Development of Acceptance Criteria of Compacted Hot Mixture Asphalt Bulk Specific Gravity Based on Vacuum Sealed Specimens: Final Report

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A number of test methods are available to measure the bulk specific gravity of compacted hot mix asphalt (HMA). The most commonly used test methods (ASTM D 2726 and AASHTO T 166) were designed for use with specimens that do not contain open or interconnected air voids. With increased traffic loading, coarse and open-graded asphalt mixtures have become more common to improve in-situ performance. These mixtures are known for open or interconnected air voids. The current methods for addressing coarse and open-graded mixtures (ASTM D 1188 and AASHTO T 275) can lead to erroneous bulk specific gravity measurements and can prevent specimens from further testing. Thus a vacuum sealing method (ASTM D 6752) was developed to address asphalt mixtures that contain interconnected or open air voids. In an evaluation of the new method for determining bulk specific gravity it has been found that a criterion test would help to identify when the new test method would be most suitable.

The research objective is to define the point at which the vacuum sealing method (ASTM D 6752) more accurately predicts the bulk specific gravity of an HMA as compared to the conventional method (ASTM D 2726 and AASHTO T 166). For this reason permeability was the fundamental property that was investigated. Permeability is a measure of the asphalt mixtures ability to transmit fluid, which in turn represents the mixtures connectivity of void space. A laboratory method for measurement of permeability of hot mix asphalt (ASTM PS 129-01) has been hypothesized as a criterion test for method selection in determining the bulk specific gravity of hot mix asphalt.</td></tr>
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Executive Summary

Introduction

This report summarizes work conducted to establish a preliminary acceptance criterion for Hot Mix Asphalt (HMA) to determine bulk specific gravity of compacted samples. Establishment of criterion addresses emerging issues with increased use of coarse-graded HMA mixtures. Characterization of materials, calculation of bulk specific gravity via three methods, and statistical analyses were all employed in establishing a preliminary guideline for determining the bulk specific gravity. The devised guideline will hopefully ensure that the best method is used for ascertaining the bulk specific gravity of compacted HMA samples.

The project consisted of several phases, each listed below.

1. Conduct a literature review to aid in establishing and experimental plan.
2. Collect loose material and cores from Michigan job sites that meet the experimental plan matrix.
3. Prepare the loose material and cores for testing. Preparation includes compacting loose material and wet sawing the bottom of the cores.
4. Determine volumetric properties of the mixtures.
5. Obtain additional bulk specific gravity measurements via the Dimensional Analysis Method (DAM) and Vacuum Sealing Method(VSM).
6. Compare and analyze the bulk specific gravity values based on mixture volumetric categorizing.
7. Establish restrictions, based on mixture properties, for bulk specific gravity measuring methods.

Literature Review

Bulk specific gravity of compacted HMA (henceforth referred to as bulk specific gravity) is a major component in the determination of volumetric properties and performance characteristics of HMA pavements. Volumetric properties such as air voids, voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), and percent maximum density, are determined based upon bulk specific gravity (Cooley et al, 2002). The advent of Superpave has initiated the use of more coarse-graded mixtures and stone matrix asphalt (SMA), which create issues when determining the bulk specific gravity correctly. Accurately determining bulk specific gravity has become increasingly more important, particularly for quality control/quality assurance types of specifications. With owner agencies typically accepting pavements based on percent compaction (density as a function of bulk specific gravity and maximum theoretical specific gravity), there is an increase in the need to identify the most suitable, economic, and accurate method to determine bulk specific gravity.

A number of test methods are available to measure the bulk specific gravity of compacted HMA. The most commonly used test methods (ASTM D 2726 and AASHTO T 166) were designed for use with specimens that did not contain open or interconnected air voids. With increased traffic loading, coarse and open-graded asphalt mixtures have become more common to improve in-situ performance. These mixtures are known for open or interconnected void space. The current methods for addressing coarse and open-graded mixtures (ASTM D 1188 and AASHTO T 275) can lead to erroneous bulk specific gravity measurements and possibly prevent further testing of specimens. Thus a VSM (ASTM D 6752) was developed to address asphalt mixtures that contain interconnected or open air voids. In an evaluation of the new method for determining bulk specific gravity it has been found that a preliminary criterion test would help to identify when the new test method would be most suitable.

In order to implement a VSM to determine bulk specific gravity, many owner/agency specifications will require modification to account for any shift in measured bulk specific gravity values. This shift will most likely occur since the SSD method can overestimate the bulk specific gravity in coarser mixtures, while methods such as the VSM can yield lower measured bulk specific gravity readings. Also, if a VSM is to be used by the industry, the method will need to be implemented during the design process as well as the construction process, allowing measurements to be compared to each other throughout the entire design and construction processes. Although, the actual density of the mixture may never be obtained, a comparative or "true" density can be used for design and construction use.

A number of studies have been completed thus far involving the VSM and its measurement of bulk specific gravity. A number of different research techniques were employed to compare the VSM method to two other accepted methods commonly employed. Many researchers agree that although the true value of bulk specific gravity may never be determined, the VSM method may provide more accurate results than some of the other methods available.

Material Collection

The material collected consists of two forms; loose uncompacted HMA and compacted in-place HMA roadway cores. Field sampling of projects was initiated shortly after the start of the project and progressed at an aggressive rate. Unfortunately, there was difficulty in identifying in advance whether or not a mixture was either fine or coarse-graded and resulted in four mixtures being sampled in the experimental plan that exceed the number of projects for an experimental block. These additional mixtures are indicated in Table 1 with an asterisk (*). Table 1 details the projects sampled.

Table 1: Projects Sampled

Mixture Size	Type of Gradation	Traffic Level	
		≤3m ESAL	>3m ESAL
2 (25mm)	Coarse	M-153	X
3 (19mm)	Coarse	M-50 Dundee	US-23 M-59 Brighton
		M-36 Pinckney	Michigan Ave. Detroit
		M-21 St. Johns	US-23 Heartland 3E30
	Fine	M-84 Saginaw	VanDyke Detroit
4 (12.5mm)	Coarse	M-50 Dundee	M-53 8 mile
		US-12 MIS	I75 Clarkston
		M-36 Pinckney	Michigan Ave. Detroit
	Fine	BL-96 Howell	US-127 Lansing
		* M-66 Battle Creek	
		* US-2 Wakefield	
5 (9.5mm)	Coarse	M-26 Painesdale	I-196 Grand Rapids
		M-50 Dundee	I-75 N. of Toledo (in MI)
		US 12 MIS	US-12 Michigan Ave.
	Fine	US-41 Hancock	VanDyke Detroit
		US -41 Calumet	US-127 Mason
		M-35 Menominee	US-131 Big Rapids
		* US-2 Norway	
		* M-21 Owosso	

Five replicate Superpave Gyratory Compactor (SGC) samples were required for each of the three chosen air voids, for a total of fifteen SGC specimens per job sampled. In order to generate fifteen SGC specimens and two Maximum Theoretical Specific Gravity (G_{mm}) specimens, approximately 160 lbs (73 kg) of material was required from each location. Applying a factor of safety for loss of material, a total of 475 lbs (215kg) of material was sampled from each site.

The material was obtained from the back of trucks in accordance with the appropriate ASTM standards D 979 and D 3665 or from a mini-stockpile.

Once the loose HMA was collected from the plant, roadway cores were extracted from the job site. The coring followed ASTM standards D 5361 and D 979. Cores were extracted when the roadway was cool.

The five-gallon buckets of loose mixture were heated to 135 °C for about two hours to allow the samples to be split into smaller fractions. Splitting was done in accordance with ASTM C 702. The samples were split to achieve two G_{mm} specimens and fifteen 4500 gram specimens for SGC compaction. The minimum mass of the G_{mm} specimens was based on their nominal maximum aggregate size (NMAS) as stated in ASTM D 2041 and AASHTO T 209.

The compaction of the loose HMA specimens was completed with the SGC in accordance with AASHTO TP 4. The gyratory compactor was calibrated and set to apply a vertical load of 600 kPa at an angle of gyration of 1.25°. The number of gyrations was based on the trafficking levels of the in-place HMA and the desired air void content.

In order to test the roadway cores in the VSM device, specimens must have relatively smooth surfaces to prevent puncturing the encasing bag. This required that all roadway cores be cut to remove the jagged surface caused by the aggregate base – HMA layer interface. Sawing was achieved with a water-cooled diamond bladed saw, which minimized damage to the specimen from the heat generated by friction. The saw was set to automatically feed the specimen through the blade at a constant speed.

G_{mm} specimens were produced, and tested in accordance with ASTM D 2041 and AASTHO T 209. As mentioned previously, two G_{mm} samples were prepared and tested for each job. The values obtained from G_{mm} testing made it possible to determine the air void content of the specimens once the bulk specific gravity testing was completed.

Statistical Analysis

The first analysis that was conducted was to create preliminary plots of the data to check for outliers and note any possible relationships between the data. After the preliminary plots were completed and the entire data set had been collected, statistical analysis was conducted on the data set. For this analysis, SAS, a statistical software package, was utilized to complete the computations required. The statistical analysis utilized was mean groupings and was used to determine if the test methods were significantly different using a 95% confidence.

The plots helped identify if an outlier was present in the collected data. These preliminary plots also served as a visual verification of tendencies occurring with data collected from the three bulk specific gravity test methods (VSM, SSD, and DAM Tests) that were used in this study.

One of the plots evaluated was a comparison between the three bulk specific gravity measuring methods by percent absorption. It was seen that the SSD and VSM had significant overlap between about 0% and 1% absorption. As the percent of absorption increased, the two methods tended to overlap one another less frequently. The DAM used was also overlapped by both methods throughout the span of percent absorption range, but there is a significant shift to the left, lower bulk specific gravity value is also apparent. From the graph, it appeared that the minimum bulk specific gravity value is continuously obtained by the DAM, while the SSD method yields the maximum value frequently.

The box plot analysis indicated that the spread of bulk specific values for the DAM was greater than either the VSM or SSD range, indicating that DAM was less precise. VSM and SSD methods appeared to have about the same level of precision. Both VSM and SSD also appeared to have some outliers, but not as severe as the DAM.

After examining the results of the t-tests which analyzed the data categorized by target air voids and NMAS separately, tests were conducted to inspect the data grouped by target air voids within each NMAS level. Since earlier studies indicated that the fine-graded HMA mixtures displayed similar results for the SSD and VSM, only the coarse-graded mixtures were analyzed. All of the core sample bulk specific gravity values calculated by the SSD and VSM methods are statistically equivalent with the exception of the mixtures with an NMAS of 19 mm. All of the target air void levels for the mixtures with an NMAS of 25 mm, 19 mm, and 12.5 mm have differing results for all three bulk specific gravity measuring methods. The mixtures with an NMAS of 9.5 mm, however, exhibited similar values for all target air void levels except 10% for the SSD and VSM

The previous analyses indicated that VSM or SSD method can be utilized to measure bulk specific gravity and attain statistically similar results for fine-graded mixtures. The question remains, when is the SSD method no longer appropriate for measuring the bulk specific gravity? To help answer this question, the relationship between the bulk specific gravity and percent absorption was examined. The initial analysis examined the bulk specific gravity and percent absorption relationship on data grouped by gradation, NMAS size, and target air void level. To determine the range at which bulk specific gravity measuring methods yielded similar results, t-tests were employed.

The percent absorption was divided into 7 different levels to analyze the bulk specific gravity values. The statistical results indicated that an appropriate restriction for the SSD method is to only test coarse mixture specimens with a percent absorption of less than 0.50%. Coarse mixture specimens with a percent absorption greater than 0.50% should be subjected to the VSM method to obtain the bulk specific gravity.

The fine-graded HMA mixtures exhibited similar bulk specific gravity results between the SSD and VSM for all 7 levels of percent absorption. Results of the t-tests on the fine-graded HMA indicate that either the SSD or VSM is appropriate at all absorption levels.

The VSM and SSD methods provide statistically similar values of bulk specific gravity for fine-graded mixtures. The DAM provides a significantly different measurement of bulk specific gravity as compared to the VSM and the SSD methods for fine-graded mixtures and coarse-graded mixtures. In general, the VSM and SSD provide significantly different measurements of bulk specific gravity for coarse-graded mixtures. These findings were based on a 95% confidence level, using Tukey's Studentized Range Test to complete the mean comparison.

The statistical analyses and graphs indicate there is overlap in bulk specific gravity values when comparing the SSD and VSM. Percent absorption was used to determine when solely the VSM is the appropriate method to use in calculating the bulk specific gravity. Fine-graded HMA mixture bulk specific gravity values emerged as statistically similar for SSD and VSM measurements, thus implying that either method is appropriate for measuring bulk specific gravity values. The coarse-graded HMA bulk specific gravity values differed significantly for levels of percent absorption greater than 1 (0-0.50%). The results indicate that for coarse-graded specimens with a percent absorption greater than 0.50%, the VSM should be used for determining the bulk specific gravity of compacted HMA.

Conclusion

In short, bulk specific gravity of compacted HMA plays a significant role in the production and acceptance of quality HMA pavements. Although most states do not necessarily specify bulk specific gravity as a criterion, they do specify other properties that are derived from the bulk specific gravity measurement. In addition, as HMA pavements become coarser and more gap-graded it becomes more difficult to accurately determine the bulk specific gravity and thus the resulting calculated properties. With a number of different test methods available to determine bulk specific gravity it makes it difficult to choose an accurate, reliable method based on the mixture type and gradation. Based on the literature, the VSM may be a viable option for accurately determining the bulk specific gravity of mixtures that are fine-graded as well as those mixtures that have a coarser gradation.   In total, thirty-three different mixtures were collected from around the state based on the NMAS and trafficking level. These mixtures and roadway cores were tested using two of the more common test methods for comparison with the VSM.

The final outcome of this research helped to determine if the VSM is a feasible alternative for determining bulk specific gravity of compacted HMA.

The results of the bulk specific gravity data indicate there is a significant difference between coarse and fine-graded mixtures when using the different test methods. For all fine-graded HMA mixtures, the bulk specific gravity values for SSD and VSM were statistically similar. The DAM tended to differ statistically from both the SSD and VSM. Either SSD or VSM appears to be appropriate for fine-graded mixtures based on the data acquired. For the coarse-graded HMA mixtures, either SSD or VSM may be used for level 1 percent absorption specimens, but the VSM seems to be the best method for coarse mixtures with a percent absorption level greater than 1. The VSM has demonstrated to be advantageous for coarse-graded mixtures. The Michigan Department of Transportation should consider implementing the VSM for measuring the bulk specific gravity of compacted hot mix asphalt and concurrently examine if additional data needs to be gathered for implementation.

1 Introduction

1.1 Background

Producing quality pavements that withstand the test of time is difficult to achieve. Hot mix asphalt (HMA) designs have improved and continue to advance to combat heavier traffic volumes and loads. These improvements affect how some of the important properties of the HMA are determined. As a result, a number of issues have arisen when determining the bulk specific gravity of certain HMA mixtures. Moreover, accurate assessment is necessary since bulk specific gravity, which is the ratio of a materials density to that of water, plays a significant role in the production and acceptance of quality pavements. To address the issues associated with coarser HMA mixtures, new technologies have been developed to help measure bulk specific gravity. One of the more recent technological advancements is a VSM for determining the bulk specific gravity.

Bulk specific gravity is a major component in the determination of mixture volumetric properties, which in turn have a direct impact on the performance characteristics of HMA pavements. Volumetric properties such as air voids, voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), and percent maximum density at a given number of gyrations are determined based upon bulk specific gravity (Cooley et al, 2002). The advent of Superpave has resulted in the use of more coarse-graded mixtures and Stone Matrix Asphalt (SMA), making the calculation of bulk specific gravity increasingly more important to achieve, particularly in quality control/quality assurance specifications. Table 1.1, as compiled by Burati et al (1999) from a survey of state highway agencies, shows how a number of different states and the Canadian province of Ontario use certain volumetric properties and their statistical measures for pay adjustments in their construction specifications. Although none of the surveyed states directly specify bulk specific gravity, a majority specify properties derived from the bulk specific gravity measurement.

Table 1.1 Statistical Measures Used by States (Burati et al, 1999)

State	Bulk Spec. Gravity	Air Voids	VMA	Density	% AC	Max. Spec. Gravity	Thickness	Gradation
AK				X	X			X
AR		X	X	X	X			
CO				X	X			X
CT				X	X			X
IA				X			X	
ID				X	X			X
IL							X	
LA		X	X	X	X			X
MD				X				
ME		X	X	X	X			X
MI		X	X	X	X			
MN		X	X		X			X
MS		I	X	X	X			X
MT				X				X
NC		X	X	X	X			X
ND				X	X			X
NE				X			X	
NJ		X		I			X	
NM		X	I	X	X			X
NV		X	I	I	X			X
NY	X	X	I	I	X	X		X
OH				X	X			
Ontario		X	I	X	X			X
OR				X	X			X
PA				X	X			X
SC		X	X	X	X			
TX				X				
VA					X			X
WA				X	X			X
WI		X	X	I	X	X		
WY				X	X			X
31	1	13 (14)[1]	9 (13)	24 (28)	24	2	4	20

X: Property is measured/calculated.
I: Property can be calculated from other property measurements.
1: Sum of X (X&I).

Additionally, pay reductions and bonuses are generally applied based on percent compaction, which is also calculated from the bulk specific gravity. Inaccurate values of bulk specific gravity can affect both the contractor and the owner agency. For example, air voids are determined from the bulk specific gravity measurement. If the bulk specific gravity is measured incorrectly, the air voids could deviate from the job specification resulting in erroneous pay penalties or pay bonuses for the contractor and poor quality pavement for the owner agency.

1.2 Current Issues

Accurate values for bulk specific gravity have become increasingly more important to achieve with the escalating use of coarse-graded and SMA mixtures. With the use of these mixtures, the internal voids tend to be larger and more interconnected. These larger, interconnected voids are problematic for conventional methods used to determine bulk specific gravity (e.g., water displacement or SSD method). As shown in the schematic of Figure 1.1, the conventional, fine-graded mixture on the right has the same internal void space as the coarse-graded Superpave mixture on the left. However, the larger voids in the coarser mixture tend to be interconnected throughout.

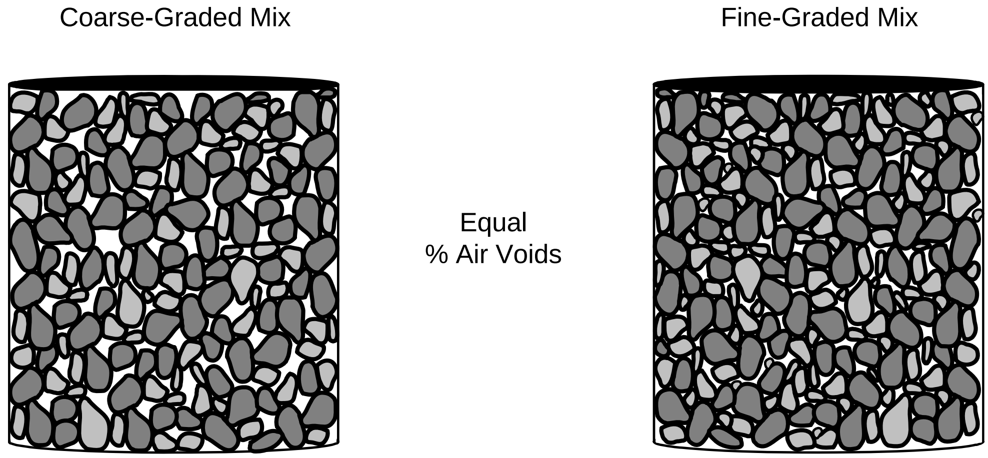

Figure 1.1: Differences in Internal Void Structure

Through these interconnected voids, water quickly infiltrates into the sample once submerged in water. However, the water just as quickly escapes these interconnected voids once the sample is removed from the water (Cooley et al, 2002). This void structure can cause problems when using the water displacement or SSD method resulting in an overestimate of bulk specific gravity property. Crouch et al (2002) reported that water penetration into open or interconnecting voids and subsequent drainage before the SSD mass can be determined, results in an underestimation of sample volume, thus inflating the bulk specific gravity of the mixture. As a result of this overestimation of the bulk specific gravity, volumetric properties such as air voids, VMA, and VFA can be misrepresented. These properties have a profound impact on mixture density and are directly related to pavement distresses such as rutting, shoving, fatigue cracking, flushing, and raveling, which will affect the mixture once it has been placed (Buchanan, 2002).

1.3 Scope

As traffic volumes increase on roadways, coarse-graded HMA pavements will be constructed to resist damage inflicted by heavier loads. A new method for determining the bulk specific gravity needs to be implemented to ensure the owner agencies are receiving the quality pavements paid for and the contractors are not unfairly being penalized. One solution to the need for a new method for determining the bulk specific gravity is the use of a VSM. Several researchers have investigated the benefits of VSM. Now that the method has been evaluated for appropriateness for bulk specific gravity measurements, a criterion for determining when to implement the VSM needs to be developed. The current project explored the establishment of a preliminary criterion for the VSM. The proposed experimental plan consisted of two elements: the measurement of bulk specific gravity of compacted mixtures in a Superpave Gyratory compactor (SGC) over a range of air voids, and the measurement of bulk specific gravity of field cores obtained by a coring machine of in-situ mixtures. Table 1.2 below outlines the number of projects that was anticipated for sampling.

Table 1.2 Experimental Plan Matrix

Nominal Maximum Aggregate Size	Type of Gradation	Trafficking Level	
		$\leq 3 \times 10^6$	$> 3 \times 10^6$
2^1 (25mm)	Coarse	X	X
	Fine		
3 (19mm)	Coarse	XXX	XXX
	Fine	X	X
4 (12.5mm)	Coarse	XXX	XXX
	Fine	X	X
5 (9.5mm)	Coarse	XXX	XXX
	Fine	XXX	XXX

1.4 Hypotheses

It was anticipated that the VSM would routinely yield lower bulk specific gravity values resulting in higher apparent air void contents for coarse-graded mixtures. This is consistent with the findings of previous research. Thus, it was conjectured that the findings would indicate that the VSM is a better method for measuring bulk specific gravity of Open Graded Friction Coarse (OGFC), Stone Mastic Asphalt (SMA), and Superpave coarse-graded mixtures, as well as mixtures containing a high level of air voids. However, it was hypothesized that fine-graded HMA samples with low levels of air voids would have similar bulk specific gravity measurements for the VSM and SSD methods. In which case, it is postulated that the best method for identifying when the VSM is providing a better measure of bulk specific gravity will be defined by an absorption value.

1.5 Objectives

The objectives of the study were to consider the mixture size, type of gradation, and trafficking level (in Equivalent Single Axle Loads - (ESALs)) as potentially relevant statistical factors affecting variation between bulk specific gravity measuring methods. In all, a total of 33 mixtures were sampled with varying mixture sizes, gradations, and trafficking levels. When possible, the roadway cores of mixtures were collected.

The field mixtures were compacted in a SGC at three different nominal air void levels: 4, 7 and 10 percent. Table 1.3 below outlines the experimental plan for the laboratory compacted specimens.

Table 1.3 Experimental Plan for Laboratory Compacted Samples

		Measurement Method of Bulk Specific Gravity		
		Volumetric	SSD	VSM
Air Voids	4%	XXXXX	XXXXX	XXXXX
	7%	XXXXX	XXXXX	XXXXX
	10%	XXXXX	XXXXX	XXXXX

X- Denotes a specimen to be tested.

This experiment aided in determining if there is an air void threshold at which a certain method of measuring the bulk specific gravity of the compacted mixture should not be measured.

The bulk specific gravity of five cores, from each project, were measured by the three methods: Dimensional Analysis, SSD, and VSM. Five specimens are sufficient for determining a mean and standard deviation of volumetric properties.

The analysis was completed on both laboratory compacted specimens and field cores. The laboratory compacted specimens allowed for the determination of the relationship between the different methods and volumetric properties of the HMA mixtures. The results obtained from the laboratory samples helped determine if a method may become prone to error and thus inappropriate to use. The cored samples also aided in the statistical analyses.

1.6 <u>Deliverables</u>

The products and deliverables for the project are a draft specification for the VSM for compacted HMA specimens based on the current Michigan Department of Transportation (MDOT) specification of the mean value. However, MDOT is anticipating the implementation of a percent within limit specification in the next two years, which emphasizes statistical values such as standard deviation. Due to the change in the pay factor system for MDOT, information on the mean and standard deviation will be included in the report as a preliminary guideline for a specification. The guidelines should be revisited after several years of data collection for possible refinement of the specification.

1.7 <u>Document Organization</u>

The report describes previous research on the VSM and information concerning the current project. Chapter 2 summarizes various bulk specific gravity measuring methods and previous research on the VSM. Chapter 3 outlines the setup and testing completed for the project. Chapter 4 summarizes the statistical analyses performed to determine the trial specification criteria. Chapter 5 presents the conclusions of the research team.

2 Literature Review

2.1 Introduction

Bulk specific gravity of compacted HMA (henceforth referred to as bulk specific gravity) is a major component in the determination of volumetric properties and performance characteristics of HMA pavements. Volumetric properties such as air voids, VMA, VFA, and percent maximum density, are determined based upon bulk specific gravity (Cooley et al, 2002). As mentioned, coarse-graded mixtures and SMAs are being used more frequently and these mixtures tend to consist of interconnected or open air voids. Measuring the bulk specific gravity of such mixtures is prohibited, in most cases, for the SSD method because of the errors created by the air void structure. Both contractors and owner agencies have an interest in finding accurate methods for measuring air voids. The proceeding sections outline available bulk specific gravity test methods and recent research on the VSM.

2.2 Bulk Specific Gravity Test Methods

A number of test methods are available to measure the bulk specific gravity of compacted HMA. Table 2.1 shows a number of these existing methods as partially compiled by Crouch et al (2002). The most commonly used test methods (ASTM D 2726 and AASHTO T 166) were designed for use with specimens that did not contain open or interconnected air voids. With increased traffic loading, coarse and open-graded asphalt mixtures have become more common to improve in-situ performance. These mixtures are known for open or interconnected void space. The current method for addressing coarse and open-graded mixtures (ASTM D 1188 and AASHTO T 275) can lead to erroneous bulk specific gravity measurements and possibly prevent further testing of specimens. Thus a VSM (ASTM D 6752) was developed to address asphalt mixtures that contain interconnected or open air voids.

Table 2.1 Existing Methods with References (Crouch et al, 2002)

Method	Author/Reference
Water Displacement or SSD Method	AASHTO T-166 or ASTM D 2726
Dimensional Analysis	AASHTO T-269
Paraffin Coating	AASHTO T-275
Parafilm Coating	ASTM D 1188
Gamma Ray Technology	Troxler Electronic Laboratories, Inc.
Non-Nuclear Density Gauges	Troxler Electronic Laboratories, Inc. & TransTech Systems, Inc.
Nuclear Density Gauges	Troxler Electronic Laboratories, Inc.
VSM	ASTM D 6752
Cut and Measure	Buchanan NCAT
Masking Tape Wrapping	TTI NCHRP 386
Glass Beads	TTI NCHRP 386
Weighting in Plastic Bags	TTI NCHRP 386
Zinc Coating	Harvey et al. (ASTM)
Rubber Membrane Jacketing	Harvey et al. (ASTM)
Sand Replacement	Rorie et al. TDOT(unpublished)
Catching Absorbed Water	Unknown

With the increasing number of coarse-graded and SMA mixtures being used, a few new methods have been developed to quantify bulk specific gravity for these coarser mixtures. Additional research needs to be performed in order to establish the validity of these new methods. Described in the following sections are a few of the more common test methods currently used to determine bulk specific gravity.

2.2.1 ***Dimensional Analysis Method***

Dimensional Analysis Method (DAM), performed in accordance with AASHTO T 269, is a simplistic, volumetric approach for determining bulk specific gravity. This method assumes the sample is smooth, although in reality the specimen has surface irregularities. By ignoring the surface irregularities that exist in the specimen, the bulk specific gravity can be underestimated. To minimize the erroneous results caused by the surface irregularities, DAM can be performed with cut specimen surface(s). In order to calculate the bulk specific gravity, the mass of the specimen must be obtained along with the average height and diameter of the specimen. Many of the errors associated with DAM occur during the height and diameter measurements (Buchanan, 2000). The bulk specific gravity using DAMis calculated by the following equation.

$$G_{mb} = \frac{M_{Dry}}{\left(\frac{\pi \cdot d^2}{4}\right) \cdot h \cdot \rho_w} \qquad \textbf{(2.1)}$$

where:

$G_{mb} = specimen\ bulk\ specific\ gravity\ at\ 25^\circ C\ \left(77^\circ F\right),$
$M_{Dry} = mass\ of\ dry\ specimen\ \left(g\right),$
$d = specimen\ diameter\ \left(cm\right),$
$h = specimen\ height\ \left(cm\right),\ and$
$\rho_w = density\ of\ water\ at\ 25^\circ C\ \left(77^\circ F\right),\ \left(g/cm^3 \right).$

2.2.2 ***Saturated Surface Dry***

The Saturated Surface Dry (SSD), as defined by ASTM D 2726 or AASHTO T 166, is the most common method employed to determine bulk specific gravity of compacted HMA. Based on Archimedes' principle, the SSD method approximates the volume of a compacted HMA specimen as the volume of water displaced when submerged under water (Tarefder et al, 2002).

According to the test procedure, the SSD is only valid for water absorption of less than two percent and the procedure is not recommended for specimens that contain open or interconnecting air voids. Also, the reliability of the SSD decreases with increasing depth of the surface irregularities and the presence of interconnected voids that are open to the surface of the solid (Troxler Electronic Laboratories, Inc., 2001). In order to determine the bulk specific gravity using the SSD the following procedure is abided by.

Step 1: Obtain the dry weight of the specimen.

Step 2: Place the specimen under water for 4 minutes ± 1 minute and record the submerge weight.

Step 3: Specimen is removed from the water and the saturated surface dry condition specimen weight is taken.

This SSD condition is very difficult to determine as it is subject to individual interpretation of when a specimen is SSD, thus the procedure is prone to variability and error. The equation used to calculate the bulk specific gravity is given by equation **(2.2)**.

$$G_{mb} = \frac{M_{Dry}}{M_{SSD} - M_{Sub}} \tag{2.2}$$

where:

$G_{mb} = specimen\ bulk\ specific\ gravity,$
$M_{Dry} = mass\ of\ dry\ specimen\ (g),$
$M_{SSD} = mass\ of\ saturated\ surface\ dry\ condition\ specimen(g),\ and$
$M_{Sub} = mass\ of\ submerged\ specimen\ (g).$

2.2.3 Paraffin and Parafilm Method

The paraffin and parafilm method, as described by AASHTO T 275 and ASTM D 1188 respectively, addresses the water absorption problems inherent in AASHTO T 166 and ASTM D 2726. The compacted HMA specimens are either coated with paraffin or wrapped in parafilm. The use of paraffin or parafilm can be time consuming, awkward to perform, and in the case of paraffin, messy (Buchanan, 2000). The paraffin coating also may limit the further evaluation of the specimen after the bulk specific gravity testing is completed, whereas the parafilm is easily removed to allow for further testing. The testing procedure is similar to that of AASHTO T 166 and ASTM D 2726.

Step 1: The dry, uncoated weight of the sample is determined.

Step 2: The mass of the completely coated specimen is recorded.

Step 3: The mass of the coated sample under water is ascertained.

Step 4: The specific gravity of the coating is determined as outlined in ASTM D 1188. Equation **(2.3)** is then used to determine the bulk specific gravity of the specimen, as described by AASHTO T 275 and ASTM D 1188.

$$G_{mb} = \frac{M_{Dry}}{\left[M_{CD} - M_{CS} - \frac{M_{CD} - M_{Dry}}{G_C} \right]} \tag{2.3}$$

where:

$G_{mb} = specimen\ bulk\ specific\ gravity,$
$M_{Dry} = mass\ of\ dry,\ uncoated\ specimen\ (g),$
$M_{CD} = mass\ of\ dry,\ coated\ specimen\ (g),$
$M_{CS} = mass\ of\ submerged,\ coated\ specimen\ (g),\ and$
$G_C = specific\ gravity\ of\ coating,\ as\ determined\ in\ the\ test\ method.$

2.2.4 Gamma Radiation Method

In addition to the previously mentioned methods for determining bulk specific gravity, gamma ray technology is also used to measure bulk specific gravity. The gamma ray method is simple, non-destructive, and is not dependent on specimen surface texture or connectivity of the voids in the sample. As shown in Figure 2.1, the gamma ray method for bulk specific gravity measurement is based on the scattering and adsorption properties of gamma rays within matter (Malpass, 2001).

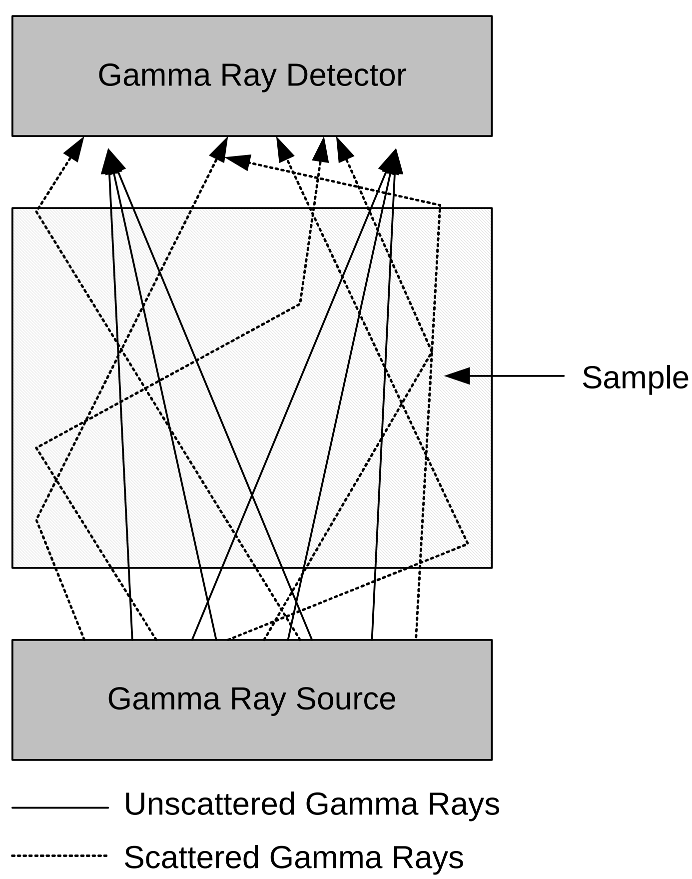

Figure 2.1 Gamma Ray Device (Troxler Electronic Laboratories, Inc.)

The gamma rays at a specific energy interact with matter through the mechanism known as Compton scattering or inelastic scattering (Troxler Electronic Laboratories, Inc., 2001). As gamma rays are passed through the sample, collisions occur between the photons of the gamma rays and the electrons in the specimen. These collisions cause the photons to lose energy and change directions as they pass through the sample. Compton scattering is a function of electronic specific gravity of the material, hence, a function of the mass specific gravity of the material. With proper calibration, the photon count is directly converted to the bulk specific gravity of the specimen (Malpass, 2001). The advantages of the gamma ray method are that it is quick and requires little human intervention. However, because the method is relatively new, more research needs to be conducted to ascertain its role for determining bulk specific gravity of compacted HMA specimens. Licensing from the manufacturer is required for operation. Furthermore, the depth of the layer to be tested is also important as 95% of the reading is obtained in the top two inches of the layer.

2.2.5 <u>Non-Nuclear Gauges</u>

For many years, nuclear gauges have been used to measure density of in-place HMA. Recently, a number of non-nuclear gauges have been introduced to the industry to measure density using electromagnetic signals. The use of electromagnetic signals has the advantage of completely eliminating the licenses, training, specialized storage, and risks associated with devices that incorporate a radioactive source (Romero, 2002). Two of these devices, Pavement Quality Indicator™ and PaveTracker™, use these electromagnetic signals in lieu of a radioactive source. Figure 2.2 and Figure 2.3 show the Pavement Quality Indicator™ and the PaveTracker™, respectively. The TransTech Pavement Quality Indicator™ uses electrical waves to measure a dielectric constant using an innovative, toroidal electric sensing field established by the sensing plate (TransTech, 2000). The PaveTracker™ from Troxler Laboratories, Inc. can be used to measure pavement densities as well as segregation and overall pavement uniformity (Troxler Electronic Laboratories, Inc., 2003).

Figure 2.2 Pavement Quality Indicator™

Figure 2.3 PaveTracker™

The two non-nuclear devices described above are generally calibrated with an HMA specimen of known density. Both the Pavement Quality Indicator™ and the PaveTracker™ require the operator to record a number of different measurements from the same pavement location and average the values to obtain the density. Figure 2.4 shows an artistic rendering of how the non-nuclear gauges operate.

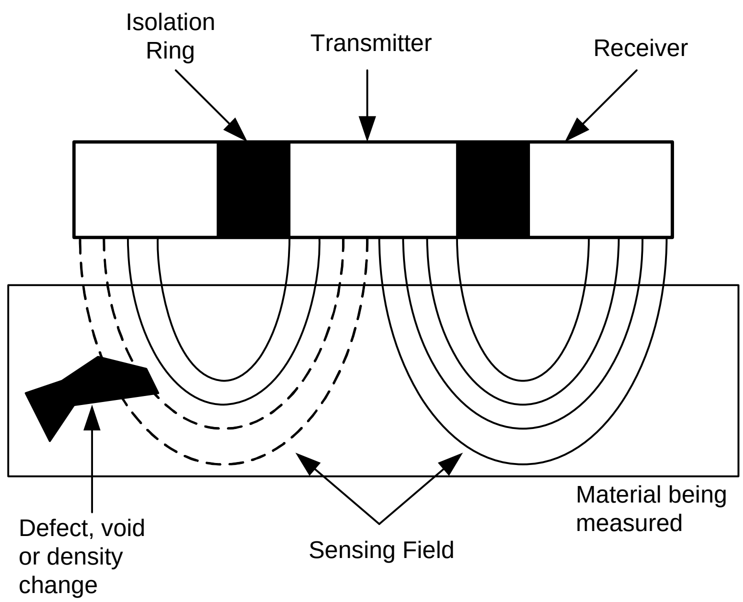

Figure 2.4 Operation Diagram (TransTech Systems, Inc.)

In addition, both accuracy and length of time for testing are important issues (Williams et al, 1996).

Certain problems arise when using electromagnetic signals to detect density when internal or external moisture is present. According to Romero (2002), the density readings tended to deviate from the expected values when the H_2O number read by the gauge was greater than five. Therefore, it is recommended that readings not be taken when the H_2O number is greater than five.

In addition, the non-nuclear devices do not measure density directly, instead measuring changes in the electromagnetic signals which are proportional to the accepted density as a baseline measurement. The non-nuclear devices show promise in the quality control aspect of construction, however, not enough research has been conducted as of yet for the devices to be used for quality assurance (Romero, 2002).

2.2.6 Vacuum Sealing Method

Much like the gamma ray device, the VSM device has been developed to determine the bulk specific gravity of the coarser-graded Superpave mixtures. The VSM device is a VSM that eliminates the need for weighing the specimen in the SSD condition. Through the use of flexible, puncture resistant vacuum bags, the sample is sealed and remains dry during testing (InstroTek Inc., 2003). The process of determining the bulk specific gravity with the VSM system is similar in nature to ASTM D 1188 and AASHTO T 275 and, which uses a paraffin wax or parafilm to prevent water infiltration from occurring during the submersion of the sample. The VSM device, as shown in Figure 2.5, can accommodate 4-in. diameter, 6-in. diameter, and even the larger 15-in. long beam specimens.

Figure 2.5 VSM Device

The VSM system requires very little involvement from the operator, which in turn means the test results may be more reproducible. Also, when compared to DAM and the SSD, the VSM method has the smallest multi-operator variability, as defined by a standard deviation of test results (Hall et al, 2001). The steps involved in determining the bulk specific gravity of compacted HMA specimens via the VSM method are as follows (InstroTek Inc., 2003):

Step 1: Determine the density of the plastic bag (generally manufacturer provided).

Step 2: Place the compacted HMA sample into a bag.

Step 3: Place the bag containing the HMA sample inside the vacuum chamber.

Step 4: Close the vacuum chamber door. The vacuum pump will start automatically and evacuate the chamber to 760mm (30 in.) Hg.

Step 5: In approximately two minutes, the chamber door will automatically open with the sample completely sealed within the plastic bag and ready for water displacement testing.

Step 6: Perform SSD testing and correct the results for the bag density and the displaced bag volume.

Once the values from steps one through six are determined, a computer program is used to calculate the bulk specific gravity of the specimen by an equation similar to equation (2.4).

$$G_{mb} = \frac{M_{Dry}}{\left[M_{AT} + \left(M_{Bag} - M_{Dry}\right)\right] - M_{SS} - \dfrac{M_{Bag} - M_{Dry}}{G_{Bag}}} \tag{2.4}$$

where:

$G_{mb} = specimen\ bulk\ specific\ gravity,$
$M_{Dry} = mass\ of\ dry,\ unsealed\ specimen\ (g),$
$M_{AT} = mass\ of\ unsealed\ specimen\ after\ testing\ (g),$
$M_{Bag} = mass\ of\ sealing\ bag\ (g),$
$M_{SS} = mass\ of\ submerged,\ sealed\ specimen\ (g),\ and$
$G_{Bag} = specific\ gravity\ of\ sealing\ bag,\ as\ determined\ in\ the\ test\ method.$

Although the VSM method has potential for use in the asphalt industry, the repeatability and reproducibility of the procedure needs to be evaluated before the device can be specified by agencies (Cooley et al, 2002).

2.2.7 Method Summary

In order to use the previously mentioned new methods to determine bulk specific gravity, many owner/agency specifications will need to be modified in order to account for the shift in the measured bulk specific gravity values. This shift will occur due to the fact that the SSD method can overestimate the bulk specific gravity in coarser mixtures, while methods such as the VSM can yield lower measured bulk specific gravity readings. Also, if a new method is to be used by the industry, the method will need to be implemented during the design process as well as the construction process, allowing measurements to be compared from design through construction. Although, the actual density of the mixture may never be obtained, a comparative or “true” density can be used for design and construction use.

2.3 Previous Vacuum Sealing Method Research

This section includes studies that have been conducted involving the investigation of VSM of measuring bulk specific gravity. A number of studies have been completed thus far involving the VSM and its measurement of bulk specific gravity. The following is a brief overview of the results and conclusions that different entities have reached when studying the VSM device. For reading ease, the proceeding sections are divided into sections by the agency that sponsored the respective study.

2.3.1 Florida Department of Transportation (FDOT)

Sholar (2004) reported on a limited study in which the Florida Department of Transportation (FDOT) compared the VSM to FM 1-T 166, a procedure of determining bulk specific gravity, which is fundamentally the same as AASHTO T166 (SSD). The department studied nine Superpave gyratory compacted specimens, six of which were 150 mm in diameter and the remaining were 100 mm in diameter. The nine compacted specimens were comprised of mixtures ranging from 9.5 mm fine-graded mixtures to 19.0 mm coarse-graded mixtures. FDOT ran all ten specimens uncut by means of both the VSM and FM 1-T 166 method, then cut the top and bottom off six of the specimens and then re-evaluated. The report noted a tendency of the bulk specific gravity values to vary between the VSM and SSD methods of measurement for the uncut specimens. The VSM had notably lower values of bulk specific gravity than the SSD method. The researchers also noticed that the VSM vacuum bags did not completely conform to the surface texture of the specimen. Six samples were wet sawed and retested to overcome the issue of the bags not conforming to the specimens. The results of the six specimens tested indicated that much of the previously observed variance between the VSM and SSD methods could be attributed to the surface texture since the variation significantly decreased with the wet sawed specimens.

2.3.2 National Center for Asphalt Technology (NCAT)

Buchanan (2000), working at the National Center for Asphalt Technology (NCAT), evaluated selected methods for measuring bulk specific gravity. The study considered four different mixture types; fine- and coarse-graded Superpave, SMA, and Open-Graded Friction Course

(OGFC). Three replicate gyratory compacted samples were produced for three different air void contents and two different aggregate types. After preparation, the samples were tested using four different methods to estimate the bulk specific gravity. These methods included DAM, SSD, parafilm coating, and VSM. After initial testing, the samples were wet sawed into 75 mm x 75 mm x 75 mm cubes and retested using all four methods. A statistical analysis was completed to compare the different methods of estimating bulk specific gravity. An analysis of variance was performed along with Duncan's multiple range comparison on each of the factors (aggregate type, mixture type, air voids and cut or uncut) with a confidence level of 95%. The statistical analysis concluded that less variability existed between the methods when specimens were tested cut versus uncut. This decrease in variability can be attributed to methods, like DAM and parafilm coating, dependent on surface conditions. Additionally, there was a surprising reduction in air voids between cut and uncut specimens for all methods. This is thought to be a result of the density gradient of gyratory compacted samples which in preliminary research shows a difference in air void contents between the top third and bottom third of the sample when compared to the middle third. Duncan's multiple range comparison often indicated that statistical differences did not exist, when in fact differences are known to exist and vice versa. The discrepancy between the statistical analysis and reality was overcome by considering both the data statistically and practically. For both the fine and coarse-graded Superpave mixtures of limestone and granite, the water displacement and VSM agreed 79% of the time. These similarities were seen mostly in the fine and coarse-graded Superpave mixture with lower air void contents. The remaining 21% of the time, VSM led to higher air void contents than the SSD. These differences tended to be with high void content, coarse-graded Superpave mixtures and the SMA and OGFC mixtures. It is believed the differences are a result of open and/or interconnected voids in the test sample. The interconnected voids allow the absorbed water to drain prior to obtaining the SSD weight of the sample in the SSD. Differences between the SSD and the VSM also increased as the percent water absorption increased. As previously mentioned, the water displacement should not be performed on samples having percent water absorptions greater than 2% by percent of dry mass. It was found that water absorptions of 0.5% resulted in approximately a 1% difference in air voids between the SSD and the VSM. In addition, water absorptions of 2% could result in a 6% difference in air voids between the two methods, illustrating a high amount of error.

DAM provided the highest air voids 59% of the time. For the fine- and coarse-graded mixtures the average air void difference between the DAM and the VSM was 0.78 %. The difference was 1.64 % for the SMA and OGFC mixtures, which again illustrates that the DAM has problems with surface irregularities. Although DAMmay be the best method for determining bulk specific gravity on cut plane specimens, it was not chosen as a desirable method because of its inconsistency with surface irregularities.

Air voids measured by the parafilm method agreed with the DAM 53% of the time. With the fine and coarse-graded Superpave mixtures, the parafilm method generally agreed with the VSM. As with DAM the parafilm method tended to deviate from the VSM as surface irregularities increased. The deviation is a product of the parafilm wrapping bridging the surface voids and increasing the apparent volume of the specimen. Overall, the parafilm method works well when used on cut plane specimens or specimens with a low amount of surface irregularities.

Finally, the VSM seems to provide the best estimate of bulk specific gravity and is independent of mixture parameters (mixture type, air void content, aggregate type and cut or uncut) unlike the other methods examined.

2.3.3 Arkansas State Highway and Transportation Department (AHTD)

Through work conducted by Hall et al (2001), in conjunction with Arkansas State Highway and Transportation Department (AHTD) and Federal Highway Administration (FHWA), it was again stated that there were significant statistical differences between the VSM and SSD. The testing conducted in the AHTD project is very similar to the testing that will be completed for this project, except the AHTD project researchers tested only 24 laboratory compacted samples taken from 6 sites in the State of Arkansas. All of the mixtures tested were surface mixtures with a nominal maximum aggregate size (NMAS) of 12.5 mm. Specimens for two of the sites were compacted to N_{max}, while the specimens for the other four sites were compacted to N_{design}. Samples were randomly selected for testing by one of nine randomly selected operators. Each specimen was tested three times for a single method by one of three randomly chosen operators. An analysis of variance, as well as Duncan's multiple range tests, was performed at a level of significance of 95%. Based upon analysis of the data, it was found that the VSM had the smallest multi-operator variability of the three test methods (VSM, SSD, and DAM). Furthermore, because of the scrutiny that surrounds the SSD, especially with coarser mixtures, VSM may be a practical option.

2.3.4 Federal Highway Administration (FHWA)

Cooley et al (2002), determined through round robin testing, that the variability of the VSM appears to be less sensitive with changes in air void content than the SSD. Each laboratory involved in the study was responsible for testing 27 (9 fine-graded, 9 coarse-graded, and 9 SMA mixtures) gyratory lab compacted samples with both the VSM and the SSD. Analyses were performed on the bulk specific gravity by mixture and gyration level.

This testing involved 18 laboratories and it was determined that a majority of those laboratories produced more variable and erroneous results when using the VSM. This may however be credited to the inexperience of the operators performing the tests. NCAT also determined from this testing that the single operator standard deviation of the VSM was 0.0124, meaning that if a competent operator conducted two individual tests on the same material using the VSM, their bulk specific gravity results should not differ by more than 0.035. In addition, NCAT discovered that significant differences existed between the VSM and the SSD with changes in gradation and/or void content. Furthermore, the VSM did not overestimate the bulk specific gravity at increasing void levels like the water displacement did, thus the VSM may be a better estimator of bulk specific gravity when air void contents are high. Absorption also played a major role in the determination of bulk specific gravity as the two methods diverged at 0.4 % water absorption. NCAT later states that these conclusions are solely based on laboratory compacted specimens and may not be indicative of field compacted samples or roadway cores.

2.3.5 Oklahoma Department of Transportation (ODOT)

Tarefder et al (2002) explored the VSM device on 170 pavement cores consisting of two different gradations. Some of the cores tested were from surface courses while others were base courses. The surface course field specimens had a NMAS of 12.5 mm, while the base course specimens had a NMAS of 19 mm. The cores were collected from various sites in Oklahoma. In addition to field cores, the researchers also produced 22 laboratory compacted specimens with a similar gradation to the base course field cores.

The conclusions drawn, based on the DAM, were that the VSM estimated the bulk specific gravity of the specimens better than the SSD. The researchers found through regression analysis that the VSM and the SSDs agreed well when testing laboratory compacted specimens that were both less than 10% air voids and 2% absorption. Another interesting discovery was the DAM results correlate better with the VSM than with the SSD results. With laboratory compacted specimens containing more than 10% air void contents, the SSD, on average, overestimated the bulk specific gravity when compared to the VSM by 0.068.

The VSM and water displacement also compared well when testing field cores with voids less than 10% and absorption values less than 2%. Again, the DAM concurred with the VSM better than it did with the SSD. As with the laboratory compacted samples, the bulk specific gravities deviated from the two methods when testing specimens with voids greater than 10% and/or absorption greater than 2%.

In addition, it was found that the differences between the two methods, VSM and water displacement, was not solely attributed to either absorption or air voids, but a combination of both.

2.3.6 Tennessee Department of Transportation (TDOT)

The Tennessee Department of Transportation (TDOT) and FHWA contracted Crouch et al (2002), to do similar testing as the previously mentioned studies. The project consisted of two different studies; a feasibility study and a precision and accuracy study. The feasibility study consisted of seven different methods of determining bulk specific gravity. The methods included water displacement, dimensional analysis, DAM (top and bottom cut plane), DAM(all surfaces cut plane), parafilm coating, glass beads, and the VSM. A total of ten laboratory and field compacted samples with varying gradations were used. Each sample was tested with five replicates of the individual test methods. From the feasibility study, the three methods with the lowest precision were removed before beginning the precision and accuracy study. Thus, the DAM(top and bottom cut plane), DAM(all surfaces cut plane) and the glass beads were removed from the next study as they had the lowest precision.

For the precision and accuracy study, 30 laboratory compacted samples (both SGC and Marshall compacted) from six different gradations along with 20 field cores from four sites were tested. As before the different groups of specimens had varying mixture types ranging from dense to coarse-graded. In addition to the assorted mixtures, four aluminum cylinders were tested by each method. Three of these aluminum cylinders had holes drilled in them corresponding to different void contents.

Upon analysis of the data, it was found that the SSD tended to produce the lower bound values, while the DAM tended to produce the upper bound values of bulk specific gravity. Due to issues of surface irregularities with dimensional analysis, it was determined that it would not be suitable for the estimation of bulk specific gravity. With the elimination of the dimensional analysis, the parafilm method became the new upper bound of bulk specific gravity. Because of the inconsistencies with the SSD and the parafilm method, the researchers believed that these values are in fact upper bounds and lower bounds of the true bulk specific gravity. A statistical analysis was performed to verify if the VSM values fall between lower bound (SSD) and the upper bound (parafilm values) in every instance. With a 95% level of significance, a paired t-test was performed. It was found that the VSM values are situated between the upper and lower bound values of the bulk specific gravity. From this study the researchers determined that although the true bulk specific gravity may never be found, the VSM might be an applicable method for estimating it.

2.3.7 __New England Transportation Consortium (NETC)__

Bhattacharjee et al (2002) conducted a study involving the VSM at Worcester Polytechnic Institute in cooperation with the New England Transportation Consortium. HMA was collected from ten sites throughout Massachusetts, New Hampshire, and Connecticut. From these ten sites, three replicate laboratory compacted samples were produced using a different number of gyrations to achieve each of the three air voids (5, 7, and 10%) chosen to analyze. The study explored the differences between the SSD and the VSM, as well as the permeability of the mixtures.

As supported by other literature, the researchers determined that the SSD consistently yielded lower air voids than the VSM. This was believed to be a direct result of water draining from the voids of the specimen before the SSD weight could be obtained. The differences between the two methods increased as the air void content increased. Finally, it was concluded that the VSM provides a better estimation of the sample air voids for coarse-graded mixtures and fine-graded mixtures at high air void contents.

2.3.8 __Research Summary__

In summary, research studies have been conducted involving the measurements of bulk specific gravity from the VSM and comparisons with other methods for determining the bulk specific gravity. A number of different research techniques were employed to compare the VSM to other accepted methods. Many of the researchers agree that although the true value of bulk specific gravity may never be determined, the VSM may provide more accurate results than some of the other methods available.

3 Procedures

3.1 <u>Material Collection</u>

The material collected consists of two forms; loose uncompacted HMA and compacted in-place HMA roadway cores. The following two sections outline the amount of material collected and the procedures followed when sampled.

Field sampling of projects was initiated shortly after the start of the project and progressed at an aggressive rate. Unfortunately, there was difficulty in identifying in advance whether or not a mixture was either fine or coarse-graded and has resulted in four mixtures being sampled in the experimental plan that exceed the number of projects for an experimental block. Table 3.1 details the projects that were sampled.

Table 3.1 Sampled Projects

Mixture Size	Type of Gradation	Traffic Level	
		≤3m ESAL	>3m ESAL
2 (25mm)	Coarse	M-153	X
3 (19mm)	Coarse	M-50 Dundee	US-23 M-59 Brighton
		M-36 Pinckney	Michigan Ave. Detroit
		M-21 St. Johns	US-23 Heartland 3E30
	Fine	M-84 Saginaw	VanDyke Detroit
4 (12.5mm)	Coarse	M-50 Dundee	M-53 8 mile
		US-12 MIS	I75 Clarkston
		M-36 Pinckney	Michigan Ave. Detroit
	Fine	BL-96 Howell	US-127 Lansing
		* M-66 Battle Creek	
		* US-2 Wakefield	
5 (9.5mm)	Coarse	M-26 Painesdale	I-196 Grand Rapids
		M-50 Dundee	I-75 N. of Toledo (in MI)
		US 12 MIS	US-12 Michigan Ave.
	Fine	US-41 Hancock	VanDyke Detroit
		US -41 Calumet	US-127 Mason
		M-35 Menominee	US-131 Big Rapids
		* US-2 Norway	
		* M-21 Owosso	

* Extra project sampled

3.1.1 <u>Loose Mixture</u>

Five replicate Superpave Gyratory Compactor (SGC) samples were required for each of the three chosen air voids, for a total of fifteen SGC specimens per job sampled. In order to generate fifteen SGC specimens and two Maximum Theoretical Specific Gravity (G_{mm}) specimens, approximately 160 lbs (73 kg) of material was required from each location. Applying a factor of safety for loss of material, a total of 475 lbs (215kg) of material was sampled from each site. The material was obtained from the back of the truck in accordance with the appropriate ASTM standards D 979 and D 3665 or from a mini-stockpile. Regardless of the sampling method, the load number of the mixture to be sampled was checked to ensure that the HMA was not sampled from one of the first loads of the day. This process was adopted to reduce variability in the analysis, as an asphalt plant requires some initial time for the HMA production to stabilize to target values. Once it was determined that the truck was not one of the plant's first loads it was stopped at the sampling rack for collection. During the collection process the material was placed in metal five-gallon pails that were clearly marked with the collection date, truck information, and job name. The job mixture formula (JMF) was obtained from the plant along with a weigh ticket from the scale house. The JMF was collected in order to compare the laboratory results and to determine the mixture gradation, while the weigh ticket was kept for record only.

3.1.2 <u>Cored Specimens</u>

Once the loose HMA was collected from the plant, roadway cores were extracted from the job site. The coring followed ASTM standards D 5361 and D 979. Cores were extracted once the roadway was cooled. The coring plan was initiated to hasten the process of collecting cores. For instance, coring from where the sampled loose HMA was placed would require waiting for a number of rollers to compact the mat to density and the HMA to cool, which could take several hours before cores would be cool enough to extract. In most cases, all five cores were taken from the smallest possible area allowed by the Michigan Department of Transportation (MDOT) to minimize movement and accelerate the sampling process. In all possible cases the contractor's QC/QA person extracted the cores. Upon extraction from the roadway, the cores were properly marked with the date, roadway stationing, and the job name. The cores were carefully packaged for delivery back to the Michigan Technological University laboratories where testing occurred.

3.2 Sample Preparation

This section describes the procedures that were followed in order to prepare the samples for testing. The first two sections pertain to the loose mixture samples since roadway cores were already compacted and the last section is only applicable to the cored specimens.

3.2.1 Splitting

The five gallon buckets of loose mixture were heated to 135 ºC for about two hours to allow the samples to be split into smaller fractions. Splitting was in accordance with ASTM C 702. The samples were split to achieve two G_{mm} specimens and fifteen 4500 gram specimens for SGC compaction. The mass of the G_{mm} specimens was based on their NMAS as stated in ASTM D 2041 and AASHTO T 209. The SGC samples were placed back in the oven for one hour in individual containers at a predetermined compaction temperature based on the temperature-viscosity relationship of the asphalt binder. The G_{mm} samples were spread out on large sheet pans and allowed to cool to room temperature prior to testing.

3.2.2 Compaction

The compaction of the loose HMA specimens was completed with the SGC in accordance with AASHTO TP4. The gyratory compactor was calibrated and set to apply a vertical load of 600 kPa at an angle of gyration of 1.25º. The number of gyrations was based on the trafficking levels of the in-place HMA and the desired air void content. The specimen height was determined by the equation 3.1 below.

$$h = \frac{W}{G_{mb_{estimated}} \cdot \pi \cdot r^2} \qquad \textbf{3.1}$$

where:

$h = compaction\ height\ to\ produce\ the\ desired\ level\ of\ air\ voids\ (mm),$
$W = weight\ of\ the\ sample\ prior\ to\ compaction\ (g),$
$G_{mb_{estimated}} = estimated\ specimen\ bulk\ specific\ gravity\ as\ a\ function\ of\ the\ desired\ air\ void\ content\ and\ G_{mm},\ and$
$r = radius\ (75mm)\ of\ the\ final\ compacted\ specimen\ (mm).$

Once the specimens were compacted to the target air void level, the specimens were removed from the SGC, compaction papers removed, labeled, and allowed to cool to room temperature before being subjected to the three bulk specific gravity testing procedures.

3.2.3 <u>Sawing</u>

In order to test the roadway cores in the VSM device, specimens must have relatively smooth surfaces to prevent puncturing the bag that encases them. This required that all roadway cores be cut to remove the jagged surface caused by the aggregate base – HMA layer interface. Sawing was achieved with a water-cooled diamond bladed saw, which minimized damage to the specimen from the heat generated by friction. The saw was set to automatically feed the specimen through the blade at a constant speed. The specimens were dried using an electric fan before further testing was permitted after sawing was complete.

3.3 Sample Testing

Testing of the samples was crucial for data collection and further data analysis relevant to the project. Brief outlines of the standards and procedures for the testing will be presented in the following sections.

3.3.1 Maximum Theoretical Specific Gravity

G_{mm} specimens were produced, and tested in accordance with ASTM D 2041 and AASTHO T 209. As mentioned previously, two G_{mm} samples were prepared and tested for each job. The values obtained from G_{mm} testing made it possible to determine the air void content of the specimens once the bulk specific gravity testing was completed.

3.3.2 Dimensional Analysis Method

The simplistic approach to measuring density was completed first. This approach calculates density through the ratio of a specimens' mass to its respective volume defined in AASHTO T269. A calibrated standard laboratory scale capable of measuring to the nearest tenth of a gram was used to obtain the mass of the specimens. The height and diameter measurements were recorded using a digital caliper capable of recording to the nearest one-thousandth of a millimeter. In order to obtain an average height, the specimen was measured in four places approximately 90º apart. In addition, the diameter was measured in two places approximately 90º apart to be used as the average diameter measurement. The measurements were then used to calculate the density.

3.3.3 Vacuum Sealing Method

Next, the VSM was employed to obtain another measurement of bulk specific gravity. During this process, the specimen was subjected to items outlined in section 2.2.6.

All of the appropriate bags and procedures were used and followed as set forth by the manufacturer. Testing was completed by a trained, qualified operator following the standard implemented in ASTM D 6752. The computer software provided by the vendor, was implemented to calculate the bulk specific gravity from the given raw data upon completion of the testing. This value was recorded as the VSM measurement for the i^{th} job, j^{th} sample, where j goes from 1 to 20.

3.3.4 Saturated Surface Dry

Finally, the most common method, the SSD, was used to obtain yet another measurement of bulk specific gravity. The SSD is the last bulk specific gravity test because it is the only method that requires the specimen to be submerged in water allowing water to potentially be absorbed into a specimen. This saved time, as there was no need to wait for the specimens to dry back to a constant weight before further testing can be completed. Again, a calibrated scale capable of recording to the nearest tenth of a gram was used to obtain the three weights required to calculate the bulk specific gravity of the specimen. The test was completed in accordance with ASTM D 2726 and AASHTO T 166. Once the weights are recorded, the bulk specific gravity of the specimen is calculated. This value was recorded as the water displacement measurement for the i^{th} job, j^{th} sample, where j goes from 1 to 20.

3.3.5 Falling Head Permeability

After the bulk specific gravity testing was completed, the permeability testing was completed on the same specimens. Two separate flexible wall permeameter apparatuses were used. One apparatus was for the 100 mm diameter cores and the other apparatus was for the 150 mm diameter cores. Both apparatuses were Karol-Warner permeameters. This test was completed in accordance with ASTM PS129. After the measurements were recorded, equation 2.1 was used to calculate the coefficient of permeability of the specimens.

3.4 Sampling

Jobs that met the criteria set forth in the experimental plan were sampled when they became available. In all, the sample matrix called for thirty jobs to be sampled; a total of 33 jobs were sampled at the completion of the project.

The type of gradation was determined by plotting the combined gradation percentages of each respective JMF on a 0.45 power curve. Gradation lines that crossed over the maximum density line from left to right, after the restricted zone were considered coarse gradations. Lines that crossed the maximum density line before the restricted zone when going from left to right, were considered fine gradations. Figure 3.1 and Figure 3.2, illustrate the two examples for a coarse and fine gradation.

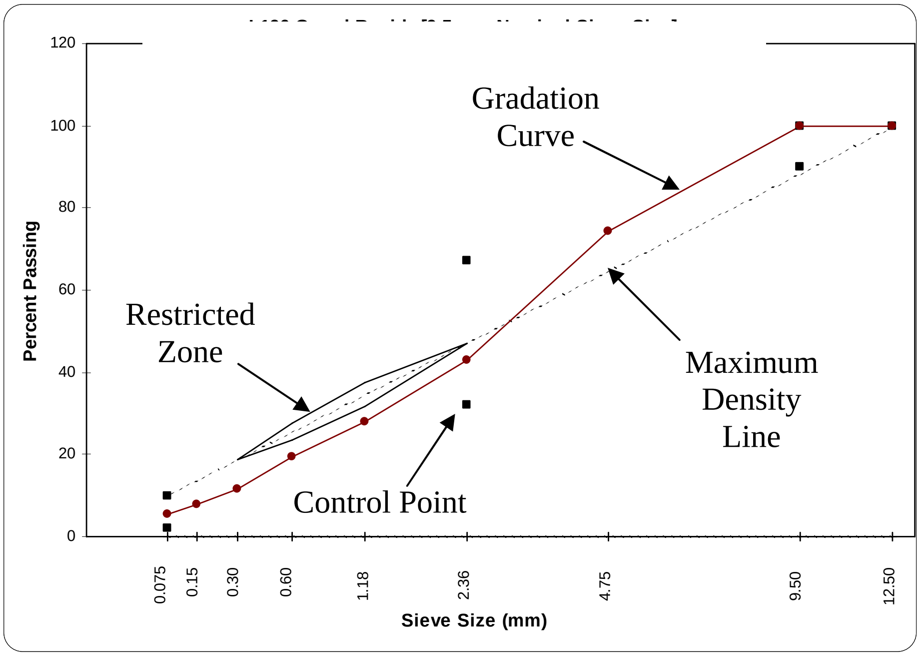

Figure 3.1 Coarse Gradation Example (Stanton, 2004)

As shown in Figure 3.1, the gradation curve below the restricted zone, signifying a coarse gradation. In Figure 3.2, however, the gradation curve passes above the restricted zone indicating a fine gradation.

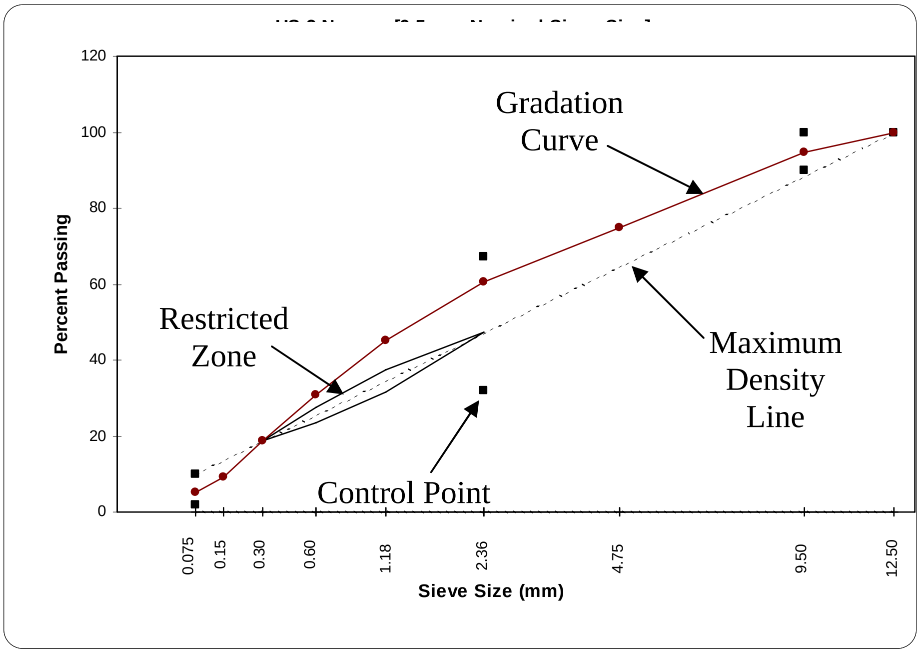

Figure 3.2 Fine Gradation Example (Stanton, 2004)

4 Statistical Analysis

4.1 <u>Analysis Introduction</u>

This chapter presents the results of the jobs tested and describes the test method analysis. The first analysis that was conducted was to create preliminary plots of the data to check for outliers and to note any possible relationships between the data. After the preliminary plots were completed and the entire data set had been collected statistical analysis was conducted on the data set collected. For this analysis the SAS statistical software was utilized to complete the computations required. The statistical analysis utilized was mean groupings, used to analyze whether or not the test methods were significantly different using a 95% level of confidence.

4.2 <u>Preliminary Plots</u>

The preliminary plots for individual jobs are included in Appendix B and serve as an initial inspection for the raw data. Graphs included in Appendix B represent the data from various perspectives. The plots help identify if an outlier was present in the collected data. These preliminary plots also served as a visual verification of tendencies occurring with data collected from the three bulk specific gravity test methods (VSM, SSD, and DAM Tests) that were used in this study. The plots discussed in the remaining part of this section represent all of the HMA mixtures collected instead of by individual mixture.

One of the plots evaluated was a comparison between the three bulk specific gravity measuring methods by percent absorption, as seen in Figure 4.1. It can be seen that the SSD and VSM have significant overlap between about 0% absorption and 1% absorption. As the percent of absorption increases the two methods tend to overlap one another less frequently. DAM is also overlapped by both methods throughout the span of percent absorption range, but there is a significant shift to the left, lower bulk specific gravity values, also apparent. From the graph it is apparent that the minimum bulk specific gravity value is continuously obtained by the DAM, while the SSD method yields the maximum value frequently.

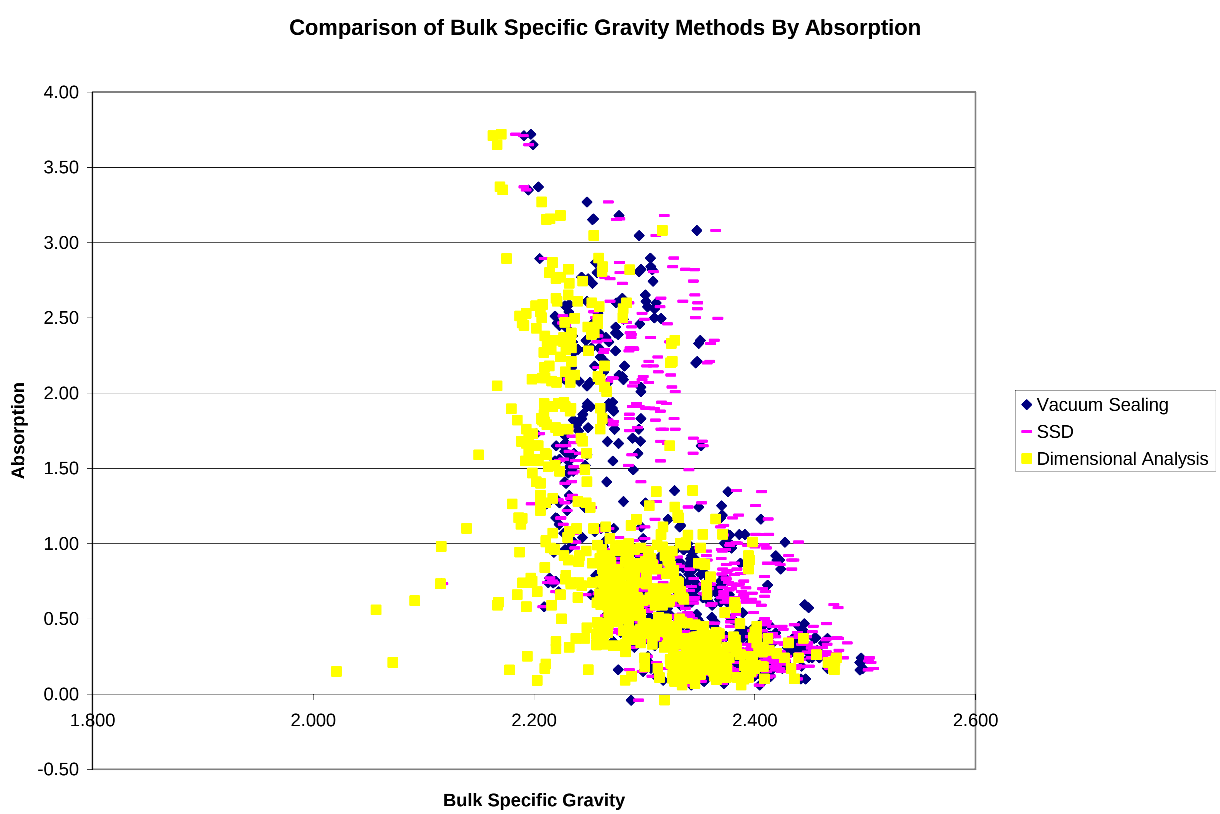

Figure 4.1 Comparison of bulk Specific Gravity Measuring methods By Percent Absoprtion

A graphical tool that is commonly used to examine distributions is a box plot. Box plots are graphs based on a datasets statistical moments. The box part of a box plot represents the data range between the 25th and 75th percentile. A long rectangular box indicates a dataset with a lot of variability. The mean of the dataset is represented by the grey colored cross within the boxes.

Medians of the datasets are marked by a horizontal line within the box. The range of data from the minimum value to the maximum is illustrated by the long vertical line.

The two box plots displayed in this section also list statistical data associated with the datasets. Several terms used within Figure 4.2 and Figure 4.3 are common to both. The term Nobs is an abbreviation for number of observations. Min and Max are indicating the minimum and maximum value, respectively, for the data sets. The columns of data displayed are in order of the values listed along the x-axis from left to right.

The first box plot analyzed consisted of all of the data collected categorized by bulk specific measuring method. Figure 4.2 displays the box plot, generated by SAS, that was analyzed. DAM was represented by type 1, VSM by type 2, and SSD by type 3 in the box plot (labeled along the x-axis). The bulk specific gravity range is displayed along the y-axis. It can be seen that the spread of bulk specific values for the DAM is greater than either the VSM or SSD range, indicating that DAM is less precise. VSM and SSD methods appear to have about the same level of precision. All three boxes are about the same length indicating DAM has several outliers since the range of values is quite large outside below the 25^{th} percentile and above the 75^{th} percentile. Both VSM and SSD also appear to have some outliers, but not as severe as the DAM.

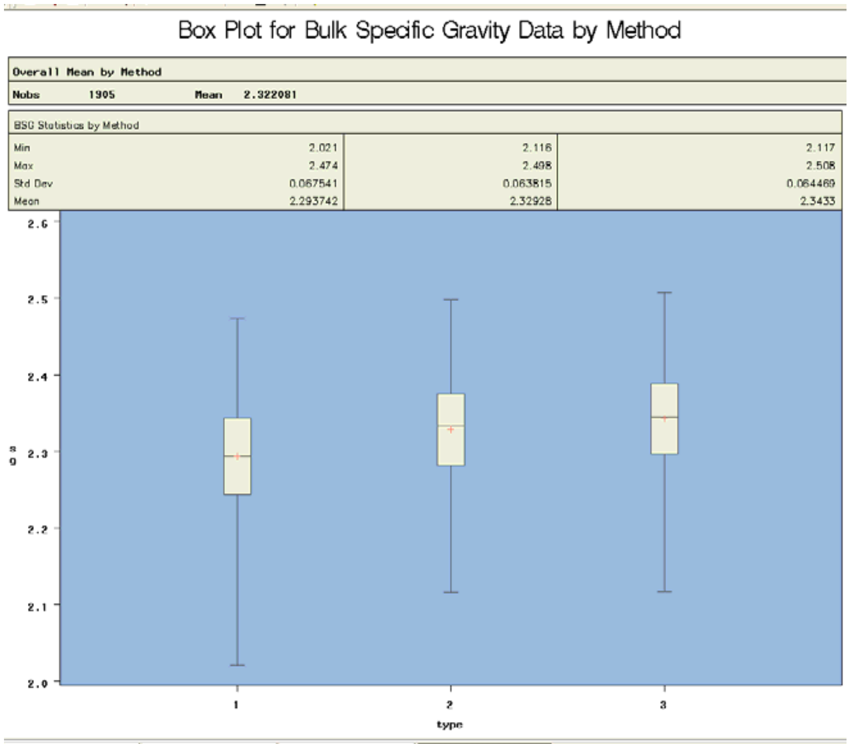

Figure 4.2 Box Plot of the Bulk Specific Gravity Data by Measuring Method

The second box plot considered all bulk specific gravity values by target air voids level and is displayed in Figure 4.3. Along the y-axis is the bulk specific gravity range. The target air void levels and cores are represented along the x-axis; 1 indicates cores, 4 symbolizes 4% target air void level, and 7% and 10% target air voids is represented in a similar fashion as the 4% level. Cores appear to be the most variable compared to the laboratory prepared specimens. Out of the laboratory prepared specimens, the 4% target air voids is the most dispersed followed by the 10% target air void level. The length of the box for the cores is significantly smaller than the combined lengths of the vertical lines sprouting from the box, indicating that there is an outlier issue. Out of the 4 categories examined, the 4% and7% target air void levels appear to be the most precise, as implied by the box sizes.

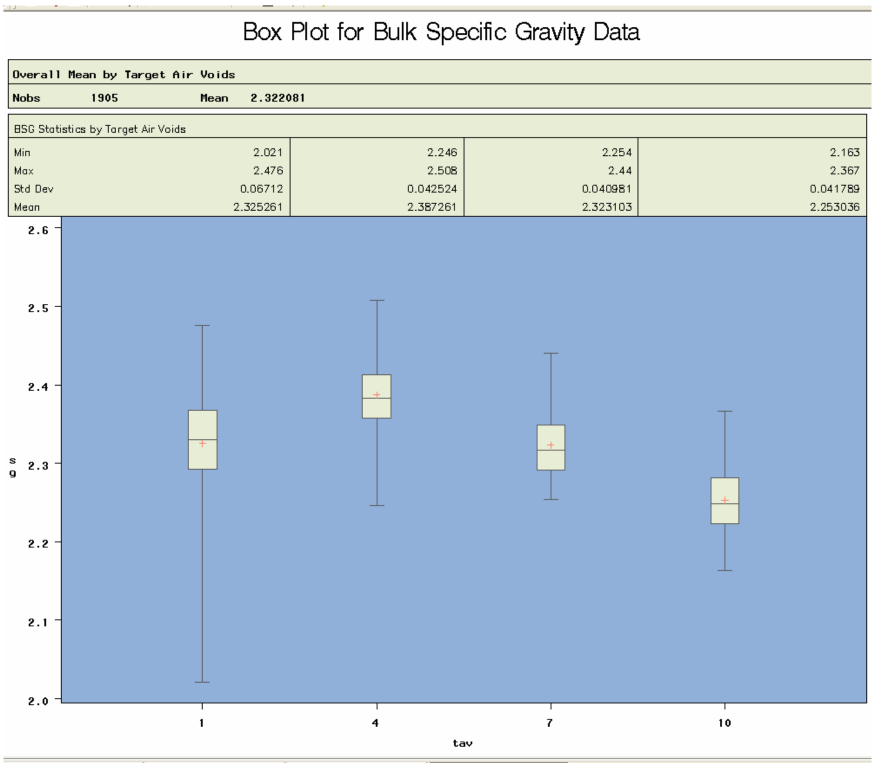

Figure 4.3 Box Plot of All Bulk Specific Gravity Values by Target Air Void Level

4.3 Mean Grouping Analysis

One of the goals of the project was to determine if the bulk specific gravity measurements obtained from the three different measuring methods differed from one another. One way to determine if the measurements differ is to compare the mean bulk specific gravities attained from the three methods employed. A common statistical test used to compare means is t-test. This test tends to be conservative. For this project, all of the t-tests assumed a confidence of 95%.

Table 4.1 summarizes the results of the t-tests calculated to determine if any of the bulk specific gravity measuring methods yielded the same results at a certain air voids level. The analysis indicated that for all levels of air voids, each method results in a different bulk specific gravity values with the exception of the VSM and SSD methods at the 10% air void level.

Table 4.1 Comparison of Bulk Specific Gravity Values By Air Void Level

Air Void Level	Methods Compared	Means Equal	Means Unequal
Core	DAM to VSM		♦
	DAM to SSD		♦
	VSM to SSD		♦
4%	DAM to VSM		♦
	DAM to SSD		♦
	VSM to SSD		♦
7%	DAM to VSM		♦
	DAM to SSD		♦
	VSM to SSD		♦
10%	DAM to VSM		♦
	DAM to SSD		♦
	VSM to SSD	♦	

As mentioned earlier in the report, it was hypothesized that gradation level could affect the bulk specific gravity values. Several t-tests were employed to determine if the methods would yield similar bulk specific gravity values for fine mixtures and significantly different values for coarse mixtures. Table 4.2 outlines the results of t-tests examined to reveal any influence of NMAS on the results of bulk specific gravity measuring methods. As suspected, the fine-graded HMA mixtures exhibit statistically similar results for the VSM and SSD methods. Interestingly, the coarse-graded HMA mixtures with an NMAS of 2 or 5 also demonstrated like values for the VSM and SSD methods. The DAM results continued to differ from the two other bulk specific gravity measuring methods.

Table 4.2 Bulk Specific Values Compared By Gradation and NMAS

Gradation	NMAS	Methods Compared	Means Equal	Means Unequal
Coarse	2	DAM Versus SSD		♦
		DAM Versus VSM		♦
		SSD Versus VSM	♦	
	3	DAM Versus SSD		♦
		DAM Versus VSM		♦
		SSD Versus VSM		♦
	4	DAM Versus SSD		♦
		DAM Versus VSM		♦
		SSD Versus VSM		♦
	5	DAM Versus SSD		♦
		DAM Versus VSM		♦
		SSD Versus VSM	♦	
Fine	3	DAM Versus SSD		♦
		DAM Versus VSM		♦
		SSD Versus VSM	♦	
	4	DAM Versus SSD		♦
		DAM Versus VSM		♦
		SSD Versus VSM	♦	
	5	DAM Versus SSD		♦
		DAM Versus VSM		♦
		SSD Versus VSM	♦	

After examining the results of the t-tests which analyzed the data categorized by target air voids and NMAS separately, tests were conducted to inspect the data grouped by target air voids within NMAS level. Since earlier studies indicated that fine-graded HMA mixtures displayed similar results for the SSD and VSM, only the coarse-graded mixtures were analyzed. Table 4.3 encapsulates the outcome of the t-tests performed. All of the core sample bulk specific gravity values calculated by the SSD and VSM are statistically equivalent with the exception of the mixtures with an NMAS of 3. All of the target air void levels for the mixtures with an NMAS of 2, 3, and 4 have differing results for all three bulk specific gravity measuring methods. The mixtures with an NMAS of 5, however, exhibited similar values for all target air void levels except 10% for the SSD and VSM.

Table 4.3 Bulk Specific Gravity Values Compared By NMAS and Air Void Levels for Coarse-graded HMA Mixtures

Gradation	NMAS	Air Void Level	Methods Compared	Means Equal	Means Unequal
Coarse	2	Cores	DAM Versus SSD		♦
			DAM Versus VSM	♦	
			SSD Versus VSM	♦	
		4%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
		7%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
		10%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
	3	Cores	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
		4%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
		7%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
		10%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
	4	Cores	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM	♦	
		4%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
		7%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
		10%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦
	5	Cores	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM	♦	
		4%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM	♦	
		7%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM	♦	♦
		10%	DAM Versus SSD		♦
			DAM Versus VSM		♦
			SSD Versus VSM		♦

The previous analyses indicates that VSM or SSD method can be utilized to measure bulk specific gravity and attain statistically similar results. The question remains, when is the SSD method no longer appropriate for measuring the bulk specific gravity? To help answer this question, the relationship between the bulk specific gravity and percent absorption was examined. The initial analysis examined the bulk specific gravity and percent absorption relationship was conducted on data grouped by gradation, NMAS level, and target air void level. Figures 4.4, 4.5, 4.6, and 4.7 illustrate the relationship of the bulk specific gravity and percent absorption for coarse-graded mixtures by target air void and NMAS level. From the graphs, it can be seen that there is definite overlap in bulk specific gravity values within certain percent absorption ranges, indicating that in those ranges bulk specific gravity measuring methods will result in statistically similar results. To determine the range at which bulk specific gravity measuring methods will yield similar results, t-tests were employed.

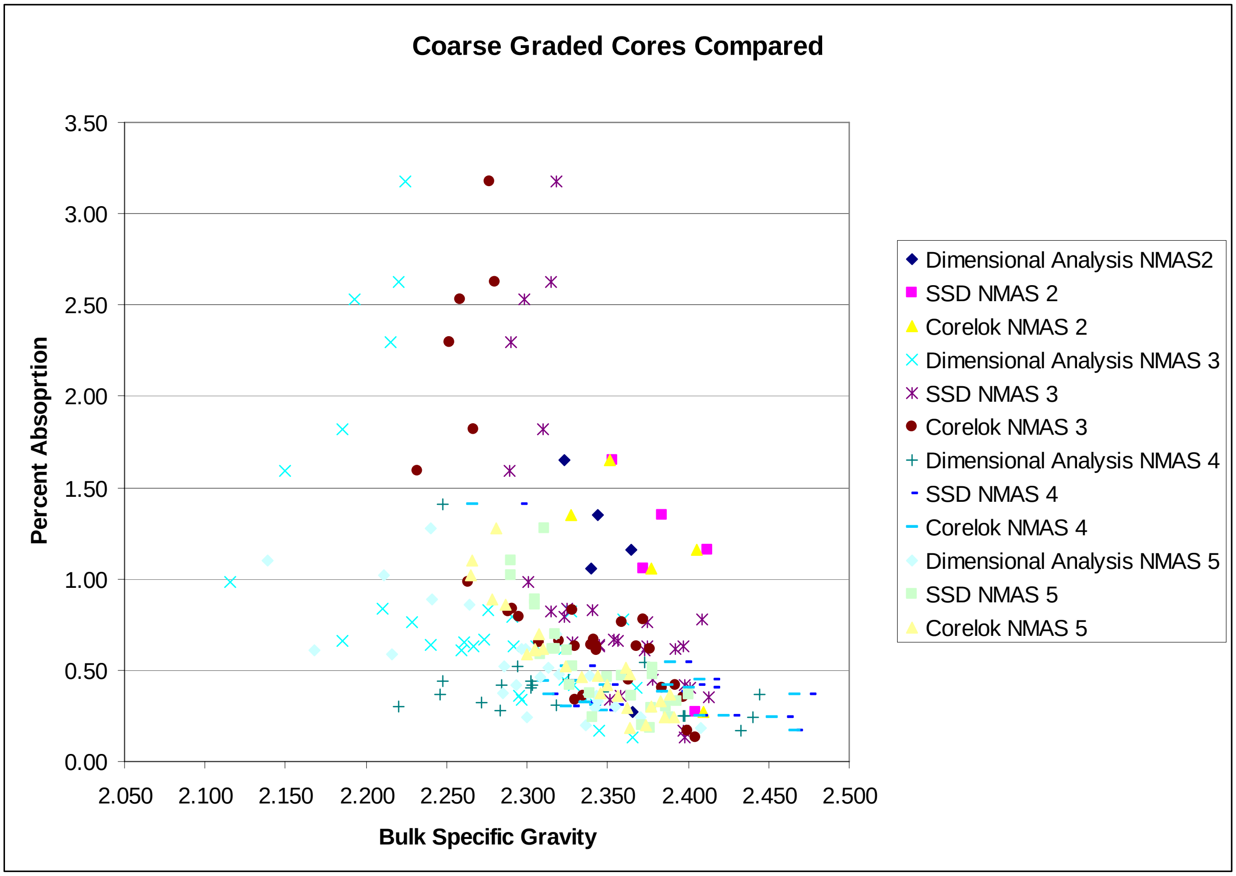

Figure 4.4 Comparison Between Bulk Specific Gravity and Percent Absorption for Coarse-graded Cores

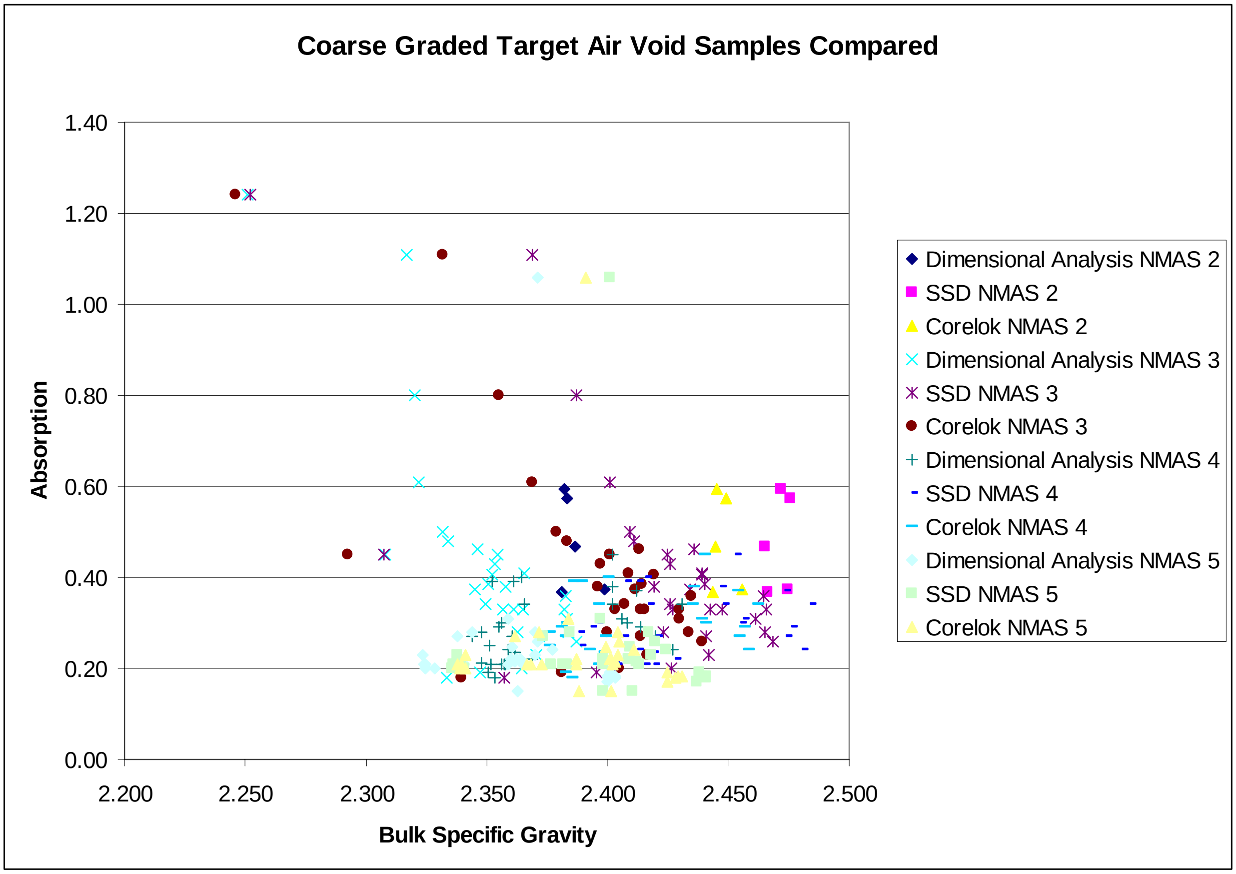

Figure 4.5 Comparison Between Bulk Specific Gravity and Percent Absorption for Coarse-graded 4% Target Air Void Level Specimens

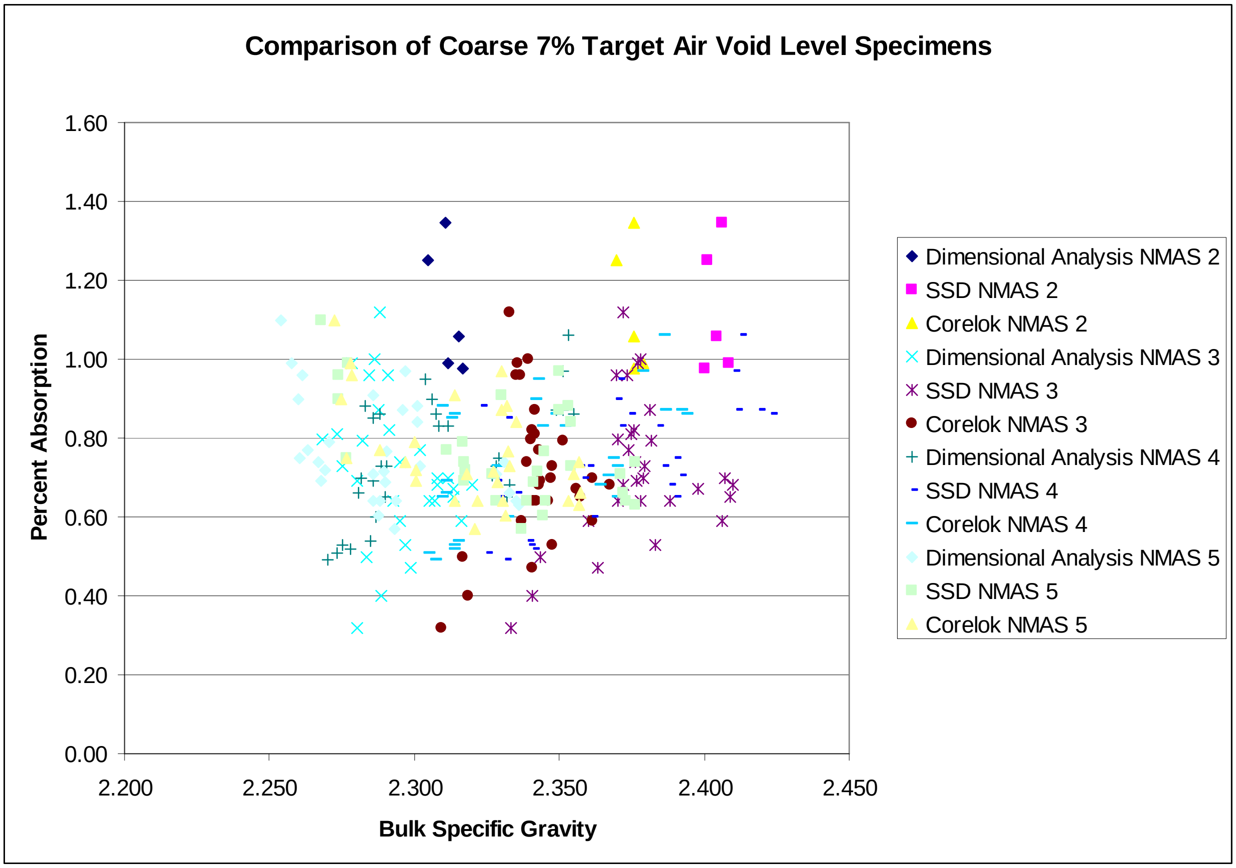

Figure 4.6 Comparison Between Bulk Specific Gravity and Percent Absorption for Coarse-graded 7% Target Air Void Level Specimens

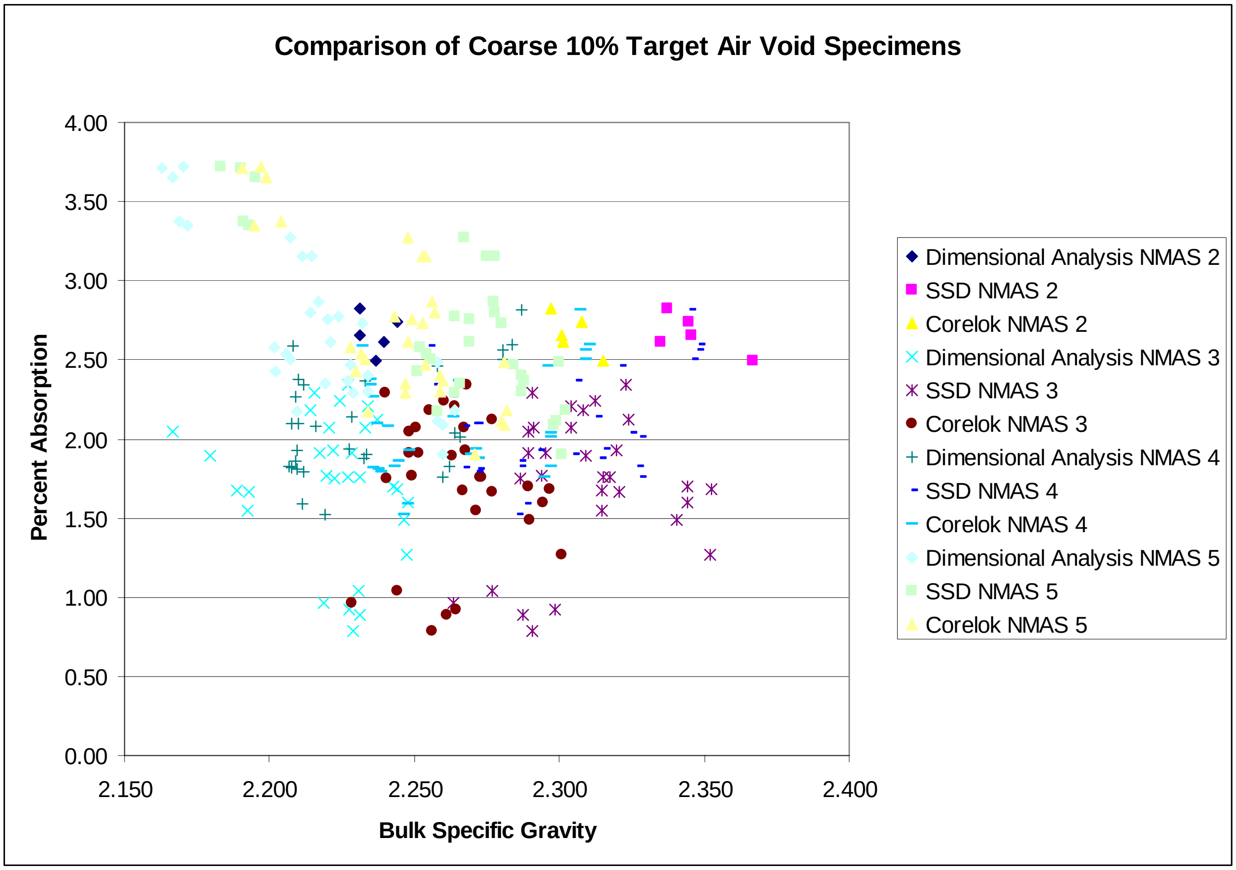

Figure 4.7 Comparison Between Bulk Specific Gravity and Percent Absorption for Coarse-graded 10% Target Air Void Level Specimens

The percent absorption was divided into 7 different levels to analyze the bulk specific gravity values. Table 4.4 displays the divisions used to create the 7 levels of percent absorption. Table 4.5 summarizes the results of the t-tests which compared the SSD to VSM for coarse-graded HMA mixtures. The table only lists the comparisons between SSD and VSM since any comparisons to DAM indicated data was statistically different. All percent absorption levels above 3 resulted in statistically different data. Cells without adequate data or any data were marked N/A. All of the percent absorption level 1 core comparisons yielded similar results for the SSD and VSM. The similarity implies that either SSD or VSM may be used to determine the bulk specific gravity value. Most of the laboratory compacted samples resulted in dissimilar values for the SSD and VSM. The statistical results indicate that an appropriate restriction for the SSD method is to only test coarse mixture specimens with a percent absorption of less than 0.50%. Coarse mixture specimens with a percent absorption greater than 0.50% should be subjected to the VSM to obtain the bulk specific gravity. However, no cores for coarse-graded mixtures with an NMAS of 2 and a percent absorption of level 1 were tested and low level percent absorptions data for NMAS of 4 or 5 was also limited. The majority of the data for the first two absorption levels were for material with an NMAS of 2 or 3, therefore a more complete analysis should be conducted when more data has been acquired.

The fine-graded HMA mixtures exhibited similar bulk specific gravity results between the SSD and VSM for all 7 levels of percent absorption. Results of the t-tests on the fine-graded HMA indicate that either the SSD or VSM is appropriate at all absorption levels.

Table 4.4 Percent Absorption Levels

Level	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Minimum	0	0.51	1.01	1.51	2.01	2.51	3.01
Maximum	0.50	1.00	1.50	2.00	2.50	3.00	3.50

Table 4.5 Bulk Specific Gravity Comparison By NMAS, Target Air Void Level, and Percent Absorption Level for Coarse Mixtures

Gradation	NMAS	Air Void Level	Percent Absorption Level	Methods Compared	Means Equal	Means Unequal
Coarse	2	Cores	1	SSD Versus VSM	N/A	N/A
			2	SSD Versus VSM	N/A	N/A
			3	SSD Versus VSM	♦	
		4%	1	SSD Versus VSM		♦
			2	SSD Versus VSM		♦
			3	SSD Versus VSM	N/A	N/A
		7%	1	SSD Versus VSM	N/A	N/A
			2	SSD Versus VSM		♦
			3	SSD Versus VSM		♦
		10%	1	SSD Versus VSM	N/A	N/A
			2	SSD Versus VSM	N/A	N/A
			3	SSD Versus VSM	N/A	N/A
	3	Cores	1	SSD Versus VSM	♦	
			2	SSD Versus VSM		♦
			3	SSD Versus VSM	N/A	N/A
		4%	1	SSD Versus VSM		♦
			2	SSD Versus VSM		♦
			3	SSD Versus VSM	♦	
		7%	1	SSD Versus VSM		♦
			2	SSD Versus VSM		♦
			3	SSD Versus VSM	N/A	N/A
		10%	1	SSD Versus VSM	N/A	N/A
			2	SSD Versus VSM		♦
			3	SSD Versus VSM	N/A	N/A
	4	Cores	1	SSD Versus VSM	♦	
			2	SSD Versus VSM	♦	
			3	SSD Versus VSM	N/A	N/A
		4%	1	SSD Versus VSM		♦
			2	SSD Versus VSM	N/A	N/A
			3	SSD Versus VSM	N/A	N/A
		7%	1	SSD Versus VSM	N/A	N/A
			2	SSD Versus VSM		♦
			3	SSD Versus VSM	N/A	N/A
		10%	1	SSD Versus VSM	N/A	N/A
			2	SSD Versus VSM	N/A	N/A
			3	SSD Versus VSM	N/A	N/A
	5	Cores	1	SSD Versus VSM	♦	
			2	SSD Versus VSM	♦	
			3	SSD Versus VSM		♦
		4%	1	SSD Versus VSM	♦	
			2	SSD Versus VSM	N/A	N/A
			3	SSD Versus VSM	N/A	N/A
		7%	1	SSD Versus VSM	N/A	N/A
			2	SSD Versus VSM	♦	
			3	SSD Versus VSM	N/A	N/A
		10%	1	SSD Versus VSM	N/A	N/A
			2	SSD Versus VSM	N/A	N/A
			3	SSD Versus VSM	N/A	N/A

4.4 Analysis of Core Testing

As mentioned, cores were extracted whenever possible. Along with determining the bulk specific gravity of the cores via the three methods, the permeability of each core was ascertained through testing with a flexible wall permeameter. This section discusses the conclusions gleaned from the analyses of the data collected through the various test methods.

4.4.1 Graphical Analysis of Core Data

Graphical analyses were performed to reveal important relationships within the data. Box plots were developed to determine the dispersion and extent of outliers. The first box plot considered the permeability of all coarse-graded cores categorized by NMAS. From Figure 4.8 it can be seen that NMAS 4 cores exhibit the least amount of dispersion while NMAS 3 cores appear to be the most varied for permeability values. NMAS 3 cores also have the most extreme outliers.

Interestingly, the NMAS 4 fine-graded cores display the largest spread between the 25^{th} and 75^{th} percentiles, while the NMAS 3 fine-graded exhibit the least amount of dispersion for permeability values. For the fine-graded cores, the NMAS 5 specimens seem to have the most extreme outliers.

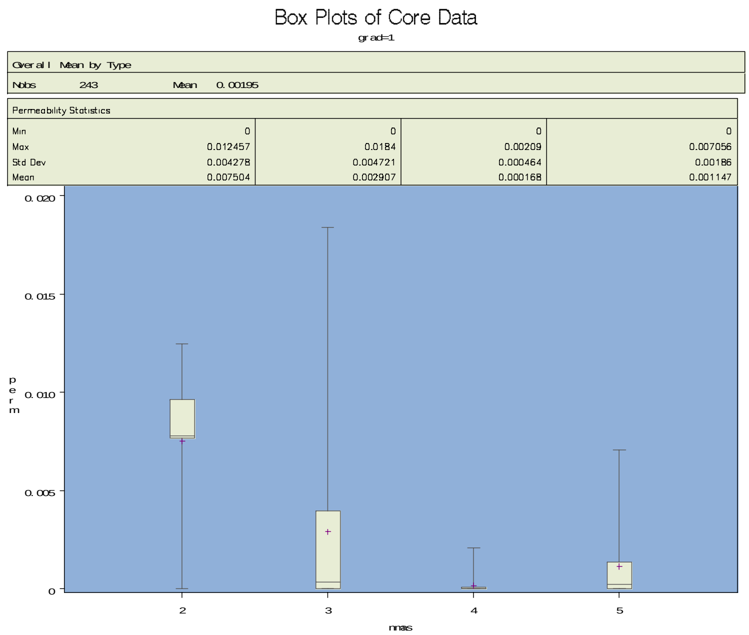

Figure 4.8 Permeability Data by NMAS for Coarse-Graded Cores

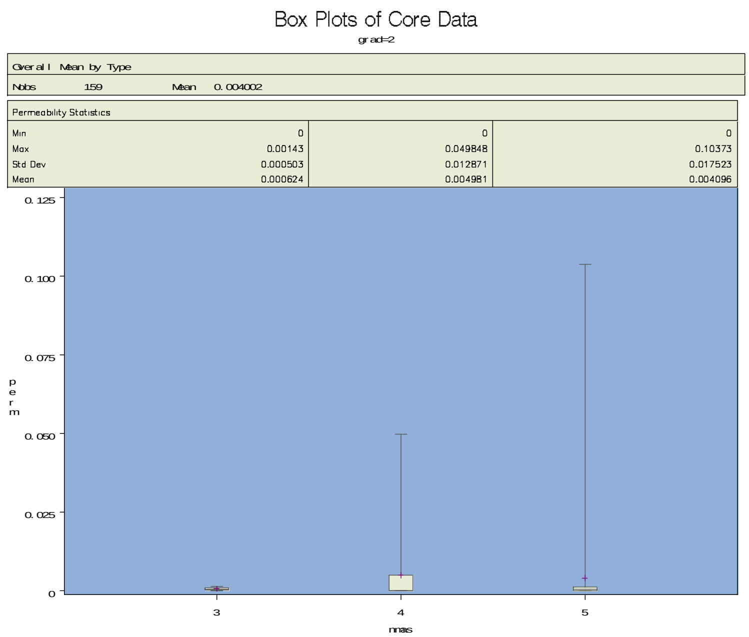

Figure 4.9 Permeability Data by NMAS for Fine-Graded Cores

The next set of box plots examined the percent absorption by gradation and NMAS. The fine-graded specimens appeared to have less extreme outliers than the coarse-graded percent absorption values. However, the percent absorption range of the 25th through 75th percentiles is much smaller for the coarse-graded cores than it is for the fine-graded cores.

Figure 4.10 Percent Absorption Data by NMAS for Coarse-Graded Cores

Figure 4.11 Percent Absorption Data by NMAS for Fine-Graded Cores

The final group of box plots considered examined the variability of bulk specific gravity values for each method categorized by gradation and NMAS type. In general, the fine-graded cores appeared to be the least disperse, as found when all the data was examined.

Figure 4.12 Bulk Specific Gravity Data by Method of Coarse-Graded-NMAS 2 Cores

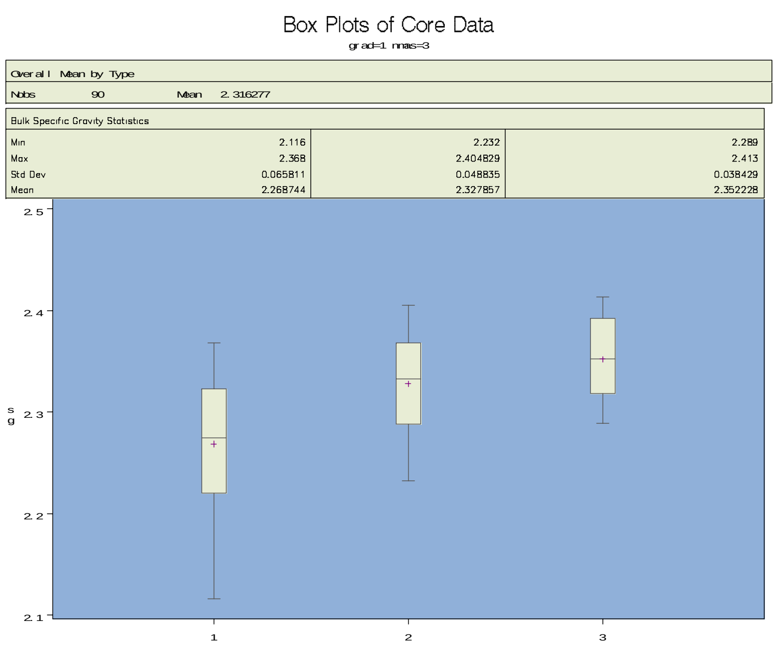

Figure 4.13 Bulk Specific Gravity Data by Method of Coarse Graded-NMAS 3 Cores

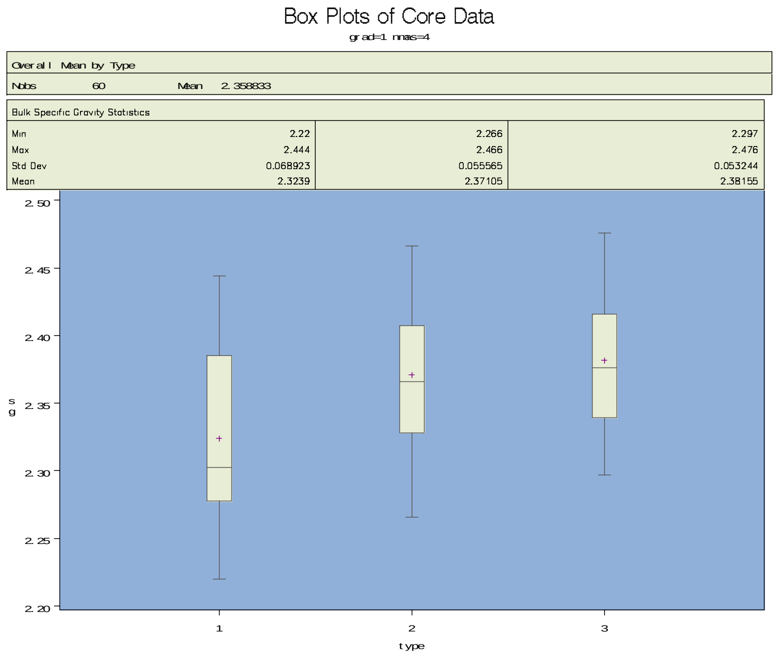

Figure 4.14 Bulk Specific Gravity Data by Method of Coarse-Graded NMAS 4 Cores

Figure 4.15 Bulk Specific Gravity Data by Method of Coarse-Graded NMAS 5 Cores

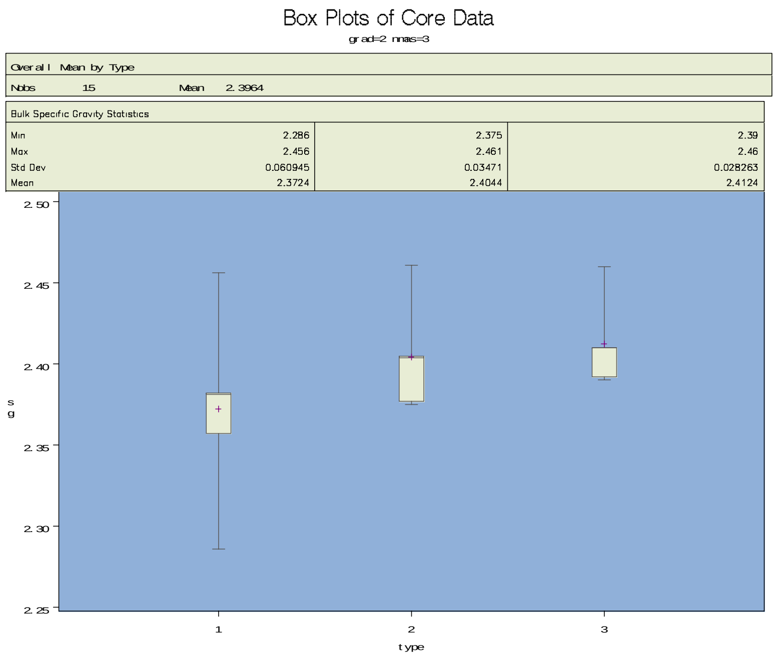

Figure 4.16 Bulk Specific Gravity Data by Method of Fine-Graded NMAS 3 Cores

Figure 4.17 Bulk Specific Gravity Data by Method of Fine-Graded NMAS 4 Cores

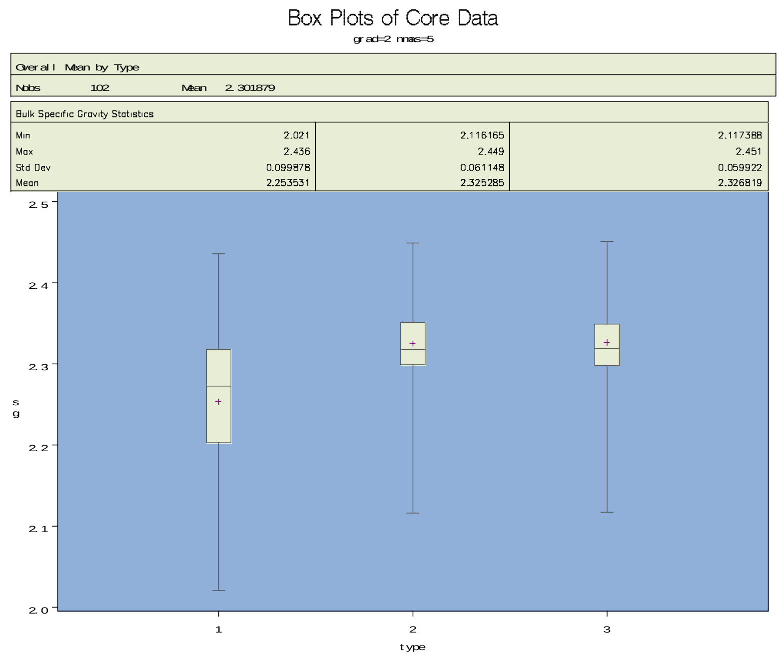

Figure 4.18 Bulk Specific Gravity Data by Method of Fine-Graded NMAS 5 Cores

4.4.2 <u>Density Analysis of Core Data</u>

Another visual inspection tool often used is a density plot. Density plots graph a 3-D interpretation of the data. The density plots examined the relationships between permeability, percent absorption, and bulk specific gravity. Figure 4.19 depicts the relationship between permeability and percent absorption. It can be seen that between about 0 and 0.15 permeability and -0.04 and 1.65 percent absorption the data bulk of the data occurs. The small bumps throughout the graph indicate pockets of concentrated data, much smaller than the previously mentioned peak. Figure 4.20 indicated that the majority of the data has a permeability value extremely close to zero, but a relatively high bulk specific gravity value. Figure 4.21 shows that in comparison to the permeability relationship, the majority of the bulk specific gravity values occur between -0.04 and 1.03 percent absorption.

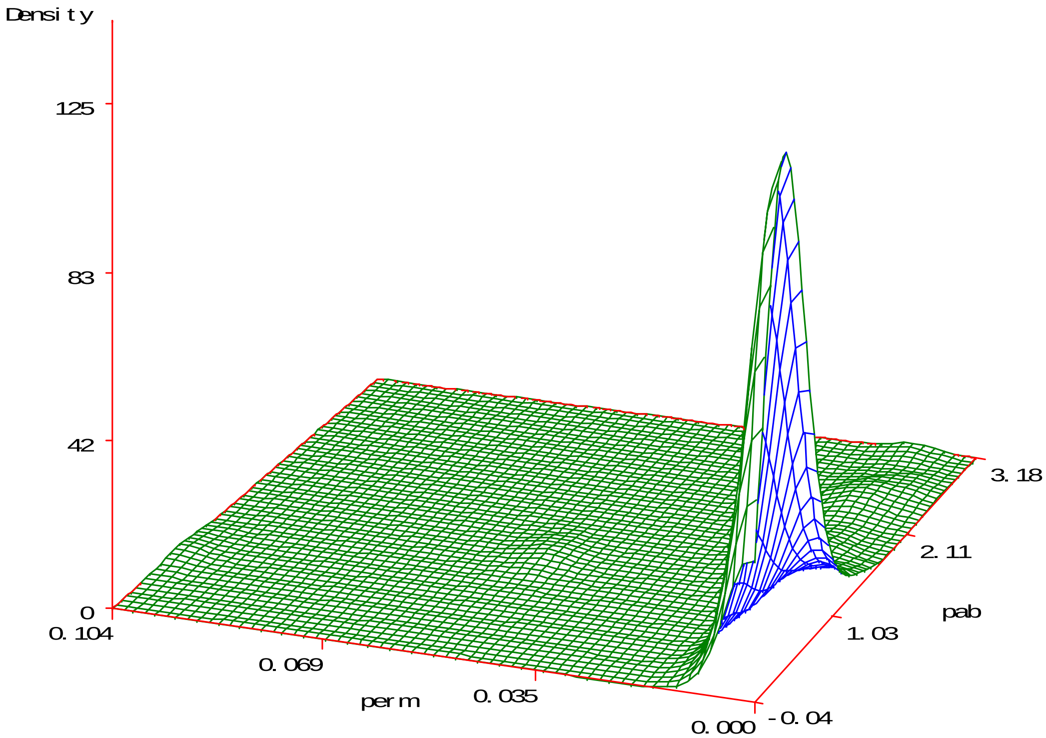

Figure 4.19 Density Plot Relating Permeability to Percent Absorption

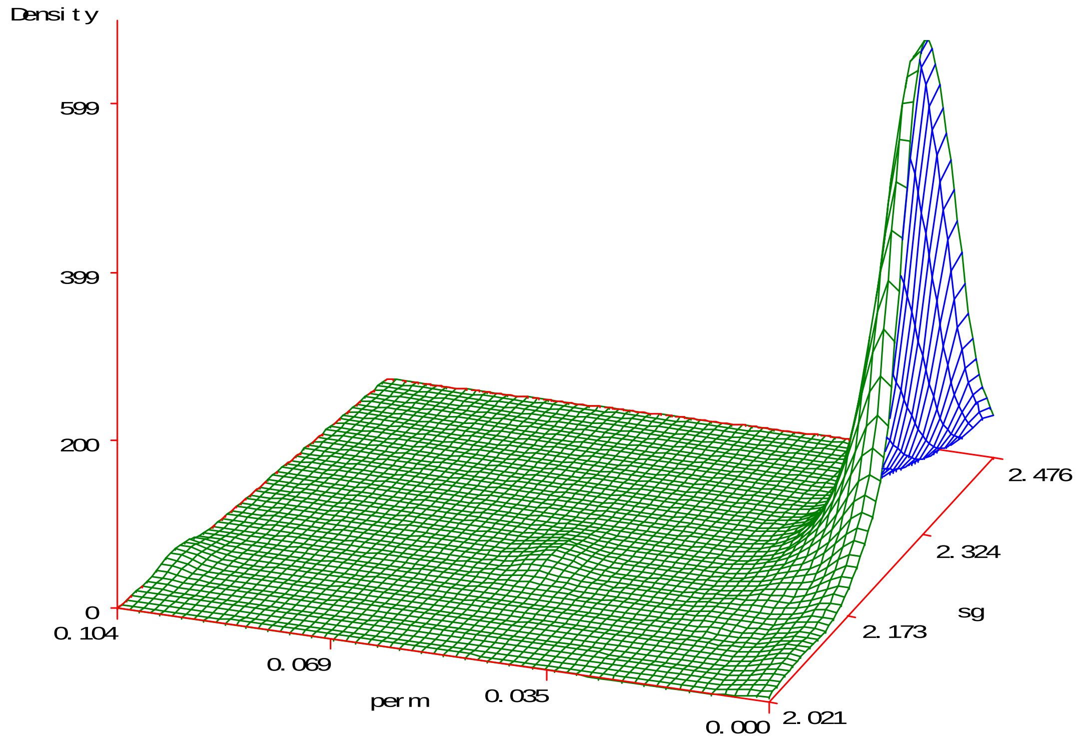

Figure 4.20 Density Plot Relating Permeability to Bulk Specific Gravity

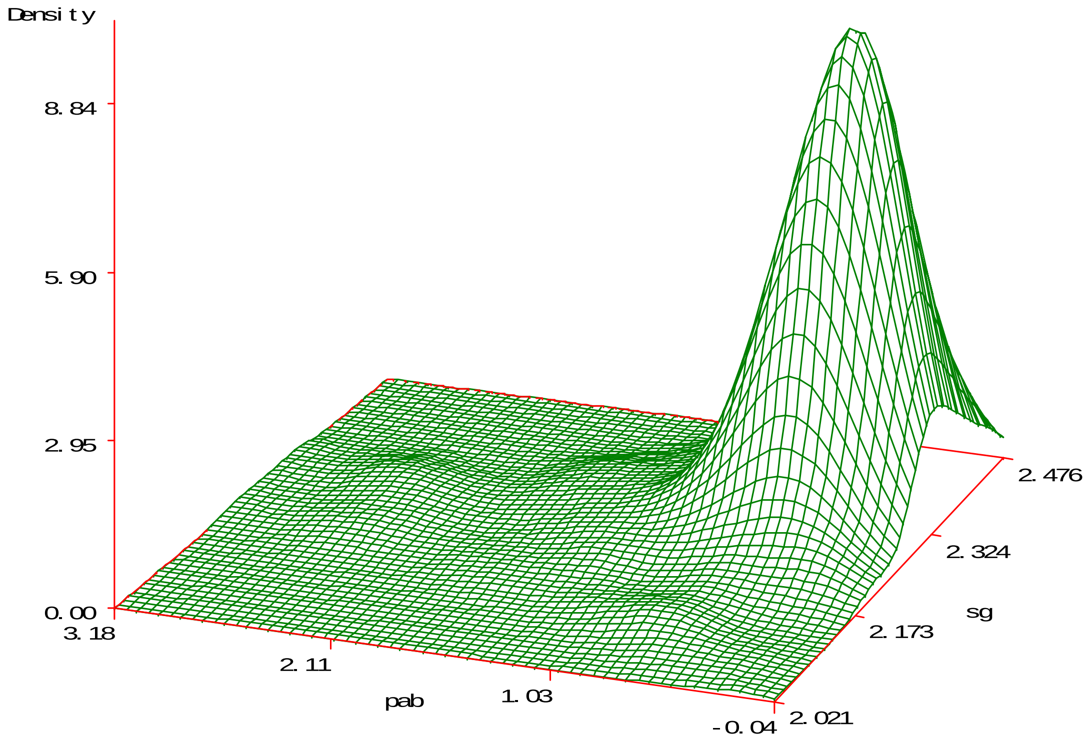

Figure 4.21 Density Plot Relating Percent Absorption to Bulk Specific Gravity

4.4.3 Correlation Analysis of Cores

Correlation is a statistical measure that indicates whether or not two variables are related. Pearson's Correlation Coefficient was examined to determine if any of the variables are strongly related. Pearson's Correlation Coefficient ranges between positive 1 and negative 1. If the coefficient is close to zero, two variables are said to be not strongly related. Any coefficients close to 1 or -1 implies there is a strong relationship between two variables. For this project, correlations were examined to reveal which variables are strongly related to bulk specific gravity measurements. The analysis investigated the correlations for each bulk specific gravity measuring method within the gradation type.

Strong relationships existed between fine-graded bulk specific gravity and percent absorption measurements for all bulk specific gravity methods. Fine-graded permeability measurements were not as strongly related to bulk specific gravity measurements as the percent absorption. The relationship would be considered moderate for both the DAM and VSM, but it was weak for the SSD method.

For the coarse-graded specimens, neither permeability nor percent absorption was strongly related to bulk specific gravity. However, permeability and bulk specific gravity did exhibit a relationship of moderate strength for the VSM and SSD methods. Percent absorption was also moderately related to bulk specific gravity for VSM and SSD, but not as strong as permeability.

The results of the correlation analysis suggests that percent absorption is an adequate measure for fine-graded mixtures since there is a strong relationship between percent absorption and bulk specific gravity. The strong relationship between percent absorption and bulk specific gravity did not exist for the coarse-graded mixtures and the permeability correlation with bulk specific gravity was only slightly better than the percent absorption correlation. Based on the very small difference in correlation coefficient improvement with permeability, using either permeability or percent absorption would be adequate. However, since the relationships for the coarser graded mixtures were not as strong as the fine relationships, another measurement method might be considered.

4.4.4 Hypothesis Testing of Core Data

Several hypothesis tests were performed to evaluate the data collected from the core specimens. As with the previous hypothesis tests for this study, Tukey's was used to test if the sample means differed. The hypothesis tests compared the permeability and percent absorption means grouped by NMAS and gradation level. The results of the t-tests are summarized in Figure 4.22 and Figure 4.23. Figure 4.22 presents the information related to the t-tests that compared the mean permeability values of different NMAS cores within either a coarse- or fine-graded mixture. In general the permeability values are not significantly different. However, NMAS 2 coarse-graded cores are significantly different than NMAS 4 and 5 coarse-graded cores. If the tests had been examined with lower confidence though, the permeability means would be statistically the same. Figure 4.23 displays the results of testing the mean permeability values for different gradations. For all tests examining if there is a difference between coarse- and fine-graded cores, the results indicated there was no significant statistical difference. Even though there are statistical differences between these groupings when comparing bulk specific gravity measurements, there is no or minimal difference between the permeability means, indicating that permeability is not the best measure for determining criterion for measuring bulk specific gravity.

Gradation	NMAS Compared	Permeability Means Equal	Permeability Means Unequal
Coarse	2 and 3	♦	
	2 and 4		♦
	2 and 5		♦
	3 and 4		♦
	3 and 5	♦	
	4 and 5	♦	
Fine	3 and 4	♦	
	3 and 5	♦	
	4 and 5	♦	

Figure 4.22 Comparison of NMAS Levels of Core Data

Gradations Compared	NMAS	Permeability Means Equal	Permeability Means Unequal
Fine and Coarse	3	♦	
Fine and Coarse	4	♦	
Fine and Coarse	5	♦	

Figure 4.23 Comparison of Gradations of Core Data

4.5 Statistical Summary

In short, bulk specific gravity of compacted HMA plays a significant role in the production and acceptance of quality HMA pavements. Although most states do not necessarily specify bulk specific gravity as a criterion, they do specify other properties that are derived from the bulk specific gravity measurement. In addition, as HMA pavements become coarser and more gap-graded it becomes more difficult to accurately determine the bulk specific gravity and thus the resulting calculated properties. With a number of different test methods available to determine bulk specific gravity it makes it difficult to choose an accurate, reliable method based on the mixture type and gradation. Based on the literature, the VSM may be a viable option for accurately determining the bulk specific gravity of mixtures that are fine-graded as well as those mixtures that have a coarser gradation. Reasonable judgment can be used to understand expectations. In total, thirty-three different mixtures were collected from around the state based on the nominal maximum aggregate size and trafficking level. These mixtures and roadway cores were tested using two of the more common test methods for comparison with the VSM. The final outcome of this research helped to determine if the VSM is a feasible alternative for determining bulk specific gravity of compacted HMA.

The results of the bulk specific gravity data indicate there is a significant difference between coarse and fine-graded mixtures. For all fine-graded HMA mixtures, the bulk specific gravity values for SSD and VSM were statistically similar. The DAM tended to differ statistically from both the SSD and VSM. Either SSD or VSM appear to be appropriate for fine grade mixtures based on the data acquired. For the coarse-graded HMA mixtures, either SSD or VSM may be used for level 1 percent absorption specimens, but the VSM seems to be the best method for coarse mixtures with a percent absorption level greater than 1. The VSM has demonstrated to be advantageous for coarse-graded mixtures.

5 Conclusion

This chapter provides a summary of the findings from the investigation of the VSM being implemented in Michigan for determining the bulk specific gravity of an HMA. The project provided many findings which will be discussed with recommendations for further research.

5.1 Findings

The VSM and SSD methods provide statistically similar values of bulk specific gravity for fine-graded mixtures. The DAM provides a significantly different measurement of bulk specific gravity as compared to the VSM and the SSD methods for fine-graded mixtures and coarse-graded mixtures. In general, the VSM and SSD method provide significantly different measurements of bulk specific gravity for coarse-graded mixtures. These findings were based on a 95% confidence level, using Tukey's Studentized Range Test to complete the mean comparison.

The statistical analyses and graphs indicate there is overlap in bulk specific gravity values when comparing the SSD and VSM. Percent absorption was used to determine when solely the VSM is the appropriate method to use in calculating the bulk specific gravity. Fine-graded HMA mixture bulk specific gravity values emerged as statistically similar for SSD and VSM measurements, thus implying that either method is appropriate for measuring bulk specific gravity values. The coarse-graded HMA bulk specific gravity values differed significantly for levels of percent absorption greater than 1 (0-0.50%). The results indicate that for specimens with a percent absorption greater than 0.50% the VSM should be used to determine the bulk specific gravity.

Examination of the cores indicated that using either permeability or percent absorption could be used for determining when to use certain bulk specific gravity measuring methods, but that percent absorption appeared to be sensitive to changes in bulk specific gravity readings.. The initial hope had been that permeability would yield more significant results in pinpointing restriction zones for SSD and DAM, but the data analysis shows that in general, permeability is no better of a measure than percent absorption.

5.2 <u>Recommendations for Further Research</u>

There are prospective research opportunities if the VSM is implemented into the MDOT specifications. The initial restrictions on when to use the VSM can be used until further data is collected. It is hypothesized that the percent absorption restriction could be broadened to a greater percent absorption if more data is collected.

To ensure that the VSM is providing a more accurate measurement of air void content when it diverges from the SSD method, an air void point count using a scanning electron microscope may provide further reassurance. The point count method has been used successfully in the determination of the air void content of portland cement concrete (ASTM C457-98).

If the VSM were implemented as the new method for measuring bulk specific gravity, further research would be required to access the risk, to establish new specification limits, and to provide a new pay factor system. This research would be necessary since it has been shown that the VSM does provide significantly different measurements of bulk specific gravity for coarse-graded mixtures as compared to the SSD method. It is the recommendation of the research team that the same method of determining the bulk specific gravity of compacted mixtures be used in mixture design as well as for payment (QC/QA).

Research on the VSM's ability to complete further testing such as theoretical maximum specific gravity of HMA, porosity of compacted HMA, percent asphalt content, apparent specific gravity of aggregates, absorption of aggregates, and bulk specific gravity of aggregates may be beneficial. This may further justify the initial cost of the VSM equipment by providing a higher return on investment through additional uses in laboratory testing

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Appendix A: Distribution Data

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	1894
Error Mean Square	0.001622
Critical Value of Studentized Range	2.77358
Minimum Significant Difference	0.0037
Harmonic Mean of Cell Sizes	930.274

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	grad
A	2.329071	1098	1
B	2.312571	807	2

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	1894
Error Mean Square	0.001622
Critical Value of Studentized Range	3.63639

Comparisons significant at the 0.05 level are indicated by ***.

nmas Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
2 - 3	0.024856	0.010681	0.039030	***
2 - 4	0.045144	0.031068	0.059220	***
2 - 5	0.057194	0.043340	0.071049	***
3 - 2	-0.024856	-0.039030	-0.010681	***
3 - 4	0.020288	0.013836	0.026740	***
3 - 5	0.032339	0.026386	0.038292	***
4 - 2	-0.045144	-0.059220	-0.031068	***
4 - 3	-0.020288	-0.026740	-0.013836	***
4 - 5	0.012051	0.006335	0.017766	***
5 - 2	-0.057194	-0.071049	-0.043340	***
5 - 3	-0.032339	-0.038292	-0.026386	***
5 - 4	-0.012051	-0.017766	-0.006335	***

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	1894
Error Mean Square	0.001622
Critical Value of Studentized Range	2.77358
Minimum Significant Difference	0.0037
Harmonic Mean of Cell Sizes	934.6205

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	traff
A	2.325167	822	2
B	2.319740	1083	1

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	1894
Error Mean Square	0.001622
Critical Value of Studentized Range	3.63639

Comparisons significant at the 0.05 level are indicated by ***.

tav Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
4 - 1	0.061999	0.055134	0.068865	***
4 - 7	0.064158	0.057575	0.070740	***
4 - 10	0.134224	0.127639	0.140810	***
1 - 4	-0.061999	-0.068865	-0.055134	***
1 - 7	0.002158	-0.004707	0.009024	
1 - 10	0.072225	0.065356	0.079093	***
7 - 4	-0.064158	-0.070740	-0.057575	***
7 - 1	-0.002158	-0.009024	0.004707	
7 - 10	0.070067	0.063481	0.076652	***
10 - 4	-0.134224	-0.140810	-0.127639	***
10 - 1	-0.072225	-0.079093	-0.065356	***
10 - 7	-0.070067	-0.076652	-0.063481	***

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	1894
Error Mean Square	0.001622
Critical Value of Studentized Range	3.31711

Comparisons significant at the 0.05 level are indicated by ***.

type Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
3 - 2	0.014019	0.008716	0.019323	***
3 - 1	0.049558	0.044256	0.054859	***
2 - 3	-0.014019	-0.019323	-0.008716	***
2 - 1	0.035538	0.030239	0.040837	***
1 - 3	-0.049558	-0.054859	-0.044256	***
1 - 2	-0.035538	-0.040837	-0.030239	***

type=1 grad=1

The CAPABILITY Procedure
Variable: sg

Moments

N	367	Sum Weights	367
Mean	2.29547139	Sum Observations	842.438
Std Deviation	0.06329248	Variance	0.00400594
Skewness	-0.0914582	Kurtosis	-0.6502513
Uncorrected SS	1935.2585	Corrected SS	1.46617345
Coeff Variation	2.75727605	Std Error Mean	0.00330384

Basic Statistical Measures

Location		Variability	
Mean	2.295471	Std Deviation	0.06329
Median	2.295000	Variance	0.00401
Mode	2.286000	Range	0.32800
		Interquartile Range	0.10700

NOTE: The mode displayed is the smallest of 2 modes with a count of 7.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	694.7888	Pr > |t|	<.0001
Sign	M	183.5	Pr >= |M|	<.0001
Signed Rank	S	33764	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.444
99%	2.431
95%	2.400
90%	2.370
75% Q3	2.348
50% Median	2.295
25% Q1	2.241
10%	2.211
5%	2.202
1%	2.163
0% Min	2.116

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.116	138	2.427	212
2.139	285	2.431	215
2.150	262	2.433	228
2.163	172	2.440	231
2.167	319	2.444	96

The CAPABILITY Procedure
Fitted Lognormal Distribution for sg

Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	0.830558
Shape	Sigma	0.027627
Mean		2.295475
Std Dev		0.06343

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0680021		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.3042725		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	1.9561777		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	54.7349806	8	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Lognormal Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.13	0.545	0.575
2.16	2.180	1.900
2.19	2.452	4.835
2.22	18.256	9.571
2.25	9.264	14.879
2.28	17.166	18.333
2.31	14.169	18.059
2.34	15.259	14.340
2.37	14.169	9.253
2.40	4.905	4.888
2.43	1.635	2.130

Quantiles for Lognormal Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.16300	2.15176
5.0	2.20200	2.19266
10.0	2.21100	2.21478
25.0	2.24100	2.25224
50.0	2.29500	2.29460
75.0	2.34800	2.33776
90.0	2.37000	2.37730
95.0	2.40000	2.40128
99.0	2.43100	2.44692

-- **type=1 grad=2** ---------------------------------

The CAPABILITY Procedure

Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.2913829	Sum Observations	616.382
Std Deviation	0.07299467	Variance	0.00532822
Skewness	-0.2347243	Kurtosis	0.6177456
Uncorrected SS	1413.79514	Corrected SS	1.42796356
Coeff Variation	3.18561654	Std Error Mean	0.00445056

Basic Statistical Measures

Location		Variability	
Mean	2.291383	Std Deviation	0.07299
Median	2.289000	Variance	0.00533
Mode	2.328000	Range	0.45300
		Interquartile Range	0.08900

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	514.8523	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.474
99%	2.472
95%	2.398
90%	2.388
75% Q3	2.338
50% Median	2.289
25% Q1	2.249
10%	2.198
5%	2.189
1%	2.072
0% Min	2.021

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.021	467	2.466	491
2.057	524	2.471	487
2.072	447	2.472	488
2.092	522	2.473	489
2.115	612	2.474	490

The CAPABILITY Procedure
Fitted Lognormal Distribution for sg

Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	0.828647
Shape	Sigma	0.032025
Mean		2.291392
Std Dev		0.0734

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0705516		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.2090457		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	1.3751373		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	32.4587369	7	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Lognormal Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.025	0.372	0.026
2.075	1.115	0.312
2.125	0.372	2.087
2.175	8.922	8.049
2.225	14.870	18.531
2.275	27.138	26.288
2.325	28.996	23.655
2.375	13.383	13.865
2.425	2.602	5.426
2.475	2.230	1.450

Quantiles for Lognormal Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.07200	2.12580
5.0	2.18900	2.17270
10.0	2.19800	2.19813
25.0	2.24900	2.24128
50.0	2.28900	2.29022
75.0	2.33800	2.34022
90.0	2.38800	2.38617
95.0	2.39800	2.41409
99.0	2.47200	2.46736

-------------------------------------- type=2 grad=1 --------------------------------

The CAPABILITY Procedure

Variable: sg

Moments

N	366	Sum Weights	366
Mean	2.33451639	Sum Observations	854.433
Std Deviation	0.06179279	Variance	0.00381835
Skewness	-0.0403044	Kurtosis	-0.8190712
Uncorrected SS	1996.08154	Corrected SS	1.3936974
Coeff Variation	2.64692042	Std Error Mean	0.00322996

Basic Statistical Measures

Location		Variability	
Mean	2.334516	Std Deviation	0.06179
Median	2.338500	Variance	0.00382
Mode	2.248000	Range	0.27500
		Interquartile Range	0.10300

NOTE: The mode displayed is the smallest of 5 modes with a count of 6.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	722.7692	Pr > |t|	<.0001
Sign	M	183	Pr >= |M|	<.0001
Signed Rank	S	33580.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.4660
99%	2.4590
95%	2.4350
90%	2.4120
75% Q3	2.3840
50% Median	2.3385
25% Q1	2.2810
10%	2.2480
5%	2.2370
1%	2.1990
0% Min	2.1910

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.191	808	2.457	849
2.195	807	2.459	848
2.197	811	2.462	851
2.199	809	2.466	732
2.204	810	2.466	863

The CAPABILITY Procedure
Fitted Lognormal Distribution for sg

Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	0.847455
Shape	Sigma	0.026499
Mean		2.334519
Std Dev		0.061874

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0570881		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.2738033		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	1.8824627		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	44.9767514	9	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Lognormal Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.1875	1.093	0.906
2.2125	0.273	2.294
2.2375	9.563	4.812
2.2625	10.656	8.414
2.2875	8.470	12.334
2.3125	12.022	15.242
2.3375	17.486	15.964
2.3625	9.836	14.242
2.3875	13.661	10.876
2.4125	9.290	7.144
2.4375	5.191	4.055
2.4625	2.459	1.997

Quantiles for Lognormal Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.19900	2.19418
5.0	2.23700	2.23416
10.0	2.24800	2.25578
25.0	2.28100	2.29236
50.0	2.33850	2.33370
75.0	2.38400	2.37579
90.0	2.41200	2.41431
95.0	2.43500	2.43767
99.0	2.45900	2.48209

type=2 grad=2

The CAPABILITY Procedure
Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.32215613	Sum Observations	624.66
Std Deviation	0.06591852	Variance	0.00434525
Skewness	0.15577705	Kurtosis	-0.0720302
Uncorrected SS	1451.72258	Corrected SS	1.16452744
Coeff Variation	2.83867746	Std Error Mean	0.00401912

Basic Statistical Measures

Location		Variability	
Mean	2.322156	Std Deviation	0.06592
Median	2.324000	Variance	0.00435
Mode	2.283000	Range	0.38200
		Interquartile Range	0.08100

NOTE: The mode displayed is the smallest of 5 modes with a count of 5.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	577.7768	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.498
99%	2.496
95%	2.442
90%	2.412
75% Q3	2.363
50% Median	2.324
25% Q1	2.282
10%	2.228
5%	2.220
1%	2.205
0% Min	2.116

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.116	1247	2.495	1123
2.202	1013	2.495	1126
2.205	1226	2.496	1125
2.209	1187	2.497	1124
2.212	1230	2.498	1122

The CAPABILITY Procedure
Fitted Lognormal Distribution for sg

Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	0.842095
Shape	Sigma	0.028352
Mean		2.322159
Std Dev		0.06585

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0626137		Pr > D	0.011
Cramer-von Mises	W-Sq	0.2029761		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	1.3927574		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	29.6812823	7	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Lognormal Distribution

Bin Midpoint	-------Percent------ Observed	Estimated
2.12	0.372	0.187
2.16	0.000	1.134
2.20	3.717	4.448
2.24	13.011	11.499
2.28	24.907	20.008
2.32	13.755	23.888
2.36	27.881	19.926
2.40	9.665	11.810
2.44	4.461	5.053
2.48	2.230	1.584

Quantiles for Lognormal Distribution

Percent	------Quantile------ Observed	Estimated
1.0	2.20500	2.17307
5.0	2.22000	2.21546
10.0	2.22800	2.23840
25.0	2.28200	2.27726
50.0	2.32400	2.32123
75.0	2.36300	2.36604
90.0	2.41200	2.40712
95.0	2.44200	2.43204
99.0	2.49600	2.47949

-- type=3 grad=1 ---------------------------------

The CAPABILITY Procedure
Variable: sg

Moments

N	365	Sum Weights	365
Mean	2.35739452	Sum Observations	860.449
Std Deviation	0.05908495	Variance	0.00349103
Skewness	-0.1488487	Kurtosis	-0.3136104
Uncorrected SS	2029.68849	Corrected SS	1.27073519
Coeff Variation	2.50636644	Std Error Mean	0.00309265

Basic Statistical Measures

Location		Variability	
Mean	2.357395	Std Deviation	0.05908
Median	2.357000	Variance	0.00349
Mode	2.409000	Range	0.30100
		Interquartile Range	0.08600

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	762.2578	Pr > |t|	<.0001
Sign	M	182.5	Pr >= |M|	<.0001
Signed Rank	S	33397.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.484
99%	2.476
95%	2.456
90%	2.434
75% Q3	2.401
50% Median	2.357
25% Q1	2.315
10%	2.278
5%	2.266
1%	2.193
0% Min	2.183

The CAPABILITY Procedure
Variable: sg

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.183	1446	2.475	1598
2.190	1443	2.476	1367
2.191	1445	2.476	1484
2.193	1442	2.480	1483
2.195	1444	2.484	1486

--------------------------------------- type=3 grad=1 ---------------------------------

The CAPABILITY Procedure

Fitted Lognormal Distribution for sg

Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	0.857243
Shape	Sigma	0.025128
Mean		2.357398
Std Dev		0.059245

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0574030		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.1476016		Pr > W-Sq	0.025
Anderson-Darling	A-Sq	0.9384201		Pr > A-Sq	0.019
Chi-Square	Chi-Sq	24.4007238	8	Pr > Chi-Sq	0.002

Histogram Bin Percents for Lognormal Distribution

Bin Midpoint	-------Percent------ Observed	Estimated
2.19	1.370	0.335
2.22	0.000	1.340
2.25	3.562	3.975
2.28	11.507	8.850
2.31	13.425	14.952
2.34	19.452	19.362
2.37	16.164	19.404
2.40	18.082	15.190
2.43	9.863	9.369
2.46	4.932	4.592
2.49	1.644	1.803

Quantiles for Lognormal Distribution

Percent	------Quantile------ Observed	Estimated
1.0	2.19300	2.22284
5.0	2.26600	2.26124
10.0	2.27800	2.28197
25.0	2.31500	2.31705
50.0	2.35700	2.35665
75.0	2.40100	2.39694
90.0	2.43400	2.43378
95.0	2.45600	2.45610
99.0	2.47600	2.49852

type=3 grad=2

The CAPABILITY Procedure
Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.32417472	Sum Observations	625.203
Std Deviation	0.06661537	Variance	0.00443761
Skewness	0.21293631	Kurtosis	0.01997177
Uncorrected SS	1454.27029	Corrected SS	1.18927879
Coeff Variation	2.86619455	Std Error Mean	0.00406161

Basic Statistical Measures

Location		Variability	
Mean	2.324175	Std Deviation	0.06662
Median	2.326000	Variance	0.00444
Mode	2.359000	Range	0.39100
		Interquartile Range	0.08000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	572.2298	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.508
99%	2.504
95%	2.439
90%	2.412
75% Q3	2.364
50% Median	2.326
25% Q1	2.284
10%	2.231
5%	2.224
1%	2.205
0% Min	2.117

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.117	1881	2.503	1757
2.197	1864	2.503	1758
2.205	1647	2.504	1759
2.208	1821	2.506	1760
2.209	1860	2.508	1756

The CAPABILITY Procedure
Fitted Lognormal Distribution for sg

Parameters for Lognormal Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Zeta	0.842957
Shape	Sigma	0.028604
Mean		2.324177
Std Dev		0.066494

Goodness-of-Fit Tests for Lognormal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0493092		Pr > D	0.109
Cramer-von Mises	W-Sq	0.1375911		Pr > W-Sq	0.037
Anderson-Darling	A-Sq	1.0081117		Pr > A-Sq	0.012
Chi-Square	Chi-Sq	36.6921355	8	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Lognormal Distribution

Bin Midpoint	-------Percent------ Observed	Estimated
2.12	0.372	0.183
2.16	0.000	1.102
2.20	2.974	4.298
2.24	15.242	11.133
2.28	21.190	19.533
2.32	17.100	23.660
2.36	25.651	20.140
2.40	8.922	12.249
2.44	6.320	5.407
2.48	0.372	1.758
2.52	1.859	0.427

Quantiles for Lognormal Distribution

Percent	------Quantile------ Observed	Estimated
1.0	2.20500	2.17366
5.0	2.22400	2.21645
10.0	2.23100	2.23960
25.0	2.28400	2.27883
50.0	2.32600	2.32323
75.0	2.36400	2.36848
90.0	2.41200	2.40997
95.0	2.43900	2.43515
99.0	2.50400	2.48308

-- **type=1 grad=1** --

The CAPABILITY Procedure
Variable: sg

Moments

N	367	Sum Weights	367
Mean	2.29547139	Sum Observations	842.438
Std Deviation	0.06329248	Variance	0.00400594
Skewness	-0.0914582	Kurtosis	-0.6502513
Uncorrected SS	1935.2585	Corrected SS	1.46617345
Coeff Variation	2.75727605	Std Error Mean	0.00330384

Basic Statistical Measures

Location		Variability	
Mean	2.295471	Std Deviation	0.06329
Median	2.295000	Variance	0.00401
Mode	2.286000	Range	0.32800
		Interquartile Range	0.10700

NOTE: The mode displayed is the smallest of 2 modes with a count of 7.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	694.7888	Pr > |t|	<.0001
Sign	M	183.5	Pr >= |M|	<.0001
Signed Rank	S	33764	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.444
99%	2.431
95%	2.400
90%	2.370
75% Q3	2.348
50% Median	2.295
25% Q1	2.241
10%	2.211
5%	2.202
1%	2.163
0% Min	2.116

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.116	138	2.427	212
2.139	285	2.431	215
2.150	262	2.433	228
2.163	172	2.440	231
2.167	319	2.444	96

The CAPABILITY Procedure
Fitted Normal Distribution for sg

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	2.295471
Std Dev	Sigma	0.063292

Goodness-of-Fit Tests for Normal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0686149		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.2843264		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	1.8487370		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	55.2037624	8	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Normal Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.13	0.545	0.654
2.16	2.180	1.978
2.19	2.452	4.795
2.22	18.256	9.324
2.25	9.264	14.542
2.28	17.166	18.193
2.31	14.169	18.256
2.34	15.259	14.694
2.37	14.169	9.487
2.40	4.905	4.913
2.43	1.635	2.040

Quantiles for Normal Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.16300	2.14823
5.0	2.20200	2.19136
10.0	2.21100	2.21436
25.0	2.24100	2.25278
50.0	2.29500	2.29547
75.0	2.34800	2.33816
90.0	2.37000	2.37658
95.0	2.40000	2.39958
99.0	2.43100	2.44271

type=1 grad=2

The CAPABILITY Procedure

Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.2913829	Sum Observations	616.382
Std Deviation	0.07299467	Variance	0.00532822
Skewness	-0.2347243	Kurtosis	0.6177456
Uncorrected SS	1413.79514	Corrected SS	1.42796356
Coeff Variation	3.18561654	Std Error Mean	0.00445056

Basic Statistical Measures

Location		Variability	
Mean	2.291383	Std Deviation	0.07299
Median	2.289000	Variance	0.00533
Mode	2.328000	Range	0.45300
		Interquartile Range	0.08900

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	514.8523	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.474
99%	2.472
95%	2.398
90%	2.388
75% Q3	2.338
50% Median	2.289
25% Q1	2.249
10%	2.198
5%	2.189
1%	2.072
0% Min	2.021

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.021	467	2.466	491
2.057	524	2.471	487
2.072	447	2.472	488
2.092	522	2.473	489
2.115	612	2.474	490

The CAPABILITY Procedure
Fitted Normal Distribution for sg

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	2.291383
Std Dev	Sigma	0.072995

Goodness-of-Fit Tests for Normal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0664563		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.1922806		Pr > W-Sq	0.007
Anderson-Darling	A-Sq	1.2713534		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	24.6452483	7	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Normal Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.025	0.372	0.044
2.075	1.115	0.390
2.125	0.372	2.201
2.175	8.922	7.892
2.225	14.870	18.008
2.275	27.138	26.161
2.325	28.996	24.204
2.375	13.383	14.260
2.425	2.602	5.348
2.475	2.230	1.276

Quantiles for Normal Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.07200	2.12157
5.0	2.18900	2.17132
10.0	2.19800	2.19784
25.0	2.24900	2.24215
50.0	2.28900	2.29138
75.0	2.33800	2.34062
90.0	2.38800	2.38493
95.0	2.39800	2.41145
99.0	2.47200	2.46119

type=2 grad=1

The CAPABILITY Procedure

Variable: sg

Moments

N	366	Sum Weights	366
Mean	2.33451639	Sum Observations	854.433
Std Deviation	0.06179279	Variance	0.00381835
Skewness	-0.0403044	Kurtosis	-0.8190712
Uncorrected SS	1996.08154	Corrected SS	1.3936974
Coeff Variation	2.64692042	Std Error Mean	0.00322996

Basic Statistical Measures

Location		Variability	
Mean	2.334516	Std Deviation	0.06179
Median	2.338500	Variance	0.00382
Mode	2.248000	Range	0.27500
		Interquartile Range	0.10300

NOTE: The mode displayed is the smallest of 5 modes with a count of 6.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	722.7692	Pr > |t|	<.0001
Sign	M	183	Pr >= |M|	<.0001
Signed Rank	S	33580.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.4660
99%	2.4590
95%	2.4350
90%	2.4120
75% Q3	2.3840
50% Median	2.3385
25% Q1	2.2810
10%	2.2480
5%	2.2370
1%	2.1990
0% Min	2.1910

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.191	808	2.457	849
2.195	807	2.459	848
2.197	811	2.462	851
2.199	809	2.466	732
2.204	810	2.466	863

The CAPABILITY Procedure
Fitted Normal Distribution for sg

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	2.334516
Std Dev	Sigma	0.061793

Goodness-of-Fit Tests for Normal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0581381		Pr > D	<0.010
Cramer-von Mises	W-Sq	0.2547834		Pr > W-Sq	<0.005
Anderson-Darling	A-Sq	1.7854820		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	45.0101077	9	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Normal Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.1875	1.093	0.983
2.2125	0.273	2.343
2.2375	9.563	4.753
2.2625	10.656	8.204
2.2875	8.470	12.049
2.3125	12.022	15.058
2.3375	17.486	16.012
2.3625	9.836	14.489
2.3875	13.661	11.155
2.4125	9.290	7.308
2.4375	5.191	4.074
2.4625	2.459	1.932

Quantiles for Normal Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.19900	2.19076
5.0	2.23700	2.23288
10.0	2.24800	2.25533
25.0	2.28100	2.29284
50.0	2.33850	2.33452
75.0	2.38400	2.37619
90.0	2.41200	2.41371
95.0	2.43500	2.43616
99.0	2.45900	2.47827

-- **type=2 grad=2** --------------------------------

The CAPABILITY Procedure

Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.32215613	Sum Observations	624.66
Std Deviation	0.06591852	Variance	0.00434525
Skewness	0.15577705	Kurtosis	-0.0720302
Uncorrected SS	1451.72258	Corrected SS	1.16452744
Coeff Variation	2.83867746	Std Error Mean	0.00401912

Basic Statistical Measures

Location		Variability	
Mean	2.322156	Std Deviation	0.06592
Median	2.324000	Variance	0.00435
Mode	2.283000	Range	0.38200
		Interquartile Range	0.08100

NOTE: The mode displayed is the smallest of 5 modes with a count of 5.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	577.7768	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.498
99%	2.496
95%	2.442
90%	2.412
75% Q3	2.363
50% Median	2.324
25% Q1	2.282
10%	2.228
5%	2.220
1%	2.205
0% Min	2.116

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.116	1247	2.495	1123
2.202	1013	2.495	1126
2.205	1226	2.496	1125
2.209	1187	2.497	1124
2.212	1230	2.498	1122

The CAPABILITY Procedure
Fitted Normal Distribution for sg

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	2.322156
Std Dev	Sigma	0.065919

Goodness-of-Fit Tests for Normal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0614916		Pr > D	0.014
Cramer-von Mises	W-Sq	0.1996172		Pr > W-Sq	0.005
Anderson-Darling	A-Sq	1.3911834		Pr > A-Sq	<0.005
Chi-Square	Chi-Sq	30.2416343	7	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Normal Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.12	0.372	0.248
2.16	0.000	1.266
2.20	3.717	4.508
2.24	13.011	11.226
2.28	24.907	19.553
2.32	13.755	23.830
2.36	27.881	20.321
2.40	9.665	12.124
2.44	4.461	5.060
2.48	2.230	1.477

Quantiles for Normal Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.20500	2.16881
5.0	2.22000	2.21373
10.0	2.22800	2.23768
25.0	2.28200	2.27769
50.0	2.32400	2.32216
75.0	2.36300	2.36662
90.0	2.41200	2.40663
95.0	2.44200	2.43058
99.0	2.49600	2.47551

type=3 grad=1

The CAPABILITY Procedure

Variable: sg

Moments

N	365	Sum Weights	365
Mean	2.35739452	Sum Observations	860.449
Std Deviation	0.05908495	Variance	0.00349103
Skewness	-0.1488487	Kurtosis	-0.3136104
Uncorrected SS	2029.68849	Corrected SS	1.27073519
Coeff Variation	2.50636644	Std Error Mean	0.00309265

Basic Statistical Measures

Location		Variability	
Mean	2.357395	Std Deviation	0.05908
Median	2.357000	Variance	0.00349
Mode	2.409000	Range	0.30100
		Interquartile Range	0.08600

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	762.2578	Pr > |t|	<.0001
Sign	M	182.5	Pr >= |M|	<.0001
Signed Rank	S	33397.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.484
99%	2.476
95%	2.456
90%	2.434
75% Q3	2.401
50% Median	2.357
25% Q1	2.315
10%	2.278
5%	2.266
1%	2.193
0% Min	2.183

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.183	1446	2.475	1598
2.190	1443	2.476	1367
2.191	1445	2.476	1484
2.193	1442	2.480	1483
2.195	1444	2.484	1486

The CAPABILITY Procedure
Fitted Normal Distribution for sg

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	2.357395
Std Dev	Sigma	0.059085

Goodness-of-Fit Tests for Normal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0529642		Pr > D	0.014
Cramer-von Mises	W-Sq	0.1389469		Pr > W-Sq	0.035
Anderson-Darling	A-Sq	0.8811159		Pr > A-Sq	0.024
Chi-Square	Chi-Sq	21.8259168	8	Pr > Chi-Sq	0.005

Histogram Bin Percents for Normal Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.19	1.370	0.394
2.22	0.000	1.421
2.25	3.562	3.978
2.28	11.507	8.654
2.31	13.425	14.627
2.34	19.452	19.208
2.37	16.164	19.599
2.40	18.082	15.538
2.43	9.863	9.571
2.46	4.932	4.581
2.49	1.644	1.703

Quantiles for Normal Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.19300	2.21994
5.0	2.26600	2.26021
10.0	2.27800	2.28167
25.0	2.31500	2.31754
50.0	2.35700	2.35739
75.0	2.40100	2.39725
90.0	2.43400	2.43311
95.0	2.45600	2.45458
99.0	2.47600	2.49485

--------------------------------------- type=3 grad=2 ---------------------------------------

The CAPABILITY Procedure
Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.32417472	Sum Observations	625.203
Std Deviation	0.06661537	Variance	0.00443761
Skewness	0.21293631	Kurtosis	0.01997177
Uncorrected SS	1454.27029	Corrected SS	1.18927879
Coeff Variation	2.86619455	Std Error Mean	0.00406161

Basic Statistical Measures

Location		Variability	
Mean	2.324175	Std Deviation	0.06662
Median	2.326000	Variance	0.00444
Mode	2.359000	Range	0.39100
		Interquartile Range	0.08000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	572.2298	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.508
99%	2.504
95%	2.439
90%	2.412
75% Q3	2.364
50% Median	2.326
25% Q1	2.284
10%	2.231
5%	2.224
1%	2.205
0% Min	2.117

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.117	1881	2.503	1757
2.197	1864	2.503	1758
2.205	1647	2.504	1759
2.208	1821	2.506	1760
2.209	1860	2.508	1756

The CAPABILITY Procedure
Fitted Normal Distribution for sg

Parameters for Normal Distribution

Parameter	Symbol	Estimate
Mean	Mu	2.324175
Std Dev	Sigma	0.066615

Goodness-of-Fit Tests for Normal Distribution

Test	----Statistic-----		DF	------p Value------	
Kolmogorov-Smirnov	D	0.0484983		Pr > D	0.124
Cramer-von Mises	W-Sq	0.1393323		Pr > W-Sq	0.035
Anderson-Darling	A-Sq	1.0486408		Pr > A-Sq	0.009
Chi-Square	Chi-Sq	41.3102742	8	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Normal Distribution

Bin Midpoint	-------Percent------ Observed	Estimated
2.12	0.372	0.247
2.16	0.000	1.237
2.20	2.974	4.371
2.24	15.242	10.875
2.28	21.190	19.066
2.32	17.100	23.555
2.36	25.651	20.510
2.40	8.922	12.586
2.44	6.320	5.442
2.48	0.372	1.658
2.52	1.859	0.355

Quantiles for Normal Distribution

Percent	------Quantile------ Observed	Estimated
1.0	2.20500	2.16920
5.0	2.22400	2.21460
10.0	2.23100	2.23880
25.0	2.28400	2.27924
50.0	2.32600	2.32417
75.0	2.36400	2.36911
90.0	2.41200	2.40955
95.0	2.43900	2.43375
99.0	2.50400	2.47915

--------------------------------------- **type=1 grad=1** ---------------------------------------

The CAPABILITY Procedure
Variable: sg

Moments

N	367	Sum Weights	367
Mean	2.29547139	Sum Observations	842.438
Std Deviation	0.06329248	Variance	0.00400594
Skewness	-0.0914582	Kurtosis	-0.6502513
Uncorrected SS	1935.2585	Corrected SS	1.46617345
Coeff Variation	2.75727605	Std Error Mean	0.00330384

Basic Statistical Measures

Location		Variability	
Mean	2.295471	Std Deviation	0.06329
Median	2.295000	Variance	0.00401
Mode	2.286000	Range	0.32800
		Interquartile Range	0.10700

NOTE: The mode displayed is the smallest of 2 modes with a count of 7.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	694.7888	Pr > |t|	<.0001
Sign	M	183.5	Pr >= |M|	<.0001
Signed Rank	S	33764	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.444
99%	2.431
95%	2.400
90%	2.370
75% Q3	2.348
50% Median	2.295
25% Q1	2.241
10%	2.211
5%	2.202
1%	2.163
0% Min	2.116

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.116	138	2.427	212
2.139	285	2.431	215
2.150	262	2.433	228
2.163	172	2.440	231
2.167	319	2.444	96

-- **type=1 grad=1** --------------------------------

The CAPABILITY Procedure

Fitted Weibull Distribution for sg

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	2.325956
Shape	C	39.59658
Mean		2.293483
Std Dev		0.072975

Goodness-of-Fit Tests for Weibull Distribution

Test	----Statistic-----		DF	------p Value------	
Cramer-von Mises	W-Sq	0.3557536		Pr > W-Sq	<0.010
Anderson-Darling	A-Sq	2.6491615		Pr > A-Sq	<0.010
Chi-Square	Chi-Sq	76.5302809	8	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Weibull Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.13	0.545	1.676
2.16	2.180	2.808
2.19	2.452	4.593
2.22	18.256	7.255
2.25	9.264	10.866
2.28	17.166	14.984
2.31	14.169	18.141
2.34	15.259	17.883
2.37	14.169	12.771
2.40	4.905	5.536
2.43	1.635	1.122

Quantiles for Weibull Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.16300	2.07084
5.0	2.20200	2.15787
10.0	2.21100	2.19745
25.0	2.24100	2.25391
50.0	2.29500	2.30453
75.0	2.34800	2.34522
90.0	2.37000	2.37547
95.0	2.40000	2.39131
99.0	2.43100	2.41742

type=1 grad=2

The CAPABILITY Procedure
Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.2913829	Sum Observations	616.382
Std Deviation	0.07299467	Variance	0.00532822
Skewness	-0.2347243	Kurtosis	0.6177456
Uncorrected SS	1413.79514	Corrected SS	1.42796356
Coeff Variation	3.18561654	Std Error Mean	0.00445056

Basic Statistical Measures

Location		Variability	
Mean	2.291383	Std Deviation	0.07299
Median	2.289000	Variance	0.00533
Mode	2.328000	Range	0.45300
		Interquartile Range	0.08900

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	514.8523	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.474
99%	2.472
95%	2.398
90%	2.388
75% Q3	2.338
50% Median	2.289
25% Q1	2.249
10%	2.198
5%	2.189
1%	2.072
0% Min	2.021

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.021	467	2.466	491
2.057	524	2.471	487
2.072	447	2.472	488
2.092	522	2.473	489
2.115	612	2.474	490

The CAPABILITY Procedure
Fitted Weibull Distribution for sg

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	2.326139
Shape	C	33.18052
Mean		2.287707
Std Dev		0.08658

Goodness-of-Fit Tests for Weibull Distribution

Test	----Statistic-----		DF	------p Value------	
Cramer-von Mises	W-Sq	0.4003428		Pr > W-Sq	<0.010
Anderson-Darling	A-Sq	2.9918984		Pr > A-Sq	<0.010
Chi-Square	Chi-Sq	49.1156084	7	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Weibull Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.025	0.372	0.835
2.075	1.115	1.805
2.125	0.372	3.768
2.175	8.922	7.480
2.225	14.870	13.662
2.275	27.138	21.495
2.325	28.996	25.707
2.375	13.383	18.632
2.425	2.602	5.580
2.475	2.230	0.371

Quantiles for Weibull Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.07200	2.02500
5.0	2.18900	2.12696
10.0	2.19800	2.17361
25.0	2.24900	2.24041
50.0	2.28900	2.30059
75.0	2.33800	2.34915
90.0	2.38800	2.38535
95.0	2.39800	2.40434
99.0	2.47200	2.43571

--------------------------------------- **type=2 grad=1** --------------------------------

The CAPABILITY Procedure

Variable: sg

Moments

N	366	Sum Weights	366
Mean	2.33451639	Sum Observations	854.433
Std Deviation	0.06179279	Variance	0.00381835
Skewness	-0.0403044	Kurtosis	-0.8190712
Uncorrected SS	1996.08154	Corrected SS	1.3936974
Coeff Variation	2.64692042	Std Error Mean	0.00322996

Basic Statistical Measures

Location		Variability	
Mean	2.334516	Std Deviation	0.06179
Median	2.338500	Variance	0.00382
Mode	2.248000	Range	0.27500
		Interquartile Range	0.10300

NOTE: The mode displayed is the smallest of 5 modes with a count of 6.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	722.7692	Pr > |t|	<.0001
Sign	M	183	Pr >= |M|	<.0001
Signed Rank	S	33580.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.4660
99%	2.4590
95%	2.4350
90%	2.4120
75% Q3	2.3840
50% Median	2.3385
25% Q1	2.2810
10%	2.2480
5%	2.2370
1%	2.1990
0% Min	2.1910

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.191	808	2.457	849
2.195	807	2.459	848
2.197	811	2.462	851
2.199	809	2.466	732
2.204	810	2.466	863

The CAPABILITY Procedure
Fitted Weibull Distribution for sg

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	2.36443
Shape	C	41.20233
Mean		2.332654
Std Dev		0.071377

Goodness-of-Fit Tests for Weibull Distribution

Test	----Statistic-----		DF	------p Value------	
Cramer-von Mises	W-Sq	0.3491543		Pr > W-Sq	<0.010
Anderson-Darling	A-Sq	2.7130741		Pr > A-Sq	<0.010
Chi-Square	Chi-Sq	60.2714003	9	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Weibull Distribution

Bin Midpoint	-------Percent------ Observed	Estimated
2.1875	1.093	1.848
2.2125	0.273	2.847
2.2375	9.563	4.300
2.2625	10.656	6.322
2.2875	8.470	8.940
2.3125	12.022	11.944
2.3375	17.486	14.670
2.3625	9.836	15.908
2.3875	13.661	14.344
2.4125	9.290	9.853
2.4375	5.191	4.548
2.4625	2.459	1.182

Quantiles for Weibull Distribution

Percent	------Quantile------ Observed	Estimated
1.0	2.19900	2.11465
5.0	2.23700	2.19998
10.0	2.24800	2.23875
25.0	2.28100	2.29400
50.0	2.33850	2.34349
75.0	2.38400	2.38325
90.0	2.41200	2.41278
95.0	2.43500	2.42824
99.0	2.45900	2.45371

-- **type=2 grad=2** --------------------------------

The CAPABILITY Procedure

Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.32215613	Sum Observations	624.66
Std Deviation	0.06591852	Variance	0.00434525
Skewness	0.15577705	Kurtosis	-0.0720302
Uncorrected SS	1451.72258	Corrected SS	1.16452744
Coeff Variation	2.83867746	Std Error Mean	0.00401912

Basic Statistical Measures

Location		Variability	
Mean	2.322156	Std Deviation	0.06592
Median	2.324000	Variance	0.00435
Mode	2.283000	Range	0.38200
		Interquartile Range	0.08100

NOTE: The mode displayed is the smallest of 5 modes with a count of 5.

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	577.7768	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.498
99%	2.496
95%	2.442
90%	2.412
75% Q3	2.363
50% Median	2.324
25% Q1	2.282
10%	2.228
5%	2.220
1%	2.205
0% Min	2.116

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.116	1247	2.495	1123
2.202	1013	2.495	1126
2.205	1226	2.496	1125
2.209	1187	2.497	1124
2.212	1230	2.498	1122

type=2 grad=2

The CAPABILITY Procedure
Fitted Weibull Distribution for sg

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	2.354542
Shape	C	35.16655
Mean		2.31773
Std Dev		0.082857

Goodness-of-Fit Tests for Weibull Distribution

Test	----Statistic-----		DF	------p Value------	
Cramer-von Mises	W-Sq	0.5842638		Pr > W-Sq	<0.010
Anderson-Darling	A-Sq	4.2683958		Pr > A-Sq	<0.010
Chi-Square	Chi-Sq	60.1771987	7	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Weibull Distribution

Bin Midpoint	-------Percent------ Observed	Estimated
2.12	0.372	1.641
2.16	0.000	3.032
2.20	3.717	5.418
2.24	13.011	9.209
2.28	24.907	14.432
2.32	13.755	19.752
2.36	27.881	21.511
2.40	9.665	15.973
2.44	4.461	6.320
2.48	2.230	0.912

Quantiles for Weibull Distribution

Percent	------Quantile------ Observed	Estimated
1.0	2.20500	2.06584
5.0	2.22000	2.16384
10.0	2.22800	2.20859
25.0	2.28200	2.27258
50.0	2.32400	2.33013
75.0	2.36300	2.37651
90.0	2.41200	2.41105
95.0	2.44200	2.42916
99.0	2.49600	2.45905

-- **type=3 grad=1** ---------------------------------

The CAPABILITY Procedure

Variable: sg

Moments

N	365	Sum Weights	365
Mean	2.35739452	Sum Observations	860.449
Std Deviation	0.05908495	Variance	0.00349103
Skewness	-0.1488487	Kurtosis	-0.3136104
Uncorrected SS	2029.68849	Corrected SS	1.27073519
Coeff Variation	2.50636644	Std Error Mean	0.00309265

Basic Statistical Measures

Location		Variability	
Mean	2.357395	Std Deviation	0.05908
Median	2.357000	Variance	0.00349
Mode	2.409000	Range	0.30100
		Interquartile Range	0.08600

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	762.2578	Pr > |t|	<.0001
Sign	M	182.5	Pr >= |M|	<.0001
Signed Rank	S	33397.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.484
99%	2.476
95%	2.456
90%	2.434
75% Q3	2.401
50% Median	2.357
25% Q1	2.315
10%	2.278
5%	2.266
1%	2.193
0% Min	2.183

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.183	1446	2.475	1598
2.190	1443	2.476	1367
2.191	1445	2.476	1484
2.193	1442	2.480	1483
2.195	1444	2.484	1486

The CAPABILITY Procedure
Fitted Weibull Distribution for sg

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	2.385847
Shape	C	43.50114
Mean		2.355411
Std Dev		0.068324

Goodness-of-Fit Tests for Weibull Distribution

Test	----Statistic-----		DF	------p Value------	
Cramer-von Mises	W-Sq	0.3580162		Pr > W-Sq	<0.010
Anderson-Darling	A-Sq	2.6798853		Pr > A-Sq	<0.010
Chi-Square	Chi-Sq	35.2261593	8	Pr > Chi-Sq	<0.001

Histogram Bin Percents for Weibull Distribution

Bin	-------Percent------	
Midpoint	Observed	Estimated
2.19	1.370	1.419
2.22	0.000	2.479
2.25	3.562	4.229
2.28	11.507	6.970
2.31	13.425	10.881
2.34	19.452	15.569
2.37	16.164	19.325
2.40	18.082	19.016
2.43	9.863	12.848
2.46	4.932	4.771
2.49	1.644	0.697

Quantiles for Weibull Distribution

	------Quantile------	
Percent	Observed	Estimated
1.0	2.19300	2.14643
5.0	2.26600	2.22838
10.0	2.27800	2.26556
25.0	2.31500	2.31848
50.0	2.35700	2.36583
75.0	2.40100	2.40383
90.0	2.43400	2.43203
95.0	2.45600	2.44679
99.0	2.47600	2.47109

-- **type=3 grad=2** --------------------------------

The CAPABILITY Procedure

Variable: sg

Moments

N	269	Sum Weights	269
Mean	2.32417472	Sum Observations	625.203
Std Deviation	0.06661537	Variance	0.00443761
Skewness	0.21293631	Kurtosis	0.01997177
Uncorrected SS	1454.27029	Corrected SS	1.18927879
Coeff Variation	2.86619455	Std Error Mean	0.00406161

Basic Statistical Measures

Location		Variability	
Mean	2.324175	Std Deviation	0.06662
Median	2.326000	Variance	0.00444
Mode	2.359000	Range	0.39100
		Interquartile Range	0.08000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	572.2298	Pr > |t|	<.0001
Sign	M	134.5	Pr >= |M|	<.0001
Signed Rank	S	18157.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	2.508
99%	2.504
95%	2.439
90%	2.412
75% Q3	2.364
50% Median	2.326
25% Q1	2.284
10%	2.231
5%	2.224
1%	2.205
0% Min	2.117

Extreme Observations

-----Lowest----		----Highest----	
Value	Obs	Value	Obs
2.117	1881	2.503	1757
2.197	1864	2.503	1758
2.205	1647	2.504	1759
2.208	1821	2.506	1760
2.209	1860	2.508	1756

The CAPABILITY Procedure
Fitted Weibull Distribution for sg

Parameters for Weibull Distribution

Parameter	Symbol	Estimate
Threshold	Theta	0
Scale	Sigma	2.35704
Shape	C	34.32214
Mean		2.319328
Std Dev		0.084914

Goodness-of-Fit Tests for Weibull Distribution

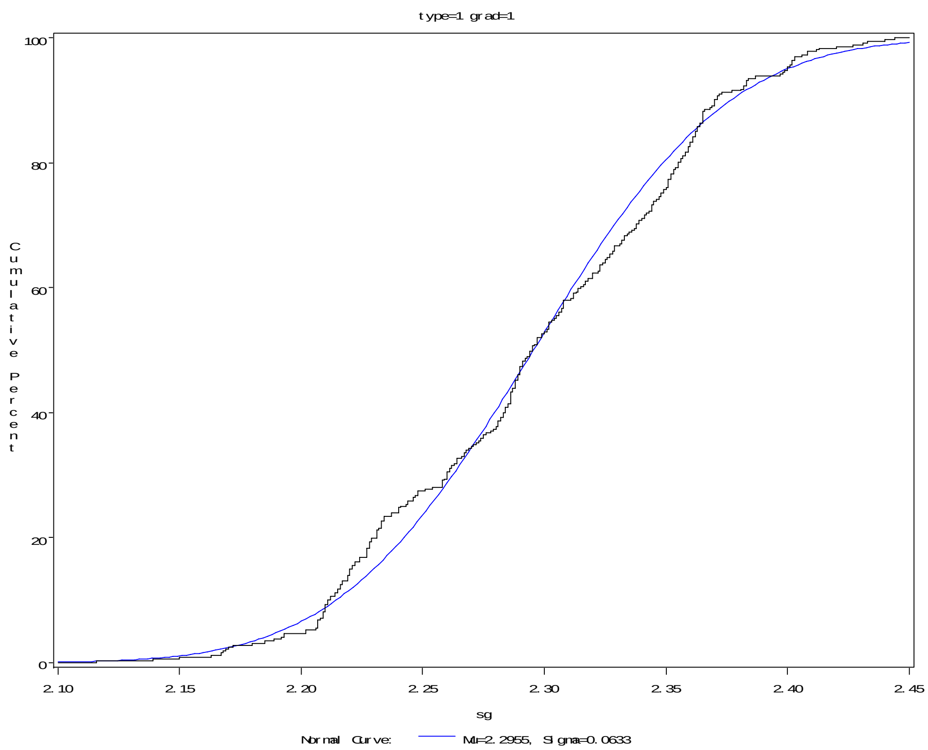
Test	----Statistic-----		DF	------p Value------	
Cramer-von Mises	W-Sq	0.624743		Pr > W-Sq	<0.010
Anderson-Darling	A-Sq	4.556146		Pr > A-Sq	<0.010
Chi-Square	Chi-Sq	216.408793	8	Pr > Chi-Sq	<0.001

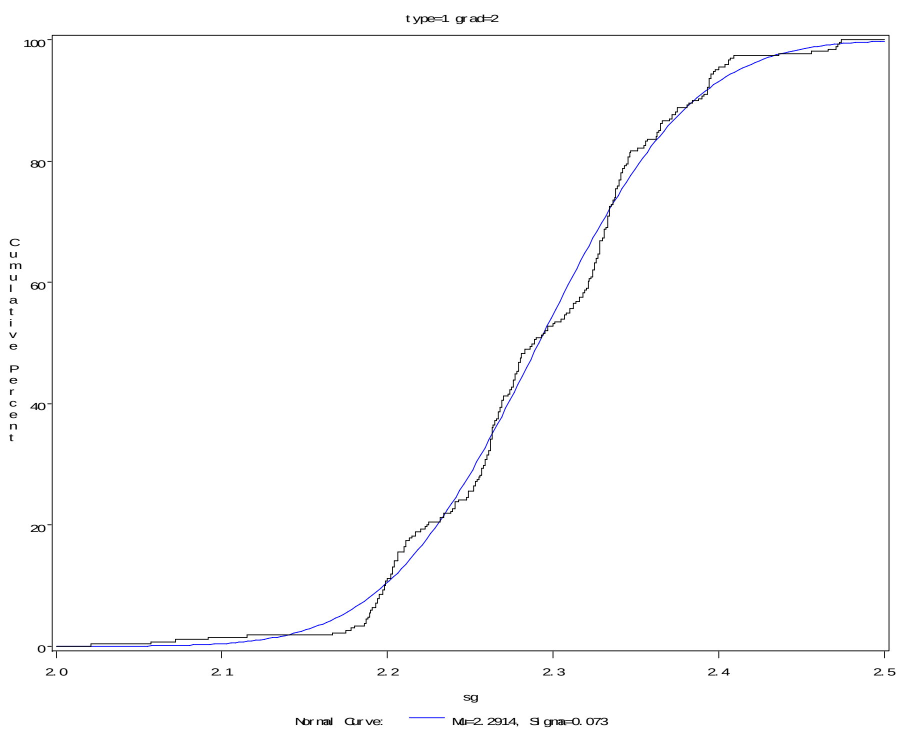
Histogram Bin Percents for Weibull Distribution

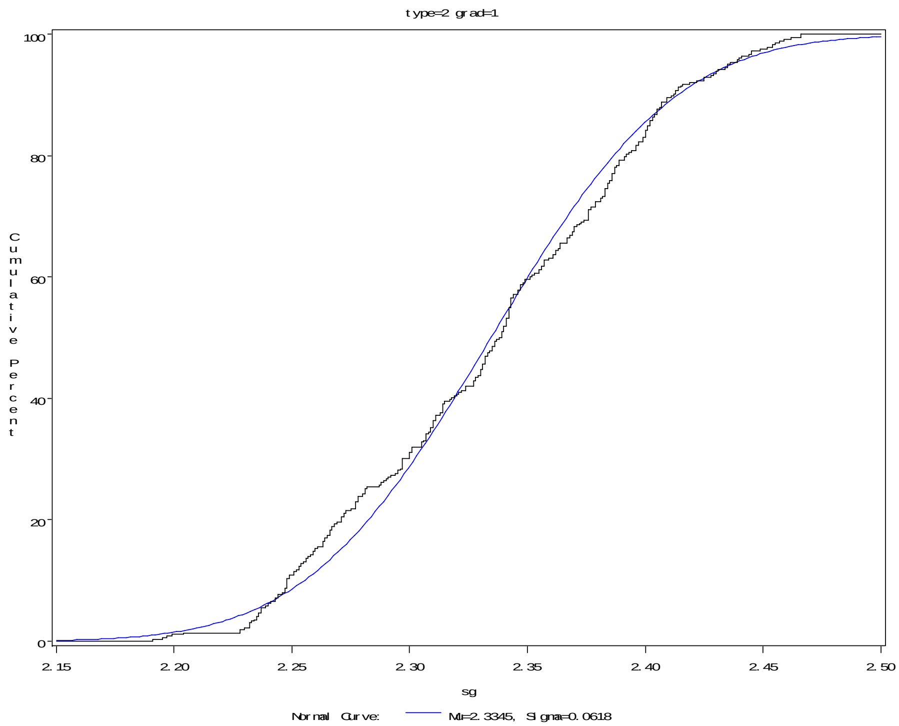
Bin Midpoint	-------Percent------ Observed	Estimated
2.12	0.372	1.684
2.16	0.000	3.061
2.20	2.974	5.386
2.24	15.242	9.027
2.28	21.190	13.998
2.32	17.100	19.101
2.36	25.651	21.071
2.40	8.922	16.342
2.44	6.320	7.141
2.48	0.372	1.253
2.52	1.859	0.053

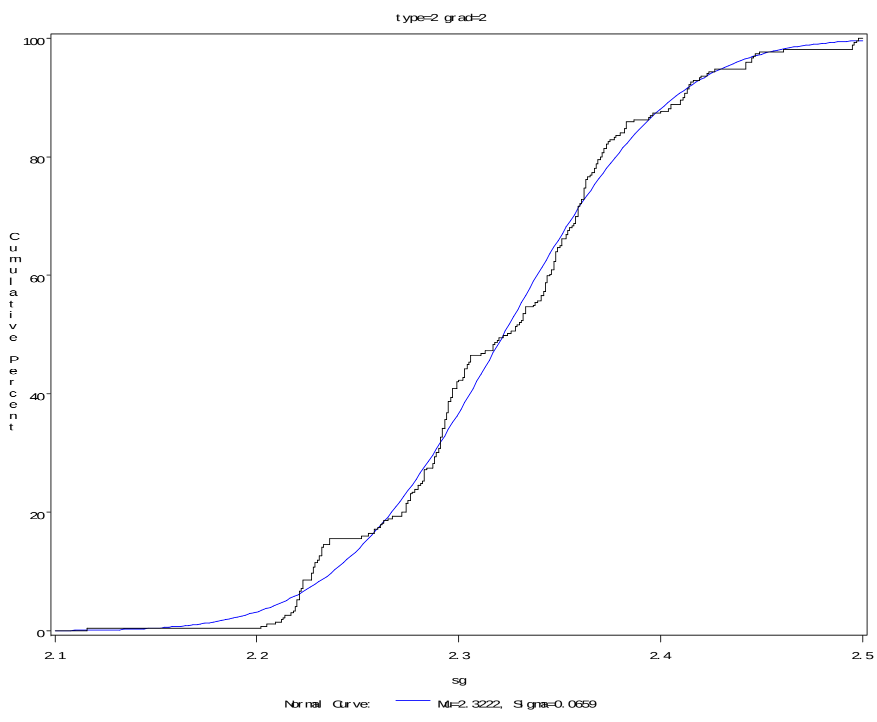
Quantiles for Weibull Distribution

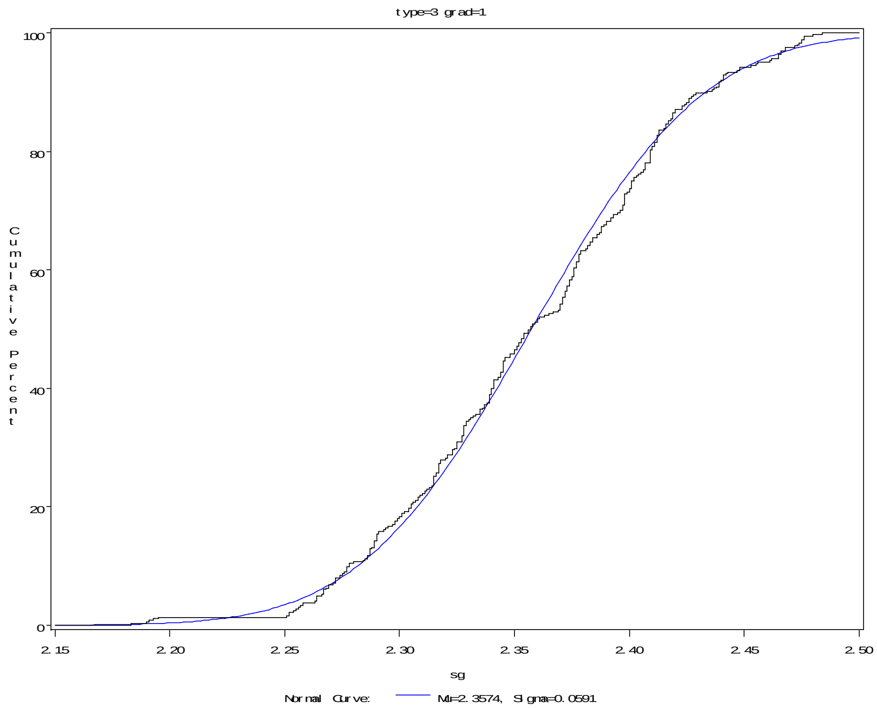
Percent	------Quantile------ Observed	Estimated
1.0	2.20500	2.06138
5.0	2.22400	2.16164
10.0	2.23100	2.20746
25.0	2.28400	2.27301
50.0	2.32600	2.33200
75.0	2.36400	2.37958
90.0	2.41200	2.41502
95.0	2.43900	2.43361
99.0	2.50400	2.46429

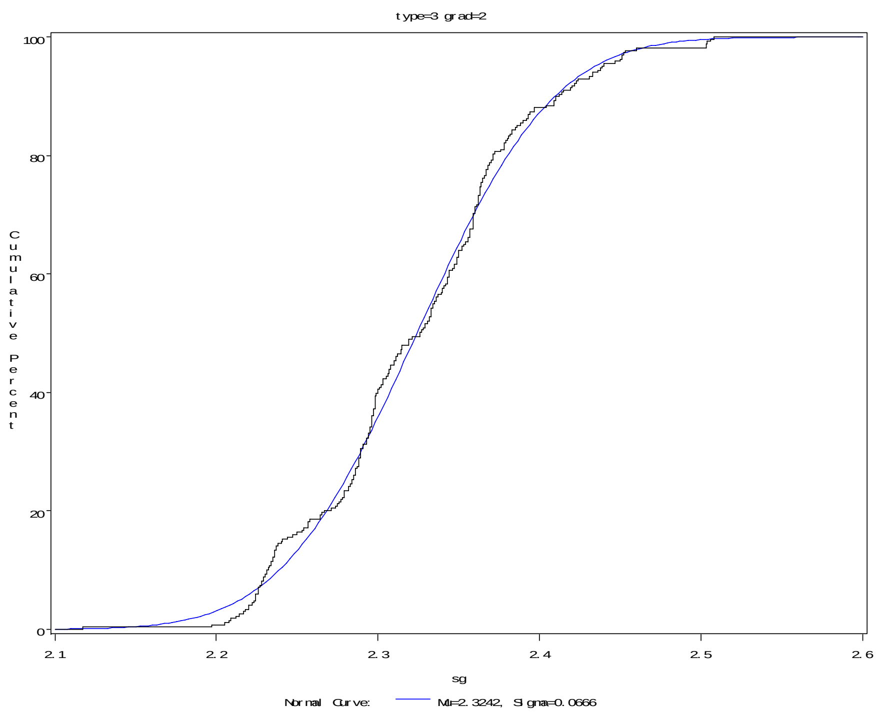

type=1 grad=1
Cumulative Percent
sg
Normal Curve: Mu=2.2955, Sigma=0.0633

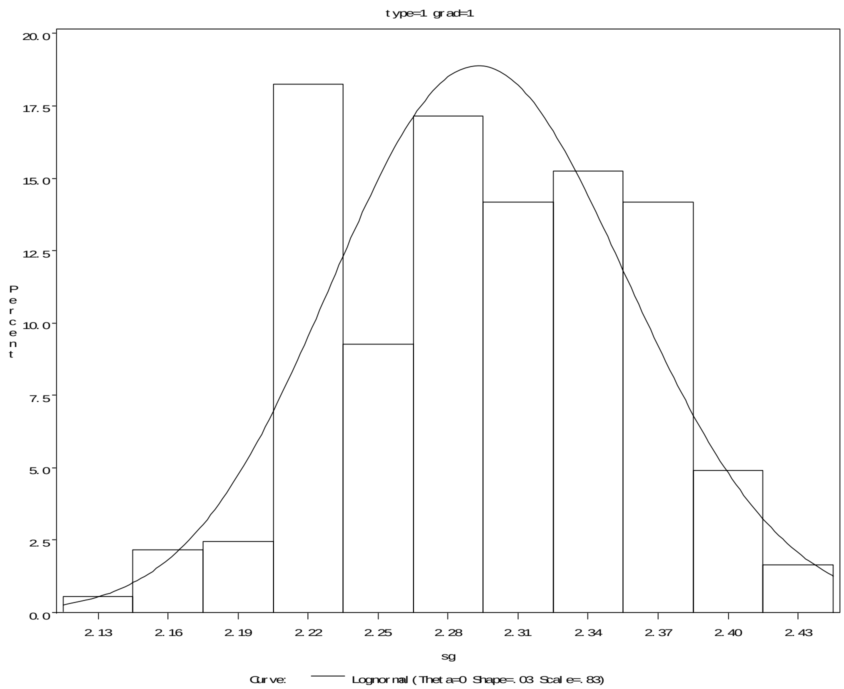

type=1 grad=2
Cumulative Percent
sg
Normal Curve: Mu=2.2914, Sigma=0.073

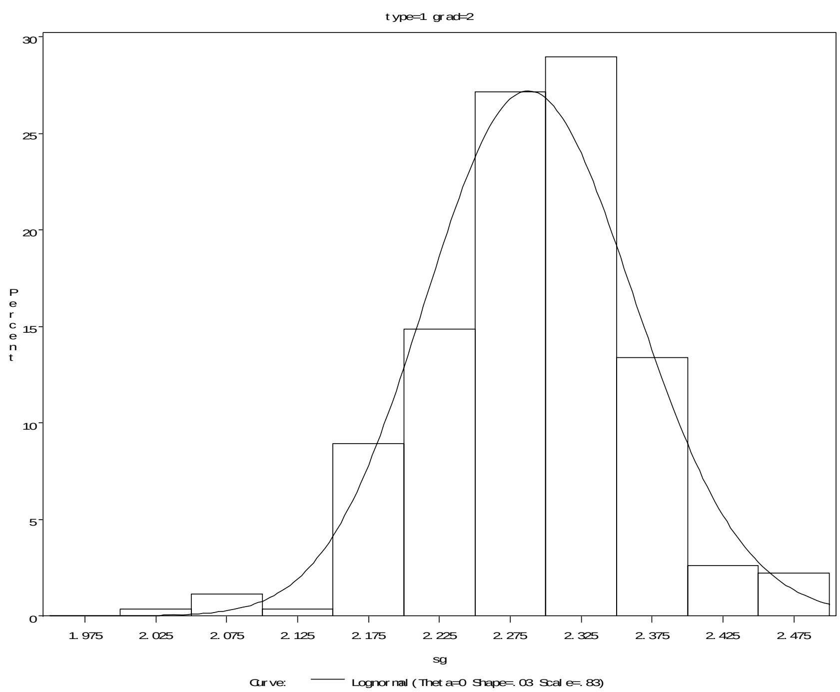

type=2 grad=1
Cumulative Percent
0
20
40
60
80
100
2.15
2.20
2.25
2.30
2.35
2.40
2.45
2.50
sg
Normal Curve: Mu=2.3345, Sigma=0.0618

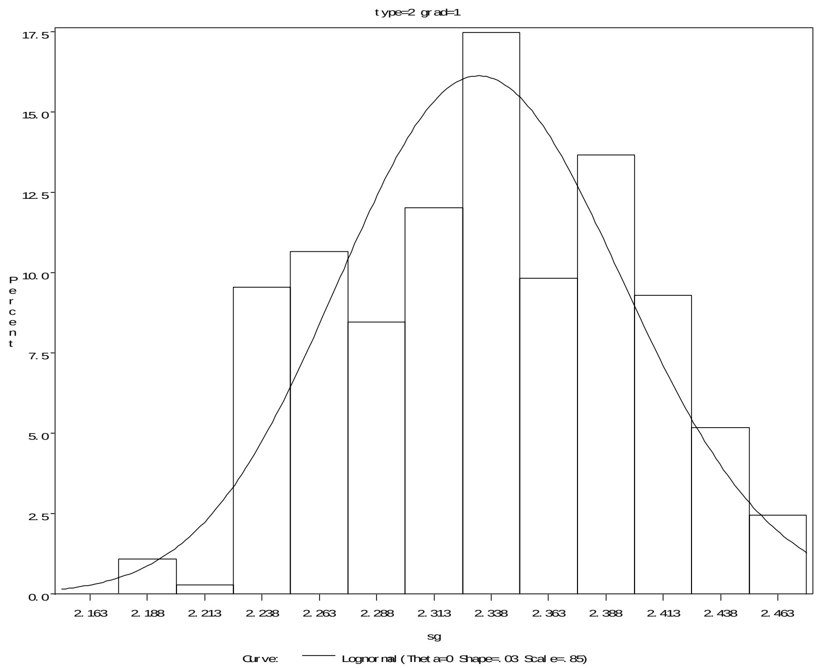

type=2 grad=2
Cumulative Percent
0
20
40
60
80
100
2.1
2.2
2.3
2.4
2.5
sg
Normal Curve: Mu=2.3222, Sigma=0.0659

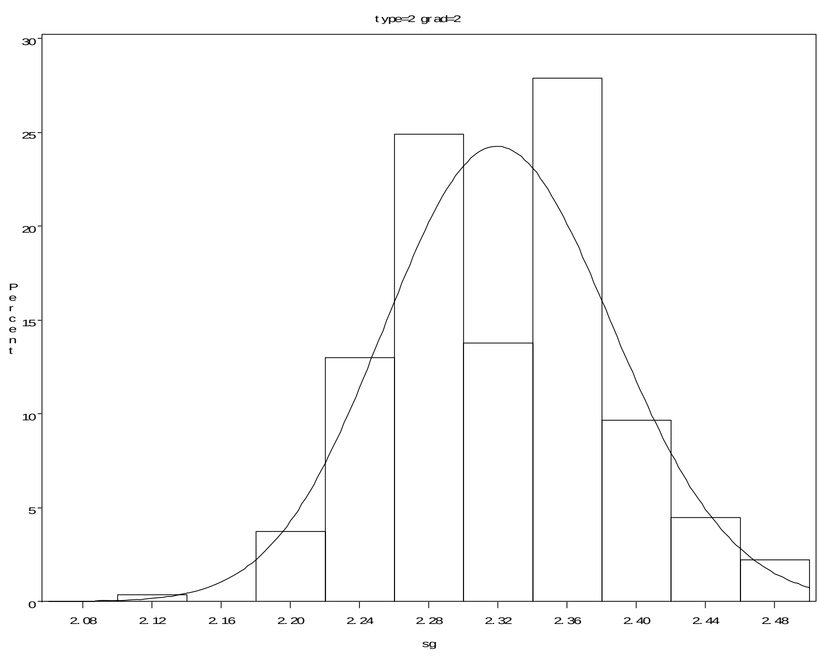

type=3 grad=1
Cumulative Percent
0
20
40
60
80
100
2.15
2.20
2.25
2.30
2.35
2.40
2.45
2.50
sg
Normal Curve: Mu=2.3574, Sigma=0.0591

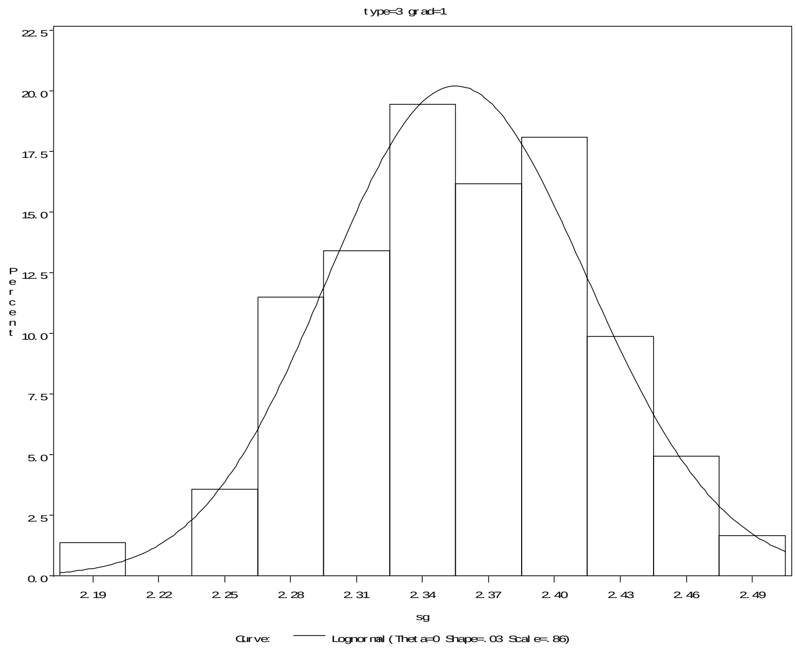

type=3 grad=2
Cumulative Percent
0
20
40
60
80
100
2.1
2.2
2.3
2.4
2.5
2.6
sg
Normal Curve: Mu=2.3242, Sigma=0.0666

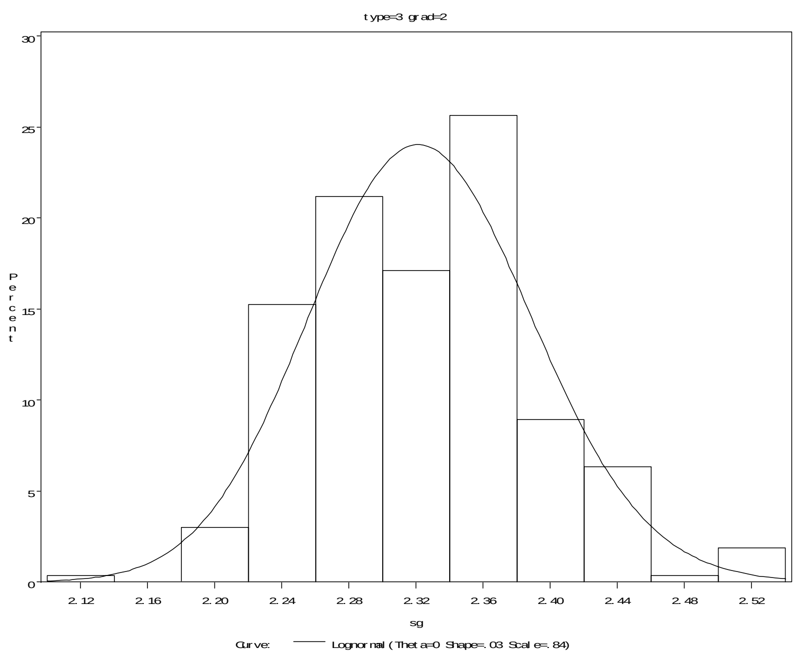

type=1 grad=1
Percent
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
2.13
2.16
2.19
2.22
2.25
2.28
2.31
2.34
2.37
2.40
2.43
sg
Curve: Lognormal (Theta=0 Shape=.03 Scale=.83)

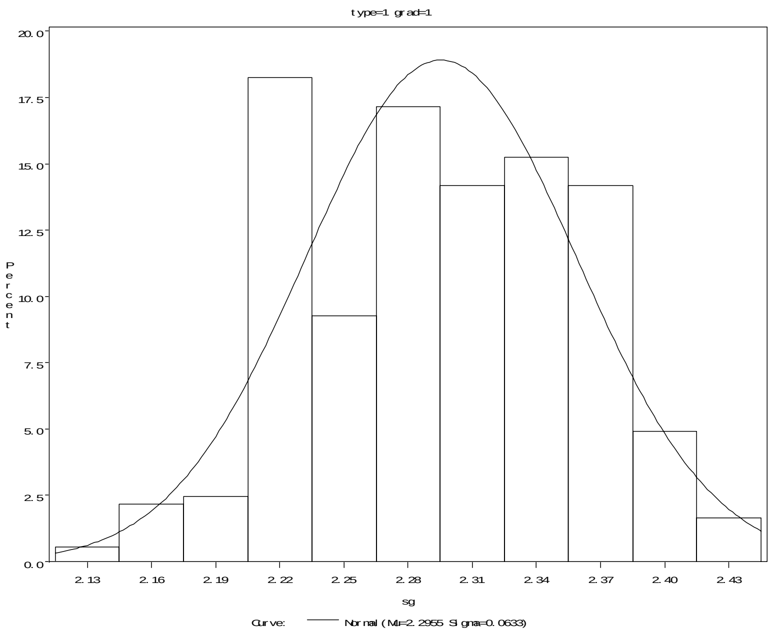

type=1 grad=2
Percent
30
25
20
15
10
5
0
1.975
2.025
2.075
2.125
2.175
2.225
2.275
2.325
2.375
2.425
2.475
sg
Curve: Lognormal (Theta=0 Shape=.03 Scale=.83)

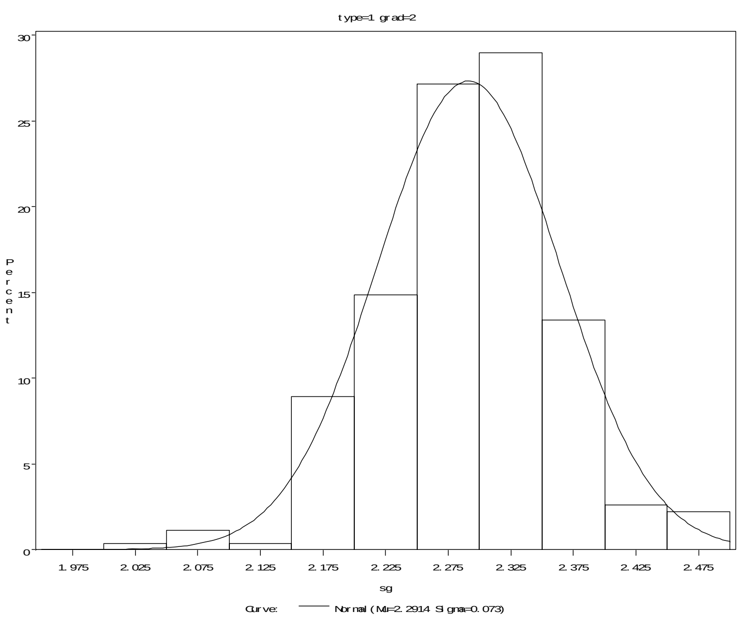

type=2 grad=1
Percent
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
2.163
2.188
2.213
2.238
2.263
2.288
2.313
2.338
2.363
2.388
2.413
2.438
2.463
sg
Curve: Lognormal (Theta=0 Shape=.03 Scale=.85)

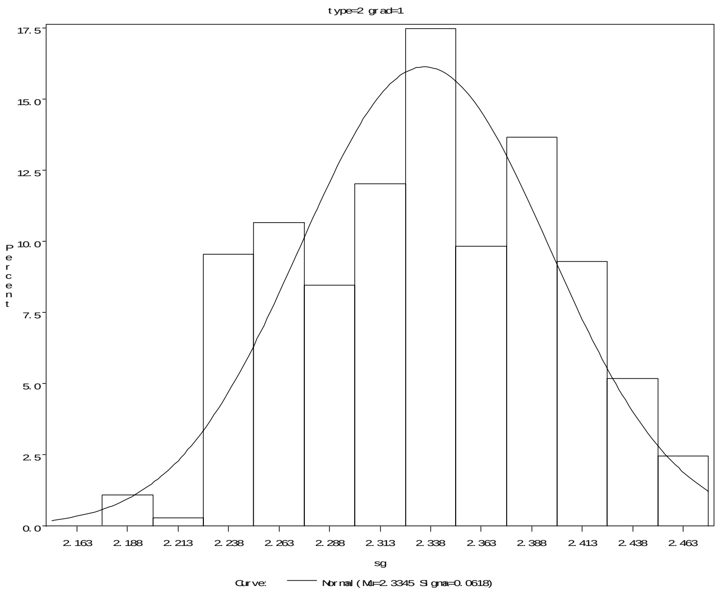

type=2 grad=2
Percent
0
5
10
15
20
25
30
2.08
2.12
2.16
2.20
2.24
2.28
2.32
2.36
2.40
2.44
2.48
sg
Curve: Lognormal (Theta=0 Shape=.03 Scale=.84)

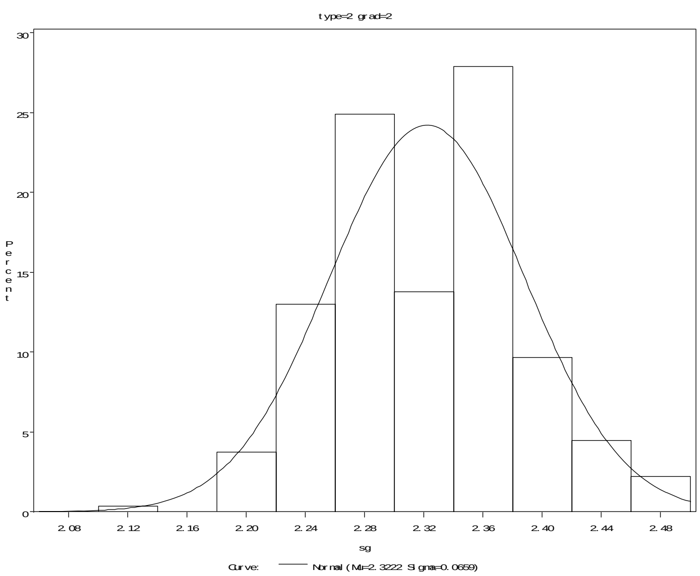

type=3 grad=1
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
Percent
2.19
2.22
2.25
2.28
2.31
2.34
2.37
2.40
2.43
2.46
2.49
sg
Curve: Lognormal (Theta=0 Shape=.03 Scale=.86)

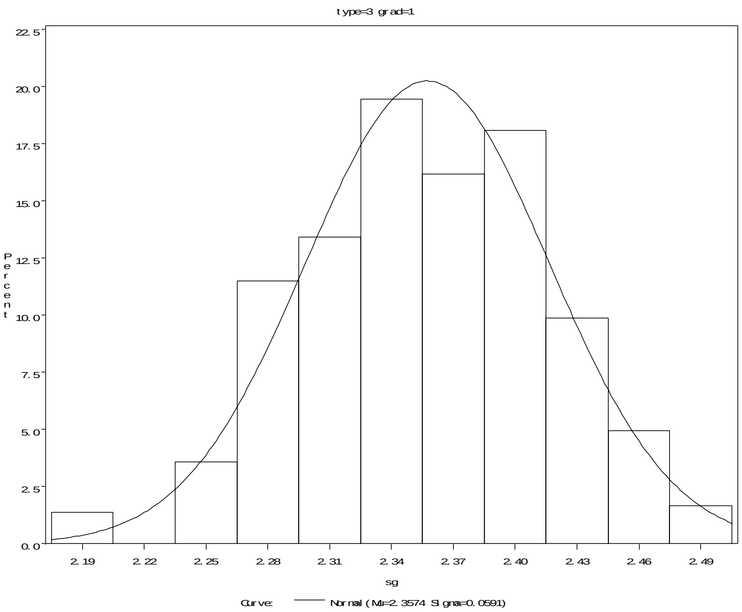

type=3 grad=2
30
25
20
15
10
5
0
Percent
2.12
2.16
2.20
2.24
2.28
2.32
2.36
2.40
2.44
2.48
2.52
sg
Curve: Lognormal (Theta=0 Shape=.03 Scale=.84)

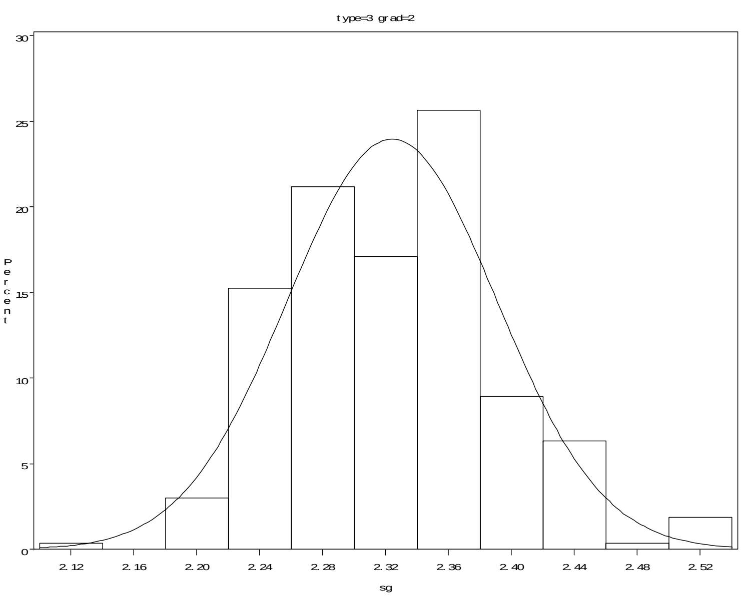

type=1 grad=1
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
Percent
2.13
2.16
2.19
2.22
2.25
2.28
2.31
2.34
2.37
2.40
2.43
sg
Curve: Normal (Mu=2.2955 Sigma=0.0633)

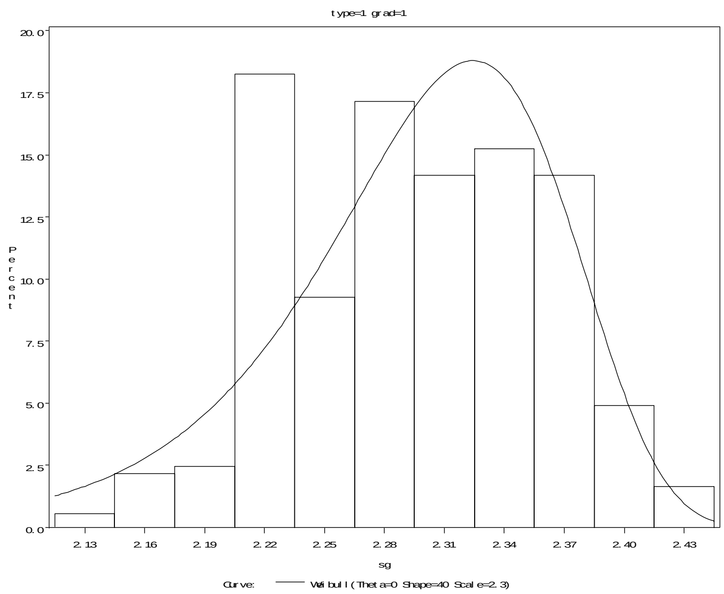

type=1 grad=2
30
25
20
15
10
5
0
Percent
1.975
2.025
2.075
2.125
2.175
2.225
2.275
2.325
2.375
2.425
2.475
sg
Curve: Normal (Mu=2.2914 Sigma=0.073)

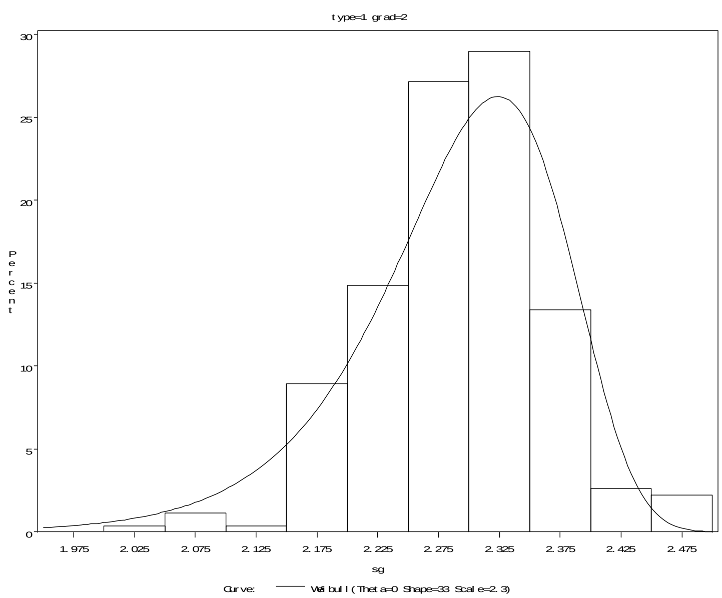

type=2 grad=1
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
Percent
2.163
2.188
2.213
2.238
2.263
2.288
2.313
2.338
2.363
2.388
2.413
2.438
2.463
sg
Curve: Normal (Mu=2.3345 Sigma=0.0618)

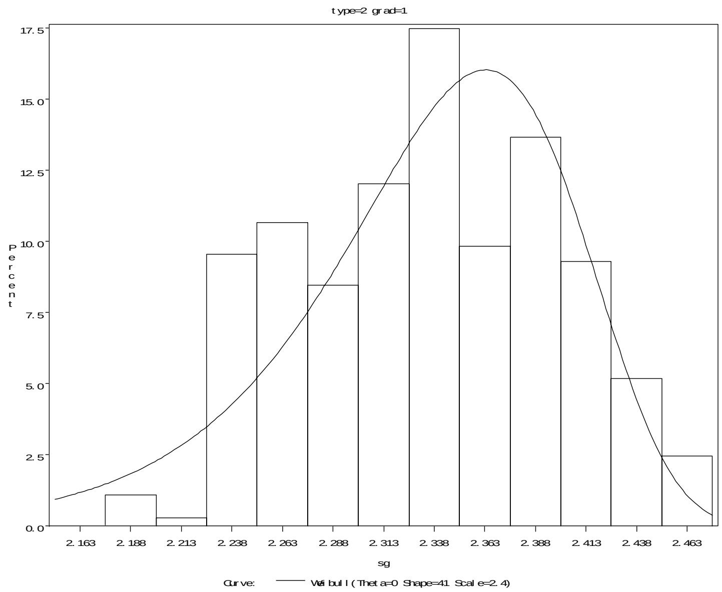

type=2 grad=2
30
25
20
15
10
5
0
Percent
2.08
2.12
2.16
2.20
2.24
2.28
2.32
2.36
2.40
2.44
2.48
sg
Curve: Normal (Mu=2.3222 Sigma=0.0659)

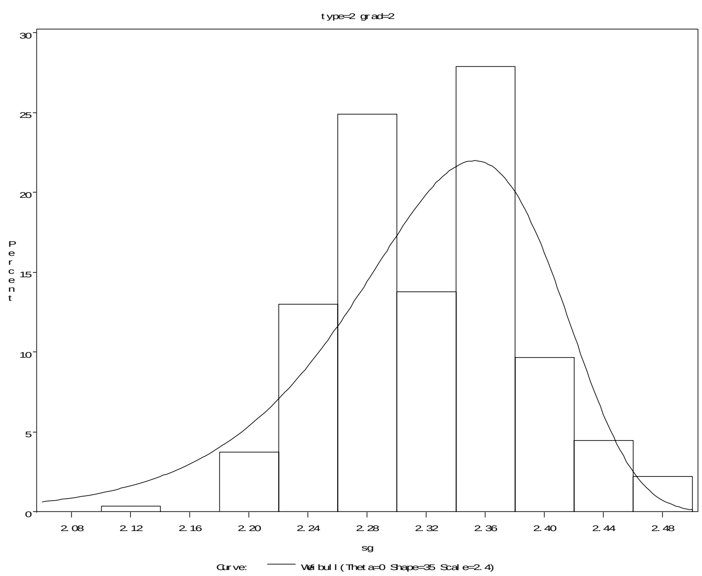

type=3 grad=1
Percent
sg
Curve: Normal (Mu=2.3574 Sigma=0.0591)

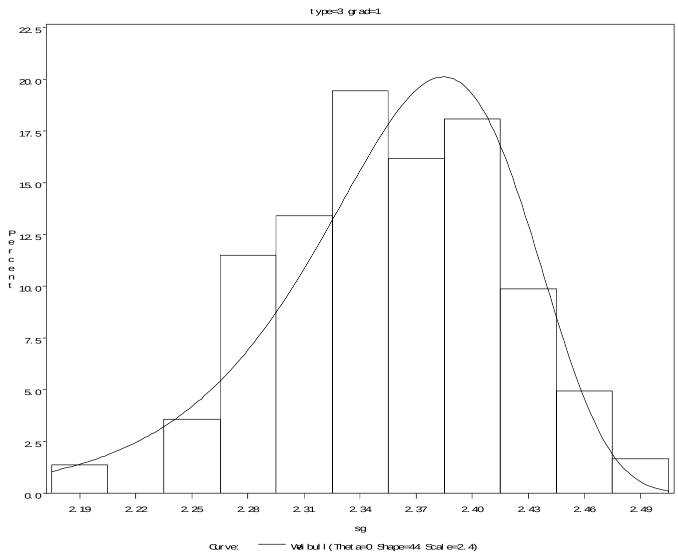

type=3 grad=2
Percent
sg
Curve: Normal (Mu=2.3242 Sigma=0.0666)

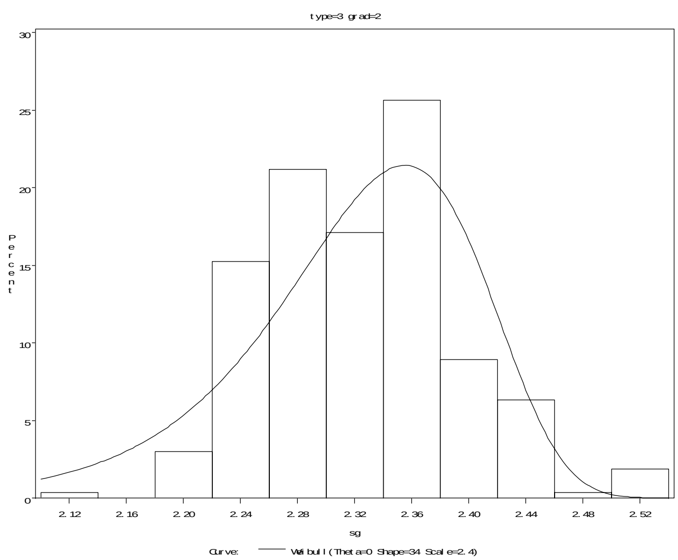

type=1 grad=1
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
Percent
2.13
2.16
2.19
2.22
2.25
2.28
2.31
2.34
2.37
2.40
2.43
sg
Curve: Weibull (Theta=0 Shape=40 Scale=2.3)


type=1 grad=2
30
25
20
15
10
5
0
Percent
1.975
2.025
2.075
2.125
2.175
2.225
2.275
2.325
2.375
2.425
2.475
sg
Curve: Weibull (Theta=0 Shape=33 Scale=2.3)

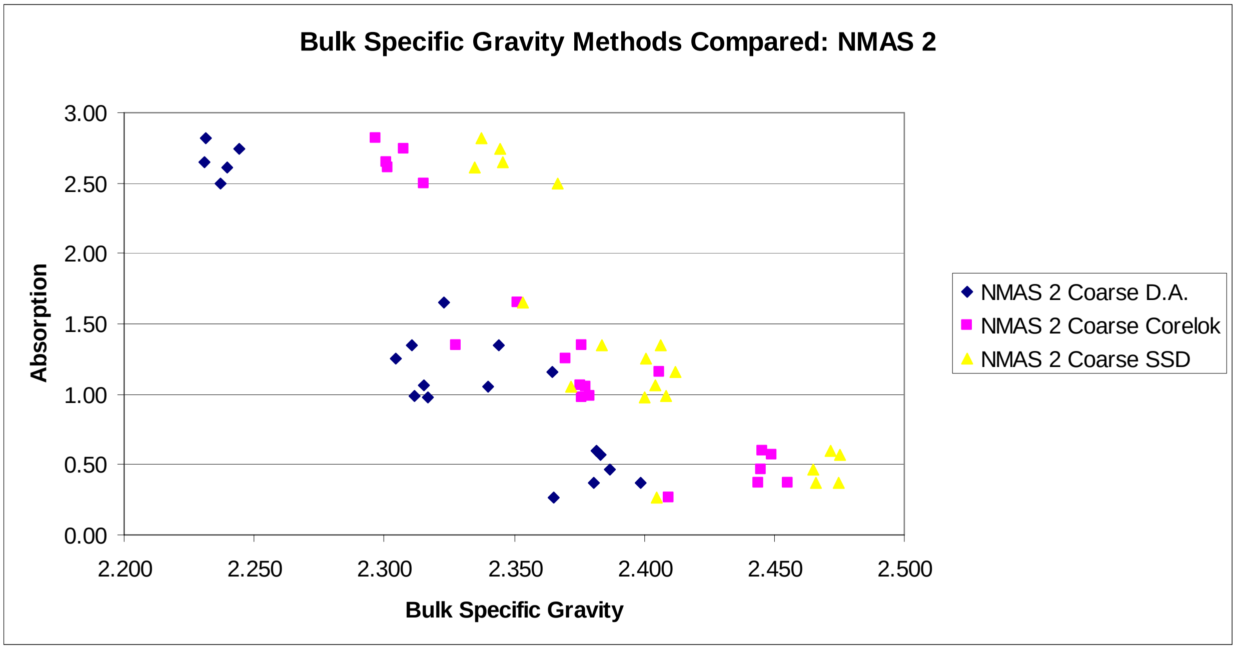

type=2 grad=1
Percent
sg
Curve: Weibull (Theta=0 Shape=41 Scale=2.4)

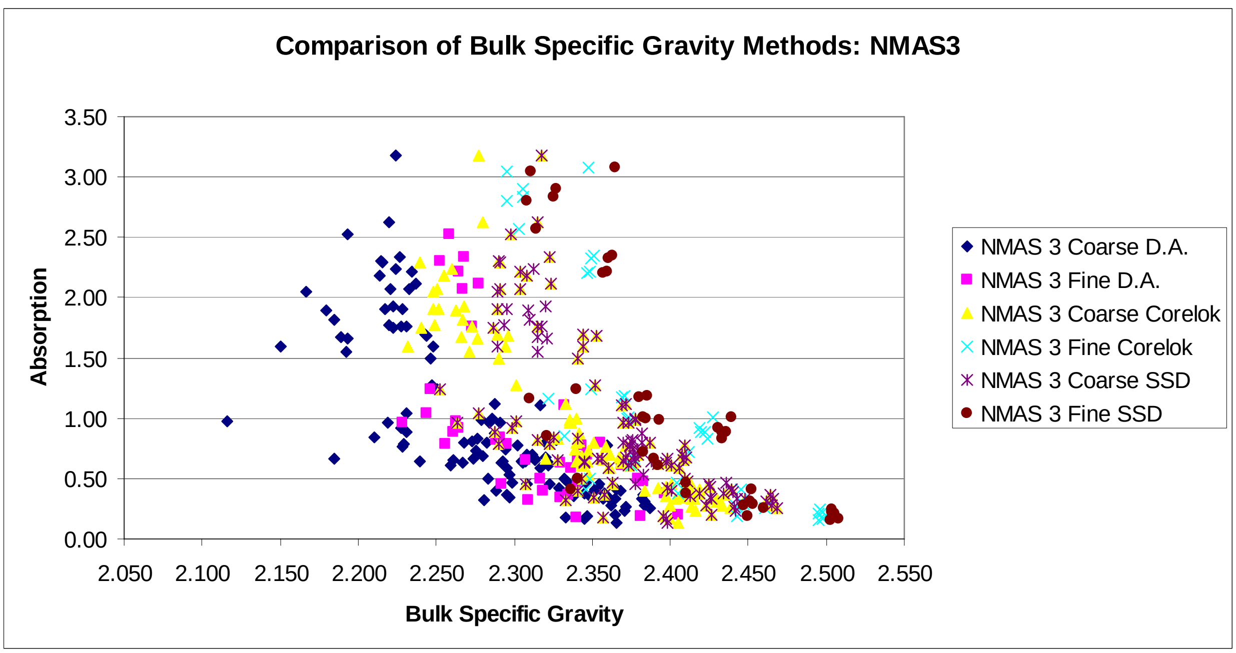

type=2 grad=2
Percent
sg
Curve: Weibull (Theta=0 Shape=35 Scale=2.4)

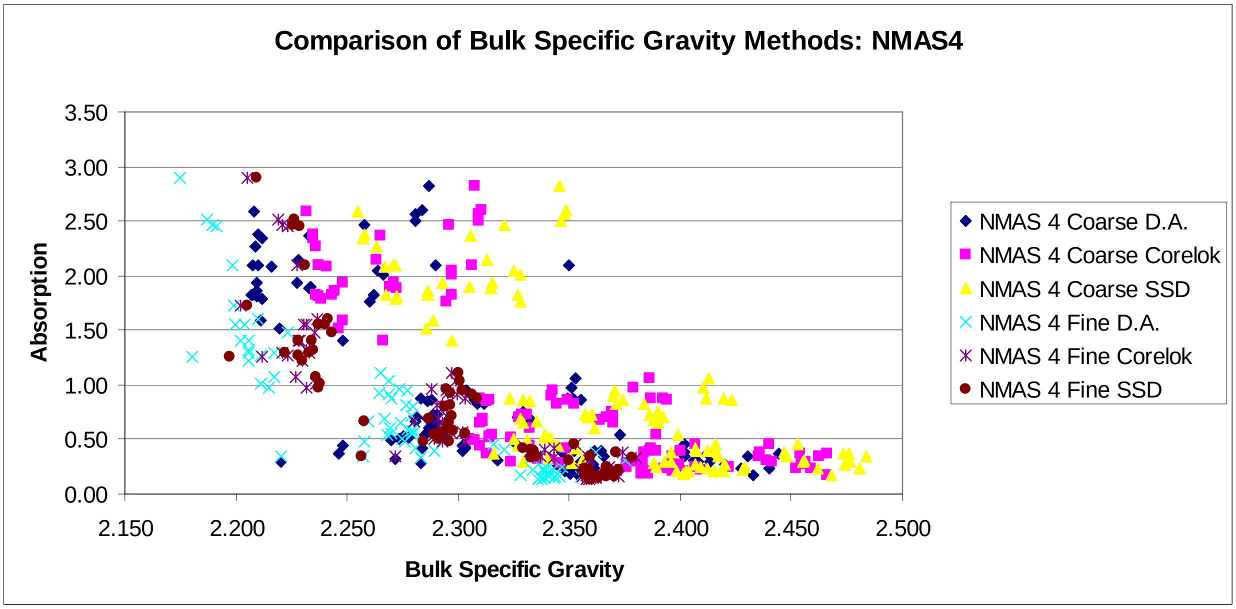

type=3 grad=1
Percent
sg
Curve: Weibull (Theta=0 Shape=44 Scale=2.4)


type=3 grad=2
Percent
sg
Curve: Weibull (Theta=0 Shape=34 Scale=2.4)

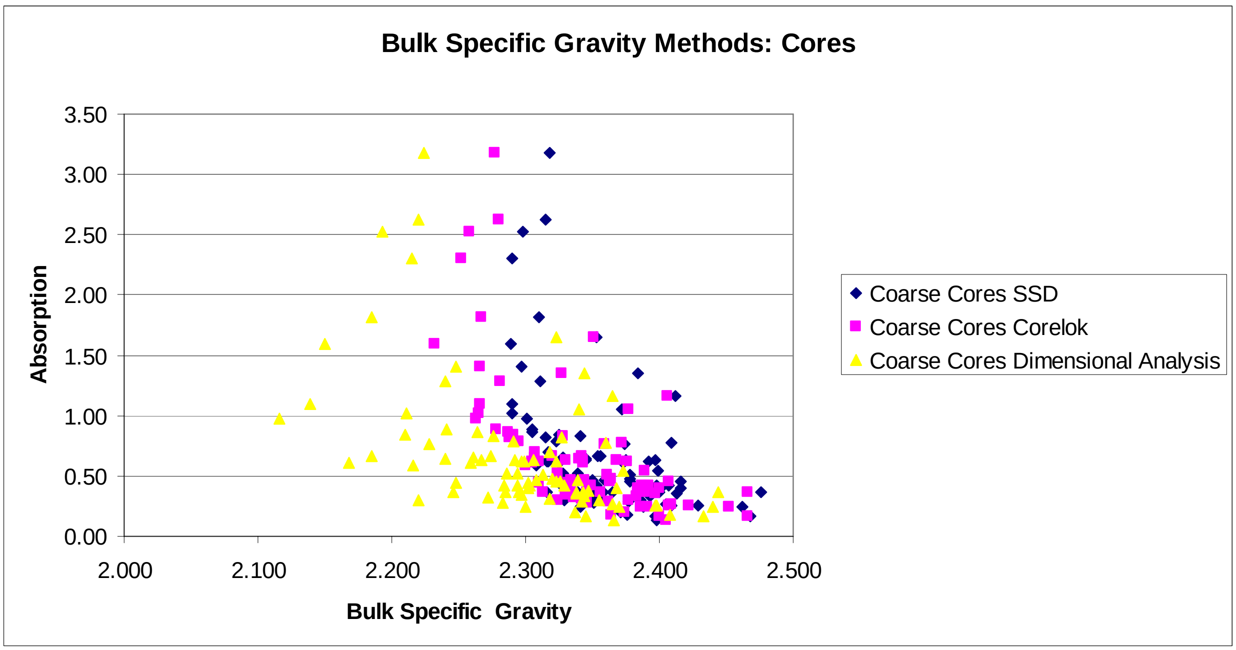
Appendix B: Plots of Bulk Specific Gravities



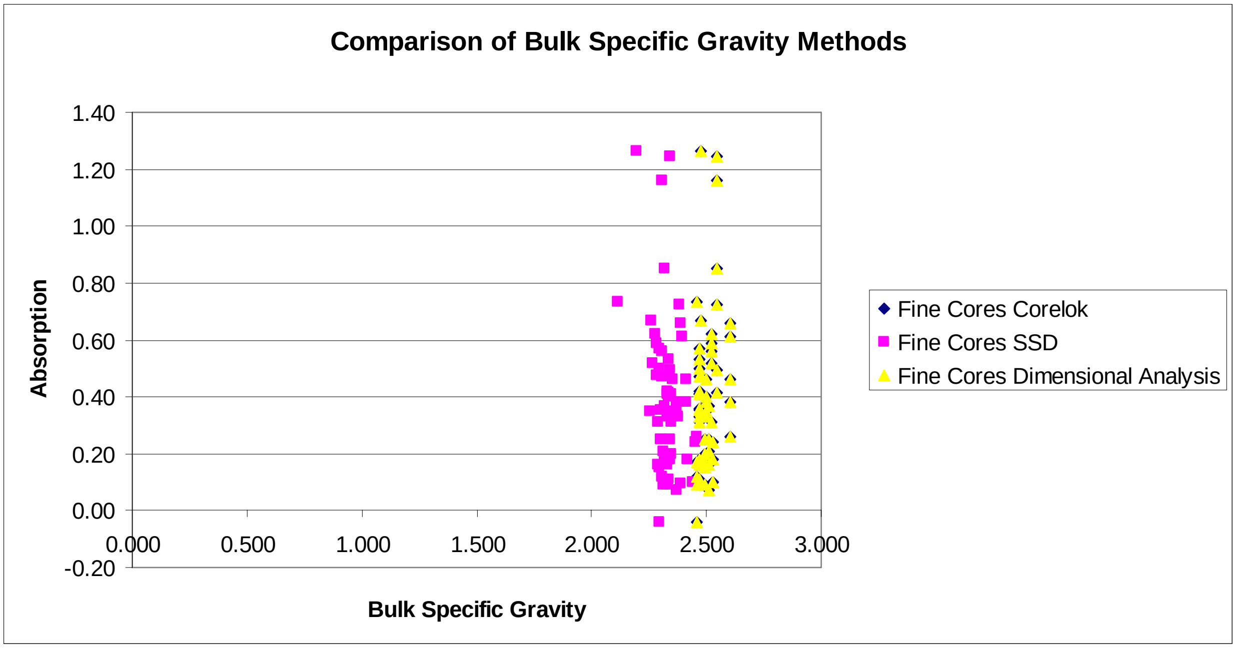


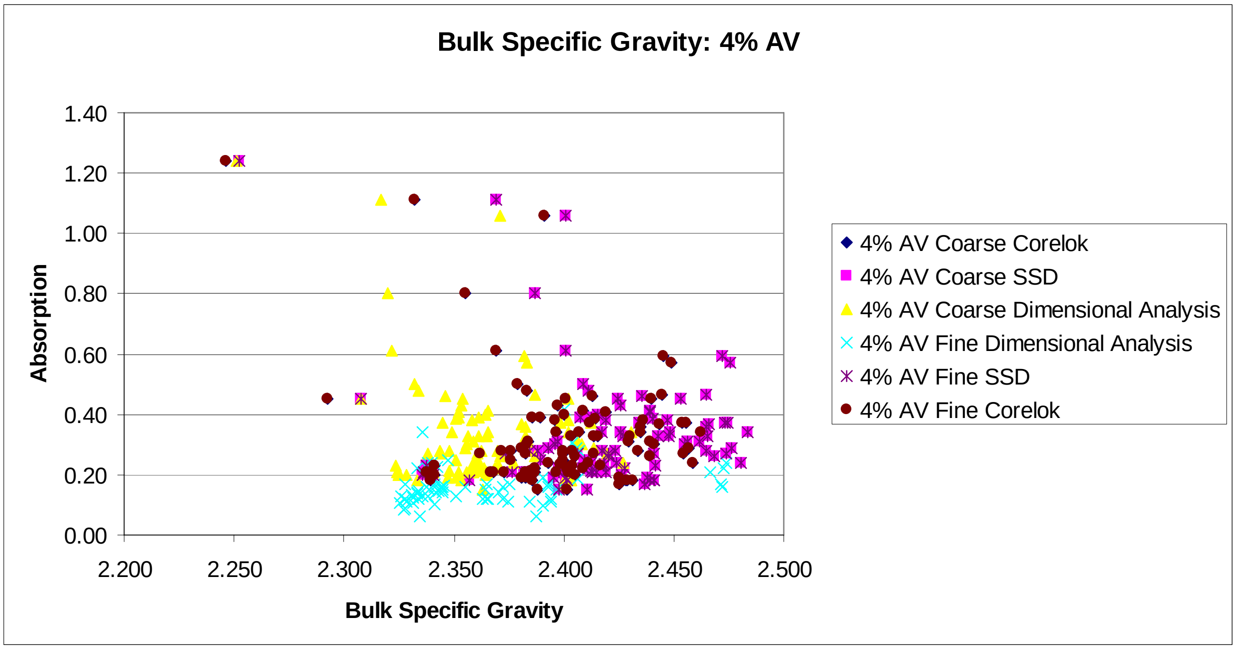


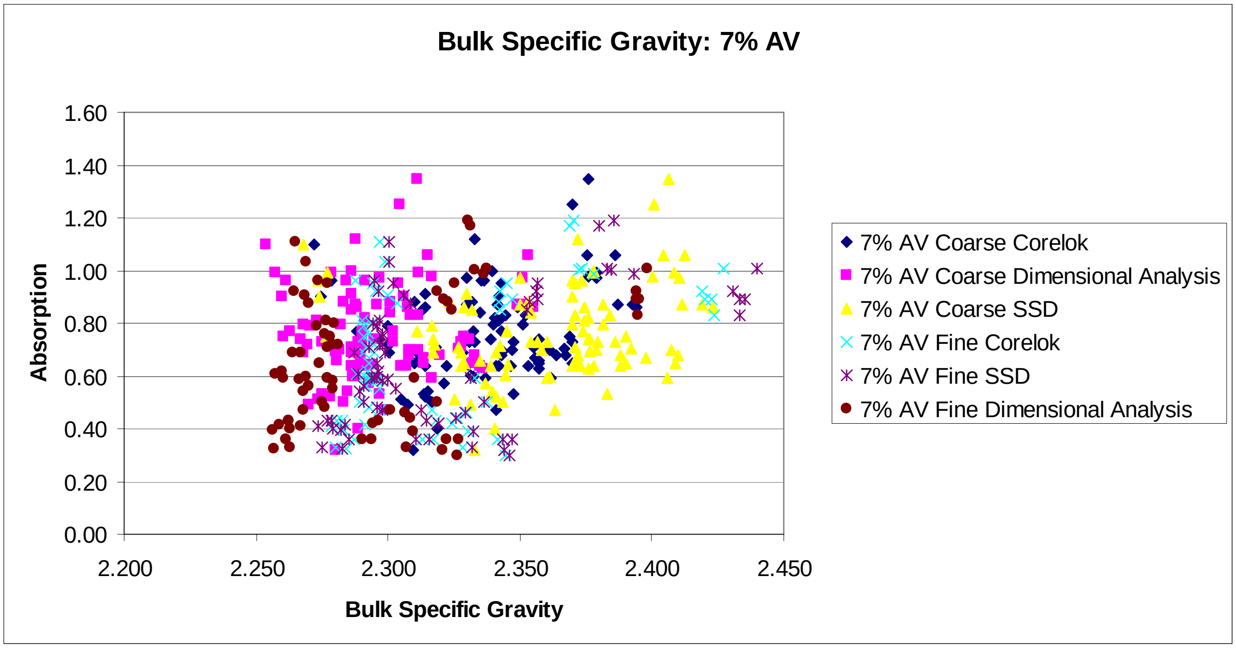
Comparison of Bulk Specific Gravity Methods: NMAS4
Absorption
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2.150
2.200
2.250
2.300
2.350
2.400
2.450
2.500
Bulk Specific Gravity
NMAS 4 Coarse D.A.
NMAS 4 Coarse Corelok
NMAS 4 Coarse SSD
NMAS 4 Fine D.A.
NMAS 4 Fine Corelok
NMAS 4 Fine SSD

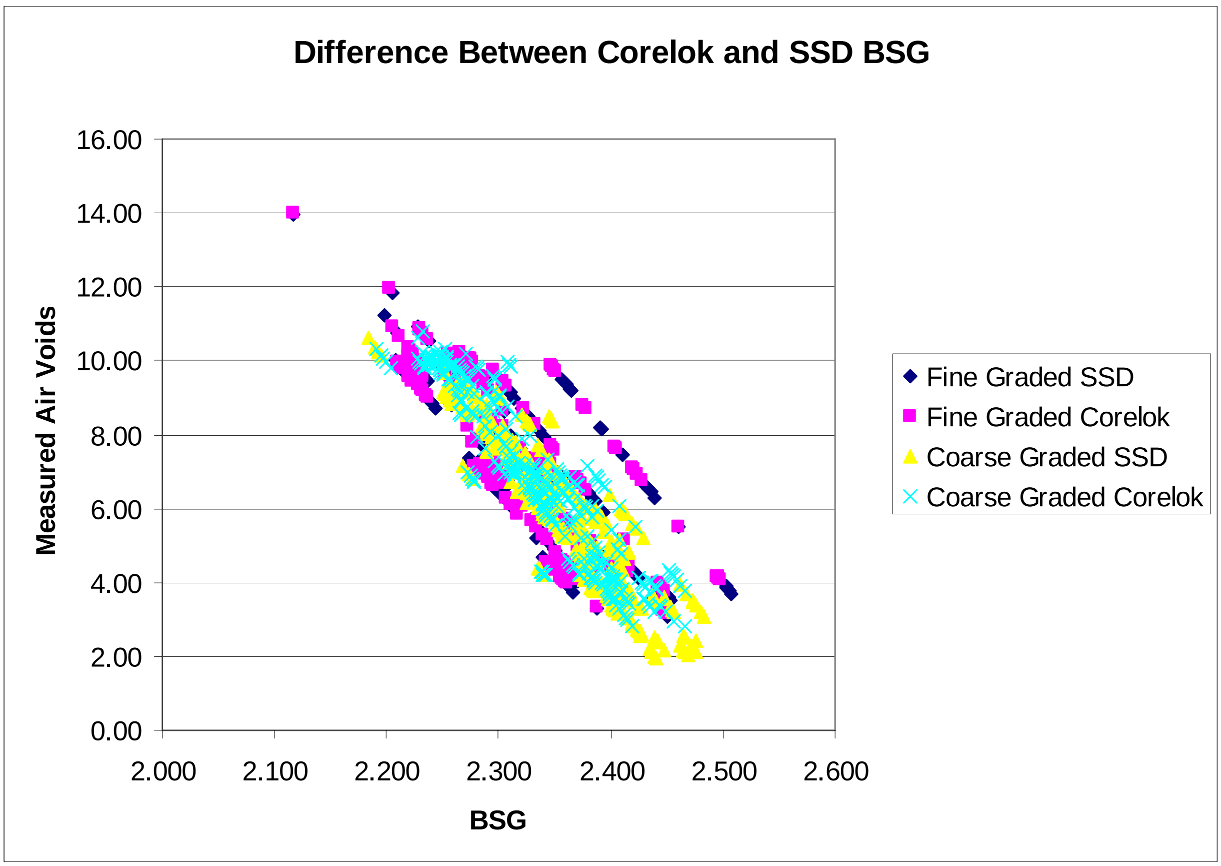


Bulk Specific Gravity Methods: Cores
Absorption
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2.000
2.100
2.200
2.300
2.400
2.500
Bulk Specific Gravity
Coarse Cores SSD
Coarse Cores Corelok
Coarse Cores Dimensional Analysis


Comparison of Bulk Specific Gravity Methods
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
0.000
0.500
1.000
1.500
2.000
2.500
3.000
Absorption
Bulk Specific Gravity
Fine Cores Corelok
Fine Cores SSD
Fine Cores Dimensional Analysis


Bulk Specific Gravity: 4% AV
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
2.200
2.250
2.300
2.350
2.400
2.450
2.500
Absorption
Bulk Specific Gravity
4% AV Coarse Corelok
4% AV Coarse SSD
4% AV Coarse Dimensional Analysis
4% AV Fine Dimensional Analysis
4% AV Fine SSD
4% AV Fine Corelok





The SAS System 1

-- job=1 --

```
                  Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

      sg ‚
   2.400 ˆ
         ‚
         ‚
         ‚
         ‚  B
   2.375 ˆ  A
         ‚  A                       A
         ‚                          A
         ‚  A                       F
         ‚  A                       B
   2.350 ˆ  A
         ‚                          A
         ‚                          C
         ‚  C
         ‚  A                       A
   2.325 ˆ
         ‚
         ‚  A
         ‚
         ‚
   2.300 ˆ
         ‚                                                  D
         ‚  A                                               E
         ‚  A                                               A
         ‚
   2.275 ˆ                                                  A
         ‚                                                  C
         ‚                                                  A
         ‚
         ‚
   2.250 ˆ
         ‚
         ‚                                                                          A
         ‚                                                                          B
         ‚                                                                          E
   2.225 ˆ
         ‚  A
         ‚
         ‚                                                                          A
         ‚                                                                          D
   2.200 ˆ                                                                          B
         ‚
         Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
            1                       4                       7                      10

                                               tav
```

```
------------------------------------------ job=2 ------------------------------------------

                 Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

      sg ,
   2.400 ˆ                     D
         ,                     A
         ,                     B
         ,                     C
         ;
   2.375 ˆ
         ,                     A
         ,                     A
         ,                     C
         ;
   2.350 ˆ
         ,
         ,                                           A
         ,                                           A
         ;                                           B
   2.325 ˆ                                           A
         ,  A                                        C
         ,  C                                        B
         ,  B
         ,  C
   2.300 ˆ  B
         ,  A                                        A
         ,                                           A
         ,  A                                        C
         ;
   2.275 ˆ
         ,                                                                   B
         ,  A                                                                C
         ,
         ;
   2.250 ˆ                                                                   B
         ,                                                                   C
         ,
         ,
         ;                                                                   A
   2.225 ˆ                                                                   A
         ,                                                                   C
         ,  A
         ,
         ;
   2.200 ˆ
         ;
         Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
            1                      4                     7                     10

                                            tav
```

```
----------------------------------------------- job=3 -----------------------------------------------

                       Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

           sg ,
        2.400 ˆ                          A
              ,                          B
              ,                          B
              ,                          B
              ,                          A
        2.375 ˆ                          B
              ,
              ,
              ,
              ,  A                       C
        2.350 ˆ                          B
              ,  A
              ,  B
              ,
              ,  A                                               D
        2.325 ˆ  B                                               A
              ,  A
              ,                                                  B
              ,  A                                               C
              ,
        2.300 ˆ  A
              ,  B
              ,                                                  B
              ,                                                  C
              ,
        2.275 ˆ
              ,
              ,  A                                                                       B
              ,                                                                          A
              ,                                                                          B
        2.250 ˆ  B
              ,
              ,                                                                          A
              ,                                                                          C
              ,                                                                          A
        2.225 ˆ
              ,
              ,                                                                          A
              ,                                                                          D
              ,
        2.200 ˆ
              ,
              Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
                 1                       4                       7                      10

                                                   tav
```

```
------------------------------------------- job=4 -------------------------------------------

                Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

     sg ‚
  2.425 ˆ                     A
        ‚                     B
        ‚                     B
        ‚                     A
        ‚                     C
  2.400 ˆ  A                  A
        ‚
        ‚  A
        ‚
        ‚  B
  2.375 ˆ                     A
        ‚                     C
        ‚  A                  A
        ‚  A
        ‚                                        C
  2.350 ˆ  A                                     B
        ‚
        ‚  A
        ‚  A                                     B
        ‚                                        C
  2.325 ˆ
        ‚  A
        ‚  A
        ‚  A
        ‚  A
  2.300 ˆ                                        C
        ‚                                        B
        ‚                                                            A
        ‚                                                            C
        ‚  A                                                         A
  2.275 ˆ
        ‚
        ‚
        ‚                                                            C
        ‚                                                            B
  2.250 ˆ
        ‚
        ‚  A
        ‚                                                            B
        ‚                                                            B
  2.225 ˆ                                                            A
        ‚
        Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
           1                    4                    7                    10

                                           tav
```

```
------------------------------------------ job=5 ------------------------------------------

              Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

 2.375 ˆ
       ‚  A                      A
       ‚  A                      B
       ‚                         G
       ‚
       ‚
 2.350 ˆ  B                      A
       ‚                         C
       ‚                         A
       ‚
       ‚  B
       ‚
 2.325 ˆ
       ‚  A
       ‚
    sg ‚
       ‚  A
       ‚  B
 2.300 ˆ                                                C
       ‚                                                B
       ‚  B                                             E
       ‚
       ‚
       ‚  A                                             B
 2.275 ˆ                                                C
       ‚
       ‚  A
       ‚
       ‚
       ‚
 2.250 ˆ
       ‚
       ‚
       ‚                                                                       A
       ‚                                                                       A
       ‚                                                                       A
 2.225 ˆ  A                                                                    E
       ‚                                                                       B
       ‚
       ‚                                                                       A
       ‚
       ‚                                                                       C
 2.200 ˆ                                                                       A
       Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
          1                      4                      7                     10

                                          tav
```

```
------------------------------------------ job=6 ------------------------------------------

                Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

   sg ,
      ;
2.425 ˆ
      ,
      ,                       A
      ;                       A
2.400 ˆ                       A
      ,
      ,                       A
      ;                       B                       A
2.375 ˆ                                               C
      ,                       B                       A
      ,
      ;                       A
2.350 ˆ                                               A
      ,  A                                            D
      ,
      ;  A                    C
2.325 ˆ  C                    A                                              B
      ,                       B
      ,                                                                      A
      ;  A                                            D                      B
2.300 ˆ                                               A
      ,  D
      ,  A
      ;
2.275 ˆ                                                                      B
      ,                                                                      B
      ,  A                                                                   A
      ;
2.250 ˆ  A
      ,
      ,                                                                      A
      ;                                                                      C
2.225 ˆ                                                                      A
      ,
      ,  B
      ;
2.200 ˆ
      ;
      Šffˆfffffffffffffffffffffffˆfffffffffffffffffffffffˆfffffffffffffffffffffffˆff
         1                       4                       7                      10

                                         tav
```

```
------------------------------------------ job=7 ------------------------------------------

                 Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

   sg ,
      ;
 2.50 ˆ
      ,
      ,
      ,  A
      ,
      ,  A
      ;                        B
 2.45 ˆ                        C
      ,  A                     B
      ,                        C
      ,
      ,
      ,  B
      ;  B                     B
 2.40 ˆ  A                     C
      ,  A                                           C
      ,  B                                           B
      ,
      ,                                              C
      ,                                              B
      ;
 2.35 ˆ  A
      ,
      ,                                              A
      ,  A                                           D                       D
      ,                                                                      A
      ,
      ;
 2.30 ˆ  B                                                                   C
      ,                                                                      B
      ,
      ,
      ,
      ,                                                                      C
      ;                                                                      B
 2.25 ˆ
      ;
      Šffˆffffffffffffffffffffffffˆffffffffffffffffffffffffˆffffffffffffffffffffffffˆff
         1                       4                       7                      10

                                           tav
```

```
------------------------------------------ job=8 ------------------------------------------

                Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

     sg ,
  2.450 ˆ
        ,
        ,                    D
        ,                    A
        ;                    C
  2.425 ˆ                    B
        ,
        ,
        ,
        ;                    B
  2.400 ˆ                    C
        ,  A
        ,
        ,  B
        ;
  2.375 ˆ  B                                      C
        ,                                         B
        ,  A
        ,  B
        ;  B                                      E
  2.350 ˆ
        ,  C
        ,  B
        ,                                         C
        ;                                         B
  2.325 ˆ
        ,
        ,
        ,
        ;
  2.300 ˆ                                                             E
        ,
        ,
        ,
        ;                                                             D
  2.275 ˆ
        ,                                                             A
        ,                                                             A
        ,                                                             D
        ;
  2.250 ˆ
        ;
        Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
           1                       4                       7                      10

                                           tav
```

```
------------------------------------------- job=9 -------------------------------------------

                    Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

     2.375 ˆ  A
           ,
           ,
           ,                                D
           ,  A                             E
           ,                                A
     2.350 ˆ  A
           ,                                A
           ,  B                             B
           ,  A                             B
           ,  C
           ,  A
     2.325 ˆ
           ,  A
           ,
        sg ,
           ,
           ,                                                              A
     2.300 ˆ  A                                                           A
           ,                                                              D
           ,  A                                                           C
           ,                                                              A
           ,
           ,  B                                                           B
     2.275 ˆ                                                              C
           ,
           ,
           ,
           ,
           ,
     2.250 ˆ
           ,
           ,
           ,                                                                                              B
           ,                                                                                              C
           ,                                                                                              A
     2.225 ˆ                                                                                              B
           ,                                                                                              B
           ,                                                                                              C
           ,                                                                                              A
           ,
           ,                                                                                              A
     2.200 ˆ
           Šffˆfffffffffffffffffffffffffffffˆfffffffffffffffffffffffffffffˆfffffffffffffffffffffffffffffˆff
              1                             4                             7                            10

                                                          tav
```

```
------------------------------------------ job=10 ------------------------------------------

                   Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

2.45 ˆ
     ,
     ,
     ,                           A
     ,
     ,                           A
2.40 ˆ
     ,                           A
     ,                           A
     ,
     ,                           A                        A
     ,  A                        A                        A
2.35 ˆ  A                        A
     ,                           A                        C
     ,  B                        A                        B
  sg ,  A
     ,  A                                                 B
     ,                           B                        A
2.30 ˆ  C                                                 A                        A
     ,  B                        A                        B                        A
     ,                                                    B                        A
     ,                                                                             A
     ,  A                                                                          B
     ,  A                                                                          B
2.25 ˆ                           C
     ,                                                                             A
     ,                                                                             B
     ,                                                                             C
     ,                                                                             A
     ,
2.20 ˆ
     ,  A
     ,
     ,
     ,
     ,
2.15 ˆ
     ,
     ,
     ,
     ,  A
     ,
2.10 ˆ
     Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
        1                        4                        7                       10

                                             tav
```

```
----------------------------------------- job=11 -----------------------------------------

                Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

2.40 ˆ                          D
     ‚                          D
     ‚                          B
     ‚  B                       D
     ‚                          A
     ‚
2.35 ˆ  A
     ‚  B
     ‚  C                                               F
     ‚                                                  D
     ‚  B
     ‚  A                                               E
2.30 ˆ  A
     ‚
     ‚
  sg ‚                                                                          B
     ‚                                                                          D
     ‚                                                                          D
2.25 ˆ                                                                          A
     ‚  A                                                                       C
     ‚                                                                          A
     ‚
     ‚
     ‚
2.20 ˆ
     ‚
     ‚
     ‚  A
     ‚
     ‚
2.15 ˆ
     ‚
     ‚
     ‚
     ‚
     ‚
2.10 ˆ
     ‚
     ‚
     ‚  A
     ‚
     ‚
2.05 ˆ
     Šffˆfffffffffffffffffffffffˆfffffffffffffffffffffffˆfffffffffffffffffffffffˆff
        1                       4                       7                      10

                                            tav
```

```
----------------------------------------------- job=12 -----------------------------------------------

                  Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

   sg ,
      ;
 2.45 ˆ
      ,
      ,
      ,                        C
      ,                        B
      ,
      ;
 2.40 ˆ  A                     D
      ,  B                     A
      ,
      ,  A                                           B
      ,                                              C
      ,                        A
      ;                        C
 2.35 ˆ                        A
      ,  A
      ,                                              E
      ,  B
      ,  B
      ,  A
      ;                                                                       A
 2.30 ˆ
      ,                                              A                        B
      ,                                              C                        B
      ,  C                                           A
      ,
      ,
      ;                                                                       A
 2.25 ˆ                                                                       B
      ,                                                                       B
      ,
      ,                                                                       A
      ,  B                                                                    B
      ,                                                                       B
      ;
 2.20 ˆ
      ;
      Šffˆffffffffffffffffffffffffˆffffffffffffffffffffffffˆffffffffffffffffffffffffˆff
         1                     4                     7                    10

                                         tav
```

```
------------------------------------------- job=13 --------------------------------------------

                       Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

         sg ,
       2.40 ˆ
            ,
            ,                          I
            ,                          D
            ,  A                       B
       2.35 ˆ  A
            ,
            ,  C
            ,  A                                               G
            ,                                                  C
       2.30 ˆ  D                                               C
            ,                                                  B
            ,
            ,
            ,                                                                          E
       2.25 ˆ                                                                          E
            ,                                                                          B
            ,                                                                          B
            ,                                                                          A
            ,  B
       2.20 ˆ  A
            ,  A
            ,
            ,
            ,
       2.15 ˆ
            ,
            ,
            ,
            ,
       2.10 ˆ
            ,
            ,
            ,
            ,
       2.05 ˆ
            ,
            ,
            ,  A
            ,
       2.00 ˆ
            ,
            Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
               1                       4                       7                      10

                                                   tav
```

```
------------------------------------------- job=14 --------------------------------------------

                  Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

     sg ,
  2.450 ˆ  B
        ,  A
        ,  C
        ,  A
        ;
  2.425 ˆ                      B
        ,                      C
        ,  B                   C
        ,  A                   B
        ;
  2.400 ˆ
        ,                      D
        ,                      A
        ,
        ;
  2.375 ˆ
        ,
        ,  A
        ,
        ;  A                                       E
  2.350 ˆ
        ,                                          D
        ,                                          A
        ,
        ;
  2.325 ˆ                                          C
        ,                                          B
        ,
        ,
        ;
  2.300 ˆ
        ,
        ,                                                              C
        ,                                                              B
        ;
  2.275 ˆ                                                              E
        ,
        ,
        ,
        ;                                                              A
  2.250 ˆ                                                              D
        ;
        Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
           1                       4                       7                      10

                                          tav
```

```
----------------------------------------- job=15 ------------------------------------------

               Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

 2.55 ˆ
      ‚
      ‚
      ‚
      ‚
      ‚
      ‚                        C
 2.50 ˆ                        D
      ‚                        C
      ‚
      ‚
      ‚                        D
      ‚  A                     A
      ‚  B
 2.45 ˆ
      ‚                                              A
      ‚                                              C
   sg ‚                                              B
      ‚                                              D
      ‚
      ‚  D
 2.40 ˆ                                              A
      ‚  B                                           D
      ‚
      ‚  D
      ‚
      ‚                                                                     B
      ‚  A                                                                  C
 2.35 ˆ                                                                     E
      ‚
      ‚
      ‚                                                                     B
      ‚                                                                     B
      ‚                                                                     A
      ‚
 2.30 ˆ
      ‚
      ‚  A
      ‚
      ‚
      ‚
      ‚
 2.25 ˆ
      Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
         1                        4                        7                        10

                                             tav
```

```
------------------------------------------ job=16 ------------------------------------------

                      Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

    sg ,
 2.350 ˆ
       ,
       ,H
       ,B
       ,A
 2.325 ˆD
       ,
       ,
       ,
       ,
 2.300 ˆ
       ,
       ,
       ,
       ,                                           B
 2.275 ˆ                                           F
       ,                                           B
       ,
       ,                                           D
       ,                                           A
 2.250 ˆ
       ,
       ,
       ,
       ,
 2.225 ˆ
       ,
       ,
       ,
       ,                                                                                       A
 2.200 ˆ                                                                                       A
       ,                                                                                       D
       ,                                                                                       C
       ,                                                                                       A
       ,
 2.175 ˆ
       ,                                                                                       C
       ,                                                                                       B
       ,
       ,
 2.150 ˆ
       ,
       Šˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒ
        4                                          7                                          10

                                                  tav
```

```
------------------------------------------ job=17 ------------------------------------------

                  Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

      sg ,
    2.45 ˆ
         ,
         ,
         ,                           A
         ,                           H
    2.40 ˆ                           A
         ,                           D
         ,                           A
         ,
         ,
    2.35 ˆ                                                     C
         ,                                                     G
         ,                                                     B
         ,                                                     C
         ,  A
    2.30 ˆ  A
         ,  C                                                                             C
         ,  D                                                                             F
         ,  B                                                                             A
         ,                                                                                C
    2.25 ˆ                                                                                B
         ,
         ,  A
         ,
         ,
    2.20 ˆ
         ,
         ,
         ,  A
         ,
    2.15 ˆ
         ,
         ,
         ,
         ,
    2.10 ˆ
         ,  A
         ,
         ,
         ,  A
    2.05 ˆ
         ,
         Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
            1                         4                         7                        10

                                                  tav
```

```
------------------------------------------ job=18 ------------------------------------------

                 Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

   sg ,
      ,
2.450 ˆ
      ,
      ,
      ,
2.425 ˆA
      ,B
      ,A
      ,B
2.400 ˆA
      ,A
      ,B
      ,                                       A
2.375 ˆ                                       A
      ,A                                      C
      ,C
      ,
2.350 ˆA                                      B
      ,                                       C
      ,
      ,
2.325 ˆ
      ,
      ,                                       A                                       C
      ,                                       D                                       B
2.300 ˆ
      ,
      ,
      ,
2.275 ˆ                                                                               A
      ,                                                                               B
      ,                                                                               B
      ,
2.250 ˆ
      ,
      ,
      ,                                                                               C
2.225 ˆ                                                                               B
      ,
      Šˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒ
       4                                      7                                      10

                                             tav
```

```
------------------------------------------ job=19 -------------------------------------------

                 Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

    2.50 ˆ
         ,
         ,
         ,
         ,                                D
         ,                                A
    2.45 ˆ
         ,                                A
         ,                                D
         ,
         ,
         ,  A                             D
    2.40 ˆ  A                                                          A
         ,
         ,                                E
      sg ,  C
         ,  A                                                          A
         ,  B                                                          D
    2.35 ˆ                                                                                          B
         ,  B                                                                                          C
         ,
         ,
         ,  A                                                          D
         ,  A                                                          A
    2.30 ˆ                                                                                          B
         ,                                                                                             C
         ,
         ,
         ,  A
         ,  A
    2.25 ˆ                                                                                          C
         ,                                                                                             B
         ,
         ,
         ,
         ,
    2.20 ˆ
         ,
         ,  A
         ,
         ,
         ,
    2.15 ˆ
         Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
            1                             4                             7                            10

                                                 tav
```

```
------------------------------------------ job=20 ------------------------------------------

                  Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

           sg ,
              ;
        2.500 ^
              ,
              ,
              ;                         B
        2.475 ^                         C
              ,  B
              ,  A                      A
              ;                         D
        2.450 ^  A
              ,
              ,  A
              ;  B                      A
        2.425 ^  A                      A                      A
              ,                         A                      A
              ,                         B                      C
              ;  B
        2.400 ^  C
              ,                                                B
              ,  A                                             B
              ;                                                A
        2.375 ^  A
              ,
              ,
              ;                                                A
        2.350 ^  A                                             D                      B
              ,                                                                       B
              ,
              ;
        2.325 ^
              ,
              ,                                                                       A
              ;                                                                       D
        2.300 ^
              ,
              ,                                                                       B
              ;                                                                       C
        2.275 ^
              ;
              Šff^ffffffffffffffffffffff^ffffffffffffffffffffff^ffffffffffffffffffffff^ff
                 1                      4                      7                      10

                                                   tav
```

```
------------------------------------------ job=21 ------------------------------------------

                  Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

   sg ,
      ,
2.425 ˆ
      ,
      ,
      ,A
2.400 ˆD
      ,
      ,B
      ,C
2.375 ˆ
      ,
      ,
      ,
2.350 ˆD
      ,A                                          A
      ,                                           B
      ,                                           A
2.325 ˆ                                           A
      ,
      ,                                           C
      ,                                           B
2.300 ˆ
      ,
      ,
      ,                                           A
2.275 ˆ                                           C                                           C
      ,                                           A                                           B
      ,
      ,
2.250 ˆ
      ,
      ,                                                                                       E
      ,
2.225 ˆ
      ,
      ,                                                                                       C
      ,                                                                                       B
2.200 ˆ
      ,
      Šˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒ
       4                                          7                                          10

                                                 tav
```

```
------------------------------------------ job=22 ------------------------------------------

                    Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

2.375 ˆ
      ,
      ,A
      ,A
      ,G
      ,B
2.350 ˆ
      ,
      ,
      ,B
      ,B
      ,
2.325 ˆ
      ,
      ,
   sg ,
      ,
      ,
2.300 ˆ                                             A
      ,                                             G
      ,                                             A
      ,                                             A
      ,
      ,                                             B
2.275 ˆ                                             C
      ,
      ,
      ,
      ,
      ,
2.250 ˆ
      ,                                                                                          A
      ,                                                                                          B
      ,                                                                                          C
      ,                                                                                          B
      ,                                                                                          B
2.225 ˆ                                                                                          A
      ,
      ,
      ,
      ,                                                                                          A
      ,                                                                                          A
2.200 ˆ                                                                                          B
      Šˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒ
       4                                            7                                           10

                                                   tav
```

```
------------------------------------------ job=23 ------------------------------------------

                  Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

   2.45 ˆ                        A
        ‚                        C
        ‚                        A
        ‚
        ‚
        ‚  A                     D
        ‚                        A
   2.40 ˆ  B
        ‚
        ‚  A                                           B
        ‚  A                                           C
        ‚  A                     B
        ‚  A                     C
        ‚
   2.35 ˆ                                              A
        ‚                                              C
        ‚  A                                           A
     sg ‚
        ‚  A                                                                 B
        ‚                                                                    A
        ‚  A
   2.30 ˆ                                              A
        ‚                                              C                     B
        ‚  A                                           A
        ‚
        ‚                                                                    B
        ‚  A
        ‚                                                                    A
   2.25 ˆ                                                                    B
        ‚
        ‚
        ‚  A                                                                 A
        ‚                                                                    C
        ‚                                                                    A
        ‚
   2.20 ˆ
        ‚
        ‚  A
        ‚
        ‚
        ‚
        ‚
   2.15 ˆ  A
        Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
           1                     4                     7                     10

                                            tav
```

```
------------------------------------------ job=24 ------------------------------------------

                   Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

  sg ,
     ,
2.36 ˆ
     ,
     ,A
     ,E
2.34 ˆE
     ,B
     ,A
     ,A
2.32 ˆ
     ,
     ,
     ,
2.30 ˆ
     ,
     ,
     ,                                           B
2.28 ˆ                                           E
     ,                                           C
     ,
     ,                                           D
2.26 ˆ                                           A
     ,
     ,
     ,
2.24 ˆ
     ,
     ,
     ,
2.22 ˆ                                                                                      C
     ,                                                                                      D
     ,                                                                                      C
     ,                                                                                      A
2.20 ˆ                                                                                      A
     ,                                                                                      C
     ,
     ,
2.18 ˆ
     ,
     Šˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆ
      4                                          7                                         10

                                                tav
```

```
------------------------------------------ job=25 ------------------------------------------

                      Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

      2.45 ˆ
           ,
           ,
           ,
           ,
           ,  A
      2.40 ˆ
           ,
           ,                                C
           ,  A                             D
           ,  A                             B
           ,                                A
      2.35 ˆ
           ,                                E
           ,
        sg ,  A
           ,                                                              D
           ,  B                                                           A
      2.30 ˆ                                                              D
           ,  B                                                           A
           ,  A
           ,                                                              A
           ,  B                                                           D
           ,                                                                                            B
      2.25 ˆ                                                                                            C
           ,  A
           ,                                                                                            D
           ,                                                                                            A
           ,
           ,  A                                                                                         C
      2.20 ˆ                                                                                            B
           ,
           ,
           ,
           ,  A
           ,
      2.15 ˆ
           ,  A
           ,
           ,
           ,
           ,
      2.10 ˆ
           Šffˆfffffffffffffffffffffffffffffˆfffffffffffffffffffffffffffffˆfffffffffffffffffffffffffffffˆff
              1                             4                             7                            10

                                                          tav
```

```
--------------------------------------- job=26 ------------------------------------------

                Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

   sg ,
      ;
 2.45 ˆ
      ,
      ,
      ,
      ,                       C
      ,                       B
      ;
 2.40 ˆ                       C
      ,                       B
      ,
      ,
      ,
      ,                       B                       A
      ;                       C                       C
 2.35 ˆ   C
      ,   B
      ,   A                                           A
      ,   A                                           D
      ,   A
      ,   B                                           A
      ;
 2.30 ˆ
      ,                                               A                       A
      ,   B                                           C                       D
      ,                                               A
      ,   A
      ,
      ;
 2.25 ˆ                                                                       C
      ,   A                                                                   B
      ,
      ,
      ,   A                                                                   A
      ,                                                                       A
      ;                                                                       C
 2.20 ˆ
      ;
      Šffˆffffffffffffffffffffffffˆffffffffffffffffffffffffˆffffffffffffffffffffffffˆff
        1                       4                       7                      10

                                          tav
```

-- job=27 --

Plot of sg*tav. Legend: A = 1 obs, B = 2 obs, etc.

```
       2.45 ˆ
            ,                          A
            ,                          C
            ,                          A
            ,                          A
            ,                          C
            ,  A                       A
       2.40 ˆ  C
            ,
            ,
            ,                                                  D
            ,  A                                               A
            ,  A
            ,  B
       2.35 ˆ                          C                       B
            ,  D                       B                       C
            ,
         sg ,
            ,                                                                          A
            ,                                                                          B
            ,                                                                          A
       2.30 ˆ
            ,
            ,                                                                          A
            ,                                                  C                       A
            ,  A                                               B                       A
            ,                                                                          B
            ,
       2.25 ˆ                                                                          A
            ,  A
            ,
            ,  A
            ,
            ,
            ,
       2.20 ˆ
            ,                                                                          B
            ,                                                                          A
            ,                                                                          A
            ,
            ,                                                                          A
            ,
       2.15 ˆ
            Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
               1                       4                       7                      10

                                                  tav
```

```
------------------------------------------ job=28 --------------------------------------------

                    Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

      sg ,
         ;
   2.475 ˆ
         ,
         ,
         ;
   2.450 ˆ                        F
         ,                        D
         ,
         ;
   2.425 ˆ
         ,
         ,  A
         ;                        D
   2.400 ˆ                        A
         ,                                    A
         ,                                    B
         ;  A                                 B
   2.375 ˆ                                    C
         ,                                    B
         ,
         ;  A
   2.350 ˆ  B
         ,  B
         ,  B                                 B
         ;  A                                 C
   2.325 ˆ  B                                             B
         ,  B
         ,  B                                             B
         ;                                                C
   2.300 ˆ  A                                             A
         ,  A                                             B
         ,
         ;
   2.275 ˆ
         ,
         ,                                                B
         ;                                                C
   2.250 ˆ
         ;
         Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
            1                         4                         7                        10

                                                 tav
```

```
------------------------------------------ job=29 ------------------------------------------

                 Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

      2.50 ˆ
           ,
           ,
           ,                          B
           ,                          A
           ,                          B
           ,                          A
      2.45 ˆ                          A
           ,                          C
           ,
           ,
           ,
           ,  A
           ,  C                                               C
      2.40 ˆ                          A                       B
           ,
           ,  A                       B
        sg ,  A                       B                       D
           ,  A                                               A
           ,  B                                                                       A
           ,
      2.35 ˆ  B
           ,  B                                                                       B
           ,                                                                          B
           ,  A
           ,  A
           ,                                                  D                       A
           ,                                                  A                       A
      2.30 ˆ                                                                          C
           ,
           ,
           ,
           ,
           ,
           ,
      2.25 ˆ
           ,                                                                          B
           ,                                                                          A
           ,                                                                          B
           ,
           ,
           ,
      2.20 ˆ
           Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
              1                       4                       7                      10

                                                  tav
```

```
---------------------------------------- job=30 ------------------------------------------

                 Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

         sg ,
            ;
      2.425 ˆ
            ,
            ,                      B
            ;                      C
      2.400 ˆ                      E
            ,  A
            ,  B
            ;
      2.375 ˆ  A
            ,  B
            ,                      E
            ;
      2.350 ˆ  A
            ,  B                                       E
            ,  B
            ;                                          C
      2.325 ˆ  C                                       B
            ,
            ,
            ;
      2.300 ˆ  A
            ,  A                                       A
            ,  B                                       D
            ;
      2.275 ˆ                                                              D
            ,                                                              A
            ,
            ;                                                              C
      2.250 ˆ                                                              B
            ,
            ,
            ;
      2.225 ˆ
            ,                                                              A
            ,                                                              C
            ;                                                              A
      2.200 ˆ
            ;
            Šffˆfffffffffffffffffffˆfffffffffffffffffffˆfffffffffffffffffffˆff
               1                   4                   7                  10

                                            tav
```

```
------------------------------------------ job=31 ------------------------------------------

                Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

    sg ,
 2.375 ˆ
       ,                      F
       ,                      D
       ,
       ,
 2.350 ˆ
       ,                      A
       ,                      D
       ,
       ,
 2.325 ˆ
       ,
       ,
       ,                                            A
       ,  A                                         B
 2.300 ˆ                                            D
       ,                                            C
       ,
       ,  A
       ,  A
 2.275 ˆ
       ,  A                                         C
       ,                                            B
       ,  C
       ,  B
 2.250 ˆ
       ,
       ,
       ,
       ,                                                                B
 2.225 ˆ                                                                D
       ,                                                                B
       ,
       ,  A                                                             A
       ,                                                                A
 2.200 ˆ                                                                A
       ,  A
       ,                                                                B
       ,                                                                A
       ,  A
 2.175 ˆ                                                                A
       ,
       Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
          1                      4                      7                      10

                                          tav
```

```
------------------------------------------- job=32 --------------------------------------------

                    Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

    2.40 ˆ
         ‚
         ‚
         ‚
         ‚
         ‚
         ‚                          B
    2.35 ˆ                          H
         ‚
         ‚  A
         ‚                          E
         ‚  A
         ‚  D
         ‚  B
    2.30 ˆ
         ‚  A                                               A
         ‚  C                                               H
      sg ‚                                                  A
         ‚
         ‚                                                  A
         ‚                                                  D
    2.25 ˆ
         ‚
         ‚
         ‚                                                                          A
         ‚                                                                          H
         ‚                                                                          A
         ‚
    2.20 ˆ
         ‚                                                                          A
         ‚                                                                          D
         ‚
         ‚
         ‚
         ‚
    2.15 ˆ
         ‚
         ‚
         ‚
         ‚
         ‚  C
         ‚
    2.10 ˆ
         Šƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒƒˆƒƒ
            1                       4                       7                      10

                                                tav
```

```
------------------------------------------ job=33 -------------------------------------------

                 Plot of sg*tav.  Legend: A = 1 obs, B = 2 obs, etc.

     sg ,
        ;
  2.400 ˆ
        ,
        ,  B
        ;
  2.375 ˆ
        ,
        ,  A                      J
        ;
  2.350 ˆ
        ,  A
        ,  A
        ;  B                      E
  2.325 ˆ
        ,
        ,  A
        ;
  2.300 ˆ  C                                              D
        ,                                                 F
        ,  A
        ;
  2.275 ˆ  A
        ,                                                 B
        ,  A                                              C
        ;
  2.250 ˆ  A
        ,
        ,                                                                        B
        ;                                                                        E
  2.225 ˆ                                                                        B
        ,                                                                        A
        ,
        ;
  2.200 ˆ                                                                        A
        ,                                                                        D
        ,
        ;
  2.175 ˆ
        ;
        Šffˆffffffffffffffffffffffˆffffffffffffffffffffffˆffffffffffffffffffffffˆff
           1                      4                       7                     10

                                           tav
```

Appendix C: Hypothesis Testing

Comparison between VSM (variable 1) and SSD (variable 2) bulk specific gravity values

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.329330678	2.343302465
Variance	0.004077856	0.004155446
Observations	634	634
Pearson Correlation	0.970686388	
Hypothesized Mean Difference	0	
df	633	
t Stat	-22.62850242	
P(T<=t) one-tail	7.95046E-84	
t Critical one-tail	1.647264394	
P(T<=t) two-tail	1.59009E-83	
t Critical two-tail	1.963718664	

Significant Statistical Difference

Comparison between VSM (variable 1) and DAM(variable 2)

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.329330678	2.293660365
Variance	0.004077856	0.004570996
Observations	634	634
Pearson Correlation	0.250968563	
Hypothesized Mean Difference	0	
df	633	
t Stat	11.15588361	
P(T<=t) one-tail	8.25778E-27	
t Critical one-tail	1.647264394	
P(T<=t) two-tail	1.65156E-26	
t Critical two-tail	1.963718664	

Significant Statistical Difference

Appendix D: Density Plots and Data for Cores

The KDE Procedure

Inputs

Data Set	WORK.CORES
Number of Observations Used	402
Variable 1	perm
Variable 2	pab
Bandwidth Method	Simple Normal Reference

Controls

	perm	pab
Grid Points	60	60
Lower Grid Limit	0	-0.04
Upper Grid Limit	0.1037	3.18
Bandwidth Multiplier	1	1

Univariate Statistics

	perm	pab
Mean	0.0028	0.56
Variance	0.0001	0.25
Standard Deviation	0.010	0.50
Range	0.10	3.22
Interquartile Range	0.0014	0.35
Bandwidth	0.0038	0.18

Bivariate Statistics

Covariance	0.0014
Correlation	0.28

Percentiles

	perm	pab
0.5	0	-0.040
1.0	0	0.070
2.5	0	0.090
5.0	0	0.10
10.0	0	0.17
25.0	0	0.28
50.0	0.0002	0.42
75.0	0.0014	0.63
90.0	0.0071	1.06

The KDE Procedure

Percentiles

	perm	pab
95.0	0.011	1.59
97.5	0.012	2.30
99.0	0.050	2.63
99.5	0.10	3.18

Levels

Percent	Density	Lower for perm	Upper for perm	Lower for pab	Upper for pab
1	1.7285	0	0.10	-0.040	3.18
5	2.7427	0	0.016	-0.040	2.58
10	9.3356	0	0.011	-0.040	1.22
50	96.3980	0	0.0035	0.18	0.61
90	124.75	0	0	0.40	0.40
95	124.75	0	0	0.40	0.40
99	124.75	0	0	0.40	0.40
100	124.75	0	0	0.40	0.40

The KDE Procedure

Inputs

Data Set	WORK.CORES
Number of Observations Used	402
Variable 1	perm
Variable 2	sg
Bandwidth Method	Simple Normal Reference

Controls

	perm	sg
Grid Points	60	60
Lower Grid Limit	0	2.021
Upper Grid Limit	0.1037	2.476
Bandwidth Multiplier	1	1

Univariate Statistics

	perm	sg
Mean	0.0028	2.32
Variance	0.0001	0.0047
Standard Deviation	0.010	0.068
Range	0.10	0.46
Interquartile Range	0.0014	0.080
Bandwidth	0.0038	0.025

Bivariate Statistics

Covariance	-26E-5
Correlation	-0.38

Percentiles

	perm	sg
0.5	0	2.07
1.0	0	2.12

2.5	0	2.17
5.0	0	2.21
10.0	0	2.25
25.0	0	2.29
50.0	0.0002	2.33
75.0	0.0014	2.37
90.0	0.0071	2.40

The KDE Procedure

Percentiles

	perm	sg
95.0	0.011	2.42
97.5	0.012	2.45
99.0	0.050	2.46
99.5	0.10	2.47

Levels

Percent	Density	Lower for perm	Upper for perm	Lower for sg	Upper for sg
1	9.6379	0	0.10	2.04	2.48
5	27.0545	0	0.016	2.17	2.48
10	73.2529	0	0.012	2.21	2.47
50	441.48	0	0.0053	2.28	2.38
90	590.83	0	0.0018	2.32	2.34
95	595.05	0	0.0018	2.32	2.34
99	598.95	0	0	2.33	2.33
100	598.95	0	0	2.33	2.33

The KDE Procedure

Inputs

Data Set	WORK.CORES
Number of Observations Used	402
Variable 1	pab
Variable 2	sg
Bandwidth Method	Simple Normal Reference

Controls

	pab	sg
Grid Points	60	60
Lower Grid Limit	-0.04	2.021
Upper Grid Limit	3.18	2.476
Bandwidth Multiplier	1	1

Univariate Statistics

	pab	sg
Mean	0.56	2.32
Variance	0.25	0.0047
Standard Deviation	0.50	0.068
Range	3.22	0.46
Interquartile Range	0.35	0.080
Bandwidth	0.18	0.025

Bivariate Statistics

Covariance	-0.011
Correlation	-0.31

Percentiles

	pab	sg
0.5	-0.040	2.07
1.0	0.070	2.12
2.5	0.090	2.17
5.0	0.10	2.21
10.0	0.17	2.25
25.0	0.28	2.29
50.0	0.42	2.33
75.0	0.63	2.37
90.0	1.06	2.40

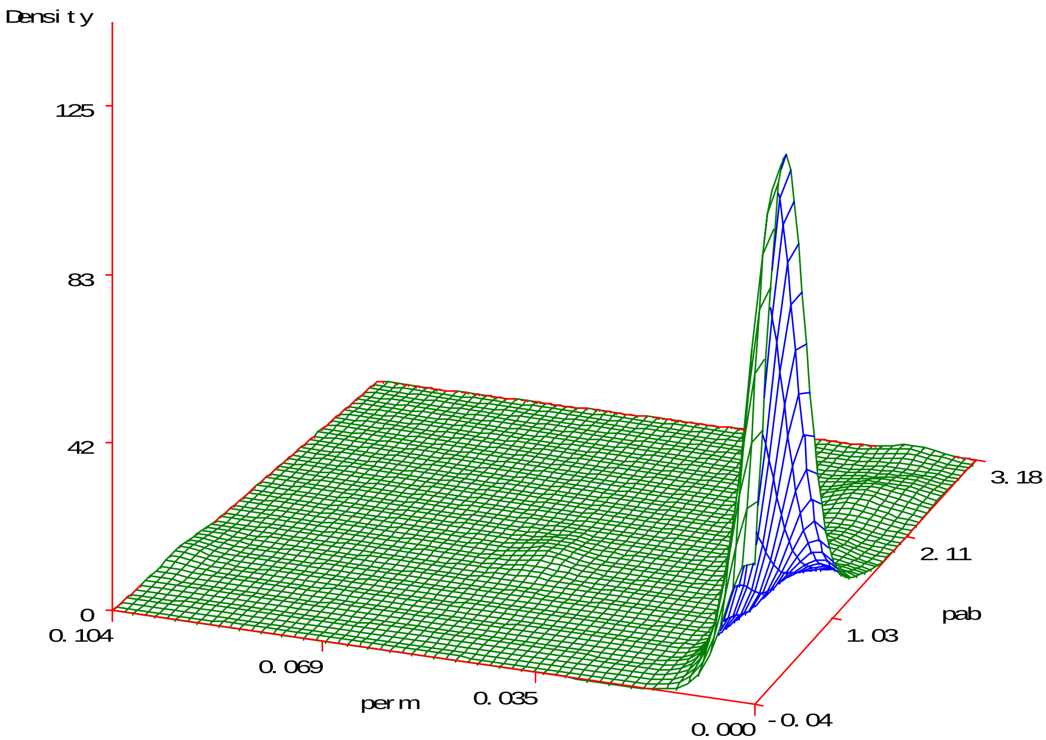
The KDE Procedure

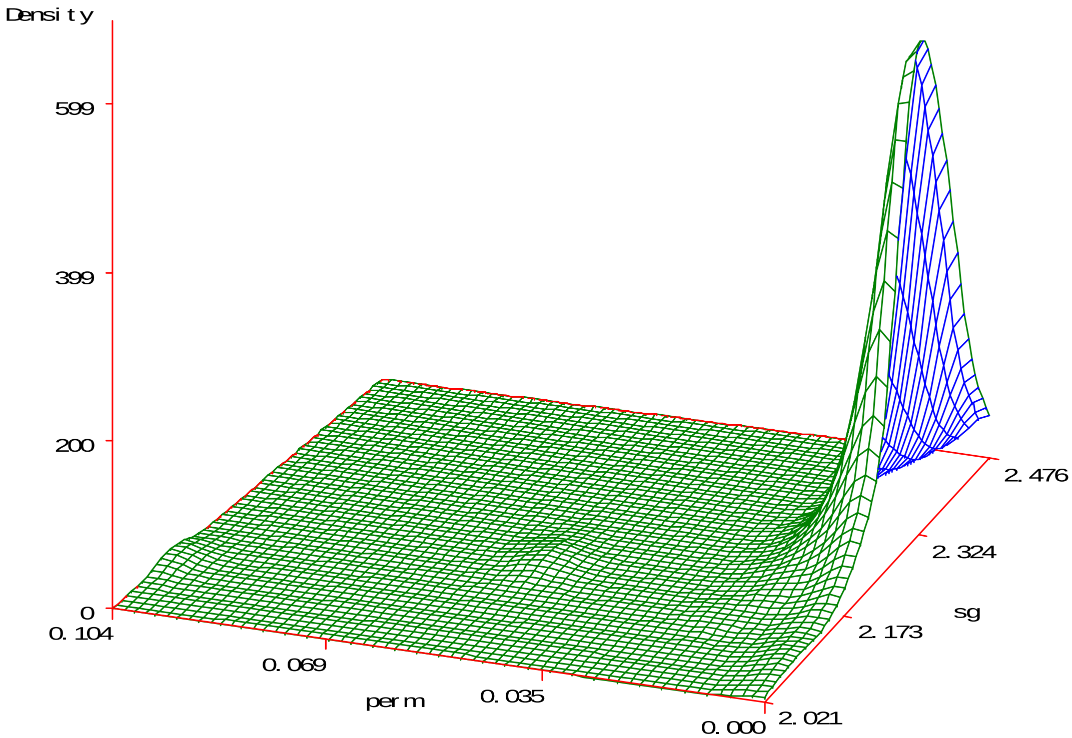
Percentiles

	pab	sg
95.0	1.59	2.42
97.5	2.30	2.45
99.0	2.63	2.46
99.5	3.18	2.47

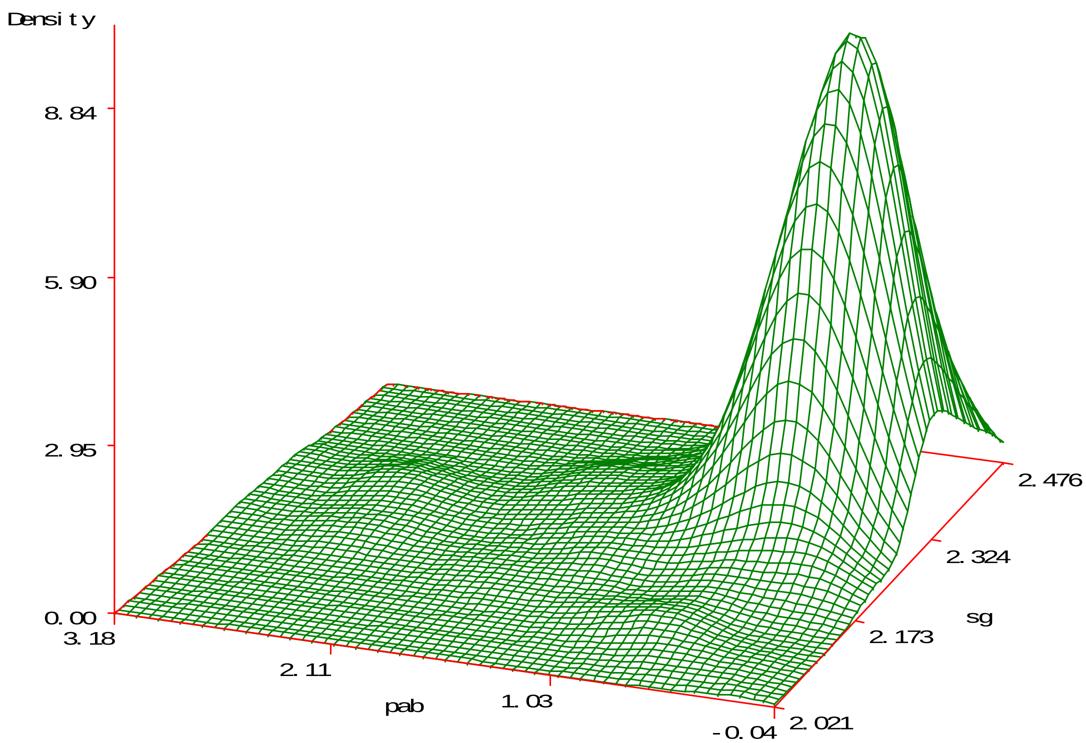
Levels

Percent	Density	Lower for pab	Upper for pab	Lower for sg	Upper for sg
1	0.1178	-0.040	2.91	2.04	2.48
5	0.2593	-0.040	2.69	2.08	2.48
10	0.3779	-0.040	1.60	2.18	2.48
50	4.6896	0.069	0.72	2.28	2.41
90	8.3664	0.29	0.51	2.31	2.36
95	8.7071	0.29	0.45	2.32	2.35
99	8.7775	0.34	0.45	2.33	2.34
100	8.8436	0.40	0.40	2.34	2.34


Density
125
83
42
0
0.104
0.069
0.035
0.000
perm
-0.04
1.03
2.11
3.18
pab



Density
599
399
200
0
0.104
0.069
0.035
0.000
perm
2.021
2.173
2.324
2.476
sg


Density
8.84
5.90
2.95
0.00
3.18
2.11
pab
1.03
-0.04
2.021
2.173
sg
2.324
2.476

Appendix E: Correlation Statistics for Core Data

--------------------------------------- grad=1 type=1 --------------------------------

The CORR Procedure

4 Variables: perm pab sg mav

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
perm	81	0.00195	0.00371	0.0000693	0	0.01840
pab	81	0.69148	0.57732	0.51000	0.13000	3.18000
sg	81	2.29570	0.06757	2.30031	2.11600	2.44400
mav	81	8.47428	2.33105	8.12494	2.79132	15.12745

Pearson Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.74432	-0.38577	0.42646
		<.0001	0.0004	<.0001
pab	0.74432	1.00000	-0.51672	0.53241
	<.0001		<.0001	<.0001
sg	-0.38577	-0.51672	1.00000	-0.95880
	0.0004	<.0001		<.0001
mav	0.42646	0.53241	-0.95880	1.00000
	<.0001	<.0001	<.0001	

Spearman Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.73786	-0.54862	0.52022
		<.0001	<.0001	<.0001
pab	0.73786	1.00000	-0.59415	0.61716
	<.0001		<.0001	<.0001
sg	-0.54862	-0.59415	1.00000	-0.95202
	<.0001	<.0001		<.0001
mav	0.52022	0.61716	-0.95202	1.00000
	<.0001	<.0001	<.0001	

--------------------------------------- grad=1 type=1 --------------------------------

The CORR Procedure

Kendall Tau b Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.57863 <.0001	-0.41962 <.0001	0.39118 <.0001
pab	0.57863 <.0001	1.00000	-0.43465 <.0001	0.45682 <.0001
sg	-0.41962 <.0001	-0.43465 <.0001	1.00000	-0.82831 <.0001
mav	0.39118 <.0001	0.45682 <.0001	-0.82831 <.0001	1.00000

Hoeffding Dependence Coefficients, N = 81
Prob > D under H0: D=0

	perm	pab	sg	mav
perm	0.83805 <.0001	0.23138 <.0001	0.11746 <.0001	0.09654 <.0001
pab	0.23138 <.0001	0.97236 <.0001	0.12975 <.0001	0.13940 <.0001
sg	0.11746 <.0001	0.12975 <.0001	0.99277 <.0001	0.58390 <.0001
mav	0.09654 <.0001	0.13940 <.0001	0.58390 <.0001	0.99907 <.0001

-- grad=1 type=2 ---------------------------------

The CORR Procedure

4 Variables: perm pab sg mav

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
perm	81	0.00195	0.00371	0.0000693	0	0.01840
pab	81	0.69148	0.57732	0.51000	0.13000	3.18000
sg	81	2.34365	0.05035	2.34300	2.23200	2.46600
mav	81	6.55931	1.65072	6.34339	2.83080	10.79881

Pearson Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.74432	-0.44198	0.50870
		<.0001	<.0001	<.0001
pab	0.74432	1.00000	-0.62091	0.66142
	<.0001		<.0001	<.0001
sg	-0.44198	-0.62091	1.00000	-0.91794
	<.0001	<.0001		<.0001
mav	0.50870	0.66142	-0.91794	1.00000
	<.0001	<.0001	<.0001	

Spearman Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.73786	-0.66754	0.63508
		<.0001	<.0001	<.0001
pab	0.73786	1.00000	-0.69235	0.72605
	<.0001		<.0001	<.0001
sg	-0.66754	-0.69235	1.00000	-0.90942
	<.0001	<.0001		<.0001
mav	0.63508	0.72605	-0.90942	1.00000
	<.0001	<.0001	<.0001	

--------------------------------------- grad=1 type=2 --------------------------------

The CORR Procedure

Kendall Tau b Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.57863 <.0001	-0.51442 <.0001	0.47970 <.0001
pab	0.57863 <.0001	1.00000	-0.52501 <.0001	0.55668 <.0001
sg	-0.51442 <.0001	-0.52501 <.0001	1.00000	-0.75460 <.0001
mav	0.47970 <.0001	0.55668 <.0001	-0.75460 <.0001	1.00000

Hoeffding Dependence Coefficients, N = 81
Prob > D under H0: D=0

	perm	pab	sg	mav
perm	0.83805 <.0001	0.23138 <.0001	0.17659 <.0001	0.13621 <.0001
pab	0.23138 <.0001	0.97236 <.0001	0.19984 <.0001	0.22571 <.0001
sg	0.17659 <.0001	0.19984 <.0001	0.99085 <.0001	0.46991 <.0001
mav	0.13621 <.0001	0.22571 <.0001	0.46991 <.0001	0.99890 <.0001

--------------------------------------- grad=1 type=3 --------------------------------

The CORR Procedure

4 Variables: perm pab sg mav

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
perm	81	0.00195	0.00371	0.0000693	0	0.01840
pab	81	0.69148	0.57732	0.51000	0.13000	3.18000
sg	81	2.35880	0.04323	2.35354	2.28900	2.47600
mav	81	5.95483	1.33110	6.00240	2.43676	8.80718

Pearson Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.74432	-0.36098	0.43121
		<.0001	0.0009	<.0001
pab	0.74432	1.00000	-0.50313	0.53381
	<.0001		<.0001	<.0001
sg	-0.36098	-0.50313	1.00000	-0.88585
	0.0009	<.0001		<.0001
mav	0.43121	0.53381	-0.88585	1.00000
	<.0001	<.0001	<.0001	

Spearman Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.73786	-0.65652	0.61318
		<.0001	<.0001	<.0001
pab	0.73786	1.00000	-0.58183	0.61206
	<.0001		<.0001	<.0001
sg	-0.65652	-0.58183	1.00000	-0.89666
	<.0001	<.0001		<.0001
mav	0.61318	0.61206	-0.89666	1.00000
	<.0001	<.0001	<.0001	

-- grad=1 type=3 ----------------------------------

The CORR Procedure

Kendall Tau b Correlation Coefficients, N = 81
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.57863 <.0001	-0.49484 <.0001	0.44346 <.0001
pab	0.57863 <.0001	1.00000	-0.42400 <.0001	0.44183 <.0001
sg	-0.49484 <.0001	-0.42400 <.0001	1.00000	-0.72694 <.0001
mav	0.44346 <.0001	0.44183 <.0001	-0.72694 <.0001	1.00000

Hoeffding Dependence Coefficients, N = 81
Prob > D under H0: D=0

	perm	pab	sg	mav
perm	0.83805 <.0001	0.23138 <.0001	0.15870 <.0001	0.11073 <.0001
pab	0.23138 <.0001	0.97236 <.0001	0.12207 <.0001	0.12391 <.0001
sg	0.15870 <.0001	0.12207 <.0001	0.98903 <.0001	0.43872 <.0001
mav	0.11073 <.0001	0.12391 <.0001	0.43872 <.0001	0.99714 <.0001

-- grad=2 type=1 --------------------------------

The CORR Procedure

4 Variables: perm pab sg mav

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
perm	53	0.00400	0.01561	0.0003440	0	0.10373
pab	53	0.34849	0.22371	0.35000	-0.04000	1.26000
sg	53	2.27353	0.09250	2.28300	2.02100	2.45600
mav	53	9.07157	3.62461	8.47995	3.66638	18.95682

Pearson Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.45929	-0.29092	0.22185
		0.0005	0.0346	0.1104
pab	0.45929	1.00000	-0.24816	0.30076
	0.0005		0.0732	0.0286
sg	-0.29092	-0.24816	1.00000	-0.91915
	0.0346	0.0732		<.0001
mav	0.22185	0.30076	-0.91915	1.00000
	0.1104	0.0286	<.0001	

Spearman Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.21439	-0.50962	0.52360
		0.1232	<.0001	<.0001
pab	0.21439	1.00000	-0.22109	0.36048
	0.1232		0.1116	0.0080
sg	-0.50962	-0.22109	1.00000	-0.86470
	<.0001	0.1116		<.0001
mav	0.52360	0.36048	-0.86470	1.00000
	<.0001	0.0080	<.0001	

-- grad=2 type=1 ------------------------------------

The CORR Procedure

Kendall Tau b Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.16938 0.0780	-0.37356 <.0001	0.37062 0.0001
pab	0.16938 0.0780	1.00000	-0.15475 0.1037	0.24526 0.0099
sg	-0.37356 <.0001	-0.15475 0.1037	1.00000	-0.75036 <.0001
mav	0.37062 0.0001	0.24526 0.0099	-0.75036 <.0001	1.00000

Hoeffding Dependence Coefficients, N = 53
Prob > D under H0: D=0

	perm	pab	sg	mav
perm	0.97301 <.0001	0.02590 0.0220	0.09090 <.0001	0.08802 <.0001
pab	0.02590 0.0220	0.96670 <.0001	0.01206 0.0899	0.03858 0.0065
sg	0.09090 <.0001	0.01206 0.0899	1.00000	0.50175 <.0001
mav	0.08802 <.0001	0.03858 0.0065	0.50175 <.0001	1.00000

-- grad=2 type=2 --------------------------------

The CORR Procedure

4 Variables: perm pab sg mav

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
perm	53	0.00400	0.01561	0.0003440	0	0.10373
pab	53	0.34849	0.22371	0.35000	-0.04000	1.26000
sg	53	2.33227	0.05950	2.33200	2.11617	2.46100
mav	53	6.72738	2.05313	6.67353	3.15228	14.00732

Pearson Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.45929	-0.62835	0.59450
		0.0005	<.0001	<.0001
pab	0.45929	1.00000	-0.43769	0.59278
	0.0005		0.0010	<.0001
sg	-0.62835	-0.43769	1.00000	-0.78220
	<.0001	0.0010		<.0001
mav	0.59450	0.59278	-0.78220	1.00000
	<.0001	<.0001	<.0001	

Spearman Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.21439	-0.73531	0.76626
		0.1232	<.0001	<.0001
pab	0.21439	1.00000	-0.28651	0.49444
	0.1232		0.0375	0.0002
sg	-0.73531	-0.28651	1.00000	-0.72193
	<.0001	0.0375		<.0001
mav	0.76626	0.49444	-0.72193	1.00000
	<.0001	0.0002	<.0001	

--------------------------------------- grad=2 type=2 --------------------------------

The CORR Procedure

Kendall Tau b Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.16938	-0.56558	0.60248
		0.0780	<.0001	<.0001
pab	0.16938	1.00000	-0.20468	0.34831
	0.0780		0.0316	0.0003
sg	-0.56558	-0.20468	1.00000	-0.60342
	<.0001	0.0316		<.0001
mav	0.60248	0.34831	-0.60342	1.00000
	<.0001	0.0003	<.0001	

Hoeffding Dependence Coefficients, N = 53
Prob > D under H0: D=0

	perm	pab	sg	mav
perm	0.97301	0.02590	0.21261	0.28297
	<.0001	0.0220	<.0001	<.0001
pab	0.02590	0.96670	0.02219	0.07135
	0.0220	<.0001	0.0317	0.0003
sg	0.21261	0.02219	0.98995	0.29362
	<.0001	0.0317	<.0001	<.0001
mav	0.28297	0.07135	0.29362	0.99820
	<.0001	0.0003	<.0001	<.0001

-- grad=2 type=3 ---------------------------------

The CORR Procedure

4 Variables: perm pab sg mav

Simple Statistics

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
perm	53	0.00400	0.01561	0.0003440	0	0.10373
pab	53	0.34849	0.22371	0.35000	-0.04000	1.26000
sg	53	2.33167	0.06082	2.33300	2.11739	2.46000
mav	53	6.22973	2.81570	6.64075	0.03314	13.95766

Pearson Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.45929 0.0005	-0.62662 <.0001	0.43847 0.0010
pab	0.45929 0.0005	1.00000	-0.45180 0.0007	0.58551 <.0001
sg	-0.62662 <.0001	-0.45180 0.0007	1.00000	-0.54701 <.0001
mav	0.43847 0.0010	0.58551 <.0001	-0.54701 <.0001	1.00000

Spearman Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.21439 0.1232	-0.70585 <.0001	0.55111 <.0001
pab	0.21439 0.1232	1.00000	-0.30902 0.0244	0.54654 <.0001
sg	-0.70585 <.0001	-0.30902 0.0244	1.00000	-0.60795 <.0001
mav	0.55111 <.0001	0.54654 <.0001	-0.60795 <.0001	1.00000

-- grad=2 type=3 ---------------------------------

The CORR Procedure

Kendall Tau b Correlation Coefficients, N = 53
Prob > |r| under H0: Rho=0

	perm	pab	sg	mav
perm	1.00000	0.16938 0.0780	-0.54669 <.0001	0.49452 <.0001
pab	0.16938 0.0780	1.00000	-0.21750 0.0226	0.39591 <.0001
sg	-0.54669 <.0001	-0.21750 0.0226	1.00000	-0.48743 <.0001
mav	0.49452 <.0001	0.39591 <.0001	-0.48743 <.0001	1.00000

Hoeffding Dependence Coefficients, N = 53
Prob > D under H0: D=0

	perm	pab	sg	mav
perm	0.97301 <.0001	0.02590 0.0220	0.20073 <.0001	0.24972 <.0001
pab	0.02590 0.0220	0.96670 <.0001	0.02713 0.0195	0.09642 <.0001
sg	0.20073 <.0001	0.02713 0.0195	0.97916 <.0001	0.18275 <.0001
mav	0.24972 <.0001	0.09642 <.0001	0.18275 <.0001	0.99507 <.0001

Appendix F: Analysis of Permeability and Absorption for Core Data

grad	nmas	type	perm Mean	perm Std	perm N
1	2	1	0.01	0.00	5.00
		2	0.01	0.00	5.00
		3	0.01	0.00	5.00
	3	1	0.00	0.00	30.00
		2	0.00	0.00	30.00
		3	0.00	0.00	30.00
	4	1	0.00	0.00	20.00
		2	0.00	0.00	20.00
		3	0.00	0.00	20.00
	5	1	0.00	0.00	26.00
		2	0.00	0.00	26.00
		3	0.00	0.00	26.00
2	3	1	0.00	0.00	5.00
		2	0.00	0.00	5.00
		3	0.00	0.00	5.00
	4	1	0.00	0.01	14.00
		2	0.00	0.01	14.00
		3	0.00	0.01	14.00
	5	1	0.00	0.02	34.00
		2	0.00	0.02	34.00
		3	0.00	0.02	34.00

			pab		
			Mean	Std	N
grad	nmas	type			
1	2	1	1.10	0.51	5.00
		2	1.10	0.51	5.00
		3	1.10	0.51	5.00
	3	1	0.94	0.78	30.00
		2	0.94	0.78	30.00
		3	0.94	0.78	30.00
	4	1	0.41	0.25	20.00
		2	0.41	0.25	20.00
		3	0.41	0.25	20.00
	5	1	0.54	0.29	26.00
		2	0.54	0.29	26.00
		3	0.54	0.29	26.00
2	3	1	0.47	0.16	5.00
		2	0.47	0.16	5.00
		3	0.47	0.16	5.00
	4	1	0.48	0.25	14.00
		2	0.48	0.25	14.00
		3	0.48	0.25	14.00
	5	1	0.28	0.19	34.00
		2	0.28	0.19	34.00
		3	0.28	0.19	34.00

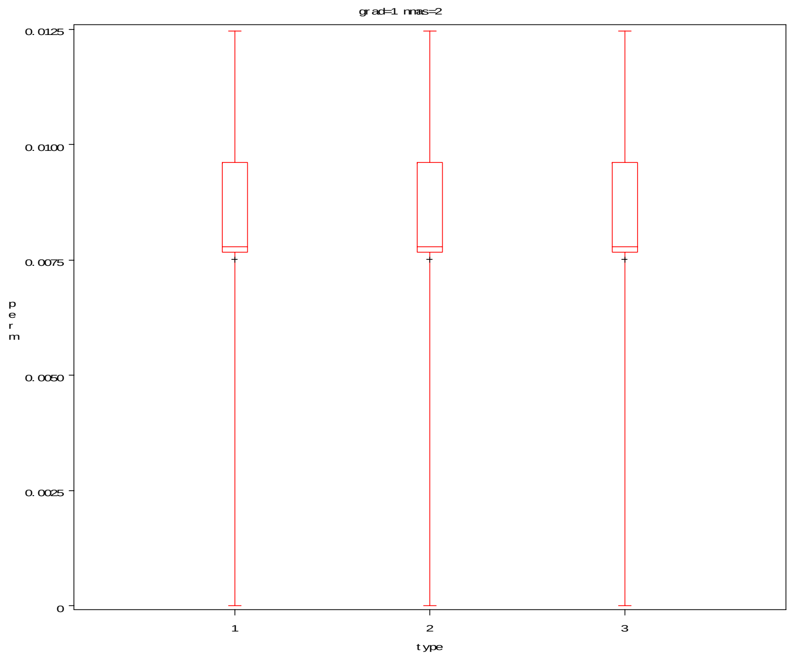
```
                Plot of perm*pab.  Legend: A = 1 obs, B = 2 obs, etc.

perm ,
0.12 ˆ
     ,
     ,
     ,
     ,
     ,
     ,                            C
0.10 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.08 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.06 ˆ
     ,
     ,
     ,
     ,                                        C
     ,
     ,
0.04 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.02 ˆ
     ,                                               C
     ,
     ,                                          C         C          C    C             C
     ,                C      C           C  C         C
     ,                    F  C   C                                          C
     ,           C  F F   CC   CCC CC   C C   C  C
0.00 ˆ              OIXOXZZZZOIOXI FFCC C
     ,
     Šƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒ
     -0.5        0.0        0.5        1.0        1.5        2.0        2.5        3.0        3.5

                                                 pab

NOTE: 16 obs hidden.
```

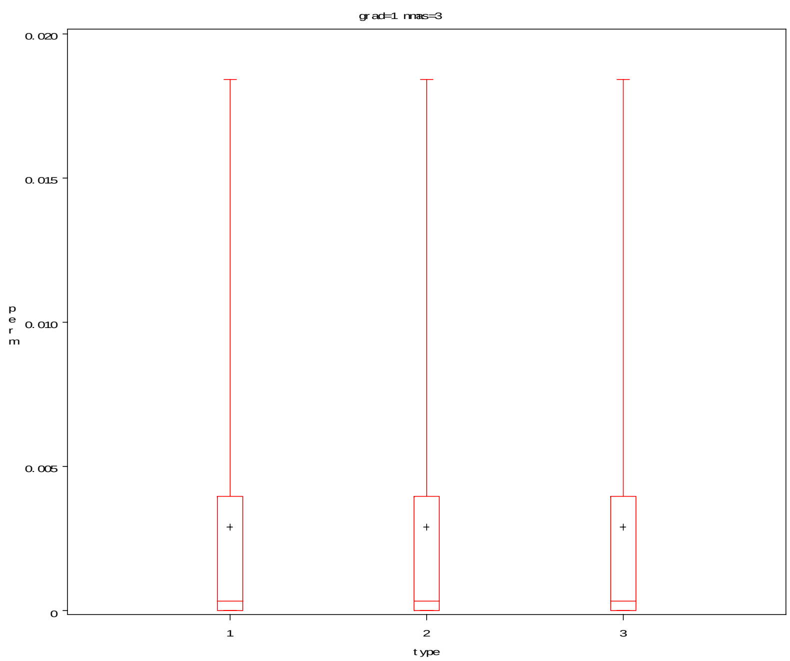
```
                      Plot of perm*sg.  Legend: A = 1 obs, B = 2 obs, etc.

perm ,
0.12 ˆ
     ,
     ,
     ,
     ,
     ,
     ,                     C
0.10 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.08 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.06 ˆ
     ,
     ,
     ,
     ,                                A   A A
     ,
     ,
0.04 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.02 ˆ
     ,                           A              A         A
     ,
     ,                                 A A   AA    AA A A A A AA A  A      A
     ,                                                   AA   AAA  A  A  A AA AAA    AA
     ,                                        A     CA ABB     AAA AA
     ,                     A   A            A  A B A BBA BCCCACB CBBCAAA CAA A
0.00 ˆ    A     A  A   A            B AA A ACABAABAA BFAFGJHHTGKIMQJPIIIIILFHHHHGDAABCCCACC A
     ,
     Šˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
    2.00     2.05     2.10     2.15     2.20     2.25     2.30     2.35     2.40     2.45    2.50

                                              sg
```

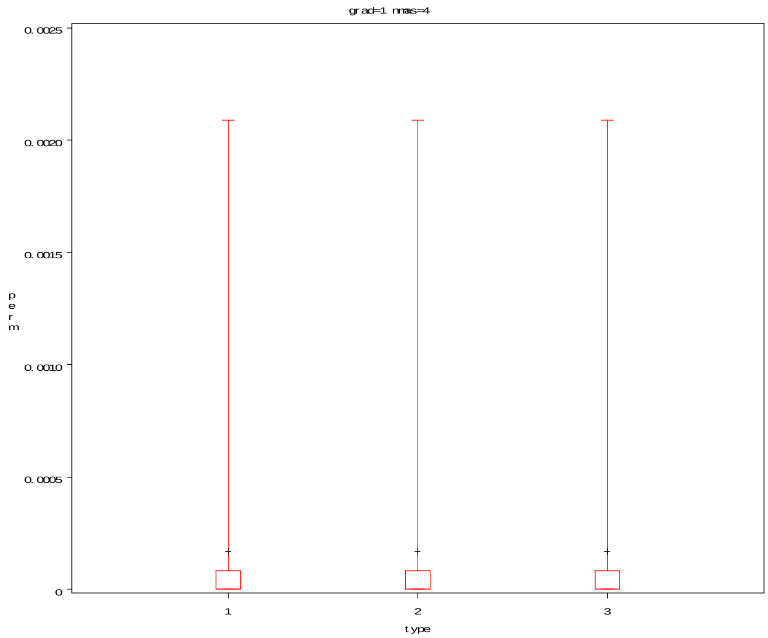
```
                                   Plot of pab*sg.  Legend: A = 1 obs, B = 2 obs, etc.

 pab ,
     ,
 3.5 ˆ
     ,
     ,
     ,                                        A         A      A
     ,
 3.0 ˆ
     ,
     ,
     ,
     ,                                        A         A      A
 2.5 ˆ                                   A          A       A
     ,                                       A     A      A
     ,
     ,
 2.0 ˆ
     ,
     ,                                 A              A       A
     ,                                                          A    AA
     ,                           A              A         A
 1.5 ˆ
     ,                                             A  A    A     A  A      A
     ,                                A   A A    A       A    A
     ,                                                                  A      AA
     ,                         A                      A   A        A     AA
 1.0 ˆ                     A                A        AA   A A
     ,                                           A    A A A  B
     ,                                      A  A        A CA   AAC A   B B      A
     ,                     C           A            AB AA    B BAA  A C   A A
     ,          A      A            B        A   A   AA CB CCFABAB AD   AACA C
 0.5 ˆ                                         A    A C ACBB DAAEBBBABACAAC A ABAA
     ,                                        A  AAABA A CABCCBCADGEEDCACC CBCDBBA    A   A A
     ,                                   A    A A      A BBA B AABDBFCBBA EB BABB AA    AB
     ,    A        A                  A     B      A    A A DBBA BCBBAABACAABAAA B  AA C AB
     ,                                     A             AA  ACA AC A   BB  B AAA   ABB
 0.0 ˆ                                                    AA   A
     ,
     ,
     ,
     ,
-0.5 ˆ
     ,
     Šˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
    2.00     2.05     2.10     2.15     2.20     2.25     2.30     2.35     2.40     2.45     2.50

                                                  sg
```

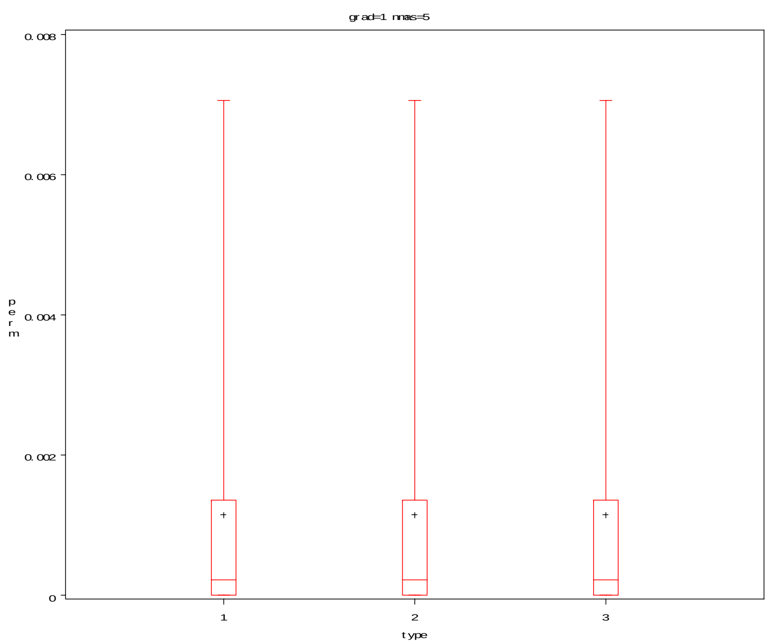
```
                      Plot of perm*mav.  Legend: A = 1 obs, B = 2 obs, etc.

perm ,
0.12 ˆ
     ,
     ,
     ,
     ,
     ,
     ,                                                              AB
0.10 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.08 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.06 ˆ
     ,
     ,
     ,
     ,                                                A A  A
     ,
     ,
0.04 ˆ
     ,
     ,
     ,
     ,
     ,
     ,
0.02 ˆ
     ,                                      A          A             A
     ,
     ,                          A     AA BA  AA AA  A A    AA  A
     , A                   A A    B A C AB A  B
     ,                             AA BA  AAACC        A
     , C                   A  CBCDAAADBABBAACBC AB A A      A      A      A
0.00 ˆ A          AB CCIDFEGLGLQNMLIYLLMLPIGFIBAFDCCC BBACB AAA  B   A            A A   A A
     ,
     Šƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒ
      0.0        2.5        5.0        7.5       10.0       12.5       15.0       17.5       20.0

                                                  mav
```

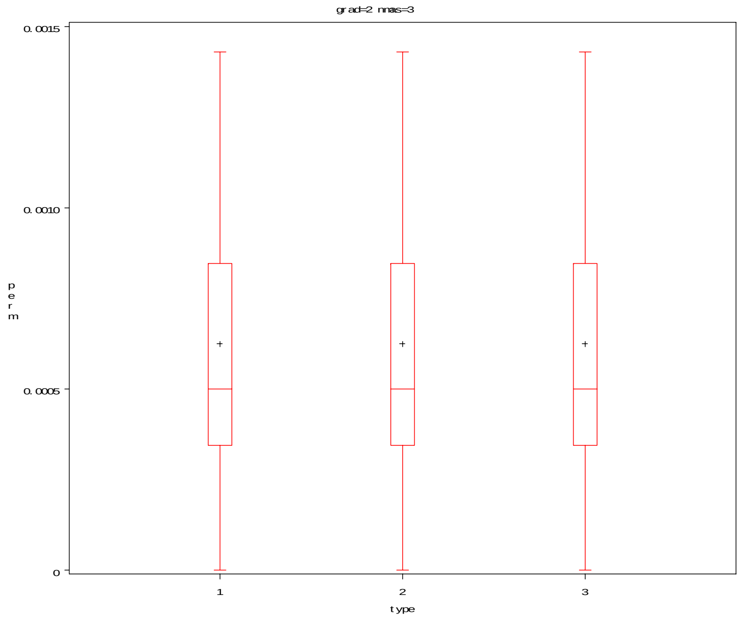
```
                      Plot of pab*mav.  Legend: A = 1 obs, B = 2 obs, etc.

    pab ,
        ;
    3.5 ˆ
        ,
        ,
        ,                                A      A        A
        ;
    3.0 ˆ
        ,
        ,
        ,
        ;                                A     A          A
    2.5 ˆ                                   A       A          A
        ,
        ,                                        A     A      A
        ,
        ;
    2.0 ˆ
        ,
        ,                                   A      A              A
        ,                                B    A
        ;                                      A          A             A
    1.5 ˆ
        ,                          A      A AA   A  A
        ,                               A    A      A    A A  A
        ,                     A A      A
        ;                            B     B    A                     A
    1.0 ˆ                                  AA   A  A     A                   A
        ,                                   AA A  AA     A
        ,                    AA  A  AAAB A B  A BB      A      A
        ,                         A A  A  C ABB CA  A A             A  AB
        ;                   A AA   BCA ABCDACBBBCA  BBBA    A    A      A            A     A
    0.5 ˆ                      AACBADBACCBEEEAAAAA A  AB        A
        , A          AA   BADB DBDGDADCHDDACDAADBB BAA    AA
        ,                  A  ACBCFEECBFCAAABA AAA B      A  A A
        , B           A B CBAAEBADAC AADBC  BBB  A          B       A                  A     A
        ; B             ACD  A AA BABACB AA                  A
    0.0 ˆ                          A    AA
        ,
        ,
        ,
        ;
   -0.5 ˆ
        ;
        Šƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒƒƒˆƒ
         0.0        2.5        5.0        7.5       10.0       12.5       15.0       17.5       20.0

                                                 Mav
```

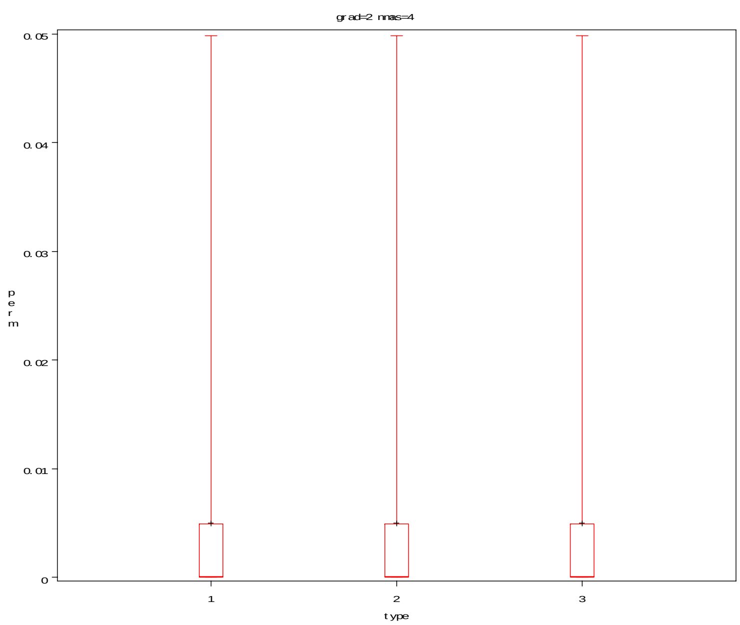

grad=1 nmas=2
0.0125
0.0100
0.0075
0.0050
0.0025
0
perm
1
2
3
type

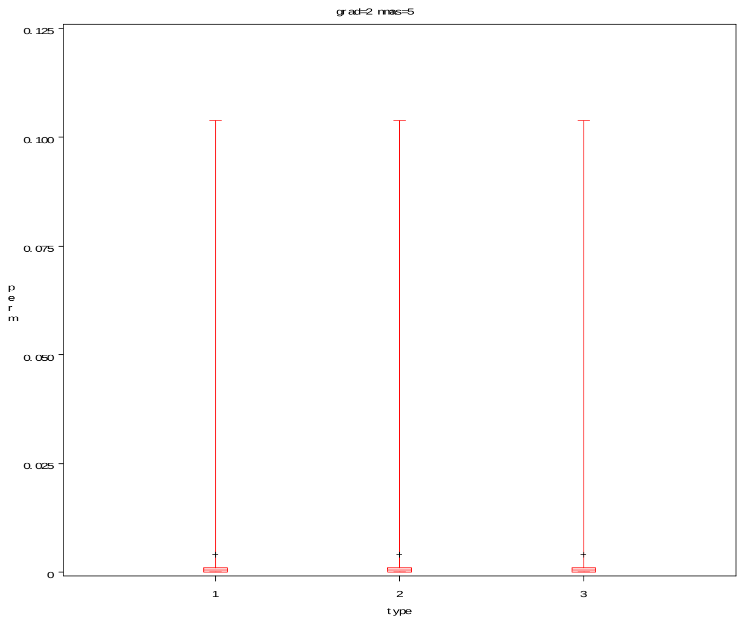

grad=1 nmas=3
0.020
0.015
0.010
0.005
0
perm
1
2
3
type

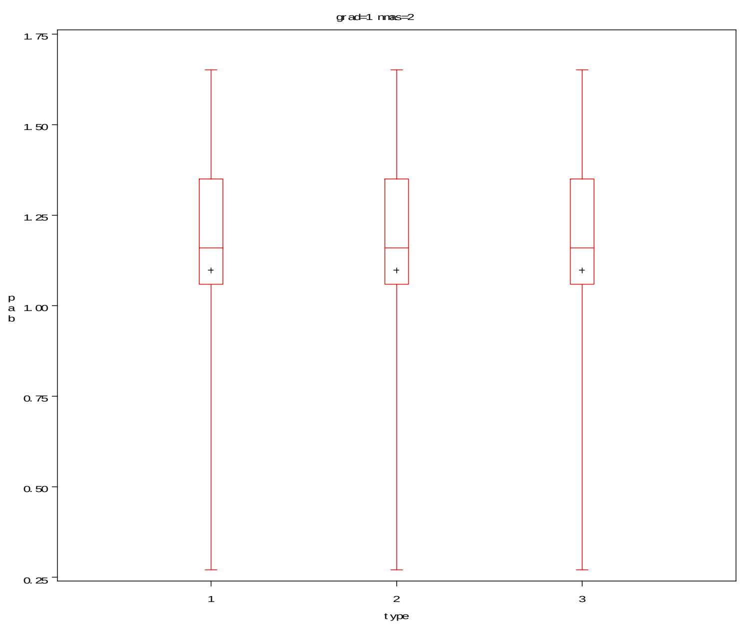

grad=1 nmas=4
0.0025
0.0020
0.0015
0.0010
0.0005
0
perm
1
2
3
type

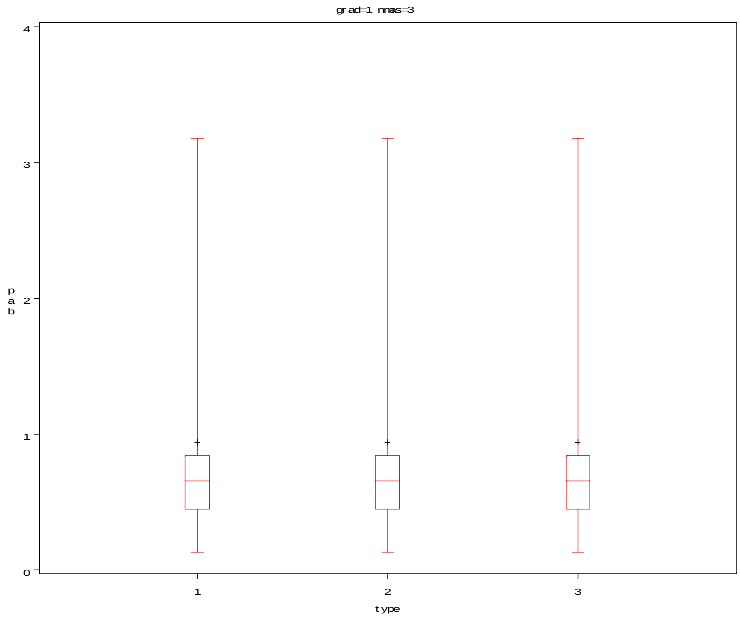

grad=1 nmas=5
0.008
0.006
0.004
0.002
0
perm
1
2
3
type

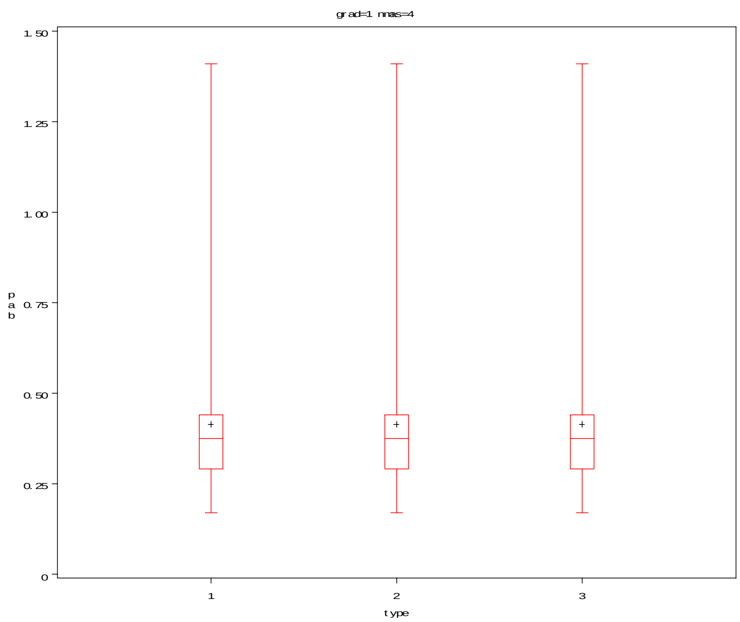

grad=2 nmas=3
0.0015
0.0010
0.0005
0
perm
1
2
3
type

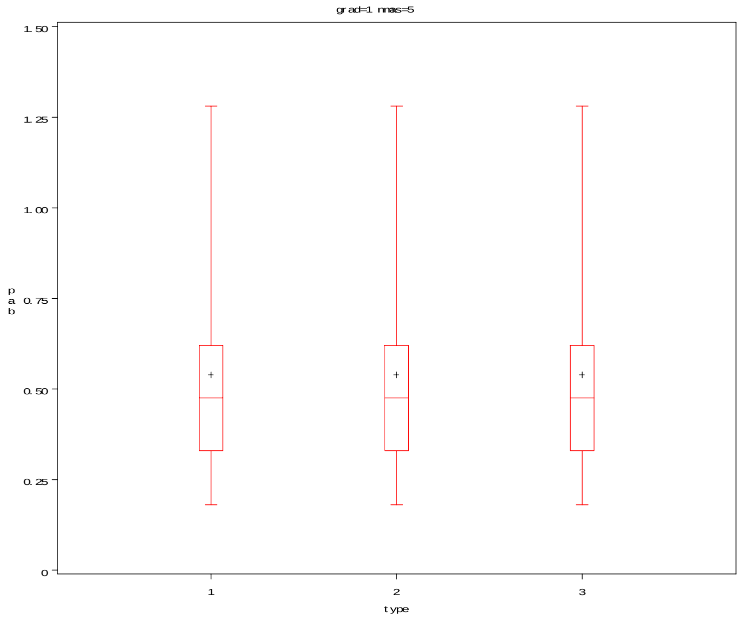

grad=2 nmas=4
0.05
0.04
0.03
0.02
0.01
0
perm
1
2
3
type

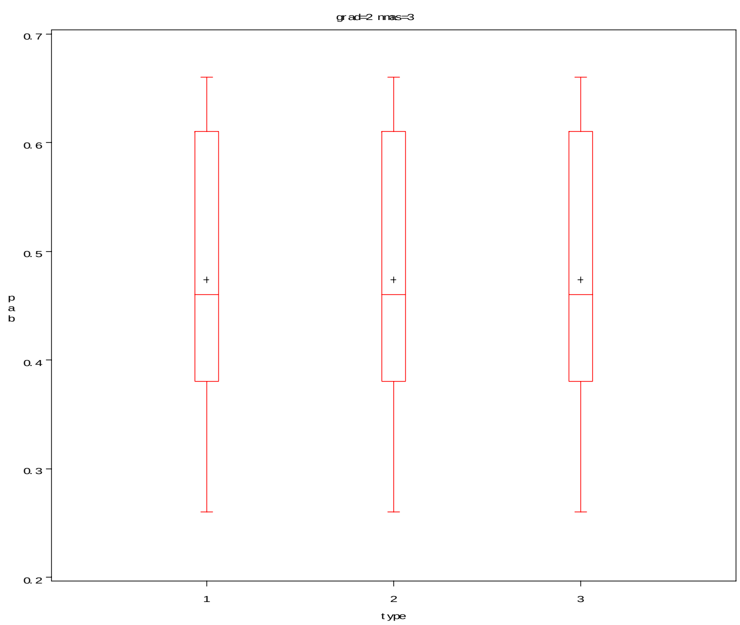

grad=2 nmas=5
0.125
0.100
0.075
0.050
0.025
0
perm
1
2
3
type

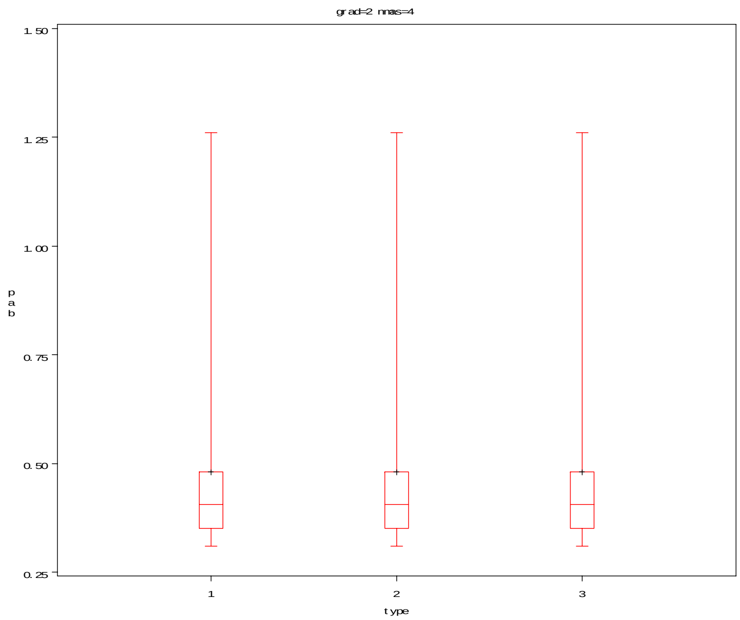

grad=1 nmas=2
1.75
1.50
1.25
1.00
0.75
0.50
0.25
pab
1
2
3
type

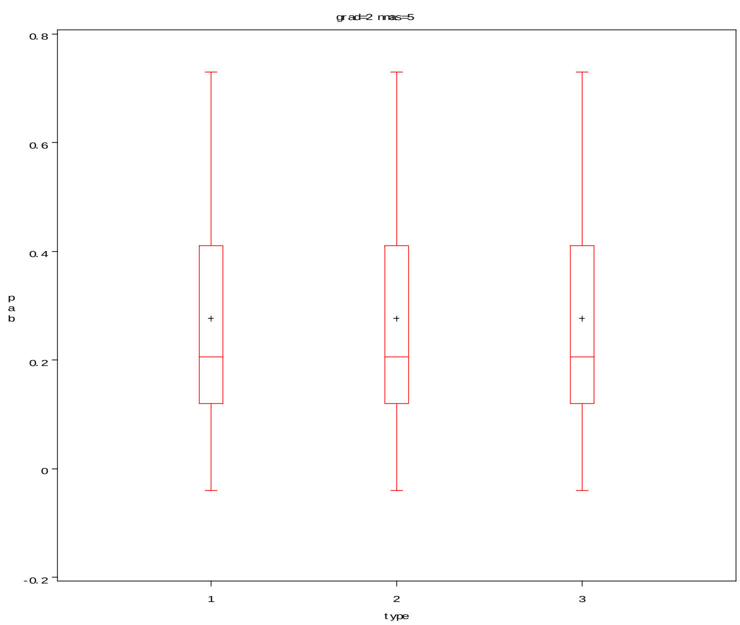

grad=1 nmas=3
4
3
2
1
0
pab
1
2
3
type

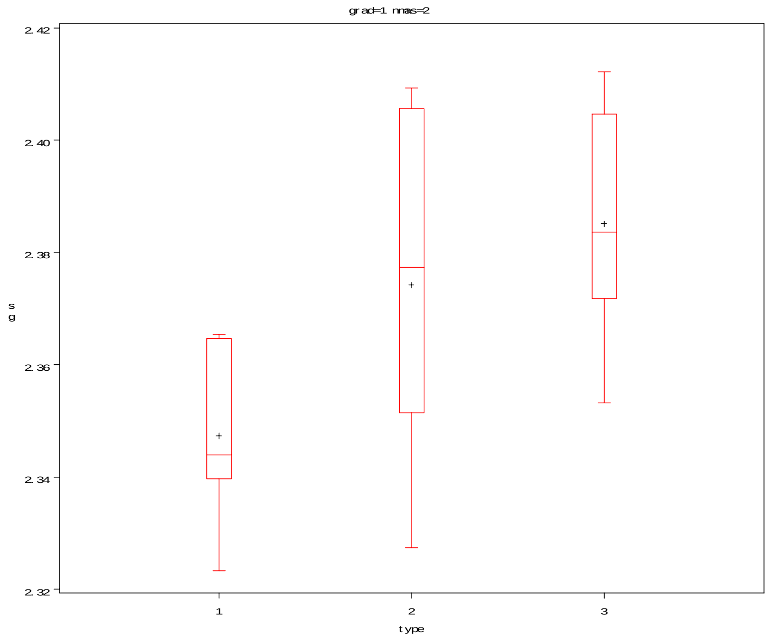

grad=1 nmas=4
1.50
1.25
1.00
0.75
0.50
0.25
0
pab
1
2
3
type

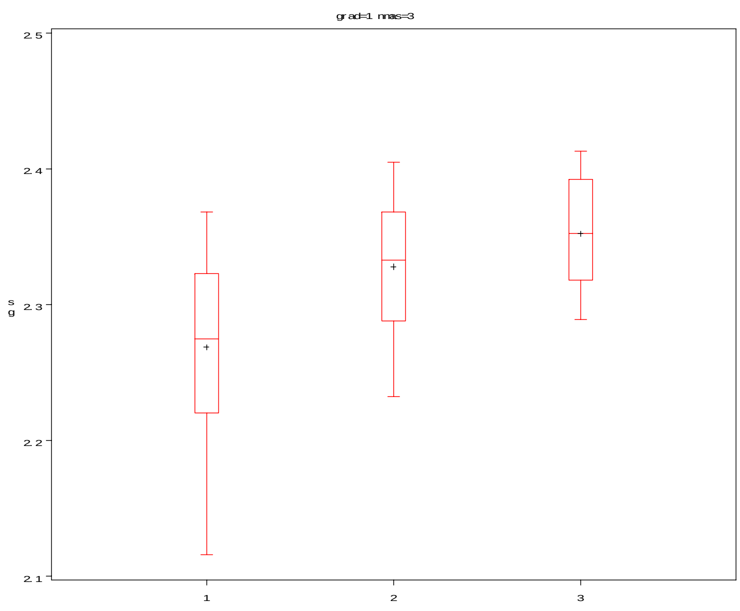

grad=1 nmas=5
1.50
1.25
1.00
0.75
0.50
0.25
0
pab
1
2
3
type

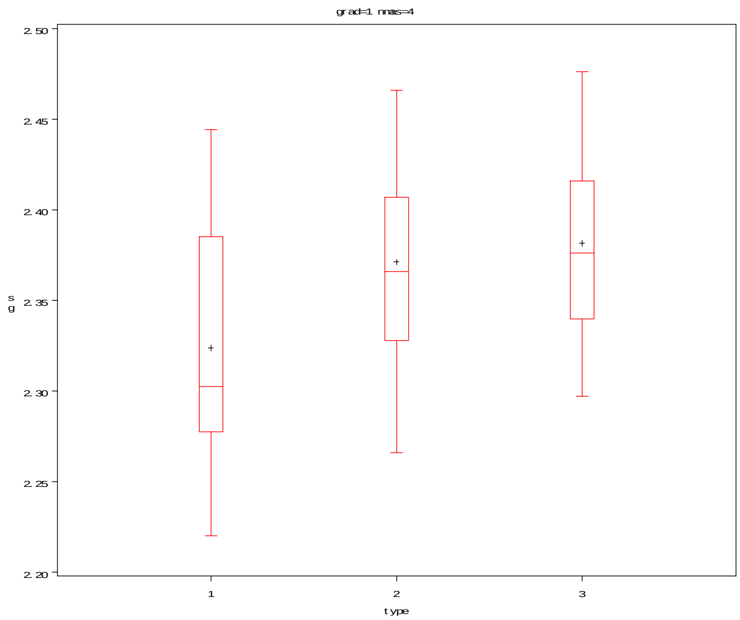

grad=2 nmas=3
0.7
0.6
0.5
0.4
0.3
0.2
pab
1
2
3
type

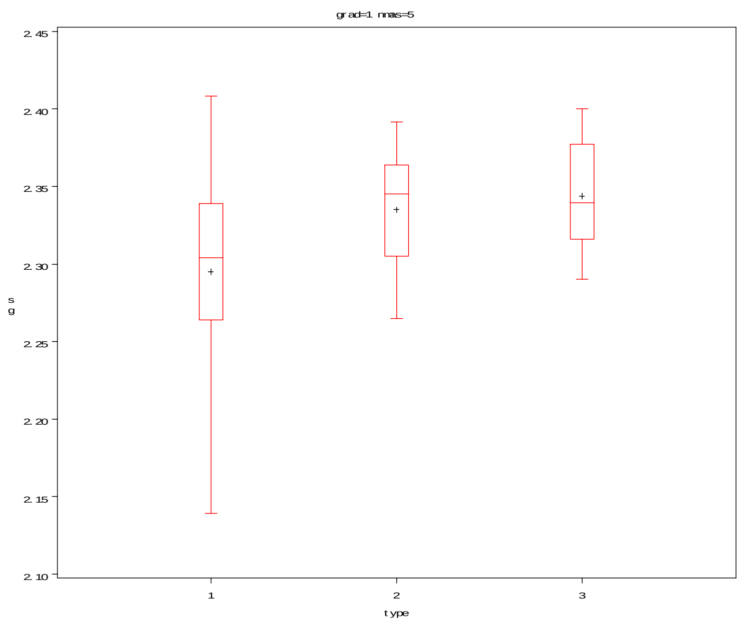

grad=2 nmas=4
1.50
1.25
1.00
0.75
0.50
0.25
pab
1
2
3
type

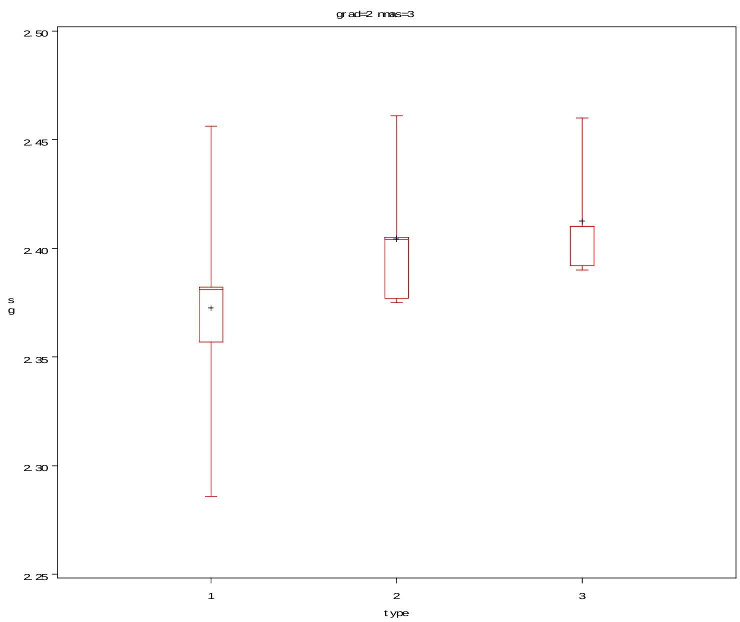

grad=2 nmas=5
0.8
0.6
0.4
0.2
0
-0.2
pab
1
2
3
type

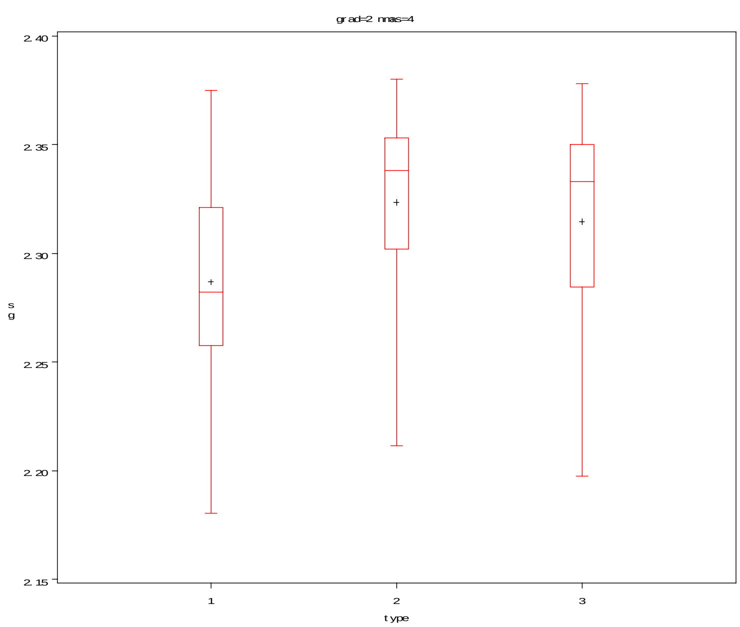

grad=1 nmas=2
2.42
2.40
2.38
2.36
2.34
2.32
s
g
1
2
3
type

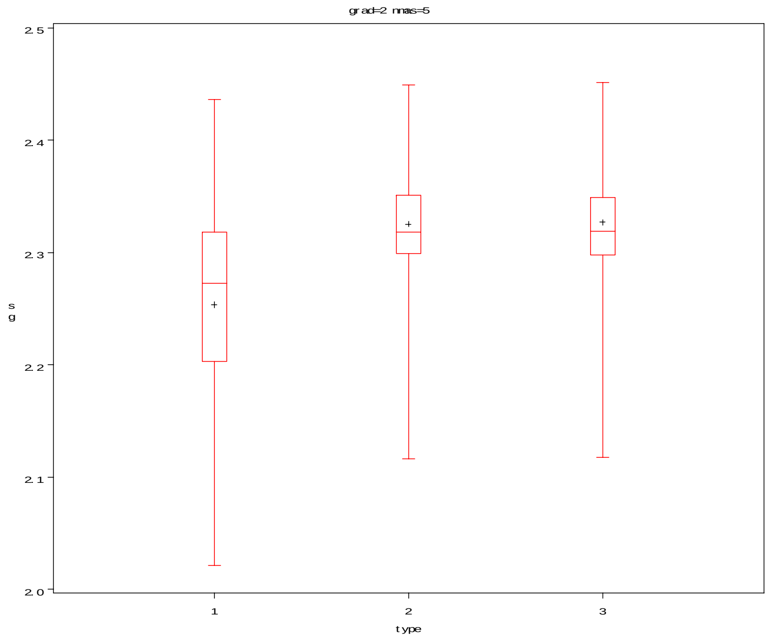

grad=1 nmas=3
2.5
2.4
2.3
2.2
2.1
s
g
1
2
3
type


grad=1 nmas=4
2.50
2.45
2.40
2.35
2.30
2.25
2.20
sg
1
2
3
type


grad=1 nmas=5
2.45
2.40
2.35
2.30
2.25
2.20
2.15
2.10
sg
1
2
3
type


grad=2 nmas=3
2.50
2.45
2.40
2.35
2.30
2.25
sg
1
2
3
type


grad=2 nmas=4
2.40
2.35
2.30
2.25
2.20
2.15
sg
1
2
3
type


grad=2 mas=5
2.5
2.4
2.3
2.2
2.1
2.0
s
g
1
2
3
type

The GLM Procedure

Class Level Information

Class	Levels	Values
grad	2	1 2
nmas	4	2 3 4 5
traff	2	1 2
type	3	1 2 3

Number of Observations Read 402
Number of Observations Used 402

Dependent Variable: sg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	0.82819763	0.03764535	13.63	<.0001
Error	379	1.04642287	0.00276101		
Corrected Total	401	1.87462050			

R-Square	Coeff Var	Root MSE	sg Mean
0.441795	2.260289	0.052545	2.324717

Source	DF	Type I SS	Mean Square	F Value	Pr > F
perm	1	0.26975499	0.26975499	97.70	<.0001
grad	1	0.02186955	0.02186955	7.92	0.0051
traff	1	0.06693355	0.06693355	24.24	<.0001
nmas	3	0.06905438	0.02301813	8.34	<.0001
type	2	0.29231265	0.14615632	52.94	<.0001
grad*type	2	0.00415139	0.00207570	0.75	0.4722
grad*nmas*type	12	0.10412112	0.00867676	3.14	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
perm	1	0.25762536	0.25762536	93.31	<.0001
grad	1	0.00270115	0.00270115	0.98	0.3232
traff	1	0.02733863	0.02733863	9.90	0.0018
nmas	3	0.09147522	0.03049174	11.04	<.0001
type	2	0.12107538	0.06053769	21.93	<.0001
grad*type	2	0.00180534	0.00090267	0.33	0.7213
grad*nmas*type	12	0.10412112	0.00867676	3.14	0.0003

Duncan's Multiple Range Test for sg

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002761
Harmonic Mean of Cell Sizes	192.2239

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.01054

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	grad
A	2.332718	243	1
B	2.312488	159	2

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002761
Critical Value of Studentized Range	2.78069
Minimum Significant Difference	0.0105
Harmonic Mean of Cell Sizes	192.2239

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	grad
A	2.332718	243	1
B	2.312488	159	2

The GLM Procedure

Duncan's Multiple Range Test for sg

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002761
Harmonic Mean of Cell Sizes	200.8209

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.01031

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	traff
A	2.332904	207	2
B	2.316025	195	1

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002761
Critical Value of Studentized Range	2.78069
Minimum Significant Difference	0.0103
Harmonic Mean of Cell Sizes	200.8209

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	traff
A	2.332904	207	2
B	2.316025	195	1

Duncan's Multiple Range Test for sg

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002761

Number of Means	2	3
Critical Range	.01262	.01329

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	type
A	2.348069	134	3
A			
A	2.339150	134	2
B	2.286931	134	1

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002761
Critical Value of Studentized Range	3.32759
Minimum Significant Difference	0.0151

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	type
A	2.348069	134	3
A			
A	2.339150	134	2
B	2.286931	134	1

Level of	Level of		--------------sg-------------		-------------perm------------	
grad	type	N	Mean	Std Dev	Mean	Std Dev
1	1	81	2.29570144	0.06756543	0.00194967	0.00371079
1	2	81	2.34365374	0.05034664	0.00194967	0.00371079
1	3	81	2.35879878	0.04322973	0.00194967	0.00371079
2	1	53	2.27352627	0.09249999	0.00400228	0.01561144
2	2	53	2.33226740	0.05949777	0.00400228	0.01561144
2	3	53	2.33167053	0.06081562	0.00400228	0.01561144

Level of grad	Level of nmas	Level of type	N	sg Mean	sg Std Dev	perm Mean	perm Std Dev
1	2	1	5	2.34735293	0.01784707	0.00750425	0.00462068
1	2	2	5	2.37419862	0.03514412	0.00750425	0.00462068
1	2	3	5	2.38507734	0.02402541	0.00750425	0.00462068
1	3	1	30	2.26874425	0.06581090	0.00290665	0.00477511
1	3	2	30	2.32785737	0.04883504	0.00290665	0.00477511
1	3	3	30	2.35222813	0.03842915	0.00290665	0.00477511
1	4	1	20	2.32390000	0.06892322	0.00016844	0.00047187
1	4	2	20	2.37105000	0.05556549	0.00016844	0.00047187
1	4	3	20	2.38155000	0.05324370	0.00016844	0.00047187
1	5	1	26	2.29518171	0.06229727	0.00114747	0.00188455
1	5	2	26	2.33493225	0.04043707	0.00114747	0.00188455
1	5	3	26	2.34382580	0.03439559	0.00114747	0.00188455
2	3	1	5	2.37240000	0.06094506	0.00062380	0.00054367
2	3	2	5	2.40440000	0.03471023	0.00062380	0.00054367
2	3	3	5	2.41240000	0.02826305	0.00062380	0.00054367
2	4	1	14	2.28677440	0.05257864	0.00498148	0.01319688
2	4	2	14	2.32346206	0.04566602	0.00498148	0.01319688
2	4	3	14	2.31462014	0.05052241	0.00498148	0.01319688
2	5	1	34	2.25353091	0.09987843	0.00409592	0.01769888
2	5	2	34	2.32528539	0.06114848	0.00409592	0.01769888
2	5	3	34	2.32681930	0.05992160	0.00409592	0.01769888

The GLM Procedure

Class Level Information

Class	Levels	Values
grad	2	1 2
nmas	4	2 3 4 5
traff	2	1 2
type	3	1 2 3

Number of Observations Read	402
Number of Observations Used	402

Dependent Variable: sg

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	0.88377209	0.04017146	15.37	<.0001
Error	379	0.99084842	0.00261438		
Corrected Total	401	1.87462050			

R-Square	Coeff Var	Root MSE	sg Mean
0.471441	2.199449	0.051131	2.324717

Source	DF	Type I SS	Mean Square	F Value	Pr > F
pab	1	0.18513976	0.18513976	70.82	<.0001
grad	1	0.13331340	0.13331340	50.99	<.0001
traff	1	0.04117443	0.04117443	15.75	<.0001
nmas	3	0.13302444	0.04434148	16.96	<.0001
type	2	0.29231265	0.14615632	55.90	<.0001
grad*type	2	0.00415139	0.00207570	0.79	0.4528
grad*nmas*type	12	0.09465602	0.00788800	3.02	0.0005

Source	DF	Type III SS	Mean Square	F Value	Pr > F
pab	1	0.31319981	0.31319981	119.80	<.0001
grad	1	0.00990082	0.00990082	3.79	0.0524
traff	1	0.01119573	0.01119573	4.28	0.0392
nmas	3	0.18581529	0.06193843	23.69	<.0001
type	2	0.12107538	0.06053769	23.16	<.0001
grad*type	2	0.00180534	0.00090267	0.35	0.7083
grad*nmas*type	12	0.09465602	0.00788800	3.02	0.0005

Duncan's Multiple Range Test for sg

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002614
Harmonic Mean of Cell Sizes	192.2239

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.01025

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	grad
A	2.332718	243	1
B	2.312488	159	2

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002614
Critical Value of Studentized Range	2.78069
Minimum Significant Difference	0.0103
Harmonic Mean of Cell Sizes	192.2239

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	grad
A	2.332718	243	1
B	2.312488	159	2

Duncan's Multiple Range Test for sg

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002614
Harmonic Mean of Cell Sizes	200.8209

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.01003

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	traff
A	2.332904	207	2
B	2.316025	195	1

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002614
Critical Value of Studentized Range	2.78069
Minimum Significant Difference	0.01
Harmonic Mean of Cell Sizes	200.8209

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	traff
A	2.332904	207	2
B	2.316025	195	1

Duncan's Multiple Range Test for sg

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002614

Number of Means	2	3
Critical Range	.01228	.01293

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	type
A	2.348069	134	3
A			
A	2.339150	134	2
B	2.286931	134	1

Tukey's Studentized Range (HSD) Test for sg

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.002614
Critical Value of Studentized Range	3.32759
Minimum Significant Difference	0.0147

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	type
A	2.348069	134	3
A			
A	2.339150	134	2
B	2.286931	134	1

Level of	Level of		--------------sg-------------		-------------pab-------------	
grad	type	N	Mean	Std Dev	Mean	Std Dev
1	1	81	2.29570144	0.06756543	0.69148148	0.57732164
1	2	81	2.34365374	0.05034664	0.69148148	0.57732164
1	3	81	2.35879878	0.04322973	0.69148148	0.57732164
2	1	53	2.27352627	0.09249999	0.34849057	0.22371338
2	2	53	2.33226740	0.05949777	0.34849057	0.22371338
2	3	53	2.33167053	0.06081562	0.34849057	0.22371338

Level of grad	Level of nmas	Level of type	N	sg Mean	sg Std Dev	pab Mean	pab Std Dev
1	2	1	5	2.34735293	0.01784707	1.09800000	0.51455806
1	2	2	5	2.37419862	0.03514412	1.09800000	0.51455806
1	2	3	5	2.38507734	0.02402541	1.09800000	0.51455806
1	3	1	30	2.26874425	0.06581090	0.94033333	0.77654177
1	3	2	30	2.32785737	0.04883504	0.94033333	0.77654177
1	3	3	30	2.35222813	0.03842915	0.94033333	0.77654177
1	4	1	20	2.32390000	0.06892322	0.41400000	0.25353086
1	4	2	20	2.37105000	0.05556549	0.41400000	0.25353086
1	4	3	20	2.38155000	0.05324370	0.41400000	0.25353086
1	5	1	26	2.29518171	0.06229727	0.53961538	0.28792333
1	5	2	26	2.33493225	0.04043707	0.53961538	0.28792333
1	5	3	26	2.34382580	0.03439559	0.53961538	0.28792333
2	3	1	5	2.37240000	0.06094506	0.47400000	0.16425590
2	3	2	5	2.40440000	0.03471023	0.47400000	0.16425590
2	3	3	5	2.41240000	0.02826305	0.47400000	0.16425590
2	4	1	14	2.28677440	0.05257864	0.48000000	0.24582671
2	4	2	14	2.32346206	0.04566602	0.48000000	0.24582671
2	4	3	14	2.31462014	0.05052241	0.48000000	0.24582671
2	5	1	34	2.25353091	0.09987843	0.27588235	0.19139231
2	5	2	34	2.32528539	0.06114848	0.27588235	0.19139231
2	5	3	34	2.32681930	0.05992160	0.27588235	0.19139231

Class Level Information

Class	Levels	Values
grad	2	1 2
nmas	4	2 3 4 5
traff	2	1 2
type	3	1 2 3

Number of Observations Read	402
Number of Observations Used	402

Dependent Variable: perm

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	0.01107729	0.00050351	6.23	<.0001
Error	379	0.03065230	0.00008088		
Corrected Total	401	0.04172959			

R-Square	Coeff Var	Root MSE	perm Mean
0.265454	325.6587	0.008993	0.002762

Source	DF	Type I SS	Mean Square	F Value	Pr > F
sg	1	0.00600482	0.00600482	74.25	<.0001
grad	1	0.00008088	0.00008088	1.00	0.3179
traff	1	0.00271840	0.00271840	33.61	<.0001
nmas	3	0.00071327	0.00023776	2.94	0.0331
type	2	0.00138308	0.00069154	8.55	0.0002
grad*type	2	0.00002362	0.00001181	0.15	0.8642
grad*nmas*type	12	0.00015322	0.00001277	0.16	0.9995

Source	DF	Type III SS	Mean Square	F Value	Pr > F
sg	1	0.00754648	0.00754648	93.31	<.0001
grad	1	0.00021947	0.00021947	2.71	0.1003
traff	1	0.00248901	0.00248901	30.78	<.0001
nmas	3	0.00084256	0.00028085	3.47	0.0163
type	2	0.00064113	0.00032057	3.96	0.0198
grad*type	2	0.00001043	0.00000522	0.06	0.9375
grad*nmas*type	12	0.00015322	0.00001277	0.16	0.9995

Duncan's Multiple Range Test for perm

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.000081
Harmonic Mean of Cell Sizes	192.2239

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.001804

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	grad
A	0.0040023	159	2
B	0.0019497	243	1

Tukey's Studentized Range (HSD) Test for perm

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.000081
Critical Value of Studentized Range	2.78069
Minimum Significant Difference	0.0018
Harmonic Mean of Cell Sizes	192.2239

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	grad
A	0.0040023	159	2
B	0.0019497	243	1

The GLM Procedure

Duncan's Multiple Range Test for perm

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.000081
Harmonic Mean of Cell Sizes	200.8209

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.001765

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	traff
A	0.0047363	207	2
B	0.0006653	195	1

Tukey's Studentized Range (HSD) Test for perm

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.000081
Critical Value of Studentized Range	2.78069
Minimum Significant Difference	0.0018
Harmonic Mean of Cell Sizes	200.8209

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	traff
A	0.0047363	207	2
B	0.0006653	195	1

Duncan's Multiple Range Test for perm

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.000081

Number of Means	2	3
Critical Range	.002160	.002274

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	type
A	0.002762	134	1
A			
A	0.002762	134	2
A			
A	0.002762	134	3

Tukey's Studentized Range (HSD) Test for perm

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.000081
Critical Value of Studentized Range	3.32759
Minimum Significant Difference	0.0026

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	type
A	0.002762	134	1
A			
A	0.002762	134	2
A			
A	0.002762	134	3

Level	Level		perm		sg	
grad	type	N	Mean	Std Dev	Mean	Std Dev
1	1	81	0.00194967	0.00371079	2.29570144	0.06756543
1	2	81	0.00194967	0.00371079	2.34365374	0.05034664
1	3	81	0.00194967	0.00371079	2.35879878	0.04322973
2	1	53	0.00400228	0.01561144	2.27352627	0.09249999
2	2	53	0.00400228	0.01561144	2.33226740	0.05949777
2	3	53	0.00400228	0.01561144	2.33167053	0.06081562

Level	Level	Level		perm		sg	
grad	nmas	type	N	Mean	Std Dev	Mean	Std Dev
1	2	1	5	0.00750425	0.00462068	2.34735293	0.01784707
1	2	2	5	0.00750425	0.00462068	2.37419862	0.03514412
1	2	3	5	0.00750425	0.00462068	2.38507734	0.02402541
1	3	1	30	0.00290665	0.00477511	2.26874425	0.06581090
1	3	2	30	0.00290665	0.00477511	2.32785737	0.04883504
1	3	3	30	0.00290665	0.00477511	2.35222813	0.03842915
1	4	1	20	0.00016844	0.00047187	2.32390000	0.06892322
1	4	2	20	0.00016844	0.00047187	2.37105000	0.05556549
1	4	3	20	0.00016844	0.00047187	2.38155000	0.05324370
1	5	1	26	0.00114747	0.00188455	2.29518171	0.06229727
1	5	2	26	0.00114747	0.00188455	2.33493225	0.04043707
1	5	3	26	0.00114747	0.00188455	2.34382580	0.03439559
2	3	1	5	0.00062380	0.00054367	2.37240000	0.06094506
2	3	2	5	0.00062380	0.00054367	2.40440000	0.03471023
2	3	3	5	0.00062380	0.00054367	2.41240000	0.02826305
2	4	1	14	0.00498148	0.01319688	2.28677440	0.05257864
2	4	2	14	0.00498148	0.01319688	2.32346206	0.04566602
2	4	3	14	0.00498148	0.01319688	2.31462014	0.05052241
2	5	1	34	0.00409592	0.01769888	2.25353091	0.09987843
2	5	2	34	0.00409592	0.01769888	2.32528539	0.06114848
2	5	3	34	0.00409592	0.01769888	2.32681930	0.05992160

Class Level Information

Class	Levels	Values
grad	2	1 2
nmas	4	2 3 4 5
traff	2	1 2
type	3	1 2 3

Number of Observations Read 402

Dependent Variable: pab

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	22	45.07540418	2.04888201	14.37	<.0001
Error	379	54.03097492	0.14256194		
Corrected Total	401	99.10637910			

R-Square	Coeff Var	Root MSE	pab Mean
0.454818	67.93083	0.377574	0.555821

Source	DF	Type I SS	Mean Square	F Value	Pr > F
sg	1	9.78786449	9.78786449	68.66	<.0001
grad	1	14.87198848	14.87198848	104.32	<.0001
traff	1	1.99998285	1.99998285	14.03	0.0002
nmas	3	14.02393307	4.67464436	32.79	<.0001
type	2	3.17462006	1.58731003	11.13	<.0001
grad*type	2	0.05422672	0.02711336	0.19	0.8269
grad*nmas*type	12	1.16278853	0.09689904	0.68	0.7712

Source	DF	Type III SS	Mean Square	F Value	Pr > F
sg	1	17.07878926	17.07878926	119.80	<.0001
grad	1	2.98177019	2.98177019	20.92	<.0001
traff	1	1.05646107	1.05646107	7.41	0.0068
nmas	3	10.35301059	3.45100353	24.21	<.0001
type	2	1.45097651	0.72548825	5.09	0.0066
grad*type	2	0.02361142	0.01180571	0.08	0.9205
grad*nmas*type	12	1.16278853	0.09689904	0.68	0.7712

Duncan's Multiple Range Test for pab

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.142562
Harmonic Mean of Cell Sizes	192.2239

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.07573

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	grad
A	0.69148	243	1
B	0.34849	159	2

Tukey's Studentized Range (HSD) Test for pab

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.142562
Critical Value of Studentized Range	2.78069
Minimum Significant Difference	0.0757
Harmonic Mean of Cell Sizes	192.2239

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	grad
A	0.69148	243	1
B	0.34849	159	2

Duncan's Multiple Range Test for pab

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.142562
Harmonic Mean of Cell Sizes	200.8209

NOTE: Cell sizes are not equal.

Number of Means	2
Critical Range	.07409

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	traff
A	0.62594	207	2
B	0.48138	195	1

Tukey's Studentized Range (HSD) Test for pab

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.142562
Critical Value of Studentized Range	2.78069
Minimum Significant Difference	0.0741
Harmonic Mean of Cell Sizes	200.8209

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	traff
A	0.62594	207	2
B	0.48138	195	1

Duncan's Multiple Range Test for pab

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.142562

Number of Means	2	3
Critical Range	.09070	.09548

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	type
A	0.55582	134	1
A			
A	0.55582	134	2
A			
A	0.55582	134	3

Tukey's Studentized Range (HSD) Test for pab

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	379
Error Mean Square	0.142562
Critical Value of Studentized Range	3.32759
Minimum Significant Difference	0.1085

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	type
A	0.55582	134	1
A			
A	0.55582	134	2
A			
A	0.55582	134	3

Level grad	Level of type	N	pab Mean	pab Std Dev	sg Mean	sg Std Dev
1	1	81	0.69148148	0.57732164	2.29570144	0.06756543
1	2	81	0.69148148	0.57732164	2.34365374	0.05034664
1	3	81	0.69148148	0.57732164	2.35879878	0.04322973
2	1	53	0.34849057	0.22371338	2.27352627	0.09249999
2	2	53	0.34849057	0.22371338	2.33226740	0.05949777
2	3	53	0.34849057	0.22371338	2.33167053	0.06081562

Level grad	Level nmas	Level type	N	pab Mean	pab Std Dev	sg Mean	sg Std Dev
1	2	1	5	1.09800000	0.51455806	2.34735293	0.01784707
1	2	2	5	1.09800000	0.51455806	2.37419862	0.03514412
1	2	3	5	1.09800000	0.51455806	2.38507734	0.02402541
1	3	1	30	0.94033333	0.77654177	2.26874425	0.06581090
1	3	2	30	0.94033333	0.77654177	2.32785737	0.04883504
1	3	3	30	0.94033333	0.77654177	2.35222813	0.03842915
1	4	1	20	0.41400000	0.25353086	2.32390000	0.06892322
1	4	2	20	0.41400000	0.25353086	2.37105000	0.05556549
1	4	3	20	0.41400000	0.25353086	2.38155000	0.05324370
1	5	1	26	0.53961538	0.28792333	2.29518171	0.06229727
1	5	2	26	0.53961538	0.28792333	2.33493225	0.04043707
1	5	3	26	0.53961538	0.28792333	2.34382580	0.03439559
2	3	1	5	0.47400000	0.16425590	2.37240000	0.06094506
2	3	2	5	0.47400000	0.16425590	2.40440000	0.03471023
2	3	3	5	0.47400000	0.16425590	2.41240000	0.02826305
2	4	1	14	0.48000000	0.24582671	2.28677440	0.05257864
2	4	2	14	0.48000000	0.24582671	2.32346206	0.04566602
2	4	3	14	0.48000000	0.24582671	2.31462014	0.05052241
2	5	1	34	0.27588235	0.19139231	2.25353091	0.09987843
2	5	2	34	0.27588235	0.19139231	2.32528539	0.06114848
2	5	3	34	0.27588235	0.19139231	2.32681930	0.05992160