University of Nevada, Reno

Review of Percent Within Limits for Dense Graded HMA

A thesis submitted in partial fulfillment of the
requirements of the degree of Master of Science in
Civil and Environmental Engineering

by

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ABSTRACT

Nevada Department of Transportation (NDOT) has asked the University of Nevada, Reno to research and develop a Percent With Limits program. They find it difficult to enforce demerits when pavement sections are measured to be out of tolerance. For example, if a pavement section is found to have poor compaction or unacceptable asphalt binder content, they are supposed to suspend the construction. However, they may allow construction to proceed if those same sections pass other parameters. This ambiguity has caused confusion among the contractors and it may have allowed inadequate pavement sections be left in place without penalty. In addition, NDOT currently evaluates pavement sections based on single test points or an average of the test points. There is no consideration for the variability or consistency of the measured parameters, as long as they are within the upper and lower specification limits.

A literature review covering 11 states was performed in order to present to NDOT how other states utilize PWL. They include Arizona, California, Colorado, Idaho, Kansas, Michigan, New Mexico, New York State, Utah, Vermont, and Washington State. These states employ the PWL methodology and details of their methods were evaluated. This report provides information such as lot and sublot sizes, parameters used for testing, frequency of testing, upper and lower specification limits, pay factor calculations, and how the pay adjustment was conducted.

Pavement performance relies heavily on how well it was constructed. By utilizing a PWL system, contractors are provided an incentive to produce higher quality roads by building them closer to the target values and with less variability. PWL allows the agency to estimate the quality of the constructed pavement and issue bonuses or penalties based on the justified results of the PWL analysis.

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Chapter 1 – INTRODUCTION

An effective way to improve the quality of constructed asphalt pavements is to provide an incentive. A system of rewards and penalties put in place will encourage the contractor to build roads that will perform at or above the desire levels. This method will promote innovation and construction of higher quality roadways; therefore increase the performance and life of the pavement. Such a concept is already used successfully by many other states and is recommended by the Federal Highway Administration (FHWA). It is known as Percent Within Limits (PWL).

Nevada Department of Transportation (NDOT) funded a research effort at the University of Nevada, Reno to investigate PWL programs in order to develop one for Nevada's conditions. Presently, NDOT measures various properties of the roadways and if they are within specified tolerances, then the contractor is paid in full at the agreed contract price. However, if these properties are not within the predetermined limits, the section may have to be removed and reconstructed. A PWL program encourages contractors to build higher quality roads. It does so by providing a monetary incentive to build roads with in-place properties that are closer to the target value and with less variability.

The construction of the HMA layer represents the most critical step toward long lasting HMA pavements. HMA mixtures are designed to resist fatigue cracking, rutting, and thermal cracking. However, if they are not constructed to the specified limits, there is a high chance that the pavement section will have lower performance than the optimum mixture. The long-term performance of the HMA pavement relies heavily on how well it is constructed.

Several PWL programs used by other State Highway Agencies (SHA) were examined. Specifics such as the type of measured properties, how the pay adjustments are calculated, and the effectiveness of their programs are researched. These findings were presented to NDOT, and an initial PWL program tailored to Nevada was recommended.

1.1 Objective

The objective of this research is to examine programs used by other SHAs and to recommend the set of parameters and properties to be included in a PWL system that meets Nevada's environmental, traffic, materials, and construction conditions.

A major part of this initial development effort is to examine NDOT's current specification system for construction of HMA mixtures and to identify the various parts of a PWL that are consistent with NDOT capabilities. In addition, it must be recognized that any recommended PWL system must be implementable by NDOT and acceptable by the construction industry in Nevada.

Chapter 2 – BACKGROUND

PWL is a quality of measurement that has been used by the Department of Defense since 1958 and more than half of SHAs, the Federal Highway Administration (FHWA), and Federal Aviation Administration (FAA) use it. A report published in 2005 by the National Cooperative Highway Research Program shows that 27 out of 45 state agencies surveyed utilize some type of PWL program (Hughes 2005).

Initially, the military developed the PWL method and called it Percent Defective (PD) (Newcomb and Epps 2001). The New Jersey Department of Transportation was the first to practice this concept in the construction of HMA pavements in the 1970s (Hughes 2006). Since then, Percent Defective has been changed to Percent Within Limits mainly for psychological reasons and the fact that the material outside the limits may not necessarily be defective. The materials produced outside the limits just meant that they are of lower, less desirable quality (Hughes 2006).

There are several advantages of using PWL:

1) It provides an incentive for contractors to reduce variability and provide a more uniform product.

2) Both the contractor and the SHA can calculate their risks using PWL.

3) PWL is a quality measure sensitive to both the average and variability.

4) It is recommended by the American Association of State Highway and Transportation Official (AASHTO) and is presented as a featured method in R 9.

5) It encourages innovation to develop better construction techniques and methods in order to produce higher quality roads.

Typically, NDOT specifies lower and upper specification limit for each property. However, there is no requirement for uniformity and precision between the allowable upper and lower limits. Because of this, a section of roadway may have inconsistent performance due to high variability of the measured parameters. Even though this is acceptable under the current standards and the properties may be within limits, having such inconstant results may reduce the life of the pavement section. Distresses such as rutting, fatigue cracking, and moisture damage are just some of the issues that may be experienced at various locations within the constructed pavement. Due to the chances of high variability, such distresses may develop and could potentially be too costly for the agency to have to later address.

There are three essential steps for the successful construction of HMA pavements: mix design, production, and quality control (QC)/quality assurance (QA). Every SHA has well documented procedures for each of the three steps. However, the processes used in each of these three steps differ dramatically between SHAs especially in the area of QC/QA. PWL deals with the QC/QA steps for acceptance and pay adjustments which is the main focus of this project.

QC represents the testing program that the contractor is required to conduct in order to assess the uniformity and acceptability of the produced HMA mixture (TRB 2005). QA represents the testing program that the SHA conducts in order to assess the conformance of the produced HMA mix with the agency’s applicable specifications (TRB 2005). For final acceptance of the HMA mix, some agencies use both the QC and QA testing results while others only use QA testing results. The specific properties measured in the QC and QA programs also vary considerably among SHAs.

2.1 Defining PWL

PWL is a measure of quality. It is the percentage of the lot of the material falling between the lower specification limit (LSL) and the upper specification limit (USL) (TRB 2005). This measure of quality uses the sample average ($\bar{X}$) and the sample standard deviation (s) to estimate the percentage of the population that is within the specification limits. It is similar in concept to determining the area under the normal curve (TRB 2005). A major assumption of the PWL method is that the population being sampled is normally distributed (Burati et al. 2003). Random samples are measured by the agency and/or the contractor. Bonus and penalty adjustments are issued based on controlling both the center and the spread of the measurements to find how much of the material represented by those measurements falls within the specification limits.

In order to clearly determine the payment adjustments, the amount of material subjected to these changes must be defined. A lot, also known as a population, is a specific quantity of similar material, construction, or units of product, subjected to either an acceptance or process control decision. The size of a lot is based on the discretion of the agency. It could be a predetermined tonnage of material or it could be the amount of material per time frame, such as one day of production. A lot is divided into sublots which are typically the amount of material one measurement of one specific property represents. Therefore, there could be a varying number of sublots per lot depending on the property that is being considered. In order to precisely determine the PWL of a lot, all the material of the lot must be measured in its entirety. However, since this is unrealistic and not practical, only a limited number of random samples are measured. The ideal number of measurements taken per lot considers the following two factors:

1) Greater number of measurements provides a better, more accurate representation of the lot.

2) Fewer measurements mean lower operating costs. Testing excessive number of samples may be expensive and unwarranted. Repairs would also need to be performed on areas where samples were removed.

There is no universally agreed upon number of sublots per lot. It is up to the agency to determine the size of the lot.

To actually determine the quality of the roadway, various properties are measured. These properties may include the following:

- Air voids (Va)
- Voids in mineral aggregate (VMA)
- Asphalt binder content (% AC)
- Compaction
- Gradation
- Smoothness

Lower and upper specification limits are established for the selected properties. These limits allow for the determination of the Quality Index. In order to calculate the Quality Index, the average and standard deviation must be determined. The average is determined using Equation 1 (AASHTO R 9 2005).

$$\bar{X} = \frac{1}{n}(X_1 + \cdots + X_n)$$

Equation 1. Average.

The standard deviation is calculated using Equation 2.

$$s = \sqrt{\sum (X_i - \bar{X})^2 / (n-1)}$$

Equation 2. Standard deviation.

where:

$\bar{X}$ = sample mean for the lot

X_i = individual measurements

n = sample size

s = sample standard deviation, also known as variance

Using the sample standard deviation and average, the upper and lower quality indexes can be found.

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

Equation 3. Lower quality index.

$$Q_U = \frac{USL - \bar{X}}{s}$$

Equation 4. Upper quality index.

where:

Q_L = quality index for the lower specification limit

Q_U = quality index for the upper specification limit

LSL = lower specification limit

USL = upper specification limit

Once the Q_L and Q_U are calculated, then PWL_L and PWL_U can be estimated respectively using Table 18. The total PWL value is determined as:

$$PWL = PWL_U + PWL_L - 100$$

Equation 5. PWL equation.

where:

PWL_U = percentage of the material falling within the upper specification limit

PWL_L = percentage of material falling above the lower specification limit

Figure 1 illustrates the concept of PWL. Percent Within Limits is the area under the normal distribution curve and between the specification limits. The more material that falls within upper and lower specification limits, the higher the PWL value will be. PWL quantifies the quality of the constructed roadway. The PWL value can be between zero and one hundred. One hundred indicates that 100% of the material falls within the allowable limits and that the variability is low. The material outside the specification limits is labeled as Percent Defective. If the measurements are inconsistent and highly variable, then the wider the PWL normal distribution curve will be, therefore allowing more area to fall outside the specification limits. Agencies generally accept 10% defective material. This means that 10% of the material can be outside of the upper and lower specification limits in order to receive full payment. Anything more than 10% defective, the contractor will be issued a penalty. If more than 90% of the material is within limits, then the contractor is awarded a bonus. Therefore, PWL is beneficial to both the contractor and the agency by rewarding contractors for quality construction and providing the agency better pavement.

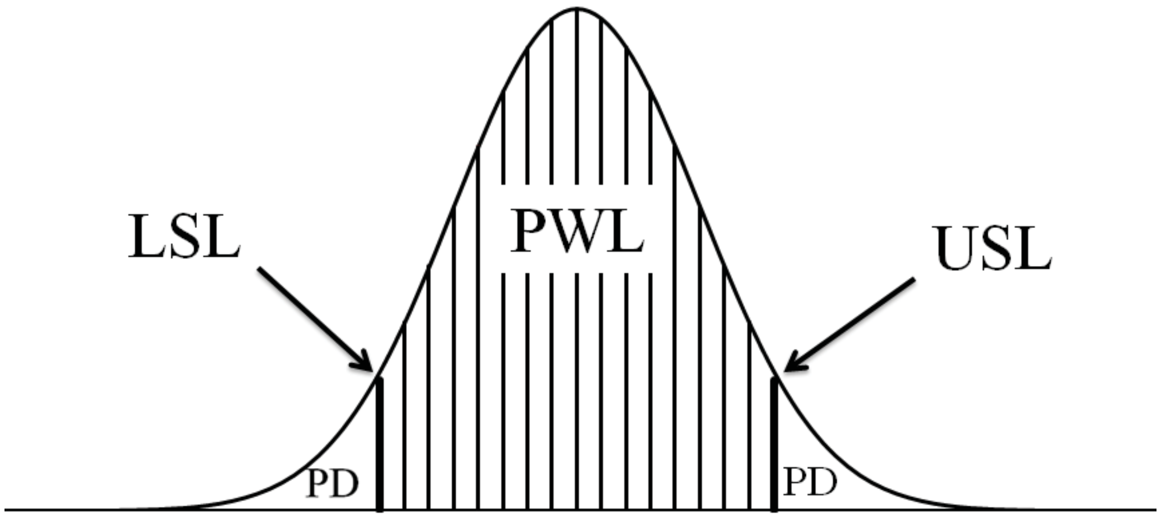

Figure 1. PWL Concept.

To translate PWL to a pay adjustment, pay factors (PF) are used (TRB 2005). An equation or table is commonly used to correlate the PWL value to the PF. The PF is determined for each parameter for each lot (i.e. one PF for Gradation, one PF for % AC, and one PF for Compaction). FHWY recommends a maximum PF of 1.05. This means that the contractor can obtain a 5% bonus if the PWL value measures to be 100%.

The pay adjustment made per lot is calculated based on the total lot pay factor (TLPF). The TLPF is determined by one of the following methods:

1) Taking an average all the PFs

$$TLPF = \frac{1}{n}(PF_1 + \cdots + PF_n)$$

Equation 6.Total Lot Pay Factor average.

2) Assigning different weights to different PFs

$$TLPF_{Weighted} = W_1 PF_1 + W_2 PF_2 + \cdots + W_n PF_n$$

Equation 7. Total Lot Pay Factor weighted average.

The agency selects different weights, W_n, for different PFs to come up with a weighted TLPF. Using a weighted average to calculate the TLPF allows the agency to put more emphasis on specific properties that they feel is more critical. The TLPF is then multiplied with the contract unit price to determine the final amount paid. The contractor can be awarded a bonus of 5% above the agreed contract price. However, if the PWL is determined to be less than 90, then the contractor may be penalized. Correlating bonuses and penalties with calculated PWL value provides a strong incentive for contractor's to build better roads.

2.2 Acceptance and Validation Testing

For agencies that use both QC and QA, there are data statistical tools such as the F and T-tests that can be used to assess, verify, and validate the two different sets of data (AASHTO R 9 2005). These statistical tools advise both parties if the information they presented is consistent with one another. If they are deemed to be different, then one of the two parties may be presenting inaccurate measurements. The null hypothesis for each test is that the contractor's QC and agency's QA results are from the same population. Level of significance (α) is recommended to be selected as a value between 0.01 and 0.05. It is the criterion used for rejecting the null hypothesis. The lower the significance level, the more the data must diverge from the null hypothesis to be significant. Therefore, a value of 0.01 is more conservative than a value of 0.05 for level of significance.

The F-test is performed to assess if the two measurements come from populations that have the same variance. It does so by comparing the ratio of two variances to a critical level. If the variances are identical, then, the ratio of the variances will be 1. F-value is defined in Equation 8.

$$F = \frac{s_c^2}{s_a^2}$$

Equation 8. F-critical value.

where:

s_c = variance of the contractor's data set

s_a = variance of the agency's data

The calculated F-value is compared to the F-critical value that is obtained from standard statistic tables as a function of degree of freedom (DF) and level of significance (α). DF is simply the sample size minus 1, (n – 1). Table 19 provides F-critical values for a level of significant of 0.025. If the calculated F-value is determined to be less than the F-critical value, then the null hypothesis is accepted. Therefore, the two sets of tests come from the same population in regards to the variance.

If the data sets pass the F-test, then the T-test is performed to determine if they have equal means. The T-value is calculated as follows:

$$t = \frac{|X_c - X_a|}{Sp\sqrt{\frac{1}{n_c} + \frac{1}{n_a}}}$$

$$S_P = \sqrt{\frac{S_c^2(n_c - 1) + S_v^2(n_a - 1)}{n_c + n_a - 2}}$$

Equation 9. T-value calculation equation.

where:

n_c = number of contractor's tests

n_a = number of agency tests

X_c = mean of contractor tests

X_v = mean of agency tests

S_p = pooled standard deviation

S_c = standard deviation of contractor's tests

S_a = standard deviation of agency's tests

The calculated T-value is compared to a T-critical value obtained from standard established tables. Table 20 displays the T-critical table for a level of significant of 0.025. Degree of Freedom is the combined number of samples from both the agency and the contractors minus two ($n_c + n_a - 2$). If the calculated T-value is less than the T-critical value found from the established table, the null hypothesis is accepted. Therefore, the two data sets have equal means and it is determined that they come from the same population.

F and T tests are the recommended statistical tools to determine if the contractor's QC and agency's QA data sets come from the same population. Passing results indicates that the contractor's QC data are validated and can be used in the payment adjustment.

2.3 Current NDOT Procedures

NDOT's present system does not utilize PWL. Variability is not considered. The Table 1 summarizes NDOT's quality assurance parameters and frequency of sampling/testing (NDOT 2003 and NDOT 2011).

Table 1. Current NDOT test methods, tolerances, and frequencies.

TEST		TEST METHOD	REQUIREMENTS	FREQUENCY		
				1-2 days	3+ days	1-3+ days
Compaction (Average of 5)		Nev. T324/T335/T336	92 - 96%	1,100 m^2	2,200 m^2	-
Compaction (Single value)		Nev. T324/T335/T336	90 - 97%	1,100 m^2	2,200 m^2	-
% AC (DWA)		Nev. T761	±0.4% TV	500 tons	500 tons	-
Gradation	≥#4	Nev. T206	±7.0% TV	500 tons	500 tons	-
	#8	Nev. T206	±4.0% TV	500 tons	500 tons	-
	#10	Nev. T206	±4.0% TV	500 tons	500 tons	-
	#200	Nev. T206	±2.0% TV	500 tons	500 tons	-
Va (Type 2 and 3)		AASHTO T269	3 - 6%	-	-	10,000 tons or 2/wk
Va (Type 2C)		AASHTO T269	4 - 7%	-	-	10,000 tons or 2/wk
Va (Type 2 and 3) Premixed		AASHTO T269	6 - 9%	-	-	10,000 tons or 2/wk
Stabilometer Value (Type 2)		Nev. T303	35 Min	-	-	10,000 tons or 2/wk
Stabilometer Value (Type 2C)		Nev. T303	37 Min	-	-	10,000 tons or 2/wk
Stabilometer Value (Type 3)		Nev. T303	30 Min	-	-	10,000 tons or 2/wk
Indirect Tensile Strength (Type 2 and 2C)		Nev. T341	65 psi Min	-	-	10,000 tons or 2/wk
Indirect Tensile Strength (Type 3)		Nev. T341	58 psi Min	-	-	10,000 tons or 2/wk
Indirect Tensile Strength (Retained Strength)		Nev. T341	70% Min	-	-	10,000 tons or 2/wk

If the measured properties are found to be outside the specification limits, then the job is supposed to be suspended. Single values or averages are used. NDOT's current practices do not provide an incentive for contractor's to build roads with high consistency. Contractors are only required to construct roadways to be within the upper and lower specification limits.

The implementation of a PWL program in Nevada can address several issues. NDOT will be able to quantity the quality of the road by calculating the PWL value. A PWL of 100 indicates all of the material represented by the random samples are estimated to be within the upper and lower specification limits and are close to the target value. A PWL of 50 indicates the road way was poorly constructed and a severe deduction in pay or removal of the section may be warranted. In addition, PWL will provide contractors an incentive to build roads closer to the target value and with higher consistency in order to be awarded a bonus.

Chapter 3 – LITERATURE REVIEW

A significant portion of this project is to conduct a thorough investigation of how other SHAs structure their PWL programs. By knowing how other PWL systems function, better recommendations can be made to NDOT.

A report published in 1998 by Schmitt et. Al conducted a survey on various properties that are measured through QA programs in of 40 states. The survey identified three primary measures of acceptance testing:

1) Mix properties
2) Density
3) Smoothness

Table 21 and Table 22 summarize the mix properties and density parameters identified by Schmitt et. al. The mix properties that are most commonly used for acceptance include:

1) Aggregate gradation
2) Asphalt content (% AC)
3) Mixture volumetrics

The data also revealed that there are significant variations among the practices used by various SHAs in terms of the following items:

1) Size of lots and sublots
2) Sampling location
3) Testing method
4) Compliance measures (method used to measure specific compliance)

The majority of the SHAs use the Quality Level Analysis to measure the compliance of the HMA mixtures to the agency's specifications. In addition, the most common Quality Level Analysis is the PWL process. This reveals that the use of the PWL method for evaluating the compliance of HMA mixtures to SHAs specifications has been very popular.

Measured properties used to identify pay adjustment were also surveyed by Schmitt et. al. Table 23 summarizes the various properties that have been used in calculations of pay adjustments by various SHAs. A summary of the information from Schmitt et. Al reveals the following:

1) The majority of the SHAs establish a factor which may result in a bonus or penalty for the pay adjustment.
2) The majority of SHAs use aggregate gradation, asphalt content, air voids, field density, and smoothness as measures of compliance with specifications.
3) The percent passing #200 sieve is the most commonly used gradation attribute.
4) The majority of the SHAs use a weigh factor to combine the influence of the various parameters towards the final pay adjustment.

Schmitt et. al's survey made it clear that many states favor the use of PWL systems. To acquire a better understanding of various PWL systems, eleven SHAs with PWL programs were further examined which include the following:

1. Arizona
2. California
3. Colorado
4. Idaho
5. Kansas
6. Michigan

7. New Mexico
8. New York
9. Utah
10. Vermont
11. Washington State

The review process consisted of identifying the following information from each of the 11 SHAs:

- Type of data used in PWL: QC, QA, or both
- Definition of lot and sublot sizes
- Measured properties
- Method used to determine the overall PWL for a lot
- Method used to determine pay adjustments for a lot
- Specification limits

ARIZONA

Type of data used: Agency's QA data

Statistical method used to assess and verify QC/QA data: No statistical method is used because only the agency's QA data is taken into consideration.

Mix design method: Marshall

Lot, sublot, measured properties, and test methods:

Lot: 1 shift of production

Sublot: 4 sublots per lot for mixture properties and 10 sublots per lot for compaction. (Each measurement constitutes as a sublot. Therefore 1 measurement is taken per sublot)

Measured properties:

1) Va
   a. Method: AASHTO T 269
2) %AC
   a. Method: ARIZ 427 (ignition oven)
3) Gradation: 3/8”, #8, #40, #200
   a. Method: ARIZ 427 (ignition oven)
4) Compaction
   a. Method: ARIZ 412 (nuclear density gage)

Specification limits:

Table 2. Arizona properties and specification limits.

<table>
<tr><th colspan="3"></th><th>Lower Limit</th><th>Upper Limit</th><th>Target Value</th></tr>
<tr><td rowspan="6">Mixture Properties</td><td colspan="2">Va</td><td>-2.0 of TV</td><td>+1.5 of TV</td><td>*</td></tr>
<tr><td colspan="2">% AC</td><td>-0.50 of TV</td><td>+0.50 of TV</td><td>*</td></tr>
<tr><td rowspan="4">Gradation</td><td>3/8"</td><td>-6.0 of TV</td><td>+6.0 of TV</td><td>*</td></tr>
<tr><td>#8</td><td>-6.0 of TV</td><td>+6.0 of TV</td><td>*</td></tr>
<tr><td>#40</td><td>-5.0 of TV</td><td>+5.0 of TV</td><td>*</td></tr>
<tr><td>#200</td><td>-2.0 of TV</td><td>+2.0 of TV</td><td>*</td></tr>
<tr><td colspan="3">In-place AV, %</td><td>4.0</td><td>9.0</td><td>7.0</td></tr>
<tr><td colspan="6">* Target Value (TV) depends on mix design.</td></tr>
</table>

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

The mixture properties lot pay adjustment is determined in accordance with the following procedure:

1) The individual PWL values and pay factor for Gradation, % AC, and Va are determined.
2) The pay factor is picked as the one with the lowest value for the individual measured characteristics for Gradation and % AC. Therefore, a single pay adjustment is used for Gradation and % AC.

Table 3 shows the pay factor in terms of the PWL for each property.

Table 3. Arizona PFs for % AC, Gradation, Va, and Compaction.

PWL	% AC and Gradation	Va	Compaction
100	$0.00	+$1.00	+$1.00
95-99	$0.00	+$0.50	+$0.00
90-94	$0.00	$0.00	$0.00
85-89	$0.00	-$0.25	-$0.25
80-84	-$0.25	-$0.50	-$0.50
75-79	-$0.50	-$0.75	-$0.75
70-74	-$0.75	-$1.00	-$1.00
65-69	-$1.00	-$1.25	-$1.30
60-64	-$1.50	-$1.50	-$1.75
55-59	-$2.00	-$2.00	-$2.25
50-54	-$2.50	-$2.50	-$3.00
< 50	Reject		

Because mixture properties and compaction have different number of sublots per lot, two adjustments are made.

Equation 10. Arizona mixture pay adjustment.

$$Lot\ Payment\ Adjustment\ (Mixture) = \left(PF_{Gradation\ \&\ \%\ AC} * + PF_{Va}\right) \times Lot\ Quantity\ (tons)$$

*Select lowest PF of all the individual Gradation and % AC pay factors.

Equation 11. Arizona Compaction PayAdjustment.

$$Lot\ Payment\ Adjustment\ (Compaction) = \left(PF_{Compaction}\right) \times Lot\ Quantity\ (tons)$$

Notes:

- Positive mixture properties lot pay factors reduces to zero when the compaction lot is in reject and the material is allowed to be left in place.
- Positive compaction lot pay factors reduces to zero when the mixture properties lot is in reject and the material is allowed to remain in place.
- For any mixture properties lot that is in reject due to asphalt cement content but allowed to remain in place, payment will not be made for asphalt cement quantities in excess of the Upper Limit.

CALIFORNIA

Type of data used:

- California uses QA data. They verify it with QC data before any penalties are issued.
- For compaction, only QA data is used.

Statistical method used to assess and verify QC/QA data: T-Test is used to assess the statistical difference between QC and QA data.

Mix design method: Hveem

Lot, sublot, measured properties, and test methods:

Lot: Typically 20 sublots

Sublot: 750 tons of material

Measured properties:

1) %AC
    a. Weight: 30%
    b. Method: CT 379 (nuclear gage) or 382 (ignition oven)
    c. QC data is used if it verifies with QA data.
    d. Measured once per sublot
2) Gradation
    a. Weight: 30%
    b. Method: CT 202 (ignition oven)
    c. QC data is used if it verifies with QA data.
    d. Measured once per sublot
3) Compaction
    a. Weight: 40%
    b. Method: CT 308 (core) or CT 375 (nuclear density gage)
    c. Only QA data is used.
    d. Measured 3 times per sublot.

Specification limits:

The gradation limits in Table 4 are based on California's ¾" HMA Type A and B. The remaining properties typically have the same limits regardless of mix type.

Table 4. California properties and specification limits.

		Lower Limit	Upper Limit	Target Value
% AC		-0.45 of TV	+0.45 of TV	*
Gradation	**1/2"**	-6.0 of TV	+6.0 of TV	70-90
	#8	-5.0 of TV	+5.0 of TV	32-40
	#200	-2.0 of TV	+2.0 of TV	2-7
Compaction, %		-2.0 of TV	+2.0 of TV	94
* Target Value (TV) depends on mix design.				

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. Instead of calculating the PWL for each of these measured properties, California calculates the Maximum Allowable Percent Defective (PD)

In order to describe PD, let’s define both PWL and PD.

PWL is defined as Percent Within Upper Limit and Percent Within Lower limit minus 100 from Equation 5.

$$PWL = PWL_U + PWL_L - 100$$

PD is defined as Percent Defective outside Upper Limit and Percent Defective outside Lower Limit.

$$PD = P_U + P_L$$

Equation 12. Percent Defective.

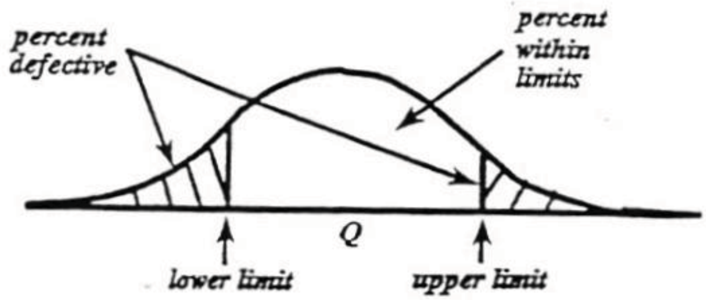

Figure 2. Percent Defective illustration.

P_U and P_L are identified using Figure 3 from California's Standard Specifications using the quality limits (Q_U and Q_L).

P_U or P_L	Upper Quality Index Q_U or Lower Quality Index Q_L												
	Sample Size (n)												
	5	6	7	8	9	10-11	12-14	15-17	18-22	23-29	30-42	43-66	>66
0	1.72	1.88	1.99	2.07	2.13	2.20	2.28	2.34	2.39	2.44	2.48	2.51	2.56
1	1.64	1.75	1.82	1.88	1.91	1.96	2.01	2.04	2.07	2.09	2.12	2.14	2.16
2	1.58	1.66	1.72	1.75	1.78	1.81	1.84	1.87	1.89	1.91	1.93	1.94	1.95
3	1.52	1.59	1.63	1.66	1.68	1.71	1.73	1.75	1.76	1.78	1.79	1.80	1.81
4	1.47	1.52	1.56	1.58	1.60	1.62	1.64	1.65	1.66	1.67	1.68	1.69	1.70
5	1.42	1.47	1.49	1.51	1.52	1.54	1.55	1.56	1.57	1.58	1.59	1.59	1.60
6	1.38	1.41	1.43	1.45	1.46	1.47	1.48	1.49	1.50	1.50	1.51	1.51	1.52
7	1.33	1.36	1.38	1.39	1.40	1.41	1.41	1.42	1.43	1.43	1.44	1.44	1.44
8	1.29	1.31	1.33	1.33	1.34	1.35	1.35	1.36	1.36	1.37	1.37	1.37	1.38
9	1.25	1.27	1.28	1.28	1.29	1.29	1.30	1.30	1.30	1.31	1.31	1.31	1.31
10	1.21	1.23	1.23	1.24	1.24	1.24	1.25	1.25	1.25	1.25	1.25	1.26	1.26
11	1.18	1.18	1.19	1.19	1.19	1.19	1.20	1.20	1.20	1.20	1.20	1.20	1.20
12	1.14	1.14	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
13	1.10	1.10	1.10	1.10	1.10	1.10	1.11	1.11	1.11	1.11	1.11	1.11	1.11
14	1.07	1.07	1.07	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
15	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02

Figure 3 . California Standard Specifications for P_U and P_L.

How the pay adjustment is made:

The pay adjustment is based on the Gradation and %AC data QA data. Before a bonus or penalty is issued, the data is verified with QC data using F and T-tests. Once the PD is found for %AC, Gradation (for all 3 sieves), and Compaction, it is used to find the corresponding PF, which is labeled as Quality Factor, using the Figure 4.

The pay adjustment is the sum of the subsequent equations:

$$\%\ AC\ Pay\ Adjustment = (QF_{\%AC} - 1) \times Lot\ Quantity\ (tons) \times Unit\ Price \times 0.30$$

$$½”\ Sieve\ Pay\ Adjustment = (QF_{1/2”} - 1) \times Lot\ Quantity\ (tons) \times Unit\ Price \times 0.05$$

$$\#8\ Sieve\ Pay\ Adjustment = (QF_{\#8} - 1) \times Lot\ Quantity\ (tons) \times Unit\ Price \times 0.10$$

$$\#200\ Sieve\ Pay\ Adjustment = (QF_{\#200} - 1) \times Lot\ Quantity\ (tons) \times Unit\ Price \times 0.15$$

$$Compaction\ Pay\ Adjustment = (QF_{Compaction} - 1) \times Lot\ Quantity\ (tons) \times Unit\ Price \times 0.40$$

Equation 13. California pay adjustments.

Quality Factors

Quality Factor	Maximum Allowable Percent Defective ($P_U + P_L$)												
	Sample Size (n)												
	5	6	7	8	9	10-11	12-14	15-17	18-22	23-29	30-42	43-66	>66
1.05				0	0	0	0	0	0	0	0	0	0
1.04			0	1	3	5	4	4	4	3	3	3	3
1.03		0	2	4	6	8	7	7	6	5	5	4	4
1.02		1	3	6	9	11	10	9	8	7	7	6	6
1.01	0	2	5	8	11	13	12	11	10	9	8	8	7
1.00	22	20	18	17	16	15	14	13	12	11	10	9	8
0.99	24	22	20	19	18	17	16	15	14	13	11	10	9
0.98	26	24	22	21	20	19	18	16	15	14	13	12	10
0.97	28	26	24	23	22	21	19	18	17	16	14	13	12
0.96	30	28	26	25	24	22	21	19	18	17	16	14	13
0.95	32	29	28	26	25	24	22	21	20	18	17	16	14
0.94	33	31	29	28	27	25	24	22	21	20	18	17	15
0.93	35	33	31	29	28	27	25	24	22	21	20	18	16
0.92	37	34	32	31	30	28	27	25	24	22	21	19	18
0.91	38	36	34	32	31	30	28	26	25	24	22	21	19
0.90	39	37	35	34	33	31	29	28	26	25	23	22	20
0.89	41	38	37	35	34	32	31	29	28	26	25	23	21
0.88	42	40	38	36	35	34	32	30	29	27	26	24	22
0.87	43	41	39	38	37	35	33	32	30	29	27	25	23
0.86	45	42	41	39	38	36	34	33	31	30	28	26	24
0.85	46	44	42	40	39	38	36	34	33	31	29	28	25
0.84	47	45	43	42	40	39	37	35	34	32	30	29	27
0.83	49	46	44	43	42	40	38	36	35	33	31	30	28
0.82	50	47	46	44	43	41	39	38	36	34	33	31	29
0.81	51	49	47	45	44	42	41	39	37	36	34	32	30
0.80	52	50	48	46	45	44	42	40	38	37	35	33	31
0.79	54	51	49	48	46	45	43	41	39	38	36	34	32
0.78	55	52	50	49	48	46	44	42	41	39	37	35	33
0.77	56	54	52	50	49	47	45	43	42	40	38	36	34
0.76	57	55	53	51	50	48	46	44	43	41	39	37	35
0.75	58	56	54	52	51	49	47	46	44	42	40	38	36
	60	57	55	53	52	51	48	47	45	43	41	40	37
	61	58	56	55	53	52	50	48	46	44	43	41	38
Reject	62	59	57	56	54	53	51	49	47	45	44	42	39
	63	61	58	57	55	54	52	50	48	47	45	43	40
	64	62	60	58	57	55	53	51	49	48	46	44	41
Reject Values Greater Than Those Shown Above													

Figure 4. California Standard Specifications Quality Factors.

COLORADO

Type of data used: Colorado uses QA data for PWL calculations.

Statistical method used to assess and verify QC/QA data: None

Mix design method: Superpave

Lot, sublot, measured properties, and test methods:

CDOT does not use lots to evaluate pavements. CDOT groups the material by processes. A process is defined as homogeneous material. As long as the material does not change it is continuously added to the current process for the various test elements. There is no upper limit to the size of a process. Any time the material changes a new process is created.

Measured properties:

1) %AC
    a. Measured: once per 1000 tons
    b. Weight: 25%
2) Gradation
    a. Measured: once per 2000 tons
    b. Weight: 15%
3) Compaction
    a. Measured: once per 500 tons
    b. Weight: 45%
4) Joint Density
    a. Measured: one core per 5000 linear feet of joint

b. Weight: 15%

Specification limits:

Table 5. Colorado properties and specification limits.

<table>
<tr><th colspan="2"></th><th>Lower Limit</th><th>Upper Limit</th><th>Target Value</th></tr>
<tr><td colspan="2">%AC</td><td>-0.3%</td><td>+0.3%</td><td>*</td></tr>
<tr><td rowspan="5">Gradation</td><td>3/8" or larger</td><td>-6.0%</td><td>+6.0%</td><td>*</td></tr>
<tr><td>#4</td><td>-5.0%</td><td>+5.0%</td><td>*</td></tr>
<tr><td>#8</td><td>-5.0%</td><td>+5.0%</td><td>*</td></tr>
<tr><td>#30</td><td>-4.0%</td><td>+4.0%</td><td>*</td></tr>
<tr><td>#200</td><td>-2.0%</td><td>+2.0%</td><td>*</td></tr>
<tr><td colspan="2">Compaction</td><td>92%</td><td>96%</td><td>94%</td></tr>
<tr><td colspan="2">Joint Density</td><td>88%</td><td>96%</td><td>92%</td></tr>
<tr><td colspan="5">* Target value depends on mix design.</td></tr>
</table>

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

After the QL is determined for each property, then the PF is calculated. PF calculation for Colorado is more complex than any other state that was reviewed. The equation to determine the PF depends on the sample size of the lot, n, which is referred to as Pn in Colorado's Standard Specifications for Road and Bridge Construction.

When the sample size, Pn is $3 \leq Pn \leq 9$ or > 200, PF is calculated using the formulas designated in Table 105-3 or (Figure 5).

Table 105-3
FORMULAS FOR CALCULATING PF BASED ON Pn

Pn	When Pn as shown at left is 3 to 9, or greater than 200, use designated formula below to calculate Pay Factor, PF = ...,when Pn is 10 to 200, use formula (1) above:	Maximum PF
3	0.31177 + 1.57878 (QL/100) - 0.84862 (QL/100)^2	1.025
4	0.27890 + 1.51471 (QL/100) - 0.73553 (QL/100)^2	1.030
5	0.25529 + 1.48268 (QL/100) - 0.67759 (QL/100)^2	1.030
6	0.19468 + 1.56729 (QL/100) - 0.70239 (QL/100)^2	1.035
7	0.16709 + 1.58245 (QL/100) - 0.68705 (QL/100)^2	1.035
8	0.16394 + 1.55070 (QL/100) - 0.65270 (QL/100)^2	1.040
9	0.11412 + 1.63532 (QL/100) - 0.68786 (QL/100)^2	1.040
10 to 11	0.15344 +1.50104 (QL/100) - 0.58896 (QL/100)^2	1.045
12 to 14	0.07278 + 1.64285 (QL/100) - 0.65033 (QL/100)^2	1.045
15 to 18	0.07826 + 1.55649 (QL/100) - 0.56616 (QL/100)^2	1.050
19 to 25	0.09907 + 1.43088 (QL/100) - 0.45550 (QL/100)^2	1.050
26 to 37	0.07373 + 1.41851 (QL/100) - 0.41777 (QL/100)^2	1.055
38 to 69	0.10586 + 1.26473 (QL/100) - 0.29660 (QL/100)^2	1.055
70 to 200	0.21611 + 0.86111 (QL/100)	1.060
$\geq$ 201	0.15221 + 0.92171 (QL/100)	1.060

Figure 5. Colorado formulas for calculating PF based on Pn.

When the sample size Pn is $10 \leq Pn < 201$, the PF is computed using the following formula:

$$PF = \frac{PF1 + PF2}{2} + \left[\frac{PF2 + PF3}{2} - \frac{PF1 + PF2}{2}\right] \times \frac{(Pn2 - Pnx)}{(Pn2 - Pn3)}$$

Equation 14. Colorado PF calculation.

where, when referring to Table 105-3:

PF1 = PF determined as the next lowest Pn formula using process QL

PF2 = PF determined using the Pn formula shown in the process QL

PF3 = PF determined at the next highest Pn formula using the process QL

Pn2 = the lowest Pn in the spread of values listed for the process Pn formula

Pn3 = the lowest Pn in the spread of values listed for the next highest Pn formula

Pnx = the actual number of test values in the process

To better illustrate Colorado's PF calculation, the subsequent examples are provided:

Example 1:

When Pn is from 3 to 9 or greater than 200

Pn = 5 and QL= 81.9

Go to Table 105-3

Go to formula for Pn = 5

PF = 0.25529 + 1.48268(QL/100) – 0.67759(QL/100)2

PF = 0.25529 + 1.48268(81.9/100) – 0.67759(81.9/100)2 = 1.015

PF = 1.015, which less than the maximum allowable PF of 1.030. Therefore, the PF is calculated as 1.015.

Example 2:

When Pn is from 10 to 200

Pn = 13 and QL = 81.9

Use Table 105-3 to solve for PF1, PF2 and PF3 of Equation 1.

Use Table 105-3 to find Pn2, Pn3 and PnX of Equation 1.

PF1 = Formula for Pn = 10 to 11

PF1 = 0.15344 + [1.50104 X (81.9/100)] – 0.58896 X (81.9/100) X 2 = 0.988

Maximum allowable PF for Pn = 10 to 11 is 1.045

PF1 = 0.988

PF2 = Formula for Pn = 12 to 14

PF2 = 0.07278 + [1.64285 X (81.9/100)] – [0.65033 X (81.9/100) X 2] = 0.982

Maximum allowable PF for Pn = 12 to 14 is 1.045

PF2 = 0.982

PF3 = Formula for Pn = 15 to 18

PF3 = 0.07826 + [1.55649 X (81.9/100)] – [0.56616 X (81.9/100) X 2] = 0.973

Maximum allowable PF for Pn = 15 to 18 is 1.050

PF3 = 0.973

Pn2 = Lowest Pn in 12 to 14

Pn2 = 12

Pn3 = Lowest Pn in 15 to 18

Pn3 = 15

Pn = 13

$$PF = \frac{0.988 + 0.982}{2} + \left[\frac{0.982 + 0.973}{2} - \frac{0.988 + 0.982}{2}\right] \times \frac{(12 - 13)}{(12 - 15)} = 0.9825$$

Maximum allowable PF for Pn = 12 to 14 is 1.045, which is greater than 0.9825.

Therefore, the PF for this example is 0.9825.

Weighted Average

A weighted average is determined for each individual lot for the different lots. Colorado refers to the weighted average as Average Pay Factor, or PFA.

The following example shows how the PFA is determined:

PF1 = 1.011 for 10,000 tons

PF2 = 0.694 for 500 tons

PF3 = 1.022 for 10,500 tons

$$PFA = \frac{[10{,}000(1.011) + 500(0.694) + 10{,}500(1.022)]}{10{,}000 + 500 + 10{,}500} = 1.009$$

Composite Pay Factor

When each of the Element Pay Factors of an item has been calculated, the Composite Pay Factor (CPF) is then determined using the weighing factors. The Composite Pay Factor is the total pay factor for an item, such as HMA. The weight for each element is shown in Table 6.

Table 6. Colorado Weighting Factors.

	Weight
% AC	25%
Gradation	15%
Compaction	45%
Joint Density	15%

Example Composite Pay Factor calculation:

PFA for %AC = 1.026

PFA for Gradation = 1.014

PFA for Compaction = 1.009

PFA for Joint Density = 0.979

$$CPF = \frac{[.25(1.026) + .15(1.014) + .45(1.009) + .15(0.979)]}{.25 + .15 + .45 + .15}$$

CPF = 1.010

How the pay adjustment is made:

The pay adjustment for the lot is calculated using Equation 15.

Equation 15. Colorado pay adjustment.

Lot Pay Adjustment = (CPF – 1) x Lot Quantity (tons) x Unit Price

IDAHO

Type of data used:

Idaho uses QC and QA data for acceptance. They use the QC data of the contractor for pay adjustments if they are found to be true and match the QA data statistically. The QA data is not used for pay adjustments. It is only used to verify that QC data is accurate.

Idaho switched from the Hveem mix-design method to the Superpave design method in 2006. They presently only use the Superpave mix-design method.

Statistical method used to verify or asses the differences between QC/QA data:

Idaho uses F and T-test.

Measured properties, lot, and sublot sizes:

Lot: 1 shift of production (typically 1 day)

Sublot: 750 tons with a minimum of 3 sublots per day.

When Idaho performed Hveem mix designs, they used the following parameters for pay adjustments:

1. % AC
2. Gradation
3. In-place density

Currently, Idaho follows Superpave mix design procedures and the updated parameters are as follows:

1. VMA

a. Weight: 30%

b. Measured once per 750 tons (or minimum of 3 times per lot)

2. Va

a. Weight: 30%

b. Measured once per 750 tons (or minimum of 3 times per lot)

3. Compaction

a. Weight: 40%

b. Measured once per 750 tons (or minimum of 3 times per lot)

c. Method: AASHTO T 166, 209 (core) or AASHTO T 310 (nuclear density gage)

Specification limits:

Table 7. Idaho properties and specification limits.

		Lower Limit	Upper Limit	Target Value
Va		3.0%	5.0%	4.0%
VMA (nominal maximum aggregate size)	**1 1/2"**	11	None	-
	1"	12	None	-
	3/4"	13	None	-
	1/2"	14	None	-
	3/8"	15	None	-
Compaction (cores)		92	95.0	93.5
Compaction (nuclear gage)		91	95.5	93.3

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

Once the PWL is determined for each property, the PF can be determined. For Va, each lot will be assigned a PF using Equation 16.

$$PF_{Va} = \frac{55 + (0.5)PWL}{100}$$

Equation 16. Idaho Va PF.

For VMA and Compaction, the PWL, labeled as Quality Level, is determined using Figure 6.

Pay Factors
Pay Factor for a given Sample Size(n) and Quality Level

Pay Factor	*n* = 3	*n* = 4	*n* = 5	*n* = 6	*n* = 7	*n* = 8	*n* = 9	*n* = 10 to *n*=11	*n* = 12 to *n*=14	*n* = 15 to *n*=18
1.05	100	100	100	100	100	100	100	100	100	100
1.04	90	91	92	93	93	93	94	94	95	95
1.03	80	85	87	88	89	90	91	91	92	93
1.02	75	80	83	85	86	87	88	88	89	90
1.01	71	77	80	82	84	85	85	86	87	88
1.00	68	74	78	80	81	82	83	84	85	86
0.99	66	72	75	77	79	80	81	82	83	85
0.98	64	70	73	75	77	78	79	80	81	83
0.97	62	68	71	74	75	77	78	78	80	81
0.96	60	66	69	72	73	75	76	77	78	80
0.95	59	64	68	70	72	73	74	75	77	78
0.94	57	63	66	68	70	72	73	74	75	77
0.93	56	61	65	67	69	70	71	72	74	75
0.92	55	60	63	65	67	69	70	71	72	74
0.91	53	58	62	64	66	67	68	69	71	73
0.90	52	57	60	63	64	66	67	68	70	71
0.89	51	55	59	61	63	64	66	67	68	70
0.88	50	54	57	60	62	63	64	65	67	69
0.87	48	53	56	58	60	62	63	64	66	67
0.86	47	51	55	57	59	60	62	63	64	66
0.85	46	50	53	56	58	59	60	61	63	65
0.84	45	49	52	55	56	58	59	60	62	64
0.83	44	48	51	53	55	57	58	59	61	63

Figure 6. Idaho PF for VMA and Compaction.

The final lot pay adjustment is determined utilizing Equation 17.

$$Lot\ pay\ adjustment = Unit\ Price\ x\ Lot\ Quantity\ x\ [((PF_{Va}\ x\ 0.3) + (PF_{VMA}\ x\ 0.3) + (PF_{Compaction}\ x\ 0.4))\text{-}1]$$

Equation 17. Idaho pay adjustment.

KANSAS

Type of data used: QC data.

Statistical method used to assess and verify QC/QA data: F and t-Tests. F-Test is used to assess to compare variance and T-test is used to compare means.

Mix design method: Superpave

Lot, sublot, measured properties, and test methods:

1) Va
    a. Lot: 3000 tons of material, 4 sublots
    b. Sublot: 750 tons of material
    c. Measured:
        i. QC: Once per sublot
        ii. QA: Once per lot for verification
    d. Method: KT-15 and KT-58
2) Compaction
    a. Lot: 1 shift of production
    b. Measured:
        i. QC: 10 times per lot
        ii. QA: 5 times per lot for verification

c. Method: KT-15 (core) or KT-32 (nuclear density gage)

Specification limits:

Table 8. Kansas properties and specification limits.

	Lower Limit	Upper Limit	Target Value
Va	3.0%	5.0%	4.0%
Compaction	92.0%	None	NA

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

Once the PWL for Va and Compaction is calculated, they are used in Equation 18 to determine the PF.

$$PF_{Va} = [(PWL_{Va} - 100) \times .003] - 0.27$$

$$PF_{Compaction} = \left(PWL_{Compaction} \times 0.004\right) - 0.36$$

Equation 18. Kansas PF for Va and Compaction.

Because the lot sizes are different for each adjustment, they are calculated separated. The unit price is $40 per ton for both Va and Compaction according to section 602 of their Standard Specifications. The pay adjustment for each component is performed using Equation 19.

$$Va\ Pay\ Adjustment = (PF_{Va} - 1) \times Lot\ Quantity\ (tons) \times \$40$$

$$Compaction\ Pay\ Adjustment = (PF_{Compaction} - 1) \times Lot\ Quantity\ (tons) \times \$40$$

Equation 19. Kansas pay adjustment equations.

MICHIGAN

Type of data used: Michigan calculates PWL for both QA and QC data but only QA data is used for pay adjustment. If there is a dispute between the results of the QA and QC data, then a 3rd party conducts another set of measurements in order to determine a new PWL value and that value is used for pay adjustments.

Statistical method used to assess and verify QC/QA data: F and t-Tests are used as the statistical tools for verifying and validating the data sets.

Mix design method: Superpave

Lot, sublot, measured properties, and test methods:

Lot: 5000 tons

Sublot: 1000 tons

Mixture properties are measured once per sublot by QC and QA. Compaction properties are measured 4 times per sublot.

Measured properties:

1) Va

a. Weight: 30%

2) % AC

a. Weight: 15%

b. Test method: MTM 319 (Ignition oven)

3) VMA

a. Weight: 15%

4) Compaction

a. Weight: 40%

b. Test method: AASHTO T 166, 209 (core)

Specification limits:

Table 9. Michigan properties and specification limits.

	Lower Limit	Upper Limit	Target Value
Va	3	5	4
% AC	-0.40 of TV	+0.40 of TV	*
VMA	14	16	15*
Compaction	92	None	NA
*Target Value (TV) changes based on mix type.			

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

A PF is determined for each individual parameter (Va, % AC, VMA, Compaction). For QA Compaction, the PWL is determined from the average of the 4 measured densities. However for

QC Compaction, the PWL is determined from the worst Compaction measurement of the 4 measured densities.

If PWL for any of the 4 properties is between 70 and 100, Equation 20 is used to determine PF.

$$PF = 55 + (0.5\ \times PWL)$$

Equation 20. Michigan PF for PWL between 70 and 100.

If PWL is between 50 and 70, Equation 21 is used to determine PF.

Equation 21. Michigan PF for PWL between 50 and 70

$$PF = 37.5 + (0.75 \times PWL)$$

If PWL less than 50, the Engineer may elect to do one of the following:

- Require removal and replacement of the entire lot with new QA sampling and testing and repeat the evaluation procedure.
- Allow the lot to remain in place and apply an Overall Lot Pay Factor of 50.0.
- Allow submittal of a corrective action plan for the Engineer's approval. The corrective action plan may include removal and replacement of one or more sublots. If one or more sublots are replaced, the sublot(s) will be retested and the Overall Lot Pay Factor will be recalculated according to this special provision. If the Engineer does not approve the plan for corrective action, subsections (1) or (2) above will be applied.

As shown previously, the four properties being measured are weighted differently. The weights and the Total Lot Pay Factor (TLPF) are shown and determined using Equation 22.

Equation 22. Michigan Total Lot Pay Factor.

$$TLPF = \left(0.40 \times PF_{Density}\right) + (0.30 \times PF_{Va}) + (0.15 \times PF_{\%AC}) + (0.15 \times PF_{VMA})$$

Usually QA data is used to determine the TLPF. This is because it gives a slightly higher PF in most instances. As stated early, the 4 Compaction measurements are averaged when using QA data for determining pay adjustment. When QC data is used, the Compaction PF is calculated by using the worst out of 4 density measurements taken per sublot. If the contractor does not like either results, they can chose to have a 3rd party come in and collect another set of data for the sublots or lot in dispute.

To determine the pay adjustment per lot, the TLPF is used to calculate the bonus or penalty the lot has warranted.

$$Lot\ Pay\ Adjustment = \left(\frac{TLPF - 100}{100}\right) \times Lot\ Quantity\ (tons) \times Unit\ Price$$

Equation 23. Michigan Lot Payment Adjustment.

NEW MEXICO

Type of data used: New Mexico uses both QC and QA data to determine acceptance and pay factors.

Statistical method used to assess and verify QC/QA data:

New Mexico DOT uses both F-test and T-tests to verify QC and QA data. If either one of them fails to validate, then only the Department's data for the particular property that fails to validate is used to determine the pay factor for that property. Level of significance is set at 0.01.

Mix design method: Superpave

Lot, sublot, measured properties, and test methods:

Lot: 15,000 tons

Sublot: 3,000 tons (1/5th the size of a lot)

Contractor measures 3 random samples per sublot for QC. Agency measures 1 random sample per sublot.

Measured properties:

1) Va
   a. Weight: 35%
   b. Method: AASHTO T 166, 209, 269
2) % AC
   a. Weight: 10%
   b. Method: AASHTO T 308 (Ignition oven)
3) VMA
   a. Weight: 20%
   b. Method: AASHTO R35
4) Compaction
   a. Weight: 35%
   b. Method: AASHTO T 166, 209 (core) or AASHTO T 310 (nuclear density gage)

Specification limits:

Table 10. New Mexico properties and specification limits.

	Lower Limit	Upper Limit	Target Value
Va	-1.6%	+1.6%	4.0%
% AC	-0.3%	+0.3%	*
VMA	-1.6%	+1.6%	*
Compaction	92.0%	97.0%	94.5%
* Target Value depends on mix design.			

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

Find the PWL for each property from the average of the collected measurements. From there, the PF is determined using the PWL value in Figure 7 from New Mexico's Standard Specifications.

Table 901.7:2
Pay Factors

Pay factor	Minimum Required Percent of Work Within Specifications Limits for a Given Pay Factor (Pu+PL) – 100														
	n=														
	3	4	5	6	7	8	9	10 to 11	12 to 14	15 to 17	18 to 22	23 to 29	30 to 42	43 to 66	67 to ∞
1.05	—	—	—	—	—	100	100	100	100	100	100	100	100	100	100
1.04	—	—	—	—	100	99	97	95	96	96	96	97	97	97	97
1.03	—	—	—	100	98	96	94	92	93	93	94	95	95	96	96
1.02	—	—	—	99	97	94	91	89	90	91	92	93	93	94	94
1.01	100	100	100	98	95	92	89	87	88	89	90	91	92	92	93
1.00	69	75	78	80	82	83	84	85	86	87	88	89	90	91	92
0.99	66	72	76	78	80	81	82	83	84	85	86	87	89	90	91
0.98	64	70	74	76	78	79	80	81	82	84	85	86	87	88	90
0.97	63	68	72	74	76	77	78	79	81	82	83	84	86	87	88

Figure 7. New Mexico Pay Factors.

Next, the Composite Pay Factor (CPF) is calculated using Equation 24.

$$CPF = \frac{(weighting\ factor * item\ pay\ factor) + \cdots\cdots\cdots}{sum\ of\ weighting\ factors}$$

$$CPF = \frac{f_1(\overline{PF_1}) + f_2(\overline{PF_2}) + \cdots + f_i(\overline{PF_i})}{\frac{\sum f_i}{i = 1\,to\ j}}$$

Equation 24. New Mexico Composite Pay Factors.

PF is the value taken from the table in the previous step. The "f" factor is determined using Figure 8.

Table 423.5.1.1:1
Weighting Factors

Characteristic	"f" Factor (%)
Mat Density	35
Air voids	35
Voids in the mineral aggregate (VMA)	20
Asphalt Content	10

Figure 8. New Mexico weighting factors.

Example:

Table 11. New Mexico weighting factors example.

Parameter	PF (%)	Multiply by	"f" Factor	Equals	Equals
Va	1.05	x	35	=	36.75
% AC	0.92		10		9.2
VMA	1.05		20		21
Compaction	0.91		35		31.85
Total			100		98.8

CPF = 98.8 / 100 = 0.988

The final pay adjustment is calculated using Equation 25.

$$Lot\ Pay\ Adjustment = (CPF - 1) \times Lot\ Quantity\ (tons) \times\ Unit\ Price$$

Equation 25. New Mexico Lot Payment Adjustment.

NEW YORK

Type of data used: The pay adjustment is made only based on the QA Compaction data.

However, New York requires QC and QA testing of mixture properties (% AC, Va, Gradation). If these mixture properties at the plant do not meet the required specifications, then the possibility of a bonus is eliminated even if the contractor compacts the material within the desired tolerances.

Statistical method used to assess and verify QC/QA data: Because only QA data is used for pay adjustment of Compaction, no statistical method is used for this step. For mixture properties testing, New York compares QC and QA data by looking at the absolute difference between the two sets of data. If they are not within the absolute difference tolerance, then only QA data is used to determine if mixture properties are within limits.

Mix design method: Superpave

Lot, sublot, measured properties, and test methods:

Lot: Daily total length of all lanes, ft

Sublot: 4 equal sizes of 1 lot minus the first 150’ (exempt area for initialization)

Example: If a 12’ wide paver produces 3 lanes at 2000’ per lane, the lot size would be 6000 feet for that day. Each sublot size is 1462.5’.

Therefore:
LOT SIZE = 6000 ft
SUBLOT SIZE = (6000 ft – 150 ft) ÷ 4 = 1462.5 ft

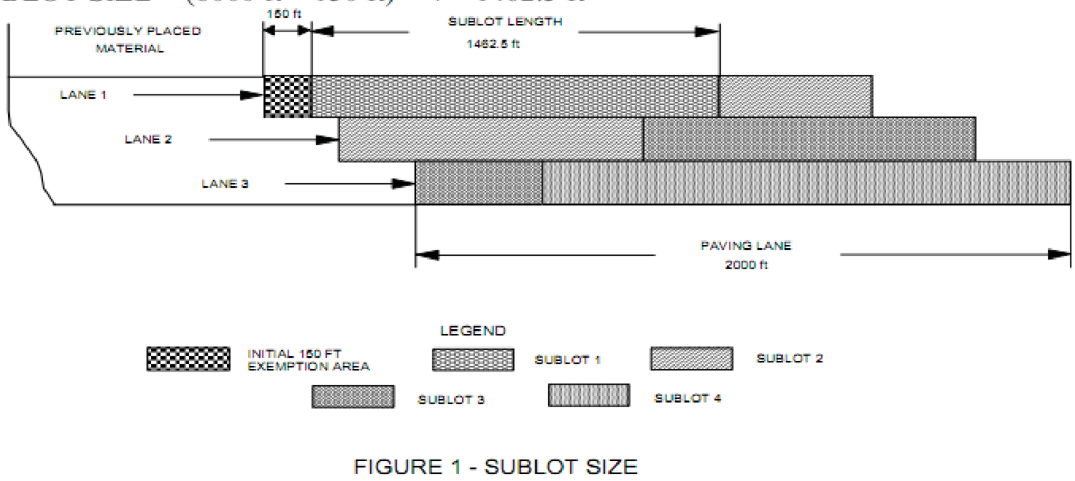

Figure 9. New York lot and sublot size illustration.

Measured properties:

1) Compaction

   a. Measured: 4 times per sublot

   b. Method: AASHTO T 166, 209 (core) or AASHTO T 310 (nuclear density gage)

Specification limits:

Compaction has a lower limit of 92% and an upper limit of 97%. Target value is 94.5%.

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

If the PWL is > 93, then the PF is = 1.05

If the PWL is ≤ 93 then proceed to Segmental Quality Adjustment Factor (QAF) Calculation. Segmental method requires the determination of PWL for each Density Range (DR), except the Lower Limit (L) and the Upper Limit (U) will not be 92 and 97 limits. Instead, the lower and upper limits for each DR will be used. The purpose of calculating the Segmental QAF is to find the area under the normal distribution curve. If the result is found to be between 93 and 96, then that range is multiplied by a PF 1.05. As you work outside of the range, the PF reduces. The following example may illustrate this idea better.

Calculate the PWL of each DR as outlined in Figure 10 using the upper and lower limits for that DR. Using the same average and standard deviation, find the PWL with the new limits (i.e. lower limit 89, upper limit 90. Then move up to the next DR). Multiply the calculated PWLs for each density range by its respective PF to determine a QAF for that DR. The lot QAF is the sum of the individual DR QAFs. The Figure 10 shows the DRs, PFs for each DR and the DR QAFs.

Given Values		Calculated Values	
Density Range (DR)	Pay Factor	PWL for DR	QAF for DR
DR ≤ 88.0	0.00	0	0
88.0 < DR ≤ 89.0	0.60	0	0
89.0 < DR ≤ 90.0	0.70	0	0
90.0 < DR≤ 91.0	0.80	0	0
91.0 < DR ≤ 92.0	0.90	11	9.90
92.0 < DR ≤ 93.0	1.00	18 *	18.00
93.0 < DR ≤ 96.0	1.05	53	55.65
96.0 < DR ≤ 97.0	1.00	17	17.00
97.0 < DR ≤ 98.0	0.90	1	0.90
98.0 < DR ≤ 99.0	0.80	0	0
DR > 99.0	0.00	0	0
		Σ PWL = 100	Σ QAF = 101.45 **

Figure 10. New York Standard Specifications density range.

The calculation for 92.0 < DR ≤ 93.0 is calculated as an example.

Mean = 94.2. Standard deviation = 1.90.

$Q_U = [U - \bar{x}]/S$ = (93.0 - 94.2)/1.90 = -0.63
$Q_L = [\bar{x} - L]/S$ = (94.2 - 92.0)/1.90 = 1.16
P_U = From Table 1, based on QU = 29
P_L = From Table 1, based on QL = 89
$PWL_{92\text{-}93}$ for $DR_{92\text{-}93}$ = PU + PL - 100 = 29+89-100 = 18
$QAF_{92\text{-}93}$ for $DR_{92\text{-}93}$ = Pay Factor x PWL for DR = 1.00 x 18 = 18

The same procedure is followed for all the other density ranges. The only difference is the Lower Limit and the Upper limit. The average and standard deviation stays the same as mentioned previously.

After all the QAFs are found, then they are summed up and Equation 26 is used to adjust for a bonus or penalty.

$$Lot\ Pay\ Adjustment_{Compaction} = \left(\frac{QAF\ \%_{Compaction} - 100}{100}\right) \times Lot\ Quantity\ (tons) \times\ Unit\ Price$$

Equation 26. New York pay adjustment.

UTAH

Type of data used: Agency's QA data

Statistical method used to verify or assess the difference between QC/QA data: No statistical method is used because only the agency's QA data is used.

Mix design method: Superpave

Lot, sublot, measure properties, and test methods:

Measured properties:

1) % AC
    a. Lot: 1 Production Day
    b. Sublot: 1/4th of the lot
    c. Method: AASHTO T 308 (ignition oven)
    d. Measured once per sublot
2) Gradation
    a. Lot: 1 Production Day
    b. Sublot: 1/4th of the lot
    c. Method: AASHTO T 30 (ignition oven)
    d. Measured once per sublot
3) Compaction
    a. Lot: 1 Production Day

b. Sublot: 1/5th of the lot

c. Method: AASHTO T 166, 209 (core)

d. Measured twice per sublot

Specification limits:

Table 12. Utah properties and specification limits.

<table>
<tr><th colspan="2"></th><th>Lower Limit</th><th>Upper Limit</th><th>Target Value</th></tr>
<tr><td colspan="2">% AC</td><td>-0.35%</td><td>+0.35%</td><td>*</td></tr>
<tr><td rowspan="7">Gradation</td><td>3/4" sieve for 1" HMA**</td><td rowspan="4">-6.0%</td><td rowspan="4">+6.0%</td><td rowspan="4">*</td></tr>
<tr><td>1/2" sieve for 3/4" HMA</td></tr>
<tr><td>3/8" sieve for 1/2" HMA</td></tr>
<tr><td>#4 sieve for 3/8" HMA</td></tr>
<tr><td>#8 sieve</td><td>-5.0%</td><td>+5.0%</td><td>*</td></tr>
<tr><td>#50 sieve</td><td>-3.0%</td><td>+3.0%</td><td>*</td></tr>
<tr><td>#200 sieve</td><td>-2.0%</td><td>+2.0%</td><td>*</td></tr>
<tr><td colspan="2">Compaction</td><td>-2.0%</td><td>+3.0%</td><td>92.5%</td></tr>
<tr><td colspan="5">* Target Value (TV) depends on mix design.
**Select only one of the four sieves depending on gradation type.</td></tr>
</table>

Compaction requirements:

- The target for compaction is 93.5 percent of Maximum Specific Gravity for projects where the design HMA thickness is greater than 2 inches. For thicknesses less than or equal to 2 inches, the target value is 92.5%.

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

Once the PWL is calculated for Gradation (all the sieves individually), %AC, and Compaction, then the PF is able to be determined. There are only 2 PFs for the 3 different properties. Compaction's PF is determined from its own PWL.

For Gradation and % AC, the PF that represents both properties is the one that has the lowest value. Table 13 is referenced to find the PF.

Table 13. Utah Pay Factors for % AC, Gradation, and Compaction.

%AC/Gradation and Compaction	
PWL (based on an average of minimum of 4 samples)	**PF ($ / ton)**
>99	$1.50
96-99	$1.00
92-95	$0.60
88-91	$0.00
84-87	-$0.26
80-83	-$0.60
76-79	-$0.93
72-75	-$1.27
68-71	-$1.60
64-67	-$1.93
60-63	-$2.27
<60	Reject

The total unit price for any unit of accepted asphaltic concrete will be the contract unit price, adjusted by the sum of the smaller of the Gradation and %AC PF and Compaction PF.

$$Lot\ Pay\ Adjustment\ (Gradation/\%AC) = \left(PF_{Grad/\%AC}\right) \times Lot\ Quantity\ (tons)$$

$$Lot\ Pay\ Adjustment\ (Compaction) = \left(PF_{Compaction}\right) \times Lot\ Quantity\ (tons)$$

Equation 27. Utah pay adjustment.

VERMONT

Type of data used: Agency's QA data.

Statistical method used to assess and verify QC/QA data: None because only QA data is used.

Mix design method: Superpave

Lot, sublot, measured properties, and test methods:

Measured properties:

1) Va
    a. Lot: 3000 tons (6 sublots)
    b. Sublot: 500 tons
    c. Measured:
        i. Once per sublot
    d. Method: AASHTO T 269 (T 166, T 209)
2) Compaction
    a. Lot: 1 Production Day
    b. Sublot: 0.6 miles of paved lane
    c. Measured:
        i. Once per sublot
        ii. Minimum of 6 samples per day
    d. Method: AASHTO T 166, 209 (core)
3) Roughness
    a. Lot: Entire project
    b. Sublot: 1 lane of the project

Specification limits:

Table 14. Vermont properties and specification limits.

	Lower Limit	Upper Limit	Target Value
Va	3.0%	5.0%	4.0%
Compaction	92.5%	96.5%	94.5%

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

After the PWL is determined for each sublot and each property, it is used in Equation 28 to determine the PF.

$$PF_{Va} = (\frac{0.28 \times PWL + 75}{100}) - 1.0$$

Equation 28. Vermont PF equation for air voids.

For compaction, the PF for each lot of bituminous concrete mixtures will be determined by using the Equation 29 and Equation 30.

Where 85 ≤ PWL ≤ 100,

$$PF_{Compaction} = (\frac{0.20 \times PWL + 83}{100}) - 1.0$$

Equation 29. Vermont PF equation for Compaction when PWL is between 85 and 100.

If the PWL for compaction is $60 \leq \text{PWL} < 85$,

$$PF_{Compaction} = \left(\frac{0.40 \times PWL + 66}{100}\right) - 1.0$$

Equation 30. Vermont PF equation for Compaction when PWL is between 60 and 85.

The roughness value used in the applicable formula below will be the average of the International Roughness Index (IRI) values measured by the Road Surface Profiler (RSP) in each lane. The corresponding Surface Tolerance Pay Factor, PF (roughness), is determined as follows:

Limited access highways:

$$PF_{Roughness} = (-0.0029 \times IRI + 1.1500) - 1.0$$

Equation 31. Vermont PF roughness equation for limited access highways.

All other state routes:

$$PF_{Roughness} = (-0.0029 \times IRI + 1.1786) - 1.0$$

Equation 32. Vermont PF roughness equation for all other states routes.

Because lot sizes are different for each property, there are 3 separate equations used to determine the pay adjustment. Pay adjustment for Va is based on every 3000 tons of plant production. Pay adjustment for Compaction is based on 1 day's paving. Pay adjustment for roughness is based on the entire project. Equation 33 summarizes the pay adjustment calculations for Vermont.

$$Lot\ Pay\ Adjustment\ (Va) = PF_{Va} \times Lot\ Quantity\ (tons) \times\ Unit\ Price$$

$$Lot\ Pay\ Adjustment\ (Compaction) =\ PF_{Compaction} \times Lot\ Quantity\ (tons) \times\ Unit\ Price$$

$$Project\ Pay\ Adjustment\ (Roughness) = PF_{Roughness} \times Lot\ Quantity\ (tons) \times\ Unit\ Price$$

Equation 33. Vermont pay adjustment equations

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WASHINGTON STATE

Type of data used: Washington only uses QA data for pay adjustment. However, in their software, they also allow the input of QC data in case they chose to implement that in the future.

Statistical method used to assess and verify QC/QA data: None

Mix design method: Superpave

Lot, sublot, measured properties, and test methods:

Lot: 15 sublots

Sublot: 800 tons

Measured properties:

1) Va
    a. Measured: Once per sublot
    b. Method: WSDOT Standard Operating Procedure SOP 73
2) % AC
    a. Measured: Once per sublot
    b. Method: AASHTO T 308 (ignition oven)

3) Gradation

   a. Measured: Once per sublot

   b. Method: AASHTO T 27 / T11 (ignition oven)

4) Compaction

   a. Measured: Once per 80 tons of material (or 10 times per sublot)

   b. Method: AASHTO T 166, 209 (core)

Specification limits:

Table 15. Washington State properties and specification limits.

		Lower Limit	Upper Limit	Target Value
Va		2.5%	5.5%	4%
% AC		-0.5%	+0.5%	*
Gradation	1", 3/4", 1/2", 3/8"	-6.0%	+6.0%	*
	#4	-5.0%	+5.0%	*
	#8	-4.0%	+4.0%	*
	#200	-2.0%	+2.0%	*
Compaction		91%	None	NA
* Target Value (TV) depends on mix design and mix type.				

How the PWL is determined:

Sample means are determined using Equation 1 for each lot. The sample standard deviation is calculated from Equation 2. The lower and upper quality indexes are calculated using Equation 3 and Equation 4. The PWL is computed using the Quality Indexes by referencing Table 18.

How the pay adjustment is made:

The pay factor is determined by plugging in the calculated PWL value into the Figure 11 from Washington State's Standard Specifications:

PAY FACTOR	Minimum Required Percent of Work Within Specification Limits for a Given Factor ($P_U + P_L$) – 100														
Category	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10 to n=11	n=12 to n=14	n=15 to n=17	n=18 to n=22	n=23 to n=29	n=30 to n=42	n=43 to n=66	n=67 to ∞
1.05						100	100	100	100	100	100	100	100	100	100
1.04					100	99	97	95	96	96	96	97	97	97	97
1.03				100	98	96	94	92	93	93	94	95	95	96	96
1.02				99	97	94	91	89	90	91	92	93	93	94	94
1.01	100	100	100	98	95	92	89	87	88	89	90	91	92	92	93
1.00	69	75	78	80	82	83	84	85	86	87	88	89	90	91	92
0.99	66	72	76	78	80	81	82	83	84	85	86	87	89	90	91
0.98	64	70	74	76	78	79	80	81	82	84	85	86	87	88	90
0.97	63	68	72	74	76	77	78	79	81	82	83	84	86	87	88
0.96	61	67	70	72	74	75	76	78	79	81	82	83	84	86	87
0.95	59	65	68	71	72	74	75	76	78	79	80	82	83	84	86
0.94	58	63	67	69	71	72	73	75	76	78	79	80	82	83	85
0.93	57	62	65	67	69	71	72	73	75	76	78	79	80	82	84
0.92	55	60	63	66	68	69	70	72	73	75	76	78	79	81	82
0.91	54	59	62	64	66	68	69	70	72	74	75	76	78	79	81
0.90	53	57	61	63	65	66	67	69	71	72	74	75	77	78	80
0.89	51	56	59	62	63	65	66	68	69	71	72	74	75	77	79
0.88	50	55	58	60	62	64	65	66	68	70	71	73	74	76	78
0.87	49	53	57	59	61	62	63	65	67	68	70	71	73	75	77
0.86	48	52	55	58	59	61	62	64	66	67	69	70	72	74	76
Note: If the value of ($P_U + P_L$) - 100 does not correspond to a ($P_U + P_L$) - 100 value in this table, use the next smaller ($P_U + P_L$) - 100 value. **(Continued)**															
0.85	46	51	54	56	58	60	61	62	64	66	67	69	71	72	75
0.84	45	49	53	55	57	58	60	61	63	65	66	68	70	71	73
0.83	44	48	51	54	56	57	58	60	62	64	65	67	69	70	72
0.82	43	47	50	53	54	56	57	59	61	62	64	66	67	69	71
0.81	41	46	49	51	53	55	56	58	59	61	63	64	66	68	70

Figure 11. Washington State Pay Factor table.

Once the PF is determined, WSDOT calculates a “composite pay factor” (CPF). Each of the parameters has Factor “F” as shown in Table 12. 1 ½”, 1”, ¾”, ½”, 3/8”, and #4 sieves each have a Factor “f” of 2.

Table of Price Adjustment Factors	
Constituent	**Factor “f”**
All aggregate passing: 1½", 1", ¾", ½", ⅜" and No.4 sieves	2
All aggregate passing No. 8 sieve	15
All aggregate passing No. 200 sieve	20
Asphalt binder	40
Air Voids (Va)	20

Figure 12. Washington State weighting factors.

Here is a worked out example. PF is the pay factor determined previously. Factor “f” is given in the above table. They are computed as follows and summed up:

Table 16. Washington State PF calculation example.

Parameter	**PF**	**Multiply by**	**Factor "f"**	**Equals**	**Equals**
3/4" sieve	1.00	x	2	=	2.00
1/2" sieve	0.99		2		1.98
3/8" sieve	1.00		2		2.00
#4 sieve	1.05		2		2.10
#8 sieve	1.00		15		15.00
#200 sieve	1.02		20		20.40
Binder	1.01		40		40.40
Voids	0.99		20		19.80
Total			103		103.68

Note that the Factor "f" does not need to add up to 100.

$$CPF = \frac{(weighting\ \ factor * item\ \ pay\ \ factor) + \cdots\cdots\cdots}{sum\ of\ \ weighting\ \ factors}$$

$$CPF = \frac{f_1(\overline{PF_1}) + f_2(\overline{PF_2}) + \cdots + f_i(\overline{PF_i})}{\underset{i=1\ to\ j}{\sum f_i}}$$

$$CPF = \frac{103.68}{103} = 1.01$$

Table 17. Washington State Composite Pay Factor.

Because lot sizes may be different, two adjustments are made. One adjustment is based on the lot quantity from the mixture properties. The other adjustment is based on the lot quantity of Compaction. 60% of the pay adjustment is based on mixture properties.

$$Lot\ Pay\ Adjustment_{Grad.,\%AC,Va} = .60 \times \left(CPF_{Grad.,\%AC,Va} - 1\right) \times Lot\ Quantity\ (tons) \times\ Unit\ Price$$

Equation 34. Washington State pay adjustment for Gradation, % AC, and Va.

40% of the pay adjustment is based only on compaction. Compaction is not used in the CPF calculation. The PF is determined by plugging in the PWL of the Compaction results from the previous table.

$$Lot\ Pay\ Adjustment_{Compaction} = .40 \times \left(PF_{Compaction} - 1\right) \times Lot\ Quantity\ (tons) \times\ Unit\ Price$$

Equation 35. Washington State pay adjustment for Compaction.

Chapter 4 - RECOMMENDED SYSTEM

The review of current PWL systems provided very thorough details current practices. The reviews were documented in a report and a meeting was held between members of NDOT, University of Nevada, and various pavement industry representatives. The discussion included topics such as lot and sublot sizes, properties to measure, frequency of testing, concerns, and current practices. The purpose of this meeting was to come to a preliminary initial agreement on the basic structure of Nevada's PWL program. The decisions and recommendations that were made may be modified based on the effectiveness of the initial plan.

The objective of an effective PWL program is to provide an incentive for contractors to improve the constructed roadways. There are several factors that influence the scale of the pay factor adjustments:

- Type of data to use for pay adjustment (QC or QA)
- Lot and Sublot sizes
- Frequency of testing
- Type of properties to measure

Type of Data

It is very important to determine which data set should be used for pay adjustments. The review of current PWLs revealed that very rarely the QC data are used for pay adjustment. AASHTO R 9 2005 and AASHTO R 42 suggests only QA data be for pay adjustments. By only using QA data to determine bonus and penalties, the agency is reducing its risk of basing a pay adjustment on the possibility of inaccurate contractor data. False information may be presented which can inaccurately reflect the estimated quality of the pavement and the pay adjustment.

Employing F and T-tests, QC and QA data may be compared statistically to determine if they are from the same population. These statistic tools may be effective in determining if contractor and agency's data comes from the same population. However, having to compare and validate data sets for pay adjustment can cause confrontations between agency and the contractor, therefore it is not recommended. It is recommended that only the agency's QA data be used for pay adjustment for simplicity and to reduce occasional disagreements between the agency and the contractor.

To ensure the accuracy of the agency's data, all technicians must be certified for the various tests that they are to perform. NDOT currently requires its technicians to attend a certification program (NDOT 2011). This will ensure that the field and lab technicians are qualified to perform these various tests and provide both parties more confidence in bonus or penalty pay adjustments. In California, it is not uncommon for agencies to hire 3rd party quality assurance certified personal during the busiest construction seasons. This allows them to reduce expenses by only having to staff enough technicians for normal construction seasons and the flexibility of utilizing an unaffiliated party to cover their busier summer months.

Even though the contractor's data is not used for pay adjustment, it is suggested that contractors have a quality control plan in order to monitor and adjust the quality of the product being produced. The contractors should be aware of the quality of the pavement they are producing without having to rely on the agency to inform them. The quality control plan should be submitted a certain period prior to the start of paving to allow the agency's engineer to review and approve. AASHTO R 42 recommends that the contractor's quality control plan cover the following information:

- Personnel, including management personnel and plant and roadway technicians;

- Plant operations including stockpile management, material feed systems, HMA storage and truck loading procedures, materials and finished product sampling, and testing procedures; and
- Compaction operations including roller type and number, roller setup (i.e. amplitude, frequency, or tire pressure), and roller speed.

The biggest issue that NDOT reportedly faces is handling constructed pavement sections that do not pass single or multiple criteria. The suspension of contraction is not typically enforced. If certain items fail, such as compaction but other parameters, such as Hveem Stability pass, the construction is allowed to continue. This ambiguity may permit inadequate pavements to remain in place.

Requiring a detailed QC plan that spells out testing frequencies and actions to take when construction is suspended will allow the contractor to be aware of their construction process and make changes early on. Contractors will be able to monitor their construction process more carefully. Because the pay adjustment is made based on the QA data, it is important that contractors are closely monitoring the results of their QC data and comparing it with the QA data. Statistical tools can be employed, such as F and T tests, to compare the data sets. The results of the statistical evaluation will reveal if the data sets come from the same population. When the QC and QA data do not match, a 3rd party with certified technicians should retest the entire lot and produce a new PWL for pay adjustment. The party that is found to be wrong should pay for the extra cost of 3rd party testing. A detailed QC plan provides clear instructions regarding the contractor's process control procedures. The results from QC testing give the contractor the ability to dispute the agency's test results.

Lot and Sublot Sizes

Lot and sublot sizes vary significantly among agencies. This high variability indicates that there is not a general consensus on the definition of a lot (Schmitt et. Al. 1998). Sublot sizes varied much less and is typically 750 – 1000 tons. Sublots were also found to be defined as 1 frequency of testing per measured property. The concept of PWL says that the pay adjustment should be made on a lot by lot basis. Therefore, the more material in one lot provides the contractor more flexibility to adjust their construction techniques.

For example, California who 20 lots per sublot, having 1 or 2 underperforming sublots would not affect the pay adjustment over the total material of that lot as dramatically as another state that has only 4 or 5 sublots per lot. In the case of Michigan who uses 5 sublots per lot, one underperforming sublot may bring down the overall lot pay adjustment. However, it is important to keep in mind that the dollar amount of the penalty is based on the quantity of material per lot. The penalty, which equates to a reduced pay factor, may be more severe but it is only applied to a smaller amount of material when comparing a hypothetical situation between Michigan and California lot sizes. Lastly, having too few sublots per lot can also reduce the accuracy of the estimated PWL.

AASHTO R 42 suggests that a sublot should be defined as 1000 tons of material for 19 mm nominal maximum aggregate size or larger mixtures. The suggested number of sublots per lot is 4 or more. During the first committee meeting of the NDOT PWL research program, all parties felt that AASHTO R 42 guidelines offered a solid foundation because it provided good justification. It is recommended that sublot sizes should be 1000 tons for all dense-graded mixtures, and a lot should be defined as having 5 sublots. In addition, AASHTO R 42 states that "Partial sublots of 100 tons or less can be added to the previous sublot. Partial sublots of 100 tons [or more] can constitute as a full sublot. Lots that contain a single sublot could be combined with the previous lot for acceptance purposes." Following the AASHTO R 42 as a guideline, the recommended sublot size is 1000 tons and the recommended lot size is having 5 sublots for all dense graded mixtures.

Properties to Measure

Several properties were discussed by the NDOT PWL committee to determine which ones were most effective and feasible for the basis of pay adjustment. These properties include:

- Gradation
- % AC
- In-place density
- Air voids, lab (Va)
- VMA
- Hveem Stability

Dense graded HMA is composed of three components: Asphalt binder, aggregate, and Va. The performance of asphalt pavement is sensitive to the variability of these components. It was recommended that asphalt content, in-place density, and gradation to be used in the proposed NDOT PWL program for pay adjustment.

The amount of asphalt binder significantly influences how the pavement will perform. Too little asphalt may cause raveling issues and produce a weaker pavement. It can also be difficult to achieve the desired compaction if binder content is too low. Excessive asphalt binder will increase rutting potential, stability issues, weaker strength, lower avoids, and reduce surface friction. It is recommended that the asphalt binder content be determined using an ignition oven. A calibration factor must be calculated in order to ensure the accuracy of the asphalt content measured by the ignition oven method. The high temperatures the mixture is exposed to in the ignition oven can degrade some aggregates and burn up smaller particles. This produces misleading results that indicates higher binder content than what is actually present.

The in-place density is also just as important. If the pavement is overly-compacted, it can reduce the amount of air voids and promote permanent deformation due to shear failure. If the pavement is under compacted, it may ravel, increase moisture damage potential, and have reduced strength. Pavements not properly compacted can also oxidize and age faster. It is recommended that NDOT drill for cores and measure the compaction. A nuclear gauge is then correlated to the cores to ensure the highest accuracy of the measurements. For the remainder of the project, nuclear gauge can be used to determine the compaction.

Gradation is also recommended for pay adjustment. The majority of an HMA layer is composed of aggregates. It is important that the aggregate gradation is within a certain range of the designed target value in order to have good aggregate interlock. Air voids and amount of binder content relies on the space between the voids of the aggregate for optimum performance. It is recommended that sieves #4 and #200 be used as the sieves for gradation in the proposed NDOT PWL. Aggregate gradation should be taken prior to mixing. New variables are introduced if the gradation is measured after mixing and/or compacting. The sample would need to be heated in the ignition oven to burn off the asphalt binder. The stresses introduced by the high temperature may disintegrate larger aggregates and deteriorating them to smaller sizes. Fines may also be lost or burnt up in the process. Therefore, it is recommended that these variables should be reduced to more accurately compare the dry aggregate gradation coming out of the plant with the dry aggregate gradation of the mix design.

Hveem Stability, lab air void, and VMA are not recommended for pay adjustment. Because NDOT uses Hveem mix designs, the samples must be compacted using a Hveem compactor to determine Stability, lab air voids, and VMA. The Hveem compactor is bulky and will not fit in a mobile trailer. If the job location was hundreds of miles away from a NDOT Hveem compactor, it can be a slow and costly process to deliver and preare the samples. In addition, Stability is a function of aggregate gradation and binder content, which are the recommended properties to measure. It may be redundant to measure Hveem Stability if the other properties provide promising results. In general Stability is expected to fail if gradation and asphalt content is out of specifications. In addition, the idea of the Hveem Stability test is to calculate the sample's peak strength by measuring the deformation of the sample when a triaxial load is applied; which means that it only requires a lower limit. It is not necessary to specify an upper limit and hinder the potential strength of a mix design. PWL makes most sense when used on parameters that has a target value, lower and upper specification limits. The Hveem Stability test can be tricky to produce consistent and repeatable results. Therefore, it is difficult to justify using Stability as a property to base pay adjustments on.

Lab air voids and VMA may be more critical than Hveem stability. Due to the lack of availability, cost, and size of the Hveem compactor, lab air voids and VMA properties are not recommended for use for on pay adjustment at this time. VMA should be re-evaluated as a property used for pay adjustment if NDOT moves to the Superpave mix design.

Acceptance

A PWL system calculates the pay adjustments based on the measured properties. It estimates the quality of the entire lot through measuring a few representative random samples. However, it is important to conduct additional testing at a lesser frequency independent of tests performed for PWL. It is recommended that NDOT implement a separate acceptance plan, independent of the PWL program. For example, NDOT should still require Hveem Stability, VMA, Dust Proportion, etc. testing but at a once or twice per lot basis. If these results fail 2 lots consecutively, then the construction process should be suspended until the contractor has provided sufficient evidence that the cause of the problem is resolved. Acceptance requirements should be implemented in addition to the PWL program to ensure that the constructed pavement meets additional properties that may not be suitable for use as pay adjustment properties. They include aggregate quality testing, Hveem Stability, lab air voids, and VMA.

Pay Factor

The PWL is determined based on the average and the standard deviation of the properties being measured. The next step to take is to apply a pay adjustment to each proper of each lot based on the quality of the pavement as indicated the calculated PWL. The adjustment is done using Pay Factors.

The AASHTO recommended method to determine Pay Factor (PF) is:

Equation 36. Recommended Pay Factor equation.

$$PF = 55 + (0.50 \text{ x } PWL)$$

If the PWL is less than 50, then the recommended course of action is as follows (decision to be made by RE):

- Remove and replace failing sections at the expense of the responsible party; and
- Keep the section in place and apply a total lot pay factor (TLPF) of 50.

As previously mentioned, the recommend properties for measurements are % AC, Compaction and Gradation. A PWL is calculated for each and a PF is calculated for each PWL. The PF’s can be averaged to determine the total lot pay factor (TLPF) per lot according to Equation 37.

Equation 37. Recommended average total lot pay factor.

$$TLPF = \frac{PF_{\%AC} + PF_{\#200\ Sieve\ Gradation} + PF_{\#4\ Sieve\ Gradation} + PF_{Compaction}}{4}$$

As an alternative, weights can be assigned to each properly. Weighing each property differently may be necessary if the agency would like to emphasize on a certain parameter over the others.

Equation 38. Alternative recommended weighted average total lot pay factor.

$$TLPF = W_1 PF_{\%AC} + W_2 PF_{\#200\ Sieve\ Gradation} + W_3 PF_{\#4\ Sieve\ Gradation} + W_4 PF_{Compaction}$$

W_1 to W_4 may be assigned different values depending on what the agency considers is most critical or needs extra attention. The sum of the weighting factors should be 1 or 100%. The final pay is calculated according to Equation 39.

Equation 39. Recommended Final Pay per Lot equation.

$$Final\ Pay\ per\ Lot = TLPF\ x\ Contract\ Unit\ Price\ (\$) x\ Material\ in\ lot\ (tons)$$

Chapter 5 – CONCLUSION

The subsequent bullets summarize the recommendations which are based on the findings of this research paper:

- Type of data used for pay adjustment: Agency's QA data only
- Lot size: 5000 tons
- Sublot size: 1000 tons
- Properties and frequencies to test:
  1) % AC
     - Once per sublot
     - Using calibrated ignition oven
  2) Gradation (#4 and #200 sieves)
     - Once per sublot
     - Measured prior to mixing
  3) Compaction
     - 5 times per sublot
     - Using nuclear gauge calibrated to cores
- Calculate PF using Equation 37 or Equation 38.
- Calculate final pay using Equation 39.

These recommendations will be implemented on a select few projects in the 2012 construction season. The effectiveness of this preliminary PWL system will be analyzed. Changes may be made in order to fine-tune this PWL system to better accommodate both the agency and contractor's construction practices.

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APPENDICES

Table 18. Quality Index values for determining PWL (AASHTO R 9).

PWL	n = 3	n = 4	n = 5	n = 6	n = 7	n = 8	n = 9	n = 10-11
100	1.16	1.50	1.79	2.03	2.23	2.39	2.53	2.65
99	-	1.47	1.67	1.80	1.89	1.95	2.00	2.04
98	1.15	1.44	1.60	1.70	1.76	1.81	1.84	1.86
97	-	1.41	1.54	1.62	1.67	1.70	1.72	1.74
96	1.14	1.38	1.49	1.55	1.59	1.61	1.63	1.65
95	-	1.35	1.44	1.49	1.52	1.54	1.55	1.56
94	1.13	1.32	1.39	1.43	1.46	1.47	1.48	1.49
93	-	1.29	1.35	1.38	1.40	1.41	1.42	1.43
92	1.12	1.26	1.31	1.33	1.35	1.36	1.36	1.37
91	1.11	1.23	1.27	1.29	1.30	1.30	1.31	1.31
90	1.10	1.20	1.23	1.24	1.25	1.25	1.26	1.26
89	1.09	1.17	1.19	1.20	1.20	1.21	1.21	1.21
88	1.07	1.14	1.15	1.16	1.16	1.16	1.16	1.17
87	1.06	1.11	1.12	1.12	1.12	1.12	1.12	1.12
86	1.04	1.08	1.08	1.08	1.08	1.08	1.08	1.08
85	1.03	1.05	1.05	1.04	1.04	1.04	1.04	1.04
84	1.01	1.02	1.01	1.01	1.00	1.00	1.00	1.00
83	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96
82	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.92
81	0.96	0.93	0.91	0.90	0.90	0.89	0.89	0.89
80	0.93	0.90	0.88	0.87	0.86	0.86	0.86	0.85
79	0.91	0.87	0.85	0.84	0.83	0.82	0.82	0.82
78	0.89	0.84	0.82	0.80	0.80	0.79	0.79	0.79
77	0.87	0.81	0.78	0.77	0.76	0.76	0.76	0.75
76	0.84	0.78	0.75	0.74	0.73	0.73	0.72	0.72
75	0.82	0.75	0.72	0.71	0.70	0.70	0.69	0.69
74	0.79	0.72	0.69	0.68	0.67	0.66	0.66	0.66
73	0.76	0.69	0.66	0.65	0.64	0.63	0.63	0.63
72	0.74	0.66	0.63	0.62	0.61	0.60	0.60	0.60
71	0.71	0.63	0.60	0.59	0.58	0.57	0.57	0.57
70	0.68	0.60	0.57	0.56	0.55	0.55	0.54	0.54
69	0.65	0.57	0.54	0.53	0.52	0.52	0.51	0.51
68	0.62	0.54	0.51	0.50	0.49	0.49	0.48	0.48
67	0.59	0.51	0.47	0.47	0.46	0.46	0.46	0.45
66	0.56	0.48	0.45	0.44	0.44	0.43	0.43	0.43
65	0.52	0.45	0.43	0.41	0.41	0.40	0.40	0.40
64	0.49	0.42	0.40	0.39	0.38	0.38	0.37	0.37
63	0.46	0.39	0.37	0.36	0.35	0.35	0.35	0.34
62	0.43	0.36	0.34	0.33	0.32	0.32	0.32	0.32
61	0.39	0.33	0.31	0.30	0.30	0.29	0.29	0.29
60	0.36	0.30	0.28	0.27	0.27	0.27	0.26	0.26
59	0.32	0.27	0.25	0.25	0.24	0.24	0.24	0.24
58	0.29	0.24	0.23	0.22	0.21	0.21	0.21	0.21
57	0.25	0.21	0.20	0.19	0.19	0.19	0.18	0.18
56	0.22	0.18	0.17	0.16	0.16	0.16	0.16	0.16
55	0.18	0.15	0.14	0.14	0.13	0.13	0.13	0.13
54	0.14	0.12	0.11	0.11	0.11	0.11	0.10	0.10
53	0.11	0.09	0.08	0.08	0.08	0.08	0.08	0.08
52	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05
51	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03
50	0	0	0	0	0	0	0	0

Table 19. F-critical value table for α = 0.025. (AASHTO R 9).

DF2\DF1	1	2	3	4	5	6	7	8	9	10
1	647.79	799.50	864.16	899.58	921.85	937.11	948.22	956.66	963.28	968.63
2	38.506	39.000	39.165	39.248	39.298	39.331	39.355	39.373	39.387	39.398
3	17.443	16.044	15.439	15.101	14.885	14.735	14.624	14.540	14.473	14.419
4	12.218	10.649	9.9792	9.6045	9.3645	9.1973	9.0741	8.9796	8.9047	8.8439
5	10.007	8.4336	7.7636	7.3879	7.1464	6.9777	6.8531	6.7572	6.6811	6.6192
6	8.8131	7.2599	6.5988	6.2272	5.9876	5.8198	5.6955	5.5996	5.5234	5.4613
7	8.0727	6.5415	5.8898	5.5226	5.2852	5.1186	4.9949	4.8993	4.8232	4.7611
8	7.5709	6.0595	5.4160	5.0526	4.8173	4.6517	4.5286	4.4333	4.3572	4.2951
9	7.2093	5.7147	5.0781	4.7181	4.4844	4.3197	4.1970	4.1020	4.0260	3.9639
10	6.9367	5.4564	4.8256	4.4683	4.2361	4.0721	3.9498	3.8549	3.7790	3.7168
11	6.7241	5.2559	4.6300	4.2751	4.0440	3.8807	3.7586	3.6638	3.5879	3.5257
12	6.5538	5.0959	4.4742	4.1212	3.8911	3.7283	3.6065	3.5118	3.4358	3.3736
13	6.4143	4.9653	4.3472	3.9959	3.7667	3.6043	3.4827	3.3880	3.3120	3.2497
14	6.2979	4.8567	4.2417	3.8919	3.6634	3.5014	3.3799	3.2853	3.2093	3.1469
15	6.1995	4.7650	4.1528	3.8043	3.5764	3.4147	3.2934	3.1987	3.1227	3.0602
16	6.1151	4.6867	4.0768	3.7294	3.5021	3.3406	3.2194	3.1248	3.0488	2.9862
17	6.0420	4.6189	4.0112	3.6648	3.4379	3.2767	3.1556	3.0610	2.9849	2.9222
18	5.9781	4.5597	3.9539	3.6083	3.3820	3.2209	3.0999	3.0053	2.9291	2.8664
19	5.9216	4.5075	3.9034	3.5587	3.3327	3.1718	3.0509	2.9563	2.8801	2.8172
20	5.8715	4.4613	3.8587	3.5147	3.2891	3.1283	3.0074	2.9128	2.8365	2.7737
22	5.7863	4.3828	3.7829	3.4401	3.2151	3.0546	2.9338	2.8392	2.7628	2.6998
25	5.6864	4.2909	3.6943	3.3530	3.1287	2.9685	2.8478	2.7531	2.6766	2.6135
30	5.5675	4.1821	3.5894	3.2499	3.0265	2.8667	2.7460	2.6513	2.5746	2.5112
35	5.4848	4.1065	3.5166	3.1785	2.9557	2.7961	2.6755	2.5807	2.5039	2.4403
40	5.4239	4.0510	3.4633	3.1261	2.9037	2.7444	2.6238	2.5289	2.4519	2.3882
50	5.3403	3.9749	3.3902	3.0544	2.8327	2.6736	2.5530	2.4579	2.3808	2.3168
60	5.2856	3.9253	3.3425	3.0077	2.7863	2.6274	2.5068	2.4117	2.3344	2.2702
75	5.2317	3.8764	3.2957	2.9617	2.7408	2.5820	2.4614	2.3662	2.2888	2.2244
100	5.1786	3.8284	3.2496	2.9166	2.6961	2.5374	2.4168	2.3215	2.2439	2.1793

Table 20. T-critical value table for α = 0.025 (Two-Tail) (AASHTO R 9).

DF\P	0.5	0.4	0.25	0.1	0.05	0.025	0.01	0.005	0.0001
1	1	1.3764	2.4142	6.3138	12.706	25.452	63.657	127.32	6366.2
2	0.81650	1.0607	1.6036	2.9200	4.3027	6.2053	9.9248	14.089	99.992
3	0.76489	0.97847	1.4226	2.3534	3.1824	4.1765	5.8409	7.4533	28.000
4	0.74070	0.94096	1.3444	2.1318	2.7764	3.4954	4.6041	5.5976	15.544
5	0.72669	0.91954	1.3009	2.0150	2.5706	3.1634	4.0321	4.7733	11.178
6	0.71756	0.90570	1.2733	1.9432	2.4469	2.9687	3.7074	4.3168	9.0823
7	0.71114	0.89603	1.2543	1.8946	2.3646	2.8412	3.4995	4.0293	7.8846
8	0.70639	0.88889	1.2403	1.8595	2.3060	2.7515	3.3554	3.8325	7.1200
9	0.70272	0.88340	1.2297	1.8331	2.2622	2.6850	3.2498	3.6897	6.5937
10	0.69981	0.87906	1.2213	1.8125	2.2281	2.6338	3.1693	3.5814	6.2111
11	0.69745	0.87553	1.2145	1.7959	2.2010	2.5931	3.1058	3.4966	5.9212
12	0.69548	0.87261	1.2089	1.7823	2.1788	2.5600	3.0545	3.4284	5.6945
13	0.69383	0.87015	1.2041	1.7709	2.1604	2.5326	3.0123	3.3725	5.5125
14	0.69242	0.86805	1.2001	1.7613	2.1448	2.5096	2.9768	3.3257	5.3634
15	0.69120	0.86624	1.1967	1.7531	2.1314	2.4899	2.9467	3.2860	5.2391
16	0.69013	0.86467	1.1937	1.7459	2.1199	2.4729	2.9208	3.2520	5.1339
17	0.68920	0.86328	1.1910	1.7396	2.1098	2.4581	2.8982	3.2224	5.0438
18	0.68836	0.86205	1.1887	1.7341	2.1009	2.4450	2.8784	3.1966	4.9657
19	0.68762	0.86095	1.1866	1.7291	2.0930	2.4334	2.8609	3.1737	4.8975
20	0.68695	0.85996	1.1848	1.7247	2.0860	2.4231	2.8453	3.1534	4.8373
22	0.68581	0.85827	1.1815	1.7171	2.0739	2.4055	2.8188	3.1188	4.7361
25	0.68443	0.85624	1.1777	1.7081	2.0595	2.3846	2.7874	3.0782	4.6191
30	0.68276	0.85377	1.1731	1.6973	2.0423	2.3596	2.7500	3.0298	4.4824
35	0.68156	0.85201	1.1698	1.6896	2.0301	2.3420	2.7238	2.9960	4.3888
40	0.68067	0.85070	1.1673	1.6839	2.0211	2.3289	2.7045	2.9712	4.3207
50	0.67943	0.84887	1.1639	1.6759	2.0086	2.3109	2.6778	2.9370	4.2283
60	0.67860	0.84765	1.1616	1.6706	2.0003	2.2990	2.6603	2.9146	4.1686
75	0.67778	0.84644	1.1593	1.6654	1.9921	2.2873	2.6430	2.8924	4.1103
100	0.67695	0.84523	1.1571	1.6602	1.9840	2.2757	2.6259	2.8707	4.0533

Table 21. Mix property acceptance attributes (Schmitt et. Al. 1998).

Attribute	Number of States Specifying		
	Aggregate Gradation	Asphalt Content	Mix Volumetrics
Sublot Size			
1 per 500 tons to 1 per 900 tons	12	17	9
1 per 1,000 tons to 1 per 2,000 tons	12	10	15
1 per 3 hours	2	6	5
4 samples	1	1	0
Variable	2	2	2
Lot Size			
1 per 500 tons to 5 per 6,000 tons	13	17	15
1 to 4 per day	7	11	7
4 Sublots	2	2	1
Project	1	1	0
Total per Mix Design	4	4	3
Variable	2	2	2
Cumulative	0	1	1
Continuous	0	1	0
Sampling Location[a]			
Coldfeeds or Hot Bins	17	0	0
Plant Discharge	4	7	4
Truck	15	19	15
Windrow	1	2	1
Volume Analysis	1	2	0
Mat	9	11	0
Asphalt Content Testing Methods[b]			
Extraction		20	
Nuclear Gauge		20	
Ignition Oven		18	
Plant Record		11	
Tank Stickings		9	
Specific Gravity		4	
Compliance Measure[c]			
Quality Level Analysis	13	14	10
Absolute Average deviation	7	8	7
Moving Average	6	7	6
Average	5	6	2
Range	3	3	3

Note: 1 ton = 0.91 Mg
[a]States may specify multiple locations for aggregates gradation and asphalt content
[b]States may specify multiple testing options for asphalt content
[c]One or more compliance measures may be specified within a state
(i.e. may vary by property being measured)

Table 22. Density attributes for 40 states (Schmitt et. Al. 1998).

Attribute	Number of States Specifying
Sublot Size	
1 per 80 to 1 per 1,500 tons	19
300 to 600 meters	5
1 to 5 per day	4
Square yards	1
Square meters	1
Variable	1
None	9
Lot Size	
1 per 400 to 1 per 6,000 tons	17
5 to 10 per day	11
300 to 1,500 meters	5
Total per Mix design	4
1 per shift	1
Cumulative	1
Variable	1
Sampling Method	
Nuclear Gauge	16
Core	15
Nuclear Gauge corrected to core[a]	9
Reference [b,c]	
Theoretical Maximum Density	32
Laboratory Maximum Density	9
Test Strip	8
Compliance Measure [b,d]	
Quality Level Analysis	20
Absolute Average deviation	8
Moving Average	4
Average	3
Range	3

Note: 1 ton = 0.91 Mg
[a]Number of cores for correcting nuclear readings ranged from 3 to 12.
[b]When the total number is less than 40, this means that not all agencies provided a response.
[c]States may specify multiple options a density reference.
[d]States may specify multiple options for compliance.

Table 23. Pay adjustment attributes for 40 states (Schmitt et. Al. 1998).

Attribute	Number of States Specifying
Type of Adjustment	
Factor	36
Fixed Rate	4
Bonus	21[a]
Aggregate Gradation Sieve Sizes	
12.5mm(1/2”)	15
9.5mm(3/8”)	15
4.75mm(#4)	17
2.36mm(#8)	18
2.07mm(#10)	10
1.18mm(#16)	7
600um(#30)	10
450um(#40)	10
300um(#50)	10
75um(#200)	25
Asphalt and Mixture Properties	
Asphalt Content	31
Air Voids	16
Voids in Mineral Aggregate	7
Stability	2
Voids Filled with Asphalt	1
Asphalt Penetration	1
Anti-strip Additive	1
Moisture Content	1
Theoretical Maximum Density	1
Density	
Percent Theoretical Maximum Density	29
Percent Test Strip Density	6
Percent Laboratory Maximum Density	4
Smoothness	
Profile Index	16
Rolling Straightedge	1
Profilometer/Mays Meter	1
Method of Combination	
Weighted[b]	25
Minimum[c]	12
Density	2
Average	1

[a]Bonus provision is contained within the Factor or Fixed Rate.
[b]Weights summing to 1.0 are multiplied to each property then summed.
[c]Minimum individual pay factor of all measured properties is used.