A STATISTICAL ANALYSIS OF GEORGIA'S

HMA QUALITY ASSURANCE PROCESS

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A STATISTICAL ANALYSIS OF GEORGIA'S HMA QUALITY ASSURANCE PROCESS

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THESIS ABSTRACT

A STATISTICAL ANALYSIS OF GEORGIA'S

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In the recent years, there has been a push towards allowing contractors to use their own test results in the quality assurance process of Departments of Transportation (DOTs). While this movement saves the states money due to less testing, it has often been wondered if the contractor's data compare well with GDOT data. An analysis was conducted on hot mix asphalt data for the 2003 construction year in the state of Georgia to evaluate statistically significant differences between the contractor's and GDOT's data with the purpose of evaluating Georgia's QA process and contractor work. It was seen that while the contractor's means compared well, significnat statistical differences were found with variances.

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STYLE MANUAL AND SOFTWARE USED

Style maunal used: MLA Handbook for Writers of Research Papers (5th Edition)

Computer Software Used: Microsoft Word, Microsoft Excel, Minitab 14

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CHAPTER ONE

INTRODUCTION

When it comes to buying products, almost any consumer wants to get exactly what he or she ordered. What would happen if a person were to visit a restaurant and ordered a sandwich without mayonnaise, but the bread was tarnished by only a trace of the unwanted condiment? Most would not accept the sandwich and require another one to be produced, preferably at some reduced cost. What would a person do if they had ordered clothes online and upon arrival found a defect in one of the shirts? That individual would most likely call the company and ask for another to be shipped to replace the faulty shirt. The idea of buying quality merchandise is nothing new to the world of personal consumerism; however, it is also something that most Departments of Transportation (DOTs) also hold in high regard for their pavements. DOTs, like consumers, want what they ordered, and if the contractor does not provide it within a specified set of limits, DOTs sometimes want new products. Other times, the DOTs request reduced prices on the inferior products because the life cycle costs of the delivered product will be greater than that of the requested product due to more frequent maintenance and the possibility of a quicker replacement.

1.1 Checking the Quality of Pavements

Quality assurance is the testing process whereby a material is said to meet the specifications set forth for it. It has long been the practice of DOTs to conduct specific tests, depending on the individual department, to determine if the material the contractor was using to construct the roadway in question met the specifications in the job-mix formula (JMF). However, in the recent years, the DOTs have been given the option of relieving themselves of that burden and placing it on the shoulders of the contractors.

In 1995, a federal regulation entitled 23 *CFR 637, Part B (Quality Assurance Procedures for Construction [QAPC]* was enacted that allowed DOTs to begin using their contractor's test results for acceptance. In order to help ease the transition between testing agencies, the American Association of State Highway and Transportation Officials (AASHTO) published the "Implementation Manual for Quality Assurance" and "Quality Assurance Guide Specification" in the year 1996. Some states have embraced the idea of using contractor's tests for material acceptance because it eases the workload for the DOTs. Not only would time be saved, but also the expenses of running tests would be minimized if the contractors were responsible. However, while some states have embraced the idea whole-heartedly, other states have been slightly more hesitant to turn over acceptance testing to contractors.

In order to investigate this concern, the National Cooperative Highway Research Program launched project 10-58 (02), *Using Contractor-Performed Tests in Quality Assurance*. The objective of the project "is to develop procedures to assist state DOTs in effectively using contractor-performed tests in the quality assurance process." To accomplish this goal, the results of different DOTs using contractor-performed quality tests in the quality assurance process needed to be studied. The methods used by each state were surveyed so that other suitable possible sources of data might be found to undergo analyzation for the stated objective, and those states that seemed to fit were asked to send data to be analyzed.

Georgia was the first state to respond to the request. While Georgia does not use contractor data in its acceptance of concrete products, it does use contractor-performed tests on hot-mix asphalt (HMA) projects. Both the contractor and DOTs test for the pavement's asphalt content and percent passing the 1.5", 1", ¾", ½", 3/8", #4, #8, #50, and #200 sieves. It should, however, be noted that the Georgia DOT tests for acceptance of mat density and smoothness.

1.2 Objectives

The objective of this project was to numerically investigate the quality assurance process in the state of Georgia by the use of statistical measures and numerical comparisons. Specifically, data were analyzed to determine if sets of results provided by the contractor differed significantly from those provided by the DOT. Differences were evaluated statistically by F-tests for variance, t-tests for means, skewness, and mean square deviations for accuracy and precision.

It is not the objective of this report to prove or disprove data manipulation occurs on the part of either the contractor or the DOT; however, data manipulation could be a possible reason if contractor and DOT results are shown to have varied significantly from each other.

1.3 Scope

The analysis process was conducted on data collected during the year 2003 for Georgia's HMA projects. Tests were performed on both independent and split samples; however, while the independent samples might show differences in material uniformity, the split sample results analyze the differences in testing methods. Figure 1-1 visually shows where variances can arise during the material testing process, and it also shows which variances are tested by independent and split samples.

$$\sigma^2_{total} = \sigma^2_{sampling} + \sigma^2_{testing} + \sigma^2_{material}$$

Independent $\longrightarrow$ σ^2_{total}

Split $\longrightarrow$ $\sigma^2_{testing}$ (theoretically)

Figure 1-1. Variance Occurrences in Testing.

Three different data sets were analyzed: the overall data set, a reduced data set, and project data sets. The overall analysis was conducted on all the data provided for the 2003 construction season. The nine properties previously mentioned were subjected to F tests, t-tests, mean square deviations, and skewness analyses to determine if the values the contractors were returning to GDOT were greatly different than those GDOT was finding from their own tests.

The reduced data set was compiled by combining all the data from projects that had at least six GDOT test results. A large project was defined as having at least six tests for the purposes of this report. F and t-tests were used on the 1/2" sieve, #200 sieve, and asphalt content data to see if many of the smaller projects might be skewing the results of the overall project analysis.

The final type of data analyzed was individual project data. Data from all projects that had at least six GDOT test results were subjected to F and t-tests for the 3/8” sieve, #200 sieve, and asphalt content. These tests were conducted to determine how many projects had significant differences in both variances and means of GDOT and contractor test results. These studies strengthened observations of tendencies, such as GDOT’s variances being larger than the contractor’s, that might consistently occur.

CHAPTER TWO

LITERATURE REVIEW

Since the policy change allowing the use of contractor data for acceptance was codified in the *Code of Federal Regulations* (CFR), *23 CFR 637, Part B (Quality Assurance Procedures for Construction [QAPC])*, state departments of transportation (DOTs) have begun to use contractor data for decisions regarding payment and acceptance. However, since the implementation of this policy, few states have investigated whether the states and contractors have adequately adapted to the change in responsibilities. The slow transition from policy to practice could be due to the fact that each state is responsible for determining what might be appropriate for its own practice instead of a standard being issued by a national authority. Other factors that might have influenced the lack of study could be reluctance on the part of the DOT to trust the contractor to adequately report the test results or the lack of understanding the terms and concepts involved in the process of verifying the quality of a material.

2.1 Terms and Definitions

If one looks through specification manuals or asks engineers across the country to define the terms related to the quality control/quality assurance process, the answers would be varied and inconsistent despite the efforts of organizations such as the Federal Highway Administration (FHWA) and the Transportation Research Board (TRB). In

1995, when the policy change occurred in the CFR, the FHWA created a list of definitions of terms pertaining to the quality control/quality assurance process; however, to further stress the point, the TRB created the *Glossary of Highway Quality Assurance Terms* in April of 2002. In this document, the original definitions were further refined to more adequately describe what the terms had come to mean.

Quality assurance is the first and most important term defined in either of the documents. The original FHWA definition stated that QA was “all those planned and systematic actions necessary to provide confidence that a product or service will satisfy the requirements for quality” (FHWA, 1995). When the TRB defined this term in its circular, it refined the definition to the following: “All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. QA addresses the overall problem of obtaining the quality of a service, product, or facility in the most efficient, economical, and satisfactory manner possible” (TRB, 2002).

The term *quality control* (QC) is often erroneously interchanged with that of quality assurance. The FHWA defined the term as “all contractor/vendor operational techniques and activities performed or conducted to fulfill the contract requirements” (FHWA, 1995); however, QC should be viewed more in the lines of process control. The TRB defined it as “those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality being produced in the end product” (TRB, 2002).

To further alleviate confusion between the terms, the *Glossary of Highway Quality Assurance Terms* included Figure 1 and Table 1 which have been recreated as

Figure 2-1 and Table 2-1 reproduced herein. As can be seen, along with the many other differences, it should be noted that contractors are responsible for QC practices while the DOT is responsible for the QA process.

Table 2-1. Quality Assurance and Quality Control Properties (*TRB,* 2002).

Quality Assurance (QA)	Quality Control (QC)
• Making sure the quality of a product is what it should be	• Making the quality of a product what it should be
• Highway agency is responsible	• Producer/contractor is responsible
• Includes QC	• A part of QA
• Doing the right thing	• Doing things right
• Motivates good QC practices	• Motivated by QA and acceptance procedures

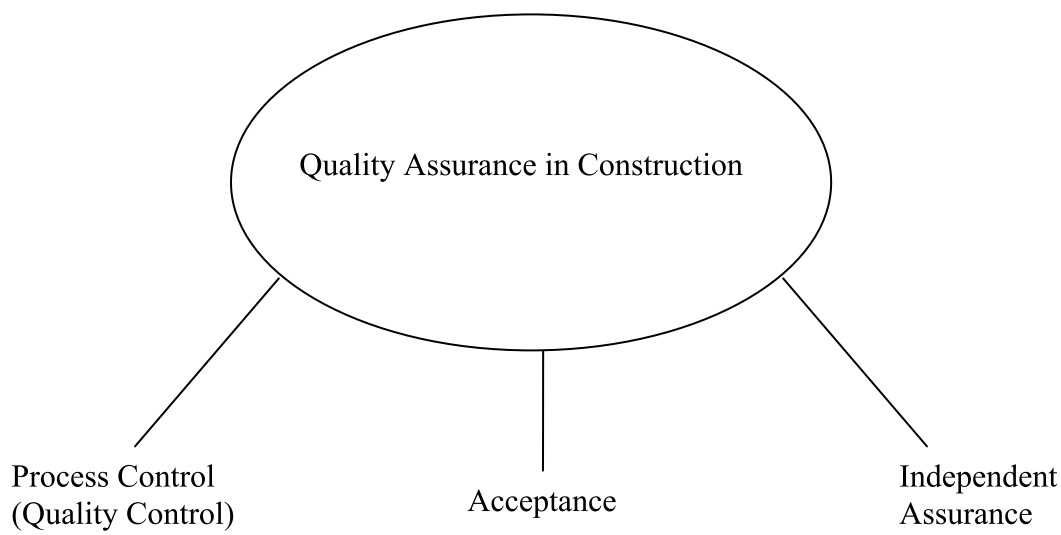

Figure 2-1. Quality Assurance Diagram (*TRB, 2002).*

As seen in Figure 2-1, there are two other legs to the QA process: acceptance and independent assurance. Acceptance is simply "the sampling and testing, or inspection, to determine the degree of compliance with contract requirements" (TRB, 2002). This definition is similar to the original quality control definition provided by the FHWA; however, the latest definitions show that acceptance relates to the contract requirements while QC is related to the creation of the contracted product.

The other process, besides acceptance and QC, is the *independent assurance* (IA) testing process. By definition, this type of testing is done by a third party, though some states' practices include IA tests conducted by DOT staff. IA is defined as "a management tool that requires a third party, not directly responsible for the control or acceptance, to provide an independent assessment of the product and/or the reliability of the test results obtained from the process control and acceptance testing" (TRB, 2002). The results of these tests are not to be used in determining if the product should be accepted or not.

The FHWA simplistically defined *verification* as that process which was used to validate the quality of a product, and the newer TRB definition did not add much to the previous. Verification is "the process of determining or testing the truth or accuracy of test results by examining the data and/or providing objective evidence" (TRB, 2002). One important thing to know about verification testing is that it can be done during multiple phases of the quality assurance process. Verification could be incorporated into the IA process, and this would be used to help verify the results of either the contractor's QC tests or the agency's acceptance tests. The acceptance program could also be a viable home for a verification program "to verify contractor testing used in the agency's acceptance decision" (TRB, 2002).

Another term pertinent to understanding the QA/QC process is *pay factor* or *pay adjustment*. The TRB says that pay factors are percentages used to raise or reduce the contractor's payment based upon the test results that estimate the quality of the product. In most cases, pay factors are attributed to the product on a characteristic by characteristic basis.

For example, a pavement might exceed the requirements for density inducing a pay factor over 100%; however, the mix might not be exceptional in its gradation causing the pay factor for the gradation to be below 100%. Many agencies determine which characteristics to include in their payment process, and they split the percentage of the pay in some way across the required characteristics. Taking the example above, the DOT might decide 60% of the pay should be based upon density while only 40% is based upon the mix's gradation. The two percentages are then multiplied by their respective pay factor, and they are then added together to produce a composite pay factor. Another common approach is to take the lowest of the pay factors among all the properties and use that as the overall pay factor.

2.2 Policy

The FHWA created requirements for process control and acceptance programs. The acceptance process can include QC testing results when the following requirements are met (FHWA, 1995):

1. The labs and personnel involved in the testing process are qualified.
2. Independent samples must be used to validate the quality of the material in question.
3. An independent assurance program must be in place.

The FHWA also produced a list of requirements for the acceptance programs including the following three items (FHWA, 1995):

1. A frequency guide schedule
2. Identification of sampling location
3. Identification of attributes to be investigated.

In order to accurately set up policies and specifications for using contractor-performed quality control (CPQC) tests, a set of objectives needed to be explicitly outlined. In a report submitted to the Kentucky Transportation Cabinet (KYTC), four distinct objectives for CPQC testing were defined (Mahboub et al., 2001).

1. Improve the quality of the materials and processes used in the construction of highway projects, and reduce the life cycle costs for the facilities involved.
2. Redirect the responsibility for quality control on projects to the contractor.
3. Reduce the disputes between the DOT and its contractors.
4. Enhance the construction schedule and the Department's effort on quality management.

If these objectives and policies are followed, then the use of CPQC testing should hold advantages for both the contractor and the DOT; however, this is not a system that does not raise any concerns among its users. Tables 2-2 and 2-3 provide lists of advantages and concerns in the CPQC process. These lists were compiled from surveys sent out in a 2001 study for the KYTC.

Table 2-2. Advantages in Using CPQC (Hancher et al., 2002).

Agency (DOT)	Contractor
• Contractor responsible for their own products • Reduction of state personnel • Gaining knowledge by contractors • Improving dispute resolution • Quality improvement	• Contractor more suitable for control • Improving schedule • Improving quality • Better dispute resolution

Table 2-3. Concerns in Using CPQC (Hancher et al., 2002).

Agency (DOT)	Contractor
• Validity of test data • Insufficient certified technician pool • Insufficient QA • Lack of training • DOT losing expertise • Contractor operating at lower end of specification • Fear of losing control on project • Lack of understanding	• Capability of technicians and facilities • Cost of QC • Lack of trust • Lack of training • Honesty of some contractors • Expensive independent test agencies • Different goals of contractor and DOTs

The agency also hopes that giving this added responsibility to the contractor will increase the importance of quality in the contractor's mind (Hancher et al., 2001).

2.3 Sampling

During the sampling process, three different types of variations can be investigated: materials, sampling, and testing. While the FHWA policy requires "all samples used for quality control and verification sampling and testing" (FHWA, 1995) to be random samples, the DOT is responsible for deciding whether it shall use independent or split samples. Each sample type has intrinsic characteristics that determine its appropriate uses.

Independent samples are, according to the *Glossary of Highway Quality Assurance Terms*, "taken without regard to any other sample that may also have been taken to represent the material in question" (TRB, 2002). These samples are taken at separate times, locations, and even possibly volumes. In turn, when independent samples are tested, they have the ability to provide data on the variabilities of all three parameters (materials, sampling, and testing) (Schmitt, 2001).

Split samples, unlike independent samples, come from one material source. One sample is taken, and then it is broken into portions to give to the laboratories running the inquiries (TRB, 2002). Due to the nature of this sampling procedure, the only variability should come from the testing procedures and technicians in the different laboratories. This is due to the samples coming from the exact same location; the materials, production, and sampling should all be the same (Schmitt, 2001).

A study conducted at the University of Wisconsin-Madison further investigated differences that might occur in split samples versus independent samples. A sample of 16 projects across six states was analyzed statistically, and the variances of the split samples were compared to the variances of the independent samples. As expected, the results showed that the independent samples had greater variances than the split samples 96.2% of the time (Schmitt, 2001).

2.4 Quality Assurance Analysis Methods

Once the samples have been taken, the test results must be analyzed by using one of many possible methods. While there are a variety of possibilities to choose from for the type of analysis to be used, two are becoming the most popular choices for state

DOTs. The percent within limits (PWL) method is a way to compare tests results to specifications. The second method, statistical analyses using F and t-tests, is a way to compare two test results to each other.

The PWL method is now highly supported by the FHWA. In this method, the state DOT must decide on upper and lower limits for the chosen characteristics. These limits are normally set up as two standard deviations in each direction from the mean using the normal distribution function. These limits can either be chosen based upon past data or experience in the field. The test results are then plotted, and the percent of test results within the two limits is calculated. Payment and acceptance is based upon how close the test result averages are to the target and variability (Sholar et al., 2004).

F and t-tests are another form of statistical analysis that are commonly used to help analyze the consistency of contractor and DOT data. While the theory behind these tests will be explained in greater detail at a later time, the purpose of each test should be noted. F-tests are used to determine if the variabilities of two data sets can be shown to be different to a specified level of significance. This test must be performed first to determine the appropriate t-test. If the F-test shows the variabilities are the same, then a t-test assuming equal variances is conducted. If the variabilities are statistically different, then a t-test using unequal variances is used. T-tests are used to the test statistical significance of differences between the means of two data sets (Mahboub et al., 2004).

If the test results come from split samples, then a different type of t-test should be conducted. Since the same material is being tested, the variabilities should be the same. The paired t-test is used on split samples because it allows a one-to-one comparison and is more powerfully statistically (Mahboub et al., 2004).

While both of these statistical analyses are both commonly and easily incorporated into the QA programs in many states, they are not perfect, and two major concerns can be voiced. The first concern is the lack of data that can be analyzed. While large projects have an abundance of quality assurance testing conducted on the project, smaller projects might only have three or four tests. It is difficult, if just a few tests are available, to accurately know whether or not the assumptions needed to conduct a proper t-test have been fulfilled. The more degrees of freedom the particular test has, the more accurate its depiction of mean and variability similarity will be (Hancher et al., 2002).

The second concern arises from the first concern. If there is a lack of data, it is difficult to prove normality, the test results following the normal distribution. While testing and studies have shown that constructor materials test data tend to conform to a normal distribution, both the percent within limits method and F and t-tests rely on data normality (Hall et al., 2002). If the data for some reason are not normal, then the tests might not accurately portray the statistical differences between the data sets (Hancher et al., 2002).

2.5 Studies

A study was conducted by the Highway Research Center at Auburn University that compared contractor's data to that of the Alabama DOT for a sampling of projects for the years 1990, 1991, and 1992. It should be noted that this study was conducted before the change in the *Code of Federal Regulations*, but the findings are still applicable to this study. When the team conducting the research specifically targeted the asphalt content's difference from the job-mix formula (JMF), they found that means of contractor and DOT measurements were different for about 1/3 of the mixes. For the first two years, neither the state DOT nor the contractor's measurements were consistently further from the target than the other. However, in 1992, there were significant differences in means for 17 out of 48 mixes. The state DOT's test results consistently showed more deviation from the target, having the larger means for 15 of the possible 17 mixes. General trends observed were that the variability decreased and the accuracy increased with time (Parker et al, 1995).

After the *CFR* changed, another project was sponsored by ALDOT to statistically analyze measurements of HMA properties as the Superpave mix design system was implemented. The team studied data from 1997 to 2000 for three properties: asphalt content, air voids, and mat density. Using a 5% significance level on F and t-tests, contractor and DOT data were analyzed. Table 2-4 provides the results which show that more statistical differences occurred with variances than means.

Table 2-4. Results from Alabama Study (Parker et al., 2002).

		Statistical Difference @ 5%	
		Variability	Means
Asphalt Content	1997	Yes	Yes
	1998	Yes	No
	1999	Yes	No
	2000	Yes	No
	Combined	Yes	No
Air Voids	1997	No	No
	1998	Yes	No
	1999	Yes	Yes
	2000	Yes	No
	Combined	Yes	No
Mat Density	1997	No	No
	1998	Yes	Yes
	1999	Yes	Yes
	2000	Yes	Yes
	Combined	Yes	Yes

The University of Kentucky conducted a statistical analysis of the Kentucky Transportation Cabinet's (KYTC) verification data versus the contractors' data. Means were compared using paired t-tests for both hot-mix asphalt (HMA) and Portland cement concrete (PCC). Results, as shown in Table 2-5, indicate that means of KYTC's data set are comparable to the means of contractors' data. Similar to the Alabama's studies, the contractors' measurements consistently had smaller standard deviations. This was explained by the possibility of using a feedback loop to correct variabilities within the project (Mahboub et al., 2004). If this is truly the reasoning behind smaller contractor variabilities, then the contractors are doing what should be done, and the DOTs should not be concerned with transferring responsibilities in the QA process to them.

Table 2-5. Paired t-Test Comparisons between Kentucky Transportation Cabinet and Contractor Data (Mahboub et al, 2004).

	Significant difference at 5%	
KY testing category	**Mean (p-value)**	**Standard Deviation (p-value)**
HMA-air	No (0.462)	Yes (<0.0001)
HMA-asphalt content	No (0.851)	Yes (<0.0001)
HMA-VMA	No (0.83)	No (0.854)
PCCP-air	No (0.823)	Yes (0.004)
PCCP-slump	No (0.822)	Yes (<0.0001)
PCCP-strength	No (0.854)	Yes (0.002)
PCC-structural-air	No (0.766)	No (0.219)
PCC-structural-slump	No (0.680)	No (0.669)
PCC-structural-strength	No (0.480)	No (0.223)

2.6 Summary of Findings

In 1995, states were allowed to begin using contractor test results in the acceptance process with the implementation of *23 CFR 637 Part B*. This was done to help the state transportation agencies save both time and money in the testing phases of projects. Since that time, studies have been conducted in Alabama and Kentucky to see how contractor test results compare to those of the DOT. The 1992 Alabama study showed that the mean asphalt contents of the contractor and DOTs were different for about 1/3 of the mixes tested; however, the later Alabama study and the Kentucky study both showed that statistically significant differences in variances were more likely to be found than in means. All three studies found contractors to have smaller variances and mean differences from the target.

CHAPTER THREE

STATE OF THE PRACTICE

The QA process has relatively few policy requirements in terms of how it should be conducted. The freedom is given to the state DOT to come up with an appropriate set of regulations for its contractors to follow as long as they conform to *23 CFR 637 Part B*. The following are just a few of the questions each state must answer:

- What properties should be considered in the QA process?
- How many times should each property be tested for by each organization?
- Who should conduct the tests?
- What will the role of the contractor be?
- What methods should be used to test each property?
- Once the test results are in, how should it be decided if they are adequate for acceptance?

With these questions and a host of others to be answered by each state, it is not surprising to see that possibly no two states conduct the QA process in the exact same way. In fact, the diversity seen from state to state is quite staggering.

3.1 2000 University of Kentucky Survey

In 2000, a group from the Kentucky Transportation Center at the University of Kentucky at Lexington sent surveys state DOTs and contractors. The survey consisted of questions in regards to which programs were implementing contractor data as a viable option for product acceptance. Another area of concern was the satisfaction with the current QA practices. Thirty state DOTs and 12 contractors responded to the survey. Table 3-1 is an overview of the four most common products included by DOTs in their 2000 QA/QC specifications. As is evident from the responses, HMA is the material for which contractor data is most widely used for QA purposes (Hancher et al., 2002).

Table 3-1. Materials Considered for QA/QC.

Materials	Percentage Using QA/QC
Grading/Earthwork	26.7%
PCCP	50.0%
HMA	86.7%
Concrete Bridge Deck	50%

Tables 3-2 and 3-3 give summaries of the responses the DOTs and contractors, respectively. Each DOT and contractor surveyed was given the chance to voice its opinion of the effects that contractor-performed acceptance testing was having in four categories where it was supposed to bring about positive influence: project quality, overall project cost, project schedule, and project disputes. The results of this survey were given in number form with a 5 representing *very positive* and 1 representing *very negative*; however, some agencies chose not to answer, and those agencies had their responses marked as unidentified.

Table 3-2. DOT Results.

Satisfaction Rating	Project Quality	Overall Project Cost	Project Schedule	Project Disputes
Very Negative	3.4%	6.9%	0%	3.6%
Negative	0%	17.2%	3.4%	7.1%
No Effect	6.9%	34.5%	69.0%	21.4%
Positive	51.7%	13.7%	3.4%	42.9%
Very Positive	13.7%	0%	0%	0%
Unidentified	24.1%	27.7%	24.1%	25%

Table 3-3. Contractor Results.

Satisfaction Rating	Project Quality	Overall Project Cost	Project Schedule	Project Disputes
Very Negative	0%	16.7%	0%	8.3%
Negative	8.3%	25%	0%	16.7%
No Effect	41.7%	8.3%	33.3%	33.3%
Positive	25%	41.7%	50%	0%
Very Positive	25%	8.3%	16.7%	41.7%

When the averages were computed, it was found that the contractors felt more positive about using their test results in the categories of *Overall Project Cost*, *Project Schedule*, and *Project Disputes*. These results are in Table 3-4. *Project Quality* is the only area where the state DOTs felt more confident. This seems odd that the DOT would feel more positive about using the contractor data than the contractors.

Table 3-4. Numerical Survey Averages (Hancher et al. 2002).

Category	DOT Averages	Contractor Averages
Project Quality	3.95	3.67
Overall Project Cost	2.76	3.00
Project Schedule	3.0	3.83
Project Disputes	3.38	3.50

3.2 2004 Auburn University Survey

In 2004, Auburn University's Highway Research Center began thoroughly looking at the QA/QC practices of different Departments of Transportation for Project 10-58(02) for the National Cooperative Highway Research Program. A survey was sent to 25 different Departments of Transportation to investigate their quality assurance practices. This survey was similar to the survey sent by the University of Kentucky, but questions were much more specific regarding details of the actual QA practices.

Fourteen states and Federal Highway Administration's Western Lands Office responded for hot mix asphalt.

Table 3-5 summarizes which organization has testing responsibilities for HMA properties. The number in each column represents how many agencies responded use what type of testing for the specified property. This table shows that while some states look at similar material properties; many states choose to test more obscure properties. The four properties that are most consistently tested by both the contractor and the agency are gradation, asphalt content, mat density, and voids in mineral aggregate. While there may be some consistency in material properties used, the testing methods for a particular property may be different.

Lot sizes vary from 500 tons maximum tonnage to one day's work. The contractors sometimes will use split samples instead of using independent samples.

Table 3-5. Property Responsibility.

Property	Contractor	Agency	Both	None
Gradation	2	0	11	2
Asphalt Content	1	1	13	0
Voids in the Mix	0	1	7	7
Voids in Mineral Aggregate	1	2	9	3
Voids Filled with Asphalt	1	0	2	12
Marshall Stability	0	0	2	13
Flow	0	0	2	13
Moisture Content	1	1	6	7
Layer Thickness	1	4	1	9
Mat Density	0	3	12	0
Smoothness	3	5	6	1
Hveem Properties	0	2	2	11
Boil Test	0	1	0	14
Abson Recovery	0	1	0	14
Maximum Gravity	0	0	1	14
Dust to Asphalt	0	0	2	13
Retained Tensile Strength	0	0	1	14
Fine Aggregate Angularity	0	0	1	14
Clay Content	0	0	1	14
Lottman	0	0	1	14
Joint Density	0	0	2	13
Lime Gradation	0	0	2	13
Sand Equivalency	0	0	1	14
Air Voids	0	0	1	14
Mat Temperature	0	1	0	14

Each agency determines the most appropriate way to decide if inconsistencies occur between the contractors' test results and their own. Table 3-6 shows the variety of analysis methods for the four most common tests performed by both the contractor and the agency. More responses would have made for a more accurate representation; however, the variety can still be seen from the small sampling.

Table 3-6. Analysis Methods.

Property	Numerical Criteria	F and t test	t test only	Other
Gradation (4 responses)	25%	50%	25%	0%
Asphalt Content (5 responses)	20%	60%	20%	0%
VMA (3 responses)	33.3%	33.3%	0%	33.3%
Mat Density (4 responses)	25%	25%	25%	25%

Like the survey conducted by the University of Kentucky, the Auburn survey asked the DOTs if they are confident the contractor's test results provide the same control of quality as their test results. This was asked for each of the properties, and then an overall satisfaction of the program question was posed. Table 3-7 summarizes survey responses. Only the overall and top four properties results are summarized in the table. The results show that, overall, the DOTs feel mostly confident using contractor test results in the quality assurance process.

Table 3-7. Confidence and Satisfaction Table.

Property	Confident	Mostly Confident	Neutral	Not Totally Confident	Not Confident
Gradation	27.3%	36.4%	27.3%	9.1%	0%
Asphalt Content	20%	60%	10%	10%	0%
VMA	14.3%	71.4%	14.3%	0%	0%
Mat Density	44.4%	33.3%	22.2%	0%	0%
Satisfaction	**Satisfied**	**Mostly Satisfied**	**Neutral**	**Not Too Satisfied**	**Not Satisfied**
Overall	33.3%	26.7%	33.3%	6.7%	0%

3.3 GDOT Practices

The Georgia DOT accepts HMA based on four material properties: asphalt content, gradation, mat density, and smoothness. However, contractors' data is used only for asphalt content and gradation. Georgia DOT tests for both mat density and smoothness are used for acceptance.

The Georgia DOT's quality assurance process terminology is different from the FHWA and TRB definitions provided in Chapter 2. GDOT uses three different terms to designate testing methods and who did the testing. QCT represents the regular contractor testing that is required, and this is related to the TRB term *quality control*. Georgia requires one test for every 500 ton sublot, and a LOT is equal to one day's production (GDOT, 2005).

The abbreviation QA stands for the Georgia DOT's testing that is compared to the QCT test results which falls under the TRB definition of *acceptance*. These tests are conducted twice for every 5 lots or 5 days, whichever is less. The QA tests are conducted on independent samples, and the results are compared to the JMF using the set of specification limits shown in Table 3-8. While there are no specification limits set, the percents passing the 1", 0.75", and #50 sieves are determined (GDOT, 2005).

Table 3-8. Specification Limits for Independent Samples (GDOT, 2005).

Property	+/- Specification Limit
Asphalt Content	0.4%
0.5" Sieve	6.0%
0.375" Sieve	5.6%
#4 Sieve	5.6%
#8 Sieve	4/6%
#200 Sieve	2.0%

If these specification limits are met with the QA test results, then the QCT tests for asphalt content and gradation are permitted for use in acceptance and the calculation of the pay factors. Pay factors are calculated for asphalt content, designated sieve sizes, and mat density. The maximum pay factor is 1; therefore, no bonuses are given for exceptional work.

The third type of testing is DOT comparison tests. These are on split samples with contractor QCT samples. The QCT and DOT Comparison tests fall under the TRB term *independent assurance*. These split samples (Contractor QCT and DOT comparison) are taken once for every 10 lots, and the results are compared one to one with criteria in Table 3-9. The purpose of the DOT comparison test is to verify the QCT results. As with the QCT and QA samples, the percents passing the 1”, 0.75”, and #50 sieves are determined (GDOT, 2005).

Table 3-9. Allowable Percent Difference Between Department and Contractor Acceptance Tests (GDOT, 2005).

Property	Surface Mixes	Subsurface Mixes
Asphalt Content	+/- 0.4%	+/-0.5%
0.5" Sieve	N/A	+/-4%
0.375" Sieve	+/-3.5%	+/-4%
#4 Sieve	+/-3.5%	+/-3.5%
#8 Sieve	+/-2.5%	+/-3.0%
#200 Sieve	+/-2.0%	+/-2.0%

If the DOT comparison and QCT test results compare favorably and if the DOT QA test results meet the specification mix requirements, QCT test results are used for pay factor computation. If these conditions are not met, additional sampling and testing is conducted to resolve the differences. If the differences cannot be resolved, the QCT test results may be replaced with the GDOT test results for pay factor computation.

3.4 Asphalt Content

GDOT allows asphalt content to be tested by either extraction or by the ignition oven as specified in its specification manual. GDT 83 is designated as the Method of Test for Extraction of Bitumen from Paving Mixtures using the Vacuum Extractor. This test method uses a solvent and a vacuum to remove the bitumen from the HMA sample. The percent asphalt is calculated by then subtracting the remaining weight of the sample from the original weight as a percentage of the original weight (GDOT, 2005).

The Method of Test for Determining AC Content by Ignition Oven, GDT 125, is a much simpler way of determining the asphalt content of a sample. A sample of the HMA is placed in an oven set to 1000^{o}F. Inside the oven is a balance that measures the weight of the sample. The HMA should remain in the oven until the balance stabilizes on a weight. The percent asphalt is then calculated in the same way as for the extraction method (GDOT, 2005).

One reason asphalt content might have been chosen to undergo the QA process is its correlation to performance. In 2004, a study conducted at North Carolina State University documented testing that had been conducted to characterize differences in a pavement's fatigue life and initial stiffness based upon its material properties. In testing asphalt content, a set of general mixes and a set of North Carolina DOT-specific mixes were created with asphalt content at its optimum level and at -0.5% of optimum. On the North Carolina DOT mixes, the reduction in asphalt content reduced the fatigue life of the pavement by 18-25%; however, the general mixes showed a reduction of fatigue life of up to 50%. The initial stiffness did not seem to be determined by the pavement's asphalt content (Tayebali and Huang, 2004).

3.5 Gradation

GDOT uses GDT 38, Method of Test for Mechanical Analysis of Extracted Aggregate, as its method for determining the gradation of the aggregate samples. The sample of aggregate is sifted through a set of vertical sieves to determine the percent passing the specified sieves indicated earlier (GDOT, 2005).

While it is easy to single out a property like asphalt content and link it to performance, it is more difficult to single out gradation. However, gradation is highly linked to the percentage of air voids in a mixture. The finer the gradation, the lower the percent air voids will be. The North Carolina State University study discussed earlier conducted an experiment where an SP 12.5 mm mix and an SP 19 mm mix were tested for fatigue life. A typical mix and a mix with a 2% increase in air voids were the two samples in the experiment. A 2% increase in air voids caused the fatigue life of the SP 12.5 mm mix to have a 40% reduction, and the increase in air voids caused the SP 19 mm mix to have a 60% reduction in fatigue life. Therefore, the gradation of a mix can make a difference in the fatigue life of a pavement since it is tied to the air voids in the pavement (Tayebali and Huang, 2004).

3.6 Summary of Findings

As shown in both the Kentucky and Auburn surveys, there are a variety of ways for states to organize their QA programs. Material properties, testing methods, and analysis methods are just three of the differences that can be seen from state to state.

Terminology is another thing that varies from state to state. While the FHWA and TRB set up standard definitions, GDOT's terminology varies somewhat. The relationships are show in Figure 3-1.

GDOT		**TRB**
QCT	→	Quality Control
QA	→	Acceptance
Comparison	→	Independent Assurance

Figure 3-1. Terminology Relationships Between Georgia DOT and TRB.

Georgia specifically uses gradation and asphalt content as their properties tested by both the contractors and GDOT for acceptance. Every LOT requires one QCT test by the contractor, and two out of every five LOTs are tested by the DOT as an independent sample as QA. One out of every ten LOTs has a DOT comparison test from a split sample. This is graphically shown in Figure 3-2.

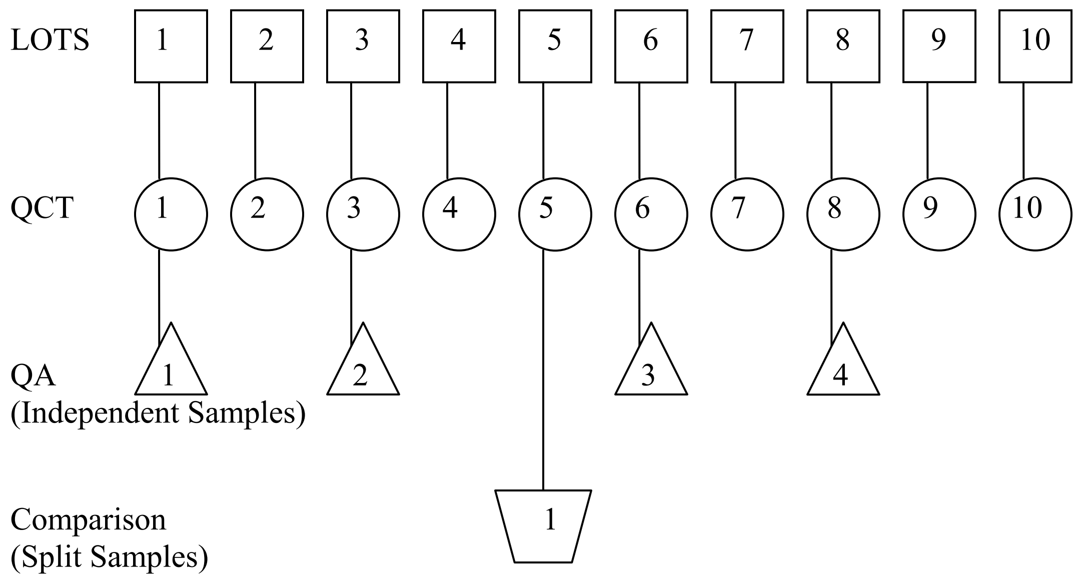

Figure 3.2. Georgia DOT Sampling Ratios.

CHAPTER FOUR

METHODOLOGY

Two comparisons were made of contractor and GDOT test results. The first consisted of comparisons of the contractor's QCT and GDOT's QA test results. The second of comparisons of the contractor's QCT results and GDOT's comparison test results. The properties compared were asphalt content and percent passing the 1", 0.75", 0.5", 0.375", #4, #8, #50, and #200 sieves.

4.1 Data Management

When the Georgia DOT sent the data to Auburn University's Highway Research Center to be analyzed, the numbers needed for the analyses were contained in three Microsoft Access databases. Once it was understood which process each file contained, the organization of the column headings was not difficult to interpret.

The difficulties arose in retrieving correct data in the project by project analyses. The overall analyses were easy as the analyzer could query a specific year and material property using built in programs in Microsoft Access. When the project by project analysis was conducted, each data row was visually inspected. A sort might have been available to speed up this process; however, many of the project titles were not consistent. The same project might have a "0" (zero) instead of an "O." Another project might have been listed by the contractor as “0100,” but GDOT listed it as “100.” This became especially difficult in trying to match projects from contractor to GDOT data.

This inconsistency might be due to different employees recording the data in different ways; however, no conclusions can be made as to why these discrepancies occurred, but in order to keep accurate records in the GDOT data system, identical project number recording is imperative. A drop down menu providing a list of the projects in service at the time might be an appropriate way to help alleviate this problem.

4.2 Overall Data Analysis

The first analysis was an overall data analysis. All of the 2003 data were divided among the various properties listed above, and then these results were put through a series of filters to find usable data. The first filter was one to exclude all of the data that did not include job mix formulas. This was accomplished through the use of queries in Microsoft Access. Only the data with job mix formulas could be used because target values were variable for each property; therefore, in order to combine data from job mix formulas, the target values had to be subtracted from the test results.

The second filter applied to the data was outlier removal. Only obvious outliers, those impossible due to the next sieve size, could be removed from the data sets because there might have been inadequate mixes in the data set, and those mixes needed to be considered in the data analysis. One method for finding outliers was doing a sort of the data in Microsoft Excel. For example, if the results or job mix formula said 100, and the test results said 10 or 1 or vice versa, then the data was considered invalid, and it was removed. Once the outliers were removed, actual analyses began.

4.2.1 The F-Test

The F-test is a test that analyzes the variances of the data sets in question. The F-test "assesses mean differences by comparing the amounts of variability explained by different sources" (Ramsey and Shafer, 2002); therefore, the results of the test explain if there are differences in the variabilities of the data sets.

The F-tests were run for each material property in both the QCT versus QA and QCT Comparison versus DOT analyses using all the data passing the two removal filters using the data analysis programs in Microsoft Excel. The null hypothesis was that the variances were not statistically different. Two values are typically used for confidence levels depending on the preference of the individual performing the analyses and how accurate the tests need to be. Those values are 95% and 99%. In the case of the F tests, and all of the other statistical tests for this analysis, a significance level of $\alpha=0.01$ was used; therefore, if the p-value was less than 0.01, the variances in the two data sets were considered different. This significance level was chosen to make finding differences between the sets more rigorous because fewer test results should be shown as different in a 1% significance level rather than a 5%.

The results of the F-tests could be important for possibly two reasons. The results of the analysis would determine which type of t-test should be used for the remainder of the analyses for that specific material data set. Secondly, the results could possibly provide insight into altering of data. Despite the differences in the number of observations, the variances should still be similar; however, if one is significantly smaller than the other, it makes one wonder why?

4.2.2 The Three T-Tests

Different forms of t-tests provide a way to determine whether the means of two data sets are statistically equal. However, in order for a t-test to be valid, at least three basic assumptions should be met.

1. The distribution of the data must be normal.
2. The two data sets must have equal standard deviations.
3. The two data sets must be independent.

If these requirements are not met, a variation of the basic t-test is used (Ramsey et al., 2002).

Each of these assumptions is dealt with in their own distinct way. When looking at normality, the Central Limit Theorem is used to justify the t-test in the case of looking at all of the data for the year. The Central Limit Theorem states, "averages based on large samples have approximately normal sampling distributions, regardless of the shape of the population distribution" (Ramsey et al. 2002). Since the sample sizes were very large, it could be assumed that the distributions were normal.

The second assumption states that each data set should have approximately the same standard deviation. This was determined using the F-test previously described. If the F-test returned a p-value less than 0.01, then the hypothesis that the two variances were equal was void, and a t-test based on equal variances in the data sets compared was not applicable. However, in this case, a t-test assuming unequal variances was used. There were some cases when testing the contractor QCT versus GDOT QA that this test was applied due to the F-test results.

The third assumption is that the data sets are independent of each other. While this was the case for the Contractor QCT versus GDOT QA test results, the QCT Comparison and GDOT Verification tests were conducted on split samples; therefore, this assumption was not met. In this case, a paired t-test was used. This test was a powerful application when it could be used, and it allowed plots to be created visually showing if the Contractor or GDOT had larger variances or mean discrepancies from the job mix formula. Lines of absolute numerical equality were drawn on the plots to make it easier to tell which values were larger.

If all three assumptions were met, then a t-test was used for the contractor QCT versus GDOT QA comparison. Figure 4-1 provides a basic decision diagram to determine which test was appropriate for each analysis.

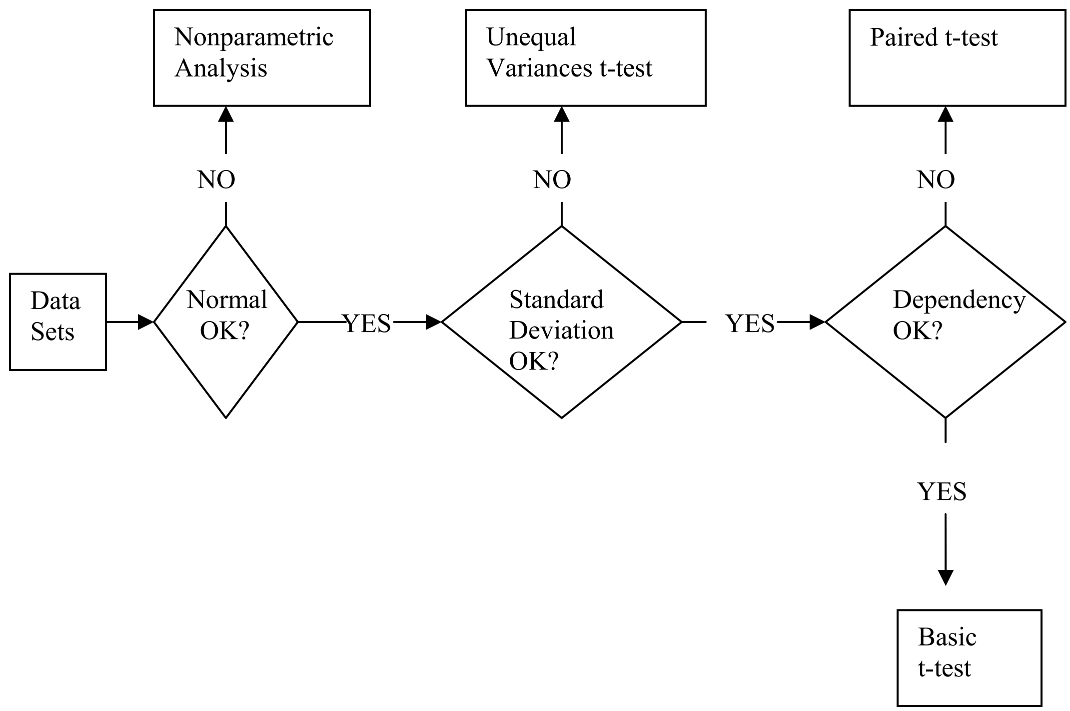

Figure 4-1. Analysis Thought Diagram.

4.2.3 Mean Squared Deviations

While the F and t-tests provide individual analyses of the variances and means, respectively, calculating a mean squared deviation (MSD) for a data set quantifies both the accuracy and precision. Three possible scenarios can be used in calculating the mean square deviation of a data set: larger is better, nominal is better, and smaller is better. Nominal is better was chosen because observations can extend from either side of the target. The formula for the nominal is better scenario is expressed as Equation 1. The nominal is better approach is the case where the results can approach from either the upper or the lower limit.

$$MSD_{NIB} = S_n^{\,2} + (\bar{x} - x_t)^2 \qquad (1)$$

where: S_n^2 = variance of data set

$\bar{x}$ = mean of data set

x_t = target value for data set, 0

Smaller MSD values indicate a high level of control in the during the mix and construction process.

In this study, MSD calculations were completed for all nine material properties for the contractor QCT, GDOT QA, contractor comparison, and GDOT comparison data. The smaller values of the four show which measurements were not only more precise but also closer to the target job mix formula.

4.2.4 Skewness

The final analysis conducted on the overall project data was a skewness test. Skewness is a way to measure the symmetry of a data set when it has been converted into a histogram. If the skewness coefficient was zero, it did not necessarily mean that the data set was symmetrical; however, non-zero values do indicate how the data set's histogram behaved. If the value of the coefficient is negative, then the data set's histogram is skewed to the left. The converse is true for a positive skewness coefficient.

Minitab was used to calculate skewness values. These tests were conducted to analyze possible data shifts. The Contractor's QCT values were compared numerically to those of GDOT's QA and Comparison tests, but no statistical analyses, such as the standard error of skewness, were conducted on the actual skewness values.

4.3 Project by Project Analysis

It was theorized that the results found for the overall data analyses might have been affected significantly by the large sample size; therefore, it was decided to conduct a further analysis for each of the large projects in Georgia's database. A project was classified as large if the smallest project data set (contractor or DOT on a particular project) that contained had at least six usable entries. In the Contractor QCT versus GDOT QA analyses, the GDOT QA data set had to have six entries for that specific project, and for the QCT Comparison versus GDOT Verification analyses, six results just had to be recorded since split samples were used for this analysis. The decision to define a large project as a project with at least six test results was arbitrarily chosen.

Three different properties were chosen for individual project analysis: asphalt content, the ½" sieve, and the #200 sieve. These two sieves were chosen because they were at the opposite ends of the gradation curve. F-tests were then run on all of the projects that had over six data entries to determine whether the variances of the data set were statistically the same at a 99% confidence level. Once the state of variances was determined, the appropriate t-test was applied to the Contactor QCT versus GDOT QA data set.

Paired t-tests were run on the QCT Comparison versus GDOT Verification data. The difference in the data sets used in the individual versus overall project analysis was size; therefore, the Central Limit Theorem could not be applied to use as a justification for the normality assumption required for the appropriate use of a t-test. However, it has been widely accepted that construction material property data tends to follow a normal distribution. In TRB's *Synthesis of Highway Practice 232: Variability in Highway Pavement Construction*, completed in 1996, it was assumed that construction material data followed a normal curve. No other possible distribution was even considered (Hughes, 1996).

Between 1996 and 1998, the Arkansas State Highway and Transportation Department and the University of Arkansas looked at the mix properties in asphalt construction in the state of Arkansas. One analysis included normality probability plots to check the normality of the construction data. The conclusion of this analysis was that "the data generated by the sampling and testing program executed for this project were found to represent a population of results that follow a normal distribution" (Hall et al., 2002). Since it is generally accepted that construction material properties follows the normal distribution, the t-test, or a variation of such a test, was a valid analysis tool for the data sets in question.

When the typical test results had the job mix formula subtracted from it, the means and variances were calculated during the F and t-test process using Microsoft Excel. Compiling these values on a project by project basis allowed for the creation of graphical comparisons for a specific material property for means and variances similar to those done in the overall project analysis with the paired t-tests. Lines of absolute numerical equality were used to show if the contractor's data or GDOT's data were farther from the target in the graphs and which sets of measurements had the largest variability.

The project by project analysis was conducted to see if there might be just a few projects influencing the results of the larger databases. However, if the majority of the projects showed significant differences, there might be deficiencies in the QA process in the state of Georgia. The project by project analysis also allowed for analyses in dealing with the tendencies of contractors to either have their results higher or lower than those of the DOTs in both means and variances.

4.4 Reduced Data Sets

The reduced data sets were similar in appearance to the overall project analysis; however, the data set consisted of a smaller sample size. In this case, if an individual project was large enough to have undergone the individual analyses previously specified, its data were recompiled into a new database called the reduced data set. These data points were analyzed by F-tests and the appropriate t-test.

This analysis was done to see if the larger sample size for the overall project analysis might have influenced the statistical tests used on the data sets. If different results were found, it could possibly mean that a few smaller projects were pulling the overall project data away from where it should have been. If the statistical differences noted for the different material properties were the same with the smaller sample size, the research team would feel more confident about proclaiming a statistical difference despite the possibility of sample size influence.

CHAPTER FIVE

RESULTS

As described in the methodology chapter, three different types of analyses were performed on the data provided by GDOT: overall project analyses, project by project analyses, and reduced data sets analyses. The overall data analyses consisted of all the data collected during the 2003 construction season for specific material properties. The project by project analyses included of all project that had at least 6 test results. These projects were individually subjected to various statistical tests. All of the data from individual projects that were analyzed were combined to make made up the reduced data set for analysis.

5.1 Overall Data Analysis

Tables 5-1 and 5-2 provide summaries of the F and appropriate t-test results for comparing the Contractor QCT and GDOT QA data sets. The tables provide numerical values for sample sizes, variances, means of differences from job mix formulas, and p-values. The tables also include if statistical differences at the 99% level were found between the data sets and if the property is included in pay factor calculation.

Table 5-1. F-Test Results for Contractor QCT versus GDOT QA.

Property	n_{GDOT}	$S^2_{GDOT,\%}$	n_{CONT}	$S^2_{CONT,\%}$	Difference	p-value	Pay
1" Sieve	832	1.425	4775	1.296	No	0.034	No
¾" Sieve	1637	4.167	9444	4.378	No	0.099	No
½" Sieve	2323	6.793	13157	5.565	Yes	<0.001	Yes
3/8" Sieve	2099	6.605	11587	6.044	Yes	0.004	Yes
#4 Sieve	1050	9.959	5532	7.707	Yes	<0.001	Yes
#8 Sieve	2488	9.488	14051	5.534	Yes	<0.001	Yes
#50 Sieve	749	4.139	4047	3.334	Yes	<0.001	No
#200 Sieve	2488	1.212	14036	0.769	Yes	<0.001	No
% Asphalt	2487	0.064	14061	0.040	Yes	<0.001	Yes

Table 5-2. t-Test Results for Contractor QCT versus GDOT QA.

Property	n_{GDOT}	$\bar{\Delta}_{GDOT}$,%	n_{CONT}	$\bar{\Delta}_{CONT}$,%	Difference	p-value	Pay
1" Sieve	832	0.187	4775	0.184	No	0.941	No
¾" Sieve	1637	0.418	9444	0.535	No	0.036	No
½" Sieve	2323	0.196	13157	0.160	No	0.530	Yes
3/8" Sieve	2099	0.246	11587	0.231	No	0.805	Yes
#4 Sieve	1050	0.320	5532	0.293	No	0.792	Yes
#8 Sieve	2488	0.253	14051	0.196	No	0.380	Yes
#50 Sieve	749	0.727	4047	0.837	No	0.170	No
#200 Sieve	2488	0.359	14036	0.400	No	0.082	No
% Asphalt	2487	0.004	14061	0.005	No	0.827	Yes

As can be seen from Table 5-1, seven of the nine properties showed statistically significant differences in the variances while none of the means were shown to be statistically different in Table 5-2... The statistical differences in the variances might stem from the sizable sample sizes used in the analyses. The greater the sample size is, the more discriminating the test becomes; therefore, having sample sizes near or about 1000 might have caused the differences in the F-tests to be so statistically profound.

While significant differences were shown in the statistical analyses, a simple visual inspection of the variances and means also was helpful in analyzing the data. Variances in the contractor's data set were smaller than the variances of the GDOT data set for eight of the nine material properties. This might lead some to believe the contractors are adjusting their results, even though slightly, closer to the target value especially since the only property where the DOT's variance was smaller was not used in pay computations. However, while this difference shows up in the variances, only five of the nine contractor means are smaller for this data set, and none of the means from the two data sets show statistically significant differences for their means.

Paired t-tests were run on the data sets comprised of split samples, QCT versus GDOT Comparison. Tables 5-3 and 5-4 provide the results of comparisons of variance and means for these data sets.

Table 5-3. F-Test Results for Contractor QCT versus GDOT Comparison.

Property	**N**	**$S^2_{GDOT,\%}$**	**$S^2_{CONT,\%}$**	**Difference**	**p-value**	**Pay**
1" Sieve	395	1.527	1.363	No	0.131	No
¾" Sieve	791	4.410	3.831	No	0.024	No
½" Sieve	1067	9.343	6.576	Yes	<0.001	Yes
3/8" Sieve	953	8.479	5.545	Yes	<0.001	Yes
#4 Sieve	402	9.450	8.606	No	0.175	Yes
#8 Sieve	1142	8.673	6.561	Yes	<0.001	Yes
#50 Sieve	282	3.971	4.004	No	0.472	No
#200 Sieve	1141	1.137	0.791	Yes	<0.001	No
% Asphalt	1135	0.088	0.045	Yes	<0.001	Yes

Table 5-4. t-Test Results for Contractor QCT versus GDOT Comparison.

Property	**N**	$\bar{\Delta}_{GDOT},\%$	$\bar{\Delta}_{CONT},\%$	**Difference**	**p-value**	**Pay**
1" Sieve	395	0.258	0.295	No	0.462	No
¾" Sieve	791	0.398	0.469	No	0.166	No
½" Sieve	1067	0.314	0.118	Yes	0.002	Yes
3/8" Sieve	953	0.516	0.329	Yes	0.005	Yes
#4 Sieve	402	0.506	0.392	No	0.128	Yes
#8 Sieve	1142	0.449	0.244	Yes	<0.001	Yes
#50 Sieve	282	0.897	0.763	No	0.094	No
#200 Sieve	1141	0.334	0.447	Yes	<0.001	No
% Asphalt	1135	0.005	0.002	No	0.634	Yes

One would expect fewer differences between split sample results than between independent sample results since the same material is being tested. This seems to be the case with the variances where only five of the nine material properties show significant differences. Four of these properties are used by GDOT for payment decisions. However, while none of the means showed statistical differences in the independent samples, four of the nine p-values for the split sample means fell below the required 0.01 to be considered statistically equal.

Once again, the variances from the contractor's test results were consistently smaller than GDOT variances. The only property where the variance of the contractor was smaller was the #50 sieve, and that sieve is not included in the pay factor formula. In looking at the means, the contractor's data were closer to the target value for only five of the nine properties; however, those five properties are the only five properties used in the pay calculations. This might once again lead one to suspect a possibility of data manipulation on the contractor's part.

To further investigate the split samples results, graphic representations were produced as shown in Figure 5-1 for asphalt content as an example. All of the graphs produced for the overall project analysis can be found in Appendix A.

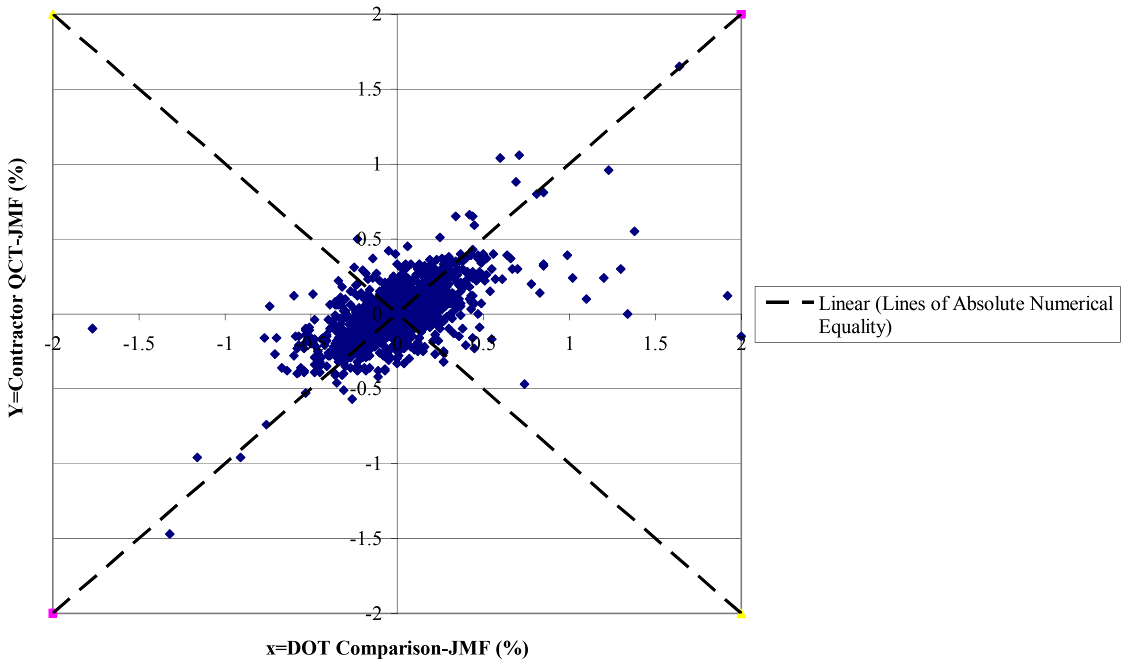

Figure 5-1. Mean Comparison from Split Sample Results for Asphalt Content.

The graphs are divided into four quadrants by two lines of absolute numerical equality to show which group's test result was the largest. Each point in Figure 5-1 represents the GDOT Comparison test value and the contractor's QC test value for a split sample. If the data point is contained in either of the quadrants also containing the horizontal axis, then the deviation from the target value for GDOT's split sample results was larger than the contractor's. If the data point is contained in either of the quadrants which also contains the vertical axis, then the converse is true.

While many of the data points are located near the center of the graph, it can be seen that there are more points near the ends of the horizontal quadrants in comparison to the vertical quadrants. This supports the statistical evidence that the contractor's test results for asphalt content were smaller in terms of both mean and variance.

Along with the F and t-tests, Means Squared Deviations (MSD) were calculated for all four data sets using the methodology described in Chapter 4. Table 5-5 shows the results from the calculations. The Contractor QCT and GDOT QA columns are the MSD results taken from independent samples while the Contractor QCT Comparison and GDOT comparison columns were calculated using the split sample test results.

Table 5-5. MSD Results.

Property	Contractor QCT	GDOT QA	Contractor QCT Comparison	GDOT Comparison
1" Sieve	1.330	1.460	1.450	1.594
¾" Sieve	4.664	4.342	4.051	4.568
½" Sieve	5.591	6.831	6.590	9.442
3/8" Sieve	6.097	6.666	5.653	8.745
#4 Sieve	7.793	10.061	8.760	9.706
#8 Sieve	5.572	9.552	6.621	8.875
#50 Sieve	4.035	4.668	4.586	4.776
#200 Sieve	0.929	1.341	0.991	1.249
% Asphalt	0.040	0.064	0.045	0.088

The MSD test is used to compare both the variances and the means of the data sets in one term. As can be seen, either the contractor's comparison or QCT test results have the smallest MSD value for every property. For eight of the nine properties, both of the contractor's test results are smaller than either of GDOT's values.

One surprising trend in the data is seen when looking at the split samples MSD values. For the values at the ½" sieve, 3/8" sieve, #8 sieve, and asphalt content, there seems to be a considerable difference in the contractor's and DOT's values. However, these are also parameters where the variances were significantly different with a p-value that was less than 0.001. This supported a hypothesis that for these data sets the variance would probably be the dominant parameter in the equation. Many of the variances were values between 1 and 10, and all of the means were less than one. The means were then squared in the equation making their significance even smaller; therefore, the correlation to the variance data is expected.

When using the skewness programs in Minitab, the program produces both a skewness coefficient and the histogram of the dataset. Table 5-6 shows the skewness coefficients, and Figure 5-2 is an example of the histograms provided. The entire set of histograms is in Appendix B.

Table 5-6. Skewness Results.

Property	Contractor QCT	GDOT QA	QCT Comparison	GDOT Comparison
1" Sieve	-0.377	-1.313	0.701	0.233
¾" Sieve	0.918	0.849	1.667	0.206
½" Sieve	0.513	1.213	0.305	0.959
3/8" Sieve	-0.351	-0.266	0.247	0.804
#4 Sieve	0.123	0.636	-0.204	-0.191
#8 Sieve	0.129	0.424	0.849	0.885
#50 Sieve	0.153	-0.480	-0.605	0.359
#200 Sieve	-0.142	1.879	-0.385	-0.156
% Asphalt	0.105	0.969	0.444	0.593

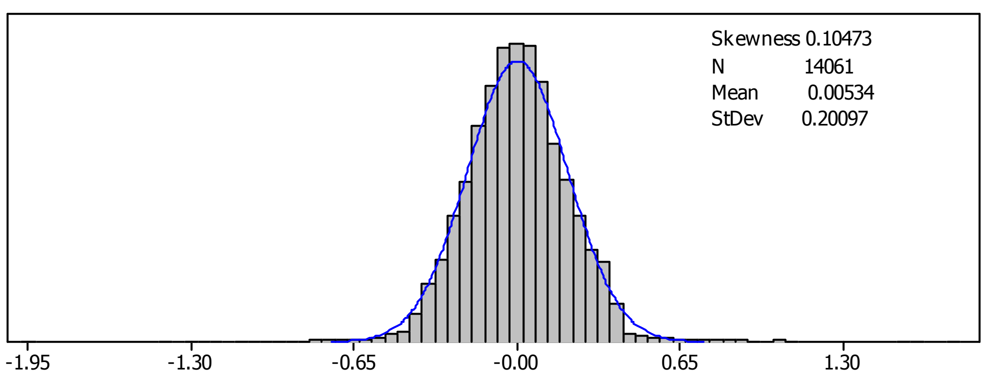

Figure 5-2. Skewness QCT-JMF for Asphalt Content.

When comparing the independent samples, seven of the nine skewness values showed the absolute value of the GDOT QA skewness coefficient to be larger than that of the QCT; however, for the split sample test results, only four of the nine results were larger for the contractor test results. It is difficult to assess the magnitude of these results as no standard errors of skewness were calculated. The most significant difference was found in the #200 sieve between the contractor QCT and the GDOT QA. The contractor's data showed a slightly negative skew; however, GDOT's skewness coefficient was highly positive. While these two sets of data did show significance differences in variances with the F-test analysis, the results would not necessarily lead one to expect the skewness results returned.

5.2 Project by Project Analysis

5.2.1 Statistical Analysis

A project by project analysis was conducted for large projects on three material properties: ½" sieve, #200 sieve, and asphalt content. In order for a project to be considered for this analysis, it had to have at least 6 records for both of the comparative tests. When the data were sorted into projects, 114 projects were analyzed for the ½" sieves and asphalt content, and 126 projects were analyzed for the #200 sieve. Tables 5-7 through 5-10 provide summaries of the project-by-project results. The column titled "Projects with Significantly Higher GDOT Variances" contains two percentages in it. The first percentage is a comparison of the projects with significantly higher GDOT variances with all the projects while the second number is a comparison to only the projects with significant differences. The detailed summaries of the project-by-project analyses can be found in Appendix C.

Table 5-7. Contractor QCT versus GDOT QA Variance Results by Project.

Property	Projects	Projects with Larger GDOT Variances	Projects with Significant Differences	Projects with Significantly Higher GDOT Variances
% Asphalt	114	77 (68%)	12 (10%)	10 (9%) (83%)
½" Sieve	114	63 (55%)	13 (11%)	10 (9%) (77%)
#200 Sieve	126	81 (64%)	17 (13%)	15 (12%) (88%)

Table 5-8. Contractor QCT versus GDOT QA Mean Results by Project.

Property	Projects	Projects with Larger GDOT Means	Projects with Significant Differences	Projects with Significantly Higher GDOT Means
% Asphalt	114	68 (60%)	8 (7%)	6 (5%) (75%)
½" Sieve	114	50 (54%)	3 (3%)	3 (3%) (100%)
#200 Sieve	126	52 (41%)	13 (10%)	6 (5%) (46%)

Table 5-9. Contractor Comparison verses GDOT Comparison Variance Results by Project.

Property	Projects	Projects with Larger GDOT Variances	Projects with Significant Differences	Projects with Significantly Higher GDOT Variances
% Asphalt	41	35 (85%)	1 (2%)	1 (2%) (100%)
½" Sieve	34	20 (59%)	2 (6%)	2 (6%) (100%)
#200 Sieve	45	34 (76%)	3 (7%)	3 (7%) (100%)

Table 5-10. Contractor Comparison verses GDOT Comparison Mean Results by Project.

Property	Projects	Projects with Larger GDOT Means	Projects with Significant Differences	Projects with Significantly Higher GDOT Means
% Asphalt	41	27 (66%)	1 (2%)	0 (0%) (0%)
½" Sieve	34	15 (44%)	0 (0%)	0 (0%) (0%)
#200 Sieve	45	21 (47%)	2 (4%)	2 (4%) (100%)

When looking at the results from the Contractor QCT and GDOT QA project by project analysis, it can be seen that projects where GDOT had larger means ranged from 41% to 60%. On the other hand, GDOT had larger variances for between 55% and 68% of the projects. Twenty-four of the 354 projects had significant differences in means, and for 15 (63%) of these, GDOT QA had the larger mean. For variances, 42 of the 354 projects had statistical differences, and for 35 (83%) of those, GDOT QA variances were the largest.

When looking at Tables 5-9 and 5-10, one can see that the results of the split sample comparisons on a project by project basis were similar to those found for the independent samples. Asphalt content sieve was the only property showing a greater significant deviation from the target by GDOT. GDOT values for all three properties were larger from 44% to 66%. However, GDOT variances were larger between 59% and 85% of the projects. Only 3 of the 120 projects had significant differences between mean values, and two of those showed larger GDOT means. Six of the 120 projects had significant differences in the variances, and all six of those projects had larger GDOT variances.

Scatterplots, as shown in Figures 5-3 and 5-4, were created to analyze the created data sets. The results of the GDOT QA would be graphically represented against the Contractor's QCT to show mean deviations and variances. One of the useful results from a graphical approach would be the easy recognition of outliers that might appear in the data set where one agency's test results were vastly different from those of the other. All the created scatterplots can be found in Appendix D.

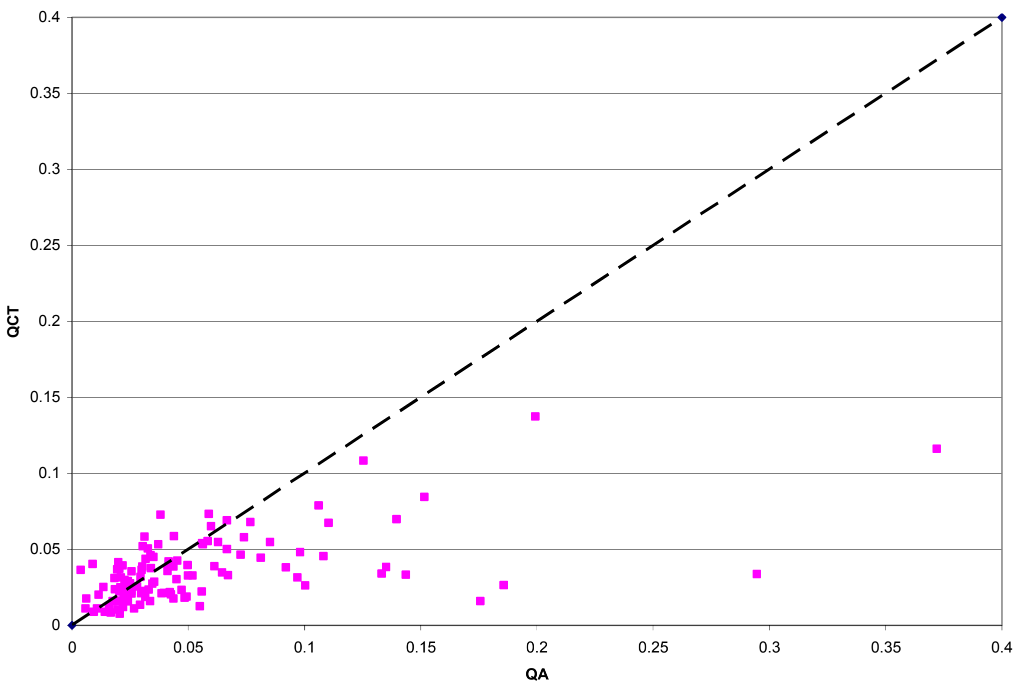

Figure 5-3. Asphalt Content Variances for GDOT QA versus Contractor QCT.

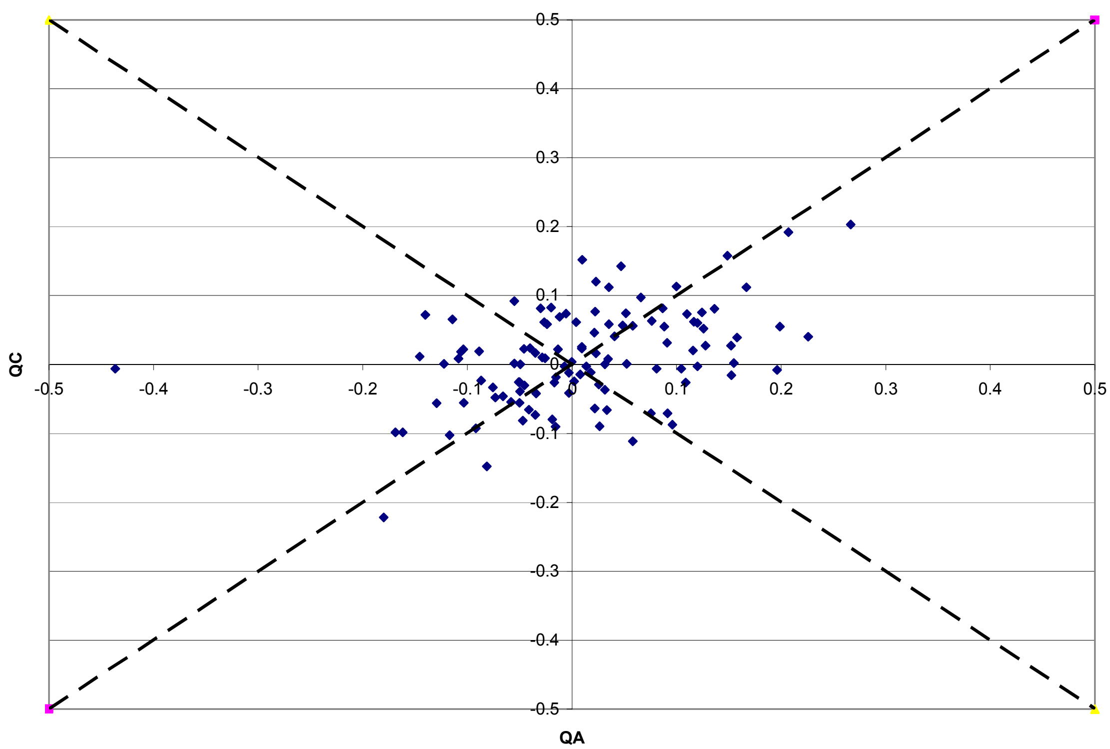

Figure 5-4. Asphalt Content Mean Deviations for GDOT QA versus Contractor QCT.

5.2.2 Precision Tests

One of the places were variances can occur is in the test itself. The American Association of State Highway and Transportation Officials (AASHTO) conducted a series of experiments on the testing methods themselves to determine appropriate levels of variation that might be explained by test itself.

For the measuring of asphalt content, Georgia allows its contractors to test the samples by either the ignition oven or the extraction method. According to AASHTO, the allowable standard deviation for a multi-laboratory ignition test is 0.06%, and the allowable standard deviation for a multi-laboratory extraction tests is 0.29%. In order to determine if the project's test fell outside that range, a pooled standard deviation was calculated. Since Georgia's data set did not specify which test was used, the extreme case was used. It was assumed that both methods were used for every project. Table 5-11 provides the results of the test (AASHTO, 2004).

Table 5-11. Asphalt Content Precision

Test Method	Independent Sample Projects	Number of Projects Outside Test Precision	Split Sample Projects	Number of Projects Outside Test Precision
Ignition	114	114 (100%)	41	41 (100%)
Extraction	114	7 (6%)	41	10 (24%)

Every project tested, whether from split or independent sample, fell outside the test precision for the ignition method; however, fewer fell outside the precision for the extraction method.

The precision for gradation was not dependent upon sieve size. It was dependent upon the percent passing the sieve. An average of the percent passing the sieve in question was calculated to determine the allowable standard deviation for the test. As with asphalt content, a pooled standard deviation was calculated using both the contractor and the GDOT data to compare to the allowable precision of the test (AASHTO, 2004). A summary of the results is in Table 5-12. The results of this analysis once again show the test standard deviations consistently falling outside the allowable precision of the test for a multi-laboratory test.

Table 5-12. Gradation Precision

Property	Independent Sample Projects	Number of Projects Outside Test Precision	Split Sample Projects	Number of Projects Outside Test Precision
½" Sieve	114	101 (89%)	34	31 (91%)
#200 Sieve	126	96 (76%)	45	36 (80%)

5.3 Reduced Data Set Analysis

The third analysis was done by combining data from individual projects that were used for the project by project analysis into appropriate contractor or GDOT data sets. The data sets were compared with F and t-tests, and Tables 5-13 and 5-14 provide the results.

Table 5-13. Reduced Data Set Analysis for GDOT QA versus Contractor QCT.

Property	Projects	n_G	S^2_G	Δ_G	n_C	S^2_C	Δ_C	Difference
% Asphalt	114	1410	0.058	0.011	8453	0.040	0.010	Variances
½" Sieve	114	1385	7.701	0.146	8072	6.439	0.208	Variances
#200 Sieve	126	1565	1.210	0.310	8908	0.741	0.367	Variances

When considering the QA versus QCT data, one can see that none of the means were significantly different, but all three variances were seen to be significantly different. These results parallel those found in the overall project analysis. In the case of variances, the GDOT QA results were always larger than those for the contractor.

Table 5-14. Reduced Data Set Analysis for GDOT Comparison versus Contractor QCT Comparison.

Property	Projects	N	S^2_{GDOT}	Δ_{GDOT}	S^2_{CONT}	Δ_{CONT}	Differences
% Asphalt	41	452	0.097	0.018	0.053	0.010	Variances
½" Sieve	35	400	12.286	0.462	9.251	0.200	Variances
#200 Sieve	45	470	7.870	0.159	7.613	0.278	Means

The results of the split sample data sets were different that those from independent samples. The contractor's variances are always smaller than those of GDOT, but only variances for percent asphalt and percent passing the ½" sieve were significantly different. The #200 sieve had variances that were statistically similar; however, the means were significantly different with the contactor having the larger mean deviation.

5.4 Summary of Findings

Statistically, the contractors and GDOT have similar means, but as seen in previous studies, the variances are where differences occur. In all three analyses, the variances were more likely to be seen as statistically significant than the means were. On the project level, it was seen that the majority of the projects had the contractor's variances being smaller than those of GDOT. A precision analysis was also conducted on project by project level to determine if the results were falling within the allowable standard deviations of the test. The analysis concluded the only test having a possibility of fewer than 76% of the projects falling within test precision was the test to determine asphalt content by extraction; however, the specification test methods are not known.

CHAPTER SIX

CONCLUSIONS

In doing an analysis such as the one described in this report, it is possible that some of the obtained results were not what was expected. On the other hand, other analyses might have played directly into preconceived ideas about what the results might be. The following paragraphs will provide conclusions and recommendations for data organization, overall and reduced project analyses, and project by project analyses.

6.1 Overall Data and Reduced Data Set Analyses

The overall data analyses were conducted on all data that had a corresponding job-mix formula for the year 2003. The reduced data set consisted of data from all projects that had at least six or more QA and/or Comparison tests results. Tables 6-1 and 6-2 provide insights into the extent of the analysis. These data sets were compared using F and t-tests as described in Chapter 4. Table 6-3 provides a brief summary of the results from these analyses indicating when differences in means or variances were statistically significant at the 99% level. Detailed results can be found in Chapter 5.

Table 6-1. Sample Sizes for Overall Data Results.

	Independent Samples		Split Samples
Property	**N_{GDOT}**	**N_{CONT}**	**N**
1” Sieve	832	4775	395
¾” Sieve	1637	9444	791
½” Sieve	2323	13157	1067
3/8” Sieve	2099	11587	953
#4 Sieve	1050	5532	402
#8 Sieve	2488	14051	1142
#50 Sieve	749	4047	282
#200 Sieve	2488	14036	1141
% Asphalt	2487	14061	1135

Table 6-2. Sample Sizes for Reduced Data Set Results

	Independent Samples		Split Samples
Property	**N_{GDOT}**	**N_{CONT}**	**N**
½” Sieve	1385	8072	400
#200 Sieve	1565	8908	470
% Asphalt	1410	8453	452

Table 6-3. Summary of Results for Overall Data Analyses and Reduced Data Set Analyses.

Property	**Overall Data Analysis**		**Reduced Data Set Analysis**	
	QCT vs. QA	**QCT vs. DOT Comparison**	**QCT vs. QA**	**QCT vs. DOT Comparison**
1” Sieve	No Differences	No Differences		
¾” Sieve	No Differences	No Differences		
½” Sieve	Variances	Variances and Means	Variances	Variances
3/8” Sieve	Variances	Variances and Means		
#4 Sieve	Variances	No Differences		
#8 Sieve	Variances	Variances and Means		
#50 Sieve	Variances	No Differences		
#200 Sieve	Variances	Variances and Means	Variances	Means
Asphalt Content	Variances	Variances	Variances	Variances

As can be seen from the table, when variances were found to be statistically different in one analysis, the other analysis seemed to follow suit. The elimination of small projects from the overall data set to the reduced data set had little impact on the statistical significance of differences. The results were what were expected based upon the Kentucky and Alabama studies described in Chapter 2. One theory for the majority of the material properties exhibiting statistical differences at the 99% confidence interval is the size of the samples used in the study. The higher the number of degrees of freedom, the more confining the test is going to become.

Another theory could also possibly explain the statistical differences seen above. If a few of the larger projects had significant statistical differences, the results of the overall analysis could be swung in a favorable or unfavorable direction towards statistical differences.

The split sample results show at least one statistically significant difference, whether for mean or variance, for 4 of the 5 pay properties. For these five properties, whether a statistical difference was noted or not, the contractor's mean value was always closer to the target, and its variance was always smaller than that provided by the DOT.

The results of the MSD and skewness analyses seemed to reiterate the findings of the F and t-tests. The contractors were consistently more accurate and precise in their test results.

6.2 Project by Project Analysis

In order for a project to be considered in the project analysis, it had to have at least six QA test results and/or Comparison tests. These analyses were conducted on the

½” sieve, #200 sieve, and asphalt content. The detailed results are found in Chapter 5. The most thought provoking data coming from these analyses were the project variance results.

While overall only a small percentage of the projects showed a statistical difference in the two data sets for variances, GDOT had the larger of the variances for the majority of the projects for all properties considered and all sample types. One would think the split sample results would have been closer since they were analyzing the testing methods and not material properties; however, the split sample results seen in Table 6-5 are even more lopsided that those for the independent samples. For the asphalt content projects, GDOT variances were larger for 85% of the projects.

Another result to consider is how many of the projects with significant differences had larger GDOT variances. As said before, while there were only a few projects with statistical differences, over all three properties considered 83% of the projects containing statistical differences had larger GDOT variances for independent samples. The split samples had 100% of the 6 projects with larger GDOT variances if a statistical difference was noted. Tables 6-4 and 6-5 summarize the individual project analyses.

Table 6-4. QCT versus QA Results Summary.

Property	**Projects**	**Projects with Larger GDOT Variances**	**Projects with Significant Variance Differences**	**Projects with Significantly Higher GDOT Variances**	**Projects with Larger GDOT Means**	**Projects with Significant Mean Differences**	**Projects with Significantly Higher GDOT Means**
½” Sieve	114	63 (58%)	13 (11%)	10 (9%)	50 (54%)	3 (3%)	3 (3%)
#200 Sieve	126	81 (64%)	17 (13%)	15 (12%)	52 (41%)	13 (10%)	6 (5%)
% Asphalt	114	77 (68%)	12(10%)	10 (9%)	68 (60%)	8 (7%)	6 (5%)

Table 6-5. Comparison Results Summary.

Property	Projects	Projects with Larger GDOT Variances	Projects with Significant Variance Differences	Projects with Significantly Higher GDOT Variances	Projects with Larger GDOT Means	Projects with Significant Mean Differences	Projects with Significantly Higher GDOT Means
½" Sieve	34	20 (59%)	2 (6%)	2 (6%)	15 (44%)	0 (0%)	0 (0%)
#200 Sieve	45	34 (76%)	3 (7%)	3 (7%)	21 (47%)	2 (4%)	2 (4%)
% Asphalt	41	35 (85%)	1 (2%)	1 (2%)	27 (66%)	1 (2%)	0 (0%)

One would think these percentages for both the independent samples and the split samples would be closer to 50%, but for some reason, the contractor's numbers seem to be consistently closer to the value specified in the JMF. This might be due to improved testing ability with frequent testing, or it might be a symptom of a larger problem.

6.3 Final Concerns and Recommendations

- A data management system should be set up to control the proper recording of project numbers. This could be accomplished by either having one person input all of the data for one project or by having a menu to select projects from.
- The properties selected by the state of Georgia to incorporate into their QA plan could possibly be amended. At the present time, contractor testing is only done on mix properties while GDOT tests for mat density and smoothness. Many states incorporate a contractor-performed mat density test which might be useful in making sure the product is laid and compacted properly. Another concern might arise in the number of sieves incorporated into the pay factor. If one of the upper sieves is collects too high or too low a percentage of the aggregates, then

the corresponding sieves below will also be off in a compounding nature. One mistake in an upper sieve might prove harmful to the actual pay of the project while not being very detrimental to the performance of the mix. Georgia has four consecutive sieves that are used for pay factor. This probably leads to a high correlation between the sieves. Spreading out the sieves used in the pay factor computation would decrease the correlation and might lead to a better representation of the mix.

- During the precision analysis, it was seen that the standard deviations for the projects were consistently falling outside the allowable standard deviation based upon precision tests conducted on the testing method. The extraction method was the only test that did not have 75% or more of its tests falling outside the allowable standard deviation. More tests failed to fall within precision limits than contained statistically significant differences.
- The biggest concern with the Georgia DOT data at this time is the variance results reported. At the present time, Georgia accepts data based upon a percentage value, but no statistical analysis is completed. Some states conduct F and t-tests in order to determine if the material is acceptable or not. It might be worthwhile for Georgia to use these statistical tests to keep a closer eye on its quality control/quality assurance process. If not these statistical analyses, then some other means of monitoring more than just the means should be employed.

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APPENDICES

APPENDIX A

OVERALL DATA ANALYSIS SCATTERPLOTS

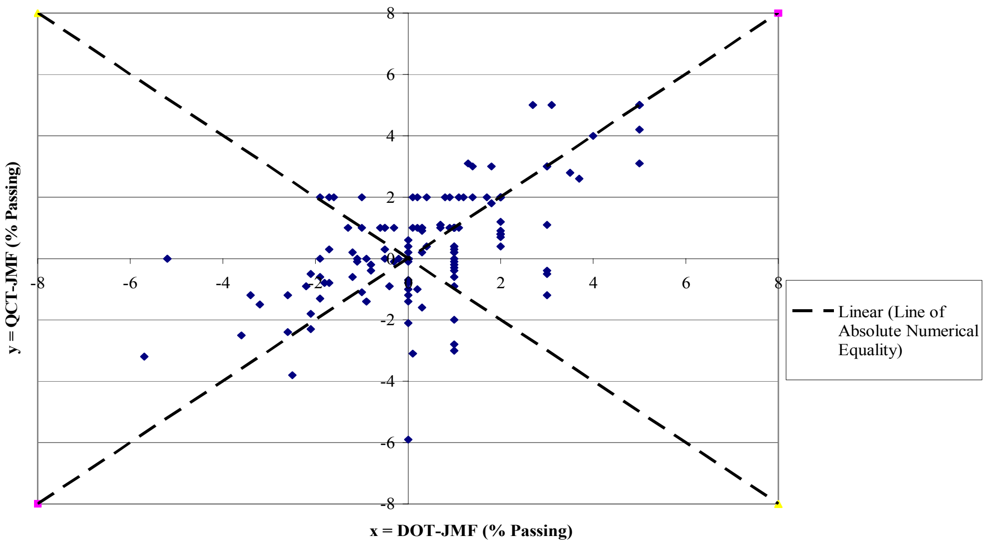

Figure A-1. Mean Comparison from Split Sample Results for 1" Sieve.

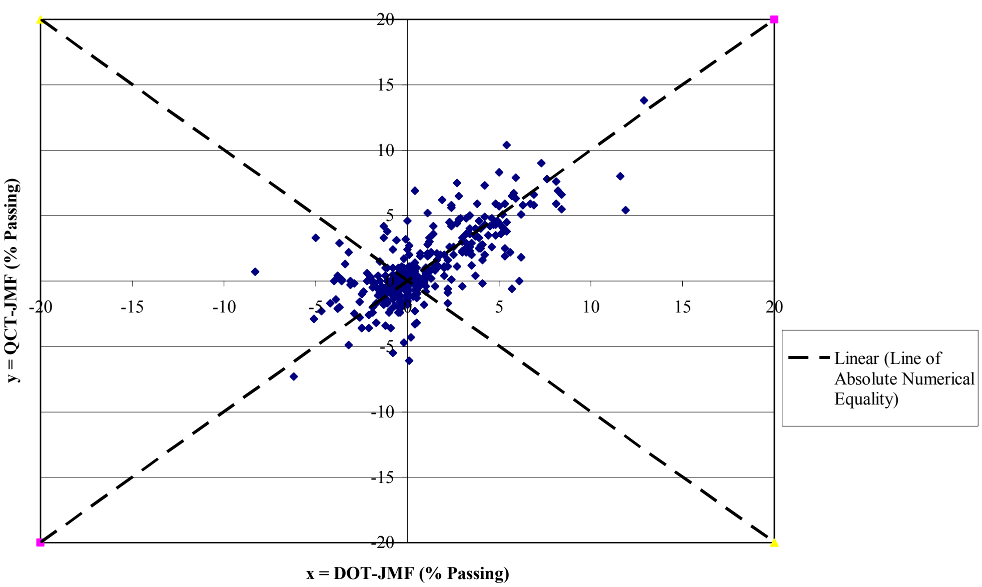

Figure A-2. Mean Comparison from Split Sample Results for 3/4" Sieve.

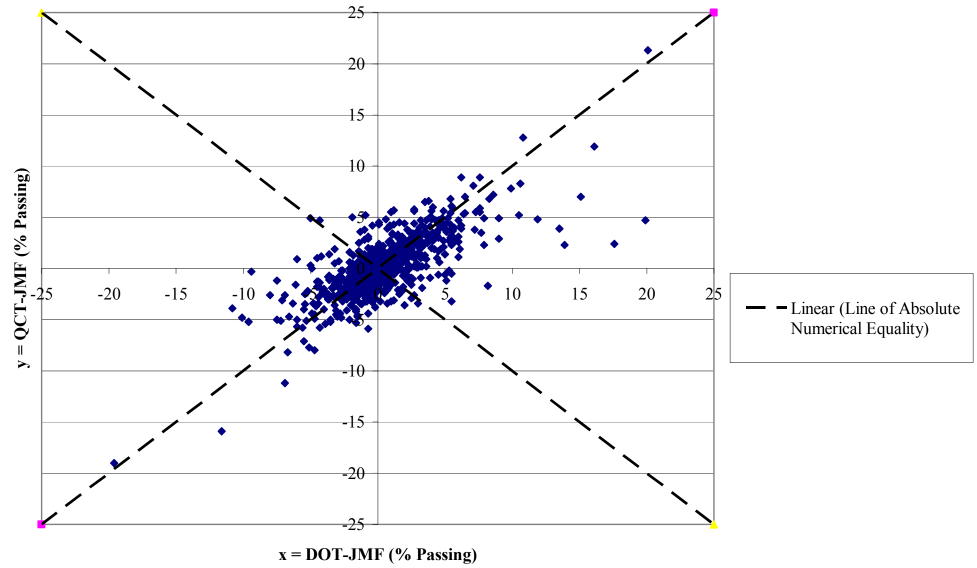

Figure A-3. Mean Comparison from Split Sample Results for 1/2" Sieve.

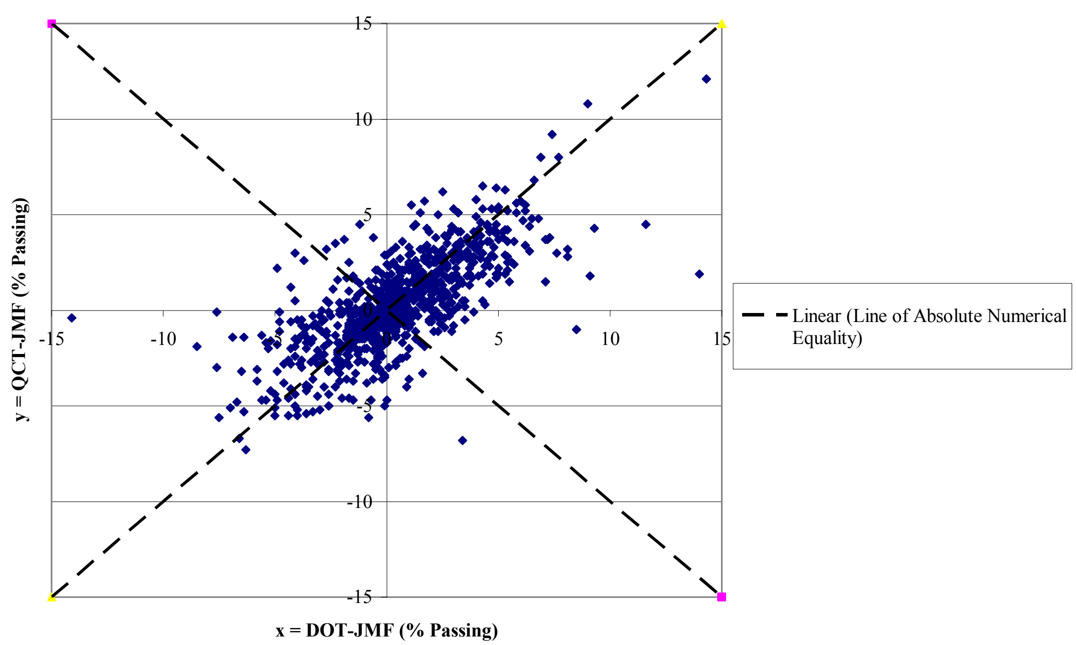

Figure A-4. Mean Comparison from Split Sample Results for 3/8" Sieve.

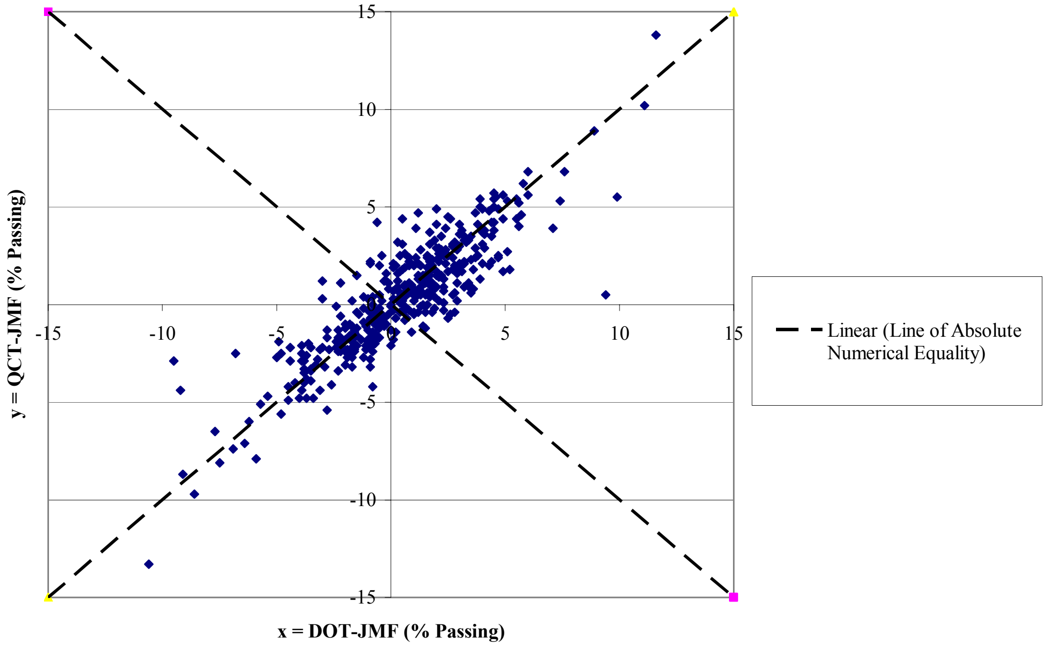

Figure A-5. Mean Comparison from Split Sample Results for #4 Sieve.

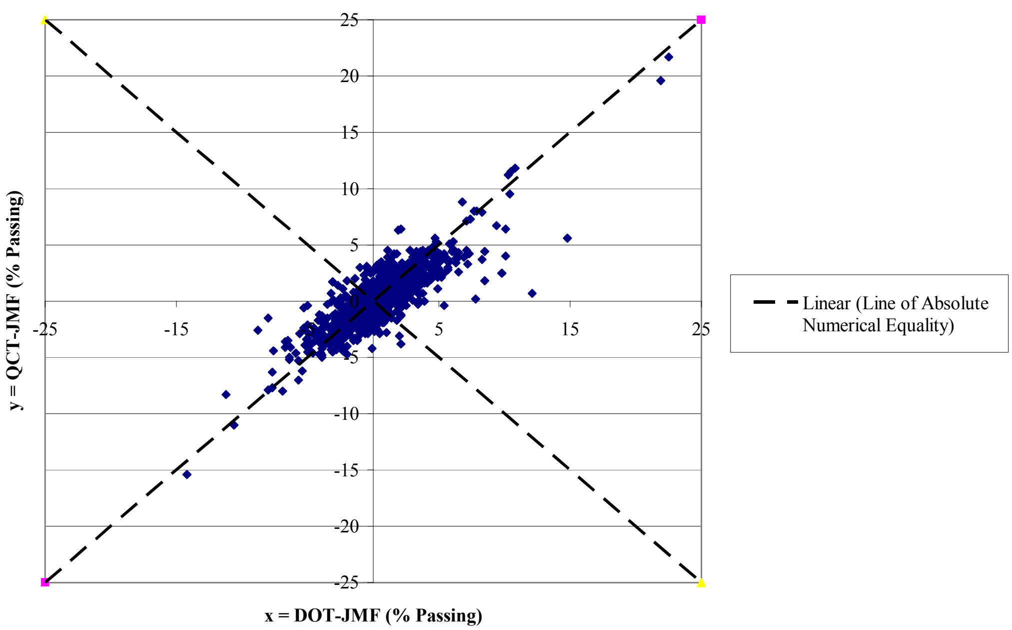

Figure A-6. Mean Comparison from Split Sample Results for #8 Sieve.

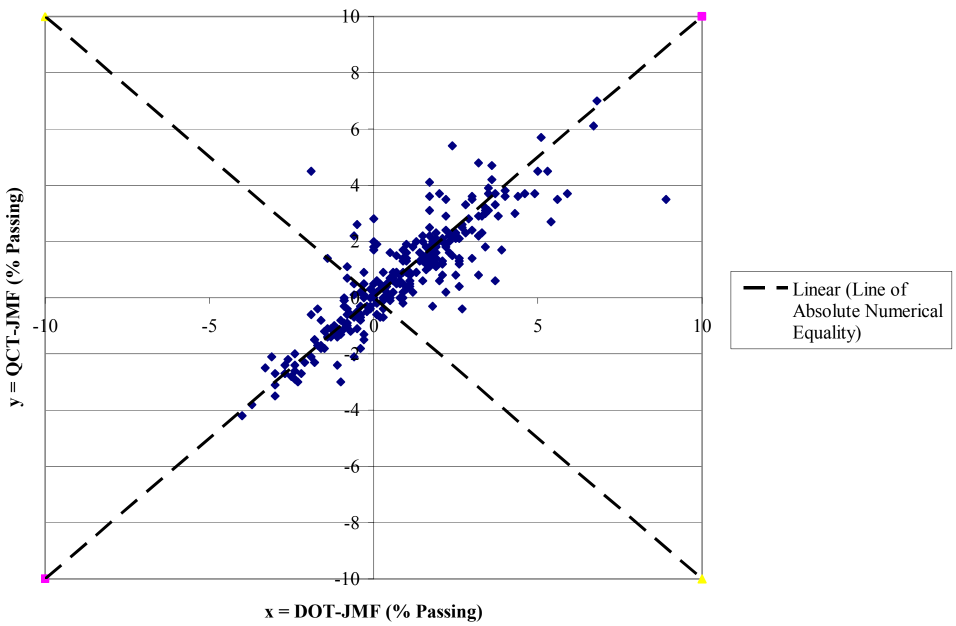

Figure A-7. Mean Comparison from Split Sample Results for #50 Sieve.

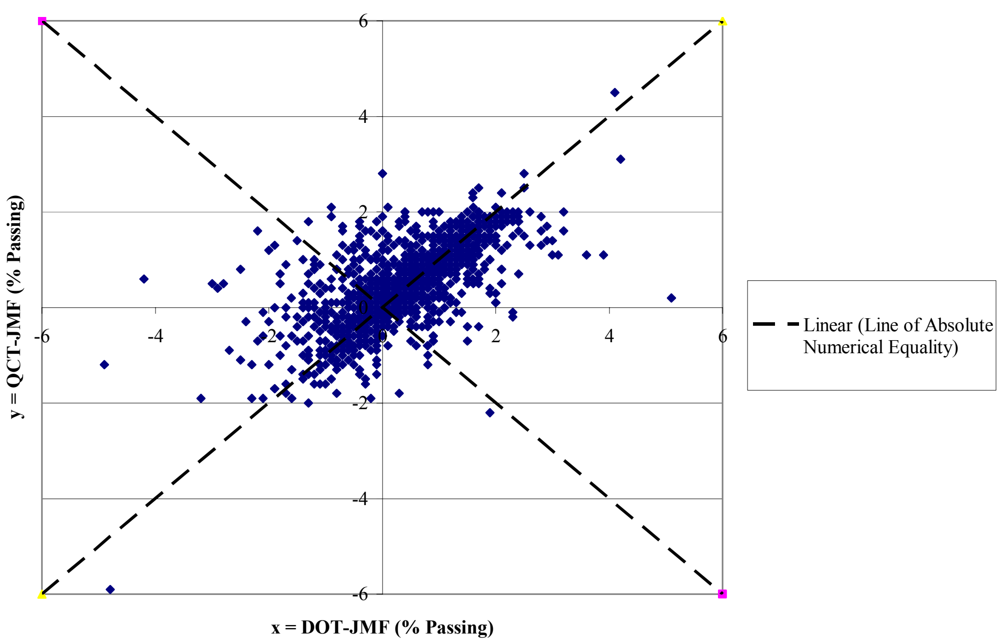

Figure A-8. Mean Comparison from Split Sample Results for #200 Sieve.

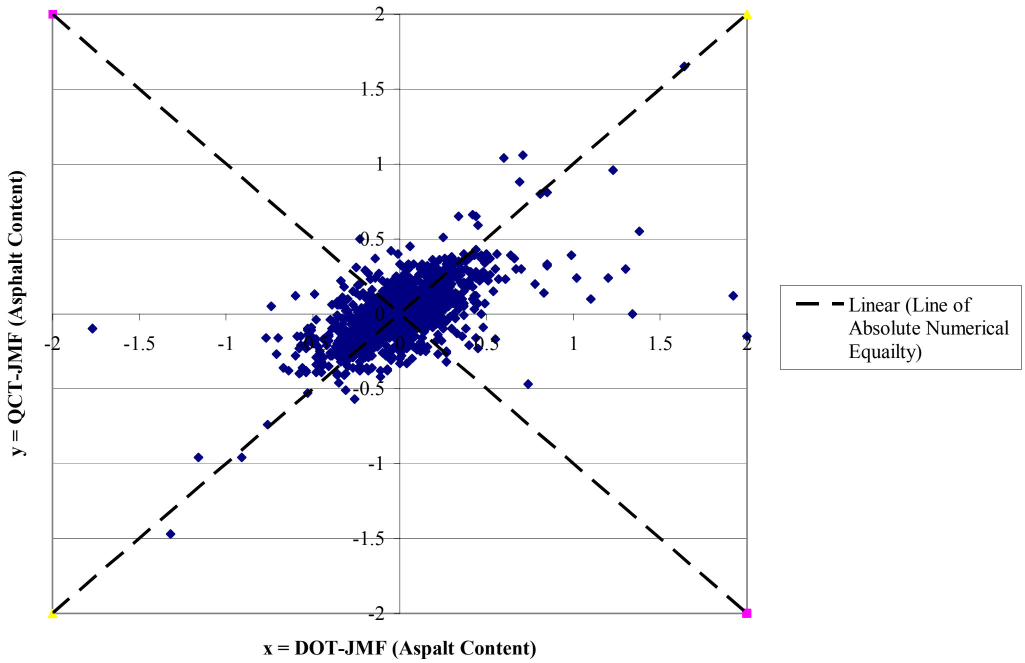

Figure A-9. Mean Comparison from Split Sample Results for Asphalt Content.

APPENDIX B

SKEWNESS ANALYSIS RESULTS

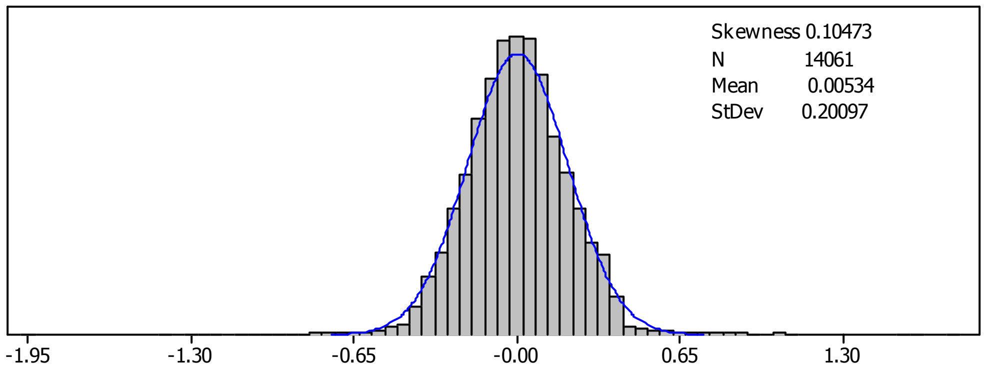

Figure B-1. QCT-JMF Asphalt Content

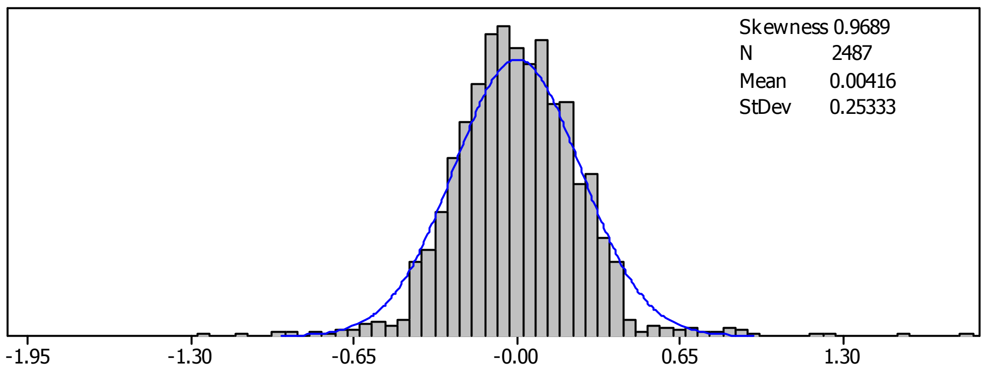

Figure B-2. QA-JMF Asphalt Content

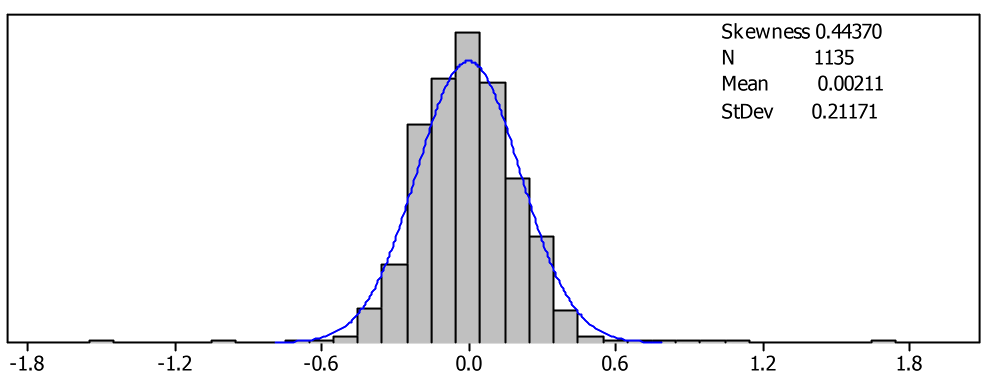

Figure B-3. QCT-JMF Asphalt Content (Split Sample)

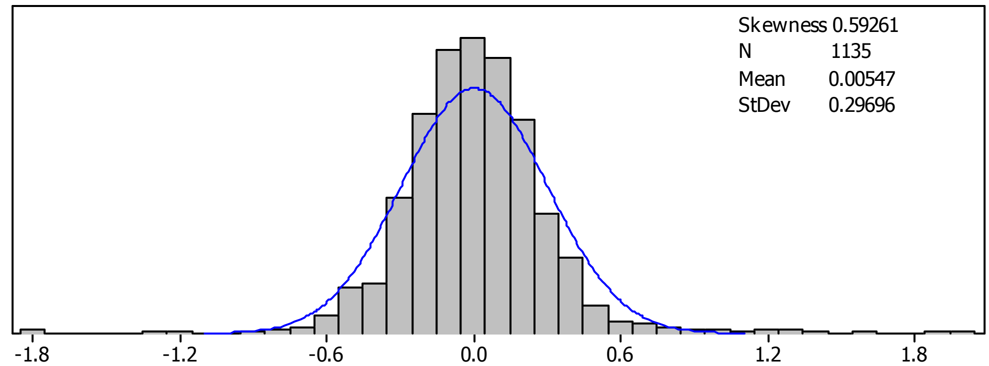

Figure B-4. DOT-JMF Asphalt Content (Split Sample)

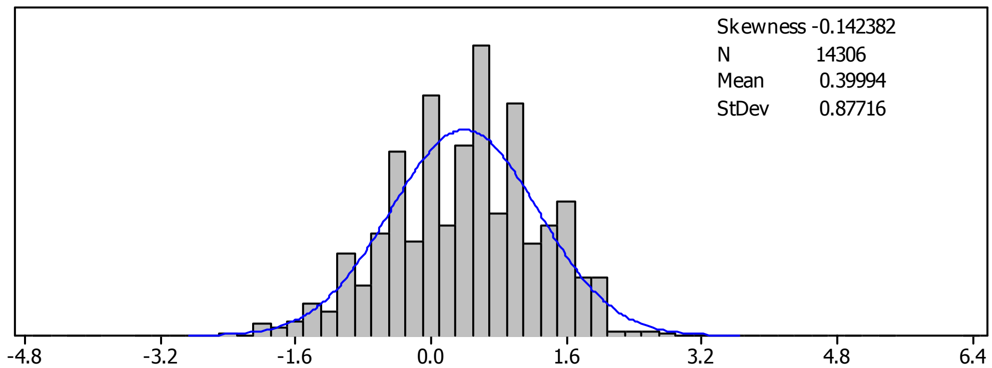

Figure B-5. QCT-JMF #200 Sieve

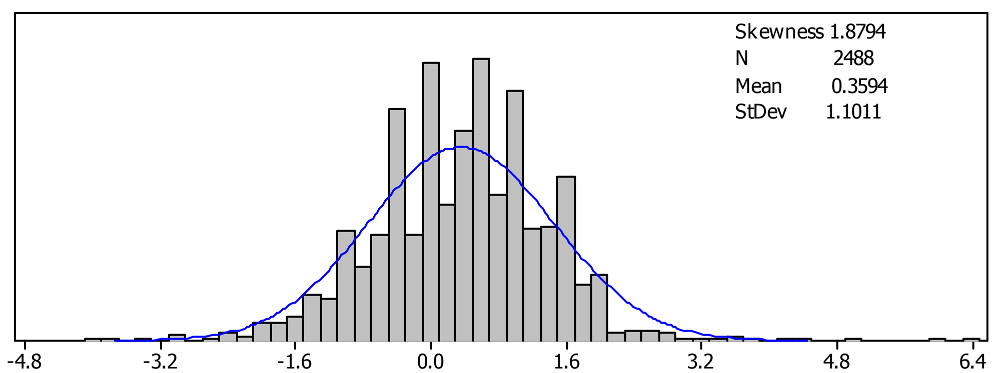

Figure B-6. QA-JMF #200 Sieve

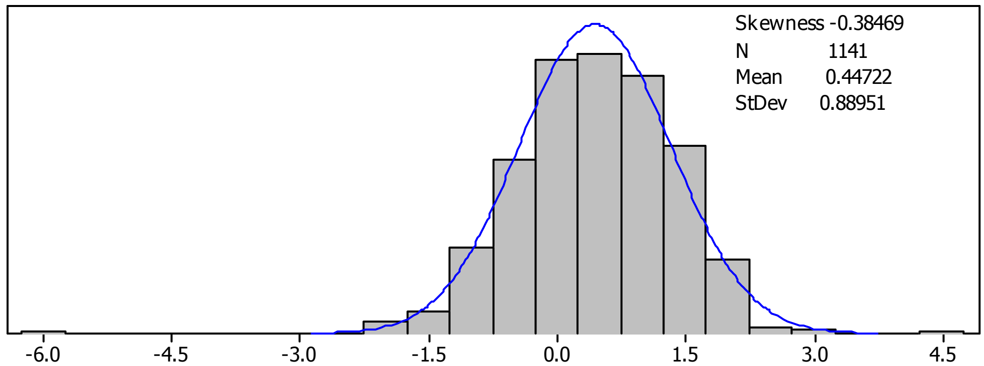

Figure B-7. QCT-JMF #200 Sieve (Split Sample)

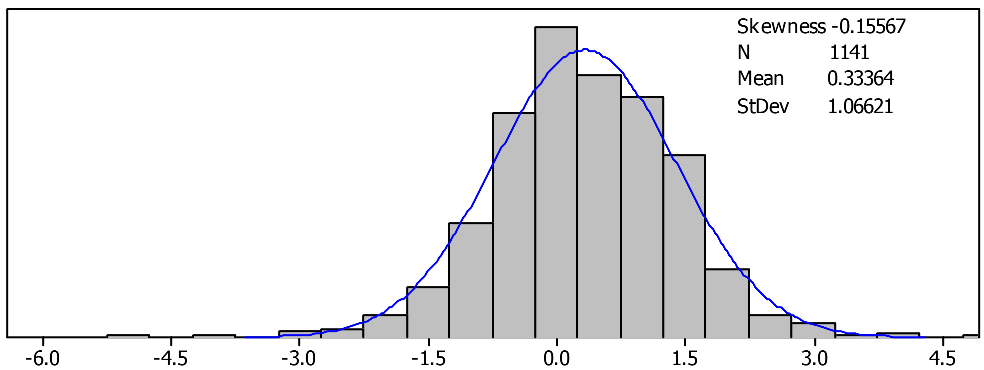

Figure B-8. DOT-JMF #200 Sieve (Split Sample)

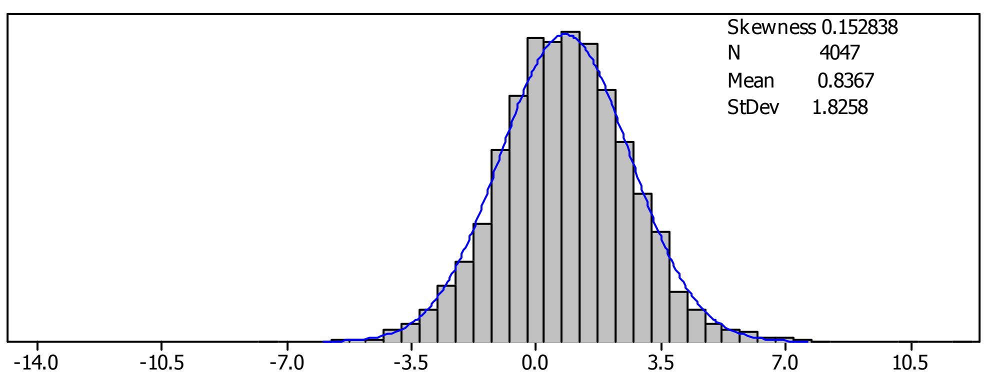

Figure B-9. QCT-JMF #50 Sieve

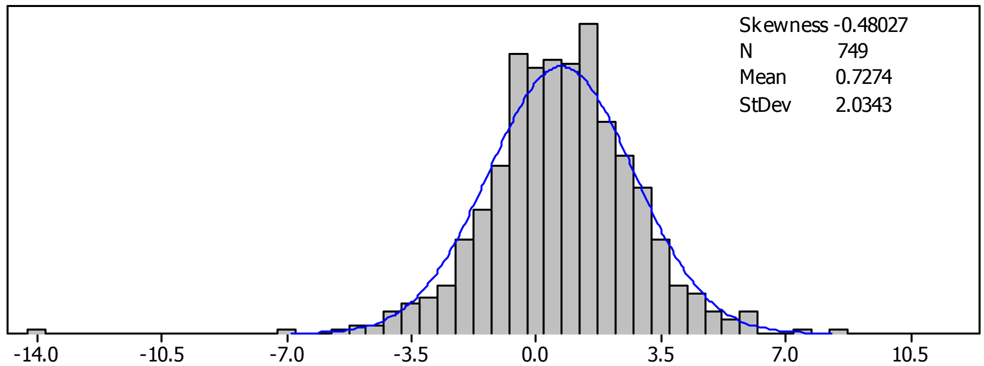

Figure B-10. QA-JMF #50 Sieve

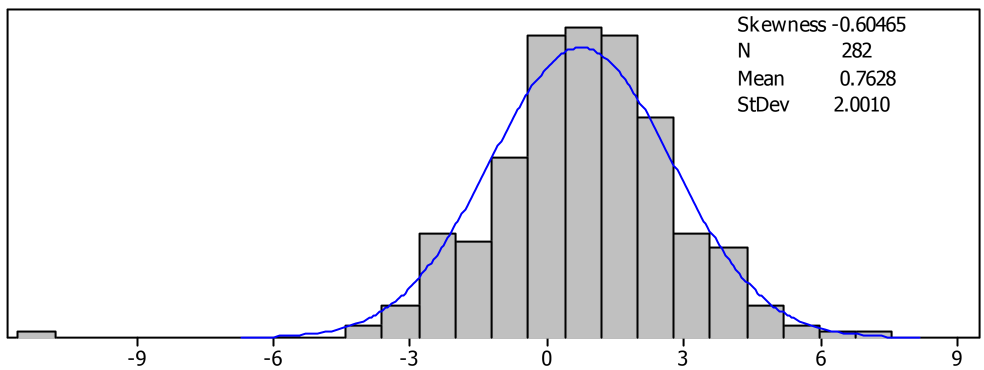

Figure B-11. QCT-JMF #50 Sieve (Split Samples)

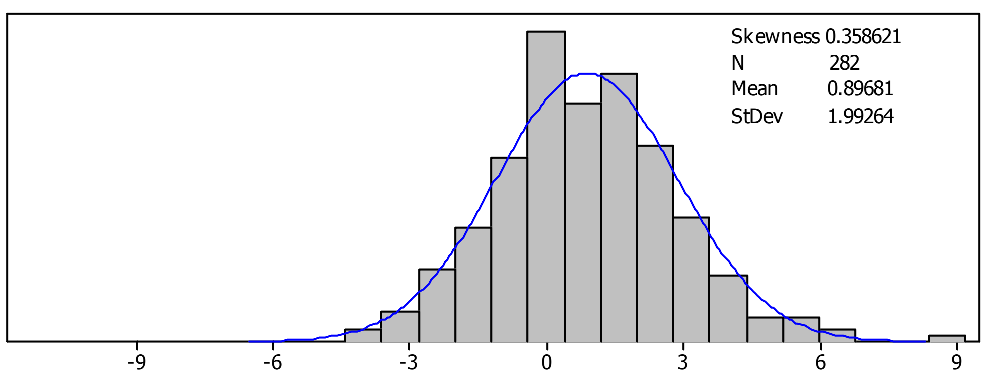

Figure B-12. DOT-JMF #50 Sieve (Split Samples)

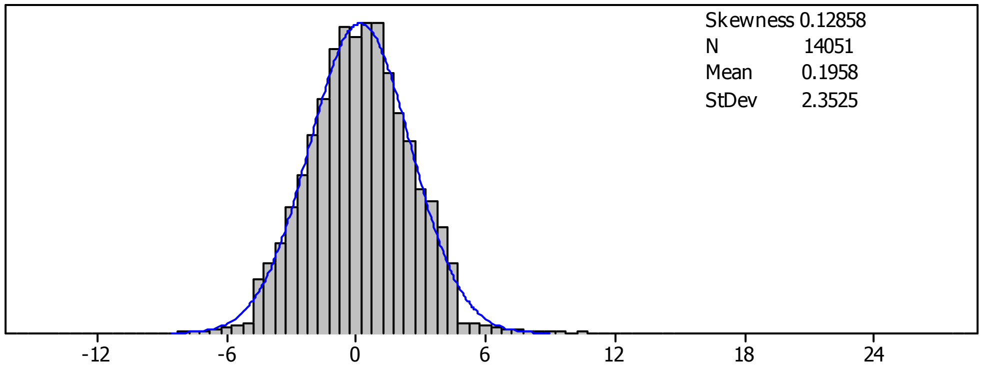

Figure B-13. QCT-JMF #8 Sieve

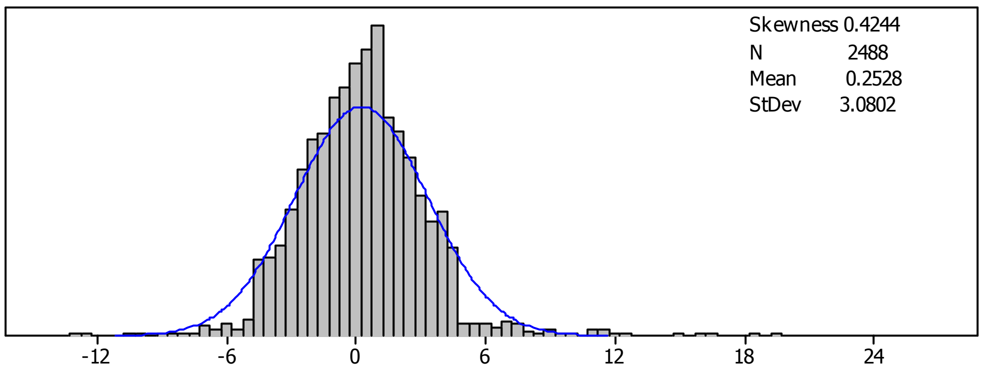

Figure B-14. QA-JMF #8 Sieve

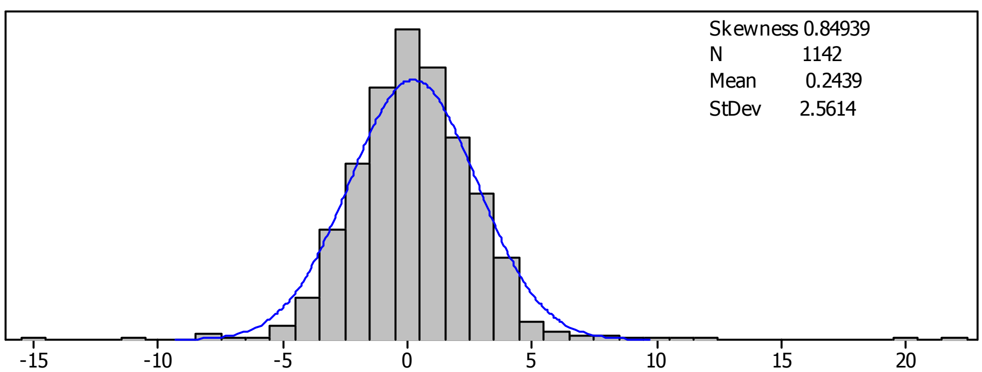

Figure B-15. QCT-JMF #8 Sieve (Split Samples)

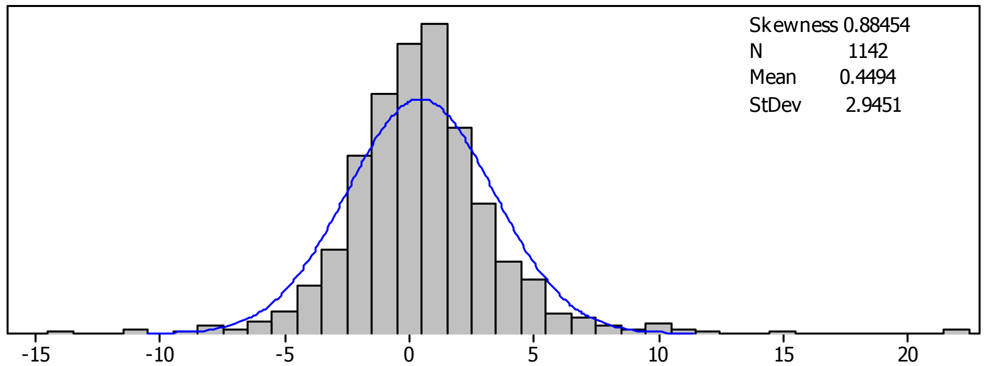

Figure B-16. DOT-JMF #8 Sieve (Split Samples)

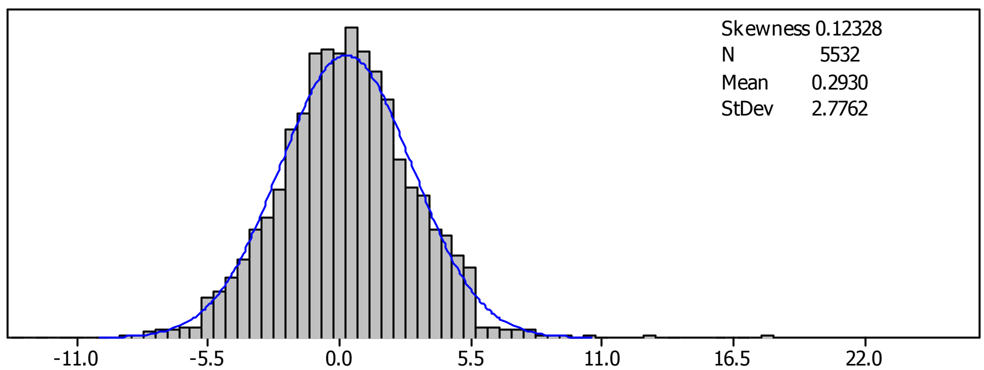

Figure B-17. QCT-JMF #4 Sieve

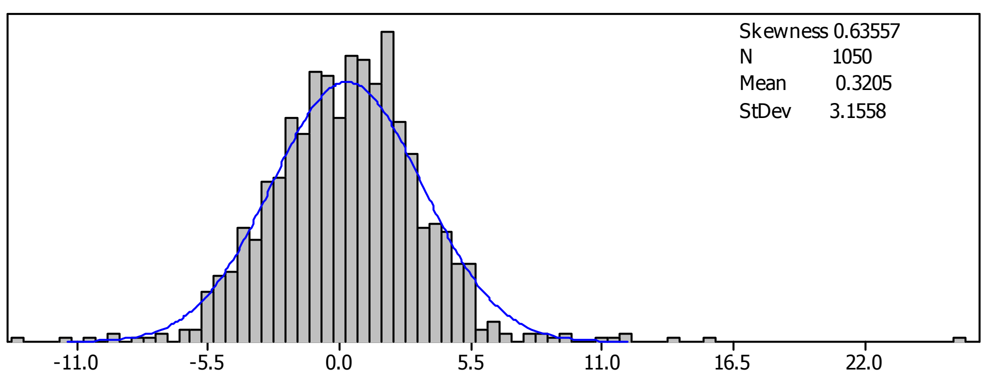

Figure B-18. QA-JMF #4 Sieve

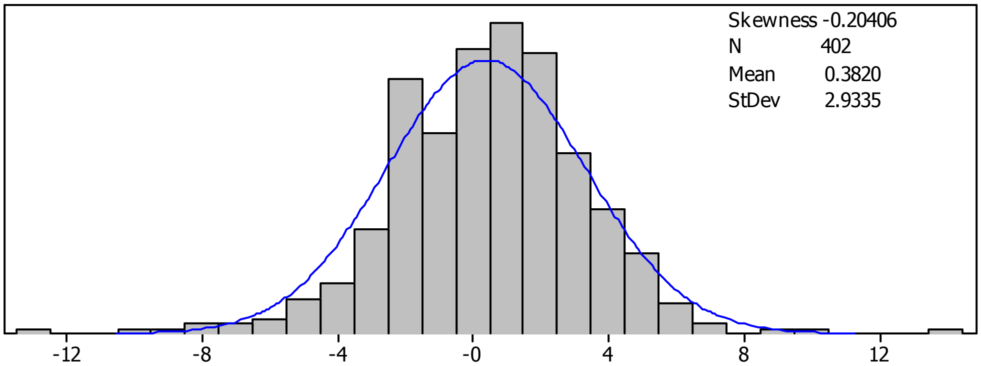

Figure B-19. QCT-JMF #4 Sieve (Split Samples)

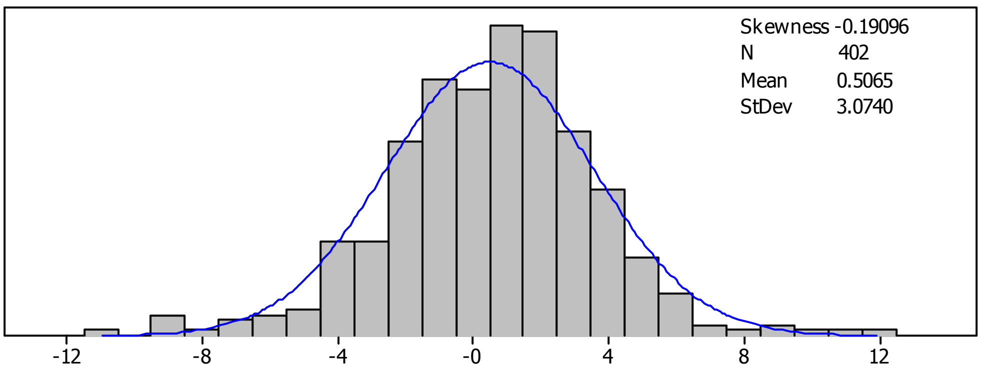

Figure B-20. DOT-JMF #4 Sieve (Split Samples)

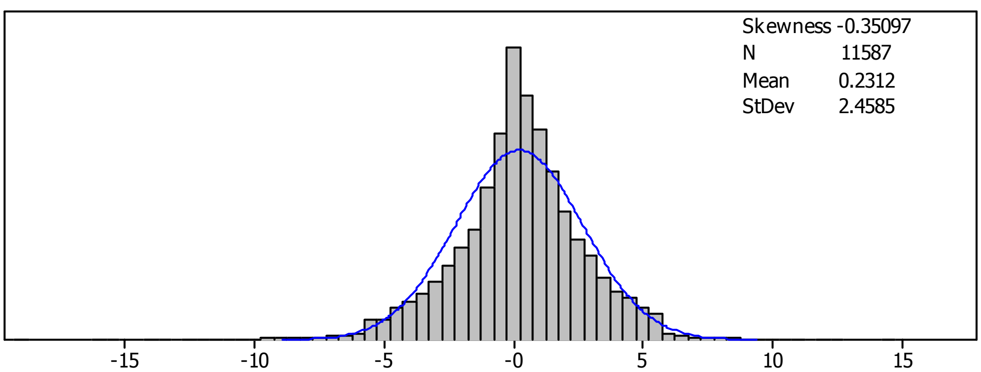

Figure B-21. QCT-JMF 0.375" Sieve

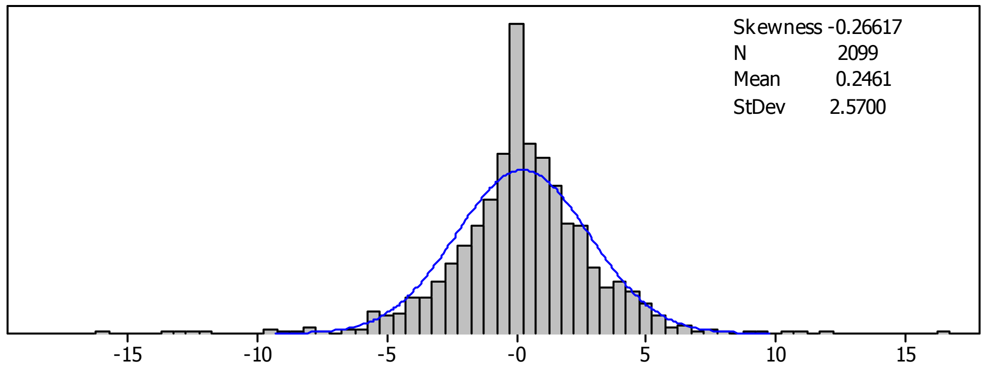

Figure B-22. QA-JMF 0.375” Sieve

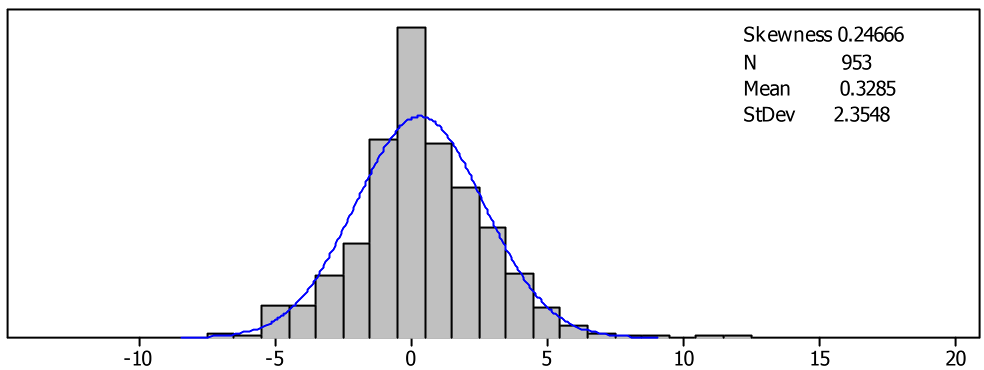

Figure B-23. QCT-JMF 0.375” Sieve (Split Samples)

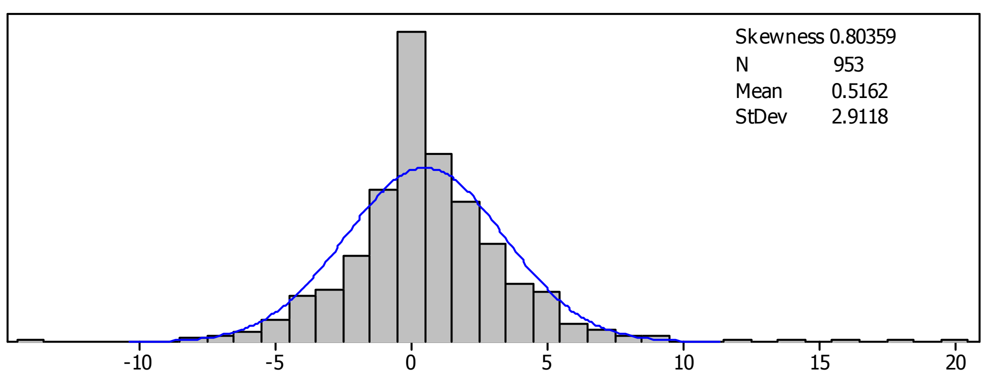

Figure B-24. DOT-JMF 0.375” Sieve (Split Samples)

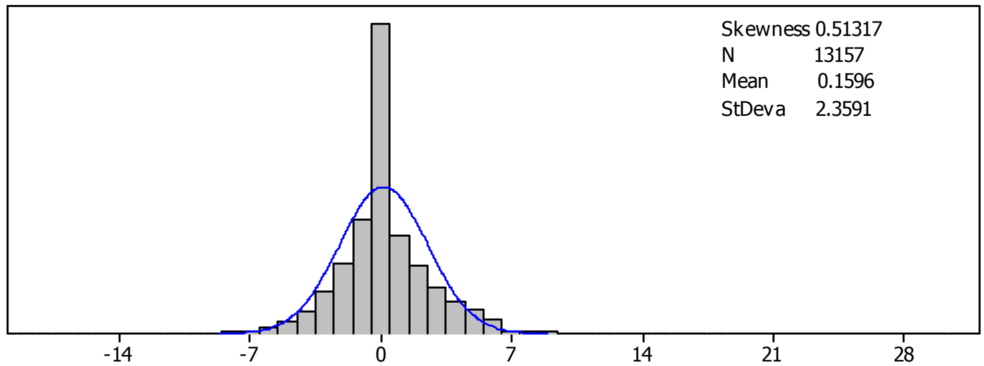

Figure B-25. QCT-JMF 0.5" Sieve

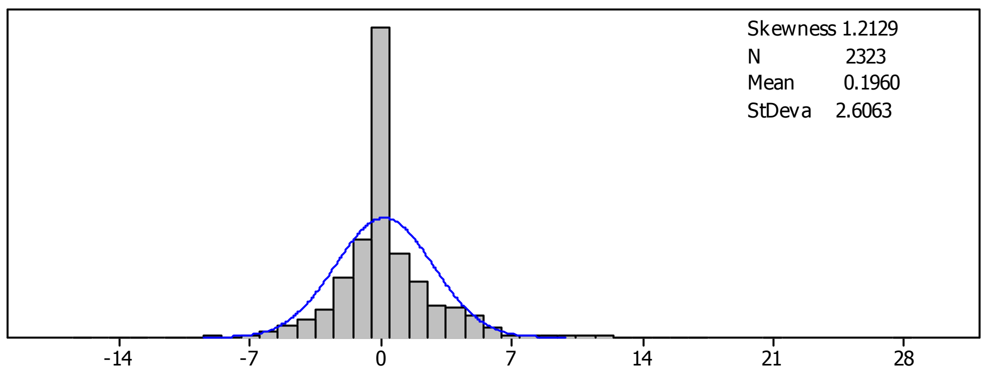

Figure B-26. QA-JMF 0.5" Sieve

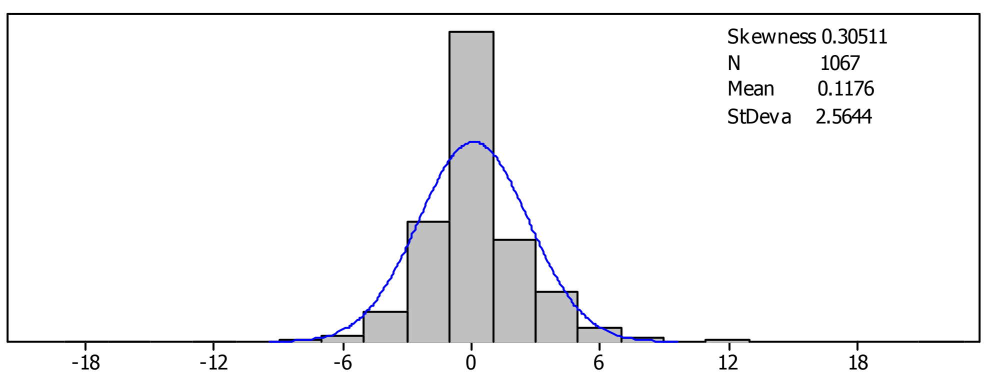

Figure B-27. QCT-JMF 0.5" Sieve (Split Samples)

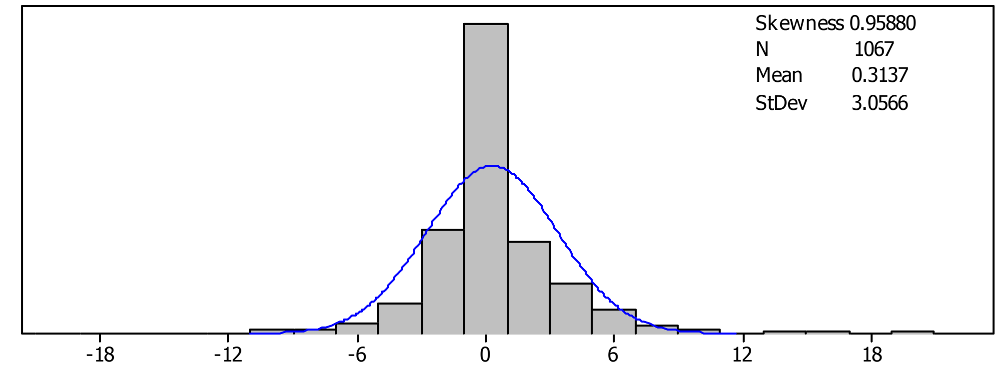

Figure B-28. DOT-JMF 0.5” Sieve (Split Samples)

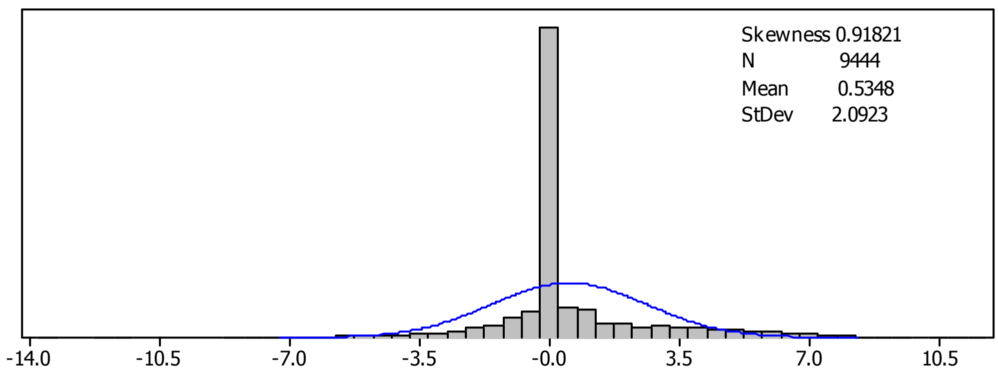

Figure B-29. QCT-JMF 0.75” Sieve

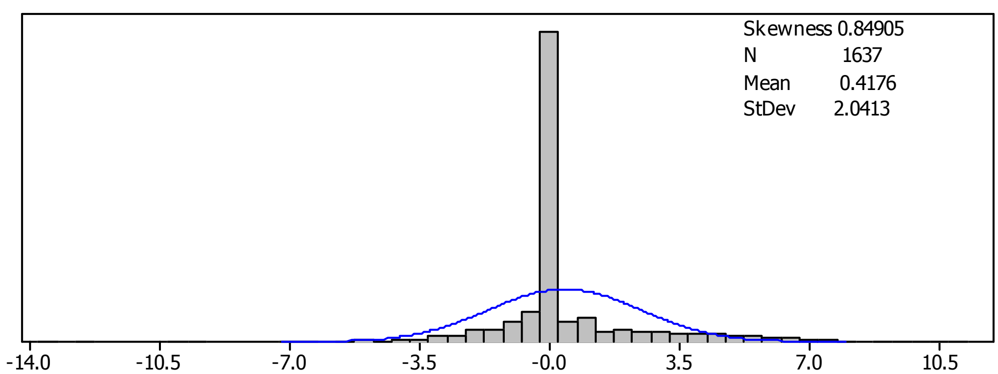

Figure B-30. QA-JMF 0.75” Sieve

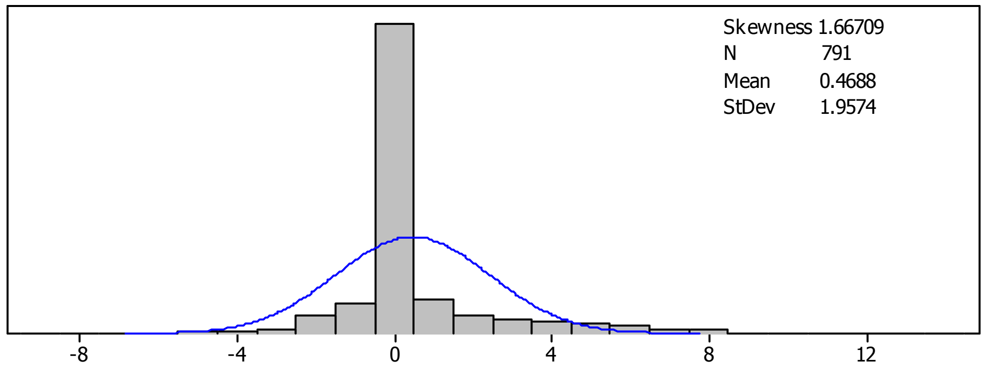

Figure B-31. QCT-JMF 0.75” Sieve (Split Samples)

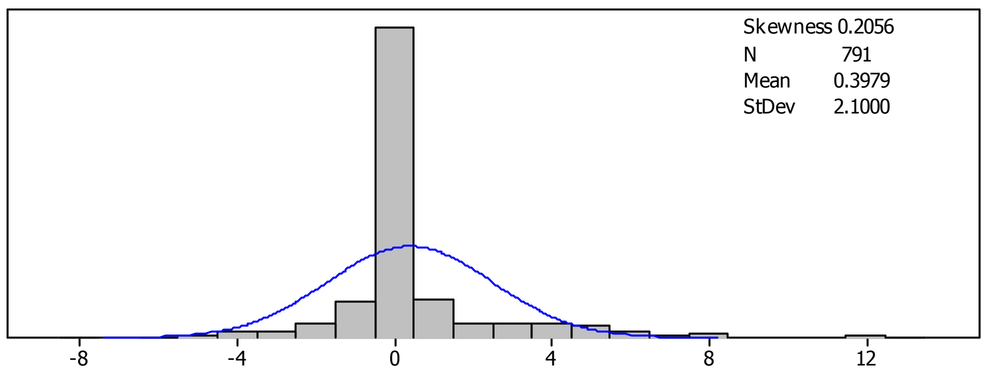

Figure B-32. DOT-JMF 0.75” Sieve (Split Samples)

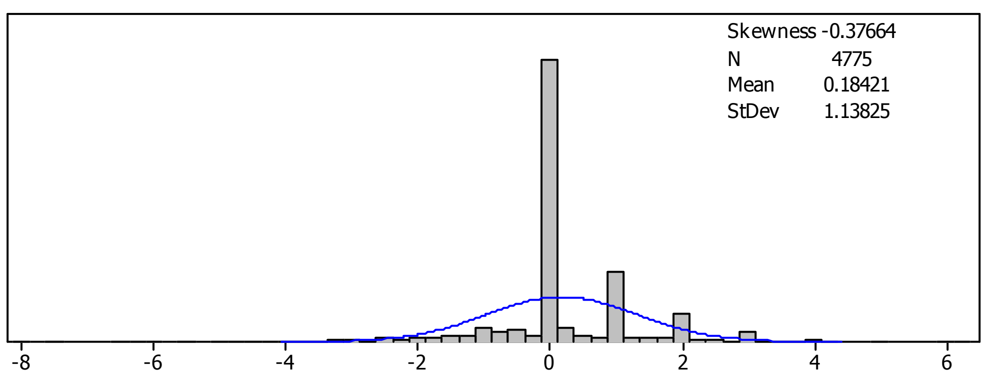

Figure B-33. QCT-JMF 1” Sieve

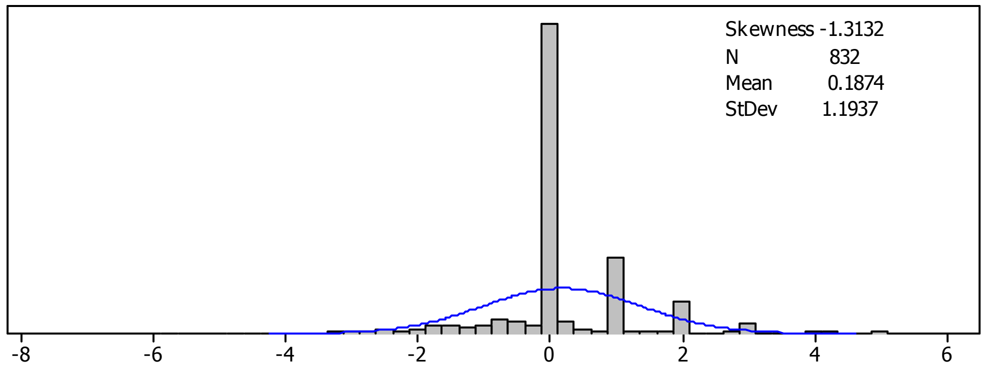

Figure B-34. QA-JMF 1" Sieve

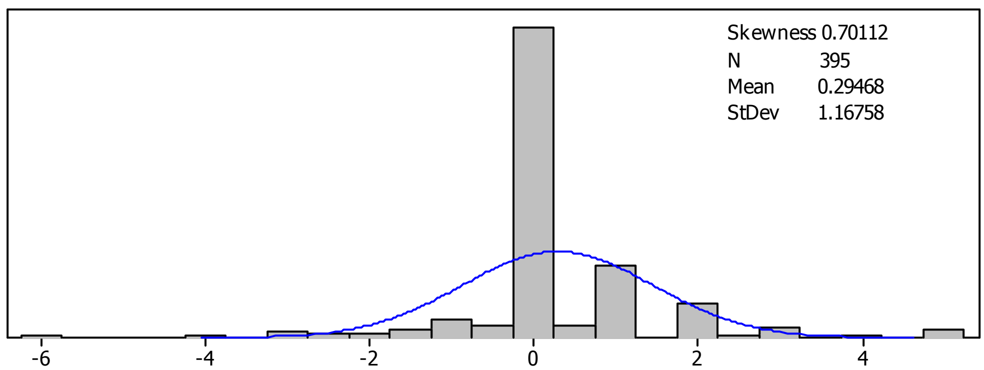

Figure B-35. QCT-JMF 1" Sieve (Split Samples)

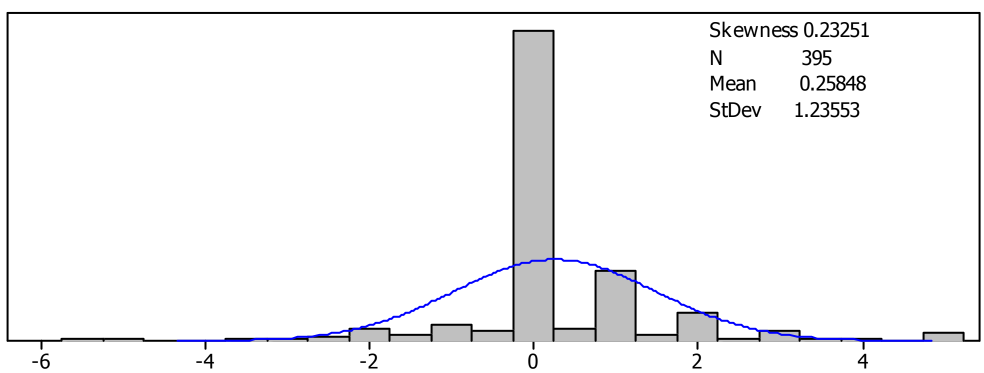

Figure B-36. DOT-JMF 1" Sieve (Split Samples)

APPENDIX C

PROJECT BY PROJECT TABLES

Table C-1. ½" Sieve Project by Project Table for QCT versus QA.

Project #	Nqc	Nqa	Vqc	Vqa	Mqc	Mqa	Differences
BRN-42-2(40)01	13	6	1.7856	1.2457	-1.1308	-1.1167	None
CM-186-1(28)01	38	7	11.1322	13.2024	0.6421	0.9286	None
CSSTP-M002-00(444)01	27	6	0.2972	1.9417	2.5519	2.4167	Variances
CSSTP-M002-00(453)01	54	7	0.0007	0.0000	-0.0037	0.0000	None
EDS-27(136)01	138	35	4.8818	28.2736	0.3449	1.6229	Variances
EDS-27(147)01	90	14	2.3432	1.5782	-1.1922	-1.0857	None
EDS-84(16)01	127	16	7.3232	5.3740	0.6583	0.5750	None
EDS-84(17)01	64	11	6.4686	9.9626	0.6000	0.2636	None
EDS-545(8)01	71	9	7.6223	4.2553	-0.4099	0.0556	None
EDS-555(6)01	73	15	7.8346	12.1884	-0.0603	1.0533	None
EDS-565(7)-01	99	7	7.8370	13.9381	0.4657	0.4143	None
EDS-565(15)-01	98	15	5.7659	8.2995	0.8276	0.7333	None
FLF-540(8)01	61	8	5.8679	4.1250	1.0672	1.2750	None
FLF-540(25)01	95	12	3.6104	3.6924	1.4168	0.9167	None
GIP-341(33)01	107	13	9.2501	9.6309	0.8533	0.6385	None
GIP-341(34)01	146	25	14.9424	27.4157	0.3671	-0.7640	None
GIP-341(38)01	203	21	14.0092	10.8481	0.9163	1.1714	None
HPP-3717-00(300)01	28	16	0.0714	0.1873	-0.3786	-0.3937	None
HPP-STP-178-1(33)01	23	7	2.1225	0.9657	0.4391	0.3714	None
IM-00MS(268)01	41	14	4.1352	8.1385	-0.2317	-0.4000	None
IM-285-1(349)01	26	7	13.5448	113.5148	-0.7346	1.3857	Variances
IM-0000-00(471)01	54	15	10.2602	6.1898	1.0593	1.5467	None
IM-0000-00(470)01	87	11	10.2481	13.3836	1.4839	1.3182	None
IM-00MS(20)01	56	17	5.4579	8.8272	1.3750	1.4706	None
IM-MS(325)01	31	7	5.9792	2.8800	-1.5484	-2.1000	None
IM-NH-85-2(148)01	175	20	10.5233	11.2510	1.1863	1.0950	None
LAR00-S005-00(593)C1	13	8	0.4990	0.4536	0.2308	0.3250	None
LAR00-S005-00(649)C1	13	6	0.0000	0.0067	0.0000	-0.0333	Variances
LAR31-87-1(067)01	23	7	0.0157	0.0057	-0.0261	-0.0286	None
LAR32-2-3(067)01	17	7	0.3368	0.3262	-0.3059	-0.3571	None
LAR32-2-5(63)C1	12	6	0.0000	0.0150	0.0000	-0.0500	Variances
LAR32-24-1(057)C1	42	8	0.7603	0.4570	-0.3214	0.0625	None
LAR32-30-2(89)01	34	9	29.7617	28.5753	0.9206	-2.5556	None
LAR32-250-1(057)01	37	8	0.6825	0.5998	-0.5973	-0.2625	None
LAR32-888-1(089)01	35	11	3.7732	7.0876	0.4971	1.7182	None
LAU32-8532-69(121)01	28	10	1.0177	0.0573	-0.6929	-0.2200	Variances
NH-8013(8)01	63	20	8.3353	4.9237	1.7175	0.4450	None
NH-11-1(44)01	32	11	11.3519	2.8787	1.7188	-0.8545	None
NH-012-1(83)01	60	10	11.4486	17.9107	0.6417	0.1800	None
NH-017-2(53)01	36	12	10.8882	16.4717	-0.3583	-0.2417	None
NH-20-2(183)01	193	24	7.0404	8.6573	0.5041	2.3083	Mean

NH-026-2(81)01	29	9	7.7946	8.5050	0.6034	-0.2333	None
NH-043-1(49)01	14	6	9.5191	4.6387	-0.5286	-0.6667	None
NH-56-1(62)01	43	16	15.4562	17.5320	1.6372	-0.6563	None
NH-75(157)01	234	30	10.0084	7.7081	0.3910	-0.2767	None
NH-75-1(203)01	180	17	9.4872	17.3468	1.1406	1.1059	None
NH-171-1(4)01	100	8	4.4169	2.1943	2.1360	1.3000	None
NH-IM-75-1(158)	174	24	9.0923	8.5748	-0.9506	-0.9208	None
NH-IM-95-1(119)01	90	13	9.5126	23.0640	-0.2078	-1.7308	Variances
NH-IM-95-1(125)01	141	29	4.7353	5.3664	-0.6099	-0.5000	None
NH-IM-95-1(155)01	71	11	15.2213	9.6702	0.7423	3.5273	None
NHS-0000-00(768)01	61	8	7.8002	11.5813	2.0426	3.4125	None
NHS-M002-00(398)01	487	53	5.3242	5.2975	0.0031	-0.0434	None
NHS-M001-00(530)01	192	9	13.0622	11.9128	1.5516	1.6556	None
NHS-M001-00(531)01	59	12	1.8749	3.7355	-0.8305	-0.5500	None
NHS-M001-00(591)01	50	13	3.5058	3.4500	-1.5560	-0.2000	None
NHS-M002-00(276)01	23	8	2.0715	3.9200	1.2652	0.9000	None
NHS-M002-00(292)01	247	10	5.9524	9.4250	-0.0142	-0.0180	None
PR000-S005-00(810)C1	18	7	0.3657	0.0129	0.1278	-0.0429	Variances
PR-147-2(055)01	8	7	0.0000	0.0000	0.0000	0.0000	None
PR131-1(63)C1	8	6	0.0000	0.0000	0.0000	0.0000	None
PR-1963-2(139)01	28	6	7.1455	12.4910	1.7536	2.0500	None
PR-8530-83(39)C1	22	10	1.1089	5.3044	0.9682	0.6000	Variances
PR-8531-21(77)C1	51	11	12.8023	14.1076	0.9078	0.6818	None
PRLOP8530-32(15)C1	31	6	5.4603	3.7147	0.0032	-0.4333	None
SAMA-60SP(4)01	30	6	2.8886	5.6800	0.2800	1.2000	None
SAMA-3(249)01	38	9	6.5743	3.4344	-0.1974	2.5222	Mean
SAMA-3(294)01	123	25	1.1791	1.0867	-0.7772	-0.8400	None
SAMA-3(298)01	198	31	2.3558	1.3203	0.3535	0.4677	None
SAMA-39(44)01	55	14	4.4110	0.9455	-0.4709	-0.3643	Variances
SAMA-53(133)01	34	6	0.6020	0.6787	0.3529	0.3333	None
SAMA-74(56)01	25	9	1.2208	0.8700	1.5920	0.8333	None
SAMA-74(58)01	121	23	1.2860	0.8421	-1.2281	-1.2130	None
SAMA-155(52)01	18	6	0.7662	2.3680	-1.1167	-2.8000	Mean
SAMA-206-C0(3)01	45	7	0.6860	1.0795	0.1244	-0.0429	None
SAMA-234-(17)01	51	8	0.6792	0.9484	2.0608	1.8625	None
SAMA-520(58)01	84	18	0.4159	0.5603	0.3798	0.4444	None
SAMA-520(59)01	144	20	0.7411	0.7887	-0.3514	-0.3850	None
SAM-M002-00(405)01	40	6	0.4058	0.8750	0.7325	0.7500	None
SAM-M002-00(417)01	46	7	0.6215	0.5690	0.5065	0.1286	None
SAM-M002-00(422)01	64	14	1.8148	1.1352	1.4016	1.8857	None
SAM-M002-00(399)01	23	7	2.6650	1.5057	0.4957	0.3714	None
STP-001-5(60)01	37	9	0.6994	0.7361	0.5000	0.5111	None
STP-9-2(78)01	18	8	0.5776	2.5255	0.4667	0.8375	Variances
STP-9-2(90)01	21	8	3.7786	2.7927	-0.0190	0.2125	None
STP-34-1(22)01	89	14	2.5506	2.8623	-1.8416	-0.7071	None
STP-36-1(13)01	49	15	10.8128	9.9617	0.5367	-0.1200	None
STP-042-2(49)01	82	8	11.3187	21.1070	-0.0171	-2.4875	None

STP-141-1(7)01	36	21	7.9551	10.5381	0.6972	-0.0286	None
STP-149-1(29)01	62	8	6.6796	9.2314	0.2065	0.9000	None
STP-803(4)01	72	18	7.2362	5.5335	-0.2694	-0.6056	None
STP-2434(2)01	14	6	0.7495	3.9710	0.6786	1.0500	Variances
STP-M00-00(703)01	34	7	0.4411	0.2733	1.8794	1.7000	None
STP-M001-00(273)01	82	19	1.4091	1.2050	-0.8329	-0.2053	None
STP-M001-00(330)01	88	14	1.9975	0.8569	-1.2477	-0.9000	None
STP-M001-00(490)01	25	6	2.4800	3.0297	0.7800	0.5167	None
STP-M001-00(492)01	50	11	0.5925	0.6945	-0.8340	-0.8364	None
STP-M001-00(493)01	97	10	3.0188	2.4827	0.4784	-0.0600	None
STP-M001-00(773)01	76	8	2.1427	3.5621	-0.0408	0.3750	None
STP-M001-00(872)01	77	6	1.7208	0.4867	-0.3909	0.2333	None
STP-M002-00(093)01	45	7	0.7053	0.2348	1.1467	1.9143	None
STP-M002-00(114)01	50	6	0.4072	0.4110	0.1240	-0.0500	None
STP-M002-00(116)01	51	9	0.5617	1.1861	0.7471	0.8111	None
STP-M002-00(154)01	62	9	0.8029	0.4453	-0.3065	-0.2556	None
STP-M002-00(155)01	44	7	0.7935	4.5029	0.3000	-0.3571	Variances
STP-M002-00(165)01	118	10	2.5686	2.3129	-1.2975	-2.1800	None
STP-M002-00(169)01	32	6	1.7600	1.3747	-0.0750	0.5333	None
STP-M002-00(175)01	122	18	1.0972	1.0406	-0.2893	-0.6944	None
STPN-12-1(110)01	44	20	4.2579	4.9531	-1.9705	-2.1450	None
STP-M002-00(395)01	47	11	1.0893	1.2420	-0.8979	-1.0000	None
STP-M002-00(236)01	32	7	0.4322	0.3495	0.5531	0.4429	None
STP-M002-00(397)01	93	16	0.0000	0.0000	0.0000	0.0000	None
STP-M001-00(330)01	87	10	2.0204	1.7250	-1.2460	-1.5500	None
STP-M002-00(115)01	73	10	2.9465	4.1610	-1.6658	-1.9100	None

Table C-2. ½" Project by Project Table for Comparison Tests

Project #	Nqct	Ndot	Vqct	Vdot	Mqct	Mdot	Differences
CM-186-1(28)01	7	7	16.8528	28.6191	-1.1429	-2.4286	None
EDS-27-(136)01	8	8	1.9498	2.2755	-0.4875	-0.5125	None
EDS-27(147)01	9	9	7.1028	14.4894	-0.4444	0.3778	None
EDS-84(16)01	7	7	11.4400	7.5295	1.5000	2.2429	None
EDS-84(17)01	11	11	7.0185	5.2827	2.2364	2.2455	None
EDS-555(6)01	7	7	14.9491	10.1029	-0.1714	0.0571	None
GIP-341(34)01	14	14	18.8644	21.8710	2.3143	2.6214	None
GIP-341(38)01	8	8	13.5041	16.6998	2.3875	3.2375	None
IM-NH-85-2(148)01	11	11	43.3587	39.1025	2.9545	4.0364	None
NH-026-2(81)01	10	10	1.7271	3.6222	-0.5600	0.6000	None
NH-56-1(62)01	8	8	10.6227	23.7070	1.9625	1.5125	None
NH-75-1(157)01	24	24	7.2089	8.4164	-0.2750	-0.2583	None
NH-75-1(203)01	15	15	11.9492	16.7910	1.8067	1.3333	None
NH-IM-75-1(158)	24	24	10.5087	8.1624	-0.1458	-0.0375	None
NH-IM-95-1(119)01	7	7	3.2548	12.8995	-0.7143	0.2429	None
NH-IM-95-1(125)01	15	15	3.8064	1.2511	-0.4933	-0.1400	None
NH-IM-95-1(155)01	6	6	17.2667	7.4617	1.6667	4.6167	None
NHS-M002-00(398)01	26	26	7.0582	9.3768	0.2692	-0.3346	None
NHS-M001-00(530)01	20	20	14.3936	43.2898	2.8250	4.7350	None
SAMA-39-(44)01	15	15	10.2470	7.2492	-0.3533	-0.9733	None
SAMA-520(59)01	12	12	0.1715	0.7936	-0.2333	-0.5417	Variances
STP-001-5(60)01	8	8	1.1543	0.3257	0.7000	0.3500	None
STP-34-1(22)01	11	11	1.8096	1.2367	-2.0182	-1.1455	None
STP-36-1(13)01	13	13	15.6133	9.4841	-1.2000	-1.6077	None
STP-803(4)01	7	7	3.5462	6.1524	-0.8429	-0.0286	None
STP-M001-00(273)01	15	15	3.1084	1.8927	-0.6133	-0.4867	None
STP-M001-00(330)01	11	11	0.6900	2.0980	-1.5000	-1.0000	None
STP-M001-00(773)01	8	8	2.5021	4.4541	0.2750	0.5625	None
STP-M002-00(093)01	7	7	0.8357	1.0695	1.3714	1.3571	None
STP-M002-00(165)01	8	8	1.1841	8.8470	-1.0875	-0.6875	Variances
STP-M002-00(175)01	15	15	0.7812	1.4784	-0.2533	-0.0867	None
STP-M002-00(397)01	11	11	0.0000	0.0000	0.0000	0.0000	None
STP-M001-00(330)01	15	15	0.6554	1.7795	-1.6400	-1.1667	None
STP-M002-00(115)01	7	7	2.1824	0.5614	-1.8714	-1.2857	None

Table C-3. #200 Sieve Project by Project Table for QCT versus QA.

Project #	QC	QA	Vqc	Vqa	Mqc	Mqa	Differences
BRN-42-2(40)01	15	6	0.0392	0.1787	0.9267	0.7333	None
CM-186-1(28)01	38	7	0.6502	0.1090	0.1895	-0.8286	Means
CSSTP-M002-00(444)01	40	9	0.5246	0.8700	-0.1050	0.2667	None
CSSTP-M002-00(453)01	53	7	0.4101	0.9567	0.2792	0.4000	None
EDS-27(136)01	140	35	0.3948	8.5014	1.0650	1.6086	None
EDS-27(147)01	129	20	0.4037	0.3521	0.5605	0.6950	None
EDS-84(16)01	129	16	0.4262	0.8333	0.0295	-0.3000	None
EDS-84(17)01	63	11	0.3243	0.3380	-0.1222	0.0000	None
EDS-545(8)01	72	9	0.1563	0.1011	-0.6583	-0.6111	None
EDS-555(6)01	73	15	0.3415	0.5064	-0.6932	-0.4067	None
EDS-565(7)-01	99	7	0.0871	0.5981	-0.3798	-0.1143	Variances
EDS-565-(15)01	98	15	0.1185	0.4054	-0.3622	-0.0400	Variances
FLF-540(8)01	61	8	0.5134	0.4850	0.3620	0.5750	None
FLF-540(25)01	92	10	0.2787	0.3129	0.1435	0.1200	None
FLF-540(28)01	116	10	0.2792	0.3877	-0.5802	-0.4100	None
GIP-341(33)01	105	13	0.2229	0.2017	0.6114	0.4000	None
GIP-341(34)01	141	25	0.8528	0.5892	0.6624	0.4560	None
GIP-341(38)01	199	21	1.1388	0.6096	0.5005	0.7190	None
HPP-3717-00(300)01	36	16	0.3483	6.6850	-0.2028	0.6313	Variances
HPP-STP-178-1(33)01	23	7	0.3036	0.1429	0.9783	1.4429	None
IM-00MS(268)01	43	14	0.5347	0.4699	0.2047	0.3071	None
IM-285-1(349)01	29	8	0.3747	0.9457	0.6552	0.1500	None
IM-0000-00(471)01	60	15	0.4679	0.4724	0.4300	0.2667	None
IM-0000-00(472)01	98	16	0.6396	0.8358	0.1357	-0.1625	None
IM-00MS(20)01	56	17	0.4090	1.2307	0.5607	0.6947	Variances
IM-MS(325)01	31	7	0.4046	0.4162	0.8452	1.0429	None
IM-NH-85-2(148)01	175	20	0.6567	0.6519	0.3851	0.2350	None
LAR00-S005-00(459)01	21	7	0.5155	0.4762	-0.4381	0.2429	None
LAR00-S005-00(593)C1	13	8	0.5286	1.2514	1.6769	1.0000	None
LAR00-S005-00(636)	21	9	0.1613	0.0761	1.0857	1.1111	None
LAR00-S005-00(649)C1	13	6	0.2881	0.4857	1.2154	1.2167	None
LAR00-S005-00(569)C1	18	7	1.1331	0.1924	-0.3611	-0.5714	None
LAR31-87-1(067)01	26	6	0.2552	3.9017	0.6654	-0.8833	Variances
LAR32-2-3(067)01	17	6	0.4088	0.3057	0.2588	0.3167	None
LAR32-2-5(63)C1	12	6	0.1663	0.5027	0.6083	0.1333	None
LAR32-24-1(057)C1	43	8	0.4962	2.0813	0.4953	0.4125	Variances
LAR32-30-2(089)01	34	9	0.7408	1.5775	1.1088	0.1667	None
LAR32-85-1(77)C1	20	6	0.1887	0.4560	-0.5650	0.1000	Means
LAR32-250-1(057)C1	37	8	0.2692	0.7364	0.1270	-0.0250	None
LAR32-888-1(089)01	45	13	0.6898	0.9869	0.3556	-0.0769	None

LAU32-8532-79(121)1	28	10	0.8504	0.7499	0.5179	0.0900	None
NH-11-1(44)01	34	11	0.8803	0.4045	1.0294	0.2364	None
NH-012-1(83)01	59	10	0.2298	0.3529	1.2051	1.0200	None
NH-017-2(53)01	36	13	0.7277	1.2076	0.6167	0.5615	None
NH-20-2(183)01	240	35	0.6932	1.2740	0.0221	-0.1686	Variances
NH-026-2(81)01	29	9	0.8698	0.1525	0.8138	0.8000	Variances
NH-043-1(49)01	15	6	0.3600	1.1800	0.3000	-0.1000	None
NH-56-1(62)01	53	17	0.2916	0.9456	0.1811	0.0059	Variances
NH-75-1(157)01	234	30	1.1829	1.5977	0.3821	0.6467	None
NH-75-1(203)01	178	18	0.4697	0.5379	0.4685	0.4556	None
NH-171-1(4)01	100	8	0.7669	1.0584	0.4790	-0.0875	None
NH-8013(8)01	64	20	0.2961	0.3768	0.4141	0.2000	None
NH-IM-75-1(158)	174	24	0.1503	0.1039	-0.4598	-0.7708	Means
NH-IM-95-1(119)01	94	14	0.3517	0.7376	-0.2553	-0.1286	None
NH-IM-95-1(125)01	142	29	0.4681	0.6280	0.5923	0.6962	None
NH-IM-95-1(155)-01	117	12	0.4071	2.0906	0.2256	-1.2833	Both
NHS-0000-00(768)01	60	8	0.2364	0.3155	-0.5517	0.2875	Means
NHS-M002-00(398)01	487	53	0.8156	1.4086	0.3357	0.1094	Variances
NHS-M000-00(436)01	26	6	0.7331	1.5347	0.4115	0.5667	None
NHS-M001-00(530)01	193	10	1.5599	0.9423	0.5508	0.2700	None
NHS-M001-00(531)01	59	12	0.1680	0.4027	0.0915	0.1500	None
NHS-M001-00(591)01	50	13	0.8509	1.0647	-0.3640	-0.4846	None
NHS-M002-00(276)01	25	8	0.5574	0.4498	0.3920	0.3125	None
NHS-MOO2-00(292)01	248	14	0.6024	0.5181	0.6867	0.8500	None
PR000-S005-00(810)C1	18	7	0.2965	0.5014	1.2333	0.1857	Means
PR-147-2(055)01	13	9	0.7323	1.2100	1.5692	1.5000	None
PR-3-3(151)01	20	6	0.4992	0.4057	-0.0350	0.2167	None
PR131-1(63)C1	8	8	0.1193	0.4279	0.3250	-0.5250	Means
PR-1963-2(139)01	28	6	0.3417	0.1350	-0.6393	-0.3500	None
PR-8530-83(39)C1	22	7	0.2492	0.5514	0.9818	0.0857	Means
PR-8531-21(77)C1	50	10	0.3372	0.3107	0.3420	0.9800	Means
PRLOP-8530-32(15)C1	33	11	0.4761	0.8736	1.1212	0.9818	None
SAMA-3(249)01	39	9	0.2983	5.2725	0.6897	-0.7333	Variances
SAMA-3(294)01	123	25	0.2046	0.4732	0.6016	0.2640	Variances
SAMA-3(298)01	238	31	0.6537	0.9971	1.0693	0.6226	Means
SAMA-39(44)01	70	18	0.4312	0.4536	0.5314	0.4222	None
SAMA-53(133)01	34	6	0.2912	0.1257	1.1971	0.8833	None
SAMA-60(5)01	51	10	1.8202	1.6254	0.0020	-0.3100	None
SAMA-74(56)01	26	9	0.4256	0.8944	0.0000	-0.5222	None
SAMA-74(58)01	121	27	0.3228	0.2156	0.3521	0.4556	None
SAMA91-(44)01	17	7	0.2328	0.1262	0.3176	0.4571	None
SAMA-155(52)01	18	6	0.3272	0.1080	-0.2389	0.2000	None
SAMA-206-CO(3)01	71	14	0.8426	1.4037	0.2169	0.1714	None
SAMA-234-(17)01	51	8	0.2353	0.1964	0.2471	0.0250	None
SAMA-520(58)01	84	18	0.3688	0.4296	0.8512	0.9389	None

SAMA-520(59)01	144	21	0.4100	0.7153	0.9639	0.6333	None
SAM-M002-00(405)01	40	6	0.4567	0.3870	0.0350	0.3500	None
SAM-M002-00(417)01	46	7	0.5425	0.7162	0.5130	-0.0429	None
SAM-M002-00(422)01	64	17	0.3435	0.1803	1.1063	0.7176	None
SAM-M002-00(399)01	23	7	0.3598	1.1314	0.8565	0.5143	None
STP-001-5(60)01	37	9	0.0835	0.1050	0.6378	0.7333	None
STP-9-2(78)01	29	12	0.2969	0.4627	1.1759	1.2500	None
STP-9-2(90)01	22	8	0.7004	0.9312	0.9682	0.5375	None
STP-34-1(22)01	89	14	0.3345	0.6146	-0.2809	-0.1071	None
STP-36-1(13)01	52	15	0.3473	0.5112	1.3827	1.1133	None
STP-042-2(49)01	81	8	0.4149	0.5684	0.7741	0.7375	None
STP-141-1(7)01	36	21	0.2936	1.6669	0.7111	-0.5905	Both
STP-149-1(29)01	62	8	0.1694	1.1993	0.4677	-0.0250	Variances
STP-803(4)01	72	18	0.4468	0.1697	1.0861	1.3556	None
STP-2434(2)01	11	6	0.0720	1.8657	-0.1000	0.1167	Variances
STP-4067(2)02	96	7	0.2505	0.1562	0.6521	0.6429	None
STP-5121(3)01	34	7	0.2820	0.5433	0.5912	0.6000	None
STP-M00-00(703)01	54	9	0.8410	1.3644	-0.1593	-0.0222	None
STP-M001-00(273)01	102	18	0.3875	0.4352	0.5863	0.4889	None
STP-M001-00(490)01	24	6	0.7910	0.3657	0.8167	0.5833	None
STP-M001-00(492)01	54	13	0.4932	0.1023	0.0130	0.2692	Variances
STP-M001-00(493)01	121	13	0.3546	0.3967	-0.9694	-0.7000	None
STP-M001-00(773)01	76	9	0.4820	0.6175	0.5737	0.4667	None
STP-M001-00(872)01	77	6	0.3587	0.4587	0.2390	0.2667	None
STP-M002-00(92)01	44	8	1.0007	1.4827	-0.0932	-0.3625	None
STP-M002-00(093)01	45	7	0.2751	0.2048	0.8889	0.6143	None
STP-M002-00(114)01	60	6	0.2947	0.0707	0.2083	-0.0333	None
STP-M002-00(116)01	51	11	0.1184	0.0756	-0.4608	-0.0818	Means
STP-M002-00(154)01	80	13	0.5608	0.4933	0.7650	0.5000	None
STP-M002-00(155)01	44	7	0.3935	0.4514	0.2000	0.3857	None
STP-M002-00(165)01	118	10	0.3073	0.5934	0.2093	-0.3300	Means
STP-M002-00(169)01	32	6	0.4019	0.4120	1.0250	1.1000	None
STP-M002-00(173)01	20	7	0.2333	0.2124	1.1800	0.7286	None
STP-MOO2-00(175)01	122	18	0.1545	0.1375	0.5992	0.5889	None
STP-M002-00(232)01	33	12	1.0950	1.8075	0.3242	-0.2750	None
STP-M002-00(236)01	32	7	0.3646	0.2790	1.0156	1.1286	None
STP-M002-00(397)01	93	16	0.5557	3.2172	0.6430	0.6625	None
STP-M001-00(330)01	88	24	0.2392	0.4448	0.1057	-0.2042	None
STP-M002-00(115)01	73	10	0.1716	0.1246	-0.0849	-0.0700	None
STP-M002-00(395)01	68	13	0.7418	0.4100	0.3103	0.3000	None
STPN-12-1(110)01	45	20	0.5239	0.7803	0.8200	0.6850	None

Table C-4. #200 Sieve Project by Project Table for Comparison Tests.

Project #	Nqc	Ndot	Vqc	Vdot	Mqc	Mdot	Differences
CM-186-1(28)01	7	7	1.1767	0.4124	-0.2000	-0.8714	None
CSSTP-M002-00(444)01	6	6	0.4907	1.1177	-0.2667	-0.1167	None
EDS-27(136)01	6	6	0.1830	0.2840	0.9500	0.9000	None
EDS-27(147)01	16	16	0.2543	0.3730	0.3313	-0.1312	None
EDS-84(16)01	6	6	0.0987	0.2297	-0.2333	-0.1167	None
EDS-84(17)01	11	11	0.3342	0.4327	-0.1273	-0.2545	None
EDS-555(6)01	7	7	0.1329	0.1614	-0.9571	-0.7143	Means
GIP-341(34)01	14	14	0.5305	0.6394	0.7857	0.6357	None
GIP-341(38)01	8	8	0.9164	0.7971	1.0750	1.1000	None
IM-MS(325)01	6	6	0.1870	0.6058	1.0500	1.2250	None
IM-NH-85-2(148)01	11	11	1.1565	3.5836	1.0636	1.3182	None
NH-20-2(183)01	7	7	0.5357	0.8162	-0.5286	-0.4429	None
NH-026-2(81)01	10	10	0.8588	1.5329	0.7900	0.4200	None
NH-56-1(62)01	8	8	0.2427	0.6784	0.0375	0.0875	None
NH-75-1(157)01	22	22	0.8371	0.8606	0.5909	0.4591	None
NH-75-1(203)01	15	15	0.5270	0.5735	0.6133	0.3933	None
NH-IM-75-1(158)	24	24	0.2786	0.3409	-0.4067	-0.6000	None
NH-IM-95-1(119)01	7	7	0.1029	1.0857	-0.2571	0.6286	Variability
NH-IM-95-1(125)01	15	15	0.5464	1.9098	0.6933	1.0533	None
NH-IM-95-1(155)01	10	10	0.3600	2.1329	0.1000	-0.7800	Variability
NHS-M002-00(398)01	25	25	0.5207	1.2893	0.5640	0.3480	None
NHS-M001-00(530)01	19	19	1.3956	5.1427	0.1000	0.3053	None
NHS-M002-00(294)01	12	12	0.3481	0.9661	0.8917	-0.1333	Means
PR-128-2(065)01	6	6	0.4720	0.3257	0.9000	0.9167	None
SAMA-39(44)01	15	15	0.4210	0.3070	0.6333	0.4467	None
SAMA-45(37)01	6	6	0.1977	0.6817	1.3167	2.0833	None
SAMA-520(59)01	12	12	0.2499	0.5130	0.7917	1.0250	None
STP-001-5(60)01	8	8	0.1827	0.1400	0.5625	0.1000	None
STP-9-2(78)01	6	6	1.7617	3.8827	0.7167	-0.1333	None
STP-34-1(22)01	11	11	0.4016	0.5000	-0.3182	-0.4000	None
STP-36-1(13)01	13	13	1.5191	0.6547	1.0077	1.3154	None
STP-803(4)01	7	7	0.2533	1.1114	1.2000	1.0143	None
STP-911(7)01	6	6	0.8987	0.1817	0.3333	0.3833	None
STP-M00-00(703)01	7	7	1.1781	1.1733	0.4143	-0.4000	None
STP-M001-00(273)01	15	15	0.5150	0.2946	0.5267	0.7200	None
STP-M001-00(773)01	7	7	0.4233	0.4029	1.0000	0.6571	None
STP-M002-00(093)01	7	7	0.2562	0.5362	0.9571	0.7571	None
STP-M002-00(114)01	6	6	0.1787	0.2937	-0.0667	-0.3167	None
STP-M002-00(165)01	8	8	0.1927	0.2612	0.3125	0.0875	None
STP-M002-00(175)01	15	15	0.1012	0.6397	0.5533	0.2600	Variability
STP-M002-00(397)01	11	11	0.2227	0.9502	0.5545	-0.0727	None
STP-M001-00(330)01	11	11	0.1849	0.3567	0.0091	-0.2455	None
STP-MOO2-00(115)01	9	9	0.0961	0.1400	-0.0889	-0.0333	None

STP-MOO2-00(252)01	6	6	6.0297	4.0067	-1.0167	-0.8333	None
STP-MOO2-00(395)01	6	6	0.6257	1.5240	0.3167	0.6000	None

Table C-5. Asphalt Content Project by Project Table for QCT versus QA.

Project #	QC	QA	Vqc	Vqa	Mqc	Mqa	Differences
BRN-42-2(40)01	13	6	0.0083	0.0168	0.0569	0.0483	None
CM-186-1(28)01	38	6	0.0370	0.0204	0.0021	0.1550	None
CSSTP-M002-00(444)01	36	9	0.0217	0.0421	0.0011	-0.1222	None
CSSTP-M002-00(453)01	53	7	0.0159	0.0337	0.0225	-0.0457	None
EDS-27(136)01	138	32	0.0159	0.0176	0.0258	0.0094	None
EDS-27(147)01	130	20	0.0102	0.0196	-0.0417	-0.0030	None
EDS-545(8)01	72	9	0.0309	0.0183	0.0275	0.1522	None
EDS-555(6)01	73	15	0.0384	0.1352	0.0403	0.2260	Variances
EDS-565-(15)01	98	15	0.0364	0.0301	0.0040	0.0000	None
EDS-565-(7)01	99	7	0.0233	0.0330	-0.0420	-0.0343	None
EDS84(16)01	130	16	0.0211	0.0298	0.0192	-0.0888	Mean
EDS-84(17)01	65	11	0.0159	0.1757	0.0809	0.1364	Variances
FLF-540(25)01	95	13	0.0189	0.0494	0.0002	0.0315	Variances
FLF-540(28)01	116	10	0.0317	0.0295	0.0391	0.1580	None
FLF-540(8)01	61	8	0.0250	0.0135	0.0816	-0.0300	None
GIP-341(33)01	107	13	0.0248	0.0209	0.0183	-0.1062	Mean
GIP-341(34)01	145	25	0.1082	0.1254	0.1427	0.0468	None
GIP-341(38)01	203	21	0.0845	0.1516	-0.0118	-0.0029	None
HPP-3717-00(300)01	36	16	0.0286	0.0355	-0.0653	-0.0413	None
HPP-STP-178-1(33)01	23	7	0.0363	0.0038	-0.2222	-0.1800	Variances
IM-0000-00(471)01	57	15	0.0396	0.0498	0.0974	0.0660	None
IM-0000-00(472)01	73	10	0.0443	0.0812	0.0164	0.0230	None
IM-00MS(20)01	56	15	0.0546	0.0852	-0.0636	0.0220	None
IM-00MS(268)01	41	14	0.0231	0.0472	0.0463	0.0214	Mean
IM-285-1(349)01	30	8	0.0331	0.1437	-0.0077	0.1963	Variances
IM-MS(325)01	31	7	0.0200	0.0115	-0.0710	0.0757	None
IM-NH-85-2(148)01	175	20	0.0674	0.1105	-0.0145	0.0080	None
LAR00-S005-00(459)01	21	7	0.0336	0.2947	-0.0795	-0.0186	Variances
LAR00-S005-00(593)C1	13	8	0.0689	0.0667	-0.0985	-0.1687	None
LAR00-S005-00(649)C1	13	6	0.0728	0.0382	-0.0062	-0.4367	Mean
LAR00-S005-00(666)C1	8	7	0.0532	0.0372	0.0825	-0.0200	None
LAR31-87-1(067)01	25	7	0.0181	0.0485	-0.0904	-0.0157	None
LAR32-2-3(067)01	18	6	0.0357	0.0412	-0.0661	0.0333	None
LAR32-888-1(089)01	44	12	0.0583	0.0312	-0.0925	-0.0917	None
LAU32-8532-79(121)01	16	6	0.0339	0.1333	0.2031	0.2667	None
NH-012-1(83)01	60	10	0.0353	0.0256	-0.1027	-0.1170	None
NH-017-2(53)01	36	13	0.0464	0.0726	-0.0711	0.0915	None
NH-026-2(81)01	29	9	0.0420	0.0417	-0.0300	-0.0456	None
NH-043-1(49)01	15	6	0.0462	0.0339	0.1200	0.0232	None
NH-11-1(44)01	34	10	0.0732	0.0590	0.0921	-0.0550	None

NH-171-1(4)01	100	8	0.0448	0.0351	-0.0253	-0.0500	None
NH-20-2(183)01	240	29	0.0326	0.0519	-0.0117	0.0179	None
NH-56-1(62)01	53	16	0.0787	0.1061	0.0721	-0.1400	None
NH-75-1(157)01	234	29	0.0584	0.0438	0.0233	0.0093	None
NH-75-1(203)01	180	18	0.0223	0.0314	-0.0245	0.0022	None
NH-8013(8)01	64	15	0.0385	0.0303	0.0587	0.0353	None
NH-IM-75-1(158)	174	21	0.0236	0.0186	-0.0389	-0.0495	None
NH-IM-95-1(119)01	90	14	0.0303	0.0449	0.0006	-0.0493	None
NH-IM-95-1(125)01	142	29	0.0210	0.0223	-0.0182	-0.0152	None
NH-IM-95-1(155)-01	117	12	0.0538	0.0561	0.0549	0.0883	None
NHS-0000-00(768)01	61	8	0.0330	0.0672	0.0631	0.0763	None
NHS-M001-00(530)01	193	9	0.0499	0.0667	-0.0331	-0.0756	None
NHS-M001-00(531)01	59	12	0.0291	0.0241	-0.0478	-0.0733	None
NHS-M001-00(591)01	51	13	0.0554	0.0584	-0.0816	-0.0469	None
NHS-M002-00(276)01	25	8	0.0224	0.0258	-0.0156	0.1525	None
NHS-M002-00(292)01	251	10	0.0425	0.0453	0.0615	0.0040	None
NHS-M002-00(398)01	487	53	0.0388	0.0613	-0.0556	-0.1036	Variances
PR-147-2(055)01	13	9	0.0698	0.1396	0.0223	-0.0133	None
PR-1963-2(139)01	28	6	0.0678	0.0768	0.0239	-0.0400	None
PR-3-3(151)01	21	6	0.0521	0.0305	0.0614	-0.0267	None
PR-8530-83(39)C1	22	10	0.0327	0.0500	-0.0873	0.0960	None
PR-8531-21(77)CT1	49	10	0.0482	0.0981	-0.0059	0.0810	None
PRLOP-8530-32(15)C1	31	11	0.0375	0.0339	0.0587	-0.0236	None
SAMA-155(52)01	18	6	0.0134	0.0294	-0.0983	-0.1617	None
SAMA-206-C0(3)01	70	14	0.0504	0.0327	0.0271	0.1279	None
SAMA-234-(17)01	51	8	0.0111	0.0058	-0.0553	-0.0500	None
SAMA-3(249)01	38	9	0.0264	0.1858	0.0618	0.1167	Variances
SAMA-3(294)01	123	25	0.0123	0.0551	0.1577	0.1488	Variances
SAMA-3(298)01	229	31	0.0579	0.0740	0.0089	-0.0258	None
SAMA-39(44)01	70	18	0.0393	0.0218	-0.0560	-0.1294	None
SAMA-520(58)02	84	18	0.0255	0.0280	0.0692	-0.0117	None
SAMA-520(59)01	144	21	0.0405	0.0416	0.1119	0.0352	None
SAMA-53(133)01	34	6	0.0175	0.0062	-0.0729	-0.0350	None
SAMA-60(5)01	50	10	0.0546	0.0628	-0.0544	-0.0580	None
SAMA-74(56)01	25	9	0.0346	0.0646	0.0312	0.0911	None
SAMA-74(58)01	121	27	0.0402	0.0089	-0.0235	-0.0867	Variances
SAM-M002-00(399)01	23	7	0.0381	0.0922	-0.0026	0.1200	None
SAM-M002-00(405)01	40	6	0.0202	0.0426	0.0015	-0.0550	None
SAM-M002-00(417)01	46	7	0.0209	0.0386	0.0654	-0.1143	Mean
SAM-M002-00(422)01	64	17	0.0261	0.1004	0.0548	0.1988	Variances
STP-001-5(60)01	37	9	0.0367	0.0196	-0.0895	0.0267	None
STP-042-2(49)01	82	8	0.0386	0.0438	0.1521	0.0100	None
STP-141-1(7)-01	36	21	0.0274	0.0346	0.0008	0.0524	None
STP-149-1(29)01	62	8	0.0454	0.1082	0.0218	-0.1037	None
STP-2434(2)01	14	6	0.0161	0.0208	0.0814	0.0867	None
STP-34-1(22)01	89	14	0.0159	0.0192	0.0201	0.1157	None
STP-36-1(13)01	49	15	0.0531	0.0564	-0.0463	-0.0660	None

STP-4067(2)02	98	7	0.0275	0.0251	0.0756	0.1243	None
STP-5121(3)01	34	7	0.0088	0.0094	0.1921	0.2071	None
STP-803(4)01	73	17	0.0222	0.0238	-0.0025	0.0135	None
STP-9-2(78)01	29	12	0.0120	0.0221	-0.0293	0.0258	None
STP-9-2(90)01	22	8	0.0221	0.0205	0.0732	0.1100	None
STP-M00-00(703)01	53	9	0.0208	0.0257	0.0740	-0.0056	None
STP-M001-00(273)01	100	18	0.0298	0.0227	0.0087	-0.1083	Mean
STP-M001-00(330)01	88	14	0.0437	0.0318	0.0102	-0.0286	None
STP-M001-00(490)01	25	6	0.1374	0.1993	0.1120	0.1667	None
STP-M001-00(492)01	54	13	0.0125	0.0160	-0.0256	-0.0508	None
STP-M001-00(493)01	121	13	0.0185	0.0315	-0.0264	-0.0169	None
STP-M001-00(773)01	76	9	0.0175	0.0438	0.0080	0.0344	None
STP-M001-00(872)01	77	7	0.0164	0.0225	0.0522	0.1257	None
STP-M002-00(093)01	45	7	0.0075	0.0206	0.0602	0.1200	None
STP-M002-00(114)01	60	6	0.0109	0.0267	0.0560	0.0583	None
STP-M002-00(115)01	73	10	0.0088	0.0155	-0.0026	-0.0070	None
STP-M002-00(116)01	51	11	0.0111	0.0109	0.0408	0.0409	None
STP-M002-00(154)01	80	13	0.1161	0.3721	0.0769	0.0223	Variances
STP-M002-00(155)01	44	7	0.0212	0.0396	0.0116	-0.1457	None
STP-M002-00(165)01	118	10	0.0089	0.0142	0.0168	-0.0350	None
STP-M002-00(169)01	32	6	0.0157	0.0241	-0.1112	0.0583	Mean
STP-M002-00(173)01	20	7	0.0223	0.0559	0.0745	0.0514	None
STP-M002-00(232)01	33	12	0.0652	0.0598	-0.0370	0.0317	None
STP-M002-00(236)01	32	7	0.0315	0.0210	0.1131	0.1000	None
STP-M002-00(395)01	68	13	0.0414	0.0199	-0.0060	0.1046	None
STP-M002-00(397)01	93	15	0.0240	0.0230	-0.0260	0.1087	Mean
STP-M002-00(92)01	44	8	0.0315	0.0970	-0.1477	-0.0813	None

Table C-6. Asphalt Content Project by Project Table for Comparison Tests.

Project #	Nqc	Ndot	Vqc	Vdot	Mqc	Mdot	Differences
CM-186-1(28)01	7	7	0.0518	0.0861	-0.0886	-0.0371	None
CSSTP-M002-00(444)01	6	6	0.0218	0.0603	-0.0983	-0.3000	None
EDS-27-(136)01	8	8	0.0231	0.0600	0.0038	-0.0062	None
EDS-27(147)01	16	16	0.0149	0.0345	0.0044	0.0762	None
EDS-84(16)01	7	7	0.0344	0.0370	0.0371	0.0071	None
EDS-84(17)01	11	11	0.0201	0.0085	0.1382	0.0918	None
EDS-555(6)01	7	7	0.1698	0.2422	0.1357	0.1857	None
GIP-341(34)01	14	14	0.1124	0.1143	0.2129	0.1757	None
GIP-341(38)01	8	8	0.0593	0.1549	0.1225	0.1350	None
IM-MS(325)01	6	6	0.0153	0.0566	-0.0467	-0.2750	None
IM-NH-85-2(148)01	11	11	0.2703	0.3765	0.1336	0.2991	None
NH-20-2(183)01	7	7	0.0534	0.0363	-0.0257	-0.0757	None
NH-56-1(62)01	8	8	0.0946	0.1336	-0.0113	0.0025	None
NH-75-1(157)01	24	24	0.0362	0.0942	-0.0092	0.0250	None
NH-75-1(203)01	18	18	0.0230	0.0299	-0.0183	0.0128	None
NH-IM-75-1(158)	24	24	0.0455	0.0591	-0.1304	-0.0933	None
NH-IM-95-1(119)01	7	7	0.0142	0.0561	-0.0486	0.0814	None
NH-IM-95-1(125)01	15	15	0.0197	0.0663	0.0060	-0.0507	None
NH-IM-95-1(155)-01	10	10	0.0447	0.0442	0.0650	0.1710	None
NHS-M002-00(398)01	29	29	0.0374	0.0773	-0.1055	-0.1072	None
NHS-M001-00(530)01	18	18	0.0713	0.2855	0.0811	0.1372	Variances
PR-8530-83(39)C1	6	6	0.0489	0.0527	-0.0050	-0.0100	None
SAMA-39-(44)01	15	15	0.0072	0.0262	-0.0447	-0.1393	None
SAMA-206-CO(3)01	9	9	0.0393	0.1971	0.1389	0.3544	None
SAMA-520(59)01	12	12	0.0529	0.0514	-0.0025	0.0383	None
STP-037-2(60)01	11	11	0.1184	0.2392	-0.1364	-0.0755	None
STP-9-2(78)01	6	6	0.0179	0.0190	-0.0683	-0.0600	None
STP-34-1(22)01	11	11	0.0214	0.0368	0.0055	0.0164	None
STP-36-1(13)01	13	13	0.0525	0.1435	-0.0008	0.1223	None
STP-803(4)01	7	7	0.0305	0.0742	-0.0629	-0.1957	None
STP-M00-00(703)01	7	7	0.0270	0.0287	0.0529	-0.0471	None
STP-M001-00(273)01	15	15	0.0156	0.0344	-0.0167	-0.1027	None
STP-M001-00(330)01	11	11	0.0643	0.0340	0.0691	0.0736	None
STP-M001-00(773)01	8	8	0.0100	0.0377	0.0675	0.0750	None
STP-M002-00(093)01	7	7	0.0199	0.0128	0.0571	0.0986	None
STP-M002-00(114)01	6	6	0.0111	0.0928	0.0383	0.0000	None
STP-M002-00[116]01	6	6	0.0063	0.0078	0.1000	0.0783	None
STP-M002-00(165)01	8	8	0.0063	0.0093	0.0437	-0.0250	None
STP-M002-00(175)01	15	15	0.0229	0.0440	0.0140	0.0920	None
STP-M002-00(397)01	11	11	0.2125	0.2669	-0.1718	0.0227	Means
STP-M002-00(115)01	7	7	0.0031	0.0200	-0.0257	-0.0357	None

APPENDIX D

PROJECT BY PROJET ANALYSIS SCATTERPLOTS

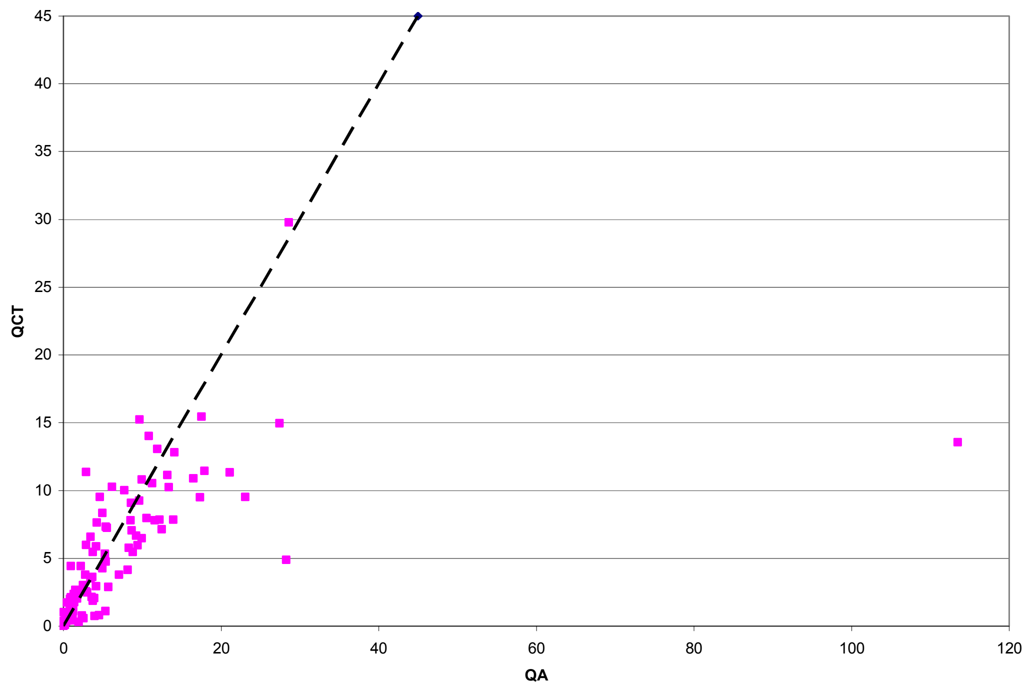

Figure D-1. Project by Project Variances for ½" Sieve QCT versus QA.

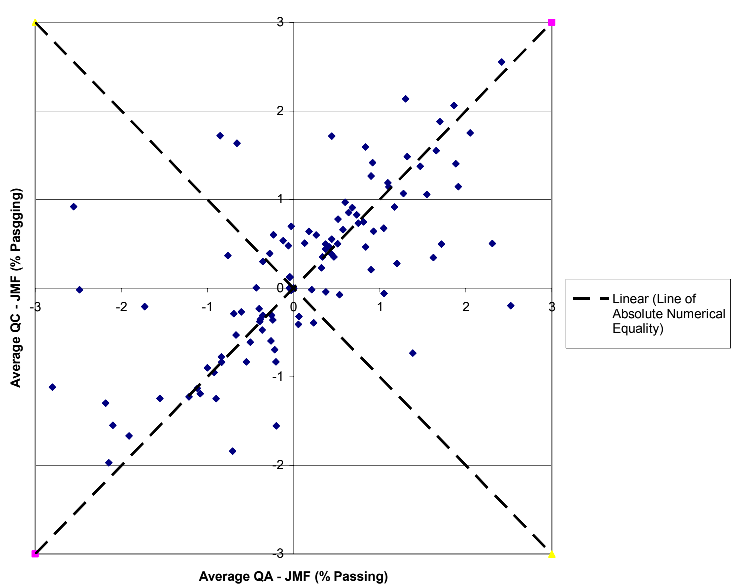

Figure D-2. Project by Project Average Means for ½" Sieve QCT versus QA.

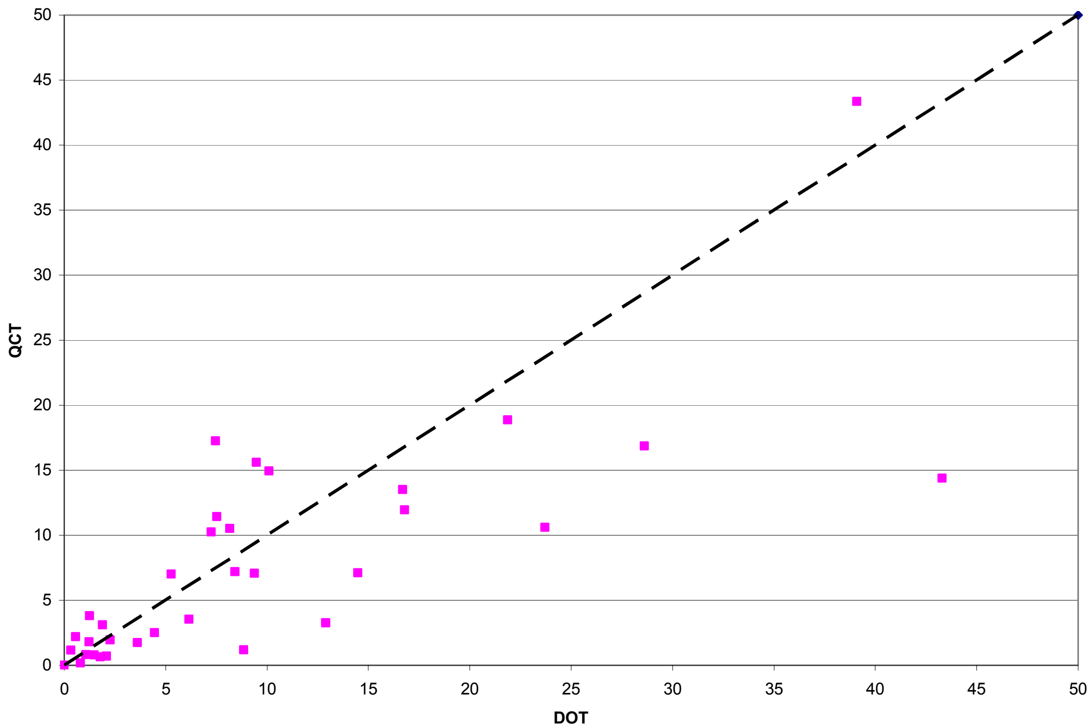

Figure D-3. Project by Project Variances for ½” Sieve for Comparison Tests.

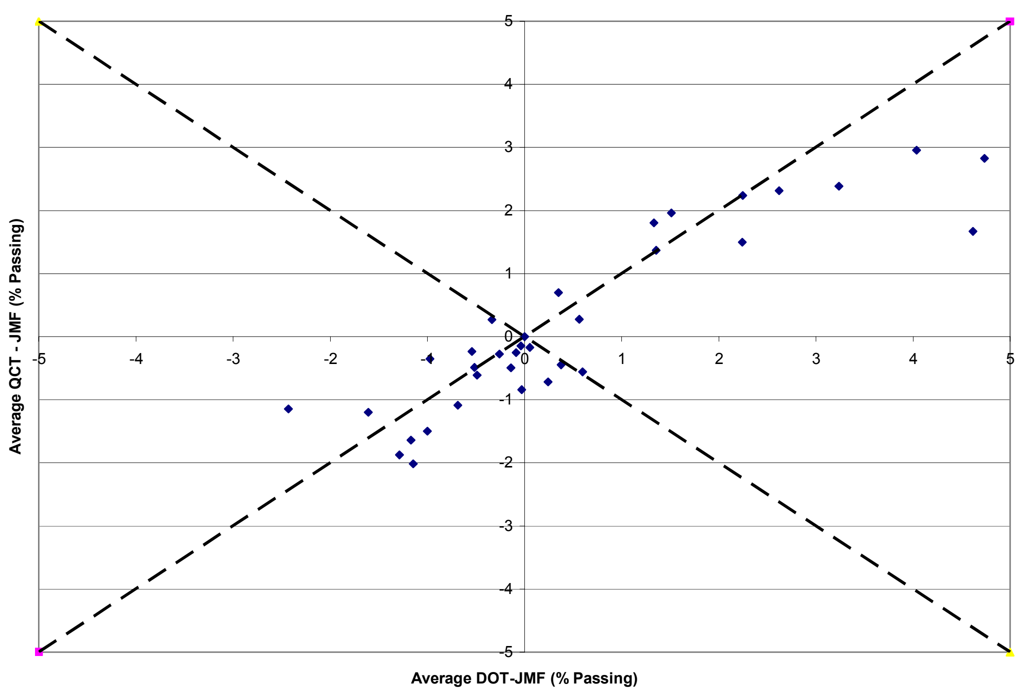

Figure D-4. Project by Project Means for ½” Sieve for Comparison Tests.

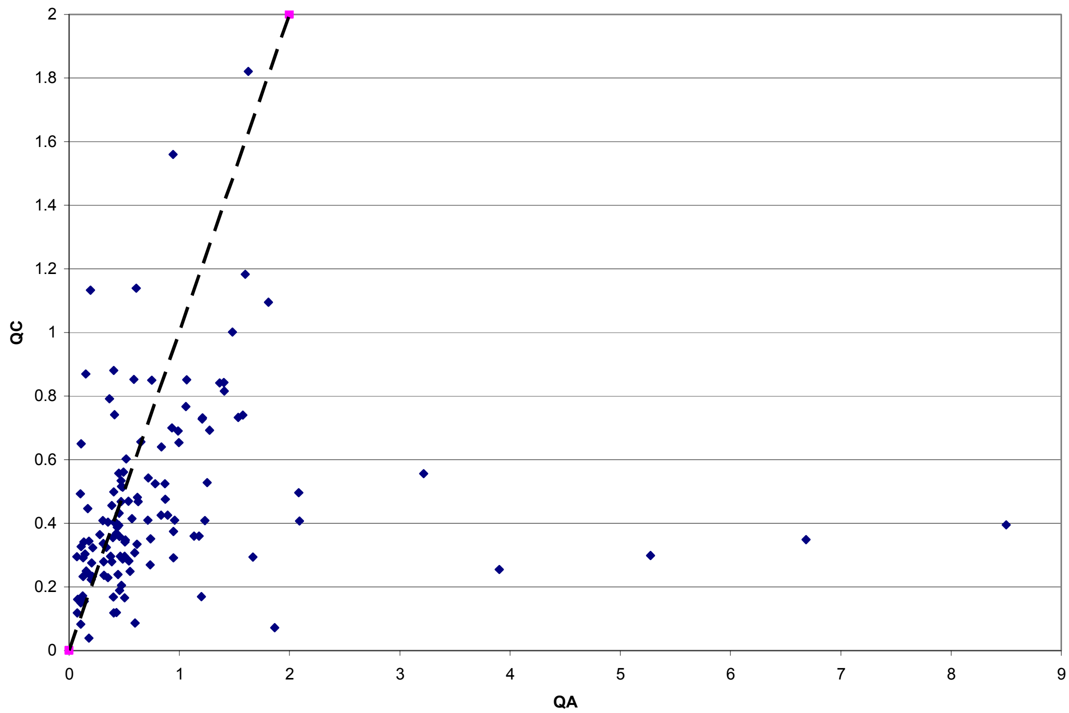

Figure D-5. Project by Project Variances for #200 Sieve QCT versus QA.

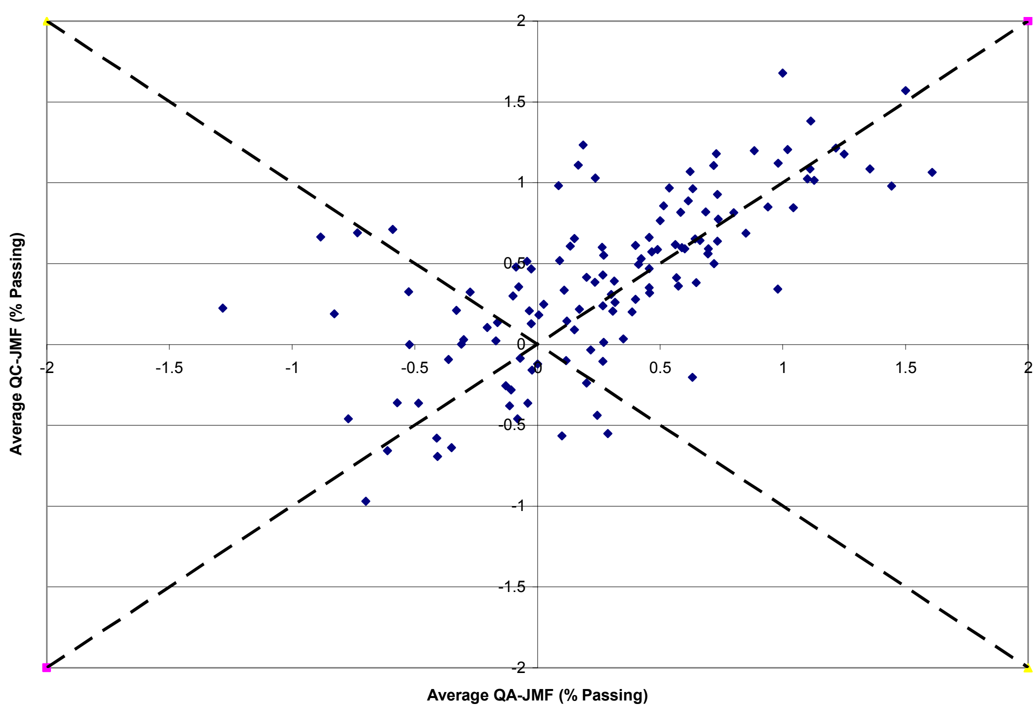

Figure D-6. Project by Project Average Means for #200 Sieve QCT versus QA.

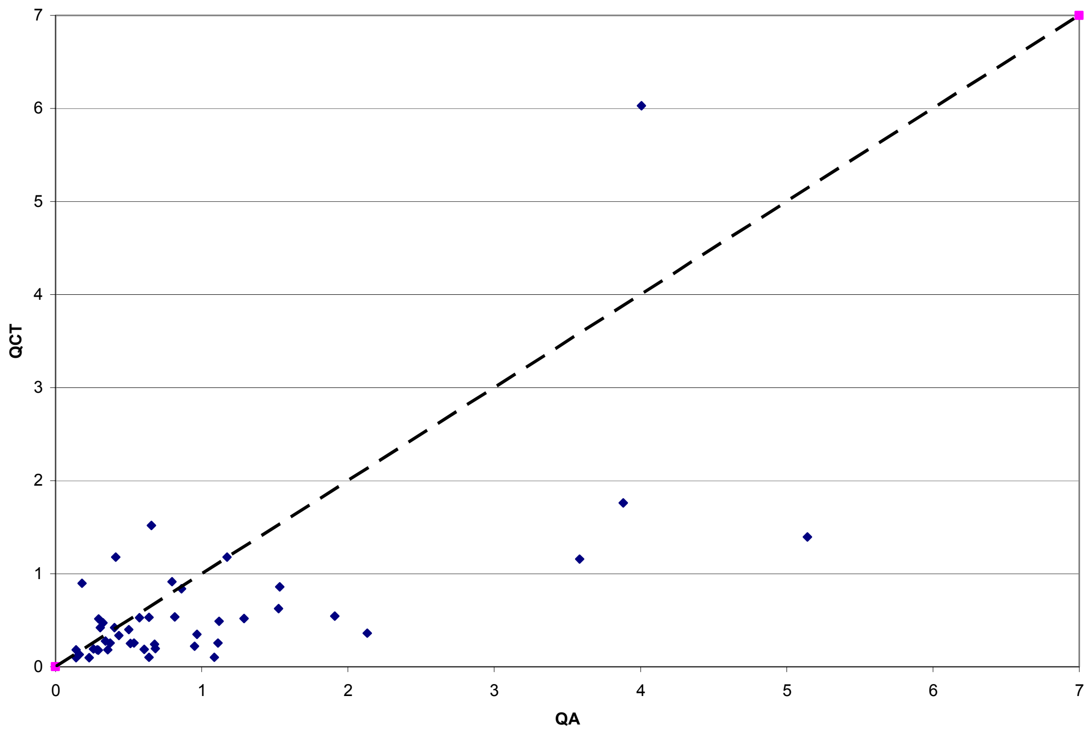

Figure D-7. Project by Project Variances for #200 Sieve Comparison Tests.

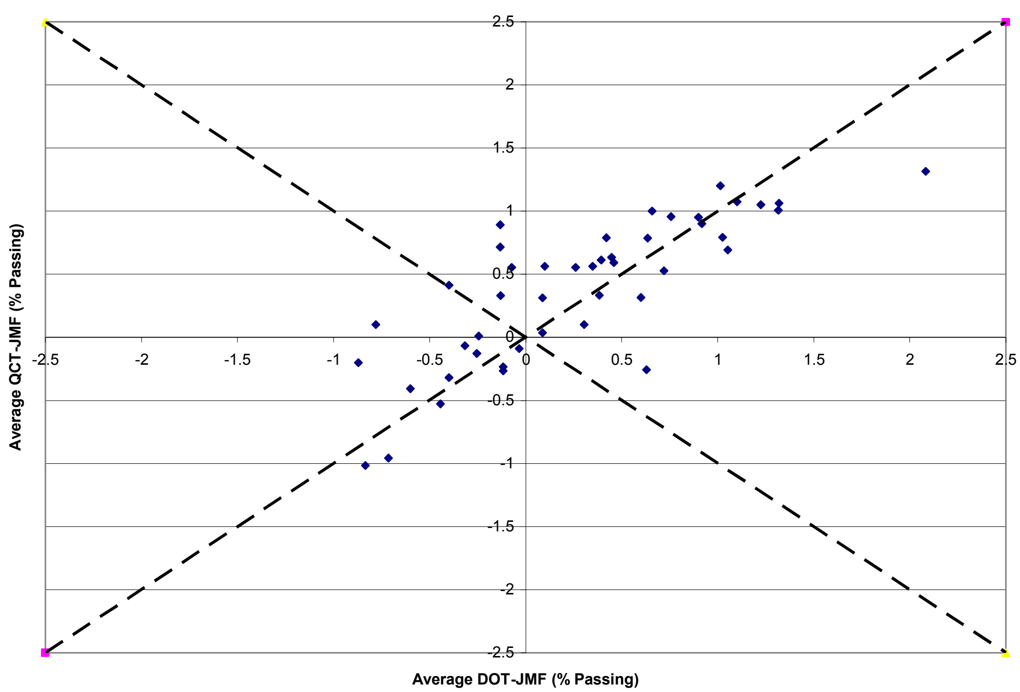

Figure D-8. Project by Project Average Means for #200 Sieve Comparison Tests.

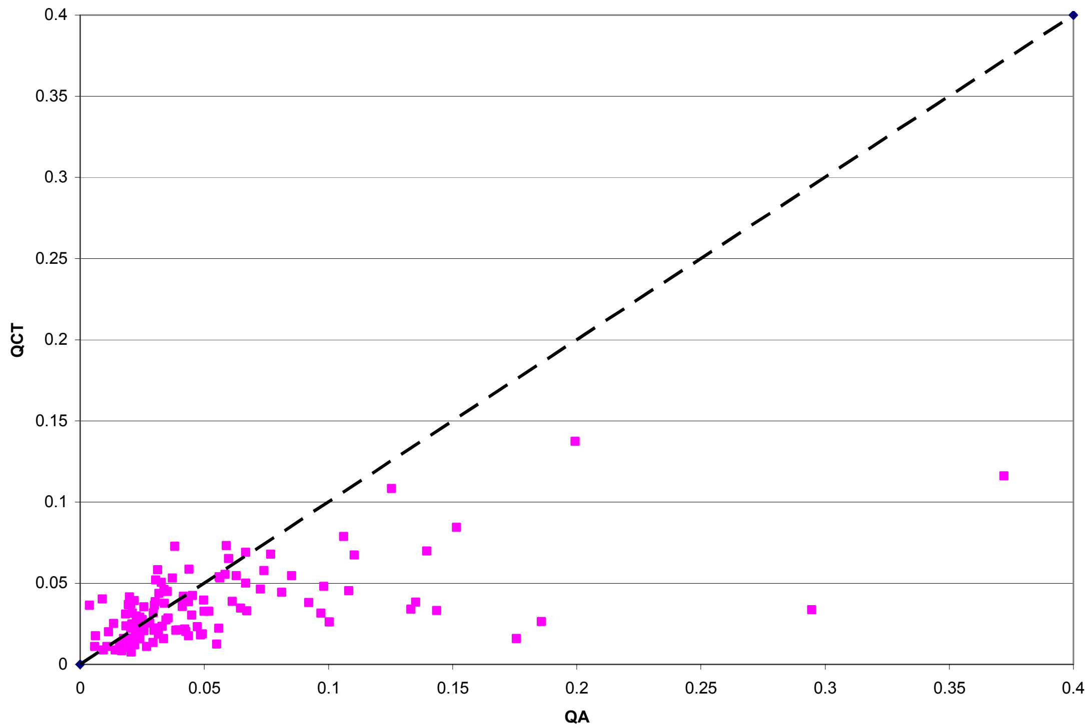

Figure D-9. Project by Project Variances for Asphalt Content QCT versus QA.

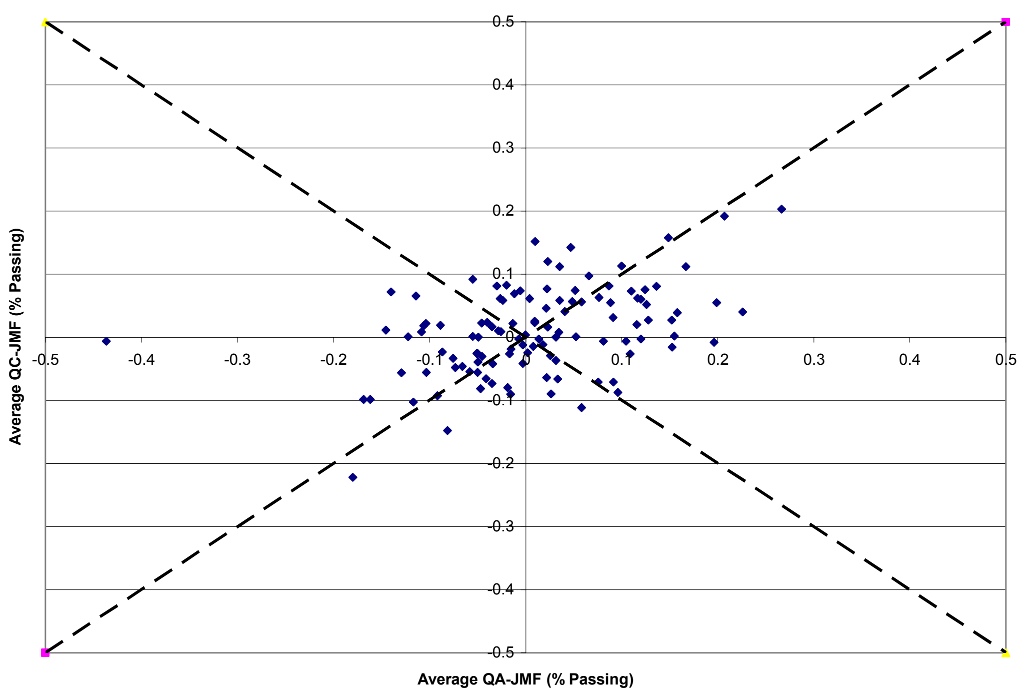

Figure D-10. Project by Project Average Means for AC for QCT versus QA.

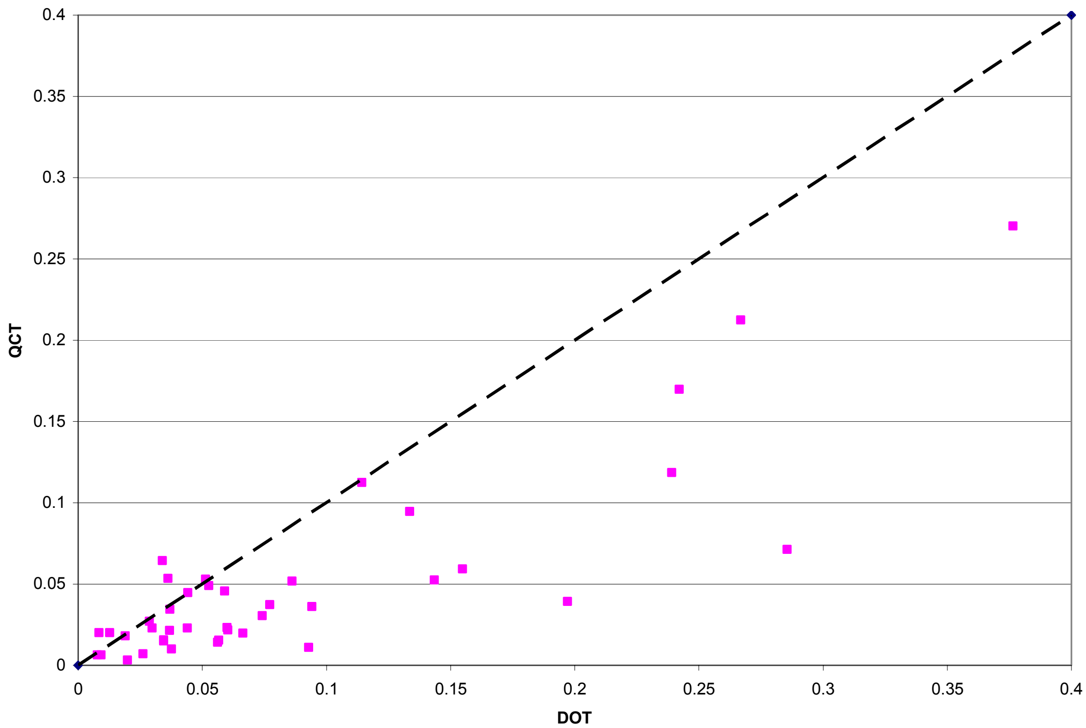

Figure D-11. Project by Project Variances for AC for Comparison Tests.

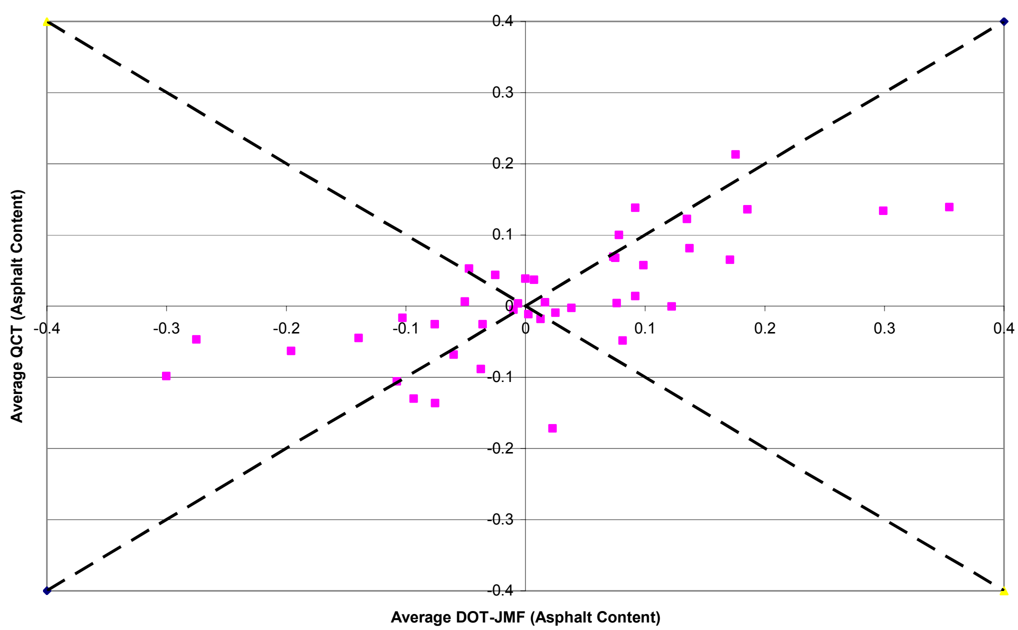

Figure D-12. Project by Project Average Means for AC for Comparison Tests.