and 3) to recommend whether ODOT should continue to pursue PWL specifications as matter of policy in their overall QA/QC programs.

The examination of the draft HMA PWL specification and analysis of the super lot data demonstrated that the specification concept is sound and will require very little additional work to develop fully. The F and t-test procedure for process verification is recommended for use.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units					Approximate Conversions from SI Units				
Symbol	**When you know**	**Multiply by**	**To Find**	**Symbol**	**Symbol**	**When you know**	**Multiply by**	**To Find**	**Symbol**
		LENGTH					**LENGTH**		
in	inches	25.40	millimeters	mm	mm	millimeters	0.0394	inches	in
ft	feet	0.3048	meters	m	m	meters	3.281	feet	ft
yd	yards	0.9144	meters	m	m	meters	1.094	yards	yds
mi	miles	1.609	kilometers	km	km	kilometers	0.6214	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.00155	square inches	in^2
ft^2	square feet	0.0929	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.8361	square meters	m^2	m^2	square meters	1.196	square yards	yd^2
ac	acres	0.4047	hectacres	ha	ha	hectacres	2.471	acres	ac
mi^2	square miles	2.590	square kilometers	km^2	km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.0338	fluid ounces	fl oz
gal	gallon	3.785	liters	L	L	liters	0.2642	gallon	gal
ft^3	cubic feet	0.0283	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.7645	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.0353	ounces	oz
lb	pounds	0.4536	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C	°C	degrees Fahrenheit	9/5(°C)+32	degrees Celsius	°F
		FORCE and PRESSURE or STRESS					**FORCE and PRESSURE or STRESS**		
lbf	poundforce	4.448	Newtons	N	N	Newtons	0.2248	poundforce	lbf
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa	kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

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CHAPTER 1

INTRODUCTION

PROBLEM STATEMENT

The Oklahoma Department of Transportation (ODOT) has let four paving jobs for construction 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 the probability of conformance to the specifications. The PWL specifications are relatively new to ODOT, as are the governing principles. In fact, the four paving jobs are the first to implement PWL specifications to calculate conformance and pay factors. There is a need to evaluate the performance of the PWL specifications and assess the suitability of the PWL specifications for future jobs.

OBJECTIVES

The objectives of this study were to:

1. Assess the accuracy of the PWL specifications in judging the overall quality of the installed pavements and the materials employed.
2. Assess the PWL specifications for its ability to enhance cooperation between ODOT and its contractors, and release ODOT from its requirements for sampling and testing on every job.
3. Assess the PWL specifications in its 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 hot mix asphalt (HMA) projects and two concrete 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 lots from each pavement which were designated “super lots.” In each HMA super lot, each of five sublots were sampled and tested three times so that there were a total of 15 additional tests for each super lot. The contractor performed his regular specified sampling and testing for each super lot. Sampling and testing consisted of the same tests prescribed by the PWL specifications.

Upon completion of the construction projects, the data obtained from sampling and testing under the research contract were compared to the data obtained from the contractor and from ODOT. The data were analyzed for its statistical value and estimates for averages, or targets, and for underlying variation and to determine:

1. Whether the PWL specifications are working as intended (evaluate the

specifications and the overall methodology, and provide some qualitative assessment of the effectiveness of the participants);

2. Recommend changes to the PWL specification if necessary, including possible changes to the limits and ranges contained within the specifications, and;
3. Recommend whether ODOT should continue to pursue PWL specifications as matter of policy in their overall QA/QC programs.

Additionally, *AASHTO R 9-05, Acceptance Sampling Plans for Highway Construction* and HMA specifications from surrounding states were obtained and reviewed.

CHAPTER 2

TEST PLAN AND TEST DATA

TEST PLAN

Projects

Two HMA projects were let for construction during the 2004 construction season using the proposed HMA PWL specification (*1*). One project was located on I-35 in Noble County and the other project on SH-19 in Garvin County. The original test plan called for four super lots from the I-35 project and two super lots from the SH-19 project. Data from only three super lots were available from the I-35 project in Noble County. Table 1 shows the super lots sampled and tested from each project.

Table 1. HMA Super Lots.

Route	County	Project Number	Mix	PG Grade	Lot
I-35	Noble	NHIY 35-4 (169) 177	S-2 R	PG 64-22	2
I-35	Noble	NHIY 35-4 (169) 177	S-3 R	PG 64-22	5
I-35	Noble	NHIY 35-4 (169) 177	S-4 I	PG 76-28	3
SH-19	Garvin	STPY – 125 C (69)	S-4 I	PG 70-28	1
SH-19	Garvin	STPY – 125 C (69)	S-3 R	PG 64-22	4

Sampling and Testing

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 from each pavement. In each super lot, each of the five sublots were sampled and tested three times so that there were a total of 15 additional tests for each super lot. The contractor performed his regular specified sampling and testing for each super lot. Sampling and testing consisted of the same tests prescribed by the HMA PWL specification (*1*). Samples that required laboratory testing were transported, in conformance with applicable standards, to the appropriate testing laboratory. The contractors on each project performed their normal testing as required by the HMA PWL specification. Test results were supplied to the researchers.

Data Analysis and Evaluation of the PWL Specifications

Upon completion of the HMA construction projects, the data obtained from sampling and testing under the research contract were compared to the data obtained from the contractor and from ODOT. The data were analyzed for its statistical value and estimates for averages, or targets, and for underlying variation and to determine:

1. Whether the HMA PWL specification is working as intended (evaluate the specifications and the overall methodology, and provide some qualitative assessment of the effectiveness of the participants);

2. Recommend changes to the HMA PWL specification if necessary, including possible changes to the limits and ranges contained within the specifications, and;
3. Recommend whether ODOT should continue to pursue HMA PWL specifications as matter of policy in their overall QA/QC programs.

Additionally, *AASHTO R 9-05, Acceptance Sampling Plans for Highway Construction* and HMA specifications from the surrounding states of Arkansas, Colorado, Kansas, Missouri, New Mexico, and Texas were obtained and reviewed.

TEST RESULTS

Hard copies of the super lot data and computer files of the test data from both HMA projects were provided by the ODOT Materials Division Liaison Engineer. Both HMA contractors supplied computer files of their test data. The super lot data was extracted from the computer files and hard copies of the test results and a data base of the test values were developed. The supplied data contained actual test values. In order to allow comparisons of the super lot test data between lots, much of the data had to be normalized. Data where the job mix formula (JMF) or target value varied by mix required normalization before statistical analysis of the data could be performed. This was accomplished by subtracting the JMF or target value from the test result or value. A positive number indicated that the test result was greater than the JMF or target value and a negative number indicated that the test result was less than the JMF or target value. Gradation and asphalt content are two examples of test values that required normalization. Laboratory compacted air voids and percent density or compaction, are two examples of values that do not require normalization.

Table 2 contains sample identification information that will help in identifying specific test locations from the I-35 project in Noble County. Tables 3-11 contain the test data from the super lots for the I-35 project that were used in the statistical analysis. Tables 3-5 contain the data from super lot 2, tables 6-8 contain the data from super lot 5 and tables 9-11 contain the data from super lot 3.

Table 12 contains sample identification information that will help in identifying specific test locations from the SH-19 project in Garvin County. Tables 13-18 contain the test data from the super lots for the SH-19 project that were used in the statistical analysis. Tables 13-15 contain the data from super lot 1 and tables 16-18 contain the data from super lot 4.

Table 2. Sample Identification for Project NHIY 35-4 (169) 177.

Site	Lab No	Type Sample	Test Number	Lot	Sublot	Mix	PG Grade
I-35	25563	SL	1	2	1	S-2 R	64-22
I-35	25556	SL	2	2	1	S-2 R	64-22
I-35	25557	SL	3	2	1	S-2 R	64-22
I-35	25560	SL	4	2	2	S-2 R	64-22
I-35	25562	SL	5	2	2	S-2 R	64-22
I-35	25561	SL	6	2	2	S-2 R	64-22
I-35	25587	SL	7	2	3	S-2 R	64-22
I-35	25593	SL	8	2	3	S-2 R	64-22
I-35	25594	SL	9	2	3	S-2 R	64-22
I-35	25592	SL	10	2	4	S-2 R	64-22
I-35	25591	SL	11	2	4	S-2 R	64-22
I-35	25598	SL	12	2	4	S-2 R	64-22
I-35	25599	SL	13	2	5	S-2 R	64-22
I-35	25596	SL	14	2	5	S-2 R	64-22
I-35	25590	SL	15	2	5	S-2 R	64-22
I-35	N/A	C	1	2	1	S-2 R	64-22
I-35	N/A	C	2	2	2	S-2 R	64-22
I-35	N/A	C	3	2	3	S-2 R	64-22
I-35	N/A	C	4	2	4	S-2 R	64-22
I-35	N/A	C	5	2	5	S-2 R	64-22

SL = Super Lot Data N/A = Not applicable
C = Contractor's Data

Table 2 (Con't.). Sample Identification for Project NHIY 35-4 (169) 177.

Site	Lab No	Type Sample	Test Number	Lot	Sublot	Mix	PG Grade
I-35	25602	SL	1	5	1	S-3 R	64-22
I-35	25600	SL	2	5	1	S-3 R	64-22
I-35	25588	SL	6	5	1	S-3 R	64-22
I-35	25597	SL	7	5	2	S-3 R	64-22
I-35	25589	SL	8	5	2	S-3 R	64-22
I-35	25620	SL	9	5	2	S-3 R	64-22
I-35	25627	SL	10	5	3	S-3 R	64-22
I-35	25628	SL	11	5	3	S-3 R	64-22
I-35	25626	SL	12	5	3	S-3 R	64-22
I-35	25625	SL	13	5	4	S-3 R	64-22
I-35	25623	SL	14	5	4	S-3 R	64-22
I-35	25622	SL	15	5	4	S-3 R	64-22
I-35	25624	SL	16	5	5	S-3 R	64-22
I-35	25617	SL	17	5	5	S-3 R	64-22
I-35	25618	SL	18	5	5	S-3 R	64-22
I-35	25619	SL	19	5	5	S-3 R	64-22
I-35	N/A	C	1	5	1	S-3 R	64-22
I-35	N/A	C	2	5	2	S-3 R	64-22
I-35	N/A	C	3	5	3	S-3 R	64-22
I-35	N/A	C	4	5	4	S-3 R	64-22
I-35	N/A	C	5	5	5	S-3 R	64-22

SL = Super Lot Data N/A = Not applicable
C = Contractor's Data

Table 2 (con't.) Sample Identification for Project NHIY 35-4 (169) 177.

Site	Lab No	Type Sample	Test Number	Lot	Sublot	Mix	PG Grade
I-35	31322	SL	1	3	1	S-4 I	76-28
I-35	31320	SL	2	3	1	S-4 I	76-28
I-35	31323	SL	3	3	1	S-4 I	76-28
I-35	31326	SL	4	3	2	S-4 I	76-28
I-35	31325	SL	5	3	2	S-4 I	76-28
I-35	31324	SL	6	3	2	S-4 I	76-28
I-35	31321	SL	7	3	3	S-4 I	76-28
I-35	31327	SL	8	3	3	S-4 I	76-28
I-35	31328	SL	9	3	3	S-4 I	76-28
I-35	31329	SL	10	3	4	S-4 I	76-28
I-35	31330	SL	11	3	4	S-4 I	76-28
I-35	31331	SL	12	3	4	S-4 I	76-28
I-35	31332	SL	13	3	5	S-4 I	76-28
I-35	31333	SL	14	3	5	S-4 I	76-28
I-35	31334	SL	15	3	5	S-4 I	76-28
I-35	N/A	C	1	3	1	S-4 I	76-28
I-35	N/A	C	2	3	2	S-4 I	76-28
I-35	N/A	C	3	3	3	S-4 I	76-28
I-35	N/A	C	4	3	4	S-4 I	76-28
I-35	N/A	C	5	3	5	S-4 I	76-28

SL = Super Lot Data N/A = Not applicable
C = Contractor's Data

Table 3. Gradation Analysis Data from Super Lot 2.

	Test			Percent Passing													
Type	#	Lot	Sublot	1.5	1	3/4	1/2	3/8	4	8	16	30	50	100	200	AC	AC
SL	1	2	1	0.0	6.0	3.5	2.6	3.2	6.3	5.9	3.4	3.5	3.2	3.4	2.28	0.10	4.10
SL	2	2	1	0.0	6.0	5.8	4.3	5.7	7.6	6.7	3.8	3.8	3.3	3.3	2.09	0.10	4.10
SL	3	2	1	0.0	6.0	5.2	5.5	7.1	10.4	9.8	6.1	5.4	4.1	4.1	2.55	0.30	4.30
SL	4	2	2	0.0	1.6	-3.9	-4.1	-1.6	1.8	1.4	-1.1	-0.1	1.4	2.8	2.05	0.30	3.70
SL	5	2	2	0.0	2.9	2.2	3.9	5.7	7.3	6.3	4.0	4.3	4.0	4.2	3.09	0.10	4.10
SL	6	2	2	0.0	4.2	0.6	-3.5	-1.9	1.5	2.3	0.9	1.9	2.3	3.0	1.96	0.10	3.90
SL	7	2	3	0.0	4.5	-2.8	-1.0	0.6	5.8	6.5	4.5	4.6	4.2	3.5	3.28	0.20	3.80
SL	8	2	3	0.0	2.8	5.2	4.9	6.5	9.6	9.5	6.7	5.9	4.8	3.8	3.06	0.00	4.00
SL	9	2	3	0.0	5.0	2.1	3.1	4.9	8.5	8.8	6.2	5.7	5.0	4.2	3.74	0.10	3.90
SL	10	2	4	0.0	6.0	5.8	9.8	9.7	12.8	12.0	8.5	7.1	5.5	4.3	3.52	0.10	4.10
SL	11	2	4	0.0	2.9	4.4	7.8	10.5	12.8	11.7	7.9	6.7	5.1	3.9	3.22	0.10	4.10
SL	12	2	4	0.0	3.9	3.1	5.2	6.8	8.4	7.3	4.6	4.6	4.1	3.4	3.09	0.10	4.10
SL	13	2	5	0.0	1.5	-5.8	-3.4	-2.7	2.4	3.7	2.1	2.7	2.9	2.8	2.64	0.40	3.60
SL	14	2	5	0.0	6.0	3.6	4.0	4.8	7.3	7.1	4.5	4.3	3.9	3.4	3.03	0.00	4.00
SL	15	2	5	0.0	4.8	3.0	4.5	5.2	8.7	7.6	4.9	4.7	4.2	3.5	3.08	0.00	4.00
SL		2	Avg		4.3	2.1	2.9	4.3	7.4	7.1	4.5	4.3	3.9	3.6	2.85	0.13	3.99
SL		2	Std		1.6	3.6	4.1	4.0	3.5	3.1	2.5	1.9	1.1	0.5	0.55	0.12	0.18
C	1	2	1	0.0	2.6	2.1	-0.2	-2.8	-0.2	0.0	3.0	-0.3	2.5	2.0	1.73	0.15	4.15
C	2	2	2	0.0	0.5	-1.4	-0.1	-2.8	-0.1	-0.2	2.6	-1.7	0.1	-1.0	-1.69	0.00	4.00
C	3	2	3	0.0	3.3	1.9	6.2	2.2	4.1	4.2	6.8	2.3	4.0	3.1	2.46	0.15	4.15
C	4	2	4	0.0	3.7	4.8	2.4	-0.9	-0.8	-0.3	3.7	0.2	2.8	2.2	1.34	0.20	4.20
C	5	2	5	0.0	2.3	2.6	3.1	-0.1	0.9	-0.2	4.1	0.8	3.5	2.8	2.55	0.05	3.95
C		2	Avg		2.5	2.0	2.3	-0.9	0.8	0.7	4.0	0.3	2.6	1.8	1.3	0.11	4.09
C		2	Std		1.2	2.2	2.6	2.1	2.0	2.0	1.7	1.5	1.5	1.6	1.7	0.08	0.11

Table 4. Laboratory Recompacted Data from Super Lot 2.

	Test		Sub				Lab Molded					Lab Molded VTM			Lab Molded VMA		
Type	#	Lot	Lot	Gmm	Gse	Gsb	Gmb 1	Gmb 2	Den 1	Den 2	Avg	Va1	Va2	Avg	VMA 1	VMA 2	Avg
SL	1	2	1	2.494	2.661	2.656	2.370	2.370	95.03	95.03	95.0	4.97	4.97	5.0	11.66	11.66	11.7
SL	2	2	1	2.494	2.661	2.656	2.377	2.380	95.31	95.43	95.4	4.69	4.57	4.6	11.40	11.29	11.3
SL	3	2	1	2.494	2.670	2.665	2.371	2.377	95.07	95.31	95.2	4.93	4.69	4.8	11.92	11.70	11.8
SL	4	2	2	2.516	2.669	2.664	2.367	2.370	94.08	94.20	94.1	5.92	5.80	5.9	12.93	12.82	12.9
SL	5	2	2	2.496	2.664	2.659	2.374	2.374	95.11	95.11	95.1	4.89	4.89	4.9	12.50	12.50	12.5
SL	6	2	2	2.503	2.663	2.658	2.377	2.380	94.97	95.09	95.0	5.03	4.91	5.0	12.36	12.25	12.3
SL	7	2	3	2.482	2.634	2.629	2.384	2.375	96.05	95.69	95.9	3.95	4.31	4.1	12.04	12.37	12.2
SL	8	2	3	2.494	2.657	2.652	2.384	2.384	95.59	95.59	95.6	4.41	4.41	4.4	12.80	12.80	12.8
SL	9	2	3	2.483	2.639	2.634	2.386	2.389	96.09	96.21	96.2	3.91	3.79	3.8	12.13	12.02	12.1
SL	10	2	4	2.502	2.671	2.666	2.382	2.377	95.20	95.00	95.1	4.80	5.00	4.9	14.23	14.41	14.3
SL	11	2	4	2.491	2.658	2.653	2.386	2.375	95.78	95.34	95.6	4.22	4.66	4.4	13.66	14.06	13.9
SL	12	2	4	2.496	2.664	2.659	2.386	2.382	95.59	95.43	95.5	4.41	4.57	4.5	13.86	14.00	13.9
SL	13	2	5	2.484	2.627	2.622	2.380	2.380	95.81	95.81	95.8	4.19	4.19	4.2	13.77	13.77	13.8
SL	14	2	5	2.501	2.665	2.660	2.389	2.389	95.52	95.52	95.5	4.48	4.48	4.5	14.68	14.68	14.7
SL	15	2	5	2.484	2.645	2.640	2.380	2.379	95.81	95.77	95.8	4.19	4.23	4.2	14.36	14.39	14.4
SL		2	Avg	2.494	2.657	2.652	2.380	2.379	95.40	95.37	95.4	4.60	4.63	4.6	12.95	12.98	13.0
SL		2	Std	0.009	0.014	0.014	0.007	0.006	0.52	0.47	0.48	0.52	0.47	0.5	1.06	1.14	1.1
C	1	2	1	2.463	2.627	2.622	2.384	2.379	96.79	96.59	96.7	3.21	3.41	3.3	9.99	10.18	10.1
C	2	2	2	2.495	2.658	2.653	2.420	2.418	96.99	96.91	97.0	3.01	3.09	3.0	10.61	10.68	10.6
C	3	2	3	2.495	2.664	2.659	2.409	2.405	96.55	96.39	96.5	3.45	3.61	3.5	12.12	12.27	12.2
C	4	2	4	2.491	2.662	2.657	2.417	2.413	97.03	96.87	96.9	2.97	3.13	3.1	12.67	12.82	12.7
C	5	2	5	2.498	2.659	2.654	2.401	2.402	96.12	96.16	96.1	3.88	3.84	3.9	14.06	14.02	14.0
C		2	Avg	2.488	2.654	2.649	2.406	2.403	96.70	96.58	96.6	3.30	3.42	3.4	11.89	11.99	11.9
C		2	Std	0.014	0.015	0.015	0.014	0.015	0.38	0.32	0.3	0.38	0.32	0.3	1.63	1.57	1.6

Table 5. Roadway Compaction Data from Super Lot 2.

	Test		Sub	JMF	Roadway Gmb				Roadway Density			
Type	#	Lot	Lot	Gmm	1	2	3	Avg	1	2	3	Avg
SL	1	2	1	2.498	2.382	2.342	2.326	2.350	95.36	93.76	93.11	94.1
SL	2	2	1	2.498	2.329	2.309	2.355	2.331	93.23	92.43	94.28	93.3
SL	3	2	1	2.505	2.317	2.367	2.334	2.339	92.50	94.49	93.17	93.4
SL	4	2	2	2.504	2.339	2.220	2.389	2.316	93.41	88.66	95.41	92.5
SL	5	2	2	2.500	2.342	2.315	2.298	2.318	93.68	92.60	91.92	92.7
SL	6	2	2	2.499	2.339	2.339	2.334	2.337	93.60	93.60	93.40	93.5
SL	7	2	3	2.475	2.333	2.219	2.357	2.303	94.26	89.66	95.23	93.1
SL	8	2	3	2.494	2.349	2.337	2.276	2.320	94.19	93.70	91.26	93.0
SL	9	2	3	2.479	2.357	2.310	2.311	2.326	95.08	93.18	93.22	93.8
SL	10	2	4	2.506	2.360	2.360	2.346	2.355	94.17	94.17	93.62	94.0
SL	11	2	4	2.495	2.346	2.342	2.351	2.346	94.03	93.87	94.23	94.0
SL	12	2	4	2.500	2.354	2.354	2.348	2.352	94.16	94.16	93.92	94.1
SL	13	2	5	2.469	2.358	2.318	2.372	2.349	95.50	93.88	96.07	95.2
SL	14	2	5	2.501	2.351	2.373	2.352	2.358	94.00	94.88	94.04	94.3
SL	15	2	5	2.484	2.370	2.357	2.315	2.347	95.41	94.89	93.20	94.5
SL		2	Avg	2.494	2.348	2.324	2.338	2.336	94.17	93.20	93.74	93.7
SL		2	Std	0.012	0.016	0.047	0.029	0.017	0.86	1.79	1.25	0.7
C	1	2	1	2.469	2.367	2.370	2.362	2.366	95.87	95.99	95.67	95.8
C	2	2	2	2.495	2.382	2.380	2.381	2.381	95.47	95.39	95.43	95.4
C	3	2	3	2.500	2.357	2.358	2.389	2.368	94.28	94.32	95.56	94.7
C	4	2	4	2.499	2.373	2.373	2.381	2.376	94.96	94.96	95.28	95.1
C	5	2	5	2.496	2.353	2.354	2.355	2.354	94.27	94.31	94.35	94.3
C		2	Avg	2.492	2.366	2.367	2.374	2.369	94.97	94.99	95.26	95.1
C		2	Std	0.013	0.012	0.011	0.014	0.010	0.71	0.72	0.53	0.6

Table 6. Gradation Analysis Data from Super Lot 5

	Test			Percent Passing												
Type	#	Lot	Sublot	1	3/4	1/2	3/8	4	8	16	30	50	100	200	AC	AC
SL	1	5	1	0.0	-0.4	4.3	9.1	6.7	6.4	7.1	3.8	2.6	3.2	3.28	0.10	4.20
SL	2	5	1	0.0	2.0	5.8	10.5	7.5	7.1	7.6	4.5	3.1	3.5	3.44	0.00	4.10
SL	6	5	1	0.0	2.0	3.5	6.9	2.5	3.6	5.6	2.9	.	2.9	2.98	0.00	4.10
SL	7	5	2	0.0	-1.6	2.3	7.0	4.0	3.9	5.4	2.6	1.8	2.7	2.89	0.00	4.10
SL	8	5	2	0.0	1.3	3.5	6.6	4.4	4.3	5.9	2.9	2.0	2.6	2.55	0.00	4.10
SL	9	5	2	0.0	0.9	3.9	5.6	3.5	4.2	5.5	2.8	2.2	3.1	3.23	0.00	4.10
SL	10	5	3	0.0	0.0	0.3	4.8	0.0	1.0	3.6	1.6	1.3	2.6	2.72	0.10	4.00
SL	11	5	3	0.0	1.2	3.9	8.5	3.7	3.7	5.4	2.7	1.8	3.0	3.19	0.10	4.20
SL	12	5	3	0.0	-0.5	2.1	5.5	3.6	3.8	5.2	2.4	1.4	2.6	2.84	0.00	4.10
SL	13	5	4	0.0	-1.2	1.7	5.6	3.2	3.8	5.3	2.5	1.6	2.5	2.53	0.10	4.00
SL	14	5	4	0.0	0.7	1.9	5.8	4.1	4.3	6.0	3.1	2.3	3.0	2.94	0.00	4.10
SL	15	5	4	0.0	-0.9	4.1	8.8	6.8	6.1	6.9	3.7	2.6	3.2	3.15	0.20	4.30
SL	16	5	5	0.0	-1.4	-0.4	3.4	1.3	2.5	4.6	1.9	0.9	2.2	2.58	0.20	3.90
SL	17	5	5	-2.6	-4.1	-3.5	-0.5	-0.6	1.3	3.5	1.0	0.3	1.9	2.37	0.20	3.90
SL	18	5	5	0.0	0.1	0.1	2.6	-0.2	1.5	3.6	1.2	0.8	2.1	2.38	0.20	3.90
SL	19	5	5	0.0	-1.0	0.3	3.7	1.7	2.9	4.9	2.4	1.7	2.8	2.80	0.00	4.10
SL		5	Avg	-0.2	-0.1	2.2	6.0	3.4	3.8	5.4	2.6	1.8	2.7	2.87	0.08	4.07
SL		5	Std	0.7	1.6	2.4	2.8	2.5	1.8	1.2	1.0	0.8	0.45	0.34	0.09	0.12
C	1	5	1	0.0	0.0	0.5	4.2	1.1	2.0	1.4	2.3	-0.8	0.9	1.97	0.18	4.28
C	2	5	2	0.0	0.5	0.6	2.3	-0.3	1.6	1.2	2.6	-0.4	0.8	1.97	0.09	4.19
C	3	5	3	0.0	2.0	1.2	4.2	2.6	4.0	2.8	3.5	0.1	1.1	1.39	0.10	4.20
C	4	5	4	0.0	1.2	1.7	4.9	3.0	3.5	1.9	2.9	-0.6	0.7	1.27	0.16	4.26
C	5	5	5	0.0	2.0	1.6	4.7	4.5	4.7	3.9	4.3	0.5	0.7	1.06	0.25	4.35
C		5	Avg	-0.2	1.1	1.1	4.1	2.2	3.2	2.2	3.1	-0.2	0.8	1.53	0.16	4.26
C		5	Std	0.8	0.9	0.6	1.0	1.8	1.3	1.1	0.8	0.5	0.2	0.42	0.07	0.07

Table 7. Laboratory Recompacted Data from Super Lot 5.

	Test		Sub				Lab Molded					Lab Molded VTM			Lab Molded VMA		
Type	#	Lot	Lot	Gmm	Gse	Gsb	Gmb 1	Gmb 2	Den 1	Den 2	Avg	Va1	Va2	Avg	VMA 1	VMA 2	Avg
SL	1	5	1	2.492	2.663	2.658	2.394	2.389	96.07	95.87	96.0	3.93	4.13	4.0	10.83	11.02	10.9
SL	2	5	1	2.496	2.664	2.659	2.399	2.400	96.11	96.15	96.1	3.89	3.85	3.9	10.68	10.64	10.7
SL	6	5	1	2.485	2.650	2.645	2.397	2.391	96.46	96.22	96.3	3.54	3.78	3.7	10.28	10.51	10.4
SL	7	5	2	2.478	2.642	2.637	2.397	2.403	96.73	96.97	96.9	3.27	3.03	3.1	10.92	10.70	10.8
SL	8	5	2	2.482	2.647	2.642	2.385	2.388	96.09	96.21	96.2	3.91	3.79	3.8	11.53	11.42	11.5
SL	9	5	2	2.479	2.643	2.638	2.398	2.395	96.73	96.61	96.7	3.27	3.39	3.3	10.92	11.03	11.0
SL	10	5	3	2.494	2.657	2.652	2.388	2.392	95.75	95.91	95.8	4.25	4.09	4.2	12.66	12.51	12.6
SL	11	5	3	2.485	2.655	2.650	2.384	2.380	95.94	95.77	95.9	4.06	4.23	4.1	12.74	12.88	12.8
SL	12	5	3	2.488	2.654	2.649	2.384	2.386	95.82	95.90	95.9	4.18	4.10	4.1	12.70	12.63	12.7
SL	13	5	4	2.496	2.659	2.654	2.381	2.378	95.39	95.27	95.3	4.61	4.73	4.7	13.87	13.98	13.9
SL	14	5	4	2.489	2.655	2.650	2.400	2.400	96.42	96.42	96.4	3.58	3.58	3.6	13.06	13.06	13.1
SL	15	5	4	2.493	2.669	2.664	2.386	2.385	95.71	95.67	95.7	4.29	4.33	4.3	14.02	14.05	14.0
SL	16	5	5	2.496	2.654	2.649	2.377	2.384	95.23	95.51	95.4	4.77	4.49	4.6	14.75	14.50	14.6
SL	17	5	5	2.491	2.649	2.644	2.391	2.387	95.99	95.82	95.9	4.01	4.18	4.1	14.09	14.23	14.2
SL	18	5	5	2.489	2.646	2.641	2.385	2.387	95.82	95.90	95.9	4.18	4.10	4.1	14.21	14.14	14.2
SL	19	5	5	2.489	2.655	2.650	2.388	2.388	95.94	95.94	95.9	4.06	4.06	4.1	14.39	14.39	14.4
SL		5	Avg	2.489	2.654	2.649	2.390	2.390	96.02	96.02	96.0	3.98	3.98	4.0	12.48	12.49	12.5
SL		5	Std	0.006	0.008	0.008	0.007	0.007	0.44	0.43	0.4	0.44	0.43	0.4	1.51	1.49	1.5
C	1	5	1	2.486	2.660	2.656	2.388	2.395	96.06	96.34	96.2	3.94	3.66	3.8	13.94	13.69	13.8
C	2	5	2	2.492	2.662	2.658	2.400	2.404	96.31	96.47	96.4	3.69	3.53	3.6	13.49	13.35	13.4
C	3	5	3	2.469	2.635	2.631	2.365	2.369	95.79	95.95	95.9	4.21	4.05	4.1	13.89	13.74	13.8
C	4	5	4	2.474	2.645	2.641	2.355	2.362	95.19	95.47	95.3	4.81	4.53	4.7	14.63	14.37	14.5
C	5	5	5	2.469	2.643	2.639	2.370	2.378	95.99	96.31	96.2	4.01	3.69	3.8	14.10	13.81	14.0
C		5	Avg	2.478	2.649	2.645	2.376	2.382	95.87	96.11	96.0	4.13	3.89	4.0	14.01	13.79	13.9
C		5	Std	0.010	0.012	0.012	0.018	0.018	0.42	0.40	0.4	0.42	0.40	0.4	0.41	0.37	0.4

Table 8. Roadway Compaction   Data from Super Lot 5.

	Test		Sub	JMF	Roadway Gmb				Roadway Density			
Type	#	Lot	Lot	Gmm	1	2	3	Avg	1	2	3	Avg
SL	1	5	1	2.496	2.333	2.315	2.213	2.287	93.47	92.75	88.66	91.6
SL	2	5	1	2.496	2.332	2.336	2.320	2.329	93.43	93.59	92.95	93.3
SL	6	5	1	2.485	2.200	2.306	2.319	2.275	88.53	92.80	93.32	91.5
SL	7	5	2	2.478	2.327	2.357	2.295	2.326	93.91	95.12	92.62	93.9
SL	8	5	2	2.482	2.287	2.232	2.325	2.281	92.14	89.93	93.67	91.9
SL	9	5	2	2.479	2.321	2.326	2.304	2.317	93.63	93.83	92.94	93.5
SL	10	5	3	2.490	2.321	2.330	2.343	2.331	93.21	93.57	94.10	93.6
SL	11	5	3	2.489	2.075	2.325	2.331	2.243	83.37	93.41	93.65	90.1
SL	12	5	3	2.488	2.319	2.257	2.305	2.293	93.21	90.72	92.64	92.2
SL	13	5	4	2.492	2.337	2.303	2.302	2.314	93.78	92.42	92.38	92.9
SL	14	5	4	2.489	2.300	2.318	2.279	2.299	92.41	93.13	91.56	92.4
SL	15	5	4	2.501	2.281	2.265	2.284	2.276	91.20	90.56	91.32	91.0
SL	16	5	5	2.488	2.279	2.302	2.328	2.303	91.60	92.52	93.57	92.6
SL	17	5	5	2.484	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	18	5	5	2.481	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	19	5	5	2.489	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL		5	Avg	2.488	2.286	2.306	2.304	2.298	91.84	92.64	92.57	92.3
SL		5	Std	0.007	0.073	0.035	0.033	0.026	2.94	1.46	1.43	1.1
C	1	5	1	2.493	2.297	2.340	2.329	2.322	92.14	93.86	93.42	93.1
C	2	5	2	2.495	2.304	2.368	2.325	2.332	92.34	94.91	93.19	93.5
C	3	5	3	2.472	2.311	2.301	2.318	2.310	93.49	93.08	93.77	93.4
C	4	5	4	2.480	2.323	2.313	2.347	2.328	93.67	93.27	94.64	93.9
C	5	5	5	2.479	2.326	2.321	2.350	2.332	93.83	93.63	94.80	94.1
C		5	Avg	2.484	2.312	2.329	2.334	2.325	93.09	93.75	93.96	93.6
C		5	Std	0.010	0.012	0.026	0.014	0.009	0.79	0.72	0.72	0.4

Table 9. Gradation Analysis Data from Super Lot 3.

	Test			Percent Passing												
Type	#	Lot	Sublot	1	3/4	1/2	3/8	4	8	16	30	50	100	200	AC	AC
SL	1	3	1		0.0	1.8	2.1	3.8	0.2	2.3	3.8	2.9	2.3	2.41	0.10	4.90
SL	2	3	1		0.0	2.9	5.0	5.7	0.0	1.6	3.1	2.4	2.1	1.79	0.00	5.00
SL	3	3	1		0.0	3.3	4.5	6.4	1.5	2.3	3.4	2.3	1.8	2.20	0.00	5.00
SL	4	3	2		0.0	2.4	4.8	4.1	-1.3	0.9	2.7	2.0	1.7	1.59	0.30	4.70
SL	5	3	2		0.0	0.5	-0.8	0.5	-1.8	1.5	3.6	2.9	2.4	2.98	0.60	4.40
SL	6	3	2		0.0	2.0	3.5	4.4	0.1	1.7	3.2	2.3	1.9	2.22	0.30	4.70
SL	7	3	3		0.0	2.1	0.6	0.9	-1.8	1.3	3.3	2.6	2.2	3.35	0.30	4.70
SL	8	3	3		0.0	3.0	6.4	8.3	1.8	2.8	3.9	2.7	2.2	3.00	0.00	5.00
SL	9	3	3		0.0	2.2	6.8	6.2	-0.6	1.6	3.3	2.6	2.2	1.63	0.10	4.90
SL	10	3	4		0.0	2.7	4.3	4.1	-0.3	1.9	3.4	2.5	2.0	1.14	0.20	5.20
SL	11	3	4		0.0	2.7	5.3	6.6	0.4	1.9	3.2	2.2	1.7	1.34	0.00	5.00
SL	12	3	4		0.0	2.0	3.4	3.8	-0.7	1.4	2.9	2.1	1.7	2.51	0.20	4.80
SL	13	3	5		0.0	1.2	2.4	2.8	-0.5	1.6	3.1	2.1	1.6	1.46	0.20	4.80
SL	14	3	5		0.0	2.4	1.9	2.6	-0.4	1.9	3.5	2.5	1.8	3.05	0.30	4.70
SL	15	3	5		0.0	0.0	2.2	1.3	-1.7	1.3	3.3	2.7	2.3	1.88	0.30	4.70
SL		3	Avg		0.0	2.1	3.5	4.1	-0.3	1.7	3.3	2.5	2.0	2.17	0.19	4.83
SL		3	Std		0.0	0.9	2.1	2.3	1.1	0.5	0.3	0.3	0.3	0.70	0.17	0.20
C	1	3	1		0.0	0.0	4.9	5.1	0.8	2.4	3.2	2.2	1.6	1.04	0.17	5.17
C	2	3	2		0.0	-2.3	-2.3	2.8	-1.8	1.1	2.3	1.6	1.3	0.41	0.02	5.02
C	3	3	3		0.0	-3.3	0.5	1.9	-2.3	1.2	2.5	1.8	1.4	1.02	0.14	5.14
C	4	3	4		0.0	-0.3	1.5	4.0	-1.5	1.4	2.6	1.7	1.2	0.62	0.18	5.18
C	5	3	5		0.0	-2.7	-0.9	2.6	-1.5	2.3	3.4	2.5	2.0	1.10	0.19	5.19
C		3	Avg		0.0	-1.7	0.7	3.3	-1.3	1.7	2.8	2.0	1.5	0.84	0.14	5.14
C		3	Std		0.0	1.5	2.7	1.3	1.2	0.6	0.5	0.4	0.3	0.31	0.07	0.07

Table 10. Laboratory Recompacted Data from Super Lot 3.

	Test		Sub				Lab Molded					Lab Molded VTM			Lab Molded VMA		
Type	#	Lot	Lot	Gmm	Gse	Gsb	Gmb 1	Gmb 2	Den 1	Den 2	Avg	Va1	Va2	Avg	VMA 1	VMA 2	Avg
SL	1	3	1	2.476	2.675	2.668	2.365	2.360	95.52	95.32	95.4	4.48	4.68	4.6	12.24	12.43	12.3
SL	2	3	1	2.472	2.675	2.668	2.355	2.356	95.27	95.31	95.3	4.73	4.69	4.7	12.61	12.58	12.6
SL	3	3	1	2.471	2.674	2.667	2.335	2.337	94.50	94.58	94.5	5.50	5.42	5.5	13.32	13.25	13.3
SL	4	3	2	2.462	2.649	2.642	2.324	2.323	94.39	94.35	94.4	5.61	5.65	5.6	13.80	13.83	13.8
SL	5	3	2	2.499	2.680	2.673	2.376	2.376	95.08	95.08	95.1	4.92	4.92	4.9	12.89	12.89	12.9
SL	6	3	2	2.497	2.692	2.685	2.341	2.342	93.75	93.79	93.8	6.25	6.21	6.2	14.56	14.52	14.5
SL	7	3	3	2.493	2.687	2.680	2.382	2.382	95.55	95.55	95.5	4.45	4.45	4.5	13.79	13.79	13.8
SL	8	3	3	2.493	2.701	2.694	2.353	2.350	94.38	94.26	94.3	5.62	5.74	5.7	15.28	15.39	15.3
SL	9	3	3	2.471	2.669	2.662	2.337	2.335	94.58	94.50	94.5	5.42	5.50	5.5	14.84	14.92	14.9
SL	10	3	4	2.480	2.694	2.687	2.345	2.342	94.56	94.44	94.5	5.44	5.56	5.5	16.22	16.33	16.3
SL	11	3	4	2.471	2.674	2.667	2.341	2.340	94.74	94.70	94.7	5.26	5.30	5.3	15.73	15.77	15.8
SL	12	3	4	2.470	2.663	2.656	2.339	2.334	94.70	94.49	94.6	5.30	5.51	5.4	15.46	15.64	15.5
SL	13	3	5	2.465	2.657	2.650	2.363	2.361	95.86	95.78	95.8	4.14	4.22	4.2	15.29	15.36	15.3
SL	14	3	5	2.483	2.675	2.668	2.364	2.365	95.21	95.25	95.2	4.79	4.75	4.8	15.82	15.79	15.8
SL	15	3	5	2.469	2.658	2.651	2.346	2.351	95.02	95.22	95.1	4.98	4.78	4.9	15.93	15.75	15.8
SL		3	Avg	2.478	2.675	2.668	2.351	2.350	94.87	94.84	94.9	5.13	5.16	5.1	14.52	14.55	14.5
SL		3	Std	0.012	0.015	0.015	0.016	0.016	0.55	0.56	0.6	0.55	0.56	0.553	1.31	1.32	1.3
C	1	3	1	2.466	2.675	2.668	2.370	2.375	96.11	96.31	96.2	3.89	3.69	3.8	12.06	11.87	12.0
C	2	3	2	2.455	2.655	2.648	2.375	2.367	96.74	96.42	96.6	3.26	3.58	3.4	12.10	12.40	12.3
C	3	3	3	2.466	2.673	2.666	2.364	2.378	95.86	96.43	96.1	4.14	3.57	3.9	13.99	13.48	13.7
C	4	3	4	2.459	2.667	2.660	2.371	2.375	96.42	96.58	96.5	3.58	3.42	3.5	14.43	14.29	14.4
C	5	3	5	2.459	2.668	2.661	2.368	2.384	96.30	96.95	96.6	3.70	3.05	3.4	15.46	14.89	15.2
C		3	Avg	2.461	2.668	2.661	2.370	2.376	96.29	96.54	96.4	3.71	3.46	3.6	13.61	13.39	13.5
C		3	Std	0.005	0.008	0.008	0.004	0.006	0.33	0.25	0.2	0.33	0.25	0.2	1.49	1.26	1.4

Table 11. Roadway Compaction   Data from Super Lot 3.

	Test		Sub	JMF	Roadway Gmb				Roadway Density			
Type	#	Lot	Lot	Gmm	1	2	3	Avg	1	2	3	Avg
SL	1	3	1	2.472	2.300	2.340	2.335	2.325	93.04	94.66	94.46	94.1
SL	2	3	1	2.472	2.385	2.347	2.358	2.363	96.48	94.94	95.39	95.6
SL	3	3	1	2.471	2.320	2.307	2.321	2.316	93.89	93.36	93.93	93.7
SL	4	3	2	2.451	2.305	2.370	2.345	2.340	94.04	96.70	95.68	95.5
SL	5	3	2	2.476	2.369	2.321	2.355	2.348	95.68	93.74	95.11	94.8
SL	6	3	2	2.486	2.355	2.365	2.380	2.366	94.73	95.13	95.74	95.2
SL	7	3	3	2.482	2.301	2.357	2.310	2.323	92.71	94.96	93.07	93.6
SL	8	3	3	2.493	2.356	2.324	2.347	2.342	94.50	93.22	94.14	94.0
SL	9	3	3	2.467	2.316	2.290	2.319	2.308	93.88	92.83	94.00	93.6
SL	10	3	4	2.487	2.324	2.281	2.263	2.289	93.45	91.72	90.99	92.1
SL	11	3	4	2.471	2.278	2.312	2.308	2.299	92.19	93.57	93.40	93.1
SL	12	3	4	2.462	2.314	2.303	2.338	2.319	93.99	93.54	94.96	94.2
SL	13	3	5	2.457	2.299	2.310	2.296	2.302	93.57	94.02	93.45	93.7
SL	14	3	5	2.472	2.325	2.332	2.302	2.320	94.05	94.34	93.12	93.8
SL	15	3	5	2.458	2.304	2.333	2.255	2.297	93.73	94.91	91.74	93.5
SL		3	Avg	2.472	2.323	2.326	2.322	2.324	94.00	94.11	93.95	94.0
SL		3	Std	0.012	0.030	0.027	0.035	0.024	1.08	1.18	1.38	0.9
C	1	3	1	2.472	2.288	2.302	2.353	2.314	92.56	93.12	95.19	93.6
C	2	3	2	2.456	2.311	2.301	2.263	2.292	94.10	93.69	92.14	93.3
C	3	3	3	2.470	2.367	2.33	2.311	2.336	95.83	94.33	93.56	94.6
C	4	3	4	2.466	2.315	2.324	2.325	2.321	93.88	94.24	94.28	94.1
C	5	3	5	2.466	2.337	2.322	2.31	2.323	94.77	94.16	93.67	94.2
C		3	Avg	2.466	2.324	2.316	2.312	2.317	94.23	93.91	93.77	94.0
C		3	Std	0.006	0.030	0.013	0.033	0.016	1.20	0.50	1.11	0.5

Table 12. Sample Identification for Project STPY-125 C (69).

Site	Lab No	Type Sample	Test Number	Lot	Sublot	Mix	PG Grade
SH-19	25897	SL	1	1	1	S-4 I	70-28
SH-19	25900	SL	2	1	1	S-4 I	70-28
SH-19	25898	SL	3	1	1	S-4 I	70-28
SH-19	25922	SL	4	1	2	S-4 I	70-28
SH-19	25928	SL	5	1	2	S-4 I	70-28
SH-19	25924	SL	6	1	2	S-4 I	70-28
SH-19	25925	SL	7	1	3	S-4 I	70-28
SH-19	25927	SL	8	1	3	S-4 I	70-28
SH-19	25926	SL	9	1	3	S-4 I	70-28
SH-19	25923	SL	10	1	4	S-4 I	70-28
SH-19	25930	SL	11	1	4	S-4 I	70-28
SH-19	25929	SL	12	1	4	S-4 I	70-28
SH-19	25952	SL	13	1	5	S-4 I	70-28
SH-19	25951	SL	14	1	5	S-4 I	70-28
SH-19	25950	SL	15	1	5	S-4 I	70-28
SH-19	N/A	C	1	1	1	S-4 I	70-28
SH-19	N/A	C	2	1	2	S-4 I	70-28
SH-19	N/A	C	3	1	3	S-4 I	70-28
SH-19	N/A	C	4	1	4	S-4 I	70-28
SH-19	N/A	C	5	1	5	S-4 I	70-28

SL = Super Lot Data N/A = Not applicable
C = Contractor's Data

Table 12 (con't.). Sample Identification for Project STPY-125 C (69).

Site	Lab No	Type Sample	Test Number	Lot	Sublot	Mix	PG Grade
SH-19	25810	SL	1	4	1	S-3 R	64-22
SH-19	25811	SL	2	4	1	S-3 R	64-22
SH-19	25813	SL	3	4	1	S-3 R	64-22
SH-19	25814	SL	4	4	2	S-3 R	64-22
SH-19	25817	SL	5	4	2	S-3 R	64-22
SH-19	25815	SL	6	4	2	S-3 R	64-22
SH-19	25843	SL	7	4	3	S-3 R	64-22
SH-19	25841	SL	8	4	3	S-3 R	64-22
SH-19	25844	SL	9	4	3	S-3 R	64-22
SH-19	25842	SL	10	4	4	S-3 R	64-22
SH-19	25840	SL	11	4	4	S-3 R	64-22
SH-19	25845	SL	12	4	4	S-3 R	64-22
SH-19	25439	SL	13	4	5	S-3 R	64-22
SH-19	25846	SL	14	4	5	S-3 R	64-22
SH-19	25847	SL	15	4	5	S-3 R	64-22
SH-19	N/A	C	1	4	1	S-3 R	64-22
SH-19	N/A	C	2	4	2	S-3 R	64-22
SH-19	N/A	C	3	4	3	S-3 R	64-22
SH-19	N/A	C	4	4	4	S-3 R	64-22
SH-19	N/A	C	5	4	5	S-3 R	64-22

SL = Super Lot Data N/A = Not applicable
C = Contractor's Data

Table 13. Gradation Analysis Data from Super Lot 1.

	Test			Percent Passing												
Type	#	Lot	Sublot	1	3/4	1/2	3/8	4	8	16	30	50	100	200	AC	AC
SL	1	1	1	.	0.0	2.4	-0.3	-2.8	-1.9	-3.8	-1.7	-0.6	-1.4	-0.53	-0.30	4.70
SL	2	1	1	.	0.0	2.6	1.5	-1.6	-1.1	-3.1	-1.1	-0.2	-1.1	-0.49	-0.30	4.70
SL	3	1	1	.	0.0	3.8	1.9	-1.9	-1.1	-3.0	-1.0	-0.1	-0.9	-0.06	-0.20	4.80
SL	4	1	2	.	0.0	2.2	-2.3	-5.1	-2.2	-3.3	-1.1	0.0	-0.6	0.00	-0.20	4.80
SL	5	1	2	.	0.0	2.8	2.5	1.2	1.6	-1.2	-0.3	0.0	-0.6	0.02	-0.10	4.90
SL	6	1	2	.	0.0	1.1	-1.1	-2.5	-0.6	-2.4	-0.9	-0.4	-0.6	0.04	-0.30	4.70
SL	7	1	3	.	0.0	2.6	-1.3	-4.3	-2.0	-4.2	-2.9	-2.7	-3.4	.	-0.30	4.70
SL	8	1	3	.	0.0	1.4	-0.9	-3.5	-1.3	-2.9	-0.9	0.2	-0.1	1.10	-0.20	4.80
SL	9	1	3	.	0.0	2.3	-0.7	-0.7	3.4	0.1	1.0	0.8	0.1	0.73	-0.20	4.80
SL	10	1	4	.	0.0	1.2	-2.2	-4.2	1.0	-1.5	-0.1	0.1	-0.3	0.55	-0.40	4.60
SL	11	1	4	.	0.0	2.7	3.0	-1.9	0.5	-1.5	-0.1	0.2	-0.4	0.06	-0.10	4.90
SL	12	1	4	.	0.0	2.3	2.5	-2.2	0.3	-2.0	-0.3	0.2	0.0	0.74	-0.20	4.80
SL	13	1	5	.	0.0	3.6	4.5	3.6	5.4	1.7	2.3	1.6	0.6	1.13	-0.40	4.60
SL	14	1	5	.	0.0	3.6	4.0	1.8	2.6	-0.5	0.9	0.9	0.4	1.03	0.10	5.10
SL	15	1	5	.	0.0	3.2	4.3	0.6	1.0	-2.1	-0.7	-0.5	-0.8	-0.05	0.00	5.00
SL		1	Avg		0.0	2.5	1.0	-1.6	0.4	-2.0	-0.5	0.0	-0.6	0.3	-0.21	4.79
SL		1	Std		0.0	0.8	2.4	2.5	2.2	1.6	1.2	0.9	0.9	0.6	0.14	0.14
C	1	1	1	.	0.0	2.6	3.6	0.2	0.1	-1.6	-0.3	0.4	-1.1	-0.54	-0.21	4.79
C	2	1	2	.	0.0	1.7	0.4	-4.9	-2.8	-2.6	-0.6	0.3	-0.5	-0.01	-0.13	4.87
C	3	1	3	.	0.0	2.4	2.1	-0.8	-0.1	-1.4	-0.1	0.5	-0.4	0.26	-0.08	4.92
C	4	1	4	.	0.0	2.4	1.5	-1.9	1.1	-0.9	0.0	-0.2	-1.0	-0.65	-0.18	4.82
C	5	1	5	.	0.0	1.5	2.0	2.5	4.2	1.4	1.7	1.1	-0.1	0.32	-0.36	4.64
C		1	Avg		0.0	2.1	1.9	-1.0	0.5	-1.0	0.1	0.4	-0.6	-0.1	-0.19	4.81
C		1	Std		0.0	0.5	1.2	2.7	2.5	1.5	0.9	0.5	0.4	0.4	0.11	0.11

Table 14. Laboratory Recompacted Data from Super Lot 1.

	Test		Sub				Lab Molded					Lab Molded VTM			Lab Molded VMA		
Type	#	Lot	Lot	Gmm	Gse	Gsb	Gmb 1	Gmb 2	Den 1	Den 2	Avg	Va1	Va2	Avg	VMA 1	VMA 2	Avg
SL	1	1	1	2.475	2.667	2.657	2.380	2.380	96.16	96.16	96.2	3.84	3.84	3.8	14.64	14.64	14.6
SL	2	1	1	2.493	2.689	2.679	2.382	2.379	95.55	95.43	95.5	4.45	4.57	4.5	15.27	15.37	15.3
SL	3	1	1	2.493	2.694	2.684	2.391	2.390	95.91	95.87	95.9	4.09	4.13	4.1	15.19	15.23	15.2
SL	4	1	2	2.478	2.675	2.665	2.393	2.391	96.57	96.49	96.5	3.43	3.51	3.5	14.52	14.59	14.6
SL	5	1	2	2.483	2.686	2.676	2.373	2.368	95.57	95.37	95.5	4.43	4.63	4.5	15.67	15.85	15.8
SL	6	1	2	2.483	2.677	2.667	2.372	2.371	95.53	95.49	95.5	4.47	4.51	4.5	15.24	15.28	15.3
SL	7	1	3	2.483	2.677	2.667	2.378	2.380	95.77	95.85	95.8	4.23	4.15	4.2	15.03	14.96	15.0
SL	8	1	3	2.478	2.675	2.665	2.396	2.398	96.69	96.77	96.7	3.31	3.23	3.3	14.41	14.34	14.4
SL	9	1	3	2.481	2.679	2.669	2.365	2.362	95.32	95.20	95.3	4.68	4.80	4.7	15.64	15.75	15.7
SL	10	1	4	2.480	2.668	2.658	2.373	2.366	95.69	95.40	95.5	4.31	4.60	4.5	14.83	15.08	15.0
SL	11	1	4	2.479	2.681	2.671	2.372	2.376	95.68	95.85	95.8	4.32	4.15	4.2	15.55	15.40	15.5
SL	12	1	4	2.470	2.666	2.656	2.372	2.374	96.03	96.11	96.1	3.97	3.89	3.9	14.98	14.91	14.9
SL	13	1	5	2.488	2.678	2.668	2.373	2.369	95.38	95.22	95.3	4.62	4.78	4.7	15.15	15.29	15.2
SL	14	1	5	2.478	2.689	2.679	2.390	2.390	96.45	96.45	96.4	3.55	3.55	3.6	15.34	15.34	15.3
SL	15	1	5	2.477	2.683	2.673	2.362	2.365	95.36	95.48	95.4	4.64	4.52	4.6	16.05	15.95	16.0
SL		1	Avg	2.481	2.679	2.669	2.378	2.377	95.84	95.81	95.8	4.16	4.19	4.2	15.17	15.20	15.2
SL		1	Std	0.006	0.008	0.008	0.010	0.011	0.45	0.50	0.5	0.45	0.50	0.5	0.46	0.46	0.5
C	1	1	1	2.495	2.696	2.686	2.383	2.383	95.51	95.51	95.5	4.49	4.49	4.5	15.53	15.53	15.5
C	2	1	2	2.485	2.687	2.677	2.397	2.399	96.46	96.54	96.5	3.54	3.46	3.5	14.82	14.75	14.8
C	3	1	3	2.486	2.691	2.681	2.404	2.403	96.70	96.66	96.7	3.30	3.34	3.3	14.74	14.78	14.8
C	4	1	4	2.485	2.684	2.674	2.393	2.392	96.30	96.26	96.3	3.70	3.74	3.7	14.82	14.86	14.8
C	5	1	5	2.496	2.689	2.679	2.368	2.372	94.87	95.03	95.0	5.13	4.97	5.0	15.71	15.57	15.6
C		1	Avg	2.489	2.689	2.679	2.389	2.390	95.97	96.00	96.0	4.03	4.00	4.0	15.13	15.10	15.1
C		1	Std	0.006	0.005	0.005	0.014	0.013	0.76	0.70	0.7	0.76	0.70	0.7	0.46	0.41	0.4

Table 15. Roadway Compaction Data from Super Lot 1.

Type	Test #	Lot	Sub Lot	JMF Gmm	Roadway Gmb 1	Roadway Gmb 2	Roadway Gmb 3	Roadway Gmb Avg	Roadway Density 1	Roadway Density 2	Roadway Density 3	Roadway Density Avg
SL	1	1	1	2.464	2.304	2.271	2.285	2.287	93.51	92.16	92.75	92.8
SL	2	1	1	2.481	2.335	2.217	2.327	2.293	94.10	89.37	93.78	92.4
SL	3	1	1	2.486	2.308	2.256	2.285	2.283	92.85	90.73	91.91	91.8
SL	4	1	2	2.470	2.295	2.291	2.299	2.295	92.90	92.75	93.06	92.9
SL	5	1	2	2.479	2.315	2.278	2.279	2.290	93.38	91.88	91.92	92.4
SL	6	1	2	2.472	2.284	2.293	2.315	2.297	92.40	92.75	93.64	92.9
SL	7	1	3	2.472	1.828	2.305	2.251	2.128	73.94	93.24	91.08	86.1
SL	8	1	3	2.470	2.282	2.300	2.330	2.304	92.38	93.13	94.32	93.3
SL	9	1	3	2.473	2.333	2.307	2.304	2.315	94.35	93.27	93.15	93.6
SL	10	1	4	2.464	2.280	2.304	2.272	2.285	92.52	93.49	92.22	92.7
SL	11	1	4	2.475	2.239	2.225	2.292	2.252	90.46	89.88	92.59	91.0
SL	12	1	4	2.463	2.252	2.250	2.284	2.262	91.45	91.34	92.72	91.8
SL	13	1	5	2.473	2.270	2.258	2.253	2.260	91.80	91.30	91.11	91.4
SL	14	1	5	2.481	2.240	2.244	2.343	2.275	90.27	90.45	94.43	91.7
SL	15	1	5	2.477	2.260	2.251	2.225	2.245	91.24	90.89	89.83	90.7
SL		1	Avg	2.473	2.255	2.270	2.289	2.271	91.17	91.78	92.57	91.8
SL		1	Std	0.007	0.122	0.030	0.032	0.044	4.92	1.33	1.27	1.8
C	1	1	1	2.487	2.279	2.339	2.325	2.314	91.64	94.05	93.49	93.1
C	2	1	2	2.480	2.293	2.312	2.275	2.293	92.46	93.23	91.73	92.5
C	3	1	3	2.483	2.293	2.317	2.209	2.273	92.35	93.31	88.96	91.5
C	4	1	4	2.477	2.284	2.262	2.254	2.267	92.21	91.32	91.00	91.5
C	5	1	5	2.481	2.295	2.283	2.280	2.286	92.50	92.02	91.90	92.1
C		1	Avg	2.482	2.289	2.303	2.269	2.287	92.23	92.79	91.42	92.1
C		1	Std	0.004	0.007	0.030	0.042	0.019	0.35	1.10	1.64	0.7

Table 16. Gradation Analysis Data from Super Lot 4.

	Test			Percent Passing												
Type	#	Lot	Sublot	1	3/4	1/2	3/8	4	8	16	30	50	100	200	AC	AC
SL	1	4	1	0.0	3.7	3.8	2.5	2.1	0.3	0.1	0.9	0.8	0.9	1.86	0.00	4.10
SL	2	4	1	0.0	0.0	5.6	4.4	3.2	0.6	0.5	1.2	1.1	1.1	1.92	-0.10	4.00
SL	3	4	1	0.0	3.8	-1.0	-2.3	-2.2	-2.6	-2.0	-0.7	-0.4	0.5	1.62	-0.20	3.90
SL	4	4	2	0.0	1.3	0.7	0.6	1.8	0.7	0.1	0.8	0.6	0.7	1.61	-0.20	3.90
SL	5	4	2	0.0	2.3	1.4	1.6	1.7	0.8	0.9	1.7	1.6	1.5	2.19	0.00	4.10
SL	6	4	2	0.0	1.7	3.3	1.9	2.6	2.3	1.5	2.1	1.9	1.3	2.04	-0.10	4.00
SL	7	4	3	0.0	4.1	0.9	-0.4	0.8	-0.4	-0.1	0.9	0.5	0.8	1.57	0.00	4.10
SL	8	4	3	0.0	3.0	4.7	1.5	1.6	-0.7	0.0	0.8	0.6	0.8	1.36	-0.10	4.00
SL	9	4	3	0.0	0.0	1.1	0.3	0.8	-0.3	0.2	1.0	0.7	0.9	1.35	-0.10	4.00
SL	10	4	4	0.0	-2.0	-0.8	-1.3	0.4	-1.4	-0.8	0.2	0.2	0.9	1.73	0.00	4.10
SL	11	4	4	0.0	1.1	2.9	1.4	2.4	0.6	0.4	1.2	1.0	1.4	2.02	0.00	4.10
SL	12	4	4	0.0	0.6	-0.5	0.9	1.2	-0.1	-0.3	0.5	0.4	1.1	2.03	0.00	4.10
SL	13	4	5	0.0	0.9	5.6	5.3	6.9	3.2	2.3	2.5	2.0	1.9	2.38	0.10	4.20
SL	14	4	5	0.0	3.2	3.3	4.2	5.1	2.7	1.7	1.8	1.1	0.9	1.41	0.00	4.10
SL	15	4	5	0.0	0.0	-6.3	-6.4	-4.0	-3.7	-2.2	-0.9	-0.6	0.0	0.84	-0.40	3.70
SL		4	Avg		1.6	1.6	0.9	1.6	0.1	0.2	0.9	0.8	1.0	1.73	-0.07	4.03
SL		4	Std		1.8	3.1	2.9	2.6	1.8	1.2	0.9	0.7	0.4	0.40	0.12	0.12
C	1	4	1	0.0	3.0	4.4	1.8	1.5	-1.3	-0.2	-0.3	-0.1	-0.4	0.31	-0.03	4.07
C	2	4	2	0.0	3.0	4.2	1.9	1.3	-1.0	-0.2	0.9	-0.5	-0.6	0.13	-0.09	4.01
C	3	4	3	0.0	4.4	1.9	1.2	-0.2	-1.1	0.4	1.2	0.9	0.7	1.19	0.00	4.10
C	4	4	4	0.0	2.9	-1.6	-2.9	-2.3	-3.4	-1.6	-0.4	-0.4	0.1	0.82	-0.27	3.83
C	5	4	5	0.0	2.7	1.4	0.2	0.7	-0.6	0.4	0.9	0.8	0.8	1.27	-0.04	4.06
C		4	Avg		3.2	2.1	0.4	0.2	-1.5	-0.2	0.5	0.1	0.1	0.74	-0.09	4.01
C		4	Std		0.7	2.4	2.0	1.5	1.1	0.8	0.8	0.7	0.6	0.51	0.11	0.11

Table 17. Laboratory Recompacted Data from Super Lot 4.

	Test		Sub				Lab Molded					Lab Molded VTM			Lab Molded VMA		
Type	#	Lot	Lot	Gmm	Gse	Gsb	Gmb 1	Gmb 2	Den 1	Den 2	Avg	Va1	Va2	Avg	VMA 1	VMA 2	Avg
SL	1	4	1	2.505	2.674	2.661	2.403	2.407	95.93	96.09	96.0	4.07	3.91	4.0	13.40	13.25	13.3
SL	2	4	1	2.524	2.692	2.679	2.399	2.397	95.05	94.97	95.0	4.95	5.03	5.0	14.03	14.11	14.1
SL	3	4	1	2.505	2.665	2.652	2.412	2.407	96.29	96.09	96.2	3.71	3.91	3.8	12.60	12.78	12.7
SL	4	4	2	2.513	2.675	2.662	2.405	2.400	95.70	95.50	95.6	4.30	4.50	4.4	13.18	13.36	13.3
SL	5	4	2	2.538	2.714	2.701	2.450	2.444	96.53	96.30	96.4	3.47	3.70	3.6	13.01	13.22	13.1
SL	6	4	2	2.510	2.676	2.663	2.407	2.406	95.90	95.86	95.9	4.10	4.14	4.1	13.23	13.26	13.2
SL	7	4	3	2.502	2.671	2.658	2.399	2.404	95.88	96.08	96.0	4.12	3.92	4.0	13.44	13.26	13.4
SL	8	4	3	2.517	2.684	2.671	2.406	2.401	95.59	95.39	95.5	4.41	4.61	4.5	13.52	13.70	13.6
SL	9	4	3	2.516	2.683	2.670	2.416	2.415	96.03	95.99	96.0	3.97	4.01	4.0	13.13	13.17	13.2
SL	10	4	4	2.514	2.685	2.672	2.422	2.410	96.34	95.86	96.1	3.66	4.14	3.9	13.07	13.50	13.3
SL	11	4	4	2.506	2.675	2.662	2.414	2.409	96.33	96.13	96.2	3.67	3.87	3.8	13.03	13.21	13.1
SL	12	4	4	2.511	2.681	2.668	2.408	2.403	95.90	95.70	95.8	4.10	4.30	4.2	13.45	13.63	13.5
SL	13	4	5	2.512	2.687	2.674	2.413	2.411	96.06	95.98	96.0	3.94	4.02	4.0	13.55	13.62	13.6
SL	14	4	5	2.521	2.693	2.680	2.400	2.400	95.20	95.20	95.2	4.80	4.80	4.8	14.12	14.12	14.1
SL	15	4	5	2.524	2.678	2.665	2.398	2.394	95.01	94.85	94.9	4.99	5.15	5.1	13.35	13.49	13.4
Avg	8.0	4.0	3.0	2.515	2.682	2.669	2.410	2.407	95.85	95.73	95.8	4.15	4.27	4.2	13.34	13.45	13.4
Std	4.5	0.0	1.5	0.009	0.012	0.012	0.013	0.012	0.47	0.45	0.5	0.47	0.45	0.5	0.39	0.35	0.4
C	1	4	1	2.525	2.696	2.683	2.400	2.399	95.05	95.01	95.0	4.95	4.99	5.0	14.19	14.22	14.2
C	2	4	2	2.522	2.690	2.677	2.410	2.406	95.56	95.40	95.5	4.44	4.60	4.5	13.58	13.73	13.7
C	3	4	3	2.498	2.666	2.653	2.412	2.411	96.56	96.52	96.5	3.44	3.48	3.5	12.81	12.85	12.8
C	4	4	4	2.504	2.661	2.648	2.407	2.407	96.13	96.13	96.1	3.87	3.87	3.9	12.58	12.58	12.6
C	5	4	5	2.500	2.666	2.653	2.401	2.400	96.04	96.00	96.0	3.96	4.00	4.0	13.17	13.21	13.2
Avg	3.0	4.0	3.0	2.510	2.676	2.663	2.406	2.405	95.87	95.81	95.8	4.13	4.19	4.2	13.27	13.32	13.3
Std	1.6	0.0	1.6	0.013	0.016	0.016	0.005	0.005	0.58	0.60	0.6	0.58	0.60	0.6	0.64	0.66	0.7

Table 18. Roadway Compaction Data from Super Lot 4.

	Test		Sub	JMF	Roadway Gmb				Roadway Density			
Type	#	Lot	Lot	Gmm	1	2	3	Avg	1	2	3	Avg
SL	1	4	1	2.505	2.322	2.369	2.343	2.345	92.69	94.57	93.53	93.6
SL	2	4	1	2.520	2.366	2.286	2.360	2.337	93.89	90.71	93.65	92.8
SL	3	4	1	2.497	2.361	2.382	2.351	2.365	94.55	95.39	94.15	94.7
SL	4	4	2	2.506	2.328	2.318	2.357	2.334	92.90	92.50	94.05	93.1
SL	5	4	2	2.538	2.342	2.319	2.351	2.337	92.28	91.37	92.63	92.1
SL	6	4	2	2.506	2.329	2.340	2.357	2.342	92.94	93.38	94.05	93.5
SL	7	4	3	2.502	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	8	4	3	2.513	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	9	4	3	2.512	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	10	4	4	2.514	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	11	4	4	2.506	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	12	4	4	2.511	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	13	4	5	2.516	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	14	4	5	2.521	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SL	15	4	5	2.508	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Avg	8.0	4.0	3.0	2.512	2.341	2.336	2.353	2.343	93.21	92.99	93.68	93.3
Std	4.5	0.0	1.5	0.010	0.018	0.036	0.006	0.011	0.85	1.81	0.57	0.9
C	1	4	1	2.523	2.272	2.365	2.305	2.314	90.05	93.74	91.36	91.7
C	2	4	2	2.518	2.318	2.321	2.313	2.317	92.06	92.18	91.86	92.0
C	3	4	3	2.498	2.36	2.35	2.321	2.344	94.48	94.08	92.91	93.8
C	4	4	4	2.494	2.361	2.357	2.363	2.360	94.67	94.51	94.75	94.6
C	5	4	5	2.498	2.35	2.356	2.356	2.354	94.08	94.32	94.32	94.2
Avg	3.0	4.0	3.0	2.506	2.332	2.350	2.332	2.338	93.07	93.76	93.04	93.3
Std	1.6	0.0	1.6	0.013	0.038	0.017	0.026	0.021	1.98	0.93	1.48	1.3

CHAPTER 3

THE STATISTICAL SPECIFICATION ENVIRONMENT

ASPHALT PAVEMENT ACCEPTANCE

The states surrounding Oklahoma all have HMA 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 dense-graded HMA and some aspects of their statistical procedures.

Arkansas

The Arkansas asphalt paving specification (*2*) is not a true PWL specification, although it does use some statistical techniques. This specification uses average asphalt cement (AC) content, laboratory compacted air voids, voids in the mineral aggregate (VMA), and in-place roadway density as acceptance and payment criteria. 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 sublot tests for the four previously mentioned criteria to determine the acceptability of the pavement lot. There are four limits on either side of the production target that determine lot and sublot test acceptability. The laboratory compacted air void criterion will be used as an example.

As mentioned in the previous paragraph, there are four sets of limits that a test result must meet. The inner set of limits are the compliance limits, which in the case of air voids are set ±1% away from the 4% air void 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 ±1.5% away from the 4% 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 every 0.1% air void deviation away from the compliance limit. As an example, if the average air void content for a lot falls at 2.5% or 5.5%, a 50% reduction in price is applied.

The final two limits are rejection limits. The lot rejection limits are set ±1.6% 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 2.1% 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 that 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 rejection limits, at laboratory air void contents of 2.5% and 5.5%. This lot population has an average of 4% air voids and a sample standard deviation of 1.73. Under the Arkansas specification, this lot would be subject to full pay. However, the actual amount of HMA that falls within the compliance limits of 3.0 and 5.0% laboratory air voids would only represent 38% of the material produced. If the limits for PWL computation are broadened to the lot rejection limits, the PWL increases to 58% of the material produced. This leaves 42% of the paving material that could have laboratory air voids below 2.4% or above 5.6%. States with true PWL specifications, like Oklahoma, 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 asphalt paving specification (*3*) is a true PWL specification with an extraordinarily complex pay factor equation. Acceptance of HMA is based on the asphalt content, gradation, in-place roadway density, joint density, and % moisture in the mixture. The Colorado specification sets the acceptable and rejectable quality limits at 90% and 65% (All other surrounding states use an RQL of 50%). The contractor is required to perform quality control testing, but the Department conducts the acceptance testing.

The contractor conducts process control testing every 500 to 2,000 tons depending on the production variable in question. Acceptance tests are conducted every 1,000 to 2,000 tons. A further independent control is conducted using a 5 sample moving average of the quality level (PWL) of the acceptance tests. If the Total Quality Level (TQL) is 90 or greater, production is permitted to continue. If the TQL is 65 to 90 and the laboratory air voids quality level is greater than 70, production continues. However, if the TQL is less than 65 or the TQL is between 65 and 90 and the laboratory air voids quality level is less than 70, production is halted until the contractor corrects the production process.

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 6% bonus is possible for large production projects with total acceptance samples exceeding 200. For a unity pay factor (PF=1.00), with a large number of samples, the quality level is equal to 92. For very small samples (n=3), a unity pay factor corresponds to a quality level of 70.

Kansas

The Kansas HMA paving specification (*4*) 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 HMA pavements is based on laboratory air voids and in-place roadway density. A unity pay factor for laboratory air voids occurs for a PWL = 90 and a unit pay factor for in-place roadway density occurs for a PWL=90. The maximum pay factor available is 1.03.

Missouri

The Missouri HMA paving specification (*5*) 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 HMA is a weighted sum of the in-place roadway density, asphalt content, laboratory air voids, and VMA. The weighting factors for the pay equation are 0.25 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.

New Mexico

The New Mexico asphalt paving specification (*6*) is a PWL specification that uses a combination of department and contractor quality control tests for acceptance with statistical process verification (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 mix characteristics used in the pay equation are roadway density, laboratory air voids, percent passing on certain specified sieves, VMA, and dust/binder ratio. The maximum pay factor available is 1.05. The AQL for a unity pay factor ranges from 69 for three 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 dense graded HMA specification (*7*) is not a PWL specification, but is statistically based. The lot size for asphalt production consists of four sublots. The first lot is set at 1,000 tons and the remaining lots range in size between 1,000 and 4,000 tons, depending on daily production. Pay is based on the department's test results for in-place roadway density and laboratory air voids.

The contractor is required to have a QC testing operation which conducts tests on a sublot and lot basis. Production continues as long as there is good agreement between the acceptance and QC test results. Good agreement is defined as the QC results and acceptance test difference falling within the tolerance limit set for the JMF. Example tolerances for acceptance and QC test comparison are ±0.020 for the Gmm values, ±0.3% for asphalt content, ±1.0% for roadway air voids and laboratory molded density.

Pay adjustment factors are used to encourage production within the specification limits. The adjustment factors are based on the measured laboratory density and in-place air voids. The maximum pay adjustment factor for in-place air voids is 1.05 for air void contents that land between 5.0% and 6.0%. In-place air void contents that fall between 4.65% and 8.50% are subject to a bonus adjustment ranging between 1.0 and 1.05. For in-place air void contents between 4.0% and 9.3% are subject to a pay adjustment of 0.9. If the in-place air void range is 2.7% and 9.9%, the pay factor is 0.70. Sublots that have air void values above and below 9.9% and 2.7%, respectively, are rejected and subject to removal and replacement or are left in place for no pay.

The pay adjustments for lab molded density are a pay factor of 1.05 for a deviation range from the JMF of ±0.2. If the density deviation is within ±1.0, the pay factor is 1.0. A deviation of ±1.3 will yield a pay factor of 0.90 and a deviation of ±1.8 will yield a pay factor of 0.72. A wider deviation of ±1.8 from the JMF in the lab molded density will result in rejection of the sublot and the pavement contained within this sublot is removed and replaced or is left in place for no pay.

SUMMARY

The above review demonstrates the different approaches to HMA statistical quality control that exists in the surrounding states. The Oklahoma DOT specification (*1*) is very similar to many of the surrounding PWL specifications and appears to be superior in some aspects to those of surrounding states. The super lot QC and quality assurance data from two pilot projects has been used in this analysis to determine the power and accuracy of the Oklahoma pilot specification. The results of that analysis are summarized in the succeeding chapters.

Table 19 shows a comparison of the surrounding states specifications for HMA pavement acceptance. Four of the six surrounding states use PWL based specifications and three of these four agencies use the process verification procedure using the F and t-test to compare contractors test results with agency test results. One agency requires their test results be within two standard deviations or ½ the specification tolerance limit of the contractor mean test result. No other agency besides Oklahoma uses the paired t-test procedure for process verification.

Pay factors showed some variation, indicating the lack of total agreement in the industry as to what material properties control pavement performance. Colorado has a very complicated PWL specification with most of the information contained in Special Provisions to the Standard Specifications. In the author's opinions, this is not a procedure Oklahoma would want to copy; therefore, an exhaustive search of Colorado Special Provisions was not attempted and the information for Colorado may not be current or completely accurate.

Pay factors ranged from a low of two items (Kansas) to a high of five items (New Mexico and Colorado). All states used in-place density as a pay factor and all but Colorado use laboratory compacted air voids as a pay factor. Three of the six states have laboratory compacted VMA as a pay factor. Three of the six agencies have asphalt content as a pay factor. New Mexico controls asphalt content using the dust to binder ratio (dust percentage). New Mexico and Colorado were the only states that checked gradation; however, they only pay on certain pre-selected or critical sieves, not all sieves as Oklahoma does.

Lot size and number of sublots per lot showed some variation. Two states used a typical lot size of 3,000 tons with four sublots per lot. One state uses a 4,000 ton lot with four sublots. Texas requires the first lot to be 1,000 tons and the remaining lots vary from a minimum of 1,000 to a maximum of 4,000 tons, depending on the size of the project. Colorado requires contractor testing every 500 to 2,000 tons and agency testing every 1,000 to 2,000 tons. Oklahoma had the largest lot size of the six surrounding states and was on the high end of tons per sublot.

Table 19. Summary of Surrounding States HMA Specifications.

	State						
	Arkansas	Colorado	Kansas	Missouri	New Mexico	Oklahoma	Texas
PWL	No	Yes	Yes	Yes	Yes	Yes	No[1]
Pay Factors							
Asphalt Content	X	X		X		X	
Lab Compacted VTM	X		X	X	X	X	X
Lab Compacted VMA	X			X	X		
Pavement Density	X	X	X	X	X	X	X
Gradation (all sieves)						X	
Gradation (certain sieves)		X			X		
Dust Percentage					X		
Joint Density		X					
% Moisture		X					
Lots							
Tonnage per Lot	3,000	varies	3,000	4,000	varies	5,000	1,000 - 4,000[2]
Number Sublots	4	varies	4	4	min. 3	5	4
Verification method	2SD[3]	F & t-test	F & t-test	2SD[4]	F & t-test	Paired t-test	

[1] Pay adjustment factors are used to encourage production within the specification limits.

[2] First lot = 1,000 tons remaining lots set by engineer with maximum lot size of 4,000 tons.

[3] State result within 2 standard deviations of contractor mean.

[4] State result within 2 standard deviations or 1/2 specification tolerance limit of contractor mean.

CHAPTER 4

EVALUATION OF OKLAHOMA'S PWL SPECIFICATION

COMPARISON TO AASHTO R 9-05

The Oklahoma draft HMA PWL specification (*1*) was compared to the recommendations of *AASHTO R 9-05, Acceptance Sampling Plans for Highway Construction* (*8*) and the requirements of FHWA *23 CFR Part 637B, Quality Assurance Procedures for Construction* (*9*). A flowchart of the requirements of 23 CFR 637B is shown in figure 1.

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.

Initialization Testing

The draft HMA PWL specification uses split samples and paired t-tests for initialization testing. Initialization is performed (*1*) "to identify any testing biases between the Contractor's and the Department's testing equipment and procedures." The Oklahoma implementation of the paired t-test requires an initialization lot consisting of 10 sublots. A split sample is taken and tested by both the department and the contractor. At the completion of the testing of the 10 initialization tests, the results are compared using the paired t-test. The requirements are found in *Part 1: Guidelines for Initial Validation of Contractor's Test Methods* of *Appendix A, Use of Contractor's Test Results for Acceptance Purposes* (*1*).

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 use of 10 samples for the initialization run sets the risk of not detecting a difference between the contractor's and agencies' tests in the neighborhood of 40 percent. The Operating Characteristic (OC) curve for this test is shown in figure 2. The vertical axis on figure 2 is the probability of not detecting a difference and the horizontal axis is the standardized difference, d.

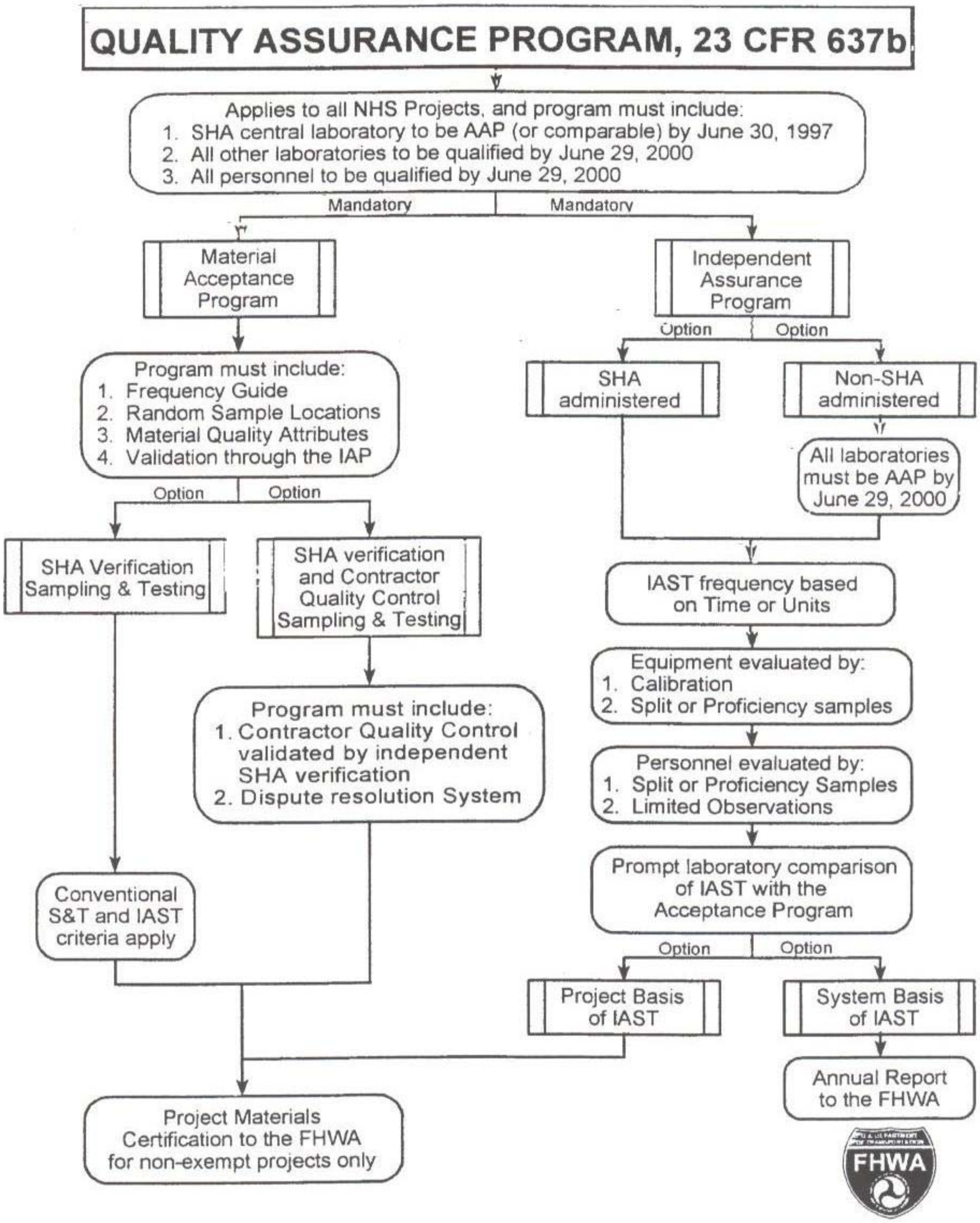
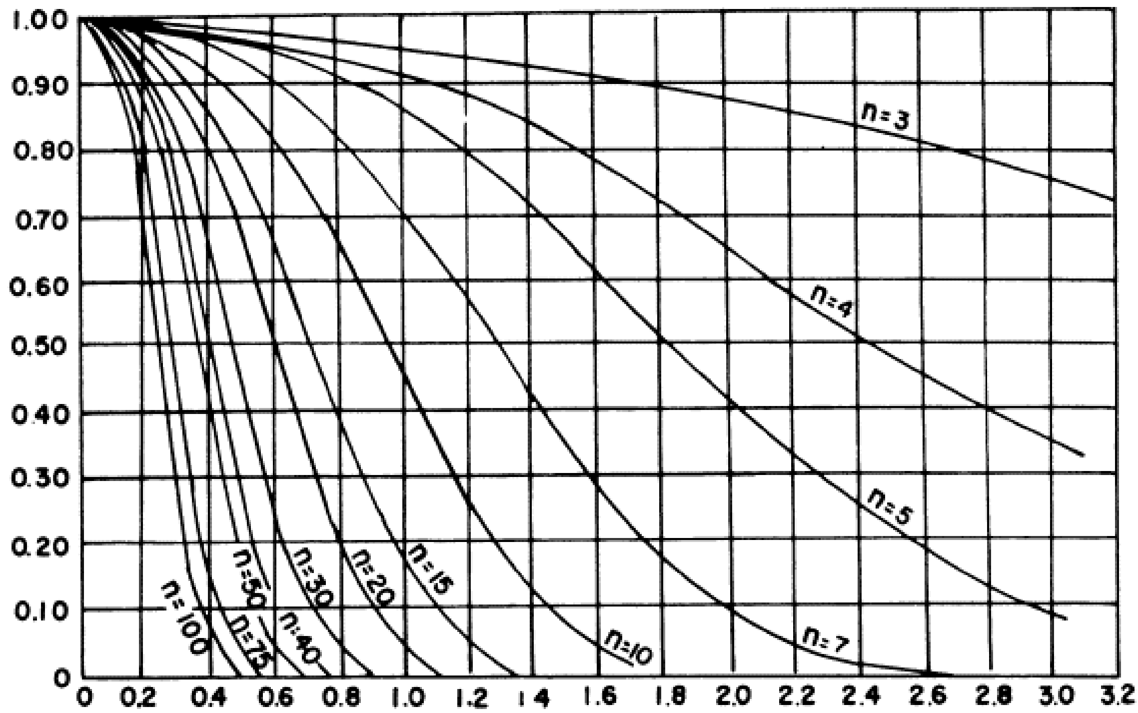


Figure 1 Flowchart of 23 CFR 637B (*10*).



Standardized Difference, d

Figure 2 OC Curves for a two-sided t-test, $\alpha = 0.01$.

As an example, for the initialization air voids test data on the I-35 project, the paired t-test indicated that there was a statistical difference between the contractor's and department's tests, but the magnitude of the average difference was less than the Allowable Testing Bias (*1*). The test data for the SH-19 project showed good agreement between department and contractor data.

AASHTO R 9-05 lists two procedures for test method verification, either D2S limits or the paired t-test. The requirements are found in section 8.21 of AASHTO R 9-05 (*8*). The use of split samples and the paired t-test is the recommended procedure for test method verification or initialization testing (*8,10*). A review of the surrounding states specifications indicated that considerably less initialization testing is usually performed. If the department wants to reduce the amount of initialization testing inherent in the paired-t procedure, the initialization data should be collected and evaluated. An analysis of the collected data could indicate a reduced testing frequency is warranted.

Process Verification

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 (5 sublots), 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 procedure is found in Part *2: Guidelines for Ongoing Validation of Contractor's Test Methods* of *Appendix A, Use of Contractor's Test Results for Acceptance Purposes* (*1*).

FHWA 23 CFR 637B states that (*9*) *"if the contractor or a third party acting on behalf of the contractor, an independent testing lab, is required to do the acceptance testing, the agency must have verification procedures to confirm or refute the acceptance test results."*

According to Burati (*10*), FHWA 23 CFR 637 B states:

> *Quality control sampling and testing results may be used as a part of the acceptance decision provided that:*
>
> *A. The sampling and testing has been performed by qualified laboratories and qualified sampling and testing personnel.*
>
> *B. The quality of the material has been validated by the verification testing and sampling. The verification shall be performed on samples that are taken independently of the quality control samples.*

The same requirements can be found in AASHTO R 9-05 in sections 8.15 (*8*). The draft HMA PWL specification meets the requirements of part A above but appears to be in violation of part B because the process verification performs paired t-tests on split samples and the use of split samples is not allowed.

AASHTO R 9-05 recommendations for process verification are found in section 8.22 (*8*). Only one procedure for process verification testing is listed, the F and t-test. This is the same procedure recommended by Burati (*10*) and used by the surrounding states with PWL specifications. Schiess (*11*) reported that 34 states use contractor test results in the acceptance decision and that one of the major concerns found in their review of PWL procedures was reliance on split samples for verification. Schiess (*11*) reported the problem with using split samples for verification is the inability of split samples to detect all sources of variability, as show in figure 3. Independent samples test for material, process, sampling and testing variance whereas split samples only test for testing variance.

AASHTO R 9-05 does not prohibit the use of split samples, just the use of paired t-tests on split samples. Burati (*10*) recommends independent samples. Figure 4 shows the advantage of independent samples for process verification. Independent samples test all components of variance. Figure 5 shows the components of variance evaluated with split sample testing and figure 3 showed the possible consequences of using split samples for verification testing. AASHRO R 9-05 allows the use of split samples if properly analyzed. To use split samples in accordance with the recommendations of AASHTO R 9-05, the agency sample from figure 5 would have to be compared to the three independent contractor samples. For process verification, the agency test can not be compared to the split sample the contractor tested.

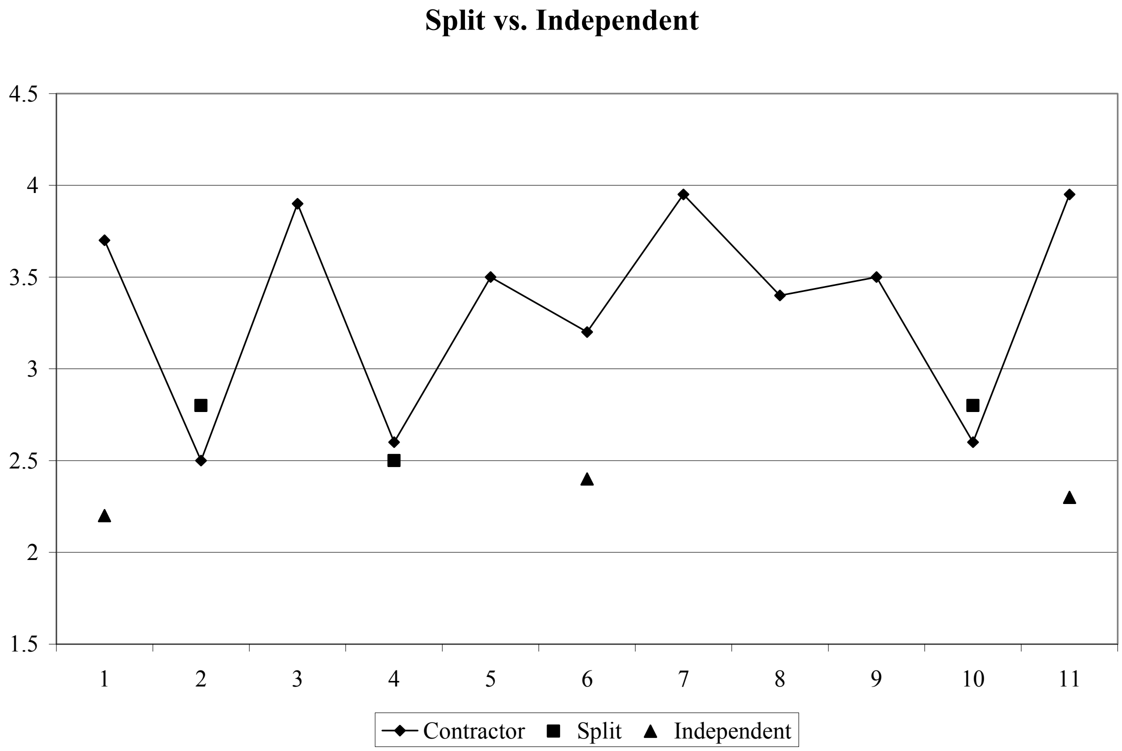


Figure 3 Results from split vs. independent sampling (*11*).

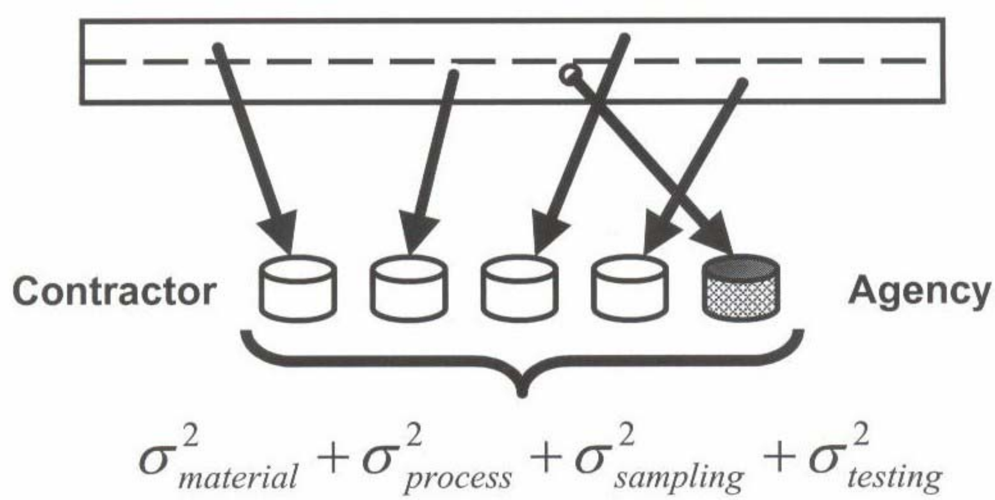


Figure 4 Components of variance for independent samples (*10*).

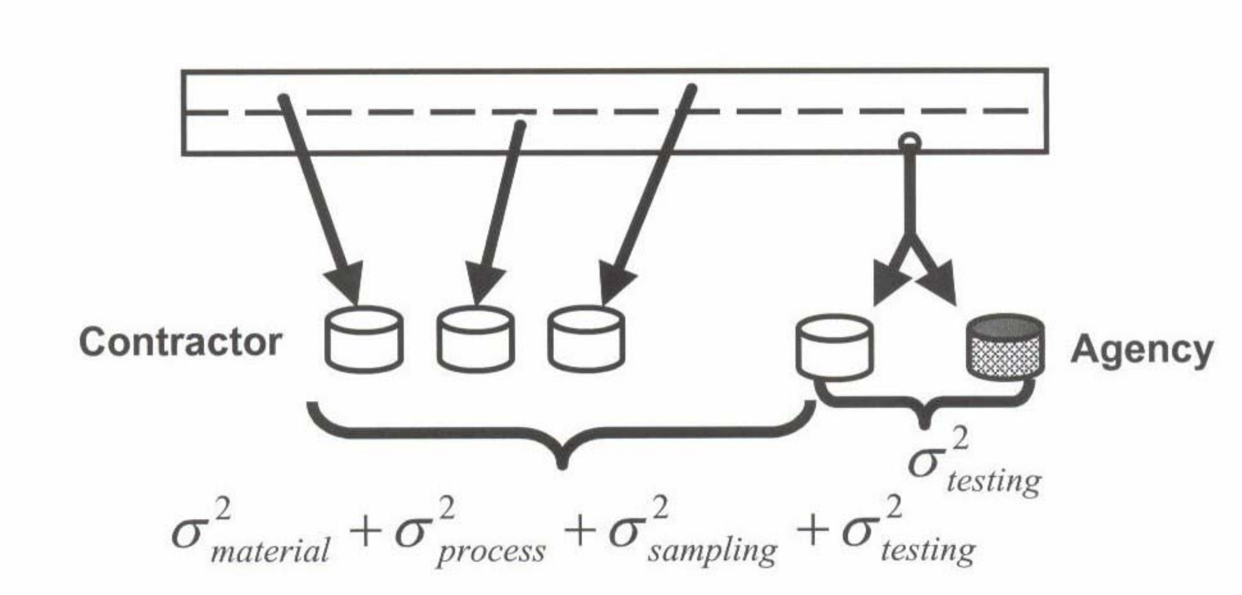


Figure 5 Components of variance for split samples (*10*).

The F and t-test method for process verification 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 super 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. The procedure is described in Appendix F of the report by Burati (*10*).

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 several lots in order to accumulate sufficient data to perform a comparison. The Kansas DOT (*4*) has developed a procedure to address this problem by using the contractor's data set to develop a measure of the production population. This system has been used by the Kansas DOT for the last 10 years with good results.

According to the Kansas DOT system (*4*), 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 two lots, incorporating the succeeding contractor's test results in the computation for the mean and standard deviation. From the third lot on, sufficient department QA test results are available and the F and t-test can be run. From the fifth lot onward, a moving average of the last five lots is used as the data for the F and t-test. Figure 6 presents the OC curves for this Kansas QA method. The OC curves represent a significance level of $\alpha = 0.05$.

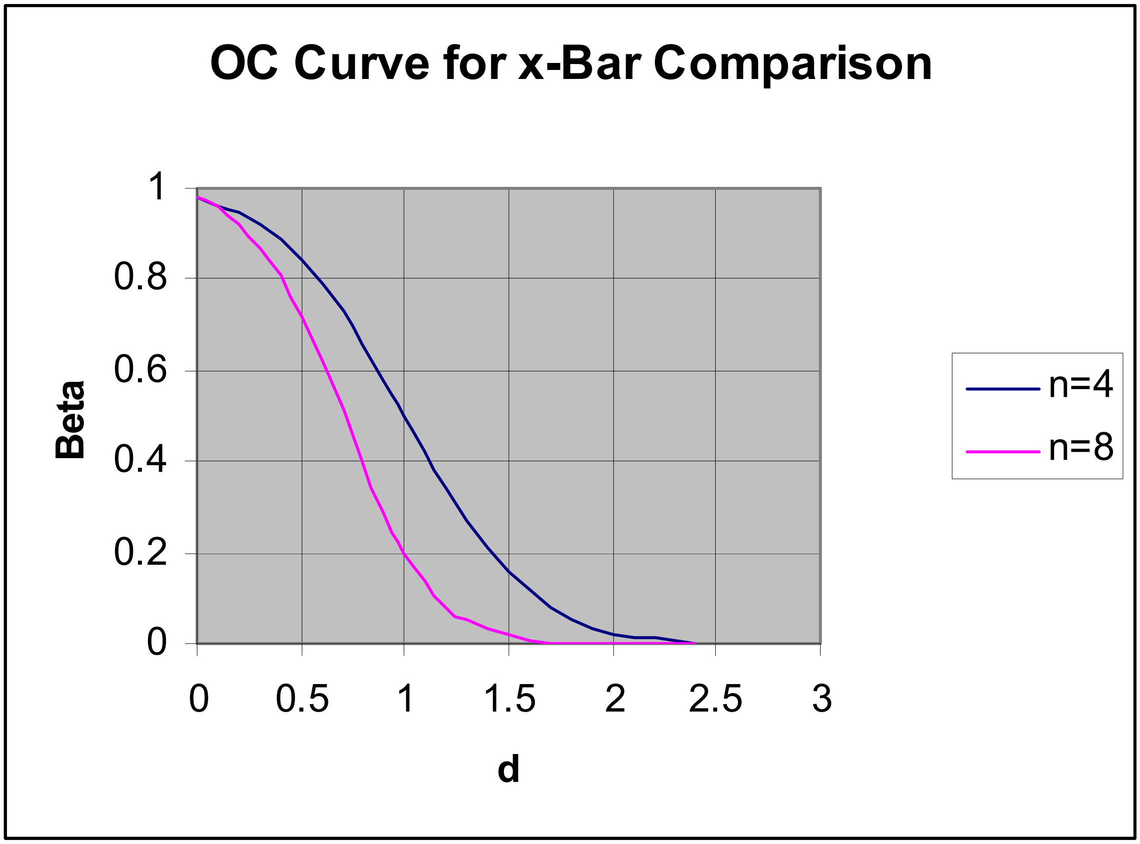


Figure 6 OC curves for $2s_x$ comparison of contractor and Department test results.

Target Adjusted Standard Deviation

The inclusion of a *Target Limit* within the *Specification Limits*, coupled with a target-adjusted standard deviation appears to be an attempt to incorporate the concept of "target value miss" into the specification. AASHTO R 9-05 contains a procedure for a *Target Miss* in section 8.8.4 – 8.8.5 (*8*). There is not sufficient information in AASHTO R 9-05 to evaluate ODOT's application of the target-adjusted standard deviation procedure. None of the surrounding states with PWL specifications appear to be using a target-adjusted standard deviation procedure.

The addition of the target-adjusted standard deviation concept is a worthy goal. However, the Oklahoma asphalt paving industry's quality control procedures may not be sufficiently mature to adopt this concept. In the author's opinion, the target-adjusted standard deviation is best used to set the specification limits, instead of being used as a control mechanism within the specifications. A more straightforward approach would be to tighten the specification limits based on an average target adjusted standard deviation derived from a number of representative projects.

PAVEMENT QUALITY-LINKED PAY AND RISK LEVEL

The pilot specification (*1*) is a good implementation of the PWL concept. The specification uses laboratory compacted air voids, in-place density, asphalt content, and gradation as pay factor items. Volumetrics (specifically air voids and VMA) and in-place density are normally the primary items that control long term serviceability of a pavement. Asphalt content also has an impact on the life of a pavement. These items are featured in the pay factor equations in most of the neighboring states' specifications.

The PWL portion of the Oklahoma specification essentially follows current thinking in both Federal and State specifications. 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 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 percent laboratory compacted air voids and the in-place density of the completed pavement. The asphalt content is another characteristic that is important to long term durability of the pavement, but is not as critical as the previous two variables. Gradation is the least important measure of the four in prediction of pavement performance. The relative weighting in the pay factor equation places 40% of the weight on in-place density and 30% of the weight on percent of air voids in the mix. Asphalt content and gradation are given a 20% and 10% weight, respectively. The relative weights seem reasonable in light of the relative impact of the various factors on pavement performance.

An analysis of the pay equation shows that the contractor has a single lot probability 100 percent pay or greater at the AQL of about 58%, this probability rises to about 61% for a 10 lot project. The pay equation probability for contractor pay compares well with the Kansas DOT specification formula (*4*), 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 7 and figure 8 shows the Kansas result. The curves on the plots represent single lot pay factors (PF) of 103, 100, 95, 90, 80, and 70 percent, respectively.

If a change in the pay factor equation is desired, the gradation component should be given serious consideration for elimination. In section 7.7 of AASHTO R 9-05 (*8*), gradation on critical sieves is mentioned as an example QC test. Gradation has a minor impact on the overall pay factor and in general, does not correlate well with pavement

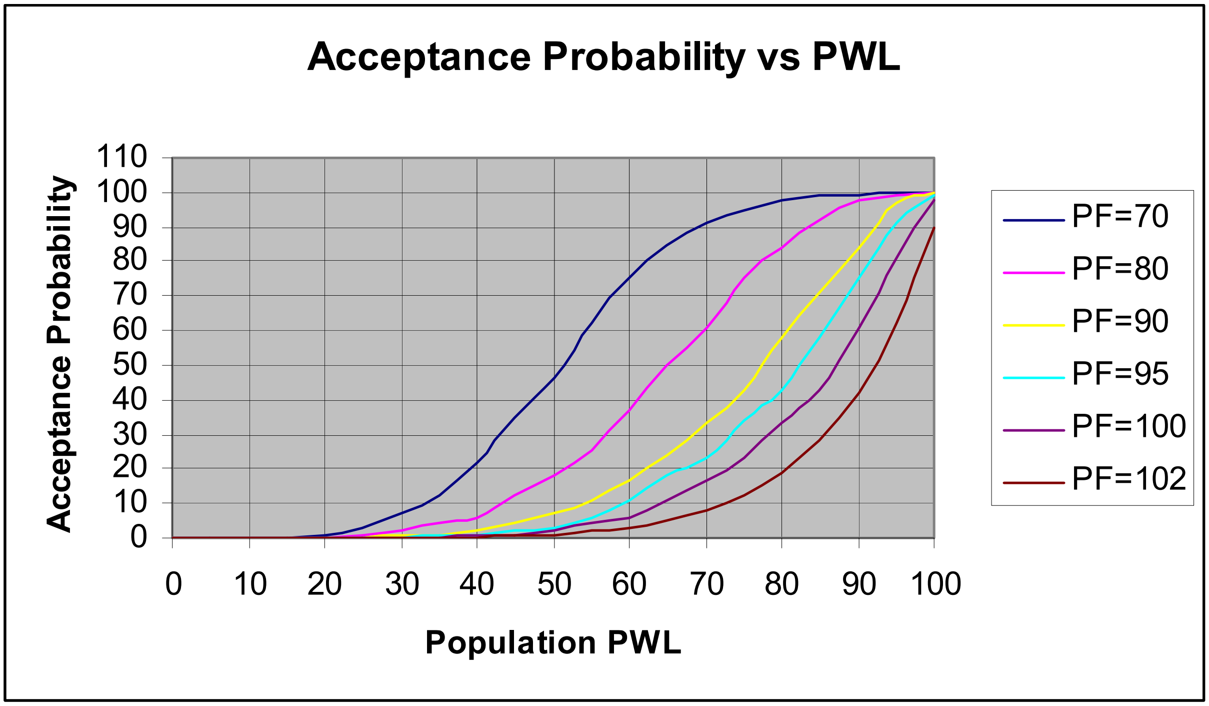


Figure 7 Oklahoma PWL specification acceptance probability vs. quality.

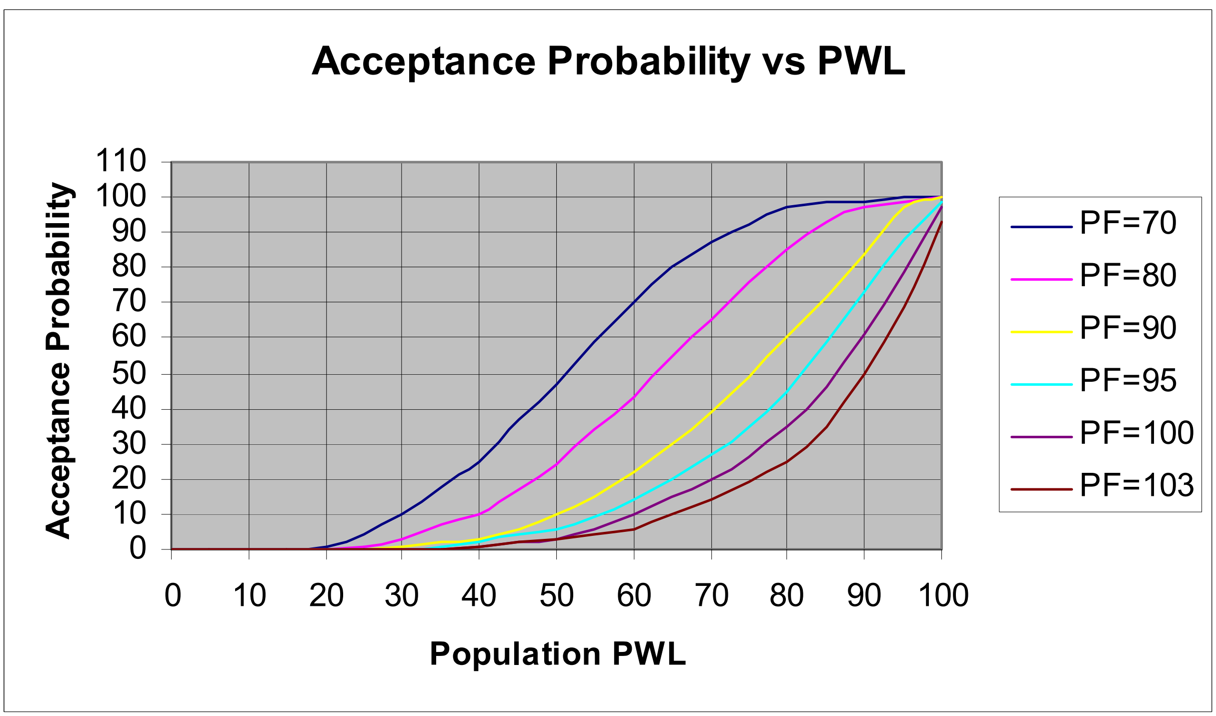


Figure 8 Kansas PWL specification acceptance probability vs. quality.

performance. Angularity and aspect ratio of the particles have a large bearing on the volumetric and compaction characteristics of the mix and these characteristics are not, in general, well represented by gradation. It is doubtful that a mix would be out of the specification limits on gradation without also being outside the specification limits on the other mix parameters as well. However, if the Department has local data that shows that gradation has an impact on pavement performance in Oklahoma, it should be retained in the pay factor equation. If the department wants to have four factors in the pay factor equation that do have a good correlation with pavement performance, a good choice in place of gradation would be VMA. VMA does correlate reasonably well to pavement performance and is included in some state's pay factor equations.

ANALYSIS OF SUPER LOT DATA

This section contains the results of a statistical analysis of the super lot data for the pilot PWL specification projects on I-35 and S-19. The test data, as supplied, did not have any identification that would allow pairing of the limited number of contractor's test results with the Department's results. Therefore, analysis of the data was accomplished using the process verification procedures mentioned earlier.

The procedures used in the process verification method consist of the F-test and the t-test. 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 super 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. If the t-test shows a statistically significant difference in means, then the contractor's data and Department's data are considered to be from different populations. In process verification a difference in means from the t-test usually prompts an investigation into the cause of the difference and the Department's test data would be used for acceptance purposes for that lot.

Tables 20 through 24 contain the mean, standard deviation, and number of tests for each group of data for both the contractor and the Department. The columns titled "F-test Result" and "t-test Result" list the result of the F and t-test comparison between the contractor's and Department's data. The F-test compares the variances and the t-test compares the means. These are two tailed tests at a 1% significance level. The word "Equal" in the columns indicates that the variance or means are statistically equivalent. The word "Diff" indicates that the variances or means are not statistically equivalent. Examination of the results for each of the super lots shows that most of the groups of data could be considered to come from the same sample populations. The word "Diff" in the t-test Results column means the contractor's data and Department's data are not from the same population. In a PWL specification, this would prompt an investigation into the cause of the difference and the use of the Department's test data for acceptance purposes.

The four quality characteristics used for pay in the HMA PWL specification are gradation, asphalt content (% AC), laboratory compacted air voids (% VTM) and roadway density (Road Gmb). A difference in gradation between the contractor's data and the Department's data was found on at least one sieve for four of the five super lots evaluated. Gradation is usually evaluated on only a few critical sieves. Using the No. 8 and No. 200 sieves as critical sieves, a difference in gradation between the contractor's data and the Department's data was found on one and three of the five super lots, respectively. The other three quality characteristics showed better agreement between the contractor's data and the Department's data. A difference between the contractor's data and the Department's data existed in two of the five super lots for asphalt content and laboratory compacted air voids and in one of the super lots for roadway density.

An interesting result becomes evident if one examines the standard deviation results for most of the super lot data. What this data shows is that the standard deviation of the Department's tests are larger, and in some cases, much larger than the contractor's. Generally, additional samples should reduce the standard deviation. This result indicates that the variability of the department's test results is larger than the contractor's. This could be due to equipment problems, variability in sampling, or poor test technique. The Department may want to examine the internal Quality Assurance test results for the time period during which the field and central lab offices conducted the tests represented by the super lot data.

Table 20. Statistical Analysis of SuperLot Data, I-35, Lot 2

	Contractor			Department			F-test	t-test
Variable	N	Mean	s	N	Mean	s	Result	Result
1"	5	2.48	1.238	15	4.27	1.619	Equal	Equal
3/4"	5	2.00	2.223	15	2.13	3.611	Equal	Equal
1/2"	5	2.28	2.640	15	2.91	4.135	Equal	Equal
3/8"	5	-0.88	2.090	15	4.30	4.044	Equal	Equal
No. 4	5	0.78	1.954	15	7.41	3.496	Equal	Diff
No. 8	5	0.70	1.960	15	7.11	3.060	Equal	Diff
No. 16	5	4.04	1.650	15	4.47	2.536	Equal	Equal
No. 30	5	0.26	1.462	15	4.34	1.856	Equal	Diff
No. 50	5	2.58	1.506	15	3.87	1.100	Equal	Equal
No. 100	5	1.82	1.638	15	3.57	0.496	Diff	Equal
No. 200	5	1.278	1.734	15	2.845	0.552	Diff	Equal
% AC	5	4.090	0.108	15	3.987	0.181	Equal	Equal
%VTM	10	3.360	0.333	30	4.615	0.485	Equal	Diff
Gmm	5	2.488	0.014	15	2.494	0.009	Equal	Equal
Gmb	10	2.405	0.014	30	2.379	0.006	Diff	Diff
Gse	5	2.654	0.015	15	2.657	0.014	Equal	Equal
Road Gmb	15	2.369	0.012	45	2.337	0.034	Diff	Diff

Table 21. Statistical Analysis of SuperLot Data, I-35, Lot 3

	Contractor			Department			F-test	t-test
Variable	N	Mean	s	N	Mean	s	Result	Result
1/2"	5	-1.72	1.481	15	2.08	0.913	Equal	Diff
3/8"	5	0.74	2.733	15	3.49	2.112	Equal	Equal
No. 4	5	3.28	1.268	15	4.10	2.258	Equal	Equal
No. 8	5	-1.26	1.197	15	-0.34	1.082	Equal	Equal
No. 16	5	1.68	0.622	15	1.73	0.475	Equal	Equal
No. 30	5	2.80	0.474	15	3.31	0.314	Equal	Equal
No. 50	5	1.96	0.378	15	2.45	0.285	Equal	Diff
No. 100	5	1.50	0.316	15	1.99	0.266	Equal	Diff
No. 200	5	0.838	0.306	15	2.170	0.697	Equal	Diff
% AC	5	5.14	0.070	15	4.833	0.195	Equal	Diff
%VTM	10	3.588	0.306	30	5.142	0.546	Equal	Diff
Gmm	5	2.461	0.005	15	2.478	0.012	Equal	Diff
Gmb	10	2.373	0.006	30	2.351	0.016	Diff	Diff
Gse	5	2.668	0.008	15	2.675	0.015	Equal	Equal
Road Gmb	15	2.317	0.025	45	2.324	0.030	Equal	Equal

Table 22. Statistical Analysis of SuperLot Data, I-35, Lot 5

	Contractor			Department			F-test	t-test
Variable	N	Mean	s	N	Mean	s	Result	Result
3/4"	5	1.14	0.893	16	-0.13	1.569	Equal	Equal
1/2"	5	1.12	0.554	16	2.23	2.328	Equal	Equal
3/8"	5	4.06	1.031	16	5.87	2.754	Equal	Equal
No. 4	5	2.18	1.840	16	2.26	2.444	Equal	Equal
No. 8	5	3.16	1.320	16	3.78	1.742	Equal	Equal
No. 16	5	2.24	1.115	16	5.38	1.202	Equal	Diff
No. 30	5	3.12	0.795	16	2.63	0.924	Equal	Equal
No. 50	5	-0.24	0.532	15	1.76	0.752	Equal	Diff
No. 100	5	0.84	0.167	16	2.74	0.448	Equal	Diff
No. 200	5	1.532	0.417	16	2.867	0.342	Equal	Diff
% AC	5	4.256	0.065	16	4.075	0.113	Equal	Diff
%VTM	10	4.012	0.410	32	3.985	0.426	Equal	Equal
Gmm	5	2.478	0.010	16	2.489	0.006	Equal	Diff
Gmb	10	2.379	0.017	32	2.389	0.007	Diff	Equal
Gse	5	2.649	0.011	16	2.654	0.008	Equal	Equal
Road Gmb	15	2.325	0.020	39	2.298	0.050	Equal	Equal

Table 23. Statistical Analysis of SuperLot Data, SH-19, Lot 1

Variable	Contractor			Department			F-test	t-test
	N	Mean	s	N	Mean	s	Result	Result
1/2"	5	2.12	0.487	15	2.52	0.836	Equal	Equal
3/8"	5	1.92	1.156	15	1.03	2.401	Equal	Equal
No. 4	5	-0.98	2.727	15	-1.57	2.461	Equal	Equal
No. 8	5	0.50	2.523	15	0.37	2.191	Equal	Equal
No. 16	5	-1.02	1.487	15	-1.98	1.569	Equal	Equal
No. 30	5	0.14	0.902	15	-0.46	1.223	Equal	Equal
No. 50	5	0.42	0.466	15	-0.03	0.935	Equal	Equal
No. 100	5	-0.62	0.421	15	-0.61	0.946	Equal	Equal
No. 200	5	-0.124	0.449	14	0.305	0.566	Equal	Equal
% AC	5	4.808	0.106	15	4.793	0.139	Equal	Equal
%VTM	10	4.016	0.690	30	4.173	0.464	Equal	Equal
Gmm	5	2.489	0.006	15	2.481	0.006	Equal	Equal
Gmb	10	2.389	0.013	30	2.378	0.011	Equal	Equal
Gse	5	2.689	0.005	15	2.679	0.008	Equal	Equal
Road Gmb	15	2.287	0.019	45	2.272	0.044	Diff	Equal

Table 24. Statistical Analysis of SuperLot Data, SH-19, Lot 4

Variable	Contractor			Department			F-test	t-test
	N	Mean	s	N	Mean	s	Result	Result
3/4"	5	3.20	0.682	15	1.58	1.752	Equal	Equal
1/2"	5	2.06	2.445	15	1.65	3.013	Equal	Equal
3/8"	5	0.44	1.986	15	0.95	2.899	Equal	Equal
No. 4	5	0.20	1.546	15	1.63	2.584	Equal	Equal
No. 8	5	-1.48	1.103	15	0.13	1.845	Equal	Equal
No. 16	5	-0.24	0.817	15	0.15	1.223	Equal	Equal
No. 30	5	0.46	0.750	15	0.93	0.924	Equal	Equal
No. 50	5	0.14	0.666	15	0.77	0.737	Equal	Equal
No. 100	5	0.12	0.630	15	0.98	0.446	Equal	Diff
No. 200	5	0.744	0.412	15	1.729	0.395	Equal	Diff
% AC	5	4.014	0.108	15	4.027	0.122	Equal	Equal
%VTM	10	4.160	0.558	30	4.209	0.455	Equal	Equal
Gmm	5	2.510	0.013	15	2.515	0.009	Equal	Equal
Gmb	10	2.405	0.005	30	2.409	0.012	Diff	Equal
Gse	5	2.676	0.016	15	2.682	0.012	Equal	Equal
Road Gmb	15	2.338	0.028	18	2.343	0.023	Equal	Equal

RISK ANALYSIS

Establishing the acceptance limits for specifications is an important step in specification development. Making the limits too tight deprives the contractor of a reasonable opportunity to meet the specifications and if the limits are too loose, they will be ineffective in controlling quality (*8,10*). Risks associated with highway specifications are usually defined in terms of contractor's or seller's risk (α) and agency's or owner's risk (β). The TRB glossary (*12*) defines α and β as:

> ***Seller's risk (α)*** *– also called risk of a type I error. The probability that an acceptance plan will erroneously reject acceptable quality level (AQL) material or construction with respect to a single acceptance quality characteristic. It is the risk the contractor or producer takes in having AQL material or construction rejected.*
>
> ***Buyer's risk (β)*** *– also called risk of a type II error. The probability that an acceptance plan will erroneously fully accept (100 percent or greater) rejectable quality level (RQL) material or construction with respect to a single acceptance quality characteristic. It is the risk the highway agency takes in having RQL material or construction fully accepted. [The probability of having RQL material or construction accepted (at any pay) may be considerably greater than the buyer's risk.]*

Burati (*10*) states that "*The appropriate level of risk a subjective decision that can vary from agency-to-agency. In reality, it is likely that few agencies have developed and evaluated the risk levels associated with their acceptance plans*."

The contractor's and agency's risk are very narrowly defined and only occur at two quality levels, the AQL and RQL, and as such are only truly appropriate for pass/fail or accept/reject decisions. These two risks do not provide a very good indication of the risks over a wide range of possible quality levels. The recommended procedure for evaluating risks over a wide range of possible quality levels is the use of OC and EP curves. The TRB glossary (12) defines OC and EP curves as:

> ***OC curve*** *– A graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and either (1) the probability of its acceptance (for accept/reject acceptance plans) or (2) the probability of its acceptance at various payment levels (for acceptance plans that include pay adjustment provisions).*
>
> ***EP curve*** *– A graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and its EP (i.e., mathematical pay expectation, or the average pay the contractor can expect to receive over the long run for submitted lots of a given quality). [Both OC and EP curves should be used to evaluate how well an acceptance plan is theoretically expected to work.]*

It is necessary to perform computer simulation to determine the risks associated with PWL acceptance plans. Buratti (*10*) recommends that when a price adjustment acceptance plan is used, it is essential that both an EP curve and OC curves over the total range of expected quality levels be developed. The FHWA (*13*) developed a computer program, OCPLOT, to develop OC and EP curves for risk evaluation of PWL specifications. OCPLOT is primarily for the case of acceptance plans based on a single property and requires the use of a pay factor equation to develop OC and EP curves. Unfortunately, the proposed pay factor in ODOT's draft HMA PWL specification is in a form that OCPLOT will not accept and multiple acceptance properties are used.

Simulation models that can fully evaluate risk associated with complex pay factor equations and multiple acceptance properties are available at OSU. In addition, the FHWA has developed a more sophisticated computer program to evaluate risk, PWL-RISK (*14*). The program is not currently available to the general public. It is highly recommended that the draft HMA PWL specification be evaluated for risk using software available at OSU or, when PWL-Risk becomes readily available or the department obtains a copy, using PWL-Risk. A third alternative is a new program (*15*), Prob.O.Prof, developed to help agencies evaluate their PCC acceptance plans. It was reported that FHWA plans to expand Prob.O.Prof to include other highway construction applications (*16*) and it should be available in the near future.

COMPARISON WITH OTHER PWL SPECIFICATIONS

There is some value in comparing Oklahoma's HMA PWL specification to the PWL specifications from the surrounding states. However, the amount of reliable information that can be obtained from a comparison is minimal due to the extremely small data set available for comparison and due to the fact that the appropriate level of risk is a subjective decision that can vary from agency-to-agency. A much larger data set would be required to evaluate the specifications with any degree of confidence.

An interesting comparison that can be made is the amount of variability that the states surrounding Oklahoma allow for full pay. Since most states use air voids as a pay item, the variability of air void test results will be used for comparison. Table 25 lists the maximum laboratory air voids standard deviation (assuming the mean value is located at the center of the specification range) required for 100% pay.

Table 25. Standard Deviations for Full Pay.

STATE	STANDARD DEVIATION
Arkansas	1.155
Kansas	0.741
Missouri	0.741
New Mexico	1.55 (3 tests)
New Mexico	0.625 (67 tests)
Oklahoma	0.868 (specification limits)
Oklahoma	0.347 (target limits)

The comparison shows that most states with PWL specifications have comparable variability for full pay on laboratory compacted air voids. The primary cause in the difference between the states' variability is the width of the specification band. This is demonstrated most clearly by comparing the variability for the Oklahoma specification and target limits.

A second comparison that can be made is to evaluate pay. The contractor's QC data from the super lots were used to evaluate the total pay and pay per lot if the same mixes were placed in Kansas and Missouri. The pay a contractor is awarded is a function of the pay factor, specification limits and number of tests per lot. A plot of the pay factor functions for Oklahoma, Kansas and Missouri are shown in Figure 9. Kansas and Missouri have different lot sizes than Oklahoma. However, both DOTs allow 5,000 ton lots. Some manipulation of the data was required to allow a comparison. For example, Kansas typically obtains ten density tests per lot and Oklahoma obtains five sets of three measurements. Ten individual density tests were randomly selected from the 15 available observations to determine the average in-place density and standard deviation for the lot if placed in Kansas. The small data set can only give an idea of the "tightness" of the Oklahoma PWL specification compared to Kansas and Missouri. A much more thorough evaluation, which was outside the scope of this project, would be required to gain an accurate picture of the "tightness" of the specification.

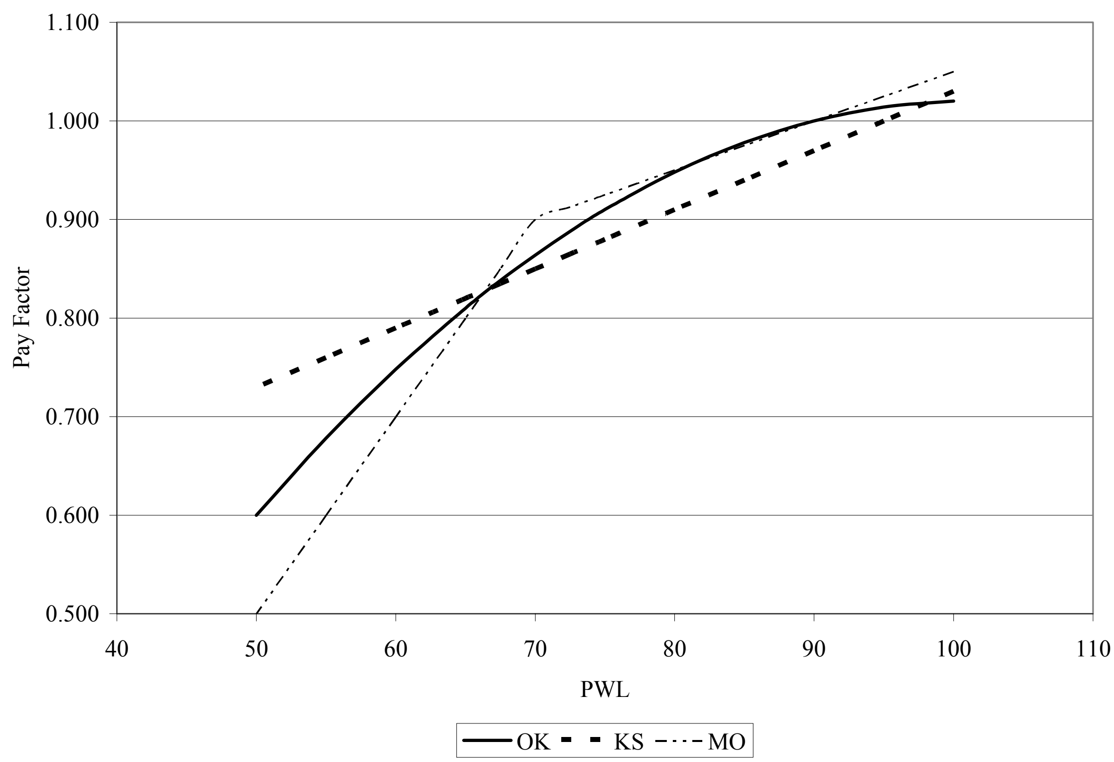


Figure 9 Pay factor equations.

Table 26 shows the results of the pay comparisons for the super lots. The pay items as well as the corresponding PWL and total pay factor are shown for Oklahoma, Missouri and Kansas. Missouri has VMA as a pay factor whereas Oklahoma does not. Therefore, Oklahoma contractors would not adjust their mixes to maintain a minimum variability on VMA as they would if VMA were a pay factor. Therefore, pay for Missouri without VMA as a pay item is shown as well. This was performed by applying a weight factor of 0.333 to the three remaining pay factors.

As shown in Table 26, there is not a consistent trend in PWL between lots for the states. It is interesting to note that gradation PWL did not pick up the low PWL in VMA for lots 1 and 4 of SH-19 but that the low VMA PWL from lot 2 of I-35 did pick up the low gradation PWL. Contractor pay does reveal a difference in the severity or tightness of the specifications. According to the Oklahoma PWL software, the in-place density data for lot 1 on SH-19 resulted in a no pay situation but not for the other states. Oklahoma paid a lower bonus than either Kansas or Missouri on every lot except lot 4 of SH-19. Based on contractor pay, Oklahoma appears to have the tightest specifications with Missouri and Kansas being very similar.

Table 27 shows the average PWL for the five lots, the composite or total pay and the percent change in pay or percent bonus based on the original bid price. Again, based on PWL, the averages show that Missouri appears to have the tighter specification, followed by Kansas and Oklahoma. When looking at total pay, Oklahoma has the most severe or tightest specification followed by Missouri and Kansas. If VMA is removed as a pay factor, Kansas and Missouri are very similar. The no pay situation for lot 1 of SH-19 shows the severe penalty for having an out of control situation. If lot 1 of SH-19 is removed from the averages, the data shows that Oklahoma and Missouri specifications are similar and tighter than Kansas. If VMA is removed from the Missouri pay factor equation then Oklahoma has the most severe or tightest specification with regard to pay, followed by Kansas or Missouri which are very similar. The above comments are made based on a very small data set and a much larger data set would be required to evaluate the severity of the specifications with any degree of confidence.

Table 26. Lot Comparisons.

Site	I-35	I-35	I-35	SH-19	SH-19
Mix	S-2 R	S-3 R	S-4 I	S-4 I	S-3 R
Lot	2	5	3	1	4
Oklahoma (PWL)					
AC	100.00	100.00	100.00	100.00	100.00
Density	98.65	98.55	100.00	53.77	80.91
VTM	100.00	100.00	100.00	98.50	100.00
Gradation	59.88	84.08	98.83	97.74	98.15
Kansas (PWL)					
Density	100.00	99.96	97.75	52.30	81.05
VTM	94.09	100.00	100.00	96.85	98.91
Missouri (PWL)					
AC	100.00	100.00	100.00	87.62	100.00
Density	100.00	100.00	95.59	56.75	69.24
VTM	88.17	100.00	100.00	93.69	97.80
VMA	54.27	100.00	100.00	68.92	79.07
Tons	5103.21	4376.14	5207.1	5700	5000
Unit Price	$28.92	$26.91	$37.93	$33.00	$28.00
Base Pay	$147,585	$117,762	$197,505	$188,100	$140,000
Oklahoma					
Bonus	-$1,121.64	$1,754.65	$3,890.79	-$188,100.00	-$910.00
Pct. Bonus	-0.76	1.49	1.97	No Pay Opt.	-0.65
Kansas					
Bonus	5459.47	$9,474.52	$9,846.46	-$24,684.99	-$1,917.35
Pct. Bonus	3.70	8.05	4.99	-13.12	-1.37
Missouri					
Bonus	-$11,949.28	$5,888.10	$8,786.37	-$22,574.35	-$2,829.75
Pct. Bonus	-8.10	5.00	4.45	-12.00	-2.02
Missouri[1]					
Bonus	$4,318.80	$5,764.45	$8,217.53	-$22,640.44	-$1,361.44
Pct. Bonus	2.93	4.90	4.16	-12.04	-0.97

[1] Removed VMA and maintained equal weight to remaining factors

Table 27. Total Compensation Comparison.

	Oklahoma	Kansas	Missouri	Missouri[1]
		Average PWL		
AC	100	N/A	97.52	.
Density	86.38	86.21	84.32	.
VTM	99.7	97.97	95.93	.
Gradation	87.74	N/A	N/A	.
VMA	N/A	N/A	80.45	.
		Total Pay		
Base Bid	$790,952	$790,952	$790,952	$790,952
Actual Pay	$606,466	$789,130	$768,273	$785,251
% Change	-23.32	-0.23	-2.87	-0.72
		Total Pay[2]		
Base Bid	$602,852	$602,852	$602,852	$602,852
Actual Pay	$606,466	$625,715	$602,748	$619,791
% Change	0.60	3.79	-0.02	2.81

[1]Removed VMA and maintained equal weight to remaining factors

[2]Excluding Lot 1, SH-19

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This examination of the Oklahoma draft HMA PWL specification and analysis of the super lot data has demonstrated that the specification concept is sound and will require very little additional work to develop fully. The specification is as accurate in determining the overall quality of HMA pavements as any of the surrounding states' specifications. A very limited evaluation showed that the Oklahoma HMA PWL specification resulted in lower pay than two of the surrounding states for the same quality of work. A detailed risk analysis of the proposed PWL specification is warranted.

The Oklahoma HMA PWL specification uses split samples and paired t-testing for initialization testing. If good agreement is obtained in the initialization lot, production proceeds with reduced split sample testing for succeeding lots and the contractor's test results are used for acceptance if good agreement, using split samples and paired t-testing, is maintained. FHWA 23 CFR 637 B allows the use of quality control sampling and testing results for the acceptance decision provided that the quality of the material is validated by verification testing and sampling performed on samples taken independently of the quality control samples. The draft HMA PWL specification appears to be in violation of this portion of FHWA 23 CFR 637 B. AASHTO R 9-05 recommends the F and t-test for process verification, the same procedure recommended by Burati (*10*) and used by the surrounding states with PWL specifications.

This study did reveal that some of the department's assurance testing showed larger variability than the corresponding contractor testing. The department may wish to conduct an investigation into the cause of the larger than expected variability in the department's super lot test results. The larger variability could be due to equipment problems, variability in sampling, or poor test technique. The department could use their internal Quality Assurance test results to investigate the cause of the larger variability.

The review indicated that Oklahoma was the only state utilizing target-adjusted standard deviation and target limits. Within the scope of this study we were not able to ascertain whether the target-adjusted standard deviation and target limits, as implemented, are supported as a specification control procedure by AASHTO R 9-05. The authors strongly recommend the retention and use of the target-adjusted standard deviation concept as an ongoing specification development tool, but not as a part of the specification during initial implementation. The Department may want to consider tightening the specification limits in lieu of using the concept of the target-adjusted standard deviation and target limits.

RECOMMENDATIONS

The study did reveal some aspects of the specification that warrant some additional consideration.

1) The author's recommend implementing a PWL specification. Without a PWL specification there is no strong incentive for the contractor to control the variability of his process. 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.
2) Consider abandoning gradation as a pay item. Gradation does not correlate well with pavement performance. AASHTO R 9-05 only suggests using gradation on critical sieves as a pay item, not all sieves as currently proposed. If four pay items are desired, VMA or some other volumetric characteristic should be considered.
3) The use of the paired t-test for initialization testing should continue. If the department wants to reduce the amount of initialization testing inherent in the paired-t procedure, the initialization data should be collected and evaluated. An analysis of the collected data could indicate that a reduced testing frequency is warranted.
4) The department should abandon the split sample procedures of *Appendix A Part 2: Guidelines for Ongoing Validation of Contractor's Test Methods*. The current procedure is not recommended for use in process verification by AASHTO R 9-05 or by Burati (*10*) and does not appear to meet the requirements of 23 CFR 637B (*9*). The paired t-test only evaluates testing variability and as such, does not capture material, process and sampling variability, which is the purpose of process verification. The F and t-test procedure is the recommended procedure for process verification according to AASHTO R 9-05 and FHWA (*9,10*). It is recommended that ODOT consider adopting the process variability approach (F and t-test used by Kansas, Colorado, or New Mexico). The system used by Kansas (*4*) may be the easiest to implement as it has been in use for 10 years and has a good performance record.
5) The department should consider a variable lot size approach and/or reducing the initial lot sizes to better match tonnage; there were several mixtures from the super lot projects that consisted of only one lot. This would be more critical if the process variability approach (F and t-test) is implemented.
6) If either the current PWL specification or a revised PWL specification is implemented, a thorough evaluation of risk is recommended. Computer simulation programs are available at OSU to perform this analysis immediately or PWL-Risk (*15*) could be used as soon as a copy is available.

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