AN INITIAL EVALUATION OF THE WSDOT QUALITY ASSURANCE SPECIFICATIONS FOR ASPHALT CONCRETE

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16. ABSTRACT

The Washington State Department of Transportation (WSDOT) did a trial implementation of a quality assurance (QA) specification for asphalt concrete during the 1989 paving season. To assess the QA specification, data from both non-QA and QA projects built that year were compared. Based on these results, the QA projects were evaluated as having improved quality. Subsequently, the QA specification was fully implemented within WSDOT.

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CHAPTER 1

BACKGROUND

1. INTRODUCTION

The trend in highway pavement specifications over the last decade has been to implement quality assurance (QA) specifications that are based on the statistical analysis of product samples to ensure quality control. Because such specifications are designed to remove bias from the inspection and acceptance of the product, while ensuring a predictable level of quality, the Washington State Department of Transportation (WSDOT) elected to implement QA specifications for several asphalt concrete (AC) paving projects during the 1989 paving season. After it received positive responses from both contractors and state employees, WSDOT continued to utilize QA specifications on subsequent projects. The purpose of this report is to determine and evaluate any initial changes in pavement quality associated with the change to QA specifications, and to make recommendations regarding WSDOT's continued use of QA specifications.

2. THEORY OF STATISTICALLY BASED QUALITY ASSURANCE

Statistically based QA specifications are based on estimates of the quality of a product "lot" that are derived from the characteristics of samples or sublots randomly selected from that lot. The following concepts are key to the understanding of QA specifications and their application to AC paving:

- Each process associated with the production and placement of AC pavement has an inherent variability that is due to variations in material, equipment, and procedures.

- It is not possible (at least for a reasonable cost) to produce an AC pavement that is entirely within all specification parameters 100 percent of the time because of the inherent variability in processes and products.

- By using QA specifications, both the buyer and the seller must make decisions about the quality of a large quantity of inherently variable product, the lot, on the basis of a small amount of inherently variable material, the sample. This decision is complicated by the additional inherent variability in sampling and testing procedures.

In other words, the inherent variability in construction materials and processes is compounded by the procedure of statistically extrapolating product characteristics from small samples to large lots. Two types of errors can result from this process. If a buyer decides to reject a material lot produced by the seller when in fact the product meets the acceptance criteria, the buyer makes a "Type I" error. The probability of making this type of error is generally called the "seller's risk" and is symbolized by the Greek letter alpha (α). Conversely, if the buyer accepts a material lot from the seller when in fact the lot fails to meet the acceptance criteria, the buyer makes a "Type II" error. The probability of making this type of error is generally referred to as the "buyer's risk" and is symbolized by the Greek letter beta (β). A more detailed explanation of this theory, called "hypothesis testing," can be found in most probability and statistics texts.

Specific relationships exist between seller's risk, buyer's risk, and the number of samples selected from each lot in a QA plan. First, if the sample size remains the same, the seller's risk increases as the buyer's risk decreases. Likewise, for a fixed sample size, the buyer's risk increases when the seller's risk is reduced. However, increasing the number of samples taken reduces both types of risk simultaneously because that will allow a more accurate estimate of the true characteristics of the lot. [1]

In developing QA specifications, the relationships between risk and sample size become a tradeoff between economics and quality. For a given sample size, keeping the buyer's risk low reduces the chance of accepting substandard product. There is a cost tradeoff, however, since the seller must charge more to compensate for the greater chance that acceptable material will be rejected. Keeping the seller's risk low means that the seller can charge a lower price the product, since the chance of having good material wrongly rejected is reduced. However, the buyer's risk increases with the greater probability of acceptance of an unacceptable product lot. This situation costs money over time because of increased pavement maintenance costs and the need for earlier pavement replacement or rehabilitation. Both types of risk can be reduced by increasing the number of tests per lot, but the tradeoff is the increased cost of sampling and testing. Because a primary goal of QA specifications is to achieve a quality product at an economical price, these tradeoffs become important factors in determining the proper QA specification for a given application.

3. HISTORY OF STATISTICALLY BASED QUALITY ASSURANCE

The theory of quality assurance through statistical analysis is not new. In 1957, the Department of Defense implemented Military Standard 414 (MIL-STD-414), "Sampling Procedures and Tables for Inspection by Variables for Percent Defective," to standardize sampling plans for inspection by variables in government procurement, supply, storage, and maintenance inspection operations. [2] Detailed procedures are outlined in MIL-STD-414 for developing sampling plans for both single and double limit specifications by using either sample ranges or sample standard deviations of test lots to estimate a level of quality. With a variables inspection plan, lots are accepted, rejected, or accepted with an adjustment in price on the basis of an allowable estimated percentage of defective. Although variables acceptance plans are limited to evaluating only one quality variable at a time, such as the percentage of aggregate that passes a certain sieve or the density of in-place pavement, they are effective at projecting the quality of a relatively large material lot on the basis of the statistical evaluation of a relatively small sample size. [3] Because of this, inspection by variables has become the basis for the majority of QA paving specifications in use today, including the AC specification evaluated in this report.

An alternative method of QA was implemented by the federal government in 1963 with MIL-STD-105D, "Standard Procedures and Tables for Inspection by Attributes." [4] It outlines plans to accept or reject product lots on the basis of the individual quality of a specified number of samples from that lot. The major advantage of this type of acceptance plan over a variables acceptance plan is that a simple "pass" or "fail" decision for each sample is all that is required to evaluate quality, regardless of the number of quality variables involved. For example, a sample of AC pavement could be evaluated for gradation and asphalt content simultaneously. If all the parameters were within acceptable limits, the sample would pass; if not, it would fail. However, a major disadvantage of this method is that a greater number of samples are required per lot to get the same level of quality assurance predicted by a variables QA plan. [5]

With the increased use and acceptance of QA specifications in industrial and manufacturing process control, the theory was logically extended to construction processes involving a continuous product, such as paving. In 1976, a two volume publication titled "Statistical Quality Control of Highway Construction" was prepared for the U.S. Department of Transportation Federal Highway Administration which provides insight into the theory and development of statistically based QA specifications. [6] Volume 1 provides information on basic statistical parameters and processes required to understand a QA program, and Volume 2 introduces the principles needed to actually develop and use such a plan. A third publication by the U.S. Department of Transportation, titled "Demonstration Project #42-Highway Quality Assurance, Process Control and Acceptance Plans," further discusses the development and implementation of QA specifications in highway paving. [7] This publication, along with Volumes 1 and 2 of "Statistical Quality Control of Highway Construction" may be consulted for a more detailed discussion of statistically based QA specifications.

A significant number of states have implemented QA specifications to achieve a desired level of quality at an economical cost. The most thorough evaluation of these specifications was conducted in 1989 as part of a detailed review of the Arizona Department of Transportation's "Quality Assurance Asphalt Concrete Specification." [8] This report summarizes ten state and federal QA specifications and provides, a detailed analysis of Arizona's QA specification with respect to testing, product variability, specification limits, and pay adjustment factors. It is important to note that no two QA specifications addressed in the report are the same. From similar diversity, WSDOT prepared its QA specification for AC paving in 1989.

4. STATEMENT OF THE PROBLEM

In the late 1980s, WSDOT began implementing statistically based QA specifications for AC pavement with the hopes of economically removing bias from the inspection and acceptance process, while maintaining or improving pavement quality at an economical cost. As the first step to implementing the program, WSDOT awarded several test AC paving contracts in 1989. The contractors were to utilize statistically based QA specifications of the inspection by variables type. A decision to convert WSDOT's entire AC paving program to QA specifications was to be based on the outcome of these jobs. The decision would be based upon the answers to the following questions:

- What effect would a QA specification have on the overall quality and consistency of in-place pavement?
- Would the local contractors (and to a lesser extent, the state inspectors and engineers) be receptive to a change to QA specifications?
- What effect would QA specifications have on the cost per ton of in-place AC pavement?
- Would the QA specification chosen be suitable for use, considering regional product characteristics?

The problem facing WSDOT was to obtain answers to these questions from the results of the test contracts. Depending upon the answers, the state could logically decide whether to implement the QA specifications without change, implement a modified version of the QA specifications, or not change to QA specifications at all.

5. REPORT PURPOSE

The purpose of this report is to

- evaluate the effects of the proposed QA specifications on the overall quality and consistency of in-place AC,

- determine the suitability of the statistical portion of the QA specifications with respect to regional materials and pavement product, and
- provide recommendations regarding the implementation of QA specifications.

CHAPTER 2

OVERVIEW OF WSDOT QA SPECIFICATIONS FOR AC PAVING

1. INTRODUCTION

To convert its AC paving specifications to statistically based QA specifications, WSDOT added a supplemental specification section titled "Statistical Evaluation of Materials for Acceptance," included as Appendix A of this report. The goal of this new section was to outline a non-biased, step-by-step procedure for sampling AC mix and in-place density, then convert these test data into a composite pay factor based on the statistically estimated quality of each lot. With the specifications selected, a contractor could earn a bonus for superior quality control during the production of AC mix only to lose it for poor placement practices, or vice versa. Only when both the mix production and placement were of high quality could the maximum pay incentive be earned. To help contractors accomplish this, the specification was separated into three areas: collection of sample data, statistical evaluation of sample data, and determination of price adjustments.

2. COLLECTION OF SAMPLE DATA

The specification calls for WSDOT to collect all samples and perform all testing. Random sample locations are based on random number tables, and tests are conducted by WSDOT employees using WSDOT equipment and facilities. Two products, uncompacted AC mix and in-place AC pavement, are subject to sampling and testing under the specification.

Uncompacted asphalt concrete mix samples are to be randomly selected from the hauling trucks. One sample, or sublot, per each 800 tons of product is required, and it may not be taken from the first or last 25 tons of a production shift. A lot is defined as the total product produced for each mix design, which is also referred to as the job mix formula. Therefore, lot sizes are variable.

Samples of AC mix must be prepared using the quick extraction method (WSDOT TM 711). As of 1993, the nuclear asphalt content gage is used in lieu of the quick extraction method. Aggregate gradation and asphalt content are thus determined and subject to statistical evaluation by the specifications.

In-place compacted asphalt concrete must be evaluated with randomly located, nuclear density tests to determine the percentage of Rice density. Each test represents one sublot of material. Five tests, each a sublot, are required per lot. Each day's production, or 400 tons, whichever is less, defines a lot. Therefore, lot sizes are variable.

3. STATISTICAL EVALUATION OF SAMPLE DATA

The goal of statistically analyzing the test data is to develop an accurate estimate of the quality of each lot of pavement on the basis of the observed quality of the sample test data. The variables acceptance plan used in WSDOT's QA Specification is based on, but not identical to, the variability unknown, double specification limit, standard deviation method presented in MIL-STD-414. This procedure is based on the premise that the product sampled conforms to a normal distribution, a premise that will be evaluated in Chapter 3 of this report.

Because only one variable can be analyzed at a time with variables inspection plans, seven aggregate sizes, asphalt content, and density are each subjected to statistical analysis in WSDOT's QA Specifications. This analysis consists of two phases: calculation of statistical parameters for each lot constituent on the basis of sample results, and the determination of estimated quality levels for each constituent analyzed. The examples that follow are based on Lot 2 of QA Project 3522. The parameter used in the example is 3/8-inch aggregate. A summary of the values for all of Lot 2 is shown in Table 2.1.

Table 2.1. Sample Evaluation, Lot 2, Project 3522 - Aggregate and Asphalt Data

ITEM:	1/2"	3/8"	1/4"	#10	#40	#200	AC
fi:	2	2	6	10	6	20	52
USL:	*100	90	70	44	21	*7.0	5.7
JMF:	96	83	64	39	17	5.8	5.2
LSL:	90	75	58	34	13	3.8	4.7
SUBLOT							
1	97	86	68	40	18	5.5	5.2
2	95	84	65	39	17	6.1	5.1
3	97	85	66	39	17	5.1	5.1
4	99	87	70	44	19	6.4	5.2
5	96	86	69	41	19	6.5	5.3
6	96	87	63	37	16	4.4	5.2
7	97	85	68	41	19	5.7	5.1
8	98	82	64	39	19	6.3	4.9
9	97	83	62	35	17	5.0	5.1
10	98	91	74	44	19	6.5	5.4
SUM x:	970	856	669	399	180	57.5	51.6
n:	10	10	10	10	10	10	10
MEAN:	97.00	85.60	66.90	39.90	18.00	5.75	5.16
s:	1.15	2.50	3.63	2.81	1.15	0.73	0.13
Q_u:	2.61	1.76	0.85	1.46	2.61	1.71	4.15
Q_L:	6.09	4.24	2.45	2.10	4.35	2.67	3.54
P_u:	100	97	80	94	100	97	100
P_L:	100	100	100	99	100	100	100
QL:	100	97	80	93	100	97	100
PF:	1.05	1.04	0.98	1.03	1.05	1.04	1.05

* Spec. ranges defined in Appendix A are limited by WSDOT's broad band specification limits. (Section 9-03.8 (6))

NOTE: All 5/8" samples were 100% passing for a pay factor of 1.05 and an adjusted pay factor (A.PF.)= 2.100.

3.1 Determination of Statistical Parameters

As the first step in statistically analyzing the sample test data, the arithmetic mean and sample standard deviation for each lot are calculated from the test results for each sublot. These sample parameters become the basis for the rest of the evaluation procedure.

Example: Calculation of statistical parameters for 3/8-inch aggregate:

Mean $= \bar{x} = (\Sigma x)/n$

$= 856/10$

$= \underline{85.60}$

Standard Deviation $= s = 2.50$

3.2 Determination of Quality Levels

The specification defines the quality level as the total percentage within the specification limits. In reality, it is an estimate of the quality of the entire lot extrapolated from the sample test data, with a built-in adjustment to account for this fact. The procedure used in the WSDOT QA Specification differs slightly from that used in MIL-STD-414, since the MIL-STD bases its estimate of quality on the percentage defective, rather than the percentage within the specification limits. WSDOT's estimate of quality is determined in three steps.

Step 1

The upper and lower quality indexes (Q_U and Q_L) are calculated from the specification limits, the lot mean, and the lot standard deviation. These values represent the increments under the sample distribution curve in terms of the sample standard deviation between the upper specification limit and the lot mean, and the lower specification limit and the lot mean. This step is identical to that found in MIL-STD-414.

Note that as the sample standard deviation decreases, the upper and lower quality indexes increase.

Example: Calculation of upper quality index (Q_u) and lower quality index (Q_L) for 3/8-inch aggregate:

$$Q_u = \frac{(USL - \bar{x})}{s} \qquad Q_L = \frac{(\bar{x} - LSL)}{s}$$

$$= \frac{(90-85.60)}{2.5} \qquad = \frac{(85.60-75)}{2.50}$$

$$= \underline{1.76} \qquad = \underline{4.24}$$

Step 2

An estimate of the percentage within the upper and lower specification limits (P_U and P_L) is obtained from WSDOT QA Specification Table 1 by using the quality indexes calculated in Step 1. WSDOT QA Specification Table 1, shown in Appendix A, is derived from Table B-5 in MIL-STD-414. It converts the quality indexes into estimates of percentage within specification limits. This is the opposite of Table B-5 in MIL-STD-414, which gives the estimates in terms of percentage defective. A second variable, n, the number of sample test values used to determine the quality levels, is also required to enter both tables. Because the sample mean and standard deviation used to calculate the quality indexes are also dependent on n, adjustments had to be incorporated into the development of Table B-5 in MIL-STD-414 for the estimates to be accurate. The mathematics behind the development of Table B-5 in MIL-STD-414, and thus WSDOT Specification Table 1, are beyond the scope of this report. [9] Note, however, that as n increases, the sample mean improves as an estimate of the lot population mean, and the buyer's and seller's risks tend to decrease.

Example: Determination of the percentage within the upper and lower specification limits (P_u and P_L) for 3/8-inch aggregate:

From WSDOT QA Specification Table 1:
($n=10$, $Q_u = 1.76$, $Q_L = 4.24$)

P_u = <u>97</u>

P_L = <u>100</u>

Thus, three percent of the lot is estimated to be "defective" (another way of saying 97 percent is within specification). Table 1 in the WSDOT QA Specification is similar to the figure in Duncan [13] which relates fraction defective ($\hat{p}$), sample size (n), and z (same as Q_u or Q_L). (The specific figure in Duncan is Figure 12.3, p. 274.) If, for example, the standard deviation (3/8" aggregate) for the lot was say 1.25 instead of 2.50, then

$$Q_u = \frac{90-85.60}{1.25} = 3.52$$

and $P_u = 100$

Thus, the PF = 1.05 (in lieu of 1.04). This illustrates that low variability production (low s) can, to some degree, overcome out of specification test results.

It should be noted that Table 1 in the WSDOT QA Specification has nothing to do with <u>risk</u> (for either WSDOT or the contractor). Table 1 is simply a way of estimating the percent of a lot within the specification limits based on a given sample of tests on that lot.

<u>Step 3</u>

An estimate of the quality level, which represents an estimate of the percentage of the lot's material that is within all the specification limits, is calculated by subtracting 100 from the percentage within the upper specification limit plus the percentage within the lower specification limit. This differs from the procedure outlined in MIL-STD-414, which adds the percentage outside the lower specification limit to the percentage outside the upper specification limit to obtain an estimate of the total percentage defective.

Example: Calculation of quality level (QL) for 3/8-inch aggregate:

$$QL = P_U + P_L - 100$$
$$= 97 + 100 - 100$$
$$= \underline{97}$$

4. DETERMINATION OF PRICE ADJUSTMENTS

Once the raw statistical data have been obtained and converted to an estimate of the lot's quality, the estimated QL is used to adjust the bid price per ton of in-place AC. This is a four phase process that consist of

- obtaining pay factor values,
- determining composite pay factors,
- calculating compliance incentive factors, and
- calculating a final price adjustment.

These steps differ from those outlined in MIL-STD-414, which concludes the analysis by comparing the percentage defective estimated for the lot to an upper limit of allowable percentage defective based on a given acceptable quality level (AQL). The AQL is further defined in Appendix C of this report.

4.1 Obtaining Pay Factor Values

Pay factor (PF) values are obtained for each lot variable from WSDOT QA Specification Table 2, shown in Appendix A. To use Table 2 and determine the PF, the QL and sample size, n, must be known.

Example: Determination of the Pay Factor (PF) Value for 3/8-inch aggregate:

From WSDOT QA Spec. Table 2: (n=10, QL = 97)

PF = <u>1.04</u>

The AQL is defined in Appendix C as the lowest level of quality WSDOT would consider acceptable as a process (or production) average. By use of MIL-STD-414 (Table B-3) and Table 2 in the WSDOT QA Specification, it appears that full pay (PF = 1.00) could be given to the contractor for <u>average</u> out of specification percentages ranging from 5 to 9 percent (depends on lot sample size - higher sample sizes result in lower AQLs). This "tolerance" on the part of WSDOT simply recognizes that zero out of specification average production is unrealistic for the purpose of compensating the contractor.

4.2 Determination of Composite Pay Factors (CPFs)

The purpose of CPFs is to combine the pay factor values determined for each variable into a composite factor that represents the entire lot. Weighted price adjustment factors are utilized to give more importance to the more critical constituents, such as asphalt content. For each compaction control lot, the composite pay factor is calculated with a weighted price adjustment factor of 1, making the composite pay factor equal to the pay factor value for density.

Example: Determination of the lot composite pay factor (CPF):
(see Table 2.1 for additional pay factors):

a. Obtain f from the pay adjustment table in the specifications.

b. CPF = [f1(PF1)+f2(PF2)+fi(PFi)]/(Σfi)

CPF = 104.16/100 = 1.04

Where:

ITEM:	fi:	PF:	fi(PF)
5/8"	2	1.05	2.10
1/2"	2	1.05	2.10
3/8"	2	1.04	2.08
1/4"	6	0.98	5.88
#10	10	1.03	10.30
#40	6	1.05	6.30
#200	20	1.04	20.80
%AC	52	1.05	54.60
TOTAL	100		104.16

4.3 Calculation of Compliance Incentive Factors

The compliance incentive factors weight the composite pay factors—calculated separately for AC mix lots (aggregate and asphalt content) and in-place AC density lots—that are used in calculating the final price per ton of in-place AC. A job mix compliance incentive factor (JMCIF) is calculated for each lot of AC. The calculation involves multiplying by 60 percent the difference between the CPF and unity, with regard to sign. A compaction incentive price adjustment factor (CIPAF) is calculated similarly, but with 40 percent as the weighting factor.

Example: Calculation of the lot JMCIF and CIPAF (assume the CPF for compaction = 1.05):

JMCIF	=	(CPF - 1)(60%)	CIPAF	=	(CPF - 1)(40%)
	=	(1.04 - 1)(.6)		=	(1.05 - 1)(.40)
	=	0.024		=	0.020

4.4 Calculation of Final Price Adjustment

Once the JMCIF and CIPAF have been calculated, the bid price per ton of in-place AC is multiplied by each of these factors to derive the final price to be paid the contractor.

Example: Calculation of final price adjustment:

Assume: Contractor bid $30/ton

the price adjustment/ton = $30 (0.024 + 0.020)

= +$1.32

CHAPTER 3

ANALYSIS AND COMPARISON OF PROJECTS

1. INTRODUCTION

To evaluate the effect of the new QA specifications on the overall quality and consistency of AC pavement, test data from four contracts completed under the "old" specification were compared with test data from four contracts completed with the new QA specification. First, sample data were standardized into percentage of the JMF percent so projects with different JMFs could be readily compared. Next, a series of statistical parameters was calculated and used to compare the quality and consistency of pavement before and after the use of the QA Specification. An analysis of normality was then conducted to evaluate the applicability of the specifications and to determine whether a comparison of all QA data with all non-QA data for each constituent was legitimate. A student t-test was also conducted to see whether the changes noted were due to chance or the specification change. Finally, the distributions of asphalt content and density data obtained before and after the use of the QA specification were evaluated to further define any changes to these important factors.

Calculations and graphics were completed with the "Quatro-Pro" spreadsheet program. [10] Slight numerical discrepancies occur in some of the tables because of rounding. In some cases, calculations were completed with more significant figures than those shown.

2. DATA SELECTION

The choice of parameters to evaluate was dictated by the parameters analyzed in the new QA specification: aggregate gradation, asphalt content, and density. To reduce the number of variables, relatively large projects with similar paving conditions were selected for analysis. Sample test data for four non-QA projects and four QA projects were obtained from WSDOT, as summarized in Tables 3.1 and 3.2. Aggregate and asphalt content data were provided via copies of WSDOT's "Daily Reports of Asphalt Plant Operations" for both QA and non-QA jobs. Computer generated summary reports of aggregate gradation and asphalt content were also provided for the QA projects. These were used to group samples into lots. Density data for the non-QA projects were obtained from copies of "Asphalt Concrete Pavement Compaction Control Reports" and for the QA projects from computer generated density summary reports that contained lot information.

3. DATA STANDARDIZATION

Specification limits for mix gradation and asphalt content varied from job to job, depending on the job mix formula (JMF). To enable the data from all jobs to be compared on an equal basis between jobs or together as a composite group, the data were converted into a percentage of job mix formula percent. For example, if the JMF required that 80 percent of the aggregate pass the 3/8-inch sieve, and 85 percent of a sample passed, the percentage of JMF percent would be (85/80)(100) =106.25 percent.

Table 3.1. Non-QA Spec. Project Summary

Project Number	Aggregate/Asphalt			Density		
	Tons	Sublots	Lots	Tons	Sublots	Lots
2861	27660	30	N/A	15570	194	40
3128	25700	27	N/A	14150	180	36
3328	12770	31	N/A	8280	135	27
3397	28060	38	N/A	24690	415	83
Totals:	94190	126	N/A	62690	924	186

Table 3.2. QA Spec. Project Summary

Project Number	Aggregate/Asphalt			Density		
	Tons	Sublots	Lots	Tons	Sublots	Lots
3491	23380	33	2	N/A	N/A	N/A
3522	14800	28	3	10490	N/A	46
3587	21830	28	3	8770	N/A	24
3636	66380	81	1	38720	N/A	131
Totals:	126390	170	9	57980	N/A	201

Even though the specification for minimum lot density based on the average of five tests was reduced from 92 percent of Rice density for non-QA jobs to 91 percent of Rice density for QA jobs, density data were not converted because the actual density values are important regardless of the specified minimum.

4. CALCULATION AND COMPARISON OF STATISTICAL PARAMETERS

4.1 Calculation Description

Statistical parameters were calculated from the standardized data for aggregate gradation and percentage of asphalt, and the raw data in percentage of Rice density for the density data. The results are shown in Tables 3.3 though 3.6. See Appendix D for a more detailed summary of statistical parameters by each project. Unless otherwise noted, the statistical parameters of mean, standard deviation, variance, coefficient of variance (CV), and range refer to sample values, not population values.

Table 3.5 was developed on the basis of weighted statistical parameters for each job. For example, if one project of 1,000 tons had a CV of 2 and a second project of 2,000 tons had a CV of 4, the combined, weighted CV would be (1,000/3,000)(2) + (2,000/3,000)(4) = 3.33.

4.2 Discussion

The quality of AC can be evaluated in several ways. Assuming a well designed mix, one measure is how close the aggregate gradation and asphalt content are to the job mix formula. Tables 3.3 and 3.4 show that composite sample means for QA projects were closer to 100 percent of the JMF percent than the non-QA means for every mix constituent evaluated. The range of samples also improved in four of the seven constituents, most notably the #10 sieve, the #200 sieve, and the asphalt content. Note that these constituents received more weight in the determination of the composite pay factors, and therefore can be considered three of the most important constituents of the mix.

Table 3.3. Summary of Statistical Parameters
(All Non-QA Jobs Combined, Values in % JMF)

	AC CONSTITUENT						
	1/2"	3/8"	1/4"	#10	#40	#200	%AC
# TESTS:	126	126	126	126	126	126	126
MEAN:	99.6	99.3	97.3	98.0	96.4	109.3	97.5
MAX:	103.1	106.9	112.1	115.8	133.3	164.9	107.1
MIN:	94.8	88.2	80.3	73.7	70.0	66.2	76.4
RANGE:	8.3	18.7	31.8	42.1	63.3	98.7	30.8
ST DEV:	1.52	3.68	6.35	7.46	11.49	20.93	5.71
CV:	1.53	3.71	6.53	7.61	11.92	19.16	5.85

Table 3.4. Summary of Statistical Parameters
(All QA Jobs Combined, Values in % JMF)

	AC CONSTITUENT						
	1/2"	3/8"	1/4"	#10	#40	#200	%AC
# TESTS:	170	170	170	170	170	170	170
MEAN:	100.1	100.4	101.2	99.6	102.9	107.0	100.1
MAX:	103.2	109.6	115.6	118.4	135.3	136.7	115.4
MIN:	95.8	87.2	83.6	84.2	70.6	75.9	85.1
RANGE:	7.4	22.4	32.0	34.2	64.7	60.8	30.3
ST DEV:	1.56	3.52	5.40	6.59	9.02	10.86	5.65
CV:	1.56	3.50	5.33	6.62	8.76	10.15	5.64

Table 3.5. Weighted Statistical Parameters

All Non-QA Projects

	AC CONSTITUENT						
	1/2"	3/8"	1/4"	#10	#40	#200	%AC
ST DEV:	1.46	4.05	6.32	8.01	10.11	16.28	6.09
CV:	1.46	4.07	6.45	8.13	10.42	14.97	6.28

All QA Projects

	AC CONSTITUENT						
	1/2"	3/8"	1/4"	#10	#40	#200	%AC
ST DEV:	1.47	3.16	4.81	6.51	8.91	8.23	5.34
CV:	1.47	3.15	4.76	6.54	8.66	7.72	5.31

Table 3.6. Statistical Comparison
QA vs. Non-QA Density

	NON-QA	QA	CHANGE
# OF LOTS:	186	201	N/A
MEAN:	93.23	92.73	-0.50
MAX:	96.90	95.52	-1.38
MIN:	89.94	88.64	-1.30
RANGE:	6.96	6.88	-0.08
STD DEV:	1.210	0.947	-0.263
CV:	1.298	1.021	-0.277
%< or = 92%:	25	16	-9
%>96%:	11	2	-9

A comparison of aggregate and asphalt content samples also showed an improvement in consistency with the implementation of QA specifications. As shown by the reductions in standard deviation, variance, and coefficient of variance in Tables 3.3 through 3.5, all constituents except for 1/2-inch aggregate improved in consistency. Coupled with means close to the JMF, these reductions are indicators of improved pavement quality with the QA specification.

A second method of evaluating the quality of AC pavement is through an assessment of the in-place density. Studies have shown that as the density drops and the number of air voids increases, the service life of an AC pavement may be reduced by as much as 10 percent for every 1 percent increase in the air voids. [11] Therefore, a pavement with a higher density and fewer air voids could be called a higher quality pavement, assuming a constant mix.

At first glance, it appears that the quality of in-place AC may have actually decreased with the introduction of QA specifications, since the composite lot mean went down (refer to Table 3.6). However, further analysis shows that the mean is not the only indicator of pavement quality that should be examined.

Decreasing the number of low density pavement lots placed in a section of road can reduce the chance of the road developing noticeable defects before the pavement reaches its potential life expectancy. This reduction can be equated to an improvement in the pavement's quality. Table 3.6 shows that the percentage of lot means that fell below the 92 percent Rice density dropped from 25 percent to 16 percent with the implementation of QA specifications. Given the 92 percent baseline, the pavement quality thus improved with the QA specifications.

Table 3.6 also suggests that the implementation of the QA specifications resulted in improved density consistency, since all measurements of variability decreased when the lumped QA data were compared to the lumped non-QA data.

To further demonstrate the relationship between density and quality, refer to Table D.9 in Appendix D. Project 3397 had an average lot mean of 93.98 percent, noticeably higher than any of the other projects evaluated. In the density lot data for project 3397, shown in Table B.9 of Appendix B, only three lots out of 83 total, or less than 4 percent, tested below 92 percent. This indication of a good product is deceiving, however. Project 3397's standard deviation of 1.203, shown in Table D.9, was the highest for any contract evaluated, indicating an inconsistent product. This observation was strengthened by a review of the project's sample data. An evaluation revealed that 41 of the 415 samples taken fell below 92 percent, meaning that almost 10 percent of the material tested fell below the desired limit. These low density sample results were in most cases balanced by higher density samples in the same lot, biasing the evaluation of quality when only the lots were reviewed. These results were predictable, however, from the high variability in the product reflected in the high standard deviation, variance, and coefficient of variance.

5. CHI-SQUARE TEST FOR NORMALITY

5.1 Test Description

The Chi-Square test for goodness of fit was used to evaluate the test data for normality. An expected normal curve, with the sample mean and standard deviation used as estimates of the population parameters, was produced and compared to the actual sample distribution. Given a certain level of confidence, if the calculated difference between the two was significant, the hypothesis of normality was rejected. If the difference was insignificant, the data were considered normal at a given level of confidence.

Composite sublot data from the non-QA projects for aggregate gradation, percentage of asphalt, and density were analyzed for normality. The same was done for the QA projects, with the exception that individual sample data were not available for density. As an alternative, mean lot densities were analyzed. Assuming that the lot means were derived from randomly drawn samples from the same population, the resulting distribution would most certainly be normal, regardless of the distribution of the population from which the samples had been drawn. For comparison, the non-QA lot means were also tested for normality.

The purpose of the normality tests was two-fold. First, WSDOT's inspection by variables method of statistically based QA is predicted on the assumption that the population of material being tested is normally distributed. [12] Thus, a comparison was required to determine the normality of the sample data and the validity of applying these specifications to WSDOT paving projects. Second, the normality test was used to determine whether the test data from separate projects were in reality test data from a larger population of either non-QA specification projects or QA specification projects. If the sample data for all projects completed with the same specification were normally distributed, they could legitimately be analyzed as a population with statistics based on normality. Appendix E contains both tabular and graphical comparisons made with the Chi-Square test for normality for each gradation of aggregate, asphalt content, and density for both QA and non-QA data. Table 3.7 summarizes the results.

5.2 Discussion

As shown in Table 3.7, six of the eight parameters evaluated proved to be normally distributed as a result of the Chi-Square test. As for the failing constituents shown in Appendix E, these parameters appear to be close to normally distributed, since they are relatively bell shaped and symmetrical. The variation from normality occurs mainly as spikes at or near the mean, a situation that is not detrimental to either the state or the contractor. These parameters are therefore considered to approximate the normal distribution. Therefore, the WSDOT QA Specifications can still be applied, with the understanding that the anticipated risk may vary somewhat from the level designed into the WSDOT QA Specification tables. [13]

Table 3.7. Summary Results of Normality Tests Conducted on Composite Data

	AC Constituents								
	1/2"	3/8"	1/4"	#10	#40	#200	%AC	S.DEN	L.DEN
NON-QA:	Y	Y	Y	Y	Y	Y	N*	N	N
					Non-QA Project 3397:			Y	
QA:	N	Y	Y	Y	N**	Y	Y	N/A	Y

Y = YES and indicates a calculated value LESS THAN the table value at ∝ = 0.05, therefore the hypothesis of normality is accepted.

N = NO and indicates the a calculated value GREATER THAN the table value at ∝ = 0.05, therefore the hypothesis of normality is rejected.

NOTE: * Rejected at ∝ =0.05, accepted at ∝ = 0.025.

** Must reduce to 0.005 to gain acceptance.

Irrespective of the shape of the distribution of a population, the distribution of lot means taken from that population will tend to be normal. [14] Therefore, the researchers were surprised that the density lot distribution for non-QA projects failed the normality test. There are several possible reasons why the failure occurred. The sample densities for all non-QA projects may not have all been from the same population, or, said in a different way, each non-QA project may have defined a statistically distinct density sample population. Another cause could have been that the samples used to calculate the lot means were biased or non-random. A final alternative is that the number of lots evaluated was too small.

As a check to see whether the density tests for individual projects could be considered normally distributed, the density sample data for the largest non-QA project,

project 3397, were tested. Because the density sample results for this large project proved normally distributed, a reasonable conclusion is that the density data for other projects would be either normal or approximately normal in distribution. However, this cannot be proven conclusively without an analysis of the sample distributions from other projects.

6. STUDENT "t" TEST COMPARISONS

6.1 Test Description

In the form used in this study, the Student t-test determines whether differences in two sample means are significant or due to chance at a selected level of confidence. First, a value of t is calculated by formula with the sample statistical parameters. Then the calculated value is compared to a table value for a given level of confidence. If the calculated value exceeds the table value, the hypothesis that the difference in the means is due to chance is rejected. [15]

The Student t-test was used to compare the composite summary results for each parameter to determine whether the differences noted in prior analyses were in fact due to a change in the specification and not due to chance alone. A summary of the results is shown in Table 3.8. Appendix F shows the analysis in greater detail.

Table 3.8. Student t-test Comparison - QA vs. Non-QA Projects

PARAMETER:	1/2"	3/8"	1/4"	#10	#40	#200	%AC	DEN
DIFFERENCE?:	Y	Y	Y	N	Y	N	Y	Y

Y = YES and indicates a calculated value GREATER THAN the table value at $\alpha = 0.05$, therefore the hypothesis of equality is rejected.

N = NO and indicates the a calculated value LESS THAN the table value at $\alpha = 0.05$, therefore the hypothesis of equality is accepted.

6.2 Discussion

Table 3.8 shows that for all but the #10 and #200 aggregate, the composite sample means were different at a risk of 5 percent (a 5 percent chance of rejecting a true hypothesis); thus it can be concluded that the populations from which they were drawn were also different. [16] Therefore, the conclusion that both pavement quality and consistency improved as a result of the QA specifications is statistically supported.

7. ANALYSIS OF ASPHALT CONTENT AND DENSITY DISTRIBUTIONS

A detailed comparison of asphalt content and density data was undertaken because the QA specifications WSDOT selected placed a greater emphasis on percentage of Rice density and percentage of asphalt content than the other parameters evaluated. This emphasis is accomplished by assigning these items greater weighting factors for determining the pay factors and price adjustments. The goal of this additional analysis was to provide further understanding of the changes in quality and consistency of the asphalt content and density that were due to the change in specifications.

7.1 Distribution Comparison for Asphalt Content

The specification limits found in the WSDOT QA Specifications (i.e., job mix formula percentage ± 0.5 percent) were compared with the distribution of asphalt content sample data for both QA and non-QA projects. The data were segregated into four increments, as defined below.

- "<LSL" indicates that the sample value fell below the lower specification limit (LSL) defined by the WSDOT QA Specifications.
- "LSL-JMF" indicates that the sample value was equal to or greater than the LSL, but less than the job mix formula (JMF) value.
- "JMF-USL" indicates that the sample value was equal to or greater than the JMF value and equal to or less than the upper specification limit (USL) defined by the WSDOT QA Specifications.
- ">USL" indicates that sample value was greater than the USL.

Tables 3.9 and 3.10 show the results for all non-QA and QA projects. The numbers in the table represent the number of samples that fell in each defined increment. A summary for all jobs combined is also provided, as well as a summary of the percentage of samples that fell in each increment.

7.2 Distribution Comparison for Density Data

The distributions of lot density averages were compared for non-QA and QA projects. The results are shown in Tables 3.11 and 3.12. The numbers represent the number of lot means that occurred in each range. For example, the number 34 for TOTAL shown under 92 percent maximum density indicates that 34 out of 186 lot averages were equal to or greater than 91 percent and less than the 92 percent Rice density. This equates to (34/186)x100 = 18 percent of all the non-QA lot averages.

Table 3.9. Comparison of Non-QA Asphalt Samples - Number of Samples Within Various Specified Ranges

PROJECT	INCREMENT				
	<LSL	LSL-JMF	JMF-MAX	>USL	TOTAL
2861	9	9	12	0	30
3128	2	13	12	0	27
3328	4	16	11	0	31
3397	0	13	25	0	38
TOTAL:	15	51	60	0	126
TOTAL:	12%	40%	48%	0%	100%

Table 3.10. Comparison of QA Asphalt Samples - Number of Samples Within Various Specified Ranges

PROJECT	INCREMENT				
	<LSL	LSL-JMF	JMF-USL	>USL	TOTAL
3391	0	10	23	0	33
3522	2	23	3	0	28
3587	2	8	13	5	28
3636	2	22	55	2	81
TOTAL:	6	63	94	7	170
TOTAL:	4%	37%	55%	4%	100%

Table 3.11. Non-QA Lot Density Distribution - Number of Lots at Various Density Levels

PROJECT	Percent maximum (Rice) Density									
	89	90	91	92	93	94	95	96	97	TOTAL
2861	0	0	5	29	4	2	0	0	0	40
3128	0	0	0	0	21	13	2	0	0	36
3328	0	1	5	4	12	5	0	0	0	27
3397	0	0	2	1	17	22	21	17	3	83
TOTAL:	0	1	12	34	54	42	23	17	3	186
TOTAL:	0%	0.5%	7%	18%	29%	23%	12%	9%	1.5%	100%

Table 3.12. QA Lot Density Distribution - Number of Lots at Various Density Levels

PROJECT	Percent maximum (Rice) Density									
	89	90	91	92	93	94	95	96	97	TOTAL
3522	0	0	0	4	15	16	7	4	0	46
3587	0	0	0	2	13	8	1	0	0	24
3636	2	0	1	24	72	28	4	0	0	131
TOTAL:	2	0	1	30	100	52	12	4	0	201
TOTAL:	1%	0%	0.5%	15%	50%	26%	6%	2%	0%	*99.5%

*slight error in total % due to rounding

7.3 Discussion

The results shown in Tables 3.9 through 3.12 further confirm the observation previously made that the AC pavement's consistency and quality improved with the implementation of WSDOT's QA Specifications. The improvement in asphalt content was reflected in a reduction from 12 percent of the tests (samples) outside the specification range before the QA Specifications to 8 percent out of specification following their implementation. As for density, the tests once again confirmed that the percentage of lot means that fell below 92 percent decreased with the implementation of the WSDOT QA Specifications, an indication of improved quality.

Further comparison of the distribution of density lots showed a noticeable reduction in lot means equal to or greater than 95 with the implementation of the WSDOT QA Specifications, indicating a possible reduction in the quantity of in-place AC of exceptional quality. This result may be deceiving, however, since the high density readings could have been due to a variation from the JMF, such as an increase in percentage of asphalt, resulting in a lower quality pavement subject to asphalt "bleeding." This hypothesis could not be verified with the available data. Also, if the lots of exceptional pavement were dispersed with lots of average or low quality pavement, the benefits would have been reduced or negated. A check revealed this to be the case, since most of the high density readings came from project 3397, which was previously shown to lack consistency in density, with almost 10 percent of its density samples below the 92 percent Rice.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

1.1 Effect of QA Specifications on AC Pavement Quality and Consistency

As shown in Chapter 3, the AC pavement produced under the WSDOT QA Specifications was, on the average, of greater consistency and higher quality than that produced under the old non-QA specifications. These improvements can be attributed to the change in specifications, since the hypothesis tests (Student t-tests) indicate that the improvements were due to something other than chance. The improvement is not surprising, since the statistical parameters of standard deviation and mean used in this report to evaluate consistency and quality are also the parameters analyzed by the WSDOT QA Specification to determine the quality level for each lot.

To get the maximum bonus, both the mix preparation and placement must be of good quality. These steps become related with WSDOT's QA Specification. First, the contractor is encouraged to ensure good quality control over the production of AC mix from the start to achieve the proper gradation and percentage of asphalt required to get the maximum composite pay factor for the mix. With a high quality mix, achieving a uniformly high density during placement is easier, resulting in the maximum bonus for compaction. Conversely, if the quality control is poor from the start, it affects both the quality of the mix and compaction adversely, resulting in a potential reduction in payment. Therefore, the desired effect was achieved with the QA specifications.

1.2 Applicability of the Specifications

The question of whether the specifications selected are appropriate for WSDOT can be answered in two ways, and in both cases the answer is yes. As previously discussed, the variables acceptance plan upon which the WSDOT QA Specifications are based is designed for use with a normally distributed population. As discussed in Chapter 3, the distribution of samples for each constituent proved to be normal, or approximately normal, as shown by a review of the sample histograms and the outcome of the Chi-Square tests. That makes the specification's statistics applicable to regional AC material.

In reality, rigidly basing the applicability of the QA specification on the normality of the pavement population may be a moot point, since the bottom line results obtained from use of the QA specifications appear to be an improved product at a reasonable cost. Given this criterion of "what works" as the second method of evaluating the specifications, the QA specifications once again prove to be applicable to WSDOT AC paving contracts.

2. RECOMMENDATIONS

- WSDOT should continue to use the QA specifications analyzed in this report, since the quality and consistency of AC pavement has improved.
- WSDOT should analyze the costs and benefits of raising the lower quality level for density to greater than the 91 percent Rice density. The data analyzed showed that the contractors are capable of consistently placing AC in the 92 to 94 percent Rice density range. With the current high cost of repairs and resurfacing, coupled with the inconvenience to highway users caused by road repairs, it may make economic sense to pay the extra costs up front and reap the benefits of longer pavement life. An alternative to raising the LQL is to increase the pay incentive for a denser pavement. The evidence provided in this report suggests that an improvement in AC density and a corresponding higher quality would result in longer lasting pavement.
- The results of more recent projects that have been completed with the WSDOT QA Specifications should be evaluated to ensure that the apparent improvements are truly due to the change in specifications and not an initial "placebo" effect. Although the pavement quality clearly increased for the test projects, this improvement could have been due to contractors and inspectors trying harder to produce good results that they knew would be scrutinized by WSDOT.

REFERENCES

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APPENDIX A

WSDOT QA SPECIFICATION SECTION

APPENDIX A: WSDOT QA SPECIFICATION SECTION

Payment

All costs and expenses in connection with providing, placing, and feathering the asphalt concrete pavement shall be included in the unit contract price per ton for *** "Asphalt Conc. Pavement Cl. B" ***.

STATISTICAL EVALUATION OF MATERIALS FOR ACCEPTANCE

Section 1-06.2 is supplemented by the following sampling and testing provisions for asphalt concrete pavement Class *** B and preleveling Class B ***:

General

Acceptance sampling and testing for this contract will be done by WSDOT and statistically evaluated for acceptance by the provisions of this subsection. All test results for a lot will be analyzed collectively and statistically by the Quality Level Analysis procedures shown at the end of this subsection to determine the total percent of the lot that is within specification limits and to determine an appropriate pay factor. Lots and sublots are defined in the appropriate subsection of the specifications for the material being statistically evaluated.

Quality Level Analysis is a statistical procedure for determining the percent compliance of the material with the specifications. Quality Level is the computed percent of material meeting the specifications and is determined from the arithmetic mean, ($\bar{X}$), and the sample standard deviation, (s), for each constituent of the lot.

Any necessary rounding off of test results or calculations will be accomplished according to the following rule:

1. The final significant digit will not be changed when the succeeding digit is less than 5.
2. The final significant digit will be increased by one when the succeeding digit is 5 or greater.

Financial Incentive

As an incentive to produce superior quality material, a pay factor greater than 1.0000 may be obtained with the maximum pay factor being 1.0500. A lot containing nonspecification material will be accepted provided the COMPOSITE PAY FACTOR is at least 0.7500. A lot containing nonspecification material which fails to obtain at least a 0.7500 COMPOSITE PAY FACTOR will be rejected by the Engineer. The Engineer will take one or more of the following actions when rejected material has been incorporated into the work:

1. Require complete removal and replacement with specification material at no additional cost to the State.
2. At the Contractor's written request, allow corrective work at no additional cost to the State and then an appropriate price reduction that may range from no reduction to no payment.
3. At the Contractor's written request, allow material to remain in place with an appropriate price reduction that may range from a 25 percent reduction to no payment.

Any lot for which at least three samples have been obtained and all of the test results meet the criteria listed below will receive at least a 1.000 composite pay factor:

1. All test results are within the allowable limits specified for the item, or

2. All test results are greater than or equal to a minimum specification limit, or

3. All test results are less than or equal to a maximum specification limit, whichever is appropriate.

Computation of the QUALITY LEVEL in these instances will be for determining the amount of any bonus which might be warranted.

If less than three samples have been obtained at the time a lot is about to be terminated, the two backup split samples will be tested to create a lot of four samples. Lots represented by a single sample or unsampled lots will be exempt from statistical based acceptance.

Removed and Rejected Materials
The Contractor may, prior to sampling, elect to remove any defective material and replace it with new material at the Contractor's expense. Any such new material will be sampled, tested, and evaluated for acceptance as a part of the sublot in accordance with this statistical sampling and testing procedure.

The Engineer may reject a sublot which tests show to be defective. Such rejected material shall not be used in the work, and the results of tests run on the rejected material will not be included in the original lot acceptance tests.

Quality Level Analysis
Procedures for determining the Quality Level and pay factors for a material are as follows:

1. Determine the arithmetic mean, ($\bar{X}$), of the test results for each specified material constituent:

$$\bar{X} = \frac{\Sigma x}{n}$$

where, Σ = summation of
x = individual test value
n = total number test values

2. Compute the sample standard deviation,(s), for each constituent:

$$s = \sqrt{\frac{\Sigma x^2 - n\bar{X}^2}{n-1}}$$

where, Σx^2 = summation of each individual test value squared

$\bar{X}^2$ = arithmetic mean squared

3. Compute the upper quantity index, (Q_U), for each constituent:

$$Q_U = \frac{USL - \overline{X}}{s}$$ where, USL (upper specification limit) = target value plus allowable tolerance

4. Compare the lower quality index, (Q_L), for each constituent:

$$Q_L = \frac{\overline{X} - LSL}{s}$$ where, LSL (lower specification limit) = target value minus allowable tolerance

5. For each constituent determine P_U (the percent within the upper specification limit which corresponds to a given Q_U) from Table 1. Note: If a USL is 100.00 percent or is not specified, P_U will be 100.

6. For each constituent determine P_L (the percent within the lower specification limit which corresponds to a given Q_L) from Table 1. Note: If a LSL is not specified, P_L will be 100.

7. For each constituent determine the QUALITY LEVEL (the total percent within specification limits).

   QUALITY LEVEL = $(P_U + P_L) - 100$

8. Using the QUALITY LEVEL from step 7, determine the pay factor (PF_i) from Table 2 for each constituent tested.

9. Determine the COMPOSITE PAY FACTOR (CPF) for each lot.

$$CPF = \frac{[f_1(\overline{PF}_1) + f_2(\overline{PF}_2) + \dots + f_j(\overline{PF}_j)]}{\sum_{i = 1 \text{ to } j} f_i}$$

Where f_i = price adjustment factor listed in the specifications for the applicable material.

From each COMPOSITE PAY FACTOR (CPF) calculated in accordance with this section, price adjustment factors will be applied to the unit contract price. The price adjustment factor will be calculated as the difference between the composite pay factor and unity.

TABLE A.1:

TABLE 1

Quality Levels

QUALITY LEVEL ANALYSIS BY THE STANDARD DEVIATION METHOD

P_U or P_L PERCENT WITHIN LIMITS FOR POSITIVE VALUES OF Q_U or Q_L	UPPER QUALITY INDEX Q_U OR LOWER QUALITY INDEX Q_L														
	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10 to n=11	n=12 to n=14	n=15 to n=18	n=19 to n=25	n=26 to n=37	n=38 to n=69	n=70 to n=200	n=201 to n=∞
100	1.16	1.50	1.79	2.03	2.23	2.39	2.53	2.65	2.83	3.03	3.20	3.38	3.54	3.70	3.83
99	-	1.47	1.67	1.80	1.89	1.95	2.00	2.04	2.09	2.14	2.18	2.22	2.26	2.29	2.31
98	1.15	1.44	1.60	1.70	1.76	1.81	1.84	1.86	1.91	1.93	1.96	1.99	2.01	2.03	2.05
97	-	1.41	1.54	1.62	1.67	1.70	1.72	1.74	1.77	1.79	1.81	1.83	1.85	1.86	1.87
96	1.14	1.38	1.49	1.55	1.59	1.61	1.63	1.65	1.67	1.68	1.70	1.71	1.73	1.74	1.75
95	-	1.35	1.44	1.49	1.52	1.54	1.55	1.56	1.58	1.59	1.61	1.62	1.63	1.63	1.64
94	1.13	1.32	1.39	1.43	1.46	1.47	1.48	1.49	1.50	1.51	1.52	1.53	1.54	1.55	1.55
93	-	1.29	1.35	1.38	1.40	1.41	1.42	1.43	1.44	1.44	1.45	1.46	1.46	1.47	1.47
92	1.12	1.26	1.31	1.33	1.35	1.36	1.36	1.37	1.37	1.38	1.39	1.39	1.40	1.40	1.40
91	1.11	1.23	1.27	1.29	1.30	1.30	1.31	1.31	1.32	1.32	1.33	1.33	1.33	1.34	1.34
90	1.10	1.20	1.23	1.24	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.28	1.28	1.28
89	1.09	1.17	1.19	1.20	1.20	1.21	1.21	1.21	1.21	1.22	1.22	1.22	1.22	1.22	1.23
88	1.07	1.14	1.15	1.16	1.16	1.16	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
87	1.06	1.11	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.13	1.13
86	1.04	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
85	1.03	1.05	1.05	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
84	1.01	1.02	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99
83	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.95	0.95	0.95
82	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
81	0.96	0.93	0.91	0.90	0.90	0.89	0.89	0.89	0.89	0.88	0.88	0.88	0.88	0.88	0.88
80	0.93	0.90	0.88	0.87	0.86	0.86	0.86	0.85	0.85	0.85	0.85	0.84	0.84	0.84	0.84
79	0.91	0.87	0.85	0.84	0.83	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.81
78	0.89	0.84	0.82	0.80	0.80	0.79	0.79	0.79	0.78	0.78	0.78	0.78	0.77	0.77	0.77
77	0.87	0.81	0.78	0.77	0.76	0.76	0.76	0.75	0.75	0.75	0.75	0.74	0.74	0.74	0.74
76	0.84	0.78	0.75	0.74	0.73	0.73	0.72	0.72	0.72	0.71	0.71	0.71	0.71	0.71	0.71
75	0.82	0.75	0.72	0.71	0.70	0.70	0.69	0.69	0.69	0.68	0.68	0.68	0.68	0.68	0.67
74	0.79	0.72	0.69	0.68	0.67	0.66	0.66	0.66	0.66	0.65	0.65	0.65	0.65	0.64	0.64
73	0.76	0.69	0.66	0.65	0.64	0.63	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.61	0.61
72	0.74	0.66	0.63	0.62	0.61	0.60	0.60	0.60	0.59	0.59	0.59	0.59	0.59	0.58	0.58
71	0.71	0.63	0.60	0.59	0.58	0.57	0.57	0.57	0.57	0.56	0.56	0.56	0.56	0.55	0.55
70	0.68	0.60	0.57	0.56	0.55	0.55	0.54	0.54	0.54	0.53	0.53	0.53	0.53	0.53	0.52
69	0.65	0.57	0.54	0.53	0.52	0.52	0.51	0.51	0.51	0.50	0.50	0.50	0.50	0.50	0.50
68	0.62	0.54	0.51	0.50	0.49	0.49	0.48	0.48	0.48	0.48	0.47	0.47	0.47	0.47	0.47
67	0.59	0.51	0.47	0.47	0.46	0.46	0.46	0.45	0.45	0.45	0.45	0.44	0.44	0.44	0.44
66	0.56	0.48	0.45	0.44	0.44	0.43	0.43	0.43	0.42	0.42	0.42	0.42	0.41	0.41	0.41
65	0.52	0.45	0.43	0.41	0.41	0.40	0.40	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.39
64	0.49	0.42	0.40	0.38	0.38	0.38	0.37	0.37	0.37	0.37	0.36	0.36	0.36	0.36	0.36
63	0.46	0.39	0.37	0.36	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.33	0.33	0.33
62	0.43	0.36	0.34	0.33	0.32	0.32	0.32	0.32	0.31	0.31	0.31	0.31	0.31	0.31	0.31
61	0.39	0.33	0.31	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28	0.28
60	0.36	0.30	0.28	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25
59	0.32	0.27	0.25	0.25	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.23
58	0.29	0.24	0.23	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20
57	0.25	0.21	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
56	0.22	0.18	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15
55	0.18	0.15	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
54	0.14	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
53	0.11	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
52	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
51	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03

NOTE: For negative values of Q_U or Q_L, P_U or P_L is equal to 100 minus the table value for P_U or P_L.
If the value of Q_U or Q_L does not correspond exactly to a figure in the table, use the next higher figure.

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TABLE A.2:

TABLE 2

Pay Factors

PAY FACTOR	REQUIRED QUALITY LEVEL FOR A GIVEN SAMPLE SIZE (n) AND A GIVEN PAY FACTOR														
	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10 to n=11	n=12 to n=14	n=15 to n=18	n=19 to n=25	n=26 to n=37	n=38 to n=69	n=70 to n=200	n=201 to n=∞
1.05	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1.04	90	91	92	93	93	93	94	94	95	95	96	96	97	97	99
1.03	80	85	87	88	89	90	91	91	92	93	93	94	95	96	97
1.02	75	80	83	85	86	87	88	88	89	90	91	92	93	94	95
1.01	71	77	80	82	84	85	85	86	87	88	89	90	91	93	94
1.00	68	74	78	80	81	82	83	84	85	86	87	89	90	91	93
.99	66	72	75	77	79	80	81	82	83	85	86	87	88	90	92
.98	64	70	73	75	77	78	79	80	81	83	84	85	87	88	90
.97	62	68	71	74	75	77	78	78	80	81	83	84	85	87	89
.96	60	66	69	72	73	75	76	77	78	80	81	83	84	86	88
.95	59	64	68	70	72	73	74	75	77	78	80	81	83	85	87
.94	57	63	66	68	70	72	73	74	75	77	78	80	81	83	86
.93	56	61	65	67	69	70	71	72	74	75	77	78	80	82	84
.92	55	60	63	65	67	69	70	71	72	74	75	77	79	81	83
.91	53	58	62	64	66	67	68	69	71	73	74	76	78	80	82
.90	52	57	60	63	64	66	67	68	70	71	73	75	76	79	81
.89	51	55	59	61	63	64	66	67	68	70	72	73	75	77	80
.88	50	54	57	60	62	63	64	65	67	69	70	72	74	76	79
.87	48	53	56	58	60	62	63	64	66	67	69	71	73	75	78
.86	47	51	55	57	59	60	62	63	64	66	68	70	72	74	77
.85	46	50	53	56	58	59	60	61	63	65	67	69	71	73	76
.84	45	49	52	55	56	58	59	60	62	64	65	67	69	72	75
.83	44	48	51	53	55	57	58	59	61	63	64	66	68	71	74
.82	42	46	50	52	54	55	57	58	60	61	63	65	67	70	72
.81	41	45	48	51	53	54	56	57	58	60	62	64	66	69	71
.80	40	44	47	50	52	53	54	55	57	59	61	63	65	67	70
.79	38	43	46	48	50	52	53	54	56	58	60	62	64	66	69
.78	37	41	45	47	49	51	52	53	55	57	59	61	63	65	68
.77	36	40	43	46	48	50	51	52	54	56	57	60	62	64	67
.76	34	39	42	45	47	48	50	51	53	55	56	58	61	63	66
.75	33	38	41	44	46	47	49	50	51	53	55	57	59	62	65
REJECT	QUALITY LEVELS LESS THAN THOSE SPECIFIED FOR A 0.75 PAY FACTOR														

NOTE: If the computed QUALITY LEVEL does not correspond exactly to a figure in the table, use the next lower value.

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Section 5-04.3(8)A is added as follows:

5-04.3(8)A Acceptance Sampling and Testing

Acceptance sampling and testing will be performed by the Engineer in accordance with Section 1-06.2 and the following:

A. Aggregates
Aggregates will be sampled in accordance with the current standards and tested for Sand Equivalent and Fracture with acceptance based on Section 9-03.8(2). Statistically based acceptance sampling will not apply to Sand Equivalent and Fracture of mineral aggregates. Sand/Silt ratio of asphalt mix and gradation variance between screens will not apply to this section.

B. Asphalt Concrete Mixture

1. Sampling

a. A sample will not be obtained from either the first or last 25 tons of mix produced in each production shift.

b. Samples for compliance of gradation and asphalt cement content will be obtained on a random basis, from the hauling vehicle.

2. Lot Size - The quantity represented by each sample will constitute a sublot and will normally be 800 tons of mixture. For the purpose of acceptance sampling and testing, a lot is defined as the total quantity of material or work produced per "job mix formula", placed and represented by randomly selected samples tested for acceptance. All of the test results obtained from the acceptance samples shall be evaluated collectively and shall constitute a lot. Only one lot per "job mix formula" will be expected to occur.

The Contractor may request a change in "job mix formula". If the request is approved, all of the material produced up to the time of the change will be evaluated on the basis of available tests and a new lot will begin.

3. Test Results - The Engineer will furnish the Contractor with a copy of the results of all acceptance testing performed in the field by 7:00 a.m. the morning of the next workday after sampling. The Engineer will also provide by noon of the next workday after sampling, the Composite Pay Factor (CPF) of the completed sublots after three (3) sublots have been produced.

a. Aggregate Gradation and Asphalt Content - Acceptance testing for compliance of gradation and asphalt content will use the Quick Extraction Procedure: WSDOT Test Method 711.

4. Reject Mixture

a. Rejection by Contractor - The Contractor may, prior to sampling, elect to remove any defective material and replace it with new material at the Contractor's expense. Any such new material will be sampled, tested, and evaluated for acceptance.

b. Rejection Without Testing - The Engineer, prior to sampling, may reject any batch, load, or section of roadway that appears defective in gradation or asphalt cement content. Material rejected before placement shall not be incorporated in the pavement. Any rejected section of roadway shall be removed.

No payment will be made for the rejected materials or the removal of the materials unless the Contractor requests that the rejected material be tested. If the Contractor elects to have the rejected material tested, a minimum of three representative samples will be obtained and tested. Acceptance will be based on conformance with the statistical acceptance except that if the COMPOSITE PAY FACTOR for the rejected material is less than 0.7500, no payment will be made for the removal costs or rejected material and in addition, the cost of the sampling and testing shall be borne by the Contractor. However, if the COMPOSITE PAY FACTOR is greater than 0.7500, the cost of sampling and testing will be borne by the State.

c. A Partial Sublot - In addition to the preceding random acceptance sampling and testing, the Engineer may also isolate from a normal sublot any material that is suspected of being defective in gradation or asphalt cement content. Such isolated material will not include an original sample location. A minimum of three random samples of the suspect material will be obtained and tested. The material will then be evaluated for price adjustment in accordance with the statistical acceptance section. This material will be considered a separate lot. Two adjoining partial sublots will be combined into a single lot with a minimum of six random samples.

d. An Entire Sublot - If an entire sublot is rejected in accordance with Section 1-06.2, Removed and Rejected Materials, four additional random samples from this sublot will be obtained and the sublot evaluated as an independent lot with the original test result included as a fifth test with the new independent lot instead of with the original lot.

e. A Lot In Progress - Whenever the COMPOSITE PAY FACTOR for a lot in progress:

1. Drops below 1.0000 and the Contractor is taking no corrective action, or

2. Is less than 0.7500, the Contractor shall shut down his operations and shall not resume asphalt concrete

placement until such time as the Engineer is satisfied that specification material can be produced.

f. An Entire Lot - An entire lot with a COMPOSITE PAY FACTOR of less than 0.7500 will be rejected.

5. Table of Price Adjustment Factors

Constituent	Factor "f"
All aggregate passing 1", 3/4", 5/8", 1/2" and 3/8" sieves	2
All aggregate passing 1/4" sieve	6
All aggregate passing No. 10 sieve	10
All aggregate passing No. 40 sieve	6
Aggregate passing No. 200 sieve	20
Asphalt cement	52

If a constituent is not measured in accordance with these specifications, its individual pay factor will be considered 1.00 in calculating the COMPOSITE PAY FACTOR (CPF).

6. Job Mix Compliance Incentive Factor

For each lot of asphalt concrete pavement produced under statistical acceptance for gradation and asphalt content, a Job Mix Compliance Factor (JMCIF) will be determined. The JMCIF equals the difference between the Composite Pay Factor and unity with regard to sign multiplied by 60 percent. The Job Mix Compliance Price Adjustment will be calculated as the product of the JMCIF, the quantity of asphalt concrete in the lot in tons, and the unit contract price per ton of mix.

Section 5-04.3(10)B is deleted and replaced by the following:

For asphalt concrete Classes B, E, and F, on Department contracts, where paving is in the traffic lanes, including lanes for ramps, truck climbing, weaving, and speed changes, and the specified compacted course thickness is greater than 0.10 foot, the acceptable level of compaction shall be a minimum of 91 percent of the reference maximum density as determined by WSDOT Test Method 705. The reference maximum density shall be determined as the moving average of the most recent five determinations for the Lot of asphalt concrete being placed. The level of compaction attained will be determined by the statistical evaluation of five nuclear density gauge tests taken on the day the mix is placed (after completion of the finish rolling) at randomly selected locations within each lot. Statistical evaluation within each lot shall be in accordance with the supplementary to Section 1-06.2, STATISTICAL EVALUATION OF MATERIALS FOR ACCEPTENCE. The quantity represented by each lot will be no greater than a single day's production or approximately 400 tons, whichever is less.

Acceptance of pavement compaction will be based on the statistical evaluation and composite pay factor so determined. For each compaction control lot, a Compaction Incentive Price Adjustment Factor (CIPAF) will be determined. The CIPAF equals the difference between the Composite Pay Factor and unity with regard to sign multiplied by 40 percent. The Compaction Compliance Price Adjustment will be calculated as the product of the CIPAF, the quantity of asphalt concrete in the compaction control lot in tons and the unit contract price per ton of mix. The Engineer will furnish the Contractor with a copy of the results of all acceptance testing performed in the field by 7:00 a.m. the morning of the next workday after testing.

For compaction lots falling below 1.00 pay factor and thus subject to price reduction or rejection, cores may be used as an alternate to the nuclear density gauge tests. When cores are taken by the State at the request of the Contractor, they shall be requested by noon of the next workday after paving. The State shall be reimbursed for the coring expenses at the rate of $75 per core when the core indicates the acceptable level of compaction within a lot has not been achieved.

At the start of paving, if requested by the Contractor, a compaction test section shall be constructed as directed by the Engineer to determine the compactibility of the mix design. Compactibility shall be evaluated as the abilitiy of the mix to attain a quality level corresponding to a pay factor of 1.00 or greater referenced to the specified minimum density (91 percent of the maximum density determined by WSDOT Test Method 705). If a compaction test section is requested, a pay factor of 1.000 shall apply until compactibility is proven. Following determination of compactibility, the Contractor is responsible for the control of the compaction effort. If the Contractor does not request a test section, the mix will be considered compactible.

Asphalt Concrete Classes B, E, F and G constructed under conditions other than listed above shall be compacted on the basis of a test point evaluation of the compaction train. The test point evaluation shall be performed in accordance with instructions from the Engineer. The number of passes with an approved compaction train, required to attain the maximum test point density, shall be used on all subsequent paving.

Asphalt Concrete Class D and preleveling mix shall be compacted to the satisfaction of the Engineer.

In addition to the randomly selected locations for tests of the control lot, the Engineer reserves the right to test any area which appears defective and to require the further compaction of areas that fall below acceptable density readings. These additional tests shall not impact the compaction evaluation of the entire control lot.

Section 5-04.5 is supplemented by the following:

18. "Job Mix Compliance Price Adjustment — Preleveling Class B —", by calculation.

19. "Job Mix Compliance Price Adjustment Class ~~ B ~~", by calculation.

Job mix compliance price adjustment Class ~~ B and preleveling Class B ~~ will be calculated and paid for as described elsewhere in this Special Provision. For the purpose of providing a common proposal for all bidders, and for that purpose only, the State has estimated the calculated amount for "Job Mix Compliance Price Adjustment Class ~~ B and preleveling Class B ~~" and has entered the amount in the proposal to become a part of the total bid by the Contractor.

Job mix compliance price adjustment Class ~~ B and preleveling Class B ~~ will not be considered a major contract bid item as defined by Section 1-01.2. In addition, conditions (1) and (2) of the first paragraph of Section 1-04.6 do not apply to this item and any impact due to an increase or decrease from plan quantity will be the sole risk of the Contractor.

20. "Compaction Price Adjustment Class ~~ B ~~" by calculation:

Compaction price adjustment Class ~~ B ~~ will be calculated and paid for as described elsewhere in this Special Provision. For the purpose of providing a common proposal for all bidders, and for that purpose only, the State has estimated the calculated amount for "Compaction Price Adjustment Class ~~ B ~~" and has arbitrarily entered the amount in the proposal to become a part of the total bid by the Contractor.

Compaction price adjustment Class ~~ B ~~ will not be considered a major contract bid item as defined by Section 1-01.2. In addition, conditions (1) and (2) of the first paragraph of Section 1-04.6 do not apply to this item and any impact due to an increase or decrease from plan quantity will be the sole risk of the Contractor.

Section 9-03.8(6) is supplemented by the following for asphalt concrete pavement Class ~~ B ~~.

Job Mix Formula

The average gradation of the completed asphalt concrete mix submitted by the Contractor in the mix design proposal, as required in Section 9-03.8(6) and the resulting Mix Design Recommendations shall be the Job Mix Formula.

The intermingling of asphalt concrete mixtures produced from more than one "job mix formula" is prohibited. Each strip of asphalt concrete pavement placed during a working shift shall conform to a single job mix formula established for the class of asphalt concrete specified unless there is a need to make an adjustment in the "job mix formula".

Based on submitted gradation from the Contractor, the Engineer will determine the asphalt content and antistrip requirement in the mix design process. The job mix formula thus established shall be changed only upon order of the Engineer. Any change or adjustment of percentages in any constituent of the "job mix formula", such as a change in asphalt percentage ordered by the Engineer, creates a new "job mix formula".

No mixture shall be produced for use on the project until the amount of asphalt material to be added, with the appropriate blend, has been established. Using the representative samples submitted and the proposed proportion of each, trial mix tests will be run to determine the percentage of asphalt, by weight, to be added.

Job Mix Formula Tolerances and Adjustments

A. Tolerances - After the "job mix formula" is determined, the several constituents of the mixture at the time of acceptance shall conform thereto within the following tolerances:

Constituent of Mixture	Narrow Band Tolerance (Plus or minus from "job mix formula")
	Shall also lie within the broad band specification (Section 9-03.8(6))
Aggregate passing 1", 3/4" 5/8", 1/2" and 3/8" sieves	Within the range of the proportions specified in the broad band specifications (Section 9-03.8(6))
Aggregate passing 1/4" sieve	6%
Aggregate passing No. 10 sieve	5%
Aggregate passing No. 40 sieve	4%
Aggregate passing No. 200 sieve	2.0%
Asphalt cement	0.5%

B. Adjustments - Upon written request from the Contractor, the Project Engineer may approve field adjustments to the "job mix formula" (JMF) a maximum of 2% for the aggregate retained on the #10 sieve and above, 1% for the aggregate passing the No. 10 and No. 40 sieves, and 0.5% for the aggregate passing the No. 200 sieve. These field adjustments to the "job mix formula" may be made by the Project Engineer provided the change will produce material of equal or better quality. The above adjustments and/or any further adjustments as ordered by the Engineer will be considered as a new "job mix formula". Adjustments beyond these limits will require development of a new "job mix formula". The adjusted "job mix formula" plus or minus the allowed tolerances shall be within the range of the broad band specifications.

No field adjustments of the "job mix formula" relative to the asphalt cement content exceeding ±0.3% from the initial JMF will be made without the approval of the Materials Engineer.

APPENDIX B

SAMPLE AND LOT DATA

TABLE B.1: RAW AGGREGATE AND ASPHALT CONTENT DATA
NON-QA PROJECT 2861

SIEVE:	1/2"	3/8"	1/4"	#10	#40	#200	%AC
JMF:	97	85	71	38	14	3.7	5.6
SAMPLE:							
1	96	81	67	37	12	4.7	4.8
2	95	84	69	37	12	5.2	5.0
3	94	75	58	32	11	4.7	4.9
4	97	86	70	38	12	4.8	5.8
5	96	82	62	35	12	4.1	5.7
6	97	89	70	34	11	5.0	5.6
7	95	82	66	36	12	5.4	6.0
8	97	83	67	37	12	5.2	5.9
9	96	89	73	43	13	4.8	5.0
10	96	85	69	37	11	4.5	4.9
11	95	85	65	34	11	4.2	5.2
12	96	82	63	33	11	4.6	5.1
13	97	88	71	38	12	4.8	5.2
14	96	83	65	34	11	4.7	4.8
15	97	86	70	38	11	4.6	5.4
16	95	79	61	33	11	4.4	4.9
17	96	82	66	35	12	5.2	5.5
18	97	87	70	38	12	4.5	5.6
19	96	86	72	43	14	5.6	5.5
20	96	84	65	35	11	4.5	5.2
21	97	82	64	34	12	4.9	5.0
22	96	84	67	35	11	4.9	4.8
23	96	87	71	38	12	5.7	5.7
24	98	87	71	39	12	5.0	5.8
25	98	88	72	39	12	4.7	5.1
26	96	82	63	34	11	3.9	5.3
27	96	83	68	37	12	5.2	5.6
28	97	88	73	42	14	5.6	5.6
29	97	85	69	38	12	4.9	5.8
30	96	87	68	38	13	6.1	5.7

NOTE: VALUES FOR AGGREGATE REPRESENT % PASSING

TABLE B.2: RAW AGGREGATE AND ASPHALT CONTENT DATA
NON-QA PROJECT 3128

SIEVE:	1/2"	3/8"	1/4"	#10	#40	#200	%AC
JMF:	96	82	66	38	20	5.3	5.5
SAMPLE:							
1	96	73	53	28	14	4.2	5.1
2	96	87	74	44	22	6.4	5.5
3	99	87	74	44	22	6.2	5.2
4	95	85	67	40	21	6.5	4.2
5	96	84	70	39	21	6.7	5.4
6	98	85	68	40	21	6.6	5.3
7	97	83	66	38	20	5.7	5.3
8	96	87	71	42	22	6.7	5.8
9	96	83	69	41	21	6.4	4.5
10	96	85	68	39	20	6.4	5.5
11	96	87	73	43	22	6.5	5.4
12	98	86	69	39	20	6.4	5.2
13	95	82	65	37	20	6.5	5.1
14	94	83	69	41	19	5.3	5.4
15	94	81	66	38	20	6.0	5.8
16	95	79	61	35	19	5.7	5.5
17	95	84	68	40	20	6.0	5.3
18	96	84	64	37	20	5.7	5.5
19	95	83	66	39	19	5.3	5.5
20	95	80	65	38	20	5.7	5.4
21	95	86	67	40	21	6.3	5.5
22	95	81	62	35	19	6.0	5.5
23	97	84	68	39	20	4.9	5.3
24	94	84	68	38	19	4.1	5.5
25	96	81	61	34	18	4.9	5.6
26	95	80	62	36	18	4.2	5.6
27	92	78	57	34	20	6.1	5.3

NOTE: VALUES FOR AGGREGATE REPRESENT % PASSING

TABLE B.3: RAW AGGREGATE AND ASPHALT CONTENT DATA
NON-QA PROJECT 3328

SIEVE:	1/2"	3/8"	1/4"	#10	#40	#200	%AC
JMF:	96	87	68	37	17	3.9	4.9
SAMPLE:							
1	99	88	70	38	17	3.9	5.0
2	97	88	70	38	17	3.7	4.2
3	98	88	73	39	17	3.8	4.3
4	98	91	75	40	18	3.8	4.5
5	94	80	64	35	16	3.3	4.7
6	98	86	70	36	17	4.0	4.7
7	94	79	59	32	15	3.8	4.2
8	91	77	59	32	14	2.8	4.1
9	96	84	67	36	16	3.9	4.9
10	96	82	62	33	15	3.8	4.6
11	97	88	71	39	17	4.2	5.2
12	96	83	67	35	16	4.8	4.9
13	97	86	69	36	16	3.9	4.9
14	97	85	67	36	16	3.8	4.8
15	95	86	69	36	16	4.0	5.1
16	98	86	68	37	16	4.2	4.8
17	97	83	64	34	16	3.9	4.4
18	98	88	71	39	17	4.0	4.7
19	99	88	75	41	18	4.2	4.9
20	97	88	71	40	19	5.3	4.8
21	97	87	72	40	19	5.1	4.9
22	98	85	68	38	19	5.3	4.8
23	99	93	76	42	20	5.3	4.9
24	97	88	69	38	18	5.2	4.6
25	98	87	71	39	19	5.3	5.0
26	95	85	67	37	18	4.6	4.9
27	97	83	64	37	19	5.1	4.6
28	97	84	68	37	20	5.1	4.8
29	97	87	69	38	19	5.2	4.8
30	97	83	66	35	18	4.9	4.6
31	98	90	72	40	20	5.0	4.6

NOTE: VALUES FOR AGGREGATE REPRESENT % PASSING

TABLE B.4: RAW AGGREGATE AND ASPHALT CONTENT DATA
NON-QA PROJECT 3397

SIEVE:	1/2"	3/8"	1/4"	#10	#40	#200	%AC
JMF:	99	87	73	40	18	6.5	5.3
SAMPLE:							
1	97	81	68	40	21	7.0	5.6
2	97	90	73	39	22	7.0	5.5
3	97	84	68	39	23	6.0	5.0
4	97	86	70	42	24	6.3	5.3
5	99	87	64	39	19	7.0	5.5
6	98	87	70	38	20	6.9	5.6
7	98	85	70	39	19	7.0	5.3
8	99	88	74	39	18	7.6	5.4
9	96	83	68	34	15	6.0	5.6
10	98	84	67	33	15	6.0	5.6
11	98	83	64	37	18	5.1	5.2
12	97	88	72	38	17	6.1	5.4
13	96	84	66	38	18	6.3	5.3
14	99	86	69	39	18	5.5	5.4
15	96	85	70	40	19	5.7	5.2
16	98	87	69	41	20	4.9	5.3
17	99	90	72	42	20	6.2	5.3
18	98	84	65	37	16	4.3	5.5
19	97	87	70	40	18	5.5	5.4
20	98	85	68	37	16	4.7	5.3
21	98	87	68	38	17	4.9	5.2
22	98	87	70	37	16	6.0	5.1
23	98	86	68	37	16	5.4	5.3
24	98	82	66	37	17	5.3	5.2
25	97	86	72	41	19	6.9	5.2
26	97	81	64	35	17	6.4	5.2
27	99	86	70	37	17	5.2	4.9
28	97	87	70	39	18	6.5	5.5
29	96	81	63	35	17	6.1	5.2
30	98	83	65	38	17	4.5	5.5
31	99	89	73	38	16	6.0	5.6
32	99	84	66	35	15	4.5	5.1
33	99	86	70	36	15	5.2	5.2
34	99	86	70	38	17	5.5	5.4
35	97	88	69	36	16	5.2	5.3
36	98	86	68	36	17	5.9	5.3
37	99	87	67	39	17	5.0	5.4
38	100	90	71	40	17	5.5	5.1

NOTE: VALUE FOR AGGREGATE REPRESENTS % PASSING

TABLE B.5: RAW AGGREGATE AND ASPHALT CONTENT DATA
QA PROJECT 3491

SIEVE:	1/2"	3/8"	1/4"	#10	#40	#200	%AC
JMF:	98	86	69	38	18	5.0	5.3
SAMPLE: (LOT#1)							
1	99	84	64	36	18	5.8	5.13
2	99	84	67	37	18	5.5	5.30
3	98	81	63	34	17	5.5	5.14
4	99	85	67	38	19	6.2	5.25
5	99	85	66	38	19	6.0	5.16
6	99	83	65	38	19	6.0	5.42
7	99	84	67	39	21	6.7	5.53
8	98	83	65	34	17	5.6	5.30
9	98	87	70	38	18	6.5	5.26
10	98	84	67	40	21	5.7	5.55
11	99	87	70	41	22	6.0	5.65
12	98	87	69	40	20	5.8	5.34
13	99	87	68	36	18	6.2	5.31
14	99	89	68	36	16	5.4	5.46
15	99	91	72	37	17	6.7	5.27
16	99	89	70	33	13	5.8	5.34
Lot #2							
17	97	84	66	37	18	5.8	5.00
18	99	86	69	40	19	5.9	4.90
19	98	84	64	34	17	6.0	4.70
20	97	81	62	36	18	5.2	5.10
21	97	85	69	39	19	5.8	5.50
22	98	84	65	35	17	5.6	5.30
23	98	89	72	40	19	6.1	5.50
24	97	87	73	42	22	6.0	5.60
25	96	86	66	39	21	5.6	5.30
26	99	87	68	40	20	5.6	5.30
27	98	86	66	35	16	5.5	5.10
28	98	88	71	37	17	6.1	5.30
29	99	85	66	36	18	5.6	5.10
30	96	81	61	33	16	5.9	4.80
31	99	82	63	36	17	5.0	5.20
32	97	84	66	38	19	5.5	5.50
33	97	84	66	37	18	6.6	5.30

NOTES: 1) VALUES FOR AGGREGATE REPRESENT % PASSING
2) ASPHALT DATA PROVIDED TO THE SECOND DECIMAL IN THE TEST REPORTS

TABLE B.6: RAW AGGREGATE AND ASPHALT CONTENT DATA
QA PROJECT 3522

SIEVE:	1/2"	3/8"	1/4"	#10	#40	#200	%AC
JMF:	96	83	64	39	17	5.8	5.2
SAMPLE: (LOT#1)							
1	96	84	67	39	17	5.0	4.9
2	96	80	62	36	16	5.2	4.6
3	97	87	71	42	18	5.7	4.9
4	96	83	64	39	17	5.8	5.2
5	98	82	64	37	17	5.3	4.9
6	97	85	67	41	19	6.0	4.8
7	99	85	64	36	17	5.3	4.9
8	96	81	59	34	16	4.4	4.7
9	98	81	67	41	17	5.3	5.1
10	97	84	68	41	17	5.9	4.8
11	99	87	70	41	17	5.5	5.2
12	98	82	64	39	19	6.3	4.9
13	97	86	68	41	19	6.0	5.0
14	95	85	68	41	18	5.6	5.2
15	98	86	71	42	19	5.5	5.2
16	97	85	67	39	18	5.4	4.9
17	97	86	67	39	18	5.6	5.1
18	97	87	69	40	18	5.4	5.3
Lot#2							
19	97	86	68	40	18	5.5	5.2
20	95	84	65	39	17	6.1	5.1
21	97	85	66	39	17	5.1	5.1
22	99	87	70	44	19	6.4	5.2
23	96	86	69	41	19	6.5	5.3
24	96	87	63	37	16	4.4	5.2
25	97	85	68	41	19	5.7	5.1
26	98	82	64	39	19	6.3	4.9
27	97	83	62	35	17	5.0	5.1
28	98	91	74	44	19	6.5	5.4

NOTE: VALUES FOR AGGREGATE REPRESENT % PASSING

TABLE B.7: RAW AGGREGATE AND ASPHALT CONTENT DATA
QA PROJECT 3587

SIEVE:	1/2"	3/8"	1/4"	#10	#40	#200	%AC
JMF:	97	86	67	38	20	6.0	5.2
SAMPLE: (LOT#1)							
1	96	84	67	39	21	6.5	5.6
2	97	85	66	38	20	6.7	6.0
3	97	83	65	36	19	6.3	4.6
4	95	80	59	34	18	6.2	4.6
5	97	88	72	41	20	6.9	5.3
6	95	83	64	36	19	6.5	4.9
7	97	88	72	44	23	7.5	4.9
8	93	77	62	36	19	6.4	4.9
9	98	87	69	39	20	6.6	5.6
10	98	84	67	38	19	6.8	5.9
11	94	83	66	38	19	6.7	5.3
12	95	80	63	36	18	6.5	5.5
13	96	85	67	39	20	7.0	6.0
14	94	75	56	32	17	5.8	5.1
15	94	83	68	39	20	6.8	5.6
16	96	79	62	35	18	6.4	5.8
17	97	88	74	44	22	7.4	5.9
18	97	83	66	39	20	7.0	5.5
19	96	83	66	38	20	6.9	5.4
20	97	85	64	35	19	6.6	5.7
21	96	85	69	41	21	7.1	5.7
22	95	82	66	38	19	7.0	5.7
23	97	89	71	41	22	7.5	4.8
24	98	88	71	41	22	8.2	4.8
25	98	88	72	41	21	7.2	4.8
26	98	87	72	41	21	7.1	5.2
27	97	87	71	42	21	7.1	5.1
28	97	82	65	37	20	6.6	5.3

NOTE: VALUES FOR AGGREGATE REPRESENT % PASSING

TABLE B.8: RAW AGGREGATE AND ASPHALT CONTENT DATA
QA PROJECT 3636

SIEVE:	1/2"	3/8"	1/4"	#10	#40	#200	%AC
JMF:	95	84	68	38	17	5.1	4.7
SAMPLE: (LOT#1)							
1	96	87	73	43	18	6.0	4.5
2	94	81	64	35	17	6.2	4.2
3	95	86	70	37	17	5.8	5.1
4	97	88	71	40	19	6.5	4.5
5	96	86	70	37	15	5.6	4.9
6	91	77	61	34	15	5.5	4.2
7	94	84	68	38	16	5.6	4.2
8	96	87	72	43	18	6.2	4.7
9	94	84	65	36	15	5.4	4.6
10	94	82	66	37	16	6.0	4.8
11	95	84	68	37	16	5.9	5.0
12	96	86	70	39	12	5.9	5.0
13	96	84	73	40	19	5.8	5.3
14	93	82	68	38	19	6.4	4.7
15	97	90	75	43	21	6.0	5.4
16	95	85	69	38	19	6.6	4.4
17	92	82	67	35	16	6.8	4.4
18	93	81	67	35	18	6.4	4.9
19	96	90	74	45	22	7.1	4.8
20	96	83	62	35	18	6.1	4.1
21	94	84	67	37	17	6.2	4.9
22	91	82	67	36	17	6.7	4.7
23	94	83	67	36	16	5.7	4.5
24	98	91	77	42	17	6.2	5.1
25	93	83	68	36	16	6.2	4.0
26	95	84	70	41	18	6.6	4.9
27	96	85	69	37	17	6.2	4.7
28	93	82	68	36	18	6.6	4.6
29	95	87	73	39	18	5.9	4.7
30	93	86	71	39	18	5.9	4.6
31	94	85	67	36	17	5.6	4.5
32	96	83	73	38	18	6.0	4.8
33	96	87	75	40	18	6.4	4.8
34	93	84	68	37	18	6.1	4.7
35	93	84	67	38	20	6.2	4.8
36	95	87	72	41	17	6.6	4.7
37	96	86	69	36	18	5.3	4.4
38	98	89	73	37	19	5.7	4.4

(CONTINUED NEXT PAGE)

TABLE B.8: RAW AGGREGATE AND ASPHALT CONTENT DATA
QA PROJECT 3636 (CONTINUED)

39	96	87	72	40	20	5.9	4.7
40	93	82	69	40	19	5.0	4.6
41	95	85	72	40	17	5.3	4.8
42	94	83	69	38	18	5.5	4.8
43	97	88	73	39	20	5.1	4.9
44	95	85	71	40	17	5.6	4.8
45	96	86	71	37	20	5.7	4.9
46	97	86	70	41	16	5.8	4.7
47	97	87	70	35	16	5.9	4.8
48	96	87	70	36	17	5.3	4.9
49	96	86	72	37	17	5.4	4.7
50	98	88	73	38	18	5.5	4.9
51	92	84	68	35	17	5.6	4.5
52	95	85	69	36	18	5.6	4.9
53	96	88	74	42	23	5.2	4.8
54	96	84	69	35	17	6.0	4.6
55	95	87	70	38	18	5.8	4.7
56	97	88	72	40	21	6.5	4.8
57	96	84	67	36	17	5.8	4.7
58	92	82	67	36	19	6.6	4.7
59	96	85	68	37	19	6.5	4.8
60	93	85	68	36	17	6.5	4.5
61	94	84	68	37	19	6.6	4.7
62	96	86	68	35	18	6.2	5.0
63	91	77	60	32	16	4.9	4.4
64	95	83	68	37	18	6.0	4.5
65	95	86	70	40	20	6.0	4.9
66	96	84	66	35	17	6.0	4.6
67	96	86	72	33	18	7.0	4.9
68	95	86	73	38	18	6.9	4.9
69	96	87	70	36	17	6.5	4.8
70	95	86	70	36	16	6.4	4.7
71	94	83	69	39	17	6.0	4.7
72	97	88	72	39	19	6.5	4.8
73	94	85	70	36	18	6.2	4.8
74	94	85	70	37	18	6.3	4.6
75	98	88	72	38	18	6.5	4.8
76	96	88	73	37	17	6.5	5.0
77	96	85	71	36	16	6.2	4.9
78	95	85	68	35	17	5.8	4.8
79	97	87	70	36	17	6.3	4.8
80	96	89	73	38	17	6.2	4.9
81	95	87	71	37	17	6.1	4.8

NOTE: VALUES FOR AGGREGATE REPRESENT % PASSING

TABLE B.9: NON-QA DENSITY DATA, %RICE DENSITY
VALUES = LOT MEANS

PROJ: LOT	2861	3128	3328	3397
1	93.62	92.36	92.16	95.30
2	92.50	92.16	93.44	95.82
3	92.60	92.30	91.66	95.84
4	91.96	94.38	92.98	95.32
5	92.20	92.42	92.74	95.74
6	93.66	93.78	92.48	94.68
7	94.22	93.08	92.38	94.18
8	95.00	93.34	90.68	93.92
9	93.22	92.90	90.36	92.26
10	92.48	92.46	89.94	92.40
11	92.10	92.32	90.82	91.26
12	92.22	92.46	90.80	94.26
13	92.62	92.62	92.70	94.04
14	92.74	93.82	93.96	94.52
15	92.94	92.38	92.78	92.76
16	92.86	92.70	92.92	93.78
17	91.96	92.74	93.02	94.00
18	92.60	92.86	93.02	95.10
19	92.80	92.16	91.98	96.06
20	92.18	92.84	92.60	93.82
21	92.30	93.06	91.86	93.18
22	92.40	93.34	90.94	92.80
23	92.52	93.52	91.94	93.58
24	92.52	93.06	93.56	94.30
25	92.46	93.42	92.92	95.02
26	92.78	92.50	92.38	94.14
27	92.28	92.12	92.66	92.64
28	92.20	92.26		94.62
29	91.88	93.86		93.78
30	91.48	93.48		94.74
31	91.98	93.26		94.52
32	92.34	92.72		93.48
33	92.62	92.30		94.54
34	92.84	93.32		93.82
35	92.66	94.80		92.68
36	92.56	92.52		94.66
37	92.58			94.22
38	92.38			93.02
39	93.10			92.86
40	92.18			93.28
41				95.26
42				95.44
43				93.40
44				92.86
45				92.90
46				93.84
47				94.70
48				92.96
49				94.32
50				92.78
51				93.30
52				93.46
53				95.12
54				95.02
55				95.78
56				94.24
57				94.84
58				94.32
59				96.08
60				96.90
61				95.10
62				95.08
63				93.46
64				92.62
65				93.48
66				92.94
67				92.56
68				93.50
69				94.36
70				92.22
71				95.38
72				94.00
73				93.78
74				94.34
75				95.44
76				95.46
77				93.82
78				93.44
79				94.44
80				92.90
81				90.62
82				90.96
83				92.38

TABLE B.10: QA DENSITY DATA, %RICE DENSITY
VALUES = LOT MEANS

PROJ: LOT	3587	3522
1	92.78	93.66
2	92.70	93.38
3	91.66	93.86
4	92.14	93.50
5	92.24	93.96
6	92.38	93.00
7	91.74	92.52
8	92.46	93.88
9	92.34	94.38
10	93.74	94.56
11	92.76	95.16
12	92.82	95.52
13	92.76	95.02
14	93.04	94.32
15	93.06	95.10
16	93.90	93.26
17	92.88	93.40
18	93.18	93.94
19	93.12	94.20
20	92.86	92.66
21	93.24	91.82
22	92.56	92.96
23	93.64	91.42
24	94.82	92.20
25		92.16
26		92.78
27		92.38
28		92.48
29		92.10
30		91.80
31		93.48
32		92.46
33		92.60
34		93.54
35		91.24

PROJ: LOT	3522
36	93.44
37	92.52
38	93.78
39	93.68
40	94.60
41	94.18
42	94.64
43	92.80
44	93.80
45	92.24
46	93.20

(CONTINUED NEXT PAGE)

TABLE B.10: QA DENSITY DATA, %RICE DENSITY
VALUES = LOT MEANS (CONTINUED)

PROJ: 3636

LOT		LOT		LOT	
1	93.08	45	93.00	89	92.26
2	92.96	46	92.02	90	93.76
3	92.48	47	92.48	91	92.04
4	92.62	48	92.28	92	91.84
5	92.04	49	91.78	93	91.82
6	92.94	50	91.62	94	93.32
7	91.16	51	93.42	95	92.40
8	92.90	52	93.60	96	92.50
9	92.52	53	93.38	97	93.14
10	91.68	54	92.70	98	92.32
11	92.22	55	93.20	99	92.44
12	92.06	56	92.60	100	93.20
13	93.44	57	93.28	101	92.94
14	91.22	58	92.58	102	91.60
15	92.36	59	92.42	103	92.62
16	92.12	60	92.38	104	90.30
17	92.68	61	91.78	105	92.18
18	92.52	62	93.18	106	92.28
19	91.58	63	94.12	107	88.64
20	92.26	64	93.06	108	88.90
21	91.68	65	93.04	109	92.82
22	91.04	66	92.62	110	92.18
23	93.40	67	92.90	111	92.62
24	93.38	68	92.06	112	92.10
25	92.96	69	91.86	113	92.84
26	93.72	70	92.38	114	91.78
27	94.42	71	91.86	115	91.98
28	93.58	72	93.26	116	93.76
29	93.12	73	92.80	117	92.90
30	94.34	74	93.88	118	92.48
31	92.50	75	94.12	119	92.12
32	93.14	76	92.30	120	93.06
33	92.98	77	93.20	121	92.48
34	92.30	78	92.14	122	93.70
35	92.36	79	93.50	123	92.50
36	91.14	80	91.86	124	91.90
37	91.16	81	92.62	125	92.99
38	93.12	82	92.16	126	92.34
39	92.70	83	92.64	127	91.60
40	92.30	84	91.30	128	92.60
41	92.24	85	93.70	129	91.66
42	92.76	86	92.80	130	92.10
43	92.84	87	92.58	131	92.28
44	92.48	88	91.38		

APPENDIX C

EXAMINATION OF WSDOT QA SPECIFICATION, TABLE 2

MIL-STD-414 was used to examine a PF = 1.00 in Table 2 of the WSDOT QA Specification. This examination was simply to see how Table B-3 for MIL-STD-414 and Table 2 compare for a PF = 1.00 (Table B-3 is titled "Master Table for Normal and Tightened Inspection for Plans Based on Variability Unknown (standard deviation method) (double specification limit and Form 2 - single specification limit)").

Sample Size (n)	Quality Level (QL)[1]	Percent Defective[2]	Acceptable Quality Level (AQL)[3]
3	68	32	9.1
4	74	26	8.2
5	78	22	7.5
7	81	19	7.5
10-11	84	16	7.0
26-37 (31.5)	89	11	≈5.6
38-69 (53.5)	90	10	≈5.6

Notes
1. From WSDOT QA Specification for a PF = 1.00
2. Percent defective = 100-QL
3. From MIL-STD-414, Table B-3

The AQL is defined by Duncan [13] as

> "...poorest level of quality or maximum fraction defective for the supplier's [contractor's] process that the consumer [WSDOT] would consider to be acceptable as a process average for the purposes of acceptance testing. It will be noted that the AQL so defined is a characteristic of the supplier's process and not of the sampling plan used by the consumer. ... It is not intended to be a specification on the product nor a target for production. It is simply the standard which the consumer indicates he will use in judging the product."

Based on the above definition and MIL-STD-414, Table B-3, it appears that full pay (PF = 1.00) for the contractor provides for an average out of specification production tolerance of about 7 percent of a lot (based on n = 10) and about 5 to 6 percent of a lot for much larger samples (n ≈ 30 to 50).

APPENDIX D

SUMMARY OF STATISTICAL PARAMETERS

TABLE D.1: SUMMARY OF STATISTICS-JOB 2861-NON-QA

	1/2"	3/8	1/4	#10	#40	#200	%AC
# Tests:	30	30	30	30	30	30	30
Mean:	99.2	99.3	95.1	96.6	84.5	131.0	95.5
Max:	101.0	104.7	102.8	113.2	100.0	164.9	107.1
Min:	96.9	88.2	81.7	84.2	78.6	105.4	85.7
Range:	4.1	16.5	21.1	28.9	21.4	59.5	21.4
St Dev:	0.92	3.70	5.29	7.38	5.96	12.53	6.69
Var:	0.86	13.70	28.01	54.52	35.48	157.04	44.80
CV:	0.93	3.73	5.57	7.65	7.05	9.57	7.01

TABLE D.2: SUMMARY OF STATISTICS-JOB 3128-NON-QA

	1/2"	3/8	1/4	#10	#40	#200	%AC
# Tests:	27	27	27	27	27	27	27
Mean:	99.6	101.3	100.5	101.2	99.6	110.0	97.1
Max:	103.1	106.1	112.1	115.8	110.0	126.4	105.5
Min:	95.8	89.0	80.3	73.7	70.0	77.4	76.4
Range:	7.3	17.1	31.8	42.1	40.0	49.1	29.1
St Dev:	1.48	3.94	7.29	8.98	8.20	14.77	6.12
Var:	2.18	15.50	53.15	80.62	67.17	218.2	37.45
CV:	1.48	3.89	7.25	8.87	8.23	13.43	6.30

TABLE D.3: SUMMARY OF STATISTICS-JOB 3328-NON-QA

	1/2"	3/8"	1/4"	#10	#40	#200	%AC
#Tests:	31	31	31	31	31	31	31
Mean:	100.9	98.5	100.7	100.5	102.1	111.8	96.3
Max:	103.1	106.9	111.8	113.5	117.6	135.9	106.1
Min:	94.8	88.5	86.8	86.5	82.4	71.8	83.7
Range:	8.3	18.4	25.0	27.0	35.3	64.1	22.4
St Dev:	1.75	3.93	6.11	6.78	9.43	17.77	5.42
Var:	3.05	15.45	37.32	45.98	88.92	315.88	29.41
CV:	1.73	3.99	6.07	6.75	9.24	15.89	5.63

TABLE D.4: SUMMARY OF STATISTICS-JOB 3397-NON-QA

	1/2"	3/8	1/4	#10	#40	#200	%AC
# Tests:	38	38	38	38	38	38	38
Mean:	98.8	98.5	94.0	94.9	99.0	89.5	100.5
Max:	101.0	103.4	101.4	105.0	133.3	116.9	105.7
Min:	97.0	93.1	86.3	82.5	83.3	66.2	92.5
Range:	4.0	10.3	15.1	22.5	50.0	50.8	13.2
St Dev:	1.04	2.77	3.75	5.21	11.97	12.58	3.30
Var:	1.08	7.65	14.05	27.19	143.24	158.37	10.91
CV:	1.05	2.81	3.99	5.49	12.09	14.06	3.29

TABLE D.5: SUMMARY OF STATISTICS-JOB 3491-QA

	1/2	3/8	1/4	#10	#40	#200	%AC
# Tests:	33	33	33	33	33	33	33
Mean:	100.2	99.1	97.1	98.0	101.7	117.1	99.4
Max:	101.0	105.8	105.8	110.5	122.2	134.0	106.6
Min:	98.0	94.2	88.4	86.8	72.2	100.0	88.7
Range:	3.0	11.6	17.4	23.7	50.0	34.0	17.9
St Dev:	0.96	2.85	4.24	6.14	10.53	7.99	4.13
Var:	0.92	8.12	17.98	37.67	110.89	63.77	17.03
CV:	0.96	2.87	4.37	6.26	10.36	6.82	4.15

TABLE D-6: SUMMARY OF STATISTICS-JOB 3522-QA

	1/2	3/8	1/4	#10	#40	#200	%AC
# Tests:	28	28	28	28	28	28	28
Mean:	101.1	102.1	104.1	101.4	104.4	96.5	97.0
Max:	103.1	109.6	115.6	112.8	111.8	112.1	103.8
Min:	99.0	96.4	92.2	87.2	94.1	75.9	88.5
Range:	4.1	13.2	23.4	25.6	17.7	36.2	15.3
St Dev:	1.13	2.87	5.11	6.26	6.12	9.59	3.75
Var:	1.28	8.26	26.08	39.20	37.49	91.93	14.09
CV:	1.12	2.82	4.90	6.18	5.86	9.94	3.87

TABLE D-7: SUMMARY OF STATISTICS-JOB 3587-QA

	1/2	3/8	1/4	#10	#40	#200	%AC
# Tests:	28	28	28	28	28	28	28
Mean:	99.2	97.6	99.8	101.3	99.6	113.9	102.7
Max:	101.0	103.5	110.4	115.8	115.0	136.7	115.4
Min:	95.9	87.2	83.6	84.2	85.0	96.7	88.5
Range:	5.1	16.3	26.8	31.6	30.0	40.0	26.9
St Dev:	1.45	4.11	6.34	7.63	7.06	7.97	8.31
Var:	2.10	16.87	40.22	58.22	49.87	63.59	69.13
CV:	1.46	4.21	6.36	7.53	7.09	7.00	8.10

TABLE D-8: SUMMARY OF STATISTICS-JOB 3636-QA

	1/2	3/8	1/4	#10	#40	#200	%AC
# Tests:	81	81	81	81	81	81	81
Mean:	100.0	101.4	102.4	99.0	104.0	104.1	100.5
Max:	103.2	108.3	113.2	118.4	135.3	122.4	114.9
Min:	95.8	91.7	88.2	84.2	70.6	84.5	85.1
Range:	7.4	16.6	25.0	34.2	64.7	37.9	29.8
St Dev:	1.73	3.01	4.45	6.33	9.57	8.09	5.14
Var:	3.00	9.09	19.80	40.11	91.55	65.44	26.44
CV:	1.73	2.97	4.34	6.40	9.20	7.77	5.12

TABLE D.9: NON-QA DENSITY DATA, %RICE DENSITY VALUES BASED ON LOT MEANS

Job:	2861	3128	3328	3397	ALL
# Lots:	40	36	27	83	186
Mean:	92.61	92.93	92.21	93.98	93.23
Max:	95.00	94.80	93.96	96.90	96.90
Min:	91.66	92.12	89.94	90.62	89.94
Range:	3.34	2.68	4.02	6.28	6.96
St Dev:	0.640	0.653	1.031	1.203	1.210
Var:	0.409	0.426	1.063	1.448	1.465
CV:	0.691	0.702	1.118	1.280	1.298

TABLE D.10: QA DENSITY DATA, %RICE DENSITY VALUES BASED ON LOT MEANS

Job:	3522	3587	3636	ALL
# Lots:	46	24	131	201
Mean:	93.34	92.87	92.49	92.73
Max:	95.52	94.82	94.42	95.52
Min:	91.24	91.66	88.64	88.64
Range:	4.28	3.16	5.78	6.88
St Dev:	1.035	0.694	0.867	0.947
Var:	1.070	0.482	0.756	0.897
CV:	1.108	0.748	0.937	1.021

APPENDIX E

NORMALITY TESTS

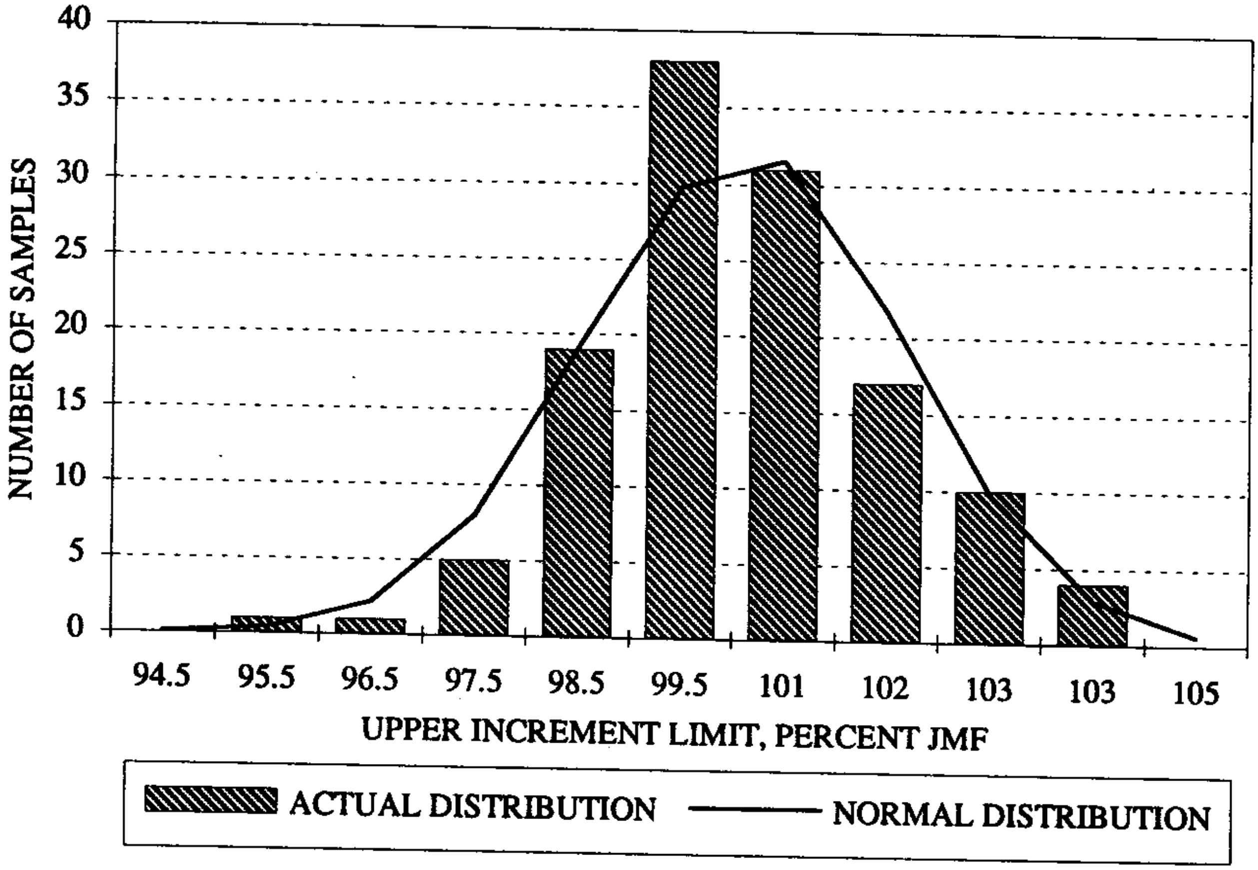

Figure E.1. Chi-Square Test for Normality - 1/2 Inch Aggregate, Non-QA

Table E.1. Chi-Square Test for Normality - 1/2 Inch Aggregate, Non-QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
97.5	-1.38	0.0838	0.0838	10.6	7	1.20
98.5	-0.72	0.2358	0.1520	19.2	19	0.00
99.5	-0.07	0.4721	0.2363	29.9	38	2.19
100.5	0.59	0.7224	0.2503	31.5	31	0.01
101.5	1.25	0.8944	0.1720	21.7	17	1.01
102.5	1.91	0.9719	0.0775	9.8	10	0.01
Infinity	Infinity	1.0000	0.0281	3.0	4	0.33
		Sum	1	125.6	126	4.75
				Table Value		9.49

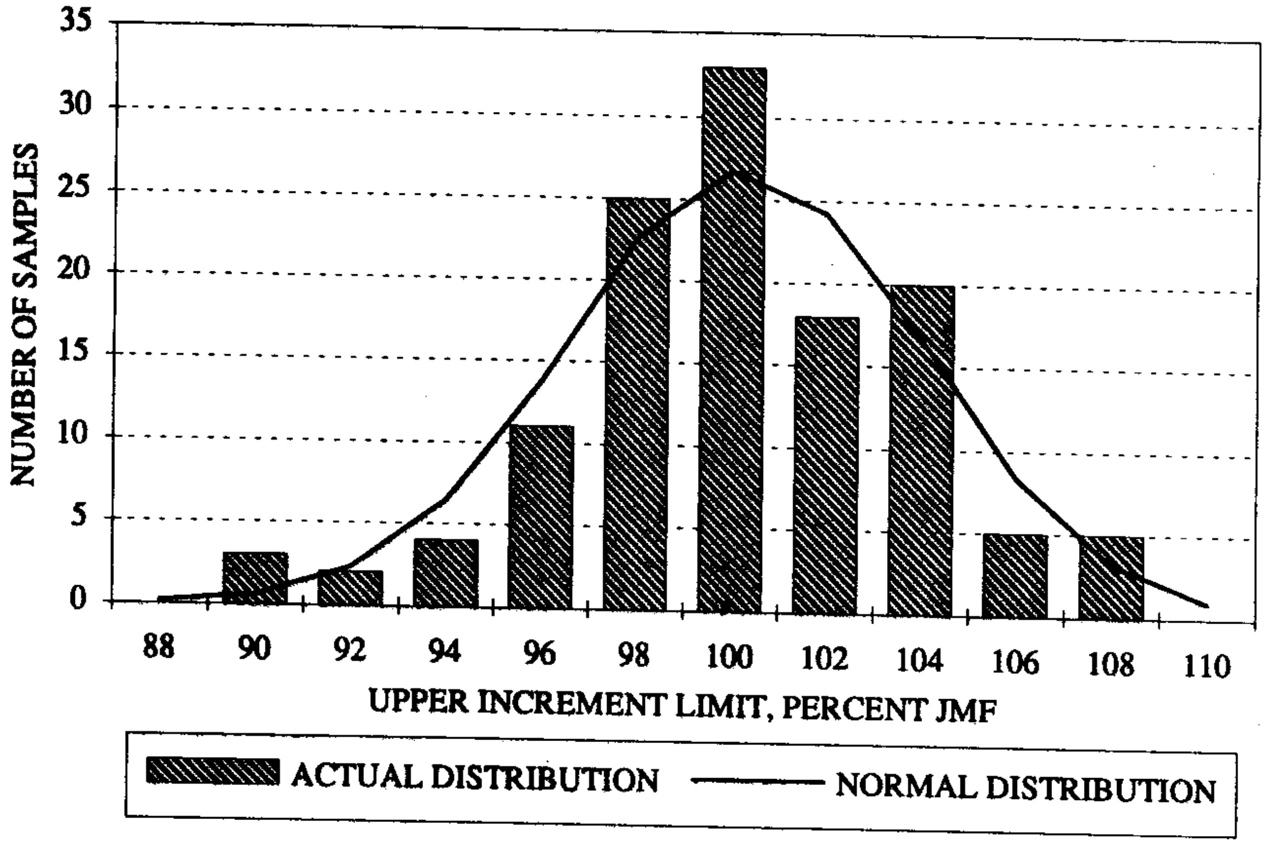

Figure E.2. Chi-Square Test for Normality - 3/8 Inch Aggregate, Non-QA

Table E.2. Chi-Square Test for Normality - 3/8 Inch Aggregate, Non-QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
92	-1.98	0.0239	0.0239	3.0	5	1.33
94	-1.44	0.0749	0.0510	6.4	4	0.92
96	-0.90	0.1841	0.1092	13.8	11	0.55
98	-0.35	0.3632	0.1791	22.6	25	0.26
100	0.19	0.5753	0.2121	26.7	33	1.47
102	0.73	0.7673	0.1920	24.2	18	1.58
104	1.28	0.8997	0.1324	16.7	20	0.66
106	1.82	0.9656	0.0659	8.3	5	1.31
Infinity	Infinity	1.0000	0.0344	4.3	5	0.10
		Sum	1	126.0	126	8.20
				Table Value		12.59

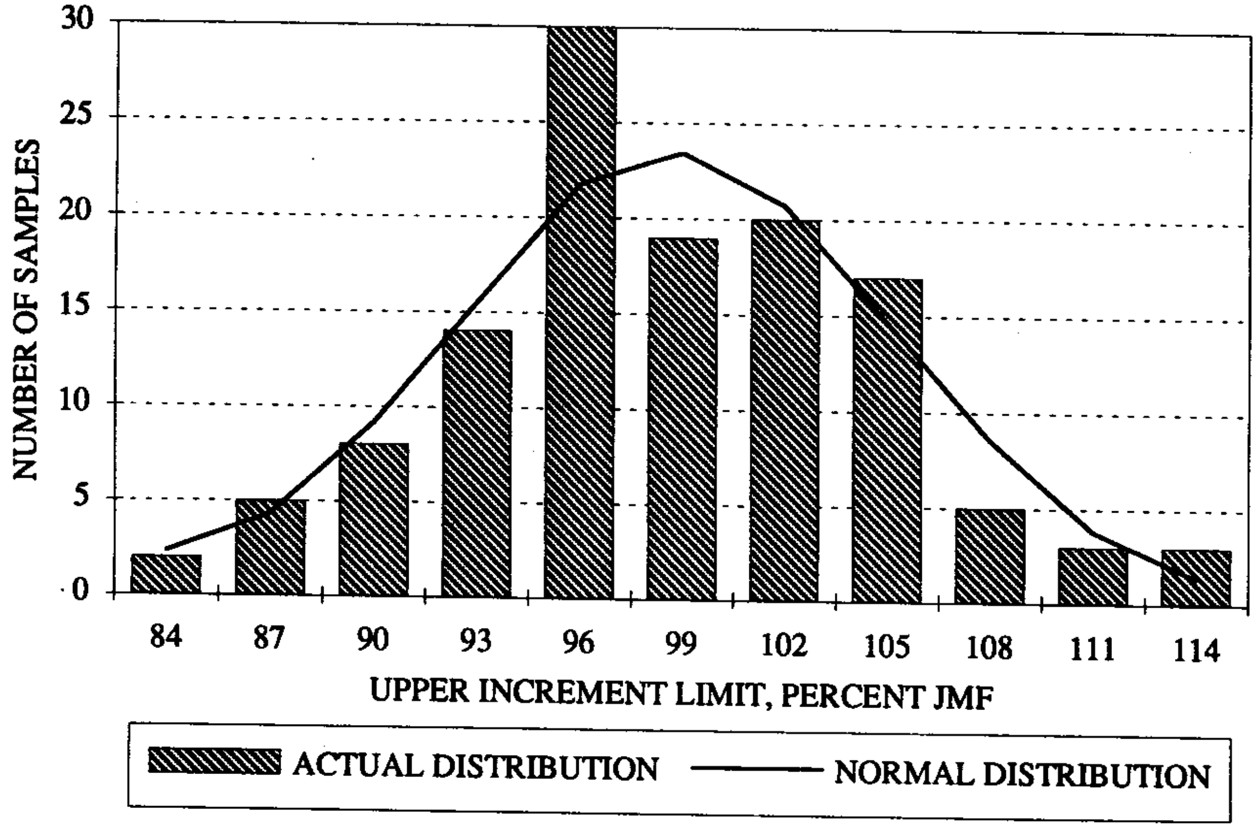

Figure E.3. Chi-Square Test for Normality - 1/4 Inch Aggregate, Non-QA

Table E.3. Chi-Square Test for Normality - 1/4 Inch Aggregate, Non-QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
87	-1.62	0.0526	0.0526	6.6	7	0.02
90	-1.15	0.1251	0.0725	9.1	8	0.14
93	-0.68	0.2483	0.1232	15.5	14	0.15
96	-0.20	0.4207	0.1724	21.7	30	3.15
99	0.27	0.6064	0.1857	23.4	19	0.83
102	0.74	0.7704	0.1640	20.7	20	0.02
105	1.21	0.8869	0.1165	14.7	17	0.37
108	1.69	0.9545	0.0676	8.5	5	1.45
Infinity	Infinity	1.0000	0.0455	5.7	6	0.01
		Sum	1	126.0	126	6.15
				Table Value		12.59

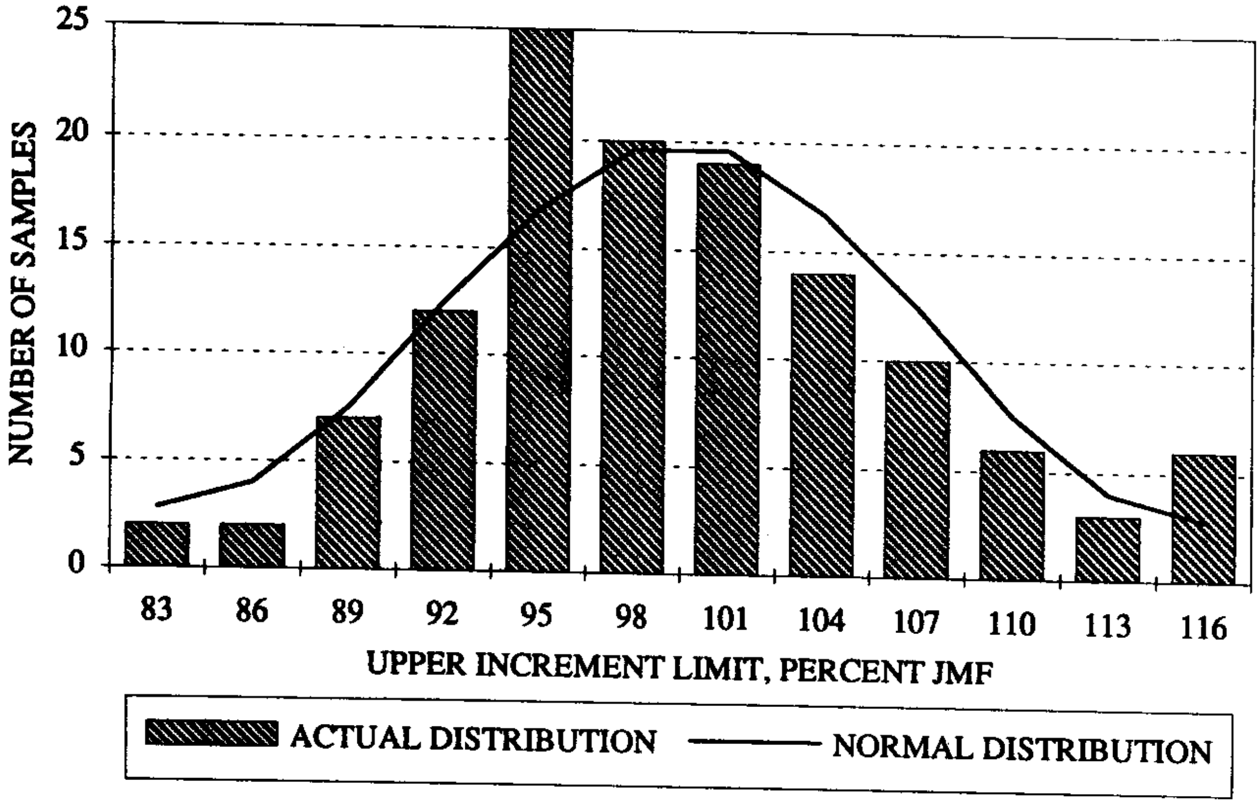

Figure E.4. Chi-Square Test for Normality - #10 Aggregate, Non-QA

Table E.4. Chi-Square Test for Normality - #10 Aggregate, Non-QA

1	2	3	4	5	6	7
X	$z = \frac{(X - \overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
86	-1.61	0.0537	0.0537	6.8	4	1.13
89	-1.21	0.1131	0.0594	7.5	7	0.03
92	-0.80	0.2119	0.0988	12.4	12	0.02
95	-0.40	0.3446	0.1327	16.7	25	4.10
98	0.00	0.5000	0.1554	19.6	20	0.01
101	0.40	0.6554	0.1554	19.6	19	0.02
104	0.80	0.7881	0.1327	16.7	14	0.44
107	1.21	0.8869	0.0988	12.4	10	0.48
110	1.61	0.9463	0.0594	7.5	6	0.29
Infinity	Infinity	1.0000	0.0537	6.8	9	0.74
		Sum	1	126.0	126	7.26
				Table Value		14.07

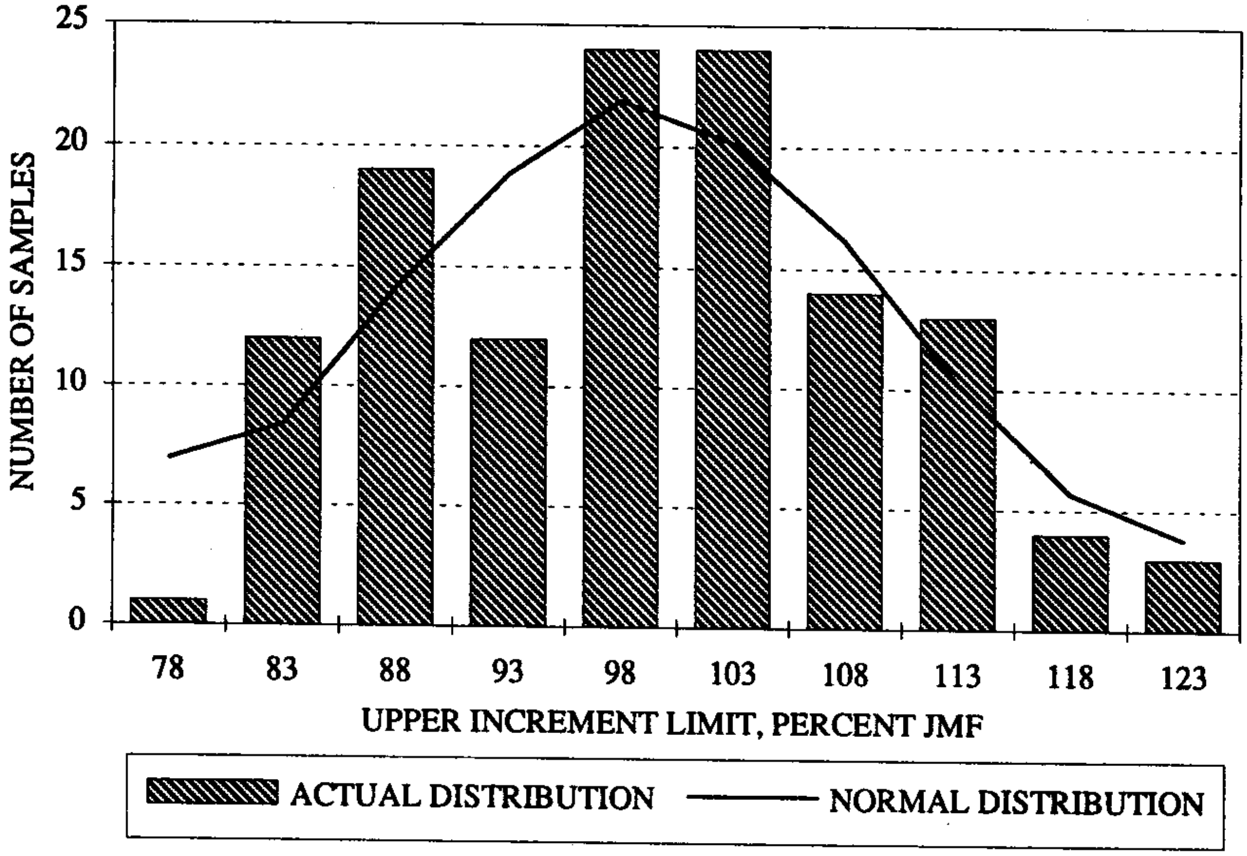

Figure E.5. Chi-Square Test for Normality - #40 Aggregate, Non-QA

Table E.5. Chi-Square Test for Normality - #40 Aggregate, Non-QA

1	2	3	4	5	6	7
X	$z = \frac{(X - \overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
83	-1.17	0.1210	0.1210	15.2	13	0.33
88	-0.73	0.2327	0.1117	14.1	19	1.72
93	-0.30	0.3821	0.1494	18.8	12	2.47
98	0.14	0.5557	0.1736	21.9	24	0.21
103	0.57	0.7157	0.1600	20.2	24	0.73
108	1.01	0.8438	0.1281	16.1	14	0.28
113	1.44	0.9251	0.0813	10.2	13	0.74
Infinity	Infinity	1.0000	0.0749	9.4	7	0.63
		Sum	1	126.0	126	7.12
				Table Value		11.07

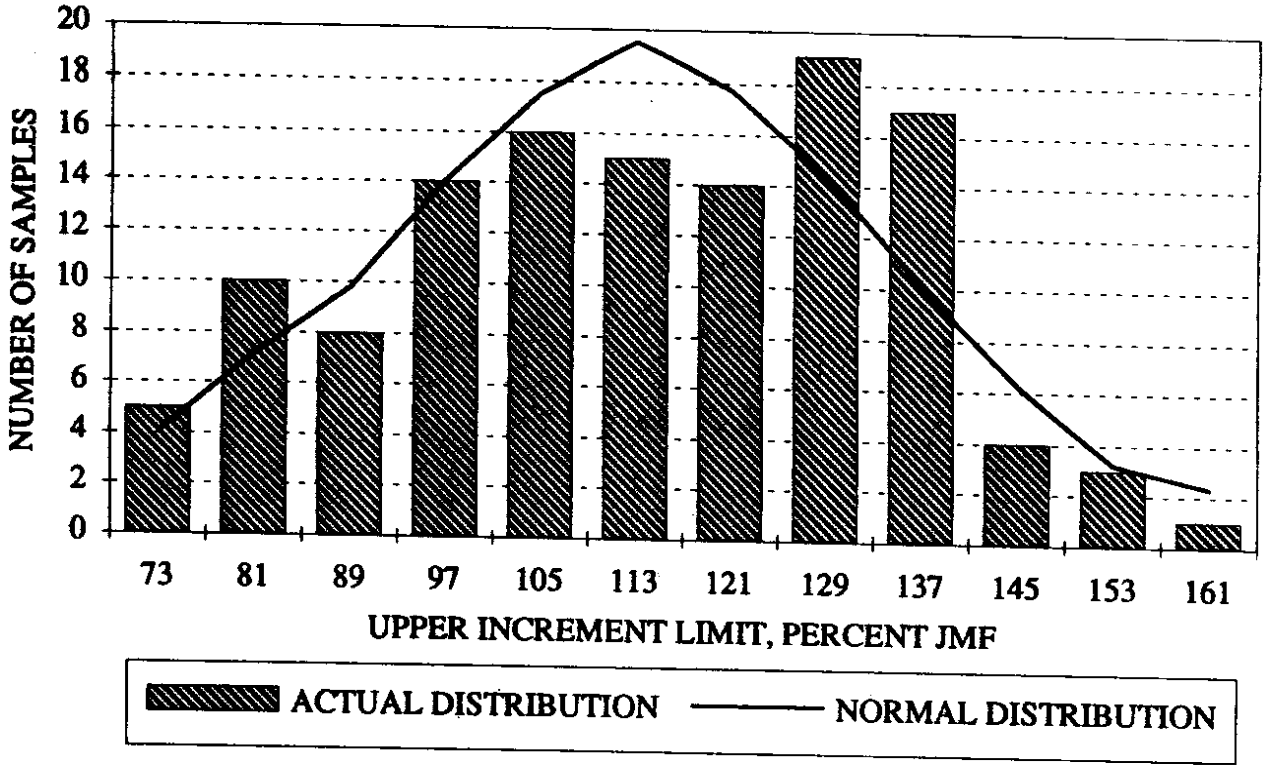

Figure E.6. Chi-Square Test for Normality - #200 Aggregate, Non-QA

Table E.6. Chi-Square Test for Normality - #200 Aggregate, Non-QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
73	-1.73	0.0318	0.0318	4.0	5	0.25
81	-1.35	0.0885	0.0567	7.1	10	1.14
89	-0.97	0.1660	0.0775	9.8	8	0.32
97	-0.59	0.2776	0.1116	14.1	14	0.00
105	-0.21	0.4168	0.1392	17.5	16	0.14
113	0.18	0.5714	0.1546	19.5	15	1.03
121	0.56	0.7123	0.1409	17.8	14	0.79
129	0.94	0.8264	0.1141	14.4	19	1.49
137	1.32	0.9066	0.0802	10.1	17	4.70
145	1.71	0.9564	0.0498	6.3	4	0.82
Infinity	Infinity	1.0000	0.0436	5.5	4	0.41
		Sum	1	126.0	126	11.09
				Table Value		15.51

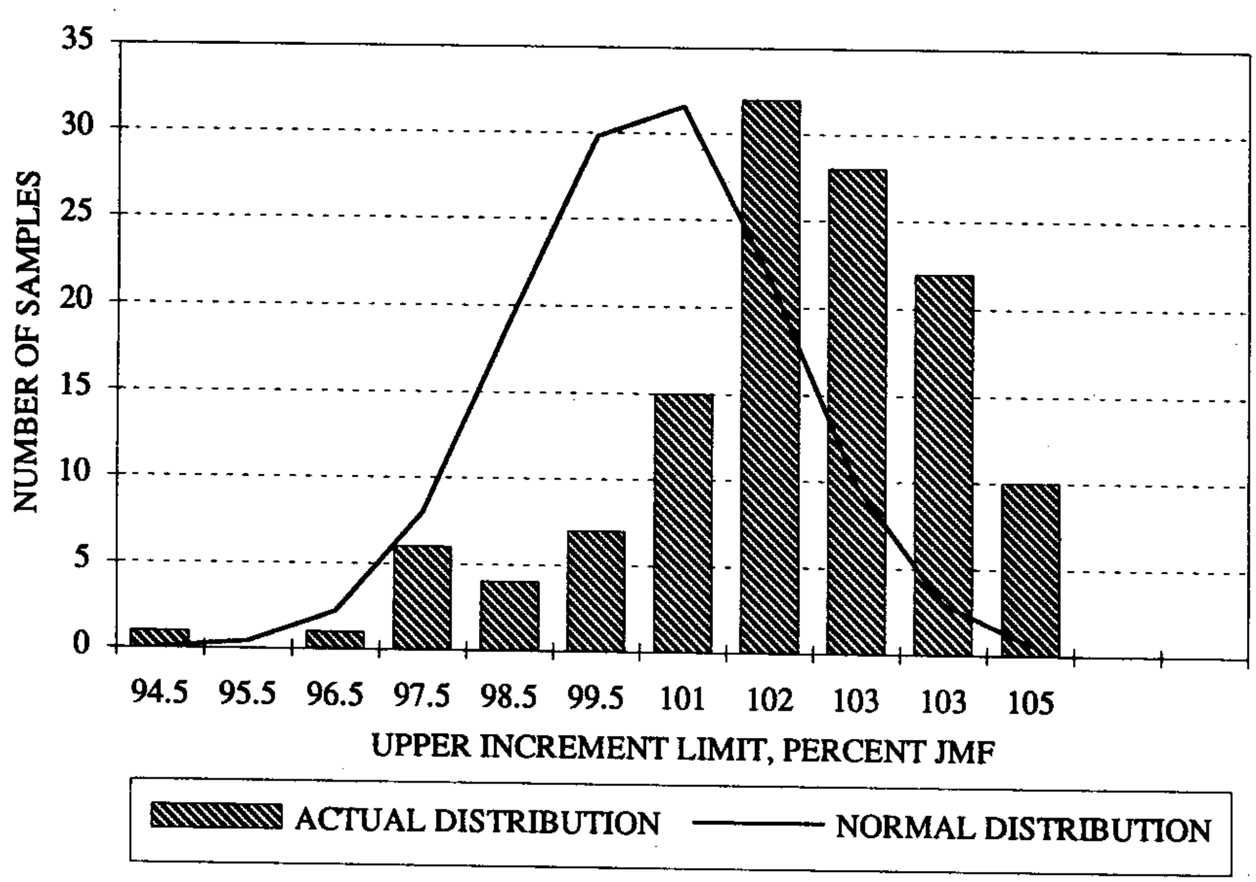

Figure E.7. Chi-Square Test for Normality - %AC, Non-QA

Table E.7. Chi-Square Test for Normality - %AC, Non-QA

1	2	3	4	5	6	7
X	$z = \frac{(X - \overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
89.25	-1.44	0.0749	0.0505	9.6	12	0.60
92.25	-0.92	0.1788	0.1039	13.1	7	2.83
95.25	-0.39	0.3483	0.1695	21.4	15	1.89
98.25	0.13	0.5517	0.2034	25.6	32	1.58
101.25	0.66	0.7454	0.1937	24.4	28	0.53
104.25	1.18	0.8810	0.1356	17.1	22	1.41
Infinity	Infinity	1.0000	0.1190	14.6	10	1.45
		Sum	1	125.8	126	10.30
					Table Value	9.49
					0.025 Table Value	11.14

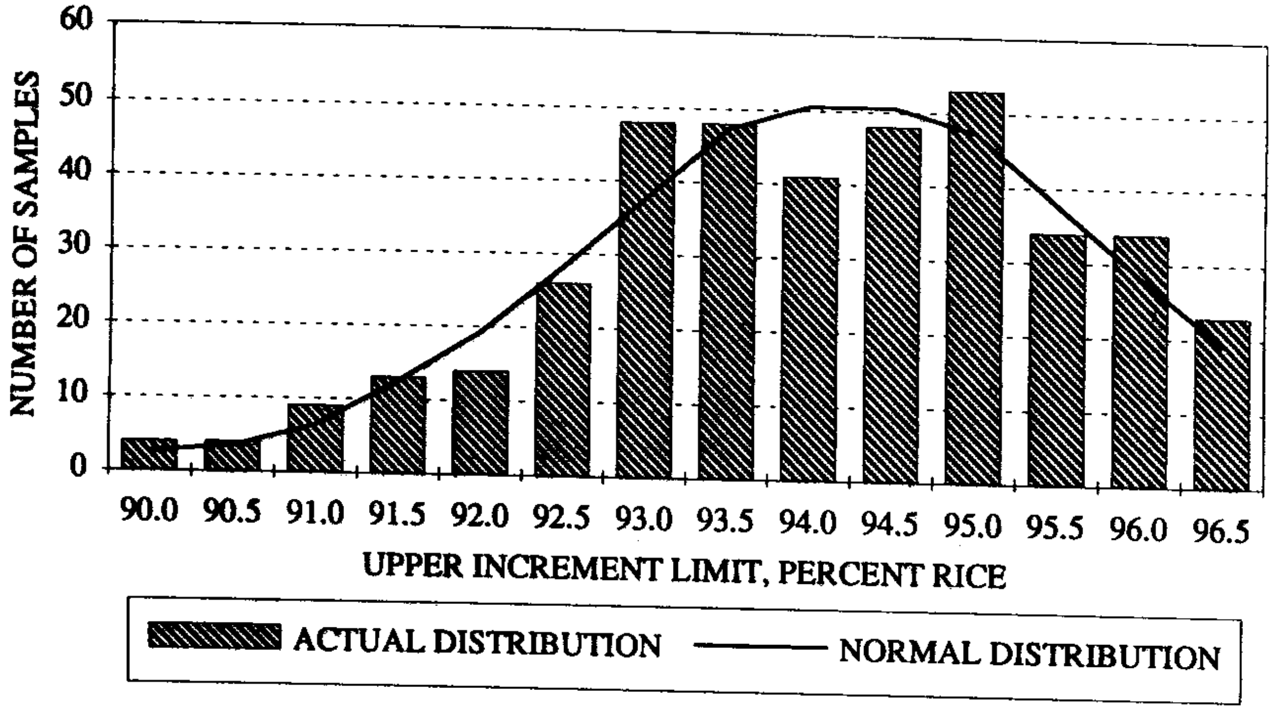

Figure E.8. Test for Normality, 3397 Sample Density

Table E.8. Test for Normality, 3397 Sample Density

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
90.0	-2.50	0.0062	0.0062	2.6	4	0.79
90.5	-2.19	0.0143	0.0081	3.4	4	0.12
91.0	-1.88	0.0294	0.0151	6.3	9	1.19
91.5	-1.56	0.0594	0.0300	12.5	13	0.02
92.0	-1.25	0.1056	0.0462	19.2	14	1.40
92.5	-0.94	0.1736	0.0680	28.2	26	0.17
93.0	-0.63	0.2643	0.0907	37.6	48	2.85
93.5	-0.31	0.3783	0.1140	47.3	48	0.01
94.0	0.00	0.5000	0.1217	50.5	41	1.79
94.5	0.31	0.6217	0.1217	50.5	48	0.12
95.0	0.63	0.7357	0.1140	47.3	53	0.68
95.5	0.94	0.8264	0.0907	37.6	34	0.35
96.0	1.25	0.8944	0.0680	28.2	34	1.18
96.5	1.56	0.9406	0.0462	19.2	23	0.76
Infinity	Infinity	1.0000	0.0594	24.7	16	3.04
		Sum	1	415.0	415	14.49
				Table Value		21.03

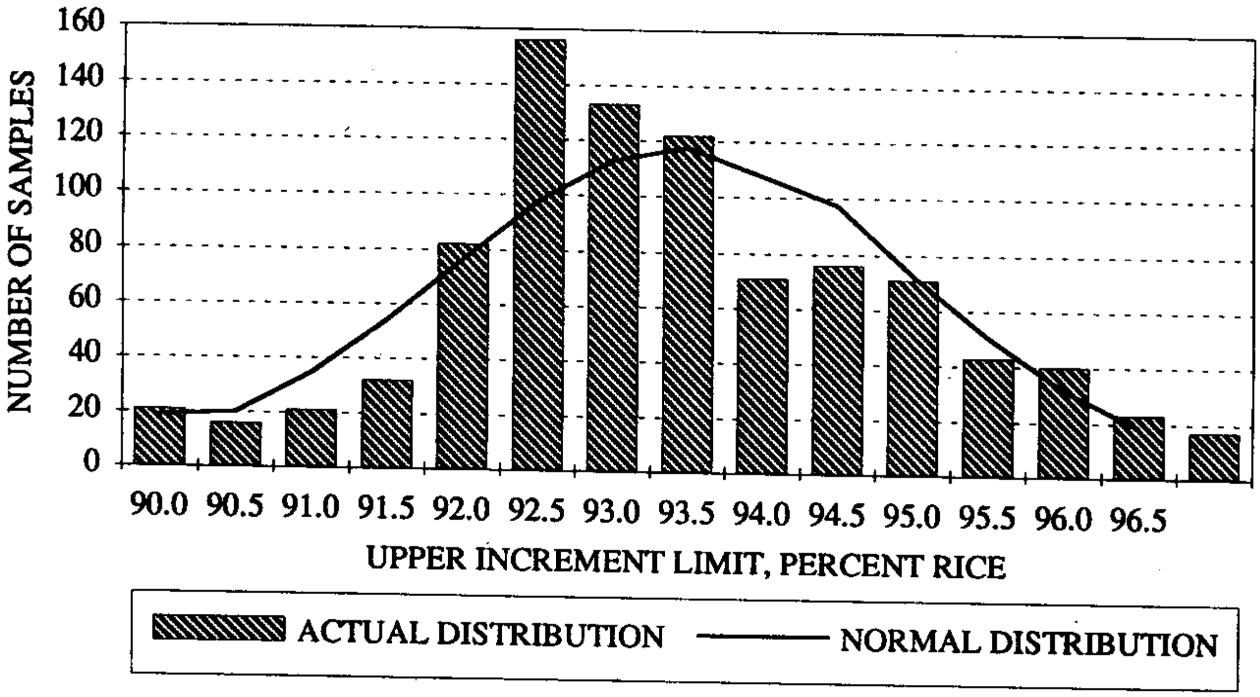

Figure E.9. Test for Normality, All Non-QA Density

Table E.9. Test for Normality, All Non-QA Density

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
90.0	-2.05	0.0202	0.0202	18.7	21	0.29
90.5	-1.73	0.0418	0.0216	20.0	16	0.79
91.0	-1.41	0.0793	0.0375	34.7	21	5.38
91.5	-1.09	0.1379	0.0586	54.1	32	9.06
92.0	-0.77	0.2206	0.0827	76.4	82	0.41
92.5	-0.45	0.3264	0.1058	97.8	156	34.70
93.0	-0.13	0.4483	0.1219	112.6	133	3.68
93.5	0.19	0.5753	0.1270	117.3	122	0.18
94.0	0.51	0.6915	0.1162	107.4	71	12.32
94.5	0.83	0.7967	0.1052	97.2	76	4.63
95.0	1.15	0.8749	0.0782	72.3	71	0.02
95.5	1.47	0.9292	0.0543	50.2	43	1.03
96.0	1.79	0.9633	0.0341	31.5	40	2.29
96.5	2.12	0.9830	0.0197	18.2	23	1.26
Infinity	Infinity	1.0000	0.0170	15.7	17	0.11
		Sum	1	924.0	924	76.14
				Table Value		21.03

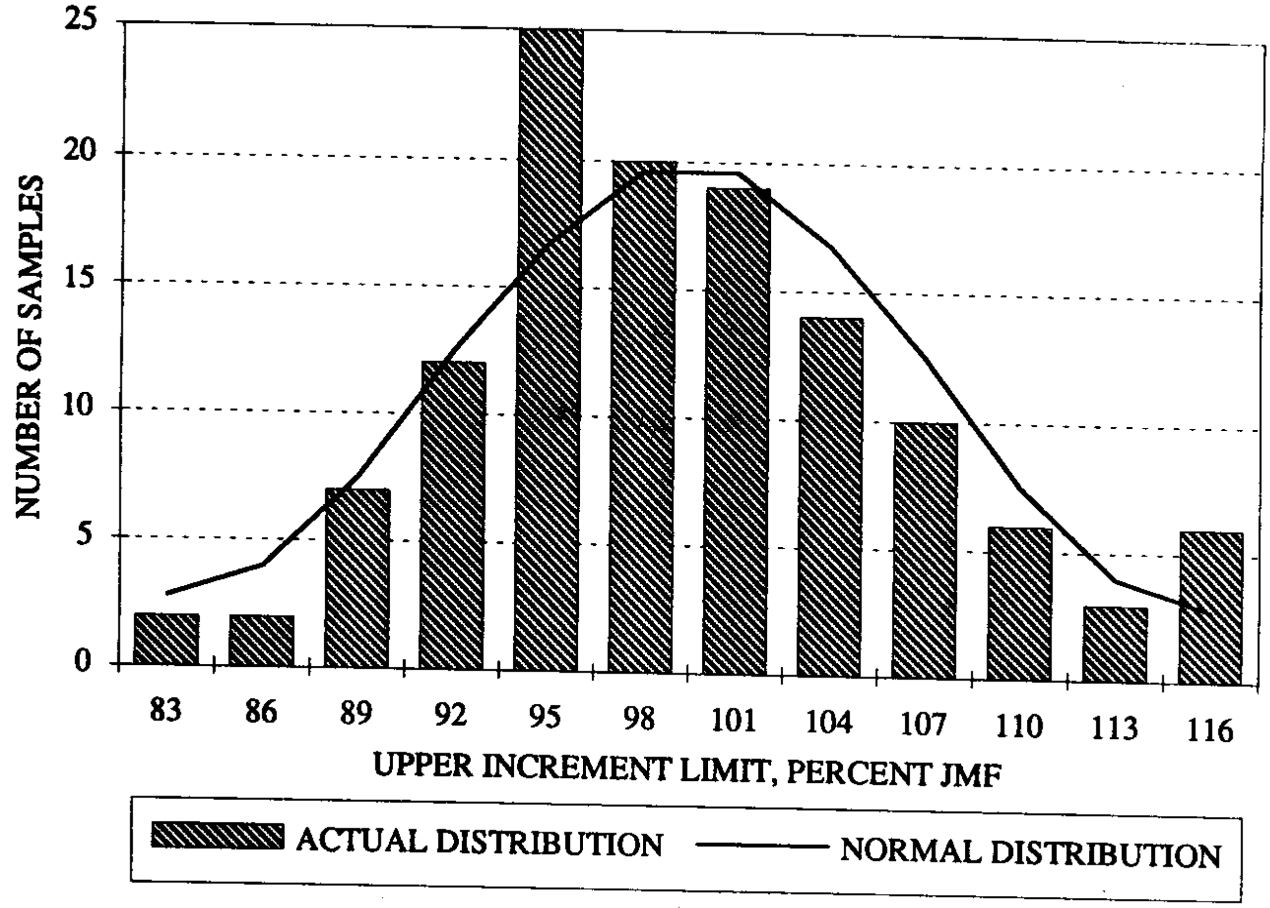

Figure E.10. Test for Normality, All Non-QA Density

Table E.10. Test for Normality, All Non-QA Density

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
90.75	-2.05	0.0202	0.0164	3.1	7	4.79
91.50	-1.43	0.0764	0.0562	10.5	3	5.31
92.25	-0.81	0.2090	0.1326	24.7	42	12.19
93.00	-0.19	0.4247	0.2157	40.1	53	4.13
93.75	0.43	0.6664	0.2417	45.0	35	2.20
94.50	1.05	0.8531	0.1867	34.7	22	4.66
95.25	1.67	0.9525	0.0994	18.5	16	0.33
Infinity	Infinity	1.0000	0.0475	8.8	7	0.38
		Sum	1	186	186	33.99
				Table Value		12.59

NOTE: Table 10 and Figure 10 are based on lot means

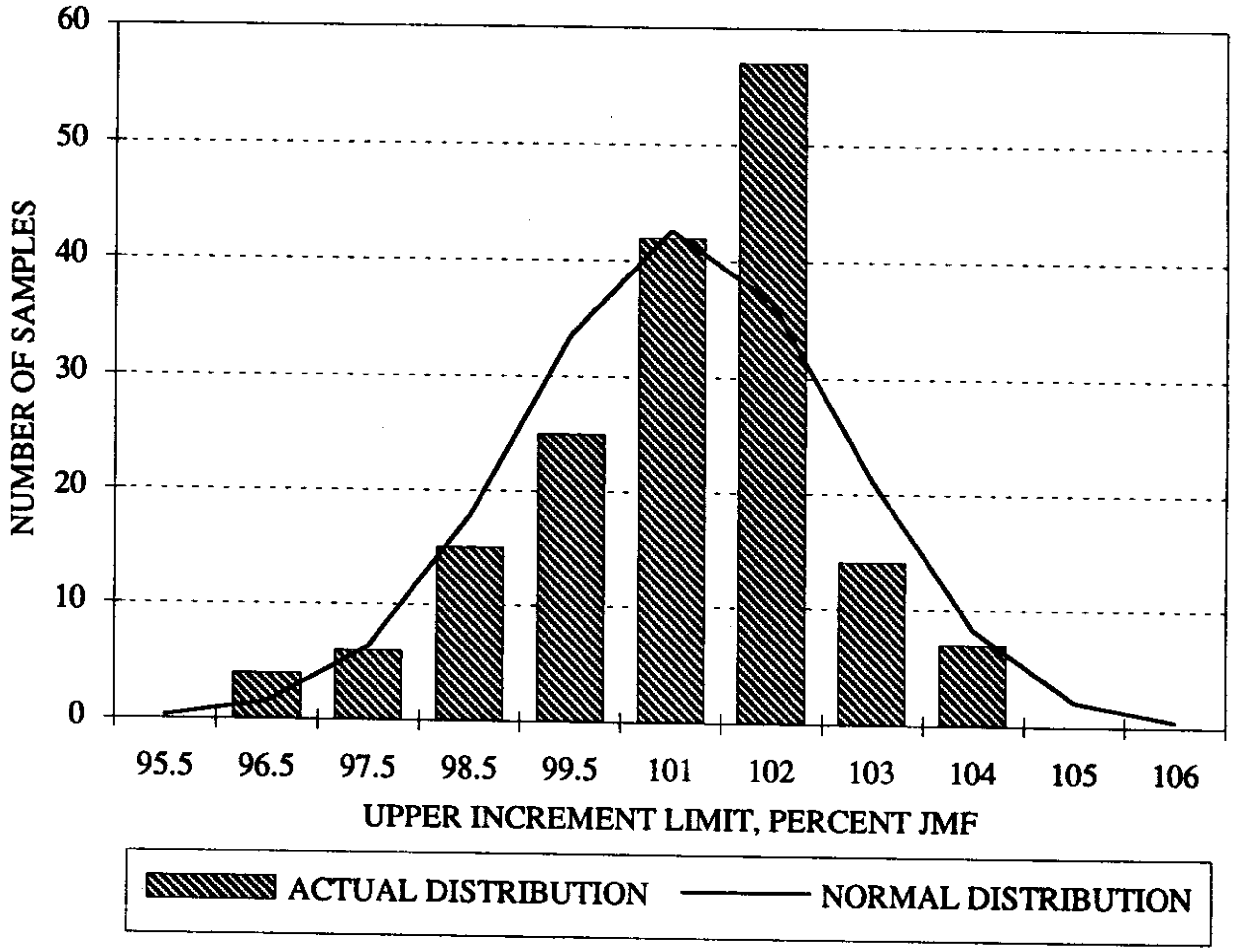

Figure E.11. Chi-Square test for Normality - 1/2 Inch Aggregate, QA

Table E.11. Chi-Square test for Normality - 1/2 Inch Aggregate, QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
97.5	-1.67	0.0475	0.0475	8.1	10	0.46
98.5	-1.03	0.1515	0.1040	17.7	15	0.41
99.5	-0.39	0.3483	0.1968	33.5	25	2.14
100.5	0.25	0.5987	0.2504	42.6	42	0.01
101.5	0.89	0.8133	0.2146	36.5	57	11.54
102.5	1.53	0.9370	0.1237	21.0	14	2.35
Infinity	Infinity	1.0000	0.0630	10.7	7	1.29
		Sum	1	170.0	170	18.2
				Table Value		9.49

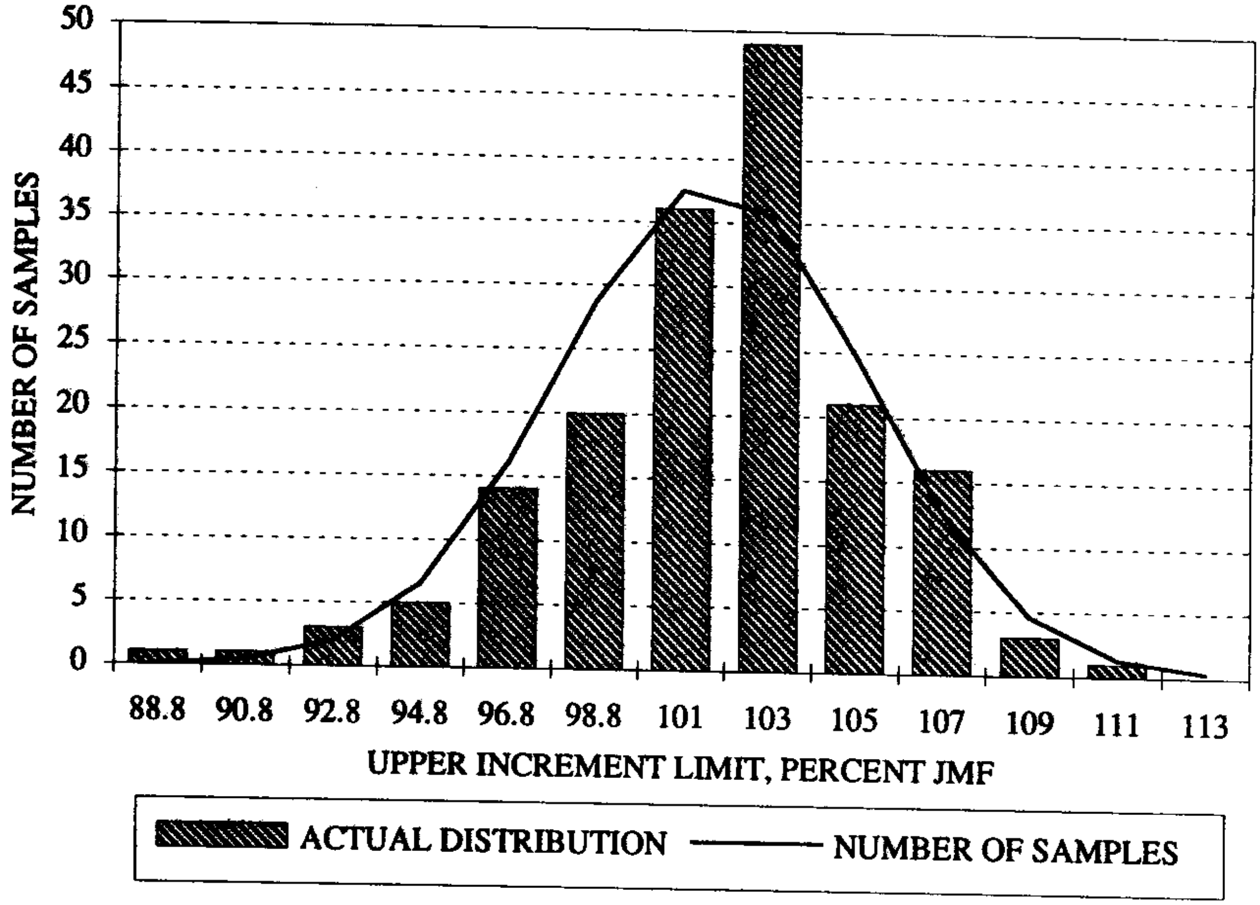

Figure E.12. Chi-Square test for Normality - 3/8 Inch Aggregate, QA

Table E.12. Chi-Square test for Normality - 3/8 Inch Aggregate, QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\bar{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
92.75	-2.19	0.0143	0.0143	2.4	4	1.01
94.75	-1.62	0.0526	0.0383	6.5	5	0.35
96.75	-1.05	0.1469	0.0943	16.0	14	0.26
98.75	-0.48	0.3156	0.1687	28.7	20	2.63
100.75	0.09	0.5359	0.2203	37.5	36	0.06
102.75	0.66	0.7454	0.2095	35.6	49	5.03
104.75	1.23	0.8907	0.1453	24.7	21	0.55
106.75	1.80	0.9641	0.0734	12.5	16	0.99
Infinity	Infinity	1.0000	0.0359	6.1	5	0.20
		Sum	1	170	170	11.08172
				Table Value		12.59

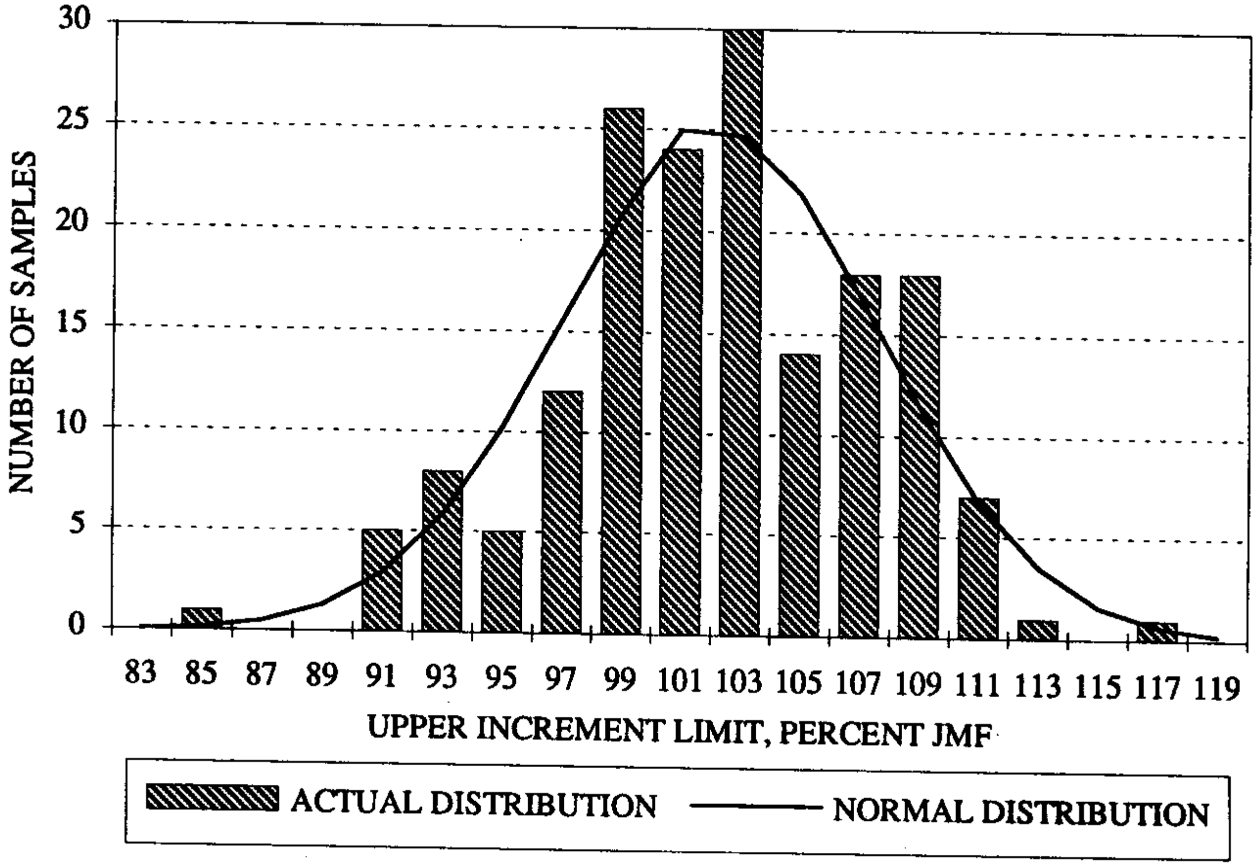

Figure E.13. Chi-Square test for Normality - 1/4 Inch Aggregate, QA

Table E.13. Chi-Square test for Normality - 1/4 Inch Aggregate, QA

1	2	3	4	5	6	7
X	$z=\frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
91	-1.90	0.0287	0.0287	4.9	6	0.26
93	-1.53	0.0630	0.0343	5.8	8	0.81
95	-1.16	0.1230	0.0600	10.2	5	2.65
97	-0.79	0.2148	0.0918	15.6	12	0.83
99	-0.42	0.3372	0.1224	20.8	26	1.30
101	-0.04	0.4840	0.1468	25.0	24	0.04
103	0.33	0.6293	0.1453	24.7	30	1.14
105	0.70	0.7580	0.1287	21.9	14	2.84
107	1.07	0.8577	0.0997	16.9	18	0.07
109	1.44	0.9251	0.0674	11.5	18	3.74
Infinity	Infinity	1.0000	0.0749	12.7	9	1.09
		Sum	1	170.0	170	14.75
				Table Value		15.51

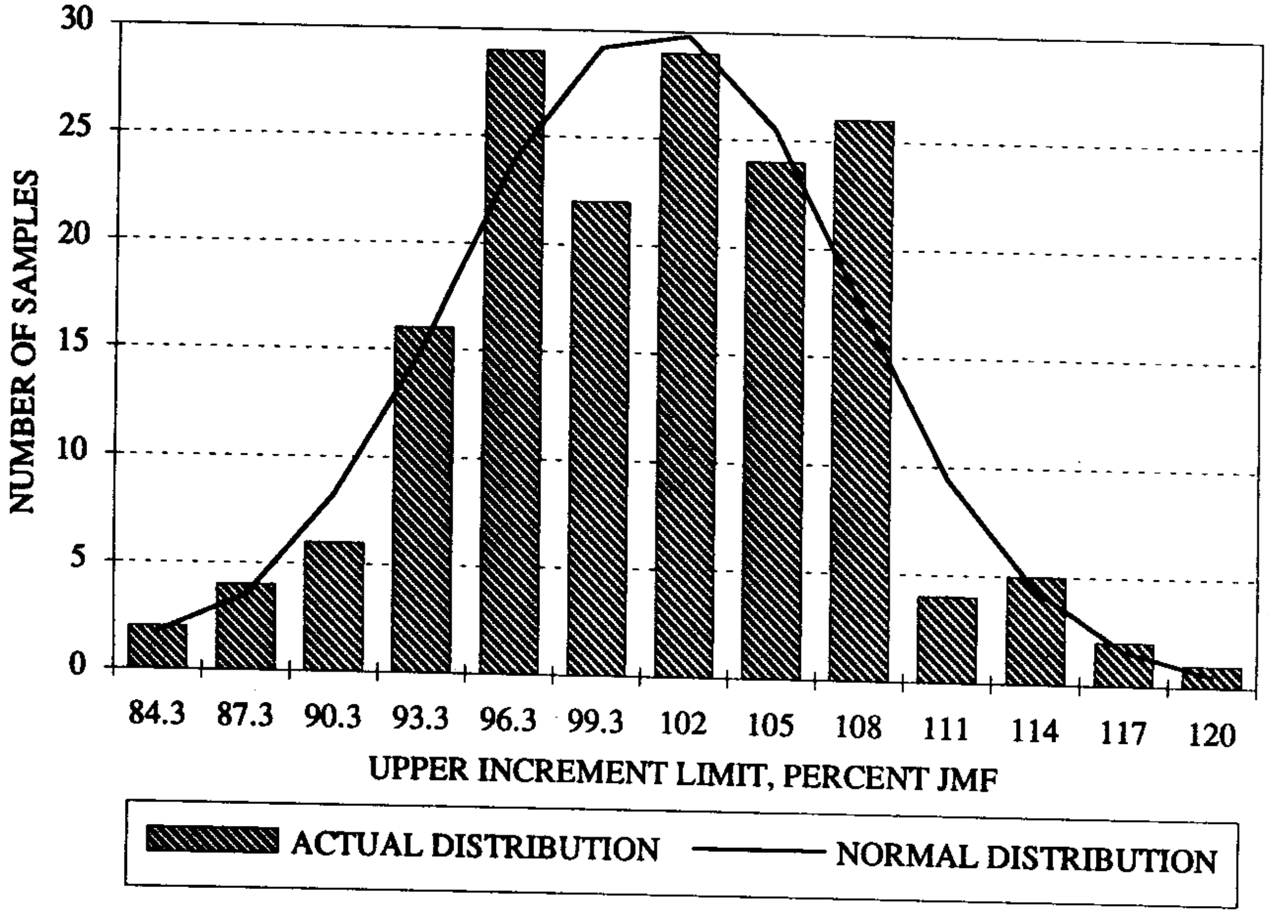

Figure E.14. Chi-Square Test for Normality - #10 Aggregate, QA

Table E.14. Chi-Square Test for Normality - #10 Aggregate, QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
87.25	-1.87	0.0307	0.0307	5.2	6	0.12
90.25	-1.41	0.0793	0.0486	8.3	6	0.62
93.25	-0.96	0.1685	0.0892	15.2	16	0.05
96.25	-0.50	0.3085	0.1400	23.8	29	1.14
99.25	-0.05	0.4801	0.1716	29.2	22	1.76
102.25	0.41	0.6554	0.1753	29.8	29	0.02
105.25	0.86	0.8051	0.1497	25.4	24	0.08
108.25	1.32	0.9066	0.1015	17.3	26	4.43
Infinity	Infinity	1.0000	0.0934	15.9	12	0.95
		Sum	1	170.0	170	9.16
				Table Value		12.59

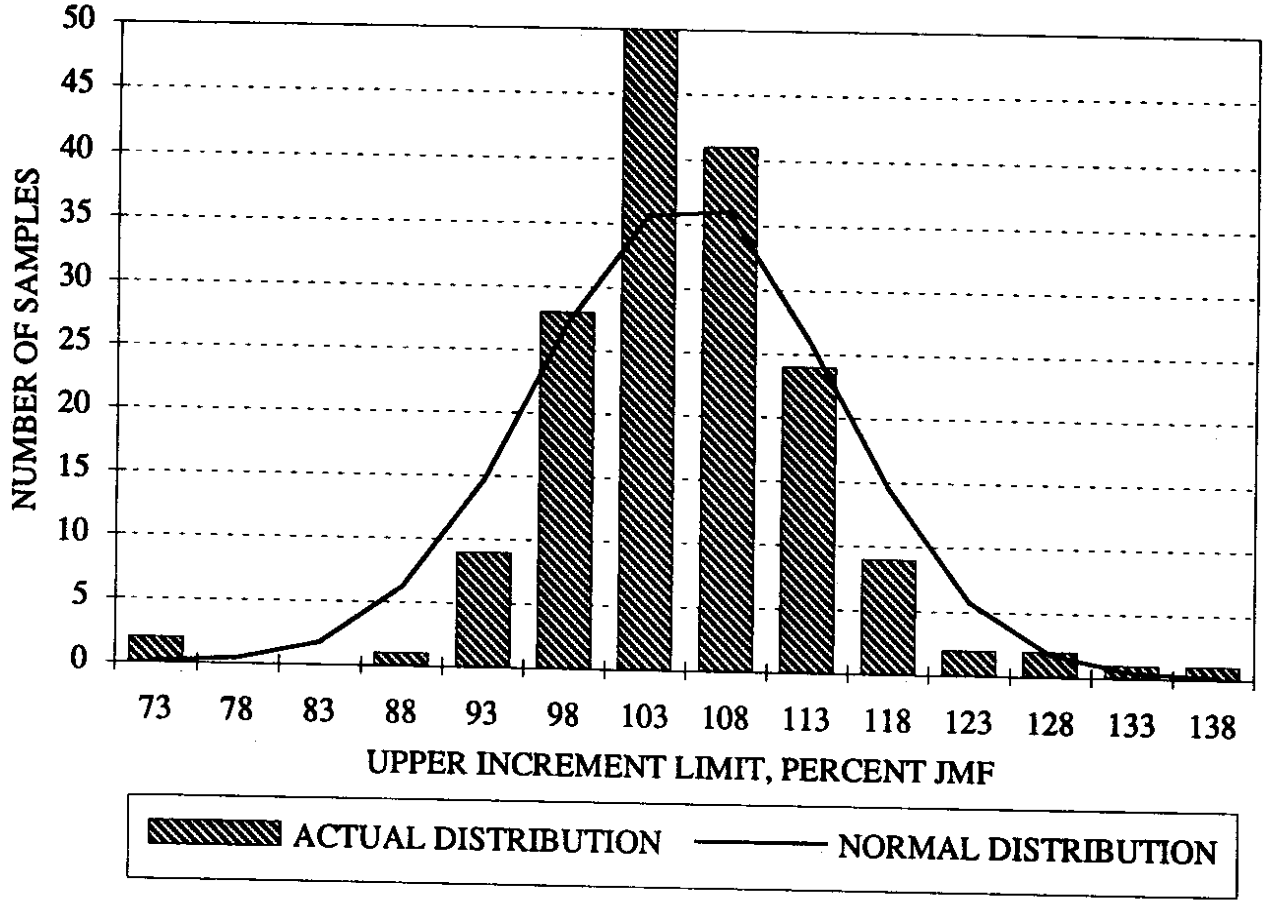

Figure E.15. Chi-Square Test for Normality - #40 Aggregate, QA

Table E.15. Chi-Square Test for Normality - #40 Aggregate, QA

1	2	3	4	5	6	7
X	$z = \frac{(X - \overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
88	-1.65	0.0495	0.0495	8.4	3	3.48
93	-1.10	0.1357	0.0862	14.7	9	2.18
98	-0.54	0.2946	0.1589	27.0	28	0.04
103	0.01	0.5040	0.2094	35.6	50	5.83
108	0.57	0.7157	0.2117	36.0	41	0.70
113	1.12	0.8686	0.1529	26.0	24	0.15
118	1.68	0.9535	0.0849	14.4	9	2.05
Infinity	Infinity	1.0000	0.0465	7.9	6	0.46
		Sum	1	170.0	170	14.88
					Table Value	11.07
					0.005 Table Value	16.75

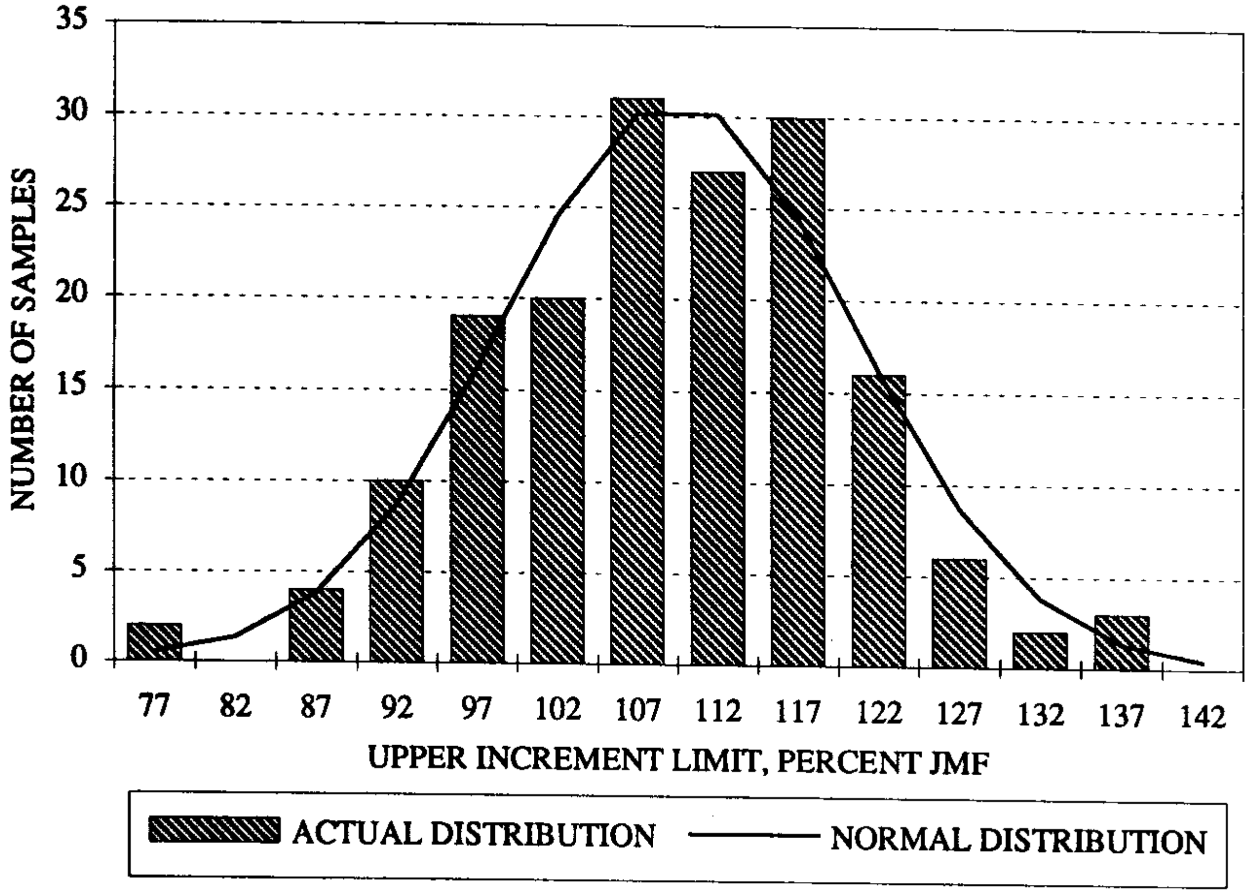

Figure E.16. Chi-Square Test for Normality - #200 Aggregate, QA

Table E.16. Chi-Square Test for Normality - #200 Aggregate, QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
87	-1.84	0.0329	0.0329	5.6	6	0.03
92	-1.38	0.0838	0.0509	8.7	10	0.21
97	-0.92	0.1788	0.0950	16.2	19	0.50
102	-0.46	0.3228	0.1440	24.5	20	0.82
107	0.00	0.5000	0.1772	30.1	31	0.03
112	0.46	0.6772	0.1772	30.1	27	0.32
117	0.92	0.8212	0.1440	24.5	30	1.24
122	1.38	0.9162	0.0950	16.2	16	0.00
127	1.84	0.9671	0.0509	8.7	6	0.81
Infinity	Infinity	1.0000	0.0329	5.6	5	0.06
		Sum	1	170.0	170	4.03
				Table Value		14.07

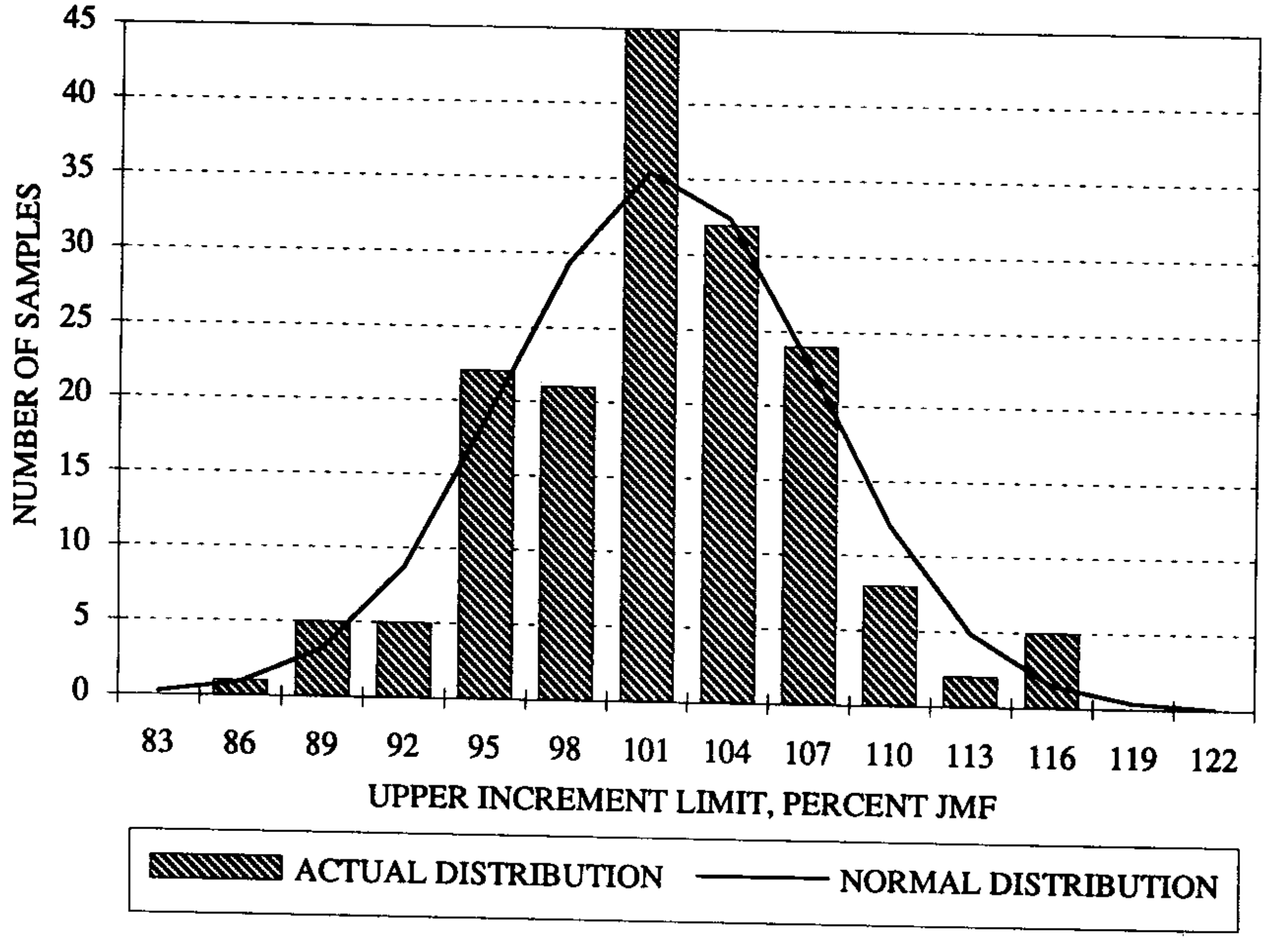

Figure E.17. Chi-Square Test for Normality - % Asphalt, QA

Table E.17. Chi-Square Test for Normality - % Asphalt, QA

1	2	3	4	5	6	7
X	$z = \frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
89	-1.96	0.0250	0.0250	4.3	6	0.72
92	-1.43	0.0764	0.0514	8.7	5	1.60
95	-0.89	0.1869	0.1105	18.8	22	0.55
98	-0.36	0.3594	0.1725	29.3	21	2.36
101	0.17	0.5675	0.2081	35.4	45	2.62
104	0.70	0.7580	0.1905	32.4	32	0.00
107	1.23	0.8907	0.1327	22.6	24	0.09
110	1.76	0.9608	0.0701	11.9	8	1.29
Infinity	Infinity	1.0000	0.0392	6.7	7	0.02
		Sum	1.0000	170.0	170	9.25
				Table Value		12.59

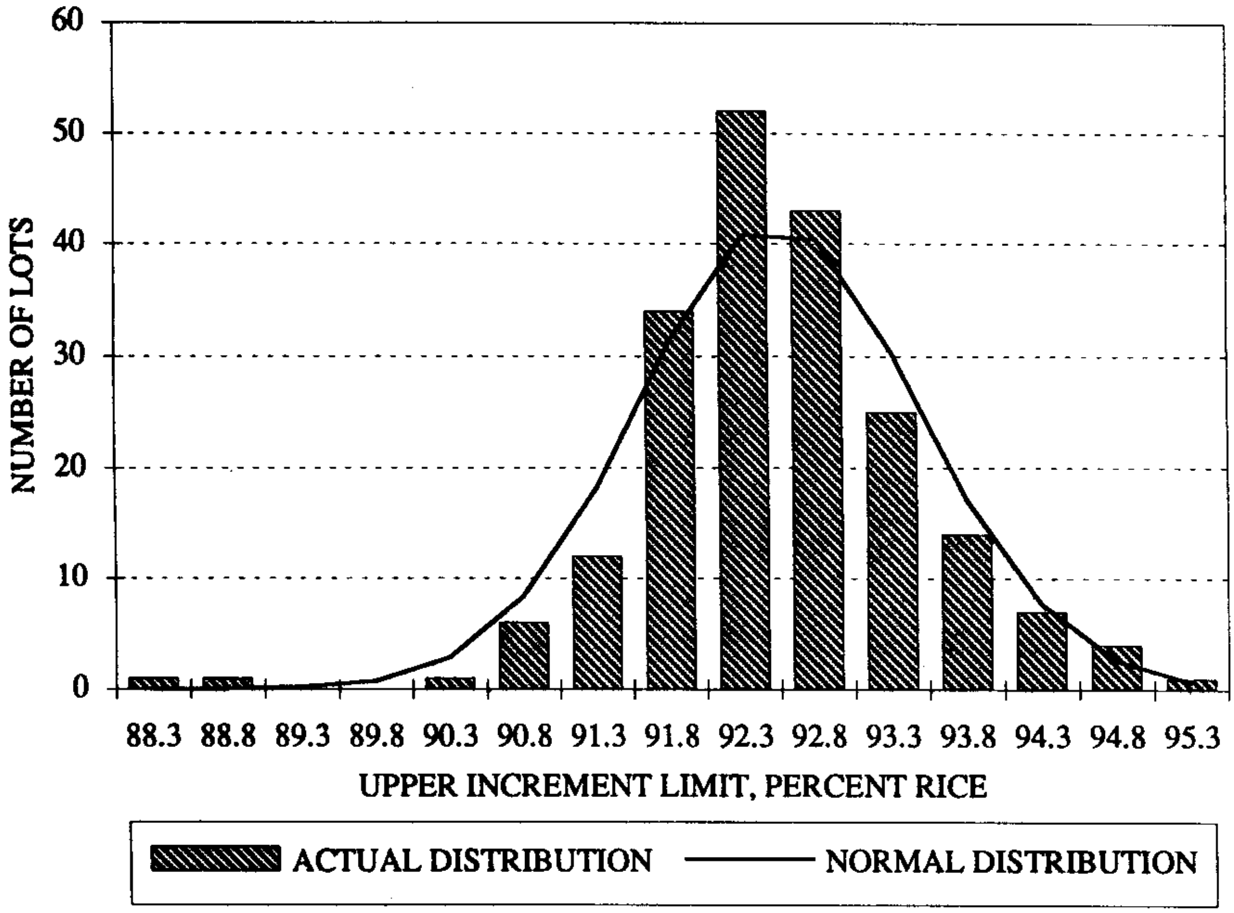

Figure E.18. Chi-Square Test for Normality - Density Tests, % Rice, QA Lots

Table E.18. Chi-Square Test for Normality - Density Tests, % Rice, QA Lots

1	2	3	4	5	6	7
X	$z=\frac{(X-\overline{X})}{s}$	Frequency - to z	Cell Frequency	(f)	(F)	$\frac{(F-f)^2}{f}$
91.25	-1.56	0.0594	0.0594	11.9	9	0.72
91.75	-1.04	0.1492	0.0898	18.0	12	2.03
92.25	-0.51	0.3050	0.1558	31.3	34	0.23
92.75	0.02	0.5080	0.2030	40.8	52	3.07
93.25	0.55	0.7088	0.2008	40.4	43	0.17
93.75	1.08	0.8599	0.1511	30.4	25	0.95
94.25	1.60	0.9452	0.0853	17.1	14	0.58
94.75	2.13	0.9834	0.0382	7.7	7	0.06
Infinity	Infinity	1.0000	0.0166	3.3	5	0.83
		Sum	1	201.0	201	8.64
				Table Value		12.59

CHI-SQUARE TEST SAMPLE CALCULATIONS: (see Duncan, Quality Control and Industrial Statistics, pp. 580-584) Sample calculations are shown for 3/8" sample data, non-QA projects combined, 92% maximum class interval. Referring to Table E.2, the numbers in ( ) below correlate to the table columns.

HYPOTHESIS: Sample data frequency = normal distribution.

(1) Determination of class intervals: The ranges and limits defining class intervals are selected based on the frequency of data, and the normality test outcome may be different depending on the intervals selected. Tables E.1-E.18 and the associated graphs are based on intervals resulting in the best fit to the normal curve. As a general rule, dispersed data from the upper and lower regions of the distribution should be combined to get a minimum of approximately 5 values in any given interval. This was done in preparing Tables E.1-E.18, but was not done in preparing Figures E.1-E.18 to provide a truer picture of the product distribution.

(2) Standardization of interval limits to the normal distribution:

given: mean=99.2635=estimate of population MEAN

s=3.6842=estimate of population standard dev.

n=126=number of samples

N=number of intervals=9

calculate: z=X-mean/s=(92-99.2635)/3.6842=-1.98

(3) from single tail z table, z=-1.98:

table value = 0.9761

relative frequency, - infinite to z = 1-0.9761=0.0239

(4) relative frequency of cell = frequency (0 to 92)=0.0239

(5) absolute theoretical frequency = $f = (126)(0.0239) = 3.0$

(6) actual frequency from sample data = $F = 5$ samples

(7) $[(F-f)^2]/f = [(5-3)^2]/3 = 4/3 = 1.33$

Values of $[(F-f)^2]/f$ are calculated for each interval and summed. If the value is greater than the table value for a given confidence interval, the hypothesis of normality is rejected.

summed values for 3/8" aggregate = 8.20

selected level of confidence = 0.05

degrees of freedom = N-3=6

table value = 12.592

$8.20 < 12.592$, hypothesis is accepted!

APPENDIX F

STUDENT "t" COMPARISONS

TABLE F.1: STUDENT "t" COMPARISONS FOR ALL ITEMS QA vs. NON-QA

ITEM	SPEC	Sd CALC	t CALC	n1+n2-2	t TABLE	DIF?
1/2"	1-2	0.1816	-2.827	294	1.96	YES
3/8"	1-2	0.4226	-2.778	294	1.96	YES
1/4"	1-2	0.6843	-5.769	294	1.96	YES
#10	1-2	0.8193	-1.860	294	1.96	NO
#40	1-2	1.1924	-5.415	294	1.96	YES
#200	1-2	1.8737	1.220	294	1.96	NO
%AC	1-2	0.6670	-3.775	294	1.96	YES
DEN	1-2	0.1100	4.520	387	1.96	YES

* BASED ON .05 LEVEL OF SIGNIFICANCE

A. FORMULAS:

t = (mean1-mean2)/sd

$$\text{where sd} = \sqrt{\frac{[s1\wedge2(n1-1)+s2\wedge2(n2-1)](n1+n2)}{(n1+n2-2)(n1)(n2)}}$$

B. HYPOTHESIS: MEAN1 = MEAN2

where MEAN = the population mean

C. SAMPLE CALCULATIONS: 3/8" AGGREGATE

	NON-QA	QA
GIVEN:	s1=3.6842 mean1=99.264 n1=126	s2=3.5161 mean2=100.438 n2=170

where s = sample standard deviation
mean = sample mean

1. $$\text{sd} = \sqrt{\frac{[3.684\wedge2(126-1)+3.516\wedge2(170-1)](126+170)}{(126+170-2)(126)(170)}}$$

sd= (1124676/6297480)^1/2

sd= (0.17859)^1/2 = 0.4226

2. t= (99.264-100.438)/0.4226 = -2.778

3. from any t table
t(table)=1.960 for 0.05 confidence interval
and 294 degrees of freedom

D. t calculated > t table:
Therefore, the hypothesis must be rejected.