STATE OF FLORIDA

Development of the Florida Department of Transportation's Percent Within Limits Hot-Mix Asphalt Specification

Research Report
FL/DOT/SMO/03-467

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October 2003

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ABSTRACT

The Florida Department of Transportation, herein referred to as the Department, adopted a percent within limits approach in July 2002 for the acceptance and payment of all hot-mix asphalt. Contractor's test data, after being verified by the Department, is used to calculate payment. Acceptance and payment for dense-graded Superpave mixtures is based on the following five asphalt material properties: 1) roadway density, 2) percent air voids, 3) asphalt binder content, 4) percent passing the No. 8 sieve, and 5) percent passing the No. 200 sieve. Acceptance and payment for open-graded friction course mixtures is based on the following four asphalt material properties: 1) asphalt binder content, 2) percent passing the 3/8 inch sieve, 3) percent passing the No. 4 sieve, and 4) percent passing the No. 8 sieve. Contractor's test data from recently completed construction projects was used to develop representative standard deviations of the asphalt material properties used for payment and acceptance. These standard deviations were then used to develop tolerance values used in the percent within limits system. A system has been developed to handle acceptance and payment of small quantity LOTs (two or less sublots) within the same specification. In lieu of the Department sampling and testing numerous independent samples and performing F and t-tests to validate the Contractor's results, an alternative verification and resolution system has been developed.

INTRODUCTION

Since 1977, the Florida Department of Transportation, herein referred to as the Department, has used a statistically based quality assurance specification for the acceptance and payment of hot-mix asphalt. Until recently, acceptance and payment of the hot-mix asphalt were based on results of randomly obtained samples tested by the Department's Quality Assurance Technician. The hot-mix asphalt properties used to determine payment for dense-graded mixtures were asphalt binder content, gradation, and roadway density (1). For asphalt binder content and gradation, the payment was based on the average deviation from the target. For roadway density, the payment was based on the percentage of the control strip density achieved. For open-graded mixtures, the hot-mix asphalt properties used to determine payment were asphalt binder content and gradation (1). For either mixture type, there were no provisions for the Contractor to obtain a bonus (with the exception of roadway density for coarse-graded Superpave mixtures). However, the Contractor could obtain a reduction in pay if the acceptance test results deviated too far from the target values. Under this quality assurance specification, Contractors were required to perform quality control testing for process control purposes but these test results were not used for payment.

In 1995, changes in 23 CFR 637, Part B (Quality Assurance Procedures for Construction [QAPC]) of the Code of Federal Regulations made it permissible for states to use Contractor's data for the determination of payment. With this stipulation in the QAPC, the Department utilized an opportunity to reduce quality assurance testing requirements, and ultimately, Department staffing levels at the asphalt plant without sacrificing the quality of the hot-mix asphalt.

The Department also made the decision at this point to implement a percent within limits (PWL) specification to replace the aforementioned method of using average deviations and percent of control strip density to determine payment. The PWL approach recognizes that construction material properties follow a normal distribution. When the appropriate standard deviations for each material property are known, then upper and lower test limits can be set around the target value of the material property. Contractor's payment is then based on the percentage of their test results that fall within these upper and lower limits. The main benefit of the PWL system is that payment is based on both the closeness of the test result average to the target and on the variability of the test results (2). The PWL system provides for bonuses and reductions in payment to the Contractor. In general, an average test result close to the target value and having a small standard deviation of the individual test results will result in a higher payment compared to an average test result that is far from the target with a large standard deviation of the individual test results.

This paper will focus on the development of the Department's current PWL specification including the selection of the material properties used for payment, the frequency of testing for these properties, development of the standard deviations and specification limits, development of a pay system for small quantities, and development of the Department's verification procedure. The development of the PWL system for dense-graded Superpave mixtures will be presented first followed by the development of the PWL system for open-graded friction course mixtures.

DEVELOPMENT OF THE PWL SYSTEM FOR DENSE-GRADED SUPERPAVE MIXTURES

Task Group

Since the development of a specification of this type would involve significant changes from current procedures, the Department decided to utilize a task group involving Department, construction industry, FHWA, and consultant members for the development of the PWL specification.

Selection of Material Properties Used for Payment

With the development of the new PWL specification, the Department and PWL task group decided to use this opportunity to refine the asphalt material properties used to determine the Contractor's payment. The Department chose the five asphalt material properties that were believed to relate most closely to the performance of the mixture. The five asphalt material properties are: 1) roadway density, 2) percent air voids, 3) asphalt binder content, 4) percent passing the No. 8 sieve, and 5) percent passing the No. 200 sieve. Roadway density is expressed as a percentage of the daily maximum specific gravity value (G_{mm}) obtained at the asphalt plant during production. Percent air voids is determined from specimens compacted in the Superpave gyratory compactor to the design number of gyrations using plant-produced mix. Each of the five material properties is weighted according to its contribution to the quality of the pavement based on engineering judgment. The sum of the individual weighs totals 100 percent. The weighting of each of the material properties is given in Table 1.

Table 1 – Weighting of Material Properties for Dense-graded Superpave Mixtures

Material Property	Weight (%)
Roadway Density	35
Percent Air Voids	25
Asphalt Binder Content	25
Percent Passing No. 8 Sieve	5
Percent Passing No. 200 Sieve	10
Total	100

LOT and Sublot Sizes and Frequency of Tests

The Department divides the production of hot-mix asphalt into LOTs and sublots for purposes of testing and payment. A typical sublot is defined as 1000 tons of asphalt mixture. A normal LOT consists of four sublots, i.e. 4000 tons of asphalt mixture. However, due to production demands, mix design changes, project limits, etc., LOTs can range from one to six sublots. The PWL system is utilized only for LOTs that contain three or more sublots. This is to ensure that there is sufficient reliability in the calculation of the means and standard deviations of the test data. Situations where there are only one or two sublots of material are deemed "small production" and will be discussed subsequently. LOTs and sublots are defined to be the same for both asphalt plant and roadway testing.

For the five asphalt material properties discussed previously, the frequency of testing is as follows:

a) Roadway density – perform density testing on five randomly obtained cores per sublot.

b) All other material properties (percent air voids, asphalt binder content, percent passing the No. 8 sieve, and percent passing the No. 200 sieve) – one random test per sublot.

Determination of Standard Deviations

The determination of the typical standard deviations of the test results for each of the material properties used for payment is necessary to calculate the specification limits that are used in the PWL system. These standard deviations represent the overall standard deviation for a variety of Contractors and projects that could be expected to be obtained for a given material property. This approach is recommended in the American Association of State Highway and Transportation Officials' (AASHTO) Implementation Manual for Quality Assurance (3), AASHTO Standard Practice R 9-97 Acceptance Sampling Plans for Highway Construction (4), and in the National Cooperative Highway Research Program (NCHRP) Report 447 (2). For example, a standard deviation of 0.21 for asphalt binder content would represent the typical variability encountered with asphalt binder content determination for a variety of Contractors and projects. The use of this standard deviation to calculate the specification limits will be discussed in a subsequent section.

Since the PWL system that the Department adopted uses Contractor's test data in the determination of payment, the Department used Contractor's quality control test data from a variety of previously constructed Superpave projects to determine the standard deviations for four of the five material properties (percent air voids, asphalt binder content, percent passing the No. 8 sieve, and percent passing the No. 200 sieve). However, Contractor data for the determination of roadway density was not available from historical records because, prior to the PWL system, quality assurance personnel performed all density testing for roadway cores. Therefore, quality assurance test data was used for the determination of the standard deviation for roadway density.

Roadway Density

Quality assurance data was examined from 20 different mixtures constructed on 12 different projects. Data from a total of 917 roadway LOTs, comprised of density values from 4,377 cores, was used in the analysis. Density was expressed as a percentage of the maximum specific gravity. Information for each project/mixture is shown in Table 2. For a particular mixture type, data was statistically "pooled" to account for varying roadway LOT sizes.

Table 2 – Roadway Density Data for Dense-graded Superpave Mixtures

Project Identification Number	Contractor	Highway	Mix Type	Number of LOTs	Number of Cores	Pooled LOT Variance % Gmm	Pooled LOT Standard Deviation % Gmm
207662-1-52-01	White Construction	US-441	12.5 Fine	93	455	2.472	1.572
207794-1-52-01	Anderson Columbia	US-301	12.5 Coarse	95	472	1.270	1.127
			FC-6 Fine	8	39	1.812	1.346
208015-1-52-01	J. B. Coxwell	US-301	12.5 Coarse	54	276	1.231	1.109
			FC-6 Coarse	10	41	1.297	1.139
208017-1-52-01	Anderson Columbia	US-301	12.5 Coarse	40	188	1.700	1.304
208478-1-52-01	Anderson Columbia	US-19	12.5 Fine	53	272	1.569	1.253
			9.5 Fine	25	133	1.478	1.216
			FC-6 Fine	12	61	1.890	1.375
210017-1-52-01	White Construction	SR-19	12.5 Fine	56	265	1.969	1.403
213300-1-52-01	Atlantic Coast Asphalt	I-10	19.0 Coarse	48	213	0.743	0.862
			9.5 Coarse	45	205	0.970	0.985
213396-1-52-01	White Construction	I-75	19.0 Coarse	60	275	1.305	1.142
			12.5 Coarse	63	255	1.558	1.248
213397-1-52-01	Anderson Columbia	I-75	19.0 Coarse	66	326	1.295	1.138
			12.5 Coarse	47	227	1.633	1.278
213439-1-52-01	Couch Construction	I-10	19.0 Coarse	25	121	0.892	0.944
			9.5 Coarse	24	114	1.286	1.134
238749-1-52-01	D. A. B. Constructors	US-301	12.5 Fine	24	111	1.738	1.318
242316-1-52-01	MacAsphalt	I-95	12.5 Coarse	69	328	1.267	1.126
			Total	917	4377		

Table 3 displays a breakdown of the median variance and standard deviation values of the 20 mixtures into categories including coarse and fine mixtures and nominal maximum aggregate size. For these 20 projects examined, the coarse mixtures were slightly less variable than the fine mixtures. There was no definitive trend when comparing nominal maximum aggregate size.

Table 3 – Categorization of Roadway Density Data for Dense-graded Superpave Mixtures

Number of Mixtures	Mixture Type	Median Pooled LOT Variance % Gmm	Standard Deviation of Median Pooled LOT Variance, % Gmm
20	All	1.392	1.180
13	Coarse	1.286	1.134
7	Fine	1.812	1.346
3	9.5 Coarse	1.286	1.134
6	12.5 Coarse	1.414	1.189
4	19.0 Coarse	1.094	1.046
1	9.5 Fine	1.478	1.216
6	12.5 Fine	1.851	1.361

Percent Air Voids, Asphalt Binder Content, Percent Passing the No. 8 Sieve, and Percent Passing the No. 200 Sieve.

Quality control data was examined from 121 different mixtures constructed by 17 different Contractors. A total of 1920 data points for each asphalt property were used in the analysis. Table 4 displays a breakdown of the median variance and standard deviation values into categories including coarse and fine mixtures and nominal maximum aggregate size. The standard deviation values were consistent between coarse and fine mixtures for the four asphalt properties examined. There was also consistency in the standard deviation values between nominal maximum aggregate sizes excluding the coarse graded FC-6 mixture, which contained the fewest number of data points.

Based on the data from Tables 3 and 4, the final standard deviations selected by the Department for use in determining the specification limits for each of the five asphalt material properties are shown in Table 5.

Table 4 – Categorization of Asphalt Plant Data for Dense-graded Superpave Mixtures

Mix Type	# Projects	# Data Points	% Air Voids		% Asphalt Binder Content		% Passing No. 8		% Passing No. 200	
			Variance	Standard Deviation	Variance	Standard Deviation	Variance	Standard Deviation	Variance	Standard Deviation
All Mixtures	121	1920	0.453	0.673	0.043	0.207	3.533	1.880	0.163	0.404
All Coarse	44	732	0.556	0.745	0.040	0.200	3.269	1.808	0.138	0.372
All Fine	77	1188	0.417	0.646	0.043	0.207	3.541	1.882	0.188	0.434
9.5 C	12	104	0.525	0.725	0.030	0.174	2.941	1.715	0.082	0.286
9.5 F	19	192	0.519	0.720	0.049	0.222	3.362	1.834	0.174	0.417
FC-6 C	3	29	1.718	1.311	0.094	0.307	4.103	2.026	0.159	0.399
12.5 C	19	347	0.682	0.826	0.036	0.189	3.197	1.788	0.163	0.404
12.5 F	34	763	0.387	0.622	0.040	0.200	3.726	1.930	0.205	0.453
FC-6 F	20	216	0.420	0.648	0.045	0.211	3.533	1.880	0.117	0.342
19.0 C	10	252	0.382	0.618	0.042	0.206	3.509	1.873	0.188	0.434
19.0 F	4	17	0.377	0.614	0.023	0.153	6.474	2.544	0.194	0.440

Table 5 – Selected Standard Deviation Values for Asphalt Material Properties for Dense-graded Superpave Mixtures

Asphalt Material Property	Median Standard Deviation
Roadway Density, % Gmm (coarse mixtures)	0.51
Roadway Density, % Gmm (fine mixtures)	0.60
% Air Voids	0.75
Asphalt Binder Content	0.21
% Passing No. 8	1.88
% Passing No. 200	0.40

The standard deviation values for roadway density shown in Table 5 are less than those shown in Table 3. The reason for this is because the standard deviations shown in Table 3 are for the variance of the individual density cores analyzed. Under the PWL system, a sublot at the roadway would consist of 1000 tons of asphalt mixture. Five cores would be randomly obtained in this sublot and the average density value of those five cores would be obtained and reported as one test result. To obtain the standard deviation of the average of five values, the following formula is used:

$$S\bar{x} = \frac{Sx}{\sqrt{5}}$$

where: $S\bar{x}$ = the standard deviation of the mean

Sx = the standard deviation of the individual values

For example, for coarse graded mixtures, the standard deviation from Table 3 is 1.134.

$$S\bar{x} = \frac{1.134}{\sqrt{5}} = 0.51$$

This agrees with the value from Table 5 for coarse graded mixtures.

Normality of Data

One of the important concepts in the PWL system is that construction test data follows a normal distribution and that appropriate standard deviations are developed from this normally distributed data (4). The specification limits developed from these standard deviations would be flawed should the data not follow a normal distribution. Histograms of test data used by the Department were plotted to verify that the frequency of the test data values produced the characteristic bell-shaped curve of a normal distribution. An example histogram for roadway density is shown in Figure 1. The histogram has the characteristic bell-shaped curve, as expected.

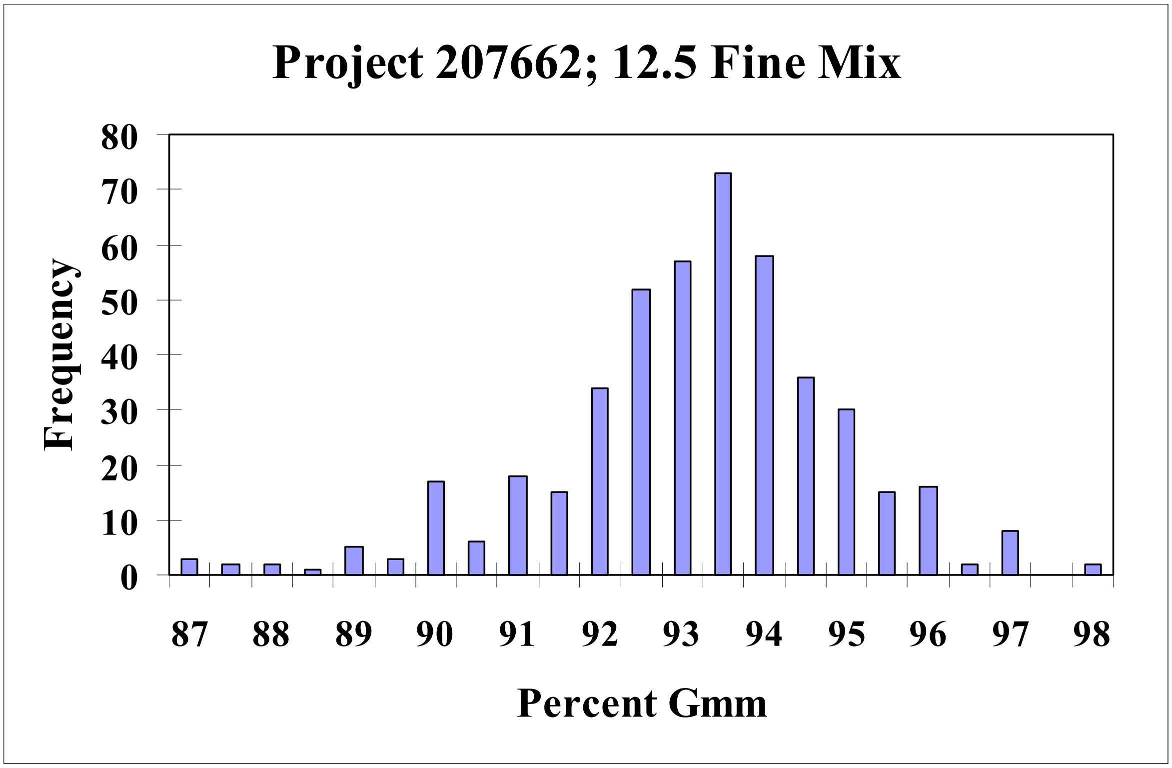


Figure 1 – Example Histogram for Roadway Density

Median Standard Deviation Versus Average Standard Deviation

Construction test data typically follows a normal distribution as previously shown. However, the variance (square of the standard deviation) values of the construction test data resemble a skewed (chi-square) distribution (see Figure 2). During the analysis of the test data presented in Tables 3 and 4, the Department used the median variance value of the test data for each asphalt material property instead of the average variance value. In the distribution of variance values, the median variance and the average variance are not equal. The average variance is greater than the median variance. This is in contrast to a normal bell-shaped distribution, where the average and median values are the same. The median value is defined as the middle value of a set of data points, which the Department believed was the representative value to be used for the variance of an asphalt material property. In contrast,

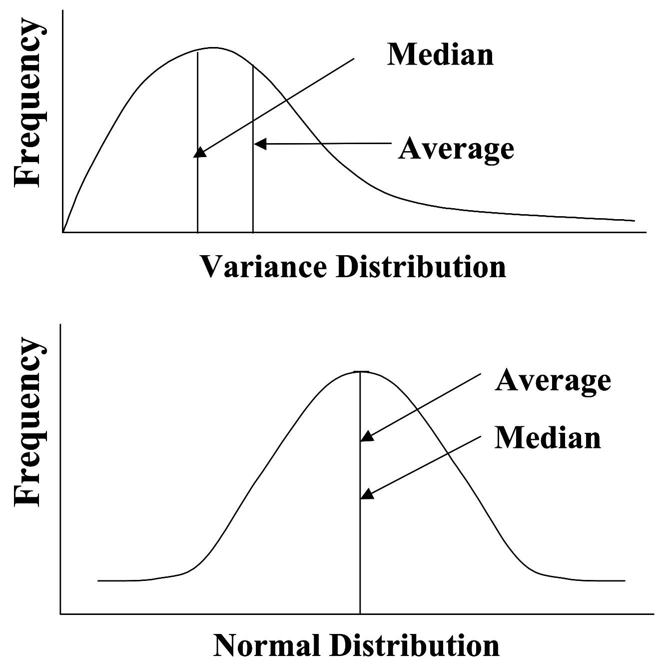


Figure 2 – Variance and Normal Distributions

the average variance value would have more data points less than the average and fewer data points greater than the average.

Development of Specification Limits

The Department used the method presented in the AASHTO Quality Assurance Guide Specification (5) and NCHRP Report 447 (4) to develop the specification limits for each asphalt material property. In this method, a Contractor can receive 100 percent payment if 90 percent of the Contractor's test results are within the upper and lower specification test limits. Therefore, the specification limits must be established such that if a Contractor's test data has representative variability and the mean of the test results is equal to the target, then 100 percent payment can be achieved. To establish these specification limits, the standard deviations shown in Table 5 are multiplied by 1.645. In a normal distribution, 1.645 represents the number of standard deviations less than and greater than the mean, in which 90 percent of the test results will exist. Table 6 displays the mathematically calculated specification limits.

Table 6 – Specification Limits for Dense-graded Superpave Mixtures

Asphalt Material Property	Median Standard Deviation	Calculated Specification Limits (Std. Dev. x 1.645)	Implemented Specificaion Limits
Roadway Density, % Gmm (coarse mixtures)	0.51	0.84	+/- 1.30
Roadway Density, % Gmm (fine mixtures)	0.60	0.99	+2.00, -1.00
% Air Voids	0.75	1.23	+/- 1.40
Asphalt Binder Content	0.21	0.35	+/- 0.40
% Passing No. 8	1.88	3.09	+/- 3.10
% Passing No. 200	0.40	0.66	+/- 1.00

Discussions with the PWL task group (involving Department, construction industry, FHWA, and consultant members) resulted in modifying the mathematically calculated specification limits to the greater values shown in Table 6 in the column titled "Implemented Specification Limits." The specification limits were modified to address concerns that industry would not be able produce hot-mix asphalt within the constraints of the mathematically calculated specification limits. The Department agreed to the larger specification limits with the stipulation that these limits would be assessed and modified, if needed, in one to two years using data from projects constructed under this PWL specification.

Target Values

In the PWL system, the specification limits establish an upper and lower range around a target value. For example, if the target value for the percent passing the No. 200 sieve was

6.0 percent, then given the specification limits of ± 1.0 percent, the range would equal 5.0 to 7.0 percent passing. This is the range that 90 percent of the test values would need to fall within for the Contractor to receive 100 percent payment.

Target values for asphalt binder content, percent passing the No. 8 sieve, and percent passing the No. 200 sieve are established on the Department approved asphalt mixture design. The target value for percent air voids is established at four percent for all Superpave mixtures. The target value for roadway density for coarse graded mixtures is 94.50 percent of G_{mm}. The target value for roadway density for fine graded mixtures is 93.00 percent of G_{mm}. Target values are summarized in Table 7.

Table 7 – Target Values and Specification Limits for Dense-graded Superpave Mixtures

Asphalt Material Property	Target Value	Implemented Specificaion Limits
Roadway Density, % Gmm (coarse mixtures)	94.50	+/- 1.30
Roadway Density, % Gmm (fine mixtures)	93.00	+2.00, -1.00
% Air Voids	4.00	+/- 1.40
Asphalt Binder Content	Mix Design	+/- 0.40
% Passing No. 8	Mix Design	+/- 3.10
% Passing No. 200	Mix Design	+/- 1.00

DEVELOPMENT OF THE PWL SYSTEM FOR OPEN-GRADED FRICTION COURSE MIXTURES

The development of the PWL system for open-graded friction course mixtures follows the same procedure as for dense-graded Superpave mixtures except the material properties used for payment, standard deviations and specification limits are different between the two mixture types.

Selection of Material Properties Used for Payment

With the development of the new PWL specification, the Department and PWL task group decided to use this opportunity to refine the asphalt material properties that the Contractor's payment would be based on. The Department chose the four asphalt material properties that were believed to relate most closely to the performance of open-graded friction course mixtures. The four asphalt material properties are: 1) asphalt binder content, 2) percent passing the 3/8 inch sieve, 3) percent passing the No. 4 sieve, and 4) percent passing the No. 8 sieve. Each of the four material properties is weighted according to its contribution to the quality of the pavement based on engineering judgment. The sum of the individual weighs totals 100 percent. The weighting of each of the material properties is given in Table 8.

Table 8 – Weighting of Material Properties for Open-graded Friction Course Mixtures

Material Property	Weight (%)
Asphalt Binder Content	40
Percent Passing 3/8 Inch Sieve	20
Percent Passing No. 4 Sieve	30
Percent Passing No. 8 Sieve	10
Total	100

LOT and Sublot Sizes and Frequency of Tests

For open-graded friction course mixtures a typical sublot is defined as 500 tons of asphalt mixture. A normal LOT consists of four sublots, i.e. 2000 tons of asphalt mixture. The PWL system is utilized only for LOTs that contain three or more sublots. Situations where there are only one or two sublots of material are deemed "small production" and will be discussed subsequently.

For each of the four asphalt material properties discussed previously, the frequency of testing is one random test per sublot.

Determination of Standard Deviations

The Department used Contractor's quality control test data from a variety of previously constructed projects to determine the standard deviations for the four asphalt material properties used to determine payment for open-graded friction course mixtures. Data was examined from 25 different projects constructed by 7 different Contractors. 319 data points for each asphalt property were used in the analysis. It should be noted that historical data for the percent passing the No. 10 sieve was used to establish the standard deviation for percent passing the No. 8 sieve, since the No. 8 sieve had not been used for gradation analysis in the past. The Department decided to use the No. 8 sieve for open-graded friction course mixtures so that sieve sizes would be consistent between dense-graded Superpave mixtures and open-graded friction course mixtures. Table 9 displays the median variance and standard deviation values for each of the four asphalt material properties.

Table 9 – Categorization of Asphalt Plant Data for Open-graded Friction Course Mixtures

# Projects	# Data Points	% Asphalt Binder Content		% Passing 3/8 Inch		% Passing No. 4		% Passing No. 8	
		Variance	Standard Deviation	Variance	Standard Deviation	Variance	Standard Deviation	Variance	Standard Deviation
25	319	0.057	0.238	8.950	2.992	4.422	2.103	1.090	1.044

Development of Specification Limits

To develop the specification limits for open-graded friction course mixtures, the Department used the same procedure as for dense-graded Superpave mixtures. The four standard deviations shown in Table 9 are multiplied by 1.645 to establish the upper and lower specification limits around the target values established on the Department approved mix design. Table 10 displays the mathematically calculated specification limits.

Table 10 – Specification Limits for Open-graded Friction Course Mixtures

Asphalt Material Property	Median Standard Deviation	Calculated Specification Limits (Std. Dev. x 1.645)	Implemented Specificaion Limits
Asphalt Binder Content	0.24	0.39	+/- 0.45
% Passing 3/8 inch Sieve	2.99	4.92	+/- 6.00
% Passing No. 4 Sieve	2.10	3.46	+/- 4.50
% Passing No. 8 Sieve	1.04	1.72	+/- 2.50

As with the specification limits for dense-graded Superpave mixtures, discussions with construction industry representatives, FHWA representatives and other Department personnel resulted in modifying the mathematically calculated specification limits to the greater values shown in Table 10 in the column titled "Implemented Specification Limits."

CALCULATION OF PAYMENT

The Department used the method presented in the AASHTO Quality Assurance Guide Specification (5) to calculate the pay factor amount (percent) used to determine the Contractor's payment. For each asphalt material property, the following equation is used to determine the pay factor:

$$\text{Pay factor (\%)} = 55 + 0.5 \times \text{PWL}$$

Where: PWL = percent within limits

The calculation of the PWL is more complicated and includes the determination of upper and lower quality indexes, look-up tables, etc. The calculations necessary to determine the PWL are thoroughly described in the AASHTO Quality Assurance Guide Specification (5) or the Department's Superpave Asphalt Concrete Specification, Section 334 (6).

As can be seen from the pay factor equation (PF = 55 + 0.5 x PWL), if the percent of test results within the specification limits is equal to 90 percent for a LOT, then the Contractor's pay factor is 100 and the Contractor receives 100 percent payment for that asphalt material property for that LOT. If the percent of test results within the specification limits is greater than 90 percent, then the Contractor's pay factor is greater than 100 and the Contractor receives greater than 100 percent payment for that asphalt material property for that LOT. The maximum PF that can be achieved for 100 percent of test results within the specification limits is 105, i.e. a five percent bonus in payment.

Mathematically, the pay factor equation would generate a pay factor of 55 percent if there were zero percent of test results within the specification limits. However, the Department's specifications have clauses that deal with low pay factor material. Refer to Specification Section 334 (6) for information related to low pay factor material.

After the pay factor has been determined for each asphalt material property, a composite pay factor (CPF) is calculated by multiplying the respective weights shown in Tables 1 or 8 by the individual pay factors. For example, the CPF equation for dense-graded Superpave mixtures is:

CPF = [(0.350 x PF Roadway Density) + (0.250 x PF % Air Voids) + (0.250 x PF % AC) +
(0.050 x PF No. 8 Sieve) + 0.100 x PF No. 200 Sieve)]

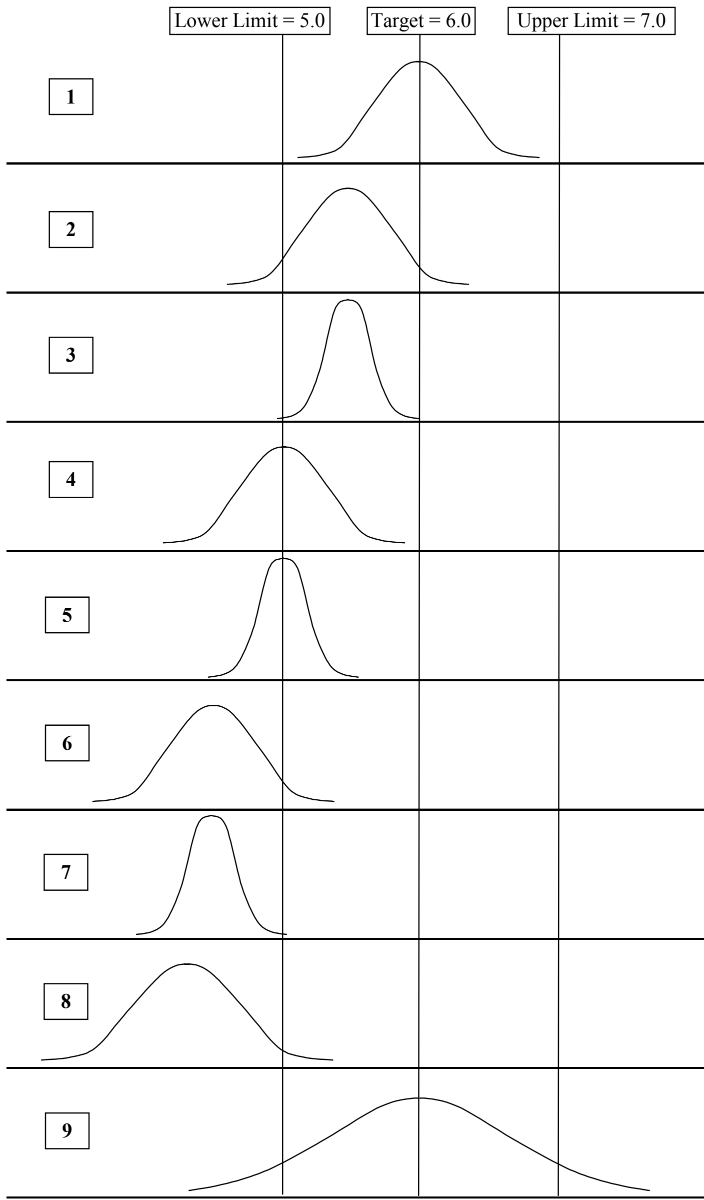
Like the individual pay factors, the composite pay factor has a maximum value of 105. Additionally, Specification Section 334 (6) contains safeguards to prevent and/or remedy low pay factor material.

There are three ways for a Contractor to increase the percent within limits to increase the pay factor: 1) reduce the difference between the mean of the test data and the established target value, 2) reduce the variability of the test results, or 3) a combination of one and two.

Figure 3 shows nine normal distributions with different means and standard deviations of fictitious test data representing percent passing the No. 200 sieve. For each of the nine distributions, the pay factor and percent within limits is shown. For distributions two through eight, the results would be the same if the distributions were symmetrically located on the upper side of the target value. This figure is included to show how varying the mean and standard deviation of the test results influences the pay factor.

SMALL QUANTITIES

Discussion up to this point has focused on the development of the statistically based percent within limits approach to determine payment for asphalt material for LOTs containing from three to six sublots. The term “small quantities” refers to LOTs containing one or two sublots. Because the PWL system is not designed to work in situations with one or two sublots, the Department developed small quantity pay tables that are similar in principle to the pay tables used prior to the development of the PWL system. Small quantity pay tables were developed for dense-graded Superpave mixtures and open-graded friction courses. Payment is based on the deviation of a test result or average deviation of two test results from the target value. Larger deviations from the target result in lower pay factors. Since the intent of the specification is to use the PWL concept as often as possible, there are no provisions for a bonus in the small quantity pay table. This is to discourage the production of small LOTs resulting in only one or two test results.



Case	% Passing No. 200 Sieve Test Values		
1	6.5	Mean	6.0
	6.0	Standard Deviation	0.408
	6.0	PWL	100.0
	5.5	Pay Factor	1.05
2	6.0	Mean	5.5
	5.5	Standard Deviation	0.408
	5.5	PWL	90.7
	5.0	Pay Factor	1.00
3	5.8	Mean	5.5
	5.5	Standard Deviation	0.245
	5.5	PWL	100.0
	5.2	Pay Factor	1.05
4	5.5	Mean	5.0
	5.0	Standard Deviation	0.408
	5.0	PWL	50.0
	4.5	Pay Factor	0.80
5	5.3	Mean	5.0
	5.0	Standard Deviation	0.245
	5.0	PWL	50.0
	4.7	Pay Factor	0.80
6	5.0	Mean	4.5
	4.5	Standard Deviation	0.408
	4.5	PWL	9.0
	4.0	Pay Factor	0.60
7	4.8	Mean	4.5
	4.5	Standard Deviation	0.245
	4.5	PWL	0.0
	4.2	Pay Factor	0.55
8	5.0	Mean	4.3
	4.4	Standard Deviation	0.577
	4.2	PWL	9.3
	3.6	Pay Factor	0.60
9	7.0	Mean	6.0
	6.5	Standard Deviation	0.913
	5.5	PWL	72.7
	5.0	Pay Factor	0.91

Figure 3 – Effect of Mean and Variance on PWL and Pay Factor (Percent Passing No. 200 Sieve)

The derivation of the values contained in the small quantity pay tables is based partially on the specification limits used in the PWL system and partially on negotiations with industry. Construction data analyzed for the development of the standard deviations used in the PWL system showed that there was very little difference in the variability of the asphalt material properties between large and small production quantities. However, due to concerns by Contractors that the variability for small quantities would be difficult to control while also striving to meet the target values, the small quantity pay tables were developed allowing slightly larger construction variability than for the PWL system. The pay table for dense-graded Superpave mixtures is shown in Table 11 and the pay table for open-graded friction course mixtures is shown in Table 12.

VERIFICATION PROCEDURE

As stated previously, Contractor's quality control test data is used in the calculation of the payment amount for a given LOT of hot-mix asphalt material. However, prior to the occurrence of these calculations, a Department representative must first verify the Contractor's test data. This verification testing provides assurance to the Department that the Contractor is performing test procedures correctly and not falsifying test data.

Initial Verification Procedure

During the initial implementation of the PWL specification, the Department's verification procedure required that a Department representative test independently obtained samples. The Department's and Contractor's test results were then statistically analyzed through the use of F and t-tests to determine the likelihood that the two data sets came from the same population. The FHWA suggested the use of a 99% confidence level. This initial verification procedure was used on only one project due to the difficulty in its implementation. Sampling and testing requirements were nearly four times greater than what the Department had been using prior to the PWL system. Furthermore, using a 99% confidence level resulted in very few test results that were determined to be unrepresentative.

Table 11 – Small Quantity Pay Table for Dense-graded Superpave Mixtures

Material Property	Pay Factor	1-Test Deviation	2-Test Average Deviation
Percent Asphalt Binder Content	1.00	0.00-0.45	0.00-0.32
	0.90	0.46-0.55	0.33-0.39
	0.80	>0.55	>0.39
Percent Passing No. 8 Sieve	1.00	0.00-4.50	0.00-3.18
	0.90	4.51-5.50	3.19-3.89
	0.80	>5.50	>3.89
Percent Passing No. 200 Sieve	1.00	0.00-1.10	0.00-0.78
	0.90	1.11-1.50	0.79-1.06
	0.80	>1.50	>1.06
Percent Air Voids	1.00	0.00-1.10	0.00-0.78
	0.90	1.11-1.50	0.79-1.06
	0.80	>1.50	>1.06
Roadway Density (Coarse Graded Mixtures) Note (1)	1.00	≥ 93.50	≥ 93.50
	0.95	93.00-93.49	93.00-93.49
	0.90	Note (2)	Note (2)
Roadway Density (Fine Graded Mixtures) Note (1)	1.00	≥ 92.00	≥ 92.00
	0.95	91.00-91.99	91.00-91.99
	0.90	90.00-90.99	90.00-90.99
	0.80	< 90.00 Note (3)	< 90.00 Note (3)

Notes:
(1) Each density test result is the average of five cores.
(2) In the event that the density of a LOT is less than 93.00% of G_{mm}, the Department will assess the pavement's permeability in accordance with FM 5-565. If the coefficient of permeability is greater than or equal to 125×10^{-5} cm/s, the Engineer may require removal and replacement at no cost or may accept the payment at 90% pay. The Contractor may remove and replace at no cost to the Department at any time.
(3) If approved by the Engineer, based on an engineering determination that the material is acceptable to remain in place, the Contractor may accept the indicated partial pay. Otherwise, the Department will require removal and replacement at no cost. The Contractor may remove and replace at no cost to the Department at any time.

Table 12 – Small Quantity Pay Table for Open-graded Friction Course Mixtures

Material Property	Pay Factor	1-Test Deviation	2-Test Average Deviation
	1.00	0.00-0.50	0.00-0.35
Percent Asphalt Binder Content	0.90	0.51-0.60	0.36-0.42
	0.80	>0.60	>0.42
	1.00	0.00-6.50	0.00-4.60
Percent Passing 3/8 inch Sieve	0.90	6.51-7.50	4.61-5.30
	0.80	>7.50	>5.30
	1.00	0.00-5.00	0.00-3.54
Percent Passing No. 4 Sieve	0.90	5.01-6.00	3.55-4.24
	0.80	>6.00	>4.24
	1.00	0.00-3.00	0.00-2.12
Percent Passing No. 8 Sieve	0.90	3.01-3.50	2.13-2.47
	0.80	>3.50	>2.47

Final Verification Procedure

To reduce the amount of sampling and testing required by the initial verification procedure, the Department decided to obtain split samples with the Contractor for every sublot acceptance sample instead of obtaining independent samples. At a randomly selected point within the production of each sublot of hot-mix asphalt material, the verification technician directs the Contractor to obtain three split samples; one for the Contractor, one for verification testing and one for resolution testing. The Contractor performs tests on each sublot split sample. The Verification Technician performs tests on one randomly selected split sample per LOT. For both the Contractor and Verification Technician, tests are conducted to determine the following six asphalt material properties: 1) maximum specific gravity of the asphalt mixture, 2) bulk specific gravity of the gyratory compacted asphalt specimen at the plant, 3) percent asphalt binder content, 4) percent passing the no. 8 sieve, 5) percent passing the no. 200 sieve, and 6) bulk specific gravity of roadway cores. The Contractor and verification test results are required to meet between-laboratory precision values established in Department test methods (see Table 13).

Table 13 – Between Laboratory Precision Values for Verification and Resolution Testing

Asphalt Material Property	Maximum Difference Between Two Tests
Maximum Specific Gravity, G_{mm}	0.019
Bulk Specific Gravity, G_{mb}	0.022
Percent Asphalt Binder	0.44
Percent Passing No. 8 Sieve	FM 1-T 030 (Fig. 2)
Percent Passing No. 200 Sieve	FM 1-T 030 (Fig. 2)

If all of the test results compare, then the LOT will be accepted with payment calculated based on the Contractor's test data. If any of the test results do not compare favorably, the verification split samples from the remaining sublots of the LOT will be tested only for the asphalt property(s) that did not compare favorably. A comparison will then be made between all of the Contractor and verification test results for the asphalt property(s) that did not compare favorably. If there is only one unfavorable comparison, then the LOT will be accepted and payment will be based on the Contractor's test results. If there are two or more unfavorable comparisons, then a laboratory identified by the Department will test all of the resolution samples for the asphalt property(s) that did not compare favorably. If all of the resolution test results compare favorably with the Contractor's test results, then the LOT will be accepted with payment calculated based on the Contractor's test data. If any of the resolution test results do not compare favorably with the Contractor's test results, then the LOT will be accepted with payment calculated based on the resolution test results.

In addition to the verification and resolution split samples that the Department uses to verify the Contractor's test data, the Department obtains independent verification samples at a minimum frequency of one sample per four thousand tons of asphalt mixture. The independent verification samples are used to monitor the effectiveness of the Contractor's quality control program. Independent verification test results must meet the requirements given in Table 14. Should any of test results not meet the tolerances given in Table 14, then the Contractor must cease production of the asphalt mixture until the problem is adequately resolved to the satisfaction of the Department.

Table 14 – Criteria for Independent Verification Test Results

Asphalt Material Property	Tolerance from Mix Design (for one test)
Roadway Density (1) - Coarse Mixtures	93.00 %G_{mm} minimum
Roadway Density - Fine Mixtures	N/A
Percent Air Voids	4.00 +/- 1.50
Percent Asphalt Binder	Target +/- 0.55
Percent Passing No. 8 Sieve	Target +/- 5.50
Percent Passing No. 200 Sieve	Target +/- 1.50
(1) Roadway Density is the average of five cores.	

The Department uses one other mechanism (Independent Assurance) to assess the quality of the Contractor's work. At any time during the project, the Department can obtain independent assurance split samples with the Contractor to verify that the testing equipment is functioning properly and that the testing procedures are being performed correctly. In the event that the Department identifies a problem with the testing equipment or the Contractor's testing techniques, the Contractor is given the opportunity to immediately correct the problem to the Department's satisfaction. If the problem cannot be immediately corrected, then the Contractor is required to stop production until the problem is adequately resolved.

ELECTRONIC SPREADSHEET FOR CALCULATIONS

The PWL system requires extensive calculations and the use of lookup tables to determine pay factors. Though these calculations can be done by hand, the amount of time and opportunity for errors is great. In addition to the PWL system, determining payment for small quantity LOTs and analyzing verification and resolution data adds to the complexity. The Department has developed an Excel spreadsheet with multiple pages that perform all of the required calculations and pay factor determinations. The spreadsheet encompasses dense-graded Superpave mixtures and open-graded friction course mixtures. Additionally, the spreadsheet generates random numbers to identify sampling points during production. The spreadsheet is password protected to prevent manipulation of specification tolerances, formulas, etc. The spreadsheet is available on the Department's website.

CONCLUSIONS AND RECOMMENDATIONS

1. The Department has developed and implemented a statistically based percent within limits approach for the acceptance and payment of hot-mix asphalt material. This approach replaces the "average deviation from target" approach used by the Department for over 20 years.
2. Acceptance and payment for dense-graded Superpave mixtures is based on the following five asphalt material properties: 1) roadway density, 2) percent air voids, 3) asphalt binder content, 4) percent passing the No. 8 sieve, and 5) percent passing the No. 200 sieve.
3. Acceptance and payment for open-graded friction course mixtures is based on the following four asphalt material properties: 1) asphalt binder content, 2) percent

passing the 3/8 inch sieve, 3) percent passing the No. 4 sieve, and 4) percent passing the No. 8 sieve.

4. Contractor's test data was used to develop representative standard deviations of the asphalt material properties used for payment and acceptance. These standard deviations were used to develop tolerance values used in the PWL system.
5. A system has been developed to handle acceptance and payment of small quantity LOTs (two or less sublots).
6. In lieu of the Department sampling and testing numerous independent samples and performing F and t-tests to validate the Contractor's results, an alternative verification and resolution system has been developed.
7. An Excel spreadsheet has been created to perform the calculations and pay factor determinations.
8. After one to two years of constructing projects using the new PWL system, construction data needs to be analyzed to assess the validity of the standard deviations and tolerance values currently being used. This should be done for both large and small quantity production levels.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Matt Dillon and Virdell Hill of the State Materials Office for their work in obtaining construction records.

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