NCAT Report 19-XX

A REVIEW OF ACCEPTANCE SCHEDULE OF PAYMENT FOR ASPHALT PAVEMENTS IN ALABAMA

Akeem Ajede

Dr. Fan Yin, P.E.

Dr. Nam Tran, P.E.

September 2019

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

277 Technology Parkway ■ Auburn, AL 36830

A Review of Acceptance Schedule of Payment for Asphalt Pavements in Alabama
(Research Project 930-948)

NCAT Report 19-XX

Akeem Ajede
Graduate Research Assistant

Fan Yin, Ph.D., P.E.
Assistant Research Professor

Nam Tran, Ph.D., P.E., MBA, LEED GA
Assistant Director and Research Professor

National Center for Asphalt Technology
Auburn University, Auburn, Alabama

Sponsored by
Alabama Department of Transportation

September 2019

ACKNOWLEDGEMENTS

This research project was funded by the Alabama Department of Transportation (ALDOT). The authors would like to thank the many personnel who contributed to the coordination and accomplishment of the work presented herein. Special thanks are extended to Chance Armstead at ALDOT for providing acceptance test results from previous paving projects for the analysis and Dr. Saeed Maghsoodloo for reviewing the statistical analysis conducted in this study. The study would not be completed without guidance from the PAC members, including Scott George (Chair), Lyndi Blackburn, Skip Powe, Ron Johnson (RAC Liaison), Calvin Smith (RAC Liaison) and Kristy Harris (FHWA Liaison).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AAD	Average Absolute Deviation
AC	Asphalt Content
ALDOT	Alabama Department of Transportation
CI	Conformal Index
DOT	Department of Transportation
FDOT	Florida Department of Transportation
G_{mm}	Maximum Specific Gravity
GTR	Ground Tire Rubber
AC	Asphalt Concrete or Asphalt Mixture
JMF	Job Mix Formula
LSL	Lower Specification Limit
MSND	Mean Signed Deviation
MTD	Material Transfer Device
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
PD	Percent Defective
PF	Pay Factor
PWL	Percent within Limits
QC	Quality Control
RAP	Reclaimed Asphalt Pavement
RAS	Reclaimed Asphalt Shingles
SD	Standard Deviation
TRB	Transportation Research Board
USL	Upper Specification Limit
VMA	Voids in Mineral Aggregate
VTM	Voids in the Total Mixture

1. INTRODUCTION

1.1 Background

The Alabama Department of Transportation (ALDOT) currently uses a quality control and acceptance program that is based on statistical analysis using average absolute deviation (AAD) for managing asphalt mixture production and construction properties. ALDOT uses validated contractors' results for acceptance. The quality characteristics used for material properties during production are asphalt content (AC) and plant-produced, laboratory-compacted design air voids in total mix (VTM). The quality characteristics used for placement properties are in-place density and pavement surface smoothness, depending on the type of mix constructed. The quality characteristics in the acceptance schedule of payment (i.e., payment adjustment factors) have incentives and disincentives. Based on the acceptance schedule of payment, ALDOT applies incentives or disincentives to a contractor depending on whether their asphalt mixture exceeds or fails to achieve the acceptance requirements established based on historical data collected during the production and construction of asphalt mixtures from 1998 through 2000, following the implementation of the Superpave mix design system by ALDOT in 1997 (*Parker, 2001*).

Over the years, ALDOT's Standard Specifications for Highway Construction have undergone some changes to allow the use of new materials, such as polymer modified asphalt and warm mix asphalt. The specifications have also allowed the use of recycled materials including reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS), and ground tire rubber (GTR). Furthermore, pavement construction practices have improved due to technological advancements, such as the use of material transfer devices (MTD) and improved pavement maintenance techniques, such as thin overlays. Thus, there is a need to review the current limits for pay adjustments. It is necessary to have a regular review to ensure that they remain representative of the current contractors' performance, ALDOT's specifications, and construction practices in Alabama.

1.2 Objective

The objective of this project is to review the current acceptance schedules of payment in the ALDOT's Standard Specifications for Highway Construction. The aim of the review is to determine if the acceptance schedule of payment is representative of the current contractors' performance. This study also reviews the level of disincentive and incentive applied to contractors based on acceptance test data from previous paving projects.

1.3 Scope of Report

Quality control and verification data used by ALDOT for accepting asphalt mixtures placed across the state of Alabama were compiled into a database and analyzed using statistical analysis tools. Results of the statistical analysis were then utilized to assess ALDOT's acceptance schedule of payment for AC, VTM and in-place density.

1.4 Organization of the Report

This report comprises of five chapters. Chapter 1 provides the introduction of the report, which contains background information, study objective, scope of the work, and organization of the report. Chapter 2 contains a review of quality control (QC) and acceptance procedures and a summary of current practices for the acceptance schedule of payment for asphalt mixtures in Alabama and neighboring states. Chapter 3 consists of a description of the compiled acceptance database and detailed discussions of the statistical analysis and results. Chapter 4 describes the methodology used to develop ALDOT's current acceptance schedule of payment and how the current acceptance schedule would change if it was based on recent acceptance data. Finally, Chapter 5 presents the conclusions and recommendations of the study.

2. LITERATURE REVIEW

2.1 Background

State departments of transportation (DOTs) have quality assurance specifications that specify minimum contractor QC activities, agency acceptance activities, specific quality characteristics, targets and limits used for acceptance, and pay adjustments related to the quality level of each product. Quality control in asphalt pavement construction is conducted by the contractor in charge of the project, and it is carried out by following a set of procedures to ensure that the job satisfies the specified level of quality. Acceptance testing, on the other hand, is a means of ensuring that the tasks specified in the contract documents are adequately executed by the contractor (*TRB, 2018*). Acceptance of a product can be done based on acceptance testing performed by DOTs or their consultants, or based on validated contractor test results (FHWA, 2006).

While all of the above components are vital in a quality assurance specification, the focus of this study is placed on quality characteristics, targets and limits used for acceptance, and pay adjustments related to the quality level of asphalt mixtures. The following subsections discuss how these components are specified by ALDOT and by other DOTs in neighboring states.

2.2 Quality Characteristics Used for Acceptance of Asphalt Mixtures

Table 1 summarizes the quality characteristics used by ALDOT and seven other neighboring state DOTs for acceptance of asphalt mixtures. It should be noted that the Code of Federal Regulations requires that contractors' results be validated if they are to be used in the acceptance decision. For mixture production, at least six of the eight state DOTs specify asphalt content (AC) and aggregate gradation for determining pay factors. Plant-mixed, laboratory-compacted air voids in total mix (VTM) are specified by five of the eight state DOTs. The other quality characteristics, including theoretical maximum specific gravity (G_{mm}) and voids in mineral aggregate (VMA), are specified by one and two of the eight state DOTs, respectively. For mixture placement, all eight state DOTs listed in Table 1 specify the in-place density for determining pay factors. Surface rideability of the pavement, such as international roughness index and profile index, is required by five of the eight agencies. Only Louisiana includes tack coat rate as a quality characteristic in its quality assurance specification.

Table 1. Quality Characteristics for Acceptance of Asphalt Mixtures

State DOT	Production/Materials					Placement		
	AC	VTM	VMA	Gradation	G_{mm}	Density	Rideability	Tack Coat
Alabama	√	√		√		√	√	
Florida	√	√		√		√	√	
Georgia	√			√		√		
Louisiana				√	√	√	√	√
Mississippi	√	√	√	√		√	√	
South Carolina	√	√	√	√		√		
Tennessee	√			√		√		
Texas		√				√	√	

2.3 Lot Size

A lot is defined as the specific amount of asphalt material from a single source, which is assumed to be produced or placed by the same controlled process, and it is evaluated for payment purposes in QC or acceptance testing (*Brown et al., 2009*). A review of DOT specifications indicated that the lot size varies from state to state. Table 2 presents the lot size used by ALDOT and other neighboring state DOTs. Among the agencies included in Table 2, four define a lot as one day's production, while the others specify a particular tonnage (ranging from 500 to 4,000 tons) as the lot size for testing and acceptance.

Table 2. Comparison of Lot Size for Testing and Acceptance

State DOT	Mix Type	Lot Size
Alabama	SMA, Superpave	2,800 tons
	OGFC	2,000 tons
Florida	Superpave	2,000 or 4,000 tons
	OGFC	2,000 tons
Georgia	-	One production day
Louisiana	-	2,400 tons
Mississippi	-	One production day
South Carolina	-	One production day
Tennessee	-	One production day
Texas	SMA, Superpave	1,000 tons (default)
	OGFC	2,000 tons (default)
	Thin Overlay	500 tons (default)

2.4 Methods of Determining the Pay Factor for Each Quality Characteristic

A number of measures can be used to determine the quality level for each quality characteristic. The arithmetic mean and mean signed deviation (*MSND*) from a target value were often used in early state DOT specifications (*Burati et al., 2003*). However, neither of these two measures accounts for the variability of individual test results, which has now been recognized as an important performance indicator. In recent years, quality measures that consider both average and variability levels are preferred by state DOTs. These quality measures include the percent defective (*PD*) and percent within limits (*PWL*), the average absolute deviation (*AAD*), the moving average, and the conformal index (*CI*). A brief description of each quality measure follows.

Arithmetic Mean

Equation 1 shows the arithmetic mean, which is defined as the sum of the numerical values of each individual test result divided by the total number of test results. The primary limitation of using the arithmetic mean to determine pay factors is that it fails to consider test result variability.

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{1}$$

where:

$\bar{X}$ = arithmetic mean;
X_i = individual test results; and
n = number of test results.

Mean Signed Deviation (MSND)

MSND represents the signed (positive or negative) deviation from the arithmetic mean of test results from a target or the specified value, as shown in Equation 2. It is essentially the same as the arithmetic mean, as it indicates the accuracy of test results but provides no measure of variability.

$$MSND = \frac{\sum_{i=1}^{n} (X_i - T)}{n} = \bar{X} - T \tag{2}$$

where:

T = target value.

Percent within Limits (PWL)

PWL refers to the percentage of test results that falls above the lower specification limit (*LSL*), below the upper specification limit (*USL*), or between the *LSL* and the *USL*. As expressed in Equations 3 through 5, the *Q*-statistic is used in conjunction with a *PWL* table to determine the estimated PWL. Conceptually, the *Q*-statistic is similar to the *Z*-statistic, except that it uses the sample mean value instead of the population mean as the reference point. According to Burati et al. (2004), *PWL* was recommended as the best quality measure because it considers both accuracy and precision of the test results; in addition, it works effectively for both one-sided and two-sided specifications.

$$Q_L = \frac{\overline{X} - LSL}{s} \tag{3}$$

where:

Q_L = quality index for the LSL; and

s = sample standard deviation.

$$Q_U = \frac{USL - \overline{X}}{s} \tag{4}$$

where:

Q_U = quality index for the USL.

$$PWL = PWL_U + PWL_L - 100 \tag{5}$$

where:

PWL_U = percent below the USL (based on Q_U and PWL table); and

PWL_L = percent above the LSL (based on Q_L and *PWL* table).

Average Absolute Deviation (AAD)

AAD is defined as the mean of absolute deviations from a target or specified value (Equation 6) (*TRB, 2018*). A low *AAD* value indicates good accuracy and precision; in other words, the sample test results are close to the target and have reasonably low variability. On the other hand, a high *AAD* implies poor accuracy or poor precision, but not necessarily both. Although *AAD* considered both accuracy and precision of the test results, it has few limitations (*Burati et al., 2004*); it can only be used for quality characteristics that have a target value, but not for those with a specification range. In addition, *AAD* does not provide a direct measure of variability; and thus, different sets of test results can yield the same *AAD* values.

$$AAD = \frac{\sum_{i=1}^{n} \left| X_i - T \right|}{n} \tag{6}$$

Moving Average

A moving average refers to a calculation used to analyze test results by creating series of averages of different subsets of the full data set. The determination of a moving average is illustrated in Figure 1. Because the moving average can smooth out the fluctuations among the individual test results, it is commonly used in the QC process. Burati et al. (2003), however, recommended not using the moving average as a quality measure for payment determination because each individual test result is used in several adjacent moving averages, and therefore, these moving averages are not independent from each other.

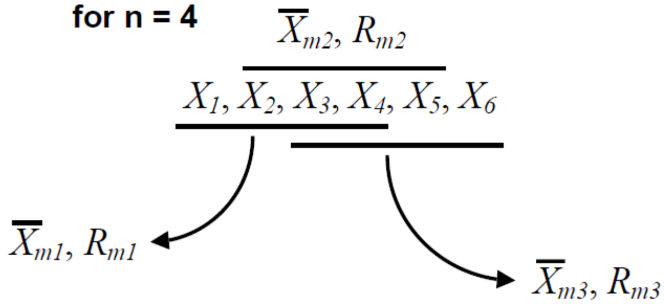


Figure 1. Illustration of the Moving Average (*Burati et al., 20036*)

Conformal Index (CI)

CI measures the dispersion of a series of test results around a target or specified value (*TRB, 2018*). As shown in Equation 7, it is expressed as the square root of the quantity obtained by summing the squares of the signed deviations from the target value and dividing by the number of test results. The *CI* performs in a similar manner as *AAD* and has the same shortcomings of not being appropriate for one-sided specifications (*Burati et al., 2003*).

$$CI = \sqrt{\frac{\sum_{i=1}^{n}(X_i - T)^2}{n}} \tag{7}$$

Quality Measures Currently Utilized by ALDOT and Neighboring States

Table 3 summarizes the quality measures used by ALDOT and seven neighboring state DOTs. Six state DOTs currently use *AAD* to determine pay factors for asphalt mixtures. Florida DOT uses *AAD* for mixtures with two or less sublots but uses *PWL* for those with three or more sublots. Louisiana DOT uses *AAD* for thin asphalt mixtures but uses *PWL* for other types of mixtures. Among the state highway agencies in Table 3, only Mississippi DOT uses *MSND* as the quality measure for asphalt mixtures.

Table 3. Practices from Selected DOTs on Quality Measure of Asphalt Mixtures

State DOT	*AAD*	*PWL*	*MSND*
Alabama	√		
Florida	√ (≤ 2 sublots)	√ (≥ 3 sublots)	
Georgia	√		
Louisiana	√ (thin mixtures)	√	
Mississippi			√
South Carolina	√		
Tennessee	√		
Texas	√		

An example is provided below to illustrate the difference between ALDOT's acceptance schedule using *AAD* method and Florida Department of Transportation (FDOT)'s acceptance schedule using *PWL* method and their effects on the calculation of pay factors. In this example, the two procedures are followed to determine the pay factor based on the asphalt contents tested for a Superpave mixture. The asphalt content of the job mix formula (JMF) is 5.0%, and four test results obtained during production are 4.5%, 4.8%, 5.1%, and 5.3%.

The ALDOT acceptance schedule calculates the pay factor using the *AAD* method. The key calculation steps are given as follows:

- Using Equation 6, the *AAD* of the test results is calculated to be 0.275%.

$$AAD = \frac{\sum |X_i - T|}{n} = \frac{|4.5-5.0| + |4.8-5.0| + |5.1-5.0| + |5.3-5.0|}{4} = 0.275(\%)$$

- Based on the ALDOT acceptance schedule (Table 4), the pay factor is 1.00 for the Superpave mix corresponding to a four-test *AAD* of 0.275% for the asphalt content test results.

Table 4. ALDOT Acceptance Schedule of Payment for Asphalt Content of Superpave Mixes

TABLE III						
SECTION 424 MIXES (SUPERPAVE)						
ACCEPTANCE SCHEDULE OF PAYMENT FOR ASPHALT PLANT MIX CHARACTERISTICS						
Arithmetic Average of the Absolute Values of Deviations of the LOT Acceptance Tests From Job Mix Formula Values						
Asphalt Content						
LOT Pay Factor ->	1.02	1.00	0.98	0.95	0.90	0.80*
1 Test	-	0.00-0.62	0.63-0.68	0.69-0.75	0.76-0.88	Over 0.88
2 Tests	-	0.00-0.44	0.45-0.48	0.49-0.53	0.54-0.62	Over 0.62
3 Tests	-	0.00-0.36	0.37-0.39	0.40-0.43	0.44-0.51	Over 0.51
4 Tests	0.00-0.19	0.20-0.31	0.32-0.34	0.35-0.38	0.39-0.44	Over 0.44
Voids in Total Mix (Lab. Compacted Samples)						
LOT Pay Factor ->	1.02	1.00	0.98	0.95	0.90	0.80*
1 Test	-	0.00-2.50	2.51-2.70	2.71-3.00	3.01-3.50	Over 3.50
2 Tests	-	0.00-1.77	1.78-1.91	1.92-2.12	2.13-2.47	Over 2.47
3 Tests	-	0.00-1.44	1.45-1.56	1.57-1.73	1.74-2.02	Over 2.02
4 Tests	0.00-0.75	0.76-1.25	1.26-1.35	1.36-1.50	1.51-1.75	Over 1.75
* If approved by the Department, the Contractor may accept the indicated LOT partial pay. The Department may require removal and replacement. If the LOT pay factor is greater than 0.80, the Contractor has the option to remove at no cost to the Department and to replace at contract unit bid price rather than accepting the reduced LOT payment.						

The FDOT acceptance schedule calculates the pay factor using the *PWL* method. The key calculation steps are given as follows:

- The arithmetic mean ($\overline{X}$) of the test results is calculated to be 4.93%.

$$\overline{X} = \frac{\sum x_i}{n} = \frac{4.5+4.8+5.1+5.3}{4} = 4.93(\%)$$

- The standard deviation (*s*) of the test results is calculated to be 0.35%.

$$s=\sqrt{\frac{n\sum x_i^{\,2}-(\sum x_i)^2}{n(n-1)}}=\sqrt{\frac{4*(4.5^2+4.8^2+5.1^2+5.3^2)-(4.5+4.8+5.1+5.3)^2}{4*(4-1)}}=0.35(\%)$$

- Referring to the FDOT specification limits (Table 5), the *USL* and *LSL* of asphalt content results are 5.4% (5.0% + 0.4%) and 4.6% (5.0% - 0.4%), respectively.

Table 5. FDOT Specification Limits

Table 334-8 Specification Limits	
Quality Characteristic	Specification Limits
Passing No. 8 sieve (percent)	Target ± 3.1
Passing No. 200 sieve (percent)	Target ± 1.0
Asphalt Content (percent)	Target ± 0.40
Air Voids (percent)	4.00 ± 1.20
Density, vibratory mode (percent of G_{mm}):	93.00 + 2.00, - 1.20
Density, static mode (percent of G_{mm}):	92.00 + 3.00, - 1.50 (1)
(1): No vibratory mode in the vertical direction will be allowed. Other vibratory modes will be allowed, if approved by the Engineer.	

- Using Equation 3, the Q_L is calculated to be 0.94.

$$Q_L=\frac{\overline{X}-LSL}{s}=\frac{4.93-4.6}{0.35}=0.94$$

- Using Equation 4, the QU is calculated to be 1.34.

$$Q_U=\frac{USL-\overline{X}}{s}=\frac{5.4-4.93}{0.35}=1.34$$

- Referring to the FDOT *PWL* table (Table 6), the PWL_L and PWL_U are 81.34 and 94.67 (obtained after data interpolation), respectively.

- Using Equation 5, the *PWL* is calculated to be 76.01.

$$PWL=PWL_U+PWL_L-100=94.67+81.34-100=76.01$$

- The pay factor is determined as 0.93.

$$PF=(55+0.5*PWL)/100=(55+0.5*76.01)/100=0.93$$

In the example above, the same set of asphalt content test results of the Superpave mix yield different pay factors for the *AAD* (PF=1.00) and *PWL* (PF=0.93) methods by following ALDOT and FDOT acceptance schedules, respectively. The difference is related to the ability of the two different quality measures to include variability. It is important for acceptance schedules to include the variability.

Table 6. FDOT PWL Table

Table 334-9 Percent Within Limits				
Quality Index	Percent within Limits for Selected Sample Size			
	n = 3	n = 4	n = 5	n = 6
0.35	59.80	61.67	62.38	62.73
0.40	61.26	63.33	64.12	64.51
0.45	62.74	65.00	65.84	66.27
0.50	64.25	66.67	67.56	68.00
0.55	65.80	68.33	69.26	69.72
0.60	67.39	70.00	70.95	71.41
0.65	69.03	71.67	72.61	73.08
0.70	70.73	73.33	74.26	74.71
0.75	72.50	75.00	75.89	76.32
0.80	74.36	76.67	77.49	77.89
0.85	76.33	78.33	79.07	79.43
0.90	78.45	80.00	80.62	80.93
0.95	80.75	81.67	82.14	82.39
1.00	83.33	83.33	83.64	83.80
1.05	86.34	85.00	85.09	85.18
1.10	90.16	86.67	86.52	86.50
1.15	97.13	88.33	87.90	87.78
1.20	100.00	90.00	89.24	89.01
1.25	100.00	91.67	90.54	90.19
1.30	100.00	93.33	91.79	91.31
1.35	100.00	95.00	92.98	92.37
1.40	100.00	96.67	94.12	93.37
1.45	100.00	98.33	95.19	94.32
1.50	100.00	100.00	96.20	95.19
1.55	100.00	100.00	97.13	96.00
1.60	100.00	100.00	97.97	96.75
1.65	100.00	100.00	98.72	97.42
1.70	100.00	100.00	99.34	98.02
1.75	100.00	100.00	99.81	98.55
1.80	100.00	100.00	100.00	98.99
1.85	100.00	100.00	100.00	99.36
1.90	100.00	100.00	100.00	99.65
1.95	100.00	100.00	100.00	99.85
2.00	100.00	100.00	100.00	99.97

2.5 Determining Composite Pay Factors

As shown previously in Table 1, state DOTs typical use multiple QC quality characteristics to determine pay factors of asphalt mixtures. There are a number of approaches available to combine the pay factors of individual quality characteristic into a single composite pay factor for acceptance. These approaches include:

- Using the minimum individual pay factor (*Minimum*). For example, $PF = \min(PF_1, PF_2)$.
- Summing the individual pay factors (*Sum*). For example, $PF = 1 - [(1 - PF_1) + (1 - PF_2)]$.

- Multiplying the individual pay factors (*Product*). For example, PF = PF_1 * PF_2.
- Using the weighted average of individual pay factors (*Weighted Average*). For example, PF = PF_1*W_1% + PF_2*W_2%, where W_1% + W_2% =100%.

The *Minimum* approach identifies the lowest individual pay factor as the composite pay factor, while the other three approaches consider the contributions from each individual pay factor. In general, the *Sum* and *Product* approaches are more conservative than the *Minimum* and *Weighted Average* approaches. Burati et al. (2003) recommended using the *Weighted Average* approach for asphalt mixtures because the individual quality characteristics, such as asphalt content, aggregate gradation, in-place density, etc., were not likely to have an identical impact on the long-term pavement performance. Table 7 presents the approaches used by ALDOT and seven other neighboring state DOTs. As shown, seven out of eight state DOTs use either the *Minimum* approach or the *Weighted Average* approach, while only one (i.e., Tennessee) uses the *Sum* approach.

Table 7. Selected DOT Practice on Determining Composite Pay Factors for Asphalt Mixtures

State DOT	Weighted Average	Minimum	Sum
Alabama	√ (placement)	√ (production)	
Florida	√		
Georgia		√	
Louisiana		√	
Mississippi		√	
South Carolina	√		
Tennessee			√
Texas	√		

An example is given below to illustrate the difference among the approaches for determining composite pay factors based on individual pay factors. According to the current ALDOT acceptance schedule, the quality characteristics of asphalt pavements include rideability, asphalt content, laboratory-molded air voids, and in-place density. For this example, the individual pay factors for these four characteristics are assumed to be 0.98, 1.00, 0.95, and 0.92, respectively. The assumed weighing factors for the *Weighted Average* approach are 20% for rideability, 30% for asphalt content, 10% for air voids, and 40% for in-place density. The determination of the composite pay factors is as follows:

- Based on the *Minimum* approach, the composite pay factor is 0.92.

$$PF = \min(PF_i) = \min(0.98, 1.00, 0.95, 0.92) = 0.92$$

- Based on the *Sum* approach, the composite pay factor is calculated to be 0.85.

$$PF = 1 - \sum(1 - PF_i) = 1 - \left[(1-0.98) + (1-1.00) + (1-0.95) + (1-0.92)\right] = 0.85$$

- Based on the *Product* approach, the composite pay factor is calculated to be 0.86.

$$PF = PF_i * PF_j = 0.98 * 1.00 * 0.95 * 0.92 = 0.86$$

- Based on the *Weighted Average* approach, the composite pay factor is calculated to be 0.96.

$$PF = \sum (PF_i * W_i\%) = (0.98*20\%) + (1.00*30\%) + (0.95*10\%) + (0.92*40\%) = 0.96$$

Figure 2 shows a comparison of composite pay factors determined from different approaches in the example. The *Weighted Average* approach yields the highest composite pay factor, followed by the *Minimum* approach, and then the *Product* approach and the *Sum* approach.

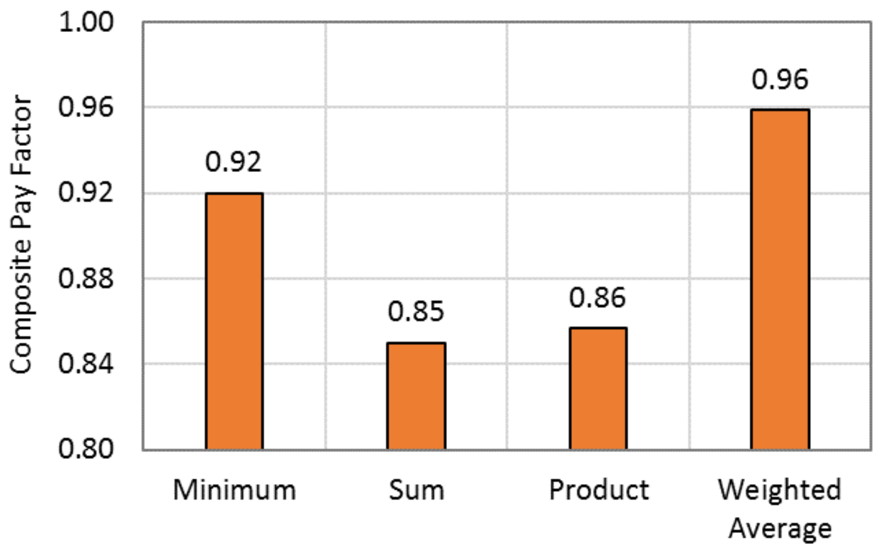


Figure 2. Comparison of Composite Pay Factors

2.6 Comparison of Acceptance Ranges

The method used by state highway agencies for determining the acceptance range is expressed in Equation 8. The acceptance range is calculated as a function of standard deviation of individual measurements (σ_1), sample size (*n*), and a constant C_i. The selection of constant C_i is based on statistical principals to control the probability of "average" contractors having measurements within the acceptance range; thus, the magnitude of this constant is a management decision (*Parker, 1995*).

$$Range = C_i \frac{\sigma_1}{\sqrt{n}} \quad (8)$$

Figures 3 through 7 compare the one-test acceptance ranges used by ALDOT and seven other neighboring state DOTs; detailed results are provided in Appendix A. Since ALDOT is using the *AAD* method, these comparisons are only applicable to state DOTs that use the same method. Additionally, since different index parameters are being used for evaluating pavement rideability, the comparison is not available for this quality characteristic. Based on these figures, the following observations can be offered:

- For asphalt content (Figure 3), ALDOT has a wider acceptance range than Florida DOT and Tennessee DOT, but its acceptance range is tighter than those of the Georgia DOT for surface and subsurface Superpave mixes.
- ALDOT has wider acceptance ranges for laboratory-molded air voids and in-place density than the other state DOTs that specify these two quality characteristics for acceptance schedule (Figures 4 and 5).
- Similar trends are also observed in Figures 6 and 7 for the aggregate gradations of OGFC mixes, where ALDOT has wider acceptance ranges than the other state DOTs.

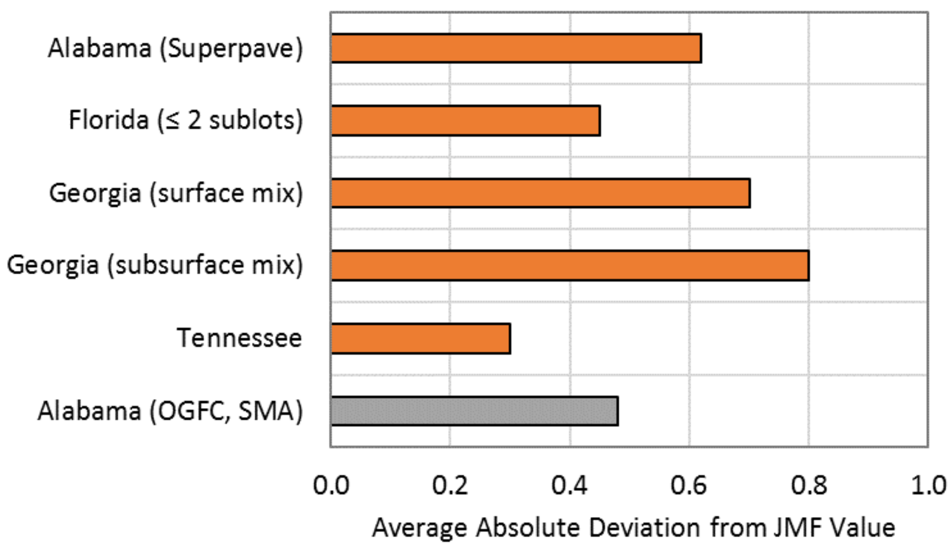


Figure 3. One-Test Acceptance Range of Asphalt Content

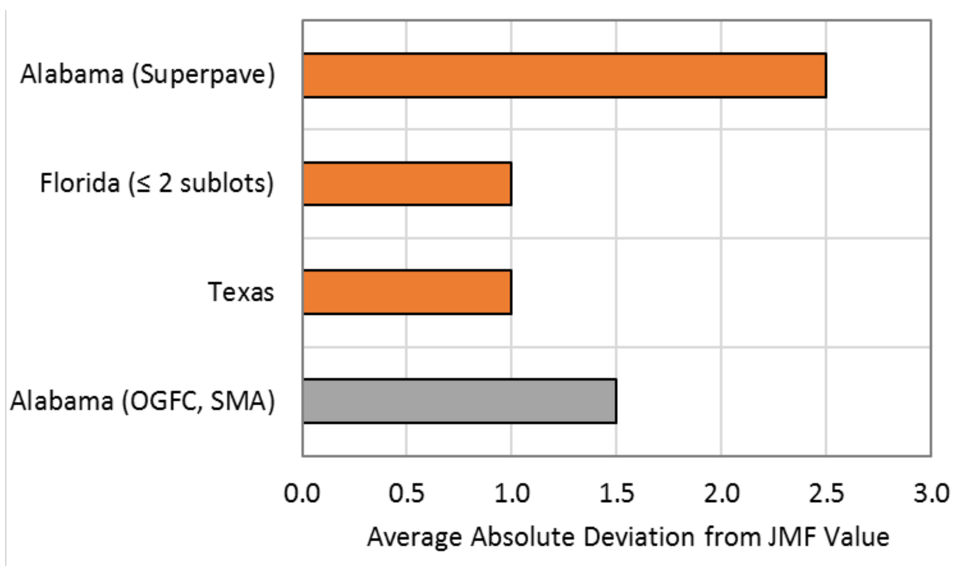


Figure 4. One-Test Acceptance Range of Laboratory-Molded Air Voids

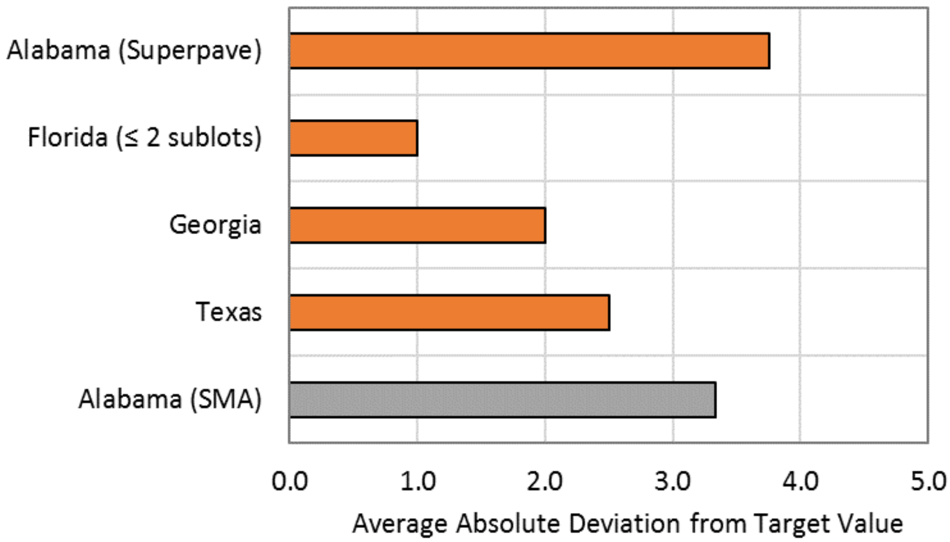


Figure 5. One-Test Acceptance Range of In-Place Density

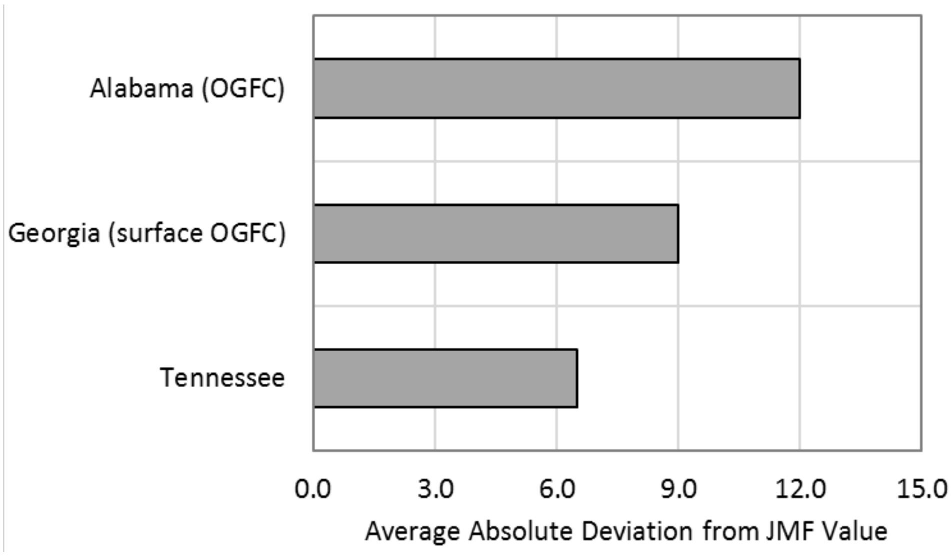


Figure 6. One-Test Acceptance Range of OGFC Gradation (3/8" Sieve)

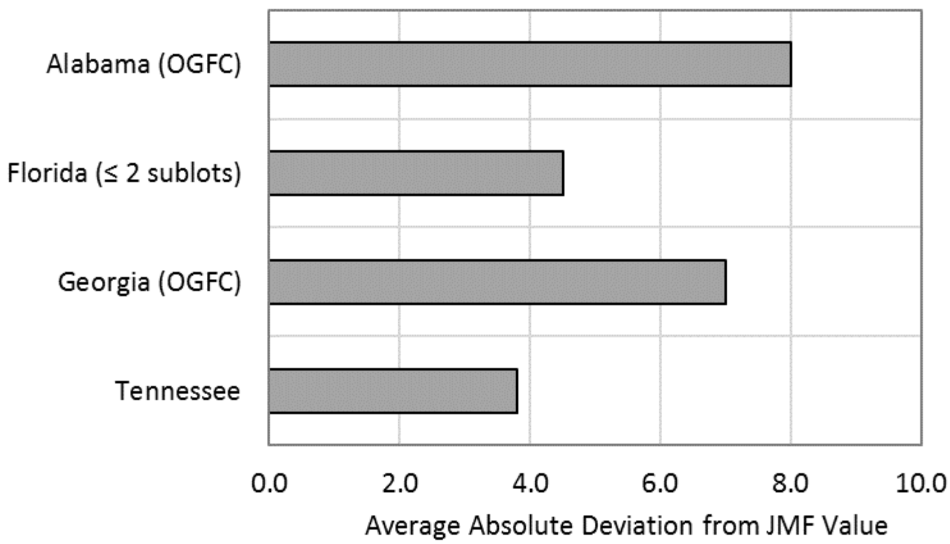


Figure 7. One-Test Acceptance Range of OGFC Gradation (No. 8 Sieve)

3. DATA ANALYSIS

3.1 Data Acquisition and Compilation

The raw data, comprising of contractor QC and state verification test results from 45 Superpave mix projects across all nine ALDOT divisions, was provided by ALDOT and delivered to NCAT in the form of hard copy paper documents, electronic document files, and Microsoft Excel spreadsheets. These data were then compiled into a single database for statistical analysis. Test results were identified and sorted by project number, pay item, and lot/sublot number, as shown in an example in Table 8. A full list of these projects is provided in Appendix B.

Table 8. Example of the Database Format

Project ID	Pay Item #	Lot #	Sublot #
1	424B-651/655/692	1	1
1	424B-651/655/692	1	2
1	424B-651/655/692	1	3
1	424B-651/655/692	1	4
1	424B-651/655/692	2	1
1	424B-651/655/692	2	2
1	424B-651/655/692	2	3
1	424B-651/655/692	2	4

The contractor QC test results of AC and VTM for each sublot were appropriately identified and compiled into different worksheets in a Microsoft Excel spreadsheet. The target, or JMF value, of each contractor's test result was also identified. While the target VTM remain relatively constant at a value of 4% for all Superpave mix projects, the JMF AC varies within and between projects. Furthermore, state verification test results were adequately matched with the respective contractor QC test results. Table 9 provides an example of the compiled database for AC and VTM.

Table 9. Example of the Compiled Database Format for AC and VTM

Project ID	Pay Item #	Lot #	AC, %			VTM, %		
			JMF	QC	Verif.	JMF	QC	Verif.
1	424B-651/655/692	1	4.500	4.27	4.38	4.000	3.94	4.71
1	424B-651/655/692	1	4.500	4.32	-	4.000	3.33	-
1	424B-651/655/692	1	4.500	4.22	4.25	4.000	3.24	5.05
1	424B-651/655/692	1	4.500	4.29	-	4.000	3.56	-
1	424A-356	2	6.600	6.48	-	4.000	3.47	-
1	424A-356	2	6.600	6.73	6.99	4.000	2.91	2.71
1	424A-356	2	6.600	7.11	7.3	4.000	2.43	2.07
1	424A-356	2	6.600	6.62	6.75	4.000	2.39	3.93

Among the 45 projects evaluated in this study, one does not have the state verification data for AC and VTM and was excluded from analysis. The AC database includes 2,836 contractor QC test results and 1,885 state verification test results, and the VTM database comprises of 2,662 contractor QC test results and 1,776 state verification results. The in-place density database includes 2,937 verification data tested by the state. For all three characteristics, both contractor QC and state verification data were analyzed in the form of *MSND* or *AAD* (for determining pay factors) from the target values. For AC, the target value is the JMF AC content. The target values for VTM and in-place density are 4% and 94%, respectively.

3.2 Statistical Evaluation Tools for Analysis

Several statistical evaluation tools were utilized to accomplish the objective of this study, each of which is briefly discussed in the subsequent sections.

Outlier Analysis (ASTM E178-16a)

ASTM E178-16a *Standard Practice for Dealing with Outlying Observations* is a standard specification that deals with outlying observations in samples. This standard was used as a reference to identify and eliminate the outliers in the ALDOT database for AC, VTM, and in-place density. The null hypothesis, H_0, of the outlier test is that there are no outliers present in the AC, VTM, and in-place density data. The alternative hypothesis, H_1, states that there are one or more actual outliers in the database. The significance level of the outlier test is 5% (i.e., α = 5%). However, ASTM E178-16a recommends using twice the selected significance level if there is a possibility of having an outlier on either side of the distribution. Hence, a significance level of 10% was used for the outlier test in the study. After conducting the outlier test, four outliers were identified in the contractor AC and VTM database each, four outliers in the state AC database, three outliers in the state VTM database, and ten outliers in the in-place density database. All of these outliers were excluded from further statistical analysis.

Anderson-Darling Test for Normality

Two-sample *t*-test and *F*-test are the most commonly used statistical tests for determining the equal mean and variability of two samples. One assumption required for these two tests is that the two samples consist of normally distributed data. Normality test, in descriptive statistics, is applicable in measuring the goodness of fit of a standard model to the available data. In this study, the Anderson-Darling normality test was used to determine the normality of AC and VTM data in the database. The test is effective in determining the departure from normality in the high and low values of a probability distribution. The test was conducted using a significance level of 0.05.

Mann-Whitney U-Test for Two-Sample Equal Mean

When the assumption of normal distribution is not satisfied, *t*-test and *F*-test are likely to yield inaccurate analysis results. The ongoing NCHRP 10-100 project recommends using nonparametric statistical tests as alternative to determine two-sample mean and variability (Figures 8 and 9), respectively (*Hand et al., 2018*). The Mann-Whitney U-test is one of the recommended nonparametric two-sample mean tests for samples that do not follow a normal distribution. The null hypothesis, H_0, of the test is that there is an equally likely chance that a randomly selected test result from the first data set will either be less than or greater than a randomly selected test result from a second data set. The evidence of accepting or rejecting a null hypothesis is the p-value as relative to the significant level of the test (i.e., 0.05); the null hypothesis would be rejected if the p-value falls below 0.05 and accepted if otherwise.

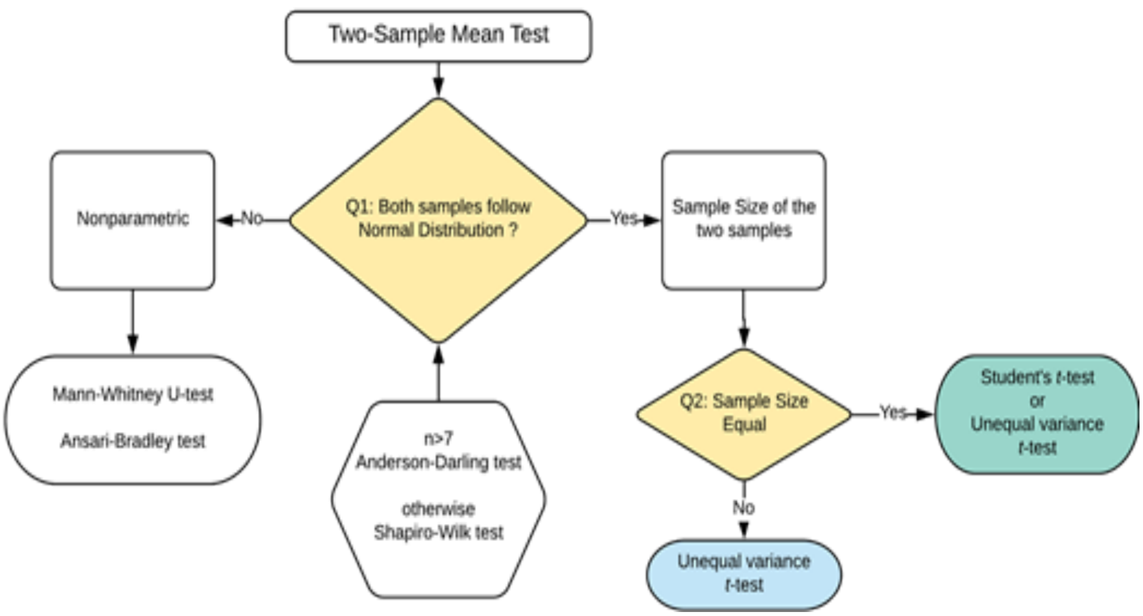


Figure 8. Proposed Two-Sample Mean Testing Flow Chart in NCHRP 10-100 Project (*Hand et al., 2018*)

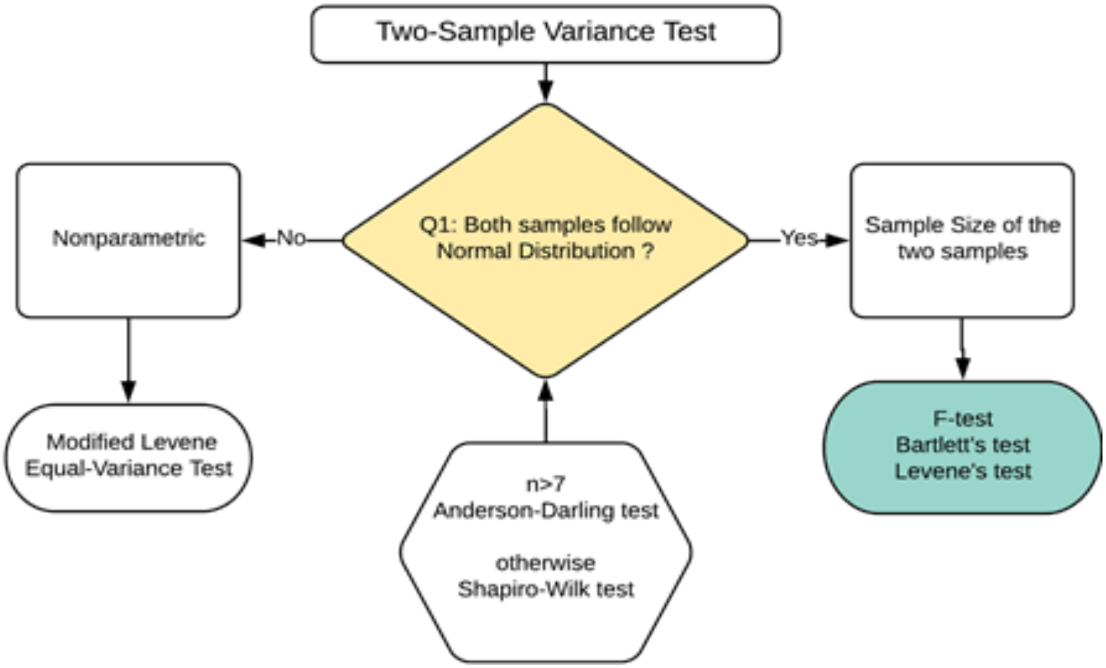


Figure 9. Proposed Two-Sample Variance Testing Flow Chart in NCHRP 10-100 Project (*Hand et al., 2018*)

Modified Levene Test for Two-Sample Equal Variance

The modified Levene equal-variance test is the recommended nonparametric statistical test in NCHRP 10-100 project for determining the equal variance of two samples that are not normally distributed (Figure 9). The test evaluates the homogeneity of variances by testing a null hypothesis, H_0, that the variances of two different datasets are equivalent. A p-value above the selected level of significance of 0.05 suggests homogeneity of variances or standard deviations. On the other hand, if the p-value falls below 0.05, then there is a significant difference between the standard deviations or variances of the two samples.

3.3 Project Level Statistical Analysis

Statistical analysis was conducted to determine the *MSND* and standard deviation (*SD*) of contractor QC and state verification test results for each lot in the entire database. Note that both contractor QC and state verification data are presented in the form of signed deviation from the target value instead of the actual AC, VTM, and in-place density data. The pavement smoothness data were not analyzed in this study. The detailed analysis outcomes for AC, VTM, and in-place density data are presented in Appendix C.

AC Data

Figures 10 and 11 present the *MSND* and *SD* results of contractor QC and state verification AC data, respectively. As shown in Figure 10, variation exists between the *MSND* values of contractor QC and state verification results for each project. The greatest variation between the two sets of data was recorded in Project 1. Despite the variations among the projects, the overall *MSND* of AC for both contractor QC and state verification data equal zero, which demonstrates the ability of contractors to achieve the JMF AC during production.

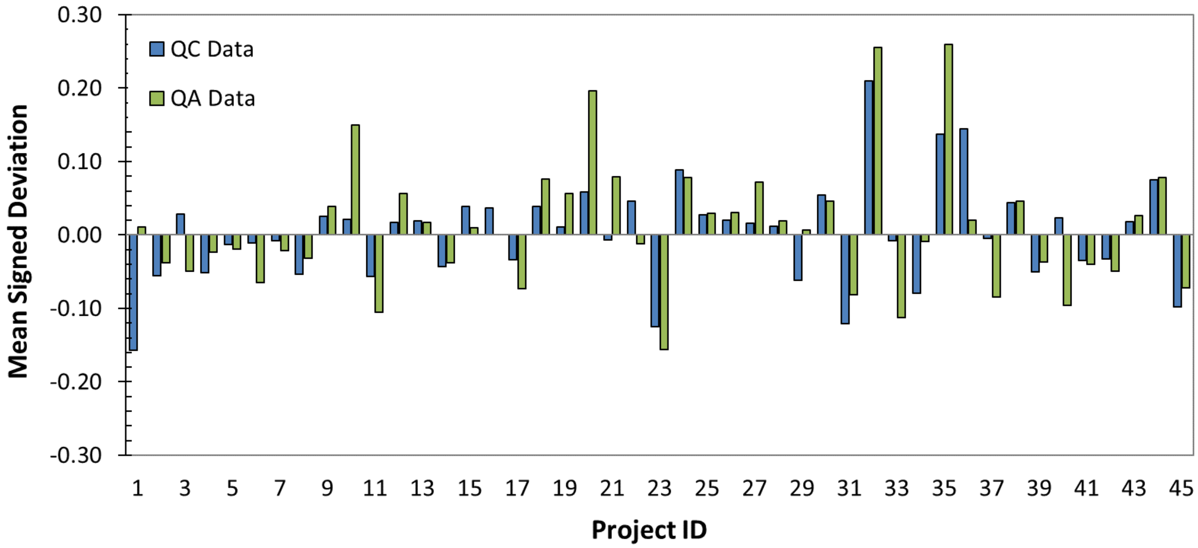


Figure 10. Project-Level AC Mean Signed Deviation Data

For all projects in the database, the *SD* of contractor QC and state verification data shown in Figure 11 are consistently lower than the *SD* value (i.e., 0.31) used in the current ALDOT specification limits. An earlier study by Parker (2001) that reviewed ALDOT production data of 86 Superpave projects constructed between 1997 and 2000 and determined an overall *SD* of 0.24. The overall *SD* of the data in the database developed for this study is 0.16. These results indicate that the level of performance of contractors has improved significantly over the years.

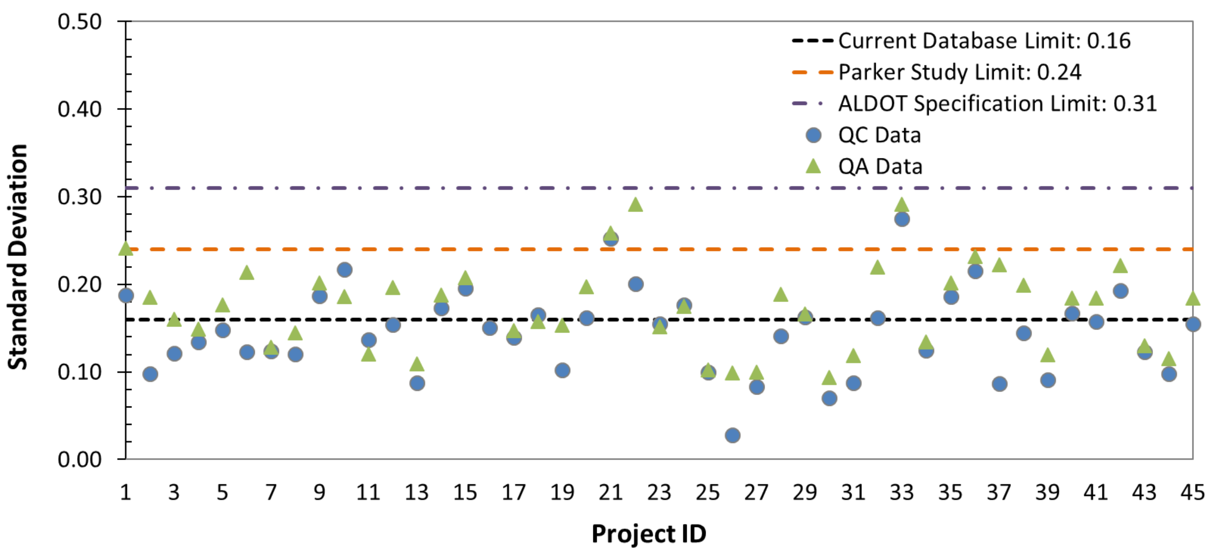


Figure 11. Project-Level AC Standard Deviation Data

VTM Data

Figures 12 and 13 present the *MSND* and *SD* results of contractor QC and state verification data for VTM, respectively. As shown in Figure 12, the *MSND* of contractor QC and state verification data varies from -1.30 to 0.50 among all projects, with the greatest variation recorded in Project 35. The overall *MSND* of contractor QC and state verification VTM data are -0.22 and -0.24, respectively, which indicates that most contractors fell short of the 4.0% target VTM during production. From Figure 13, the *SD* of virtually all VTM data, except for the verification data of Project 33, fall significantly below the ALDOT specification threshold of 1.25. The overall *SD* is 0.57. The study by Parker (2001) determined an overall *SD* of 0.93 for Superpave mix projects constructed between 1997 and 2000.

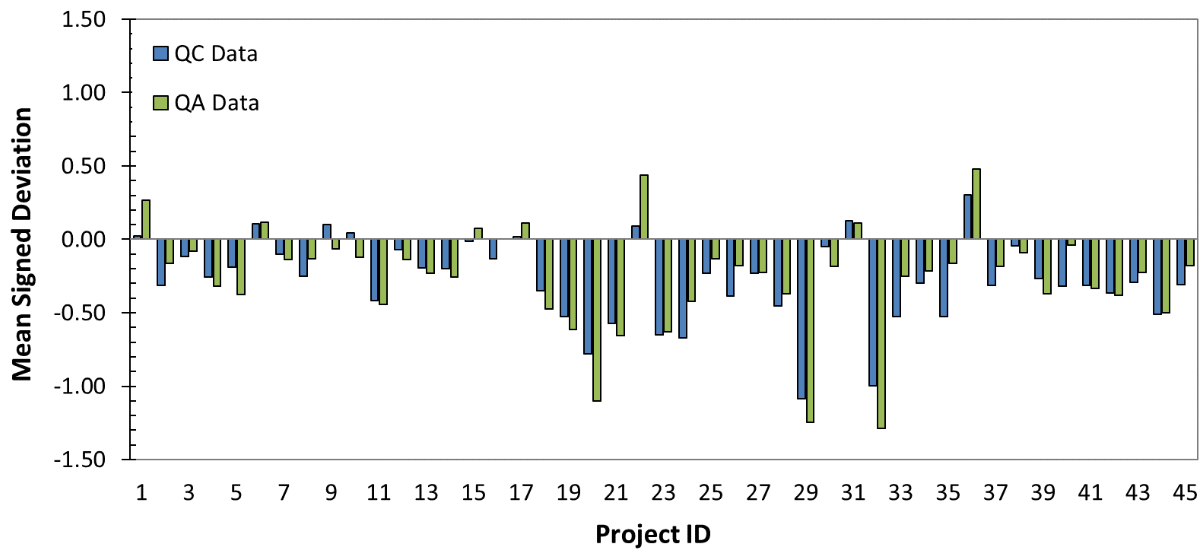


Figure 12. Project-Level VTM Mean Signed Deviation Data

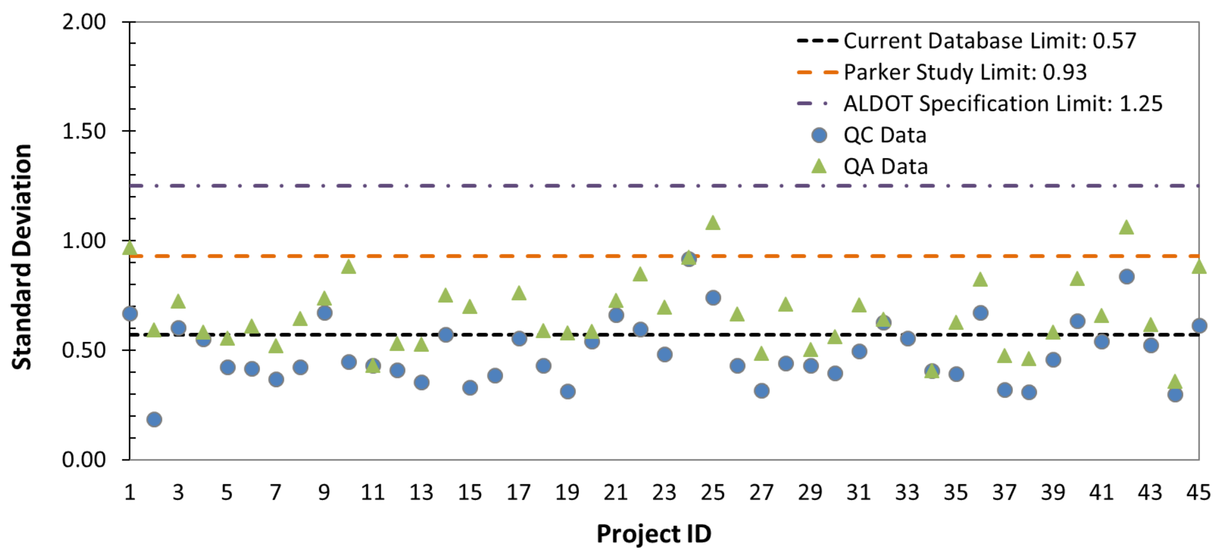


Figure 13. Project-Level VTM Standard Deviation Data

In-Place Density Data

The *MSND* results of in-place density acceptance data for the current database is delineated in Figure 14. For Projects 4, 22, and 36, in-place density verification data were not available. Virtually all projects (except Projects 2, 7, and 40) in the database have a negative *MSND* value.

The overall *MSND* of the database is -0.63, which indicates that the contractors achieved an average in-place density of approximately 93.4% instead of the target of 94.0%.

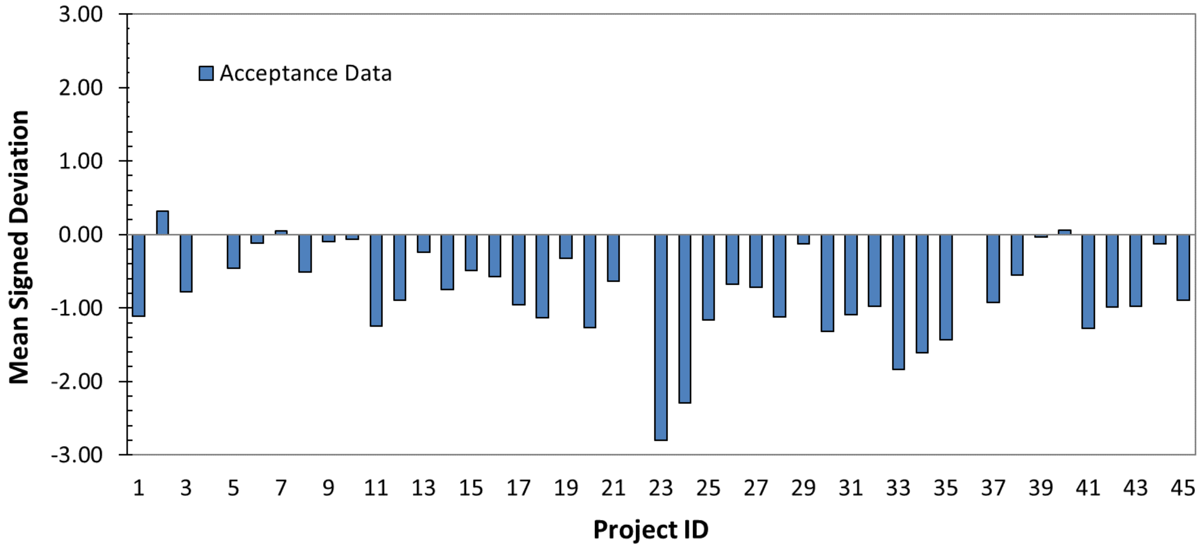


Figure 14. Project-Level In-Place Density Mean Signed Deviation Data

Figure 15 presents the *SD* results of in-place density acceptance data. As shown in Figure 15, the *SD* values of all projects in the database vary between 0.68 and 1.65, which is consistently lower than that used in the ALDOT specification limit (i.e., 1.875). The study by Parker (*2001*) showed a slightly higher overall *SD* value of 1.310 for projects constructed between 1997 and 2000.

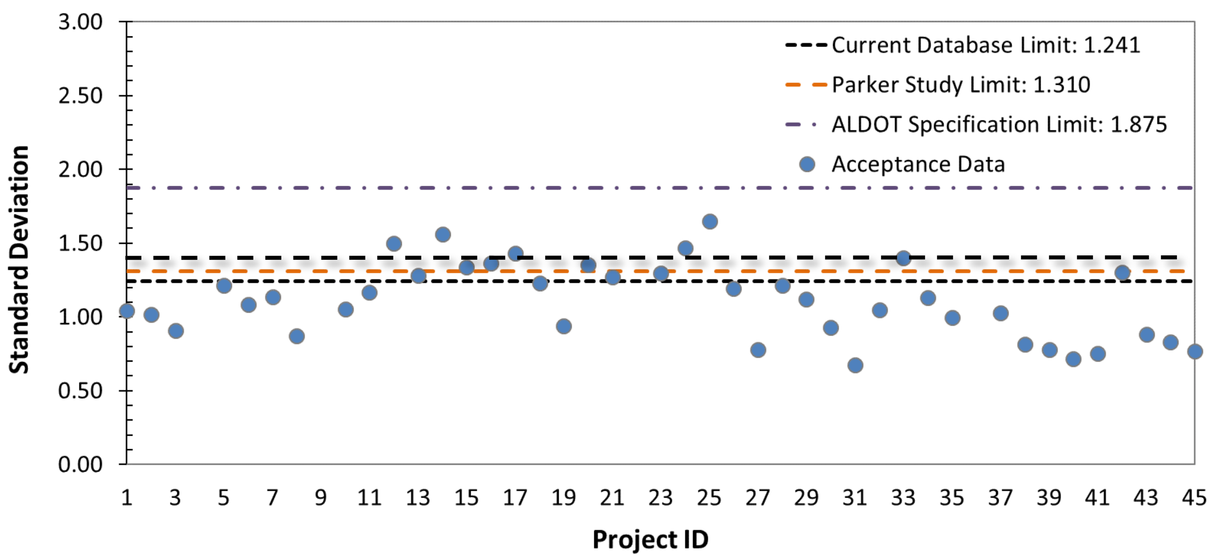


Figure 15. Project-Level In-Place Density Standard Deviation Data

Summary

Statistical evaluations of both AC and VTM databases revealed some degree of variations between contractor QC and state verification test results. For all three parameters of AC, VTM, and in-place density, the current database shows lower *SD* values than those used in the ALDOT specification limits, as summarized in Table 10. The effects of the lower *SD* values on the ALDOT specification limits are further analyzed later in this report.

Table 10. Comparison of Overall Standard Deviation Results from the Current Database versus Those Used to Develop the Current ALDOT Schedules of Payment

HMA Acceptance Parameters	Current Database	ALDOT Schedules of Payment
AC	0.16	0.31
VTM	0.57	1.25
In-place Density	1.241	1.875

3.4 Comparison of Contractor QC Data with State Verification Data

This section presents the global analysis of the database for comparing the homogeneity of contractor QC and state verification data for AC and VTM.

Anderson-Darling Normality Test Results

The null hypothesis, H_0, of the Anderson-Darling normality test is that both contractor QC and state verification data in the database follow a normal distribution. The test results in Tables 11 and 12 indicate a consistent p-value smaller than 0.05 for the four sets of data (i.e., contractor QC AC, state verification AC, contractor QC VTM, and state verification VTM). Therefore, for both AC and VTM, the null hypothesis of normal distribution data is rejected.

Table 11. Normality Test Results for AC Data

Variable	Sample Size, N	Mean Signed Deviation from the Target	Standard Deviation	AD-value	p-value
Contractor QC	2,687	0.00145	0.1572	3.314	<0.005
State Verification	1,881	0.00281	0.1875	3.065	<0.005

Table 12. Normality Test Results for VTM Data

Variable	Sample Size, N	Mean Signed Deviation from the Target	Standard Deviation	AD-value	p-value
Contractor QC	2,561	-0.2281	0.5766	4.234	<0.005
State Verification	1,773	-0.2447	0.7495	1.744	<0.005

Mann-Whitney U-Test Results

Because the basic assumption of normal distribution for two-sample *t*-test is violated, the Mann-Whitney U-test is adopted as an alternative procedure based on recommendations from the NCHRP 10-100 project (*Hand et al., 2018*). The null hypothesis, H_0, for this analysis is that the mean AC and VTM of contractor QC data are equal to those of state verification data, while the alternative hypothesis, H_1, states that they are not equal. Table 13 presents the Mann-Whitney U-test results. As shown, the overall *MSND* of AC from the JMF target of both contractor QC and state verification data is zero. The comparison of these two sets of data yields a p-value of 0.888, which indicates that at the selected level of significance (i.e., 0.05), there is no sufficient evidence to reject the null hypothesis of equal mean. For VTM, the contractor QC data has an overall *MSND* of -0.22, which is slightly higher than that of state verification data (i.e., -0.26). However, the difference was not statistically significant as indicated by a p-value of 0.195. Therefore, these results indicate that the contractor QC and state verification data have equal means for both AC and VTM.

Table 13. Equal Mean Test Results for AC and VTM Data

Variable	Sample Size, N	Mean Signed Deviation from the Target	p-value
Contractor QC (AC)	2,687	0.00	0.888
State Verification (AC)	1,881	0.00	
Contractor QC (VTM)	2,561	-0.22	0.195
State Verification (VTM)	1,773	-0.26	

Modified Levene Test Results

Because the basic assumption of normal distribution for *F*-test is violated, the modified Levene test is adopted as an alternative procedure based on recommendations from the NCHRP 10-100 project (*Hand et al., 2018*). The null hypothesis, H_0, and alternative hypothesis, H_1, for this analysis are as follows.

Null hypothesis: ${\sigma_c}^2 = {\sigma_s}^2$; Alternative hypothesis: ${\sigma_c}^2 \neq {\sigma_s}^2$

Where:

σ_c = Standard deviation of the contractor QC signed deviation data;
σ_s = Standard deviation of the state verification signed deviation data;
${\sigma^2}_c$ = Variance of the contractor QC signed deviation data; and
${\sigma^2}_s$ = Variance of the state verification signed deviation data.

Tables 14 and 15 present the outputs of the modified Levene test for AC and VTM data, respectively. As shown in Table 14, the overall *SD* of the contractor QC data for AC is 0.157, which is lower than that of the state verification data (i.e., 0.188). The difference was found statistically significant in the statistical test, as indicated by a p-value of 0.000. In addition, the 95% confidence interval of σ_c/σ_s is between 0.800 and 0.880, which is consistently lower than 1.0. These results indicate that the contractor QC data is significantly less variable than the state verification data for AC. A similar trend is also observed for the VTM data in Table 15. The contractor QC data has an overall *SD* of 0.577, which is lower than that of the state verification data (i.e., 0.750). The 95% confidence interval of σ_c/σ_s is between 0.726 and 0.802 and the p-value is 0.000. Thus, these results indicate that there is a significant difference between the standard deviations or variances of the contractor QC and state verification data for AC and VTM.

Table 14. Equal Variance Test Results for AC Data

Variable	Sample Size, N	St.Dev, σ	Variance, σ^2	95% CI for St.Dev Ratio (Levene)	95% CI for Variance Ratio (Levene)	σ_c/σ_s	σ^2_c/σ^2_s	p-value
Contractor	2,687	0.157	0.025	(0.800, 0.880)	(0.640, 0.774)	0.838	0.703	0.000
State	1,881	0.188	0.035					

Table 15. Equal Variance Test Results for VTM Data

Variable	Sample Size, N	St.Dev, σ	Variance, σ^2	95% CI for St.Dev Ratio (Levene)	95% CI for Variance Ratio (Levene)	σ_c/σ_s	σ^2_c/σ^2_s	p-value
Contractor	2,561	0.577	0.332	(0.726, 0.802)	(0.527, 0.644)	0.769	0.592	0.000
State	1,773	0.750	0.562					

Summary

Based on the Anderson-Darling normality test, the contractor QC and state verification data do not follow a normal distribution for both AC and VTM. As a result, the Mann-Whitney U-test and modified Levene test were adopted as alternatives to two-sample *t*-test and *F*-test for determining equal mean and variance between the two sets of data. Test results indicate that the contractor QC and state verification data have equal means for both AC and VTM. However, the variability of the contractor QC data is significantly lower than that of the state verification data.

3.5 Comparison of Validated and Unvalidated Contractor QC Data

This section presents the global analysis results for comparing validated versus unvalidated contractor QC data in the database. As discussed previously, each sublot in the database has the contractor QC data but not necessarily state verification data. In general, state verification data is available for only one or two out of four sublots within each lot for AC and VTM. Therefore, it is important to determine the consistency in mean and variance of validated and unvalidated contractor QC data. To conduct the analysis, the contractor QC data was first divided into two subsets: validated QC data and unvalidated QC data. The validated QC data refer to those that have state verification data available for a specific sublot, and the unvalidated QC data do not have state verification data available. The outlier analysis per ASMT E178-16a was conducted to identify outliers in the database. Only one single outlier was detected in the unvalidated contractor QC data for AC, while the other subsets of data have no outliers. The identified outlier was subsequently eliminated from further analysis.

Anderson-Darling Normality Test Results

The null hypothesis, H_0, of the Anderson-Darling normality test is that the validated and unvalidated contractor QC data for AC and VTM follow a normal distribution. The test was conducted with a level of significance of 0.05. Tables 16 and 17 present the normality test results for AC and VTM data, respectively. As shown in Table 16, the two subsets of contractor QC data for AC have a p-value lower than 0.005, which indicates the rejection of the null hypothesis for normal distribution. In Table 17, the validated QC data for VTM does not follow a normal distribution with a p-value lower than 0.005, while the unvalidated QC data is normally distributed with a p-value of 0.424. Therefore, the null hypothesis of normal distribution is rejected for the validated QC data for VTM and accepted for the unvalidated QC data for VTM.

Table 16. Normality Test Results for Validated and Unvalidated QC Data for AC

Variable	Sample Size, N	Mean Signed Deviation from the Target	Standard Deviation	AD-value	p-value
Validated QC	1,885	0.004	0.159	2.586	<0.005
Unvalidated QC	806	-0.006	0.152	1.220	<0.005

Table 17. Normality Test Results for Validated and Unvalidated QC Data for VTM

Variable	Sample Size, N	Mean Signed Deviation from the Target	Standard Deviation	AD-value	p-value
Validated QC	1,776	-0.247	0.616	3.008	<0.005
Unvalidated QC	789	-0.184	0.473	0.370	0.424

Mann-Whitney U-Test Results

As discussed previously, three out of four subsets of contractor QC data do not follow a normal distribution. Therefore, the two-sample *t*-test and *F*-test are not appropriate for use to check the homogeneity of mean and variance of the data. Alternatively, the nonparametric statistical tests of Mann-Whitney U-test and modified Levene test were adopted. The null hypothesis, H_0, of the Mann-Whitney U-test is that the mean of the validated contractor QC data is equal to that of the unvalidated QC data, while the alternative hypothesis, H_1, states that they are not equal. Table 18 presents the Mann-Whitney U-test results. For AC, the validated and unvalidated contractor QC data have a mean of 0.000 and -0.010, respectively. The difference is not statistically significant, as indicated by a p-value of 0.124. However, the VTM data showed a different trend where the difference between the two subsets of contractor QC data was statistically significant. The mean of the validated QC data for VTM is -0.240, which is lower than that of the unvalidated data (i.e., -0.190).

Table 18. Equal Mean Test Results for Validated and Unvalidated QC Data for AC and VTM

Variable	Sample Size, N	Mean Signed Deviation from the Target	p-value
Validated QC (AC)	1,885	0.000	0.124
Unvalidated QC (AC)	806	-0.010	
Validated QC (VTM)	1,776	-0.240	0.012
Unvalidated QC (VTM)	789	-0.190	

Modified Levene Test Results

The modified Levene equal-variance test was conducted for the validated and unvalidated QC data for AC and VTM with a level of significance of 0.05. The null hypothesis, H_0, and alternative hypothesis, H_1, for this analysis are listed below.

Null hypothesis: $\sigma_v{}^2 = \sigma_{uv}{}^2$; Alternative hypothesis: $\sigma_v{}^2 \neq \sigma_{uv}{}^2$.

Where:

σ_v = Standard deviation of the validated contractor QC signed deviation data;
σ_{uv} = Standard deviation of the unvalidated contractor QC signed deviation data;
$\sigma^2{}_v$ = Variance of the validated contractor QC signed deviation data;
$\sigma^2{}_{uv}$ = Variance of the unvalidated contractor QC signed deviation data.

Tables 19 and 20 present the outputs of the modified Levene test for AC and VTM data, respectively. As shown in Table 19, the overall *SD* of the validated contractor QC AC data is 0.159, which is slightly higher than that of the unvalidated contractor QC data (i.e., 0.152). However, the difference was not statistically significant, as indicated by a p-value of 0.426. The 95% confidence interval of σ_v/σ_{uv} is between 0.960 and 1.098, which contains the critical value of 1.0. These results indicate that the two subsets of contractor QC AC data have an equal variance. Table 20 shows a different trend for the VTM data. The validated contractor QC data has an overall *SD* of 0.616, which is higher than that of the unvalidated QC data (i.e., 0.473). The 95% confidence interval of σ_v/σ_{uv} is between 1.187 and 1.361, which is consistently higher than 1.0. The p-value of the modified Levene test is 0.000. Therefore, the null hypothesis of equal variance between validated and unvalidated contractor QC VTM data is rejected. The validated QC data has a higher variability than the unvalidated QC data.

Table 19. Equal Variance Test Results for Validated and Unvalidated QC Data for AC

Variable	Sample Size, N	St.Dev, σ	Variance, σ^2	95% CI for St.Dev Ratio (Levene)	95% CI for Variance Ratio (Levene)	σ_v/σ_{uv}	$\sigma^2{}_v/\sigma^2{}_{uv}$	p-value
Validated	1,885	0.159	0.025	(0.960, 1.098)	(0.922, 1.205)	1.043	1.087	0.426
Unvalidated	806	0.152	0.023					

Table 20. Equal Variance Test Results for Validated and Unvalidated QC VTM Data

Variable	Sample Size, N	St.Dev, σ	Variance, σ^2	95% CI for St.Dev Ratio (Levene)	95% CI for Variance Ratio (Levene)	σ_v/σ_{uv}	$\sigma^2{}_v/\sigma^2{}_{uv}$	p-value
Validated	1,776	0.616	0.379	(1.187, 1.361)	(1.408, 1.853)	1.301	1.693	0.000
Unvalidated	789	0.473	0.224					

Summary

According to the Anderson-Darling normality test results, only the unvalidated contractor QC data for VTM is normally distributed, while the other three subsets of data (i.e., validated AC, unvalidated AC, and validated VTM) do not follow a normal distribution. Therefore, the Mann-Whitney U-test and modified Levene test were adopted as alternatives to the two-sample *t*-test and *F*-test for determining equal mean and variance between the validated and unvalidated contractor QC data. Test results indicate that the two subsets of contractor QC data for AC have the same mean and variance. However, the validated contractor QC data for VTM has a lower mean and higher variability than the unvalidated QC data.

4. PAYMENT SCHEDULES BASED ON ACCEPTANCE DATA ANALYZED IN THIS STUDY

Acceptance data in the database complied in this study were analyzed in the previous section to determine the contractors' ability to meet the specified target values for AC, VTM, and in-place density. The results of the analysis were further analyzed to determine how the schedules of payment would change if they were determined based on more recent test results. In the following subsections, the current ALDOT schedules of payment are first reviewed to determine how the payment schedule tables were previously determined. The same method is then followed to determine new schedules of pavement based on the analysis results presented in the previous section.

4.1 Current ALDOT Schedules of Payment

ALDOT currently defines one lot of Superpave asphalt mix as 2,800 tons. Using this lot size, the acceptance schedules of payment for AC and VTM (Table 21) as well as in-place density (Table 22) were established. The acceptance schedules assume that all contractors are able to meet the AC, VTM, and in-place density targets and that the level of performance among contractors in the state is consistent. The *SD* values used in the current ALDOT acceptance schedules of payment for AC, VTM, and in-place density are 0.31%, 1.25%, and 1.875%, respectively. The acceptance limits for different pay factor levels were then determined using Equation 8.

Table 21. ALDOT Current Pay Schedule for AC and VTM

TABLE III						
SECTION 424 MIXES (SUPERPAVE)						
ACCEPTANCE SCHEDULE OF PAYMENT FOR ASPHALT PLANT MIX CHARACTERISTICS						
Arithmetic Average of the Absolute Values of Deviations of the LOT Acceptance Tests From Job Mix Formula Values						
Asphalt Content						
LOT Pay Factor ->	1.02	1.00	0.98	0.95	0.90	0.80*
1 Test	-	0.00-0.62	0.63-0.68	0.69-0.75	0.76-0.88	Over 0.88
2 Tests	-	0.00-0.44	0.45-0.48	0.49-0.53	0.54-0.62	Over 0.62
3 Tests	-	0.00-0.36	0.37-0.39	0.40-0.43	0.44-0.51	Over 0.51
4 Tests	0.00-0.19	0.20-0.31	0.32-0.34	0.35-0.38	0.39-0.44	Over 0.44
Voids in Total Mix (Lab. Compacted Samples)						
LOT Pay Factor ->	1.02	1.00	0.98	0.95	0.90	0.80*
1 Test	-	0.00-2.50	2.51-2.70	2.71-3.00	3.01-3.50	Over 3.50
2 Tests	-	0.00-1.77	1.78-1.91	1.92-2.12	2.13-2.47	Over 2.47
3 Tests	-	0.00-1.44	1.45-1.56	1.57-1.73	1.74-2.02	Over 2.02
4 Tests	0.00-0.75	0.76-1.25	1.26-1.35	1.36-1.50	1.51-1.75	Over 1.75
* If approved by the Department, the Contractor may accept the indicated LOT partial pay. The Department may require removal and replacement. If the LOT pay factor is greater than 0.80, the Contractor has the option to remove at no cost to the Department and to replace at contract unit bid price rather than accepting the reduced LOT payment.						

Table 22. ALDOT Current Pay Schedule for In-Place Density

TABLE IV ACCEPTANCE SCHEDULE OF PAYMENT FOR IN-PLACE DENSITY					
SECTION 424 MIXES (SUPERPAVE)					
Characteristic	SUBLOT PAY FACTOR	Arithmetic Average of the Absolute Values of Deviations of SUBLOT Acceptance Tests From Target**			
		1 Test	2 Tests	3 Tests	4 Tests
In-Place Density	1.02	0.0-2.25	0.0-1.59	0.0-1.30	0.0-1.12
	1.00	2.26-3.75	1.60-2.65	1.31-2.17	1.13-1.88
	0.98	3.76-4.05	2.66-2.86	2.18-2.34	1.89-2.02
	0.95	4.06-4.50	2.87-3.18	2.35-2.60	2.03-2.25
	0.90	4.51-5.25	3.19-3.71	2.61-3.03	2.26-2.62
	0.80*	Over 5.25	over 3.71	over 3.03	Over 2.62

* If approved by the Department, the Contractor may accept the indicated partial SUBLOT pay. The Department may require removal and replacement. The Contractor has the option to remove at no cost to the Department and replace at contract unit bid price rather than accepting the reduced SUBLOT payment.

** Target density shall be 94.0 % of the theoretical maximum density for all mixes except for:

- the range of placement rates given in Item 306.03(g)3 (140 pounds per square yard or greater {76 kg per square meter or greater} and less than 200 pounds per square yard {109 kg per square meter} over surface treatments) the target density shall be 92.0 % and;
- ESAL Range A and B mixes where the Contractor demonstrates and explains in writing why 94 % of the theoretical maximum density cannot be achieved and the Engineer informs the Contractor by written notification that the target density can be reduced to 93 % or 92 %.

4.2 Pay Factor Distributions in the Database

Table 23 presents the pay factor distributions among all projects in the database. Note that for AC and VTM, a pay factor is computed for each lot of asphalt mixtures, while the pay factor of in-placement density is computed for each sublot. As shown in the table, the pay factor distributions are fairly consistent among all three mix characteristics. At least 65 percent of lots/sublots received a pay factor of 1.02, which indicated a two-percent incentive over the bid price. Approximately 30 percent received full payment (i.e., a pay factor of 1.00) for AC and VTM, and 24 percent for in-place density. The percentage of lots/sublots with a disincentive is 0.4% for AC, 2.7% for VTM, and 6.1% for in-place density, respectively.

Table 23. Pay Factor Distributions in the Current Database using the Current Specification Limits

Pay Factor Levels	Asphalt Content (812 Lots)	Voids in Total Mix (759 Lots)	In-Place Density (928 Sublots)
1.02	68.0%	65.0%	69.8%
1.00	31.5%	32.3%	24.1%
0.98	0.1%	0.7%	1.7%
0.95	0.0%	1.4%	1.6%
0.90	0.2%	0.3%	0.9%
0.80	0.1%	0.3%	1.9%

4.3 Schedules of Payment based on Analysis Results of Recent Acceptance Data

As discussed in Section 3.3, the contractor QC database compiled for this study has an overall *SD* of 0.16 for AC and 0.57 for VTM, respectively. Using these *SD* values, revised schedules of payment were determined for AC and VTM (Table 24) based on Equation 8. Since the variability of the more recent AC and VTM data is approximately half of those considered in the current ALDOT schedules of payment, the allowable deviations from the specified target values are generally reduced by 50% compared to those in the current schedules of pavement for both AC and VTM (Table 21).

Table 24. Example of Revised Pay Schedule for Acceptance for AC and VTM

Asphalt Content						
Lot Pay Factor	1.02	1.00	0.98	0.95	0.90	0.80
1 Test	-	0.00-0.32	0.33-0.36	0.37-0.39	0.40-0.46	Over 0.46
2 Tests	-	0.00-0.23	0.24-0.25	0.26-0.28	0.29-0.32	Over 0.32
3 Tests	-	0.00-0.19	0.20-0.21	0.22-0.23	0.24-0.27	Over 0.27
4 Tests	0.00-0.10	0.11-0.16	0.17-0.18	0.19-0.20	0.21-0.23	Over 0.23
Voids in Total Mix						
Lot Pay Factor	1.02	1.00	0.98	0.95	0.90	0.80
1 Test	-	0.00-1.14	1.15-1.24	1.25-1.37	1.38-1.60	Over 1.60
2 Tests	-	0.00-0.81	0.82-0.88	0.89-0.97	0.98-1.13	Over 1.13
3 Tests	-	0.00-0.66	0.67-0.72	0.73-0.79	0.80-0.93	Over 0.93
4 Tests	0.00-0.35	0.36-0.57	0.58-0.62	0.63-0.69	0.70-0.80	Over 0.80

For in-place density, the current database has an overall *SD* of 1.241, which is lower than the *SD* value of 1.875 used to develop the current ALDOT acceptance schedule of payment. Table 25 presents a revised schedule of payment for in-place density using the *SD* value of 1.241 from the more recent acceptance data. As shown, the allowable deviations from the specified target value (i.e., 94 percent) are approximately 34% tighter than those in the current ALDOT schedule of payment (Table 22).

Table 25. Example of Revised Pay Schedule for Acceptance for In-Place Density

Sublot Pay Factor	1 Test	2 Tests	3 Tests	4 Tests
1.02	0.00-1.49	0.00-1.06	0.00-0.87	0.00-0.75
1.00	1.50-2.49	1.07-1.76	0.88-1.44	0.76-1.25
0.98	2.50-2.69	1.77-1.90	1.45-1.55	1.26-1.34
0.95	2.70-2.98	1.91-2.11	1.56-1.73	1.35-1.49
0.90	2.99-3.48	2.12-2.46	1.74-2.01	1.50-1.74
0.80	Over 3.48	Over 2.46	Over 2.01	Over 1.74

Tables 24 and 25 were developed to show how the *SD* values determined from the more recent acceptance data would affect the allowable deviations from the specified target values in the schedules of payment in ALDOT's Standard Specifications for Highway Construction. Table 26 presents the distribution of pay factors among all projects in the database calculated using the revised schedules of payments in Table 24 and Table 25. For all three mix quality characteristics, the percentage of lots/sublots with pay factors of 1.00 and 1.02 are above 70 percent, which indicates that the majority of contractors would still receive full payment or a two-percent incentive using the revised schedules of payment. However, because the acceptable tolerances of the revised pay schedules are tighter than those of the current ALDOT pay schedules, the percentage of lots/sublots with a pay factor of 1.02 would reduce by approximately 30 percent. In addition, slightly over 40 percent of lots/sublots would receive full payment for AC and VTM, and approximately 35 percent for in-place density. The percentage of lots/sublots with a disincentive (i.e., pay factors of 0.98, 0.95, 0.90, and 0.80) is 21.1% for AC, 28.5% for VTM, and 25.1% for in-place density, respectively.

Table 26. Pay Factor Distributions in the Current Database using Revised Schedules of Payment

Pay Factor Levels	Asphalt Content (812 Lots)	Voids in Total Mix (759 Lots)	In-Place Density (928 Sublots)
1.02	34.0%	29.1%	39.8%
1.00	44.9%	42.4%	35.1%
0.98	6.4%	3.4%	4.3%
0.95	5.2%	5.7%	5.6%
0.90	3.7%	7.1%	5.8%
0.80	5.8%	12.3%	9.4%

5. CONCLUSIONS AND RECOMMENDATIONS

This study was undertaken to review the current acceptance schedules of payment in the ALDOT Standard Specifications for Highway Construction. The objective of the review was to determine if the acceptance schedules are representative of the current level of performance of contractors in the state of Alabama. To accomplish the objective, a literature review was first conducted to summarize the QC and acceptance procedure for asphalt pavements and identify the practices for the acceptance schedules of payment utilized by neighboring states. A database was then developed by the research team with assistance of ALDOT staff, which included contractor QC and state verification test results from 45 Superpave mix projects across all nine ALDOT divisions. Finally, a statistical analysis was conducted to determine the overall mean signed deviation and standard deviation of acceptance data in the database for AC, VTM, and in-place density, and compare against those in the current ALDOT schedules of payment. In addition, the two-population differences between contractor QC versus state verification data as well as validated versus unvalidated contractor QC data were evaluated for AC and VTM data. Based on the analysis results of more recent acceptance data in this study, the following conclusions can be made:

- The current database demonstrated the ability of contractors to achieve the JMF AC during production. The overall standard deviation of contractor QC signed deviation data for AC is approximately 50 percent lower than that used in the current ALDOT schedule of payment for AC.
- Most contractors in the current database showed an overall average VTM of approximately 3.8%, which is slightly lower than the target VTM of 4.0%. The overall standard deviation of contractor QC signed deviation data for VTM is approximately 55 percent lower than that used in the current ALDOT schedule of payment for VTM.
- Contractors in the current database achieved an overall average in-place density of 93.4%, which is below the specification target of 94.0%. The overall standard deviation is approximately 35 percent lower than that used in the current ALDOT schedule of payment for in-place density.
- The contractor QC and state verification results have statistically equal means for both AC and VTM data. However, the variability of contractor QC results is significantly lower than that of state verification results.
- The validated and unvalidated contractor QC results show strong signs of similarity for AC data. However, for VTM data, the validated QC results have a consistently lower mean and higher variability than the unvalidated QC results.
- Based on the current ALDOT schedules of payment, over 93% of lots (for AC and VTM) or sublots (for in-place density) in the database received a full payment or 2% incentive over the bid price. The percentage of lots or sublots receiving a disincentive is 0.4% for AC, 2.7% for VTM, and 6.1% for in-place density, respectively.
- Using the revised schedules of payment, over 70% of lots (for AC and VTM) or sublots (for in-place density) in the database would receive a full payment or 2% incentive over the bid price. The percentage of lots or sublots receiving a disincentive is 21.1% for AC, 28.5% for VTM, and 25.1% for in-place density, respectively.

In summary, the variability of the more recent AC, VTM, and in-place density data was found to be significantly lower than those considered in the current schedules of payment. Thus, based on the overall standard deviation values determined from the current database, the allowable deviations from the specified target values are reduced by approximately 50 percent for AC and

VTM and by about 34 percent for in-place density, affecting the number of lots/sublots in the current database that would receive an incentive and/or full payment.

REFERENCES

Standard Specifications for Highway Construction. Alabama Department of Transportation. Montgomery, 2012, pp. 192-197. https://www.dot.state.al.us/conweb/pdf/Specifications/2012%20DRAFT%20Standard%20Specs.pdf.

Brown, E. R., P. S. Kandhal, F. L. Roberts, Y. R. Kim, D. Y. Lee, and T. W. Kennedy. *Hot Mix Asphalt Materials, Mixture Design, and Construction*. National Asphalt Pavement Association Research and Education Foundation, Lanham, Md., 2009.

Burati, J. L., R. M. Weed, C. S. Hughes, and H. S. Hill. *Evaluation of Procedures for Quality Assurance Specifications*. FHWA-HRT-04-046. Turner-Fairbank Highway Research Center, McLean, Va., 2004.

Burati, J. L., R. M. Weed, C. S. Hughes, and H. S. Hill. *Optimal Procedures for Quality Assurance Specifications.* FHWA-RD-02-095. Turner-Fairbank Highway Research Center, McLean, Va., 2003.

Quality Control Manual for Hot Mix Asphalt for the Quality Control Quality Assurance Process. California Department of Transportation Division of Construction, Sacramento, 2009.

Construction Inspection and Approval. 23 CFR Part 637. Federal Highway Administration, Washington, D.C., 1995.

Quality Assurance Stewardship Review: Summary Report for Fiscal Years 2003 through 2006. Federal Highway Administration, Washington, D.C., 2006. https://www.fhwa.dot.gov/pavement/materials/stewardreview2007.cfm.

Standard Specifications Construction of Transportation Systems. Georgia Department of Transportation, Atlanta, 2013, pp. 282-294. http://www.dot.ga.gov/PartnerSmart/Business/Source/specs/DOT2013.pdf.

Hancher, D. E., Y. Wang, and K. C. Mahboub. *Contractor Performed Quality Control on KYTC Projects*. Kentucky Transportation Center, Lexington, 2002.

Hand, A. et al. *Procedures and Guidelines for Validating Contractor Test Data*. NCHRP 10-100 Phase I Interim Report. 2017

Standard Specifications for Roads and Bridges. Louisiana Department of Transportation and Development, Baton Rouge, 2016. http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Standard_Specifications/Standard%20Specifications/2016%20Standard%20Specifications%20for%20Roads%20and%20Bridges%20Manual/00%20-%202016%20-%20Standard%20Specification%20(complete%20manual).pdf

Mahboub, K. C., and D. E. Hancher. *Development of Concrete QC/QA Specifications for Highway Construction in Kentucky.* Kentucky Transportation Center, Lexington, 2001.

Standard Specifications for Road and Bridge Construction. Mississippi Department of Transportation, Jackson, 2017, pp. 247-251.

http://sp.mdot.ms.gov/Construction/Standard%20Specifications/2017%20Standard%20Specifications.pdf.

Parker, F. *Implementation of a Statistically Based Quality Control/Quality Assurance (QC/QA) Procedure for HMA Construction*. Final Report for Project No. 2019-14. Alabama Department of Transportation, Montgomery, 1995.

Parker, F. *Collection and Analysis of QC/QA Data for Superpave Mixes*. Final Report for Project No. 930-389. Alabama Department of Transportation, Montgomery, 2001.

Supplemental Technical Specification for Hot Mix Asphalt Quality Assurance. South Carolina Department of Transportation, Columbia, 2010, pp. 5-28.

Standard Specifications for Road and Bridge Construction. Tennessee Department of Transportation, Nashville, 2015, pp. 345-351.

Transportation Research *Circular E-C235: Glossary of Transportation Construction Quality Assurance Terms*. Transportation Research Board of the National Academies, Washington, D.C., 2018. http://onlinepubs.trb.org/Onlinepubs/circulars/ec235.pdf.

Willis, J. R., S. Maghsoodloo, R. Brown, and M. Sakhaeifar. *Evaluation of Alabama Department of Transportation's Quality Assurance Testing Program and Pay Assessment Schedules for Asphalt Mixtures.* National Center for Asphalt Technology, Auburn, Alabama, 2011.

Newcomb, D. E., and J. A. Epps. Statistical Specifications for Hot Mix Asphalt: What Do We Need to Know? *Hot Mix Asphalt Technology,* January/February, 2001, pp. 54-60. http://www.asphaltpavement.org/images/stories/pmtspec1.pdf.

Appendix A. Comparison of Acceptance Ranges with Other DOTs

Table A-1. One-Test Acceptance Range of Asphalt Content

State Highway Agency	Acceptance Range (AAD from JMF Value)	Notes
Alabama (Superpave)	0.62%	
Alabama (OGFC, SMA)	0.48%	
Florida (≤ 2 sublots)	0.45%	
Georgia (surface mix)	0.70%	
Georgia (subsurface mix)	0.80%	
Mississippi	-	*MSND* method
South Carolina	-	*PWL* method
Tennessee	0.30%	

Table A-2. One-Test Acceptance Range of Laboratory-Molded Air Voids

State Highway Agency	Acceptance Range (AAD from JMF Value)	Notes
Alabama (Superpave)	2.50%	
Alabama (OGFC, SMA)	1.50%	
Florida (≤ 2 sublots)	1.00%	
Mississippi	-	*MSDN* method
South Carolina	-	*PWL* method
Texas	1.00%	

Table A-3. One-Test Acceptance Range of In-Place Density

State Highway Agency	Target Value	Acceptance Range (AAD from Target Value)	Notes
Alabama (Superpave)	94%	3.75%	
Alabama (SMA)	94%	3.33%	
Florida (≤ 2 sublots)	93%	1.00%	
Georgia	95%	2.00%	
Louisiana (thin mix)	-	-	Not specified
Mississippi	-	-	*MSND* method
South Carolina	-	-	*PWL* method
Tennessee	-	-	No limit provided
Texas	94%	2.50%	

Table A-4. One-Test Acceptance Range of OGFC Aggregate Gradation (3/8" Sieve)

Aggregate Size	State Highway Agency	Acceptance Range (AAD from JMF Value)	Notes
3/8" Sieve	Alabama	12.0%	
	Florida (≤ 2 sublots)	-	Not specified
	Georgia	9.0%	
	Louisiana (thin mix)	-	Not specified
	Mississippi	-	*MSND* method
	Tennessee	6.5%	
No.8 Sieve	Alabama	8.0%	
	Florida (≤ 2 sublots)	4.5%	
	Georgia	7.0%	
	Louisiana (thin mix)	-	Not specified
	Mississippi	-	*MSND* method
	Tennessee	3.8%	

Appendix B. List of Projects in the Database

ID	Project Number	County	Construction Time	Contractor	*Notes*
1	99-305-535-219-001	Perry	2010	ACI-Selma	*Projects identified in the 2011 ALDOT Study*
2	99-305-632-069-001	Tuscaloosa	2010	St Bunn	
3	EBF-0012(519)	Covington	2007-2008	Bullard	
4	HSIP-0001(552) & 99-307-351-001-901	-	-	-	
5	IM-I065 (352)	Butler	2006	Wiregrass	
6	IM-ACNHF-I020(332)	Talladega	2008-2009	McCARTNEY	
7	IM-I065(364)	-	-	-	
8	NHF-0009(505)	Montgomery	2004-2006	Wiregrass	
9	NHF-NCPD-HSIPF-0001(544)	Randolph	2010	APAC	
10	STMAA-0041(505)	ESC. & Con.	2010	MAC	
11	STMAA-0273(500)	Cherokee	2010	-	
12	STMAAF-I059(342)	Etowah	2009-2012	-	
13	STMOA-0133(501)	Lauderdale	-	-	
14	STMOA-0157(514)	-	-	-	
15	STPAA-0181(506)	Baldwin	2014	John G. Walton	
16	IM-I059 (331)	Sumter	2007	St Bunn	
17	NH-HSIP-0001(580)	Madison	2016	Whitaker Construction Co.	*New projects identified in this study*
18	NH-HSIP-0001(582)	Marshall	2015	Whitaker Construction Co.	
19	STPAA-0091(505)	Culman	2016	GOODHOPE CONTRACTING	
20	STPAA-HSIP-0004(537)	Cleburne	-	APAC MID-SOUTH	
21	STPAA-HSIP-0048(503)	Randolph	-	INGRAM - WADLEY	
22	STPAA-0281(501)	Cleburne	-	McCARTNEY	
23	STPAA-HSIP-0022 (521)	Randolph/Chambers	-	INGRAM - WADLEY	
24	STPAA-HSIP-0014 (535) & 0049 (507)	TALLAPOOSA	-	Gary Ingram	
25	STPAA-HSIP-0110 (504)	BULLOCK	2013	Wiregrass Constr.	
26	IAR-O51-000-005	Montgomery	2014	Asphalt Contractors, Inc.	
27	STPMN-7780 (600)	Montgomery	2014	Asphalt Contractors, Inc.	
28	HPP-0035(511)	Montgomery	2015	MIDSOUTH/APAC	
29	NH-0009(555)	Montgomery	2015	Wiregrass	
30	NH-HSIP-0006(556)	Montgomery	2016	ACI	
31	STPAA-HSIP-0097(505)	Lowndes	-	ACI	

32	STPAA-HSIP-0051(513)	Lee	-	EAP	
33	NH-HSIP-0013(595)	Marengo	-	H O Weaver	
34	STPAA-0028(509)	Wilcox	-	Asphalt Contractors	
35	STPAA-0017(568)	Wilcox	-	Mobile Asphalt Co.	
36	NH-0006(558)	Tuscaloosa	2015	St Bunn	
37	NH-0003(598)	Morgan	-	Wiregrass	
38	NH-0053(579)	Pike	-	APAC-Troy	
39	NH-0053(578)	Pike	-	APAC-Mt. Meigs	
40	NH-HSIP-0052(510)	Houston	-	APAC	
41	NH-0020(522)	Morgan	-	RGI	
42	NHF-0013(572)	Lauderdale	-	RGI	
43	APD-0355(507)	Franklin	-	RGI	
44	ACAPD-NHF-0355(503)	Franklin	-	APAC	
45	STPAA-HSIP-00134(504)	Dale	-	Wiregrass-Ariton	

Appendix C. Project-Level Mean Signed Deviation and Standard Deviation Results

Table C-1. *MSND* and *SD* Results of Contractor QC and State Verification AC Data by Project

Project ID	Contractor QC Data		State Verification Data	
	MSND	***SD***	***MSND***	***SD***
1	-0.157	0.188	0.011	0.241
2	-0.055	0.098	-0.038	0.185
3	0.028	0.122	-0.050	0.160
4	-0.052	0.134	-0.024	0.149
5	-0.013	0.148	-0.019	0.177
6	-0.010	0.123	-0.065	0.213
7	-0.008	0.124	-0.022	0.128
8	-0.054	0.120	-0.032	0.145
9	0.026	0.187	0.039	0.202
10	0.021	0.217	0.149	0.186
11	-0.057	0.137	-0.106	0.120
12	0.017	0.154	0.056	0.197
13	0.020	0.087	0.017	0.109
14	-0.044	0.173	-0.038	0.188
15	0.039	0.196	0.010	0.208
16	0.037	0.151	N/A	N/A
17	-0.034	0.139	-0.073	0.147
18	0.039	0.165	0.076	0.157
19	0.011	0.102	0.057	0.153
20	0.059	0.162	0.197	0.197
21	-0.007	0.252	0.079	0.258
22	0.046	0.201	-0.012	0.292
23	-0.125	0.155	-0.156	0.152
24	0.088	0.177	0.078	0.175
25	0.028	0.100	0.029	0.102
26	0.020	0.028	0.030	0.099
27	0.016	0.083	0.072	0.100
28	0.012	0.142	0.019	0.189
29	-0.062	0.163	0.007	0.167
30	0.054	0.070	0.047	0.093
31	-0.121	0.087	-0.082	0.119
32	0.210	0.162	0.255	0.220
33	-0.008	0.275	-0.113	0.291
34	-0.080	0.125	-0.008	0.134
35	0.138	0.186	0.260	0.201
36	0.145	0.215	0.020	0.232
37	-0.005	0.087	-0.085	0.223
38	0.044	0.145	0.046	0.199
39	-0.050	0.091	-0.037	0.120
40	0.023	0.167	-0.096	0.184

41	-0.035	0.158	-0.040	0.184
42	-0.033	0.193	-0.049	0.222
43	0.018	0.123	0.027	0.130
44	0.075	0.098	0.078	0.115
45	-0.098	0.155	-0.072	0.185

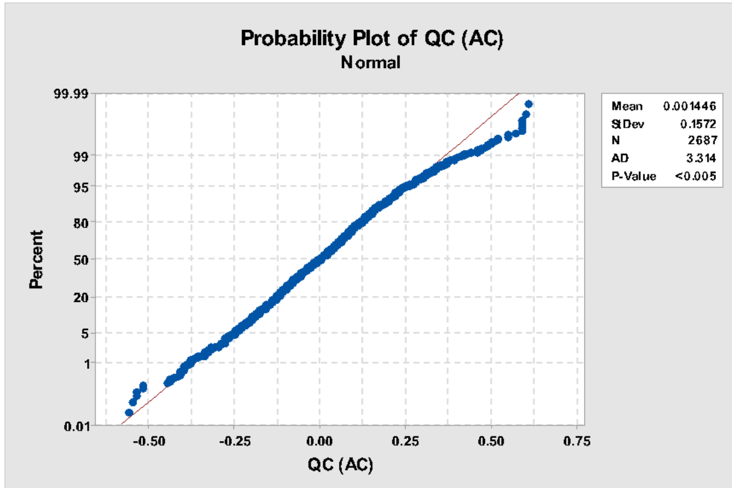
Table C-2. *MSND* and *SD* of Contractor QC and State Verification VTM Data by Project

Project ID	Contractor QC Data		State Verification Data	
	MSND	***SD***	***MSND***	***SD***
1	0.022	0.668	0.269	0.971
2	-0.314	0.185	-0.162	0.593
3	-0.116	0.602	-0.082	0.723
4	-0.254	0.551	-0.320	0.583
5	-0.190	0.424	-0.376	0.555
6	0.109	0.417	0.119	0.610
7	-0.099	0.368	-0.138	0.519
8	-0.250	0.423	-0.131	0.644
9	0.101	0.673	-0.065	0.738
10	0.045	0.446	-0.123	0.882
11	-0.417	0.431	-0.442	0.432
12	-0.069	0.411	-0.135	0.532
13	-0.196	0.353	-0.232	0.526
14	-0.199	0.571	-0.256	0.751
15	-0.013	0.331	0.077	0.701
16	-0.134	0.386	N/A	N/A
17	0.017	0.554	0.114	0.761
18	-0.351	0.429	-0.474	0.589
19	-0.526	0.314	-0.612	0.578
20	-0.781	0.542	-1.100	0.584
21	-0.574	0.662	-0.658	0.727
22	0.093	0.596	0.438	0.848
23	-0.648	0.481	-0.627	0.695
24	-0.669	0.918	-0.423	0.925
25	-0.229	0.742	-0.131	1.082
26	-0.385	0.431	-0.180	0.665
27	-0.231	0.317	-0.228	0.484
28	-0.456	0.442	-0.369	0.709
29	-1.085	0.432	-1.248	0.503
30	-0.051	0.396	-0.186	0.562
31	0.128	0.495	0.109	0.708
32	-0.998	0.626	-1.287	0.642
33	-0.524	0.556	-0.253	1.301
34	-0.297	0.405	-0.215	0.407
35	-0.525	0.394	-0.165	0.628
36	0.304	0.673	0.479	0.824

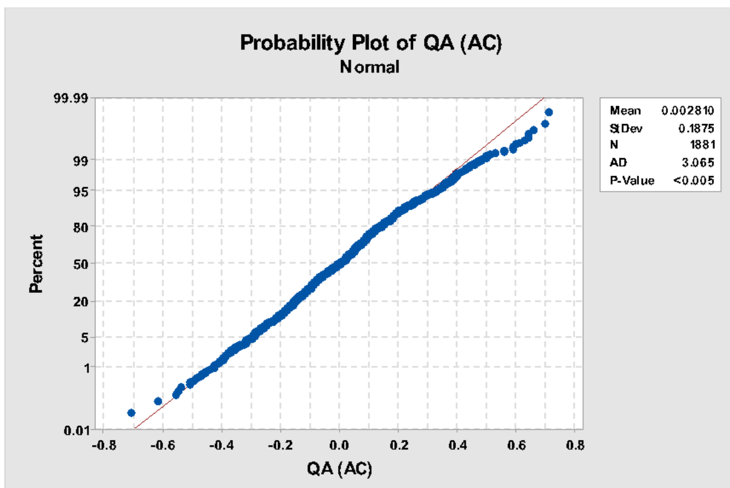
37	-0.312	0.319	-0.183	0.476
38	-0.044	0.311	-0.090	0.463
39	-0.264	0.459	-0.369	0.582
40	-0.317	0.636	-0.039	0.827
41	-0.315	0.541	-0.333	0.659
42	-0.366	0.839	-0.379	1.061
43	-0.293	0.525	-0.227	0.618
44	-0.508	0.299	-0.499	0.357
45	-0.310	0.615	-0.177	0.884

Table C-3. *MSND* and *SD* of the In-Place Density Acceptance Data by Project

Project ID	**Acceptance Data**		**Project ID**	**Acceptance Data**	
	MSND	***SD***		***MSND***	***SD***
1	-1.110	1.045	**24**	-2.295	1.468
2	0.314	1.014	**25**	-1.168	1.649
3	-0.779	0.906	**26**	-0.675	1.195
4	N/A	N/A	**27**	-0.716	0.779
5	-0.464	1.211	**28**	-1.120	1.213
6	-0.120	1.085	**29**	-0.126	1.120
7	0.049	1.133	**30**	-1.316	0.927
8	-0.508	0.872	**31**	-1.088	0.677
9	-0.100	N/A	**32**	-0.980	1.050
10	-0.064	1.053	**33**	-1.836	1.401
11	-1.250	1.167	**34**	-1.611	1.132
12	-0.895	1.500	**35**	-1.436	0.997
13	-0.238	1.279	**36**	N/A	N/A
14	-0.753	1.560	**37**	-0.921	1.025
15	-0.485	1.340	**38**	-0.548	0.813
16	-0.570	1.365	**39**	-0.035	0.777
17	-0.956	1.433	**40**	0.059	0.714
18	-1.137	1.227	**41**	-1.281	0.754
19	-0.321	0.939	**42**	-0.984	1.304
20	-1.270	1.355	**43**	-0.976	0.881
21	-0.635	1.269	**44**	-0.131	0.828
22	N/A	N/A	**45**	-0.896	0.770
23	-2.800	1.298			

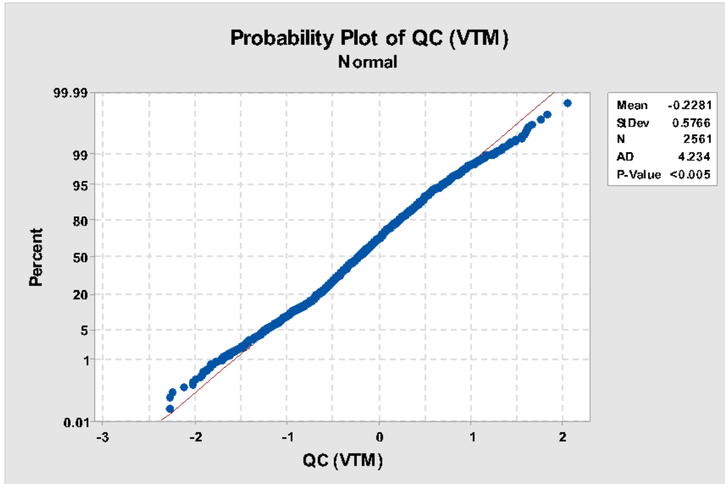


(a)

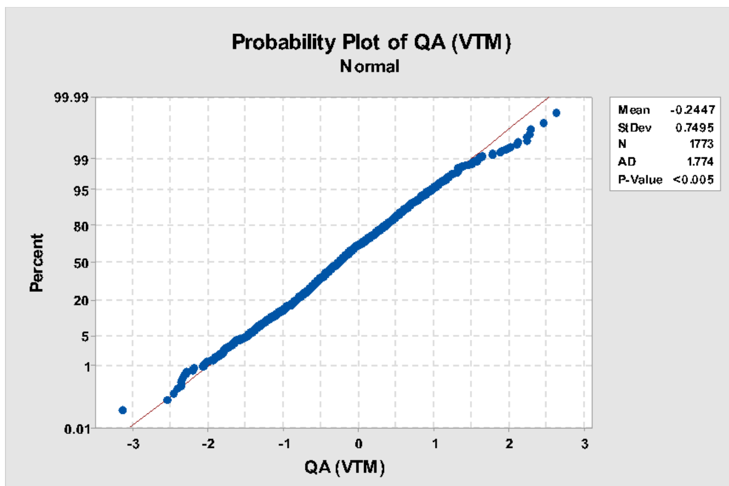


(b)

Figure C-1. Probability Plot of AC Results; (a) Contractor QC Data, (b) State Verification Data

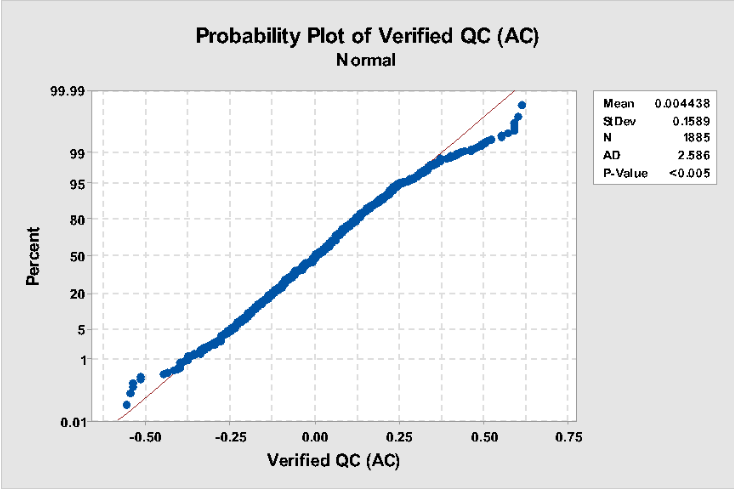


(a)

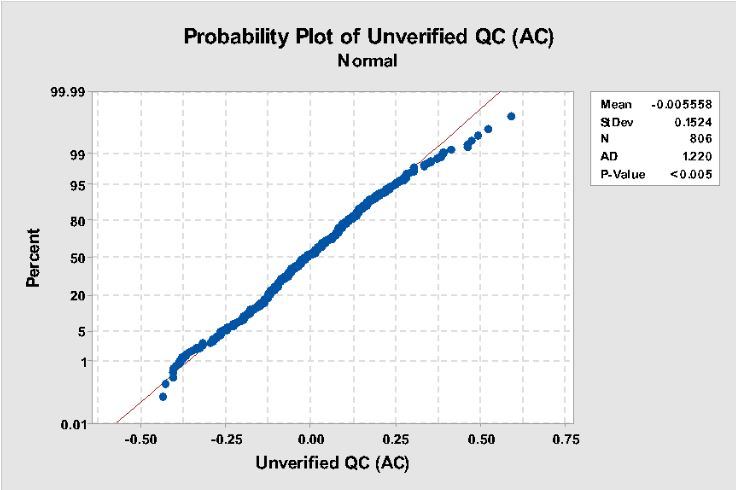


(b)

Figure C-2. Probability Plot of VTM Results; (a) Contractor QC Data, (b) State Verification Data

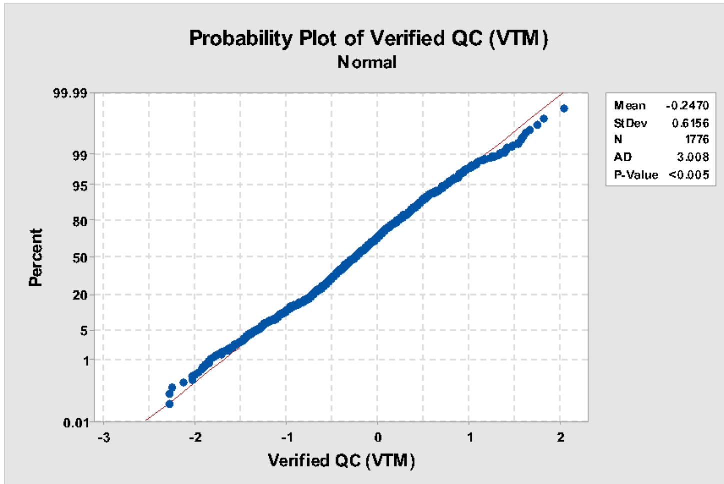


(a)

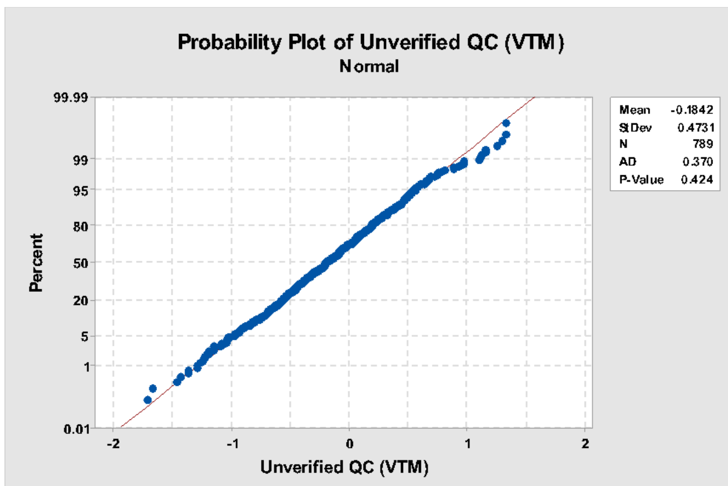


(b)

Figure C-3. Probability Plot of AC Results; (a) Validated Contractor QC Data, (b) Unvalidated Contractor QC Data

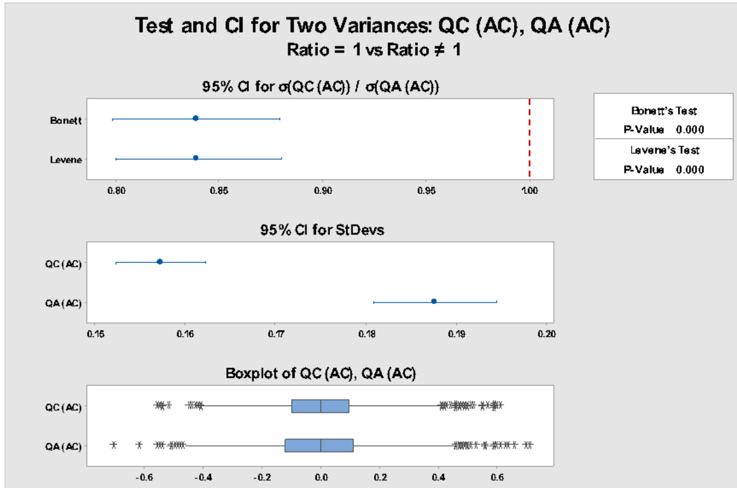


(a)

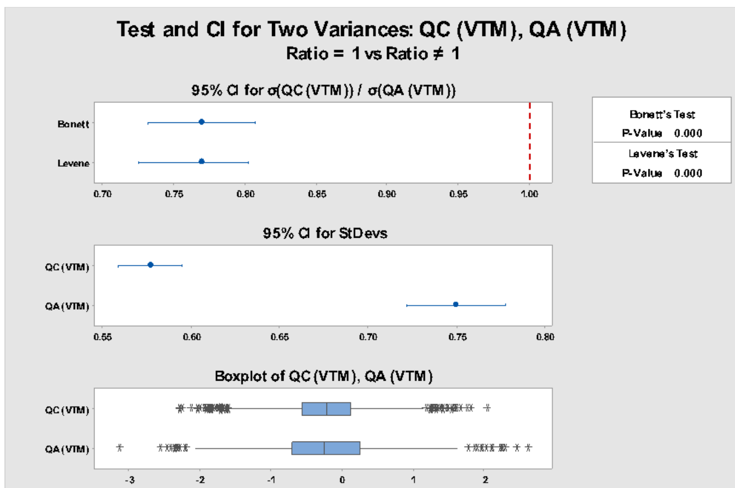


(b)

Figure C-4. Probability Plot of VTM Results; (a) Validated Contractor QC Data, (b) Unvalidated Contractor QC Data

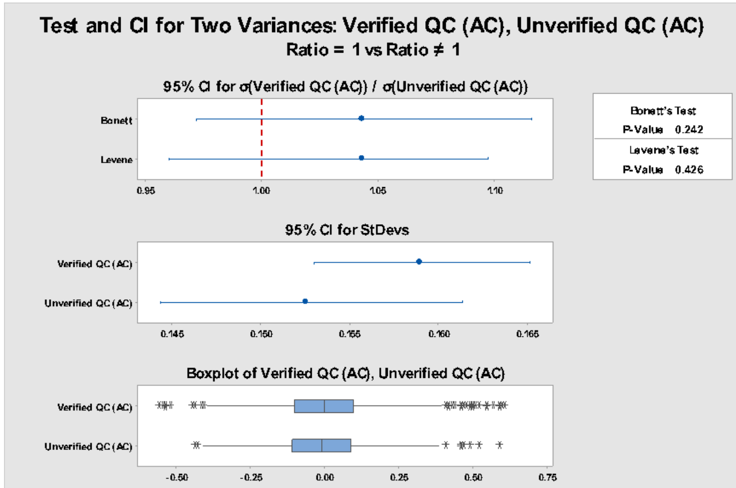


(a)

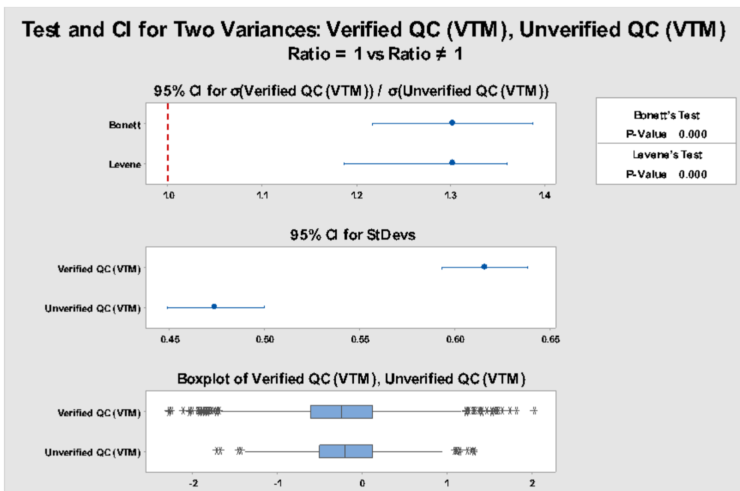


(b)

Figure C-5. Modified Levene Equal-Variance Test Results; (a) AC Data, (b) VTM Data



(a)



(b)

Figure C-6. Modified Levene Equal-Variance Test Results for AC and VTM; (a) Validated Contractor QC Data, (b) Unvalidated Contractor QC Data