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research report

The Next Step Toward End-Result Specifications for Hot-Mix Asphalt Materials and Construction

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16. Abstract

In 2000, the Virginia Department of Transportation's (VDOT) Chief Engineer asked the Virginia Transportation Research Council to develop a vision of how and when VDOT would have a working end-result specification for hot-mix asphalt. The response to that question was that it would take several years and many steps to achieve. This report discusses the next step in that ongoing effort, which includes the development and simulated application of two statistical quality assurance (SQA) special provisions, one for asphalt concrete material and the other for asphalt concrete pavement. The criteria for these prototype SQA provisions included the application of standard national terminology and approach, a firm basis in existing VDOT specifications, and quality characteristics that represent the best practical performance measures.

This report describes the outcome of a "shadow" application of the proposed SQA specifications to a subset of Virginia's annual maintenance-resurfacing projects. Although the involved production and placement activities were not subject to the requirements of the SQA specifications, the sampling and testing were designed to represent what would have been required had the special provisions been in effect. The study further determined the likely acceptance outcome for each shadow project and explored future modifications to specification limits and pay adjustment criteria.

The most desirable benefit from effective end-result specifications stems from the ability to rededicate available inspection to those key production and placement processes (e.g., joint tacking and surface preparation) that cannot be measured upon delivery to the owner/agency. A less desirable, but more tangible, financial benefit results when these specifications permit a reduction in the overall inspection force. One conservative estimate suggests that VDOT could save more than $2 million per year in inspector salaries through an end-result specification for acceptance of hot-mix asphalt pavements.

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FINAL REPORT

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ABSTRACT

In 2000, the Virginia Department of Transportation's (VDOT) Chief Engineer asked the Virginia Transportation Research Council to develop a vision of how and when VDOT would have a working end-result specification for hot-mix asphalt. The response to that question was that it would take several years and many steps to achieve. This report discusses the next step in that ongoing effort, which includes the development and simulated application of two statistical quality assurance (SQA) special provisions, one for asphalt concrete material and the other for asphalt concrete pavement. The criteria for these prototype SQA provisions included the application of standard national terminology and approach, a firm basis in existing VDOT specifications, and quality characteristics that represent the best practical performance measures.

This report describes the outcome of a "shadow" application of the proposed SQA specifications to a subset of Virginia's annual maintenance-resurfacing projects. Although the involved production and placement activities were not subject to the requirements of the SQA specifications, the sampling and testing were designed to represent what would have been required had the special provisions been in effect. The study further determined the likely acceptance outcome for each shadow project and explored future modifications to specification limits and pay adjustment criteria.

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FINAL REPORT

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INTRODUCTION

The Virginia Department of Transportation (VDOT) has worked toward end-result specifications (ERSs) in hot-mix asphalt (HMA) since the mid-1960s, although the destination has been changed by evolution. When first embarking on this journey, only the most prophetic could envision the ultimate goal as being a true ERS, i.e., one in which the final in-situ properties could be measured, related to quality and performance, and paid for relative to anticipated longevity. In 2000, VDOT's Chief Engineer asked the Virginia Transportation Research Council (VTRC) to develop a vision of how and when VDOT could have a working ERS for HMA. The response to that question was that it would take several years to achieve but an ongoing effort would be made.[1] This ongoing effort is now ready for the next step.

Some steps toward ERSs have been implemented over the years, but the latest innovations in acceptance plans have not.[2-5] The latest innovations that can be easily implemented include:

- a more efficient quality measure
- quality characteristics of mixture properties that are more performance related than those presently used
- final acceptance of construction properties
- pay factors for materials and construction that are more defensible.

The main ingredients necessary to take the next step toward ERSs are either already in the VDOT specifications or can be integrated with minimal effort.

The quality measure used by 25 of 44 state and federal agencies responding to a recent survey by the National Cooperative Highway Research Program is the percent within limits

(PWL) procedure for estimating the population of HMA material and construction.[3] This procedure is also the one stipulated by the American Association of State Highway and Transportation Officials (AASHTO) in AASHTO R-009-05, Standard Recommended Practice for Acceptance Sampling Plans for Highway Construction,[2] and the newly developed AASHTO R042-06, Recommended Practice to Develop a Quality Assurance Plan for Hot Mix Asphalt.[4]

The quality characteristics (those characteristics measured to determine conformance with specifications, e.g., asphalt content) necessary to take the next step forward are in place for acceptance of HMA materials. Currently, VDOT bases acceptance of HMA on gradation and asphalt cement content.[6] As evidenced by the wide use for acceptance of HMA by state highway agencies and the Federal Highway Administration, HMA volumetric properties have been found to be more predictive of performance than is gradation.[3,5] VDOT measures volumetric properties but does not use them for pay factor determination: they are used only as "shut-down" devices. For HMA pavement acceptance, VDOT uses contractor-run compaction test results based on a combination of nuclear and core density measurements.[6] This requires appreciable time and effort on the part of VDOT personnel to monitor the test results. There are also other modern construction testing techniques that are good predictors of performance (e.g., permeability).[7] In addition to these construction measures, VDOT's smoothness specification[11] could be easily added to a multi-characteristic end-result specification for HMA and incorporated into a single pay formula.

As inspection resources for most highway agencies continue to dwindle, ERSs that incorporate meaningful quality characteristics and discriminating quality measures become increasingly important. Effective end-product acceptance and pay criteria allow those inspectors who remain (as inspection forces are reduced) to concentrate on important aspects of construction quality that can be "inspected in" to a project but are difficult, if not impossible, to measure after final compaction and striping. Examples that are relevant to HMA construction are preparing the underlying surface (e.g., cleanliness and/or soundness of milled surfaces) and tacking along longitudinal joints.

PURPOSE AND SCOPE

The purpose of this study was to develop and apply statistical quality assurance (SQA) specifications for the acceptance of HMA. The criteria for these prototype SQA provisions were to use the following:

- AASHTO R-009[2] and AASHTO R-42-06[4] to ensure compatibility as much as possible with AASHTO standards
- Section 211, Asphalt Concrete, and Section 315, Asphalt Concrete Pavement, of VDOT's *Road and Bridge Specifications* to the greatest extent possible to maintain continuity with traditional specifications.[6]

- acceptance quality characteristics that represented the best practical performance measures.

The application of the prototype provisions was on a "shadow" basis. Although the involved production and placement activities were not subject to the requirements of the SQA specifications, the sampling and testing were designed to represent what would have been required had the special provisions been in effect. The study further determined the likely acceptance outcome for each shadow project and explored future modification to specification limits and pay adjustment criteria.

METHODS

The study objectives were achieved by conducting two tasks:

1. *Develop prototype statistical quality assurance (SQA) specifications for the acceptance of HMA in Virginia.*

2. *Develop and apply an implementation sequence for the developed specifications.* The first phase of that implementation process is reported here and involves the shadow application of the proposed SQA provisions to resurfacing schedule activity in various locations around Virginia.

Development of Prototype Specifications

The SQA specifications were developed by combining the guidance provided in the AASHTO sources[2,4] (referenced earlier) with VDOT's current asphalt concrete material and pavement specifications.[6] The researchers also considered similarly designed specifications from other states,[3] input from the Asphalt Program Office of VDOT's Materials Division, and prior work by the principal investigators.[3,7,10-12]

Shadow Application of the Specification

Since the projects involved in the application of the specifications were not bid under the prototype provisions, the test results were used for data analysis only, and any calculated pay adjustments were for informational purposes only. Pilot testing the special provisions in this manner has advantages and disadvantages. It allows data to be collected quickly without a bidding process, but it has the disadvantage of not requiring the contractor to respond to the requirements of the new provisions.

This initial phase was designed to gather and analyze data to get an idea of how well the new provisions would work under actual production and field conditions. Line items from VDOT's 2006 resurfacing schedule contracts were reviewed to find projects that would represent between 6,000 and 10,000 tons of HMA production on primary or higher type roadways. After

several meetings with area construction engineers from the relevant residencies, candidate projects were selected and VDOT field inspection personnel and the contractor's supervisors were consulted to prepare for additional sampling and testing activities.

Original sample collection and testing plans included significant contributions from VDOT's central and district materials offices. Unfortunately, the lack of available testing resources forced VTRC research staff to work primarily from the mix production reports provided by contractors through the current quality assurance program. Research technicians also acquired mix during field trips and were able to supplement some of the production data with test results from the VTRC laboratory. VTRC field crews obtained the field density and permeability data as testing resources allowed, and the Non-Destructive Testing Unit of VDOT's Materials Division supplied the smoothness data.

RESULTS

The Prototype Specifications

The SQA specifications are provided in Appendices A and B. The proposed special provision in Appendix A refers specifically to the asphalt concrete mix properties and provides for acceptance in terms of the percent of material within specification limits for gradation, Superpave™ volumetric properties, and asphalt content. Appendix B covers field-measured properties and addresses compaction and smoothness.

Gradation, Volumetric Properties, and Asphalt Cement Content (Appendix A)

For mixture requirements, the proposed changes in Appendix A include the quality measure, from using the average and standard deviation separately to incorporating them in one formula; changes in the lot and sublot sizes to 5,000 tons and 1,000 tons, respectively; the use of voids in the total mix and voids in the mineral aggregate as quality characteristics related to the pay factor with a reduction in the sieves (i.e., the special provision includes only the No. 4 and No. 200 sieves) used for pay factor determination; and introduction of the pay factor equation of 73 + 0.3(PWL). The SQA provision also proposes the use of the lowest PWL value in the pay factor equation.

Compaction and the Continuous International Roughness Index (Appendix B)

The compaction or density requirements as proposed in Appendix B call for one 6-inch core for every 3,000-ft sublot of paving. These cores are to be located in a stratified random method by the engineer and the density is to be determined in accordance with Virginia Test Method (VTM) 22. As with mixture properties (Appendix A), acceptance for density is based on the PWL. Calculations to determine pay adjustments for a lot are normally to be based on test results from five samples. The upper specification limit and lower specification limit vary depending on the mix; the upper limit ranges from 96 to 98 percent, and the lower limit ranges from a 92 to 94 percent maximum theoretical density (MTD).

The proposed smoothness provision is modeled after the most recent draft of the AASHTO Provisional Protocol (PP51-07 pending), Pavement Ride Quality When Measured Using Inertial Profiling Systems. This draft of the protocol, which went to ballot over the winter of 2007, incorporates the concept of continuously reported roughness, or a running International Roughness Index (IRI). The concept is introduced in two documents referenced in the AASHTO draft protocol.[8,9] It is also described and promoted in two previous reports by one of the investigators.[10,11] One important element of the provision for smoothness includes a return to a 528-ft (0.1-mi) base length for assessing ride quality and corresponding pay adjustments. The provision also incorporates a 50-ft running base length for identifying localized roughness.

The Shadow Application of the SQA Specifications

General Project and Data Description

As nearly as possible, the produced used for the data reduction for this study followed the proposed specifications provided in the appendices. Unfortunately, the lack of data availability prevented the research team from following the lot size, sublot size, and sample size requirements called for in the specifications for the mixture or field samples. For this reason, the results should be viewed as indicative of only what they would be under the proposed specifications.

Seven projects on HMA maintenance schedules involving six contractors were investigated during the summer of 2006. A contractor identifier, project route, mix type, and approximate quantities represented are shown in Table 1. Unfortunately, contiguous projects of the scale originally targeted for this project (6,000 tons) proved to be few and far between. The average size project was closer to 4,000 tons. The research team considered combining two projects from Contractor D (same job mix) to increase the samples size. However, since the projects were tested more than 1 month apart, this was deemed statistically inappropriate (i.e., likely different populations).

Table 1. Contractors, Projects, and Quantities

Contractor	Project	Mix Type	Quantity (tons)
A	Route 11	SM-9.5D	4600
B	Route 612	SM-12.5D/RAP	4600
C	Route 231	SM-9.5A/RAP	5800
D-1	Route 151	SM-12.5D	1600
D-2	Route 29	SM-12.5D	3800
E	Route 33	SM-9.5A	3000
F	Route 64	SM-9.5D	4800

Mixture Properties

The mixture data, which included gradation, asphalt content, and volumetric properties, were taken from normal contractor testing. Essentially this meant there was approximately twice the sample size for gradation and asphalt content as for volumetric properties, since gradation is typically collected on 500-ton sublots and volumetric properties on 1,000-ton sublots. The number of tests performed by the contractor for mixture properties is shown in Table 2.

Table 2. Sample Size (n) for Mixture Tests

Contractor	Project	Gradation and AC%, *n*	Volumetric, *n*
A	Route 11	7	4
B	Route 612	10	5
C	Route 231	13	8
D-1	Route 151	4	3
D-2	Route 29	8	6
E	Route 33	6	3
F	Route I-64	9	6

The mixture test gradation data consisted of the 3/8 in, No. 4, No. 8, and No. 200 sieves for most of the contractors. The special provision for HMA mix used the quality characteristics of the No. 4 and No. 200 sieves, voids in the mineral aggregate (VMA%), voids in the total mix (VTM%), and asphalt content (AC%) to determine the pay factor. Contractors B and D did not have data for the No. 4 sieve. The use of the proper individual sieve size is important because the SQA specification included the No. 4 but not the No. 8 sieve as a pay factor quality characteristic. One of the goals of a SQA specification is to eliminate or reduce the redundancy of quality characteristics, particularly those used for pay factor determination. Thus, although both the No. 4 and No. 8 sieves may be tested for information, they should not both be required as pay factor quality characteristics. Thus, in the analysis, the No. 4 sieve was used when it was tested and the No. 8 sieve was used when the No. 4 sieve was not tested. Therefore both were not included in the analysis. A determination of which is used should be made in the future special provision.

Field Properties

The VTRC test data consisted of density (core), permeability, and smoothness. Nuclear density data were also obtained but are not presented. The sample sizes for density and permeability by project are shown in Table 3. Only field density from cores (6-in diameter) is used as a pay factor quality characteristic in the special provision for asphalt pavement. Permeability was included as a default measure in case of a very low-density result. The falling head permeability test was performed on the cores in accordance with VTM 120 after the density testing was completed. It was anticipated that some quality characteristics would not be measured in the first phase of the study. Bond strength is an example of a quality characteristic that was included in the SQA special provision for future data collection.

Although only three of the field projects would have qualified as complying with VDOT's *Guidelines for Application of the Rideability Specification,*[12] all seven were tested for

Table 3. Sample Size *(n)* for Field Tests

Contractor	Project	Density, *n*	Permeability, *n*
A	Route 11	12	11
B	Route 612	9	9
C	Route 231	10	10
D-1	Route 151	6	6
D-2	Route 29	9	9
E	Route 33	7	7
F	Route I-64	14	14

ride quality in accordance with VTM 106. Table 4 reports the general descriptive statistics that are relevant to the tests for rideability.

Table 4. Lengths and Paylots for Rideability Testing

Contractor	Project	Length (mi)	Potential Paylots (total)
A	Route 11	16.1	1570
B	Route 612	6.7	661
C	Route 231	11.0	1084
D-1	Route 151	12.4	1239
D-2	Route 29	6.4	632
E	Route 33	5.6	551
F	Route I-64	16.8	1403

Test Results

Mixture Properties

The contractor mixture test results for gradation, asphalt content, and volumetric properties are shown in Tables 5 through 11.

Table 5. Contractor A: Gradation and Asphalt Content Results

Property	No. 4 Sieve	No. 8 Sieve	No. 200 Sieve	AC%	VTM%	VMA%
JMF	57.0	38.0	6.0	5.70	3.5	15.3
n	7	7	7	7	4	4
Average	54.8	35.8	6.4	6.0	3.2	16.0
Std Dev	1.72	1.12	0.29	0.16	0.88	0.37
TPWL	84.70	75.98	99.07	58.93	84.00	100.00
PF_{min}		NA		90.68		
PF_{ave}	97.94					

JMF = job mix formula, TPWL = total percent within limits (PWL), PF_{min} = pay factor based on lowest PWL, PF_{ave} = average of pay factors for 5 quality characteristics, AC% = proportion (by weight) liquid asphalt cement, VTM% = proportion (by volume) of voids in total mix, VMA% = proportion (by volume) of voids in mineral aggregate, NA = not applicable.

Table 6. Contractor B: Gradation and Asphalt Content Results

Property	No. 4 Sieve	No. 8 Sieve	No. 200 Sieve	AC%	VTM%	VMA%
JMF	-	40.0	5.5	5.40	3.6	15.8
n	10	10	10	10	5	5
Average	-	41.3	5.8	5.5	3.6	16.3
Std Dev	-	1.57	0.22	0.21	0.85	0.43
TPWL	-	86.03	100.00	81.54	88.61	100.00
PF_{min}	-			97.46		
PF_{ave}	99.17					

JMF = job mix formula, TPWL = total percent within limits (PWL), PF_{min} = pay factor based on lowest PWL, PF_{ave} = average of pay factors for 5 quality characteristics, AC% = proportion (by weight) liquid asphalt cement, VTM% = proportion (by volume) of voids in total mix, VMA% = proportion (by volume) of voids in mineral aggregate.

Table 7. Contractor C: Gradation and Asphalt Content Results

Property	No. 4 Sieve	No. 8 Sieve	No. 200 Sieve	AC%	VTM%	VMA%
JMF	60.0	43.0	5.7	5.50	4.0	15.7
n	13	13	13	13	8	8
Average	60.2	42.3	5.6	5.6	3.4	15.4
Std Dev	1.95	1.65	0.26	0.19	0.39	0.35
TPWL	97.46	91.36	100.00	83.77	93.32	87.70
PF_{min}		NA		98.13		
PF_{ave}	100.74					

JMF = job mix formula, TPWL = total percent within limits (PWL), PF_{min} = pay factor based on lowest PWL, PF_{ave} = average of pay factors for 5 quality characteristics, AC% = proportion (by weight) liquid asphalt cement, VTM% = proportion (by volume) of voids in total mix, VMA% = proportion (by volume) of voids in mineral aggregate, NA = not applicable.

Table 8. Contractor D-1 (Rt. 151): Gradation and Asphalt Content Results

Property	No. 4 Sieve	No. 8 Sieve	No. 200 Sieve	AC%	VTM%	VMA%
JMF	-	38.0	5.7	5.80	3.9	17.2
n	-	4	4	4	3	3
Average	-	36.1	4.7	5.9	3.1	16.7
Std Dev	-	0.52	0.17	0.07	0.90	0.64
TPWL	-	100.00	50.00	100.00	62.44	57.23
PF_{min}	-		88.00			
PF_{ave}	95.18					

JMF = job mix formula, TPWL = total percent within limits (PWL), PF_{min} = pay factor based on lowest PWL, PF_{ave} = average of pay factors for 5 quality characteristics, AC% = proportion (by weight) liquid asphalt cement, VTM% = proportion (by volume) of voids in total mix, VMA% = proportion (by volume) of voids in mineral aggregate.

Table 9. Contractor D-2 (Rt. 29): Gradation and Asphalt Content Results

Property	No. 4 Sieve	No. 8 Sieve	No. 200 Sieve	AC%	VTM%	VMA%
JMF	-	38.0	5.7	5.80	3.9	17.2
n	-	8	8	8	6	6
Average	-	35.6	4.8	5.9	2.8	16.7
Std Dev	-	1.25	0.45	0.25	0.59	0.65
TPWL	-	66.32	54.16	75.71	54.04	57.23
PF_{min}	-				89.21	
PF_{ave}	91.94					

JMF = job mix formula, TPWL = total percent within limits (PWL), PF_{min} = pay factor based on lowest PWL, PF_{ave} = average of pay factors for 5 quality characteristics, AC% = proportion (by weight) liquid asphalt cement, VTM% = proportion (by volume) of voids in total mix, VMA% = proportion (by volume) of voids in mineral aggregate.

Table 10. Contractor E: Gradation and Asphalt Content Results

Property	No. 4 Sieve	No. 8 Sieve	No. 200 Sieve	AC%	VTM%	VMA%
JMF	62.0	41.0	5.0	5.70	4.0	16.6
n	6	6	6	6	3	3
Average	64.3	43.8	5.4	5.5	4.2	16.3
Std Dev	2.73	1.88	0.38	0.12	0.71	0.64
TPWL	71.75	54.40	96.00	69.72	100.00	66.43
PF_{min}		NA				92.93
PF_{ave}	97.23					

JMF = job mix formula, TPWL = total percent within limits (PWL), PF_{min} = pay factor based on lowest PWL, PF_{ave} = average of pay factors for 5 quality characteristics, AC% = proportion (by weight) liquid asphalt cement, VTM% = proportion (by volume) of voids in total mix, VMA% = proportion (by volume) of voids in mineral aggregate, NA = not applicable.

Table 11. Contractor F: Gradation and Asphalt Content Results

Property	No. 4 Sieve	No. 8 Sieve	No. 200 Sieve	AC%	VTM%	VMA%
JMF	69.0	51.0	5.5	5.60	4.1	16.7
n	9	9	9	9	6	6
Average	67.1	49.0	6.5	5.5	4.6	16.9
Std Dev	3.50	2.94	0.56	0.17	0.41	0.53
TPWL	71.75	60.15	50.00	92.24	96.89	100.00
PF_{min}		NA	88.00			
PF_{ave}	95.92					

JMF = job mix formula, TPWL = total percent within limits (PWL), PF_{min} = pay factor based on lowest PWL, PF_{ave} = average of pay factors for 5 quality characteristics, AC% = proportion (by weight) liquid asphalt cement, VTM% = proportion (by volume) of voids in total mix, VMA% = proportion (by volume) of voids in mineral aggregate, NA = not applicable.

Field Properties

Density and Permeability

The cores obtained for density and permeability determination were taken by VTRC soon after paving was completed. The sample size is given in Table 3. The results are shown in Table 12.

Table 12. Density and Permeability Results

		Density (%MTD)			Permeability, 10^{-5}cm/sec	
Contractor	Project	Average	Std Dev	PF_{SQA}[a]	Average	Std Dev
A	Route 11	93.1	0.99	89.16	78	67.0
B	Route 612	91.9	2.25	82.54	310	533.9
C	Route 231	92.8	2.67	82.25	48	55.6
D-1	Route 151	93.0	1.12	88.00	72	91.7
D-2	Route 29	92.4	1.10	82.02	67	57.9
E	Route 33	92.7	1.17	77.42	103	106.6
F	Route I-64	92.1	2.51	83.33	196	371.5

%MTD = percent maximum theoretical density.
[a]Pay factor in the SQA special provisions.

Ride Quality

The data collected via VTM 106 (for ride quality) were reduced in two ways. The first approach followed VDOT's current *Special Provision for Rideability*,[13] which uses a discrete paylot system through which adjustments are applied on a per 0.01-mi basis. The second approach applies the continuous IRI approach as proposed in Appendix B. For both analyses, the "target" mean roughness index (MRI) for full payment, or upper specification limit for roughness, was held at 80 in/mi for every project except I-64, which used 70 in/mi (as per the current special provision). Table 13 reports the overall average MRI for each field project; the percentage of discrete paylots that would have been eligible for at least 100 percent payment; and the percentage of the overall project for which the continuous MRI stayed below the upper specification limit.

Table 13. Ride Quality Summary

Contractor	Project	MRI (in/mi)	Portion of Project Within Specification Limits	
			Discrete	Continuous
A	Route 11	69.1	82%	85%
B	Route 612	97.0	34%	10%
C	Route 231	79.0	65%	64%
D-1	Route 151	71.2	74%	81%
D-2	Route 29	60.3	90%	99%
E	Route 33	91.7	42%	16%
F	Route I-64	59.2	79%	84%

Note: Maximum MRI for full payment = 80 in/mi, non-interstate; 70 in/mi interstate.

DISCUSSION

Mixture Properties

The data reveal that of the seven projects, the lowest total percent within limits (TPWL) values were caused by the averages being too close to one specification limit. Some of the standard deviations were higher than might be expected, but with the relatively small sample sizes involved, this should not be unexpected and, in general, this did not adversely affect the pay adjustment. This indicates that contractors would not have to be particularly concerned about the variability being too high but instead should concentrate on better hitting the job-mix formula target.

The SQA special provision for asphalt concrete (Appendix A) proposed using the lowest of the TPWL calculations for determining the pay factor of the lot. The initial thinking was that this would not penalize the contractor as much as using all the pay factors and would apply the "weak link" theory, which assumes that the quality characteristic with the least percentage of product within the specification limits is also that most likely to cause the greatest loss of pavement life. For these data, that quality characteristic was asphalt content for three of the seven projects, the No. 200 sieve on two projects, and the No. 8 sieve and voids in the total mix being the weak link on the other two projects. (It should be kept in mind that the SQA special provision included the No. 4 sieve and not the No. 8 but the analysis used the No. 8 sieve when the No. 4 sieve was not tested. In the event both sieves are tested, only one will be used as a pay factor quality characteristic.) As the data show, using the weak link approach can impose a severe negative price adjustment. For example, a negative price adjustment of almost 15 percent would have resulted on one project. This approach also almost guarantees that a positive price adjustment will not result for a lot. Thus, the analysis also looked at averaging the pay factors for the six quality characteristics. This assumes that each of the quality characteristics provides equal weight to the pavement performance. This assumption may not be completely accurate but appears more reasonable than using the minimum. Another alternative would be to develop a composite weighted pay factor, but reaching consensus on the weights to be used may be difficult.

A comparison between the two methods of determining the pay factors is shown in Table 14.

Table 14. Mixture Property Pay Factors: Minimum Versus Average TPWL

Contractor	Project	PF_{min} [a]	QC_{min} [b]	PF_{ave} [c]
A	Route 11	90.68	AC%	97.94
B	Route 612	97.46	AC%	99.17
C	Route 231	98.13	AC%	100.74
D-1	Route 151	88.00	No. 200	95.18
D-2	Route 29	89.21	VTM%	91.94
E	Route 33	92.93	No. 8	97.23
F	Route I-64	88.00	No. 200	97.48

[a]Pay factor based on the minimum total percent within limits (TPWL).
[b]Quality characteristic causing the minimum TPWL.
[c]Pay factor based on the average TPWL.

Field Properties

Density

The density averages varied from 91.9 to 93.1 percent MTD (Table 12), which are sufficient in the currently used specifications for the contractor to receive 100 percent pay. The standard deviations varied from 0.99 to 2.67 percent MTD. Three standard deviations were higher than would normally be expected: 2.25, 2.51, and 2.67.[14] A possible reason for this was the condition of the existing pavement on two of the projects, which might have affected the ability to achieve compaction. One of those projects, Route 612, was a secondary road. The second, Route 231, is a primary system roadway but clearly one with a "traditional" alignment (including significant curvature and grade changes). The third project with high variability and low average density values was an interstate system project: I-64. Unfortunately, the resurfacing work (mill and inlay) on I-64 took place very late in the season (early November). The workdays were short and tended to start and end under relatively cool temperatures. When this SQA special provision is fully implemented, it will be important to ensure that the density portion of the specification is used for appropriate roadways. It is also clear, given the results from I-64, that existing temperature and seasonal restrictions are important and necessary.

The SQA special provision contains different specification limits for density depending on mix type: D-mix designations have limits of 93 to 97 percent MTD and A mixes have limits of 94 to 98 percent MTD. These limits were used in the initial analysis and indicate severe negative pay factor adjustments (Column 5, Table 12). Thus, a follow-up analysis also included the use of a lower specification limit. The results of this analysis are shown in Table 15 with the original results from Table 12.

It is clear that pay factors in the proposed SQA special provision for asphalt concrete pavement (Appendix B) are too severe for the levels of compaction being achieved through current VDOT specifications. The specifications presently used by VDOT require the average density to be between 90.6 and 94.4 for 100 percent pay.[6] Retaining these limits through the

Table 15. Density Pay Factors: Proposed SQA Versus Lower Limit of 92%

Contractor	Project	Mix Type	PF_{SQA}[a]	PF_{92}[b]
A	Route 11	D	89.16	99.02
B	Route 612	D(w/RAP)	82.54	87.54
C	Route 231	A (w/RAP)	82.25	90.87
D-1	Route 151	D	88.00	97.19
D-2	Route 29	D	82.02	92.06
E	Route 33	A	77.42	95.10
F	Route I-64	D	83.33	87.93

[a]Pay factor in the SQA special provisions

[b]Pay factor based on a lower specification limit of 92% maximum theoretical density.

proposed SQA special provision will undermine its implementation. Even with a lower specification limit of 92 percent MTD, negative price adjustments would have occurred on all the projects. The lower specification limit on the Route 288 design-build job reported by Schmidt[15] was 92; however, the target was 94, which was higher than that in the SQA special provision and higher than the average density achieved on the projects in this study. (With a 93 minimum and a standard deviation of 1.2, the target for 90 PWL would have to be about 95.4; with a 92 minimum, it would have to be about 94.4.) A decision must be made as to whether the density requirements should be raised to improve compaction, which will require the consideration of changes in mix design requirements, or whether the lower specification limit should be reduced to produce average payments equivalent to those of the current specification. A possible compromise may be to reduce the lower specification limit for a specified period of time with the understanding that it will be increased as appropriate in the future. In implementing a PWL specification, the Florida Department of Transportation attempted to set specification limits to yield a payment equivalent to the payment that would have been obtained using the previous specification.[16]

Permeability

Permeability values were obtained for all cores, although in the SQA special provision, permeability would be used only on cores with abnormally low density. The average and standard deviation results were shown in Table 11. These results are shown in Table 15 along with the number of cores with permeability values greater than 150 and the resultant TPWL using 150 as the upper specification limit.

One of the reasons not to use permeability as a quality characteristic is the variability of the test results. This variability is obvious from the data in Table 16. However, these data tend to track the density results in that the higher permeability values and number of values above 150×10^{-5}cm/sec occur on the projects with the lower density results. Retaining the permeability value as a secondary quality check for low-density cores seems reasonable.

Table 16. Permeability Results (10^{-5}cm/sec)

Contractor	Project	Average	Std Dev	N > 150	TPWL
A	Route 11	78	67.0	2	86.03
B	Route 612	310	533.9	3	38.66
C	Route 231	48	55.6	1	97.15
D-1	Route 151	72	91.7	1	79.43
D-2	Route 29	67	57.9	0	93.33
E	Route 33	103	106.6	1	66.16
F	Route I-64	196	371.5	3	44.95

TPWL = total percent within limits.

Ride Quality

Figure 1 is a bar graph depicting Columns 4 and 5 of Table 13. It provides a visual comparison of how the projects would have been judged under the discrete paylot and continuous IRI smoothness provisions. Note that the three projects that would likely have qualified as applicable for the smoothness provision[13] (Route 11, U.S. 29, and I-64) would have faired slightly better under the continuous IRI than under the current discrete paylot. On the other hand, the two projects with the poorest overall ride quality (Route 612 and Route 33) would have received a significantly less favorable assessment under the continuous IRI provision.

Figure 2 provides a more project-level perspective on the roughness. It depicts a 1-mi portion of the Route 11 project that appears to have two pronounced areas of higher roughness. The triangles show the MRI for each prospective paylot: one point every 52.8 ft for a total of approximately 100 paylots per mile. The solid line show the continuous MRI data: represented by a point for every profile elevation reading (3-in interval, 400 points total) along the pavement. The "smoothing" effect of the 528-ft running base length is quite evident in this plot. However, although approximately 78 percent of the discrete lots fell below the specification limit of 80 in/mi, only 75 percent of the continuous data falls below threshold for full payment. Thus, despite how it visually appears, the continuous assessment is actually stricter in this instance.

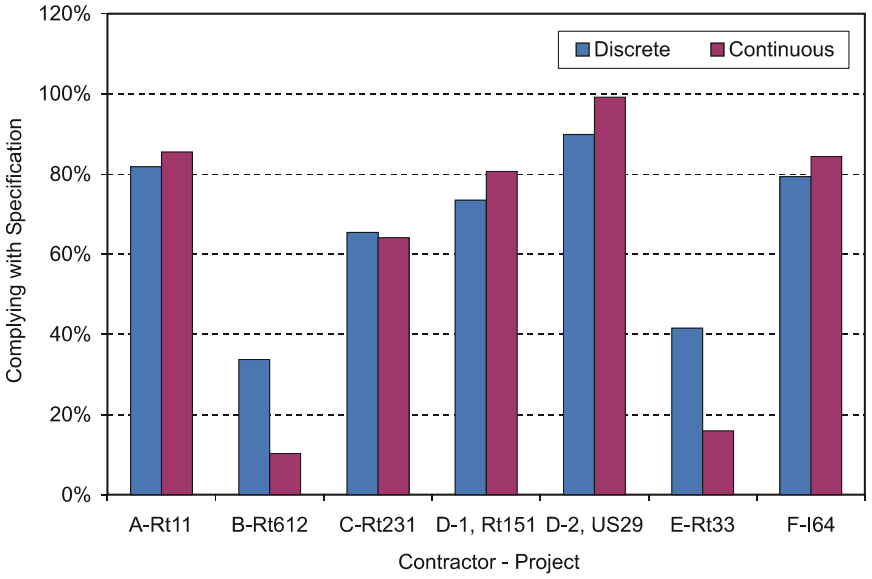

Figure 1. Discrete Paylot and Continuous IRI Comparison

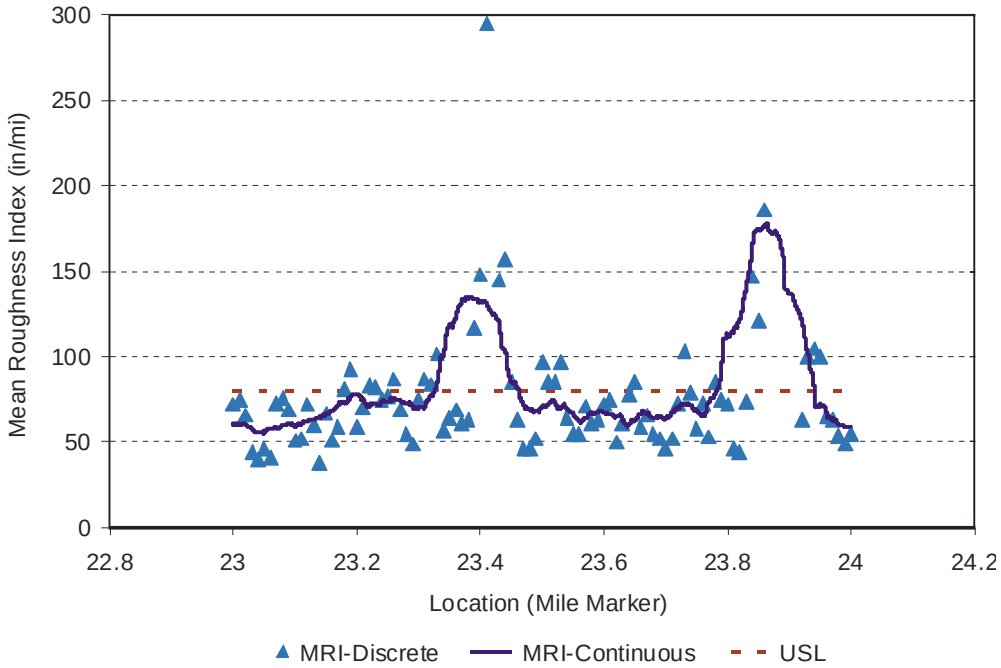

Figure 2. Discrete Paylot Versus Continuous MRI

CONCLUSIONS

- *The largest pay factor adjustments for mixture properties were almost always triggered by traditional quality characteristics.* The largest adjustments were caused by asphalt content on three projects, the No. 200 sieve on two projects, and the No. 8 sieve and voids in the total mix on one project each. All but one of these are pay factor quality characteristics in the current specifications. In other words, only one project would have had a pay factor adjustment based on a new pay factor quality characteristic.

- *The pay factor adjustments were caused by the average being too close to the lower specification limit, not by the variability component of PWL.* This indicates that Virginia contractors should not be overly concerned about having to reduce variability but should instead place more attention on selecting the correct target.

- *Using the minimum TPWL is not equitable for the contractor.* The use of the average of the five TPWLs is more reasonable.

- *The No. 8 sieve should be used in the SQA Special Provision for Asphalt Concrete (Appendix A) as the quality characteristic related to mid-size aggregate.* The No. 4 sieve is simply not tested by all contractors.

- *The density requirements in the SQA Special Provision for Asphalt Concrete Pavement (Appendix B) are too severe at present.*

- *The permeability test results are too variable to use permeability as an acceptance quality characteristic*. However, higher permeability does seem to be common in projects with lower and more variable density. For that reason, retaining permeability as a secondary quality check for low-density cores seems reasonable.

- *For the projects tested in this study, the continuous IRI approach for assessing ride quality (using a 528-ft base length) appears to identify less localized roughness on smooth overall projects and more localized roughness on very rough ones (than does the current Special Provision for Rideability[13]).*

RECOMMENDATIONS

1. *The Virginia Transportation Research Council and VDOT's Materials Division should partner to revise the SQA special provisions, which should involve the following:*

    - Change the pay factor determination to use the average TPWL rather than the minimum.

    - Replace the No. 4 sieve with the No. 8 sieve as the quality characteristic associated with the mid-size aggregate component.

    - Explore density expectations and modify the density requirements accordingly.

    - Maintain the current 500-ton sublot size for mix acceptance. Although the proposed lot size of 5,000 tons with sublots of 1,000 tons has not been tried, keeping the 500-ton lot size in the current specifications appears to be more desirable.

    - Consider lot sizes of 2,500 tons in order to reduce the risk to the contractor (with 500-ton sublots, this would be five rather than four samples per lot). This would require only a change in the data analysis, not data collection.

    - Consider the potential application of other quality characteristics with continued development of the SQA special provisions. Examples that should receive special consideration are bond strength and joint density.

2. *The Virginia Transportation Research Council, VDOT's Materials Division, and VDOT district quality assurance personnel should collect and analyze more data using the methods proposed in the SQA special provisions.* This must be done to ensure reasonableness. One approach would be to advertise a project(s) in which sampling and testing would be conducted in accordance with the SQA special provisions with no adjustments applied. Unfortunately, this would not determine how the contractor would respond to the specification under typical conditions. Still, perhaps running the revised SQA special provisions alongside the conventional specifications on one schedule per district would give the proposed methodology some needed "exposure."

COSTS AND BENEFITS ASSESSMENT

The tools promoted through this research would provide benefits to the Commonwealth on two levels. First, the quality measure, percent within limits, would place a special emphasis on uniformity of material and construction. Establishing criteria that not only promote adequate average quality but also insist on consistent production and placement is key to achieving the most serviceable, long-lasting, and predictable (i.e., programmable) highway system. A fundamental (and tangible) example of non-uniformity is mix segregation. Research by Stroup-Gardiner and Brown[17] suggested that the agency costs for segregation range from 10 percent to as much as 50 percent of the original cost of the pavement. In Virginia, an average of 10 percent life lost to low-level segregation equates to a per-lane-mile loss of approximately $3,500 (10 percent of 1.5 in, $60/ton mix). Expanding this calculation to cover the more than 5,000 miles of pavement that is resurfaced each year, improved specifications that mitigate segregation could result in savings that exceed $17 million per year.

Applying these tools to quality characteristics that relate to performance is an essential principle of good specifications. When these quality characteristics can be easily measured at the end of a process, the second level of benefits can be realized. These benefits relate to effective use of inspection personnel. When construction inspectors can rely on end-result specifications for final acceptance and payment decisions, they become available to monitor those key production and placement procedures (e.g., joint tacking and surface preparation) that are every bit as important to good performance but are not easily measured upon delivery to the owner/agency. At the inspection level, the most important benefit would be realized through the rededication of available inspection to the important, “inspect-able” details.

A less desirable, but perhaps more tangible, inspection-level benefit would come through a reduced inspection workforce. VDOT currently administers about 80 resurfacing schedule projects per year. Assuming that there is currently the equivalent of 1½ inspectors devoted to each schedule, it is reasonable to think that VDOT could eliminate the need for the half-time inspector per schedule with an effective end-result specification. If it costs $50 per hour (includes salary, overtime, transportation, and other support—a conservative estimate) to keep the inspector available for a scheduled project that lasts 6 months, the annual costs are nearly $26,000 per schedule (this is not unreasonable, considering that as much as $20,000 per hour can be spent buying the material). The total cost savings from eliminating the need for a “half-time” inspector from all 80 schedules, therefore, amounts to just over $2 million per year.

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APPENDIX A

SPECIAL PROVISION FOR SECTION 211—ASPHALT CONCRETE (STATISTICAL QUALITY ASSURANCE—END RESULT) Modified

Note: VTRC Working Document (Not a VDOT-endorsed Draft Specification)

211.03—Job-Mix Formula.

The Contractor shall submit for the Engineer's approval, a job-mix formula for each mixture to be supplied. The job-mix formula shall be within the design range specified. The job-mix formula shall establish a single percentage of aggregate passing each required sieve, a single percentage of asphalt material to be added to the aggregate, a temperature at which the mixture is to be produced and a temperature at which the mixture is to be compacted for SUPERPAVE testing according to the requirements of AASHTO PP28-99. Each approved job-mix formula shall remain in effect, provided the results of tests performed on material currently being produced consistently meet the requirements of the job-mix for grading, SUPERPAVE volumetric properties, asphalt content, and temperature.

(a) SUPERPAVE mixes shall be designed and controlled according to the requirements of AASHTO PP28-99 and as specified herein. The SUPERPAVE mixes shall conform to the requirements of Table II-13 and Table II-14 (see VDOT *Road and Bridge Specifications*). Section 7.1.2 of AASHTO PP-2-99 shall be modified such that the compaction temperature is as specified in (c) 2 herein. The mixture shall be designed and compacted at the N design gyrations specified in Table II-14. The N max requirement shall be verified as part of the design process by compacting a minimum of 2 specimens at the design asphalt content.

(b) In conjunction with the submittal of a job-mix formula, the Contractor shall submit complete SUPERPAVE design test data, ignition furnace calibration data according to VTM-102 prepared by an approved testing laboratory and viscosity data or supplier temperature recommendations for the asphalt cement if different from (c)2 herein.

(c) The SUPERPAVE design test data shall include but not be limited to the following information:

1. The following SUPERPAVE volumetric properties of the compacted mixture, calculated on the basis of the mixture's maximum specific gravity determined by AASHTO T-209. The mixture shall be aged in accordance with AASHTO PP-2-99 and the bulk specific gravity of the specimens determined by AASHTO T-166, Method A for each asphalt content tested. Properties shall be determined and reported in accordance with the requirements of AASHTO PP28-99.
   a. Voids in total mix (VTM)
   b. Voids in mineral aggregate (VMA)

c. Voids filled with Asphalt (VFA)
d. Fines/Asphalt ratio (F/A)

2. The mixing and compaction temperature for testing shall be as follows:
   a. For mix designation A and all Base mixes, the mix temperature shall be 300 degrees F to 310 degrees F and the compaction temperature shall be 285 degrees F to 290 degrees F.
   b. For mix designation D, the mix temperature shall be 310 degrees F to 320 degrees F and the compaction temperature shall be 295 degrees F to 300 degrees F.
   c. In cases involving PG 76-22 or modified binders, the temperatures shall be based on documented supplier's recommendations.

3. Field correction factor. The field correction factor is determined by subtracting the bulk specific gravity of the aggregate from the effective specific gravity of the aggregate at the design asphalt content.

4. Permeability test data shall be submitted in accordance with VTM-120 using either single point verification or the regression method for each surface mix having a different gradation. If the average of the permeability results from the single point verification method exceeds 150 X 10^{-5} cm/sec, or if the regression method predicts a permeability exceeding 150 X 10^{-5} cm/sec at 7.5% voids, the Contractor shall redesign the mixture to produce a permeability less than 150 X 10^{-5} cm/sec.

(d) The SUPERPAVE design test data shall be plotted on graphs provided by the software of the test equipment manufacturer and shall show that the proposed job-mix formula conforms to the requirements of the mix type.

(e) A determination will be made that any asphalt concrete mixture being produced conforms to the job-mix formula approved by the Department. The Department will test the mixture using samples removed from production. The following tests will be run to determine the properties listed:

1. Asphalt Content	VTM-102 (VTM-36 when approved)
2. Gradation	AASHTO T-30
3. SUPERPAVE Properties	AASHTO PP28-99
4. Asphalt Cement Material	AASHTO TP-48 or T-201

At the discretion of the Engineer, the Department in accordance with VTM-110 will perform rut testing. If the results of the rut testing do not conform to the table below, the Engineer reserves the right to require adjustments to the job-mix formula.

Mix Designation	Maximum Rut Depth, mm
A	7.0
D	5.5
E, (M), (S)	3.5

In the event the Department determines that the mixture being produced does not conform to the approved job mix formula and volumetric properties in Table II-14 based on Department or Contractor's test results, the Contractor shall immediately make corrections to bring the mixture into conformance with the approved job-mix formula or cease paving with that mixture.

Subsequent paving operations, using either a revised or other job-mix formula which has not been verified as described herein, shall be limited to a test run of 100 to 300 tons of mixture if such material is to be placed in Department project work. No further paving for the Department using that specific mixture shall occur until the acceptability of the mixture being produced has been verified using the 100 to 300 ton constraint.

Asphalt concrete mixtures used in surface, intermediate, and base courses shall conform to the following requirements when tested in accordance with the requirements of AASHTO PP28-99:

TABLE II-14A
RECOMMENDED PERFORMANCE GRADE OF ASPHALT

	Percentage RAP in Mix	
Mix Type	0.0 - 20.0	Over 20.1
SM-9.0A, SM-9.5A, SM-12.5A	PG 64-22	PG 58-28
SM-9.0D, SM-9.5D, SM-12.5D	PG 70-22	PG 64-28
SM-9.0E, SM-9.5E, SM-12.5E	PG 76-22	PG 70-28
IM-19.0A	PG 64-22	PG 58-28
IM-19.0D	PG 70-22	PG 64-28
BM-25.0	PG 64-22	PG 64-22*
BM-37.5	PG 64-22	PG 64-22*

*BM-25.0 and BM-37.5 mixes using more than 25 percent RAP shall use a PG 58-22.

Base mixes shall have a minimum asphalt content of 4.0 percent determined by SUPERPAVE design as specified herein.

Based on rut testing performed by the Department and/or field performance of the job-mix, the Engineer reserves the right to require adjustments to the job-mix formula. Based upon a plot of aggregate grading, which indicates an aggregate grading passes through

the restricted zone established by Table II-14A, the Engineer reserves the right to require rut testing of the job-mix. Based on the rut testing, the Engineer reserves the right to require adjustments in the job-mix formula.

211.04—Asphalt Concrete Mixtures.

Asphalt concrete mixtures shall conform to the requirements of Table II-14 and the following:

(a) **Types SM-9.0A, SM-9.0D, SM-9.0E, SM-9.5A, SM-9.5D, SM-9.5E, SM-12.5A, SM-12.5D, and SM-12.5E asphalt concrete** shall consist of crushed stone, crushed slag, or crushed gravel and fine aggregate, slag or stone screenings or a combination thereof combined with asphalt cement.

NOTE: For all surface mixes, except where otherwise noted, no more than 5 percent of the aggregate retained on the No. 4 sieve and no more than 20 percent of the total aggregate may be polish susceptible. At the discretion of the Engineer, a SM-9.5AL or SM-12.5AL may be specified and polish susceptible aggregates may be used (without percentage limits).

(b) **Types IM-19.0A and IM-19.0D asphalt concrete** shall consist of crushed stone, crushed slag, or crushed gravel and fine aggregate, slag or stone screenings or a combination thereof combined with asphalt cement.

NOTE: At the discretion of the Engineer, an intermediate mix may be designated as either a SM-19.0A or SM-19.0D. When designated as such, no more than 5 percent of the aggregate retained on the No. 4 sieve may be polish susceptible. All material passing the No. 4 sieve may be polish susceptible.

(c) **Types BM-25.0 and BM-37.5 asphalt concrete** shall consist of crushed stone, crushed slag, or crushed gravel and fine aggregate, slag or stone screenings or a combination thereof combined with asphalt cement.

(d) **Type C (curb mix) asphalt concrete** shall consist of a blend of No. 78 or No. 8 crushed aggregate, No. 10 crushed aggregate, fine aggregate, mineral filler and a stabilizing additive from the Department's approved list; combined with 6.0 – 9.0 percent of PG 64-22. This mix does not require a volumetric mix design or volumetric testing under the SUPERPAVE system.

(e) **Asphalt mixtures Type SM-9.5, SM-12.5, IM-19.0, BM-25.0, and BM-37.5** may be designated (M) for modified, (S) for stabilized or (M) or (S) for Contractor's option. Asphalt mixtures with the E designation may be modified, but shall not be stabilized.

1. Type (M) asphalt mixtures shall consist of mixes incorporating a neat asphalt material with polymer modification meeting the requirements of a PG 76-22 and have a Rolling Thin Film Oven Test residue elastic recovery at 77 degrees F of a minimum 70 percent. Modified mixtures shall be designated with a (M) following the standard mix designation. Type (M) asphalt mixtures shall not be permitted to exceed 15 percent reclaimed asphalt pavement material.

2. Type (S) asphalt mixtures shall consist of mixes incorporating a stabilizing additive from the Department's approved list. These mixes shall be designated with a (S) following the standard mix designation. The minimum required additive shall be as specified on the approved list.

211.05—Testing.

The Contractor shall provide the quality control and assurance necessary for the Department to determine conformance with the required grading, SUPERPAVE volumetric properties, asphalt content, and temperature properties for asphalt concrete.

Aggregate specific gravity and aggregate property tests shall be conducted on each aggregate component (including RAP) or total aggregate mixture once at design and once prior to beginning production in each calendar year. Sand equivalent shall not be performed on RAP. In addition, for each 50,000 tons of each aggregate size used at each plant, aggregate specific gravity and aggregate property test shall be reported on each aggregate component or the total aggregate mixture. Otherwise, if the total blend (cold feed) is used to obtain aggregate specific gravity and aggregate properties, then these tests shall be run for each 50,000 tons of the total blend.

211.06—Tests.

The Department may sample materials entering into the composition of the asphalt concrete, the mixture or the completed pavement. The Contractor shall cooperate with the Engineer in obtaining these samples. When samples are obtained from the pavement, the resulting voids shall be filled and refinished by the Contractor without additional compensation.

When asphalt cement is extracted and recovered in accordance with AASHTO T170, the recovered asphalt cement shall have the following penetration and ductility at 77 degrees F:

Mix Type	Recovered Penetration	Ductility at 77 degrees F
SM-9.0A, 9.5A, 12.5A	min 35	min 40 cm
SM-9.0D, 9.5D, 12.5D	min 25	min 40 cm
IM-19.0A	min 35	min 40 cm
IM-19.0D	min 25	min 40 cm
BM-25.0, 37.5	min 35	min 40 cm

NOTE: Recovered penetration and ductility shall not be performed on M-9.5E, 12.5E, and all (M) and (S) mixes.

Abson recovery samples that fail recovered penetration or ductility shall be PG graded according to AASHTO MP-1. If the samples meet the required grade specified in Section 211.01, they shall be deemed acceptable.

When the Department performs PG grading on a Contractor's liquid asphalt storage tank, the Engineer will notify the Asphalt Concrete Producer and Binder Supplier if tests indicate that the binder properties of the asphalt material differs from the approved job-mix. It will be the responsibility of the Asphalt Concrete Producer and Binder Supplier to determine corrective action with the approval of the Engineer.

211.08—Acceptance.

Acceptance shall be made under the Department's quality assurance program which includes the testing of material production samples by the Contractor and monitor samples by the Department. Sampling and testing for the determination of grading, SUPERPAVE volumetric properties, asphalt cement content and temperature shall be performed by the Contractor, and the Department will perform independent monitor checks at a laboratory of its discretion. The Contractor shall provide copies of such test results to the Department on forms furnished by the Department. In the event the Contractor's test results indicate that the mixture conforms to the gradation, SUPERPAVE volumetric properties, asphalt cement content and mix temperature requirements of the Specifications, the mixture will be acceptable for these properties; however, nothing herein shall be construed as waiving the requirements of Sections 106.06, 200.02 and 200.03 or relieving the Contractor of the obligation to furnish and install a finished functional product which conforms to the requirements of the Contract. In the event a statistical comparative analysis of the Contractor's test results and the Department's monitor tests indicate a statistically significant difference in the results and either of the results indicate that the material does not conform to the grading, SUPERPAVE volumetric properties, and or asphalt cement content requirements of the Specifications, an investigation will be made to determine the reason for the difference. In the event it is determined from the investigation that the material does not conform to the requirements of the Contract, price adjustments will be made in accordance with the requirements of Section 211.09.

Field SUPERPAVE tests shall be performed to N design gyrations as specified in Table II-14. At the Engineer's discretion, the N max requirement may be checked.

Acceptance for gradation, SUPERPAVE volumetric properties, and asphalt cement content will be based on the Percent Within Limits (PWL) from the Quality Index (QI) calculated using the results of five tests performed by the Contractor on samples taken from each 1000 ton sublot in a stratified random manner from each 5000 ton lot. Calculations to determine pay factors for a lot will normally be based on test results of 5 samples (n = 5). When the sample size is less than n = 5, the following procedure will be used:

If the sample size obtained from a lot is n = 3 or 4, the PWL will be determined based on the Quality Index computed from the average and standard deviation of the 3or 4 results and the corresponding PWL table for n = 3 or 4. If either one or two samples are obtained from a lot, these results will be combined with the previous lot, making the sample size either n = 6 (based on the addition of one sample) or n = 7 (based on the addition of two samples). Under either circumstance, the PWL will be determined based on the Quality Index computed from the average and standard deviation and the corresponding table for n = 6 or n = 7. If the Contractor elects to terminate a lot prior to obtaining 5 samples, the Contractor must immediately inform

the Department. The Contractor may elect to remove and replace defective asphalt concrete representing all or a portion of a lot any time, at the Contractor's discretion. Test results from any portion of a lot remaining in place will be used for acceptance and determination of the pay factor for that quantity of material.

Samples shall be obtained from the approximate center of randomly selected truckloads of material. Any statistically acceptable method of randomization may be used to determine the time and location of the stratified random sample to be taken. The Department shall be advised of the method to be used prior to the beginning of production and the random number shall be documented and retained.

The QI uses both the average and standard deviation within each lot to estimate the population and determine the percentage of the lot within the specification limits (PWL).

The Acceptable Quality Level (AQL) is that quality receiving 100% pay. The Rejectable Quality Level (RQL) is that quality requiring retesting and potentially removal and replacement. The AQL has been established at 90 Percent Within Limits (PWL) and the RQL at 30 PWL.

All material in the lot that has a pay factor less than 82% (30 PWL) shall be rejected and removed from the road. For material with a pay factor greater than or equal to 82% that the contractor does not elect to remove and replace, the unit bid price shall be computed in accordance with Section 211.09.

The specification limits are shown in Table II-15.

TABLE II-15
SPECIFICATION LIMITS FOR GRADATION, SUPERPAVE VOLUMETRIC PROPERTIES, AND ASPHALT CONTENT*

Mix Property	SM&IM	
	LSL	USL
Gradation No. 4 Sieve	-4.0	+4.0
Gradation No. 200 Sieve	-1.0	+1.0
Voids in Min Aggr. (VMA)**	-0.7%	---
Voids Total Mix (VTM)	-1.2%	+1.2%
Asphalt Content (AC%)**	-0.3%	+0.3%

*LSL = Lower Specification Limits, USL = Upper Specification Limits. All specification limits are measured from the approved JMF values.
**The contractor may revise the mix design JMF asphalt content and/or VMA based on previous test results from plant produced material with approval in writing by the Engineer. Only one revision will be approved per schedule or project.

The TPWL and pay factor are determined as follows:

1. Calculate the Q_l and Q_u using the equations below:

$$Q_l = \frac{\bar{X} - LSL}{S}$$

$$Q_u = \frac{USL - \bar{X}}{S}$$

Where:
Q_l is the lower Quality Index (calculated to two decimal places)
Q_u is the upper Quality Index (calculated to two decimal places)
$\bar{X}$ is the lot average (calculated to one decimal place)
S is the lot standard deviation (calculated to two decimal places)
LSL is the lower specification limit
USL is the upper specification limit

2. Use Q_l and Q_u to enter Table 11-16 (n=3, 4, 5, 6 or 7), Estimation of Lot PWL, to determine the Lower Percent Within Limits (LPWL) and the Upper Percent Within Limits (UPWL). For VMA, that does not have an upper specification limit, use UPWL = 100.0%.

3. Calculate the Total Percent Within Limits (TPWL).

TPWL = (LPWL + UPWL) - 100

4. Use the TPWL in the Pay Factor equations below to determine the pay factor for the lot. The lowest value of TPWL calculated for VTM, VMA and asphalt content will be used to determine the pay factor.

PF = 73 + .3(TPWL)

Should visual examination by the Engineer reveal that the material in any load or portion of the paved roadway is obviously contaminated or segregated, that load or portion of the paved roadway will be rejected without additional sampling or testing of the lot. If it is necessary to determine the SUPERPAVE volumetric properties or asphalt content of the material in any load or portion of the paved roadway, samples will be taken and tested and the results will be compared to the requirements of the approved job-mix formula. The results obtained in the testing will apply only to the quantity of mixture in question.

The temperature of the mixture at the plant shall be controlled to provide load to load uniformity during changing weather conditions and surface temperatures. The maximum temperature of mix designations A and D, and base mixes, shall not exceed 350 degrees F, unless otherwise

directed by the Engineer. The maximum temperature as recommended by the supplier shall not be exceeded for an E, (M), or (S) designated mix.

In the event the job-mix formula is modified within a lot, the lot shall be terminated, the PWL and pay factor determined and a new lot started. If a sample size less than 3 exists for the lot, the one or two values shall be added to the previous lot and the resultant sample size used.

Asphalt content will be measured as extractable asphalt or weight after ignition.

211.09—Determination of Pay Factors.

Use the TPWL from the Pay Factor equations to determine the pay factor for the lot. The lowest value of TPWL calculated for Gradation, VTM, VMA and asphalt content will be used to determine the pay factor.

PF = 73 + .3(TPWL)

211.10—Referee System.

(a) In the event the test results obtained from one of the five samples taken to evaluate a particular lot appear to be questionable, the Contractor may request in writing that the results of the questionable sample be disregarded; whereupon, the Contractor shall have either an AASHTO accredited lab or Department lab perform tests on six additional samples taken from randomly selected locations in the roadway where the lot was placed. In the event the Engineer determines that one of the five tests results appears to be questionable, the Department will perform tests on six additional samples taken from randomly selected locations in the roadway where the lot was placed. The test results of the four original (unquestioned) samples will be used with test results of the six road samples and the average and standard deviation of the test values obtained for the ten samples will be compared to the requirements shown in Table II-15.

(b) In the event the Contractor questions the PWL of the five original test results obtained for a particular lot, the Contractor may request in writing approval to have either an AASHTO accredited lab or Department lab perform additional testing of that lot. In the event the Engineer determines that the PWL of the five original test results are questionable, the Department will perform additional testing of that lot. The test results of the five original samples will be used with the test results of the five additional samples taken from randomly selected locations in the roadway where the lot was placed and the PWL obtained for the ten samples will be compared to the requirements for the shown in Table II-15.

If the Contractor requests additional tests, as described in (a) or (b) herein, the Contractor shall sample and have either an AASHTO accredited lab or Department lab test the material in accordance with Department approved procedures. The Engineer reserves the right to observe the sampling and testing.

In any case, the resultant PWL of the original and retested ten test results will be used to determine the pay specified in Section 211.09.

Samples of the size shown herein shall be saw cut by the Contractor, without the use of liquids, for testing.

Application Rate	Minimum Sample Size
125 pounds per square yard	8 by 8 inches
150 pounds per square yard	7 by 7 inches
200 pounds per square yard	6 by 6 inches
300 pounds per square yard	5 by 5 inches

211.16—Measurement and Payment.

Asphalt concrete will be measured and paid for in accordance with Section 315.08 A or B (see Appendix B).

APPENDIX B

SPECIAL PROVISION FOR
SECTION 315—ASPHALT CONCRETE PAVEMENT
(STATISTICAL QUALITY ASSURANCE)
Modified

Note: VTRC Working Document (Not a VDOT-endorsed Draft Specification)

315.05 —Density Procedures.

(a) **Compaction:** The Engineer shall perform acceptance testing for density for each lot of production by obtaining one 6-inch core at stratified random locations from each 3000 foot sublot of 12 foot wide pavement. The Contractor shall take cores as soon as practical after compaction has been completed. The Engineer will determine the random location from which each core shall be taken. The Contractor may choose to determine the density of each core before giving it to the Engineer for density determination in accordance with VTM-22. The density determined by the Engineer shall be used for density payment. All core locations shall be numbered sequentially per roadway and marked on the pavement. Subsequent to coring, the core hole shall be filled with SUPERPAVE mixture and compacted prior to the next day of production.

(b) **Acceptance:** Acceptance for density will be based on Percent Within Limits (PWL). PWL is obtained from the Quality Index (Q) calculated using the results of core density tests. Calculations to determine pay factors for a lot will normally be based on test results of 5 samples (n = 5). When the sample size is less than n = 5, the following procedure will be used:

If the sample size obtained from a lot is n = 3 or 4, the PWL will be determined based on the Quality Index computed from the average and standard deviation of the 3or 4 results and the corresponding PWL table for n = 3 or 4. If either one or two samples are obtained from a lot, these results will be combined with the previous lot, making the sample size either n = 6 (based on the addition of one sample) or n = 7 (based on the addition of two samples). Under either circumstance, the PWL will be determined based on the Quality Index computed from the average and standard deviation and the corresponding table for n = 6 or n = 7. If the Contractor elects to terminate a lot prior to obtaining 5 samples, the Contractor must immediately inform the Department. The Contractor may elect to remove and replace defective asphalt concrete representing all or a portion of a lot any time, at the Contractor's discretion. Test results from any portion of a lot remaining in place will be used for acceptance and determination of the pay factor for that quantity of material.

Q uses both the average and standard deviation within each lot to estimate the lot population and determines the percentage of the lot within the specification limits (PWL).

The Acceptable Quality Level (AQL) is that quality receiving 100% pay. The Rejectable Quality Level (RQL) is that quality requiring removal and replacement. The AQL has been established at 90 PWL and the RQL at 30 PWL.

Any lot that has a PWL below the RQL shall be rejected and removed from the road. At the option of the Engineer, any core with a MTD less than 93% shall have a permeability test determined in accordance with VTM-120. If the permeability value is below 150 cm/sec, the Engineer may allow the pavement to remain in-place with the appropriate pay factor as calculated from the pay factor equation.

The Q and PWL values for each Quality Characteristic are determined as follows:

1. Calculate the lower Quality Index, Q_l, and the upper Quality Index, Q_u, using the equations below:

   $$Q_l = \frac{\overline{X} - LSL}{S}$$

   $$Q_u = \frac{USL - \overline{X}}{S}$$

   Where:

   Q_l is the lower Quality Index (calculated to two decimal places)
   Q_u is the upper Quality Index (calculated to two decimal places)
   $\overline{X}$ is the lot average (calculated to one decimal place)
   S is the lot standard deviation (calculated to two decimal places)
   LSL is the lower specification limit
   USL is the upper specification limit

2. Use Q_l and Q_u to enter Table 1, Estimation of Lot PWL (n = 5), to determine the Lower Percent Within Limits (LPWL) and the Upper (UPWL). (LPWL and UPWL shall be calculated to two decimal places).

3. Calculate the Total Percent Within Limits (TPWL).

   TPWL = (LPWL + UPWL) – 100

4. If the TPWL is greater than 30, use the TPWL in the Pay Factors equation below to determine the pay factor for the lot.

   PF = 73 + 0.3(TPWL)

5. If the TPWL is less than or equal to 30, the Contractor shall be required to remove and replace that lot. At the option of the Engineer, any density core with a MTD ≤ 93% (92% for IM mixes) shall have a permeability tests performed and allowed to

remain in-place, at the appropriate pay factor, if the permeability value is less than 150 cm/sec.

Should visual examination by the Engineer reveal that the material in any load or portion of the paved roadway is obviously contaminated or segregated, that load or portion of the paved roadway will be rejected without additional sampling or testing of the lot.

Upper and Lower Specification Limits: The specification limits for SUPERPAVE mixes are listed in Table III-3.

TABLE III-3
LIMITS BASED ON MTD

Mixture Type	Lower Specification Limit	Upper Specification Limit
SM-9.5A, 12.5A	94	98
SM-9.5D, 12.5D	93	97
SM-9.5E, 12.5E	93	97
IM-19.0A	93	97
IM-19.0D	92	96

(c) **Dispute Resolution (Retest Provision):** In the event there is a dispute as to the average and/or standard deviation value of the density of a lot, the Contractor may request that another set of five stratified randomly selected cores be taken from the same lot. The cores shall be randomly selected by sublot, but without regard to the location of the original cores. The density values of these five additional cores shall be used with those of the five original cores to determine a new average and standard deviation. The Q and PWLPWL shall again be determined. Table II-16, Estimation of Lot PWL (n = 10) shall be used to calculate the new PWL. The pay factor of the lot shall be based on this PWL. If the PWL of the 10 cores is equal to or lower than the PWL of the original 5, the Contractor shall reimburse the Department for the cost of obtaining the additional cores.

315.06—Smoothness Tolerance.

(a) **Measurement:** Pavement smoothness will be measured in terms of the mean roughness index (MRI), which is the average of the international roughness index (IRI) values for the left and right wheel-paths. The IRI is determined from longitudinal elevation profile data collected with an inertial profiling device. The device shall measure both wheel-paths with laser height sensing instruments. The Department will conduct the testing within 30 calendar days of completion of the final surface course over the designated section. Testing will be conducted in accordance with VTM-106. The Department will conduct the testing as soon as possible after completion, providing the Contractor can arrange unimpeded access to the paved surface for constant highway speed test runs. Acceptance will be based on profile analysis from the test run (from a minimum of two runs) that produces the lowest project-long average MRI for each travel lane.

(b) **Pay Adjustment:** Pay adjustments for ride quality will be determined for each project-lane using an MRI profile with a 528-foot running interval. The MRI profile is created from two IRI profiles, one each representing the left and right wheel-paths. The IRI profile is defined as a series of IRI values, one for each elevation profile data point, that are calculated over a running interval throughout the test section. Each IRI value is provided at the midpoint of the running interval. By definition (assuming a 528-ft base-length), the IRI profile for the first 264-ft after beginning to collect elevation profile and the last 264-ft before the data collection is interrupted or completed will contain no values. Examples of locations for which no IRI profile would be available include the beginning and end of the project and any bridges that may be contained within the project limits. The length of pavement in these segments should however be included in the calculations for pay adjustments. Tables III-4a&4b provide the pay adjustment schedules for Interstate and Non-Interstate pavement based on the finished rideability. Pay adjustments will be applied to the theoretical tonnage of the surface mix asphalt material for the lane width (generally 12 feet wide) and section length tested based on testing prior to any corrective action directed by the Engineer.

TABLE III-4A
PAY ADJUSTMENT SCHEDULE FOR INTERSTATE RIDE QUALITY

MRI After Completion (Inches Per Mile)	Pay Adjustment (Percent Pavement Unit Price)	*% Pavement w/in Range	Pay Adjustment
40.0 and Under	110	X	x.xx
40.1-55.0	105	X	x.xx
55.1-70.0	100	X	x.xx
70.1-80.0	90	X	x.xx
80.1-90.0	80	X	x.xx
90.1-100.0	70	X	x.xx
Over 100.1	50 or Subject to Corrective Action	X	x.xx
		Overall Pay Factor	x.xx

*Histograms reported through ProVAL

TABLE III-4B
PAY ADJUSTMENT SCHEDULE FOR NON-INTERSTATE RIDE QUALITY

MRI After Completion (Inches Per Mile)	Pay Adjustment (Percent Pavement Unit Price)	*% of Pavement w/in range	Pay Adjustment
50.0 and Under	110	X	x.xx
50.1-65.0	105	X	x.xx
65.1-80.0	100	X	x.xx
80.1-90.0	90	X	x.xx
90.1-100.0	80	X	x.xx
100.1-110.0	70	X	x.xx
Over 110.1	50 or Subject to Corrective Action	X	x.xx
		Overall Pay Factor	x.xx

Areas excluded from testing by the road profiling device will be tested using a 10-foot straightedge. The variation of the surface from the testing edge of the straightedge between any two contacts with the surface shall not be more than 1/4 inch.

(c) **Deficiencies and Corrective Work:** Any area for which the MRI profile exceeds a threshold as listed in TableIII-5 will be considered an area of localized roughness. Localized roughness will be identified using a report of continuous MRI as described in section a) using a 50 ft base length (referred to in ProVAL as "continuous short interval"). This will yield the MRI of every possible 50 ft segment.

TABLE III-5
LOCALIZED ROUGHNESS

Roadway Type	MRI (in. per mile)
Interstate	110
Non-Interstate	120

A defective segment is any area of localized roughness and shall be corrected at the discretion of The Engineer. When corrections to the pavement surface are required, the method of correction shall be reviewed by the Engineer and correction shall be performed at the Contractor's expense. The Engineer may require correction of any or all adjoining traffic lanes or shoulders at the Contractor's expense to assure uniform cross section. Methods of correction may include, but are not limited to diamond grinding, remove and replace, and AC overlay.

Where corrections are made after the initial Department rideability test, the pavement will be retested by the Department to verify that corrections have produced the acceptable ride surface. Unit price disincentives or additional corrections may be required based on the retested IRI measurements as determined by the Engineer. No incentives will be provided for sections on which corrective actions have been required by the Engineer. In the event the corrective action(s) do not result in 100% payment, then the Contractor will be assessed the corresponding percent payment.

(d) **Single-Lift Construction:** An AC layer is defined as a material lift equal to or greater than 2.5 times the maximum nominal aggregate size for the AC mix(es) specified in the contract. A material lift less than the specified application rate or less than 2.5 times the maximum nominal aggregate size for the AC mix(es) specified in the contract is considered a "scratch course" and not an AC layer.

Where only one AC layer shall be placed, the Department will test pavement sites subject to this special provision prior to work by the Contractor. Upon request by the Contractor, the Engineer will provide the IRI testing results. If this IRI testing is conducted more than 180 calendar days prior to the scheduled beginning of the work, the Engineer or Contractor may request new IRI testing.

Based on the average MRI (original surface and completed overlay) for each lane that is subject to this special provision;

- No incentive pay adjustment will be made if the pavement lane is rougher after completion of the work.

- No corrective action will be required if the completed surface has an overall MRI (per lane) indicates a 30 percent or more improvement in the ride quality. This percent improvement is based on the MRI profile histogram for the entire project-lane. When the percent improvement is achieved, the overall PF will be calculated and the Contractor will then be paid the greater of the overall PF or 100% for that project-lane.

This rideability specification does not relieve the Contractor from responsibility concerning workmanship in accordance with the requirements of the Specifications or as defined by the Engineer.

(e) **Incentive Only Projects:** For projects designated as "incentive only," the Contractor will not be subjected to penalties on any 3000-ft section resulting from the final rideability results. Incentive only projects will not be subject to corrective action as a result of the rideability results.

Pay adjustments will be applied to the theoretical tonnage of the surface mix asphalt material for the lane width and section length tested.

This rideability specification does not relieve the Contractor from responsibility concerning workmanship in accordance with the requirements of the Specifications, other contract requirements or as defined by the Engineer.

315.07—Bond Strength.

The asphalt tack shall be applied to the pavement surface in such a manner that it will bond the overlay and the underlying surfaces together. The bond between asphalt layers shall have adhesion strength of at least 40 psi between layers when tested according to VTM-92. Under routine placement conditions, one 4-in (100-mm) diameter core will be taken for every three compaction cores (i.e., one per 9,000 feet) to evaluate adhesion strength. At the discretion of the Engineer, as many as three "bond cores" may be necessary from each day's production. (This information will be collected and analyzed for information only.

315.08—Measurement and Payment.

(a) **Method A:** Asphalt concrete will be measured in tons and paid for at the contract unit price per ton. Net weight information shall be furnished with each load of material delivered in accordance with the requirements of Section 211. Batch weights will not be permitted as a method of measurement unless the Contractor's plant is equipped in accordance with Section 211, in which case the cumulative weight of the batches will be used for payment.

(b) **Method B:** Asphalt concrete will be measured in square yards of asphalt pavement, complete-in-place, and will be paid for at the contract unit price per square yard. This price shall include furnishing and placing materials provided that for any pavement found deficient

in average thickness from cores taken for determining density, as described in VTM-120 Section 7.1.7, by more than 0.1 inch only the reduced price stated below will be paid. The width of measurement will be the average width determined at the core locations, measured to the nearest 0.1 foot.

Price adjustments: Where the average thickness of pavement is deficient by more than 0.1 inch, pavement will be made at the adjusted price as specified by the following:

Deficiency in Thickness (in)	Percent of Contract Unit price
0.00-0.10	100
0.11-0.20	90
0.21-0.30	70
Greater than 0.31	50

TABLE II-16
ESTIMATION OF LOT PERCENT WITHIN LIMITS

SAMPLE SIZE = 3

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.28	50.55	50.83	51.10	51.38	51.65	51.93	52.21	52.48
0.1	52.76	53.03	53.31	53.59	53.87	54.15	54.42	54.70	54.98	55.26
0.2	55.54	55.82	56.10	56.38	56.66	56.95	57.23	57.51	57.80	58.08
0.3	58.37	58.65	58.94	59.23	59.51	59.80	60.09	60.38	60.67	60.97
0.4	61.26	61.55	61.85	62.15	62.44	62.74	63.04	63.34	63.65	63.95
0.5	64.25	64.56	64.87	65.18	65.49	65.80	66.12	66.43	66.75	67.07
0.6	67.39	67.72	68.04	68.37	68.70	69.03	69.37	69.70	70.04	70.39
0.7	70.73	71.08	71.43	71.78	72.14	72.50	72.87	73.24	73.61	73.98
0.8	74.36	74.75	75.14	75.53	75.93	76.33	76.74	77.16	77.58	78.01
0.9	78.45	78.89	79.34	79.81	80.27	80.75	81.25	81.75	82.26	82.79
1.0	83.33	83.89	84.47	85.07	85.69	86.34	87.02	87.73	88.49	89.29
1.1	90.16	91.11	92.18	93.40	94.92	97.13	100.0	100.0	100.0	100.0

ESTIMATION OF LOT PERCENT WITHIN LIMITS

SAMPLE SIZE = 4

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.33	50.67	51.00	51.33	51.67	52.00	52.33	52.67	53.00
0.1	53.33	53.67	54.00	54.33	54.67	55.00	55.33	55.67	56.00	56.33
0.2	56.67	57.00	57.33	57.67	58.00	58.33	58.67	59.00	59.33	59.67
0.3	60.00	60.33	60.67	61.00	61.33	61.67	62.00	62.33	62.67	63.00
0.4	63.33	63.67	64.00	64.33	64.67	65.00	65.33	65.67	66.00	66.33
0.5	66.67	67.00	67.33	67.67	68.00	68.33	68.67	69.00	69.33	69.67
0.6	70.00	70.33	70.67	71.00	71.33	71.67	72.00	72.33	72.67	73.00
0.7	73.33	73.67	74.00	74.33	74.67	75.00	75.33	75.67	76.00	76.33
0.8	76.67	77.00	77.33	77.67	78.00	78.33	78.67	79.00	79.33	79.67
0.9	80.00	80.33	80.67	81.00	81.33	81.67	82.00	82.33	82.67	83.00
1.0	83.33	83.67	84.00	84.33	84.67	85.00	85.33	85.67	86.00	86.33
1.1	86.67	87.00	87.33	78.67	88.00	88.33	88.67	89.00	89.33	89.67
1.2	90.00	90.33	90.67	91.00	91.33	91.67	92.00	92.33	92.67	93.00
1.3	93.33	93.67	94.00	94.33	94.67	95.00	95.33	95.67	96.00	96.33
1.4	96.67	97.00	97.33	97.67	98.00	98.33	98.67	99.00	99.33	99.67
1.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT PERCENT WITHIN LIMITS

SAMPLE SIZE = 5

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.36	50.71	51.07	51.42	51.78	52.13	52.49	52.85	53.20
0.1	53.56	53.91	54.27	54.62	54.98	55.33	55.69	56.04	56.39	56.75
0.2	57.10	57.46	57.81	58.16	58.52	58.87	59.22	59.57	59.92	60.28
0.3	60.63	60.98	61.33	61.68	62.03	62.38	62.72	63.07	63.42	63.77
0.4	64.12	64.46	64.81	65.15	65.50	65.84	66.19	66.53	66.87	67.22
0.5	67.56	67.90	68.24	68.58	68.92	69.26	69.60	69.94	70.27	70.61
0.6	70.95	71.28	71.61	71.95	72.28	72.61	72.94	73.27	73.60	73.93
0.7	74.26	74.59	74.91	75.24	75.56	75.89	76.21	76.53	76.85	77.17
0.8	77.49	77.81	78.34	78.44	78.76	79.07	79.38	79.69	80.00	80.31
0.9	80.62	80.93	81.23	81.54	81.84	82.14	82.45	82.74	83.04	83.34
1.0	83.64	83.93	84.22	84.52	84.81	85.09	85.38	85.67	85.95	86.24
1.1	86.52	86.80	87.07	87.35	87.63	87.90	88.17	88.44	88.71	88.98
1.2	89.24	89.50	89.77	90.03	90.28	90.54	90.79	91.04	91.29	91.54
1.3	91.79	92.03	92.27	92.51	92.75	92.98	93.21	93.44	93.67	93.90
1.4	94.12	94.34	94.56	94.77	94.98	95.19	95.40	95.61	95.81	96.01
1.5	96.20	96.39	96.58	96.77	96.95	97.13	97.31	97.48	97.65	97.81
1.6	97.97	98.13	98.28	98.43	98.58	98.72	98.85	98.98	99.11	99.23
1.7	99.34	99.45	99.95	99.64	99.73	99.81	99.88	99.94	99.98	100.0

ESTIMATION OF LOT PERCENT WITHIN LIMITS

SAMPLE SIZE = 6

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.37	50.73	51.10	51.47	51.84	52.20	52.57	52.94	53.30
0.1	53.67	54.04	54.40	54.77	55.14	55.50	55.87	56.23	56.60	56.96
0.2	57.32	57.69	58.05	58.41	58.78	59.14	59.50	59.86	60.22	60.58
0.3	60.94	61.30	61.66	62.02	62.38	62.73	63.09	63.45	63.80	64.16
0.4	64.51	64.86	64.21	65.57	65.92	66.27	66.62	66.96	67.31	67.66
0.5	68.00	68.35	68.69	69.04	69.38	69.72	70.06	70.40	70.74	71.07
0.6	71.41	71.75	72.08	72.41	72.74	73.08	73.40	73.73	74.06	74.39
0.7	74.71	75.04	75.36	75.68	76.00	76.32	76.63	76.95	77.26	77.58
0.8	77.89	78.20	78.51	78.82	79.12	79.43	79.73	80.03	80.33	80.63
0.9	80.93	81.22	81.51	81.81	82.10	82.39	82.67	82.96	83.24	83.52
1.0	83.80	84.08	84.36	84.63	84.91	85.18	85.45	85.71	85.98	86.24
1.1	86.50	86.76	87.02	87.28	87.53	87.78	88.03	88.28	88.53	88.77
1.2	89.01	89.25	89.49	89.72	89.96	90.19	90.42	90.64	90.87	91.09
1.3	91.31	91.52	91.74	91.95	92.16	92.37	92.58	92.78	92.98	93.18
1.4	93.37	93.57	93.76	93.95	94.13	94.32	94.50	94.67	94.85	95.02
1.5	95.19	95.36	95.53	95.69	95.85	96.00	96.16	96.31	96.46	96.60
1.6	96.75	96.89	97.03	97.16	97.29	97.42	97.55	97.67	97.79	97.91
1.7	98.02	98.13	98.24	98.34	98.45	98.55	98.64	98.73	98.82	98.91
1.8	98.99	99.07	99.15	99.22	99.29	99.36	99.43	99.49	99.54	99.60
1.9	99.65	99.70	99.74	99.78	99.82	99.85	99.88	99.91	99.93	99.95
2.0	99.97	99.98	99.99	100.0	100.0	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 7

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.37	50.75	51.12	51.50	51.87	52.24	52.62	52.99	53.37
0.1	53.74	54.11	54.49	54.86	55.23	55.60	55.97	56.35	56.72	57.09
0.2	57.46	57.83	58.20	58.56	58.93	59.30	59.67	60.03	60.40	60.77
0.3	61.13	61.50	61.86	62.22	62.58	62.94	63.31	63.67	64.02	64.38
0.4	64.74	65.10	65.45	65.81	66.16	66.51	66.87	66.22	67.57	67.92
0.5	68.26	68.61	68.96	69.30	69.64	69.99	70.33	70.67	71.01	71.34
0.6	71.68	72.02	72.35	72.68	73.01	73.34	73.67	74.00	74.32	74.65
0.7	74.97	75.29	75.61	75.93	76.26	76.56	76.88	77.19	77.50	77.81
0.8	78. 12	78.42	78.73	79.03	79.33	79.63	79.93	80.22	80.52	80.81
0.9	81.10	81.39	81.67	81.96	82.24	82.52	82.80	82.08	83.35	83.63
1.0	83.90	84.17	84.44	84.70	84.97	85.23	85.49	85.74	86.00	86.25
1.1	86.51	86.75	87.00	87.25	87.49	87.73	87.97	88.21	88.44	88.67
1.2	88.90	89.13	89.35	89.58	89.80	90.02	90.23	90.45	90.66	90.87
1.3	91.07	91.28	91.48	91.68	91.88	92.08	92.27	92.46	92.65	92.83
1.4	93.02	93.20	93.38	93.55	93.73	93.90	94.07	94.23	94.40	94.56
1.5	94.72	94.87	95.03	95.18	95.33	95.48	95.62	95.76	95.90	96.04
1.6	96.17	96.31	96.43	96.56	96.69	96.81	96.93	97.05	97.16	97.27
1.7	97.38	97.49	97.59	97.70	97.80	97.89	97.99	98.08	98.17	98.26
1.8	98.35	98.43	98.51	98.59	98.66	98.74	98.81	98.88	98.94	99.01
1.9	99.07	99.13	99.19	99.24	99.30	99.35	99.40	99.44	99.49	99.53
2.0	99.57	99.61	99.64	99.68	99.71	99.74	99.77	99.79	99.82	99.84
2.1	99.86	99.88	99.90	99.92	99.93	99.94	99.95	99.96	99.97	99.98
2.2	99.99	99.99	99.99	100.0	100.0	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 8

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.38	50.76	51.14	51.51	51.89	52.27	52.65	53.03	53.41
0.1	53.78	54.16	54.54	54.92	55.29	55.67	56.04	56.42	56.79	57.17
0.2	57.54	57.92	58.29	58.66	59.03	59.41	59.78	60.15	60.52	60.89
0.3	61.25	61.62	61.99	62.36	62.72	63.08	63.45	63.81	64.17	64.53
0.4	64.89	65.25	65.61	65.96	66.32	66.67	67.03	67.38	67.73	68.08
0.5	68.43	68.78	69.13	69.47	69.82	70.16	70.50	70.84	71.18	71.52
0.6	71.85	72.19	72.52	72.85	73.18	73.51	73.84	74.17	74.49	74.81
0.7	75.14	75.46	75.77	76.09	76.41	76.72	77.03	77.34	77.65	77.96
0.8	78.26	78.56	78.86	79.16	79.46	79.76	80.05	80.34	80.63	80.92
0.9	81.21	81.49	81.77	82.05	82.33	82.61	82.88	82.15	83.43	83.69
1.0	83.96	84.22	84.49	84.75	85.00	85.26	85.51	85.76	86.01	86.26
1.1	86.51	86.75	86.99	87.23	87.46	87.70	87.93	88.16	88.39	88.61
1.2	88.83	89.06	89.27	89.49	89.70	89.91	90.12	90.33	90.53	90.74
1.3	90.94	91.13	91.33	91.52	91.71	91.90	92.09	92.27	92.45	92.63
1.4	92.81	92.98	93.15	93.32	93.49	93.65	93.81	93.97	94.13	94.29
1.5	94.44	94.59	94.74	94.88	95.03	95.17	95.31	95.44	95.58	95.71
1.6	95.84	95.97	96.09	96.21	96.33	96.45	96.57	96.68	96.79	96.90
1.7	97.01	97.11	97.21	97.31	97.41	97.51	97.60	97.69	97.78	97.87
1.8	97.96	98.04	98.12	98.20	98.28	98.35	98.42	98.49	98.56	98.63
1.9	98.69	98.76	98.82	98.88	98.93	98.99	99.04	99.09	99.14	99.19
2.0	99.24	99.28	99.33	99.37	99.41	99.45	99.48	99.52	99.55	99.58
2.1	99.61	99.64	99.67	99.70	99.72	99.74	99.77	99.79	99.81	99.83
2.2	99.84	99.86	99.87	99.89	99.90	99.91	99.92	99.93	99.94	99.95
2.3	99.96	99.96	99.97	99.98	99.98	99.98	99.99	99.99	99.99	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 9

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.38	50.76	51.15	51.53	51.91	52.29	52.67	53.05	53.43
0.1	53.82	54.20	54.58	54.96	55.34	55.71	56.09	56.47	56.85	57.23
0.2	57.60	57.98	58.36	58.73	59.11	59.48	59.85	60.23	60.60	60.97
0.3	61.34	61.71	62.08	62.45	62.81	63.18	63.54	63.91	64.27	64.63
0.4	65.00	65.36	65.71	66.07	66.43	66.79	67.14	67.49	67.85	68.20
0.5	68.55	68.90	69.24	69.59	69.93	70.28	70.62	70.96	71.30	71.64
0.6	71.97	72.31	72.64	72.97	73.30	73.63	73.96	74.28	74.61	74.93
0.7	75.25	75.57	75.89	76.20	76.51	76.83	77.14	77.44	77.75	78.06
0.8	78.36	78.66	78.96	79.25	79.55	79.84	80.13	80.42	80.71	81.00
0.9	81.28	81.56	81.84	82.12	82.39	82.67	82.94	83.21	83.47	83.74
1.0	84.00	84.26	84.52	84.77	85.03	85.28	85.53	85.78	86.02	86.27
1.1	86.51	86.74	86.98	87.21	87.45	87.68	87.90	88.13	88.35	88.57
1.2	88.79	89.00	89.22	89.43	89.64	89.85	90.05	90.25	90.32	90.49
1.3	90.84	91.04	91.23	91.41	91.60	91.78	91.96	92.14	92.32	92.49
1.4	92.67	92.83	93.00	93.17	93.33	93.49	93.65	93.80	93.96	94.11
1.5	94.26	94.40	94.55	94.69	94.83	94.97	95.10	95.23	95.36	95.49
1.6	95.62	95.74	95.86	95.98	96.10	96.22	96.33	96.44	96.55	96.66
1.7	96.76	96.86	96.97	97.06	97.16	97.25	97.35	97.44	97.53	97.61
1.8	97.70	97.78	97.86	97.94	98.02	98.09	98.16	98.24	98.30	98.37
1.9	98.44	98.50	98.56	98.63	98.68	98.74	98.80	98.85	98.90	98.95
2.0	99.00	99.05	99.10	99.14	99.18	99.23	99.27	99.30	99.34	99.38
2.1	99.61	99.64	99.67	99.70	99.72	99.74	99.77	99.79	99.81	99.83
2.2	99.84	99.86	99.87	99.89	99.90	99.91	99.92	99.93	99.94	99.95
2.3	99.86	99.87	99.89	99.90	99.91	99.92	99.92	99.93	99.94	99.95
2.4	99.95	99.96	99.96	99.97	99.97	99.98	99.98	99.98	99.99	99.99
2.5	99.99	99.99	99.99	100.0	100.0	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 10

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.38	50.77	51.15	51.54	51.92	52.30	52.69	53.07	53.46
0.1	53.84	54.22	54.60	54.99	55.37	55.75	56.13	56.51	56.89	57.27
0.2	57.65	58.03	58.40	58.78	59.16	59.53	59.91	60.28	60.66	61.03
0.3	61.40	61.77	62.14	62.51	62.88	63.25	63.62	63.98	64.35	64.71
0.4	65.07	65.43	65.79	66.15	66.51	66.87	67.22	67.58	67.93	68.28
0.5	68.63	68.98	69.33	69.68	70.02	70.36	70.71	71.05	71.39	71.72
0.6	72.06	72.40	72.73	73.06	73.39	73.72	74.04	74.37	74.69	75.01
0.7	75.33	75.65	75.97	76.28	76.59	76.90	77.21	77.52	77.82	78.13
0.8	78.43	78.73	79.02	79.32	79.61	79.90	80.19	80.48	80.77	81.05
0.9	81.33	81.61	81.89	82.16	82.44	82.71	82.97	83.24	83.51	83.77
1.0	84.03	84.28	84.54	84.79	85.04	85.29	85.54	85.78	86.03	86.27
1.1	86.50	86.74	86.97	87.20	87.43	87.66	87.88	88.10	88.32	88.54
1.2	88.76	88.97	89.18	89.39	89.59	89.79	90.00	90.19	90.39	90.58
1.3	90.78	90.97	91.15	91.34	91.52	91.70	91.88	92.05	92.23	92.40
1.4	92.56	92.73	92.90	93.06	93.22	93.37	93.53	93.68	93.83	93.98
1.5	94.13	94.27	94.41	94.55	94.69	94.82	94.95	95.08	95.21	95.34
1.6	95.46	95.59	95.70	95.82	95.95	96.05	96.16	96.27	96.38	96.48
1.7	96.59	96.69	96.79	96.89	96.98	97.07	97.17	97.26	97.34	97.43
1.8	97.51	97.60	97.68	97.75	97.83	97.91	97.98	98.05	98.12	98.19
1.9	98.25	98.32	98.38	98.44	98.50	98.56	98.62	98.67	98.73	98.78
2.0	98.83	98.88	98.93	98.97	99.02	99.06	99.10	99.14	99.18	99.22
2.1	99.26	99.29	99.33	99.36	99.39	99.42	99.45	99.48	99.51	99.54
2.2	99.56	99.59	99.61	99.63	99.66	99.68	99.70	99.71	99.73	99.75
2.3	99.77	99.78	99.80	99.81	99.82	99.84	99.85	99.96	99.87	99.88
2.4	99.89	99.90	99.91	99.92	99.92	99.93	99.94	99.94	99.95	99.95
2.5	99.96	99.96	99.97	99.97	99.97	99.98	99.98	99.98	99.99	99.99
2.6	99.99	99.99	99.99	99.99	99.99	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 11

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.39	50.77	51.16	51.54	51.93	52.32	52.70	53.09	53.47
0.1	53.86	54.24	54.62	55.01	55.39	55.77	56.16	56.54	56.92	57.30
0.2	57.68	58.06	58.44	58.82	59.20	59.58	59.95	60.33	60.70	61.08
0.3	61.45	61.82	62.19	62.56	62.93	63.30	63.64	64.04	64.40	64.77
0.4	65.13	65.49	65.85	66.21	66.57	66.93	67.29	67.64	67.99	68.35
0.5	68.70	69.05	69.40	69.74	70.09	70.43	70.77	71.11	71.45	71.79
0.6	72.13	72.46	72.79	73.12	73.45	73.78	74.11	74.43	74.75	75.08
0.7	75.39	75.71	76.03	76.34	76.65	76.96	77.27	77.57	77.88	78.18
0.8	78.48	78.78	79.07	79.37	79.66	79.95	80.24	80.52	80.81	81.09
0.9	81.37	81.65	81.92	82.20	82.47	82.74	83.00	83.27	83.53	83.79
1.0	84.05	84.30	84.56	84.81	85.06	85.30	85.55	85.79	86.03	86.27
1.1	86.50	86.74	86.97	87.19	87.42	87.64	87.87	88.09	88.30	88.52
1.2	88.73	88.94	89.15	89.35	89.56	89.76	89.95	90.15	90.34	90.54
1.3	90.72	90.91	91.10	91.28	91.46	91.64	91.81	91.98	92.15	92.32
1.4	92.49	92.65	92.81	92.97	93.13	93.29	93.44	93.59	93.74	93.88
1.5	94.03	94.17	94.31	94.45	94.58	94.71	94.84	94.97	95.10	95.22
1.6	95.35	95.47	95.59	95.70	95.82	95.93	96.04	96.15	96.25	96.36
1.7	96.36	96.56	96.66	96.75	96.85	96.94	97.03	97.12	97.21	97.29
1.8	97.38	97.46	97.54	97.62	97.69	97.77	97.84	97.91	97.98	98.05
1.9	98.12	98.18	98.24	98.31	98.37	98.42	98.48	98.54	98.59	98.64
2.0	98.70	98.75	98.79	98.84	98.89	98.93	98.98	99.02	99.06	99.10
2.1	99.14	99.17	99.21	99.25	99.28	99.31	99.34	99.37	99.40	99.43
2.2	99.46	99.49	99.51	99.54	99.56	99.58	99.60	99.63	99.65	99.67
2.3	99.68	99.70	99.72	99.74	99.75	99.77	99.78	99.79	99.81	99.82
2.4	99.83	99.84	99.85	99.86	99.87	99.88	99.89	99.90	99.91	99.91
2.5	99.92	99.93	99.93	99.94	99.94	99.95	99.95	99.96	99.96	99.96
2.6	99.97	99.97	99.97	99.98	99.98	99.98	99.98	99.99	99.99	99.99
2.7	99.99	99.99	99.99	99.99	99.99	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 12

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.39	50.77	51.16	51.55	51.94	52.32	52.71	53.10	53.48
0.1	53.87	54.26	54.64	55.03	55.41	55.80	56.18	56.56	56.95	57.33
0.2	57.71	58.09	58.47	58.85	59.23	59.61	59.99	60.36	60.74	61.11
0.3	61.49	61.86	62.23	62.61	62.98	63.35	63.71	64.08	64.45	64.81
0.4	65.18	65.54	65.90	66.26	66.62	66.98	67.34	67.69	68.04	68.40
0.5	68.75	69.10	69.45	69.79	70.14	70.48	70.82	71.17	71.50	71.84
0.6	72.18	72.51	72.84	73.18	73.50	73.83	74.16	74.48	74.80	75.12
0.7	75.44	75.76	76.07	76.39	76.70	76.01	77.31	77.62	77.92	78.22
0.8	78.52	78.82	79.11	79.41	79.70	79.99	80.27	80.56	80.84	81.12
0.9	81.40	81.68	81.95	82.22	82.49	82.76	83.02	83.29	83.55	83.81
1.0	84.06	84.32	84.57	84.82	85.06	85.31	85.55	85.79	86.03	86.27
1.1	86.50	86.73	86.96	87.19	87.41	87.63	87.85	88.07	88.29	88.50
1.2	88.71	88.92	89.12	89.33	89.53	89.73	89.92	90.12	90.31	90.50
1.3	90.68	90.87	91.05	91.23	91.41	91.59	91.76	91.93	92.10	92.27
1.4	92.43	92.59	92.75	92.91	93.07	93.22	93.37	93.52	93.66	93.81
1.5	93.95	94.09	94.23	94.36	94.50	94.63	94.76	94.89	95.01	95.14
1.6	95.26	95.38	95.49	95.61	95.72	95.83	95.94	96.05	96.15	96.26
1.7	96.36	96.46	96.55	96.65	96.74	96.84	97.93	97.01	97.10	97.19
1.8	97.27	97.35	97.43	97.51	97.58	97.66	97.73	97.80	97.87	97.94
1.9	98.01	98.07	98.14	98.20	98.26	98.32	98.38	98.43	98.49	98.54
2.0	98.59	98.64	98.69	98.74	98.79	98.83	98.88	98.92	98.96	99.00
2.1	99.04	99.08	99.12	99.15	99.19	99.22	99.25	99.29	99.32	99.35
2.2	99.37	99.40	99.43	99.46	99.48	99.51	99.53	99.55	99.57	99.59
2.3	99.61	99.63	99.65	99.67	99.69	99.70	99.72	99.73	99.75	99.76
2.4	99.78	99.79	99.80	99.81	99.82	99.84	99.85	99.86	99.86	99.97
2.5	99.88	99.89	99.90	99.90	99.91	99.92	99.92	99.93	99.93	99.94
2.6	99.94	99.95	99.95	99.96	99.96	99.96	99.97	99.97	99.97	99.97
2.7	99.98	99.98	99.98	99.98	99.98	99.99	99.99	99.99	99.99	99.99
2.8	99.99	99.99	99.99	100.0	100.0	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 13

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.39	50.78	51.17	51.55	51.94	52.33	52.72	53.11	53.49
0.1	53.88	54.27	54.65	55.04	55.43	55.81	56.20	56.58	56.96	57.35
0.2	57.73	58.11	58.49	58.87	59.25	59.63	60.01	60.39	60.77	61.14
0.3	61.52	61.89	62.27	62.64	63.01	63.38	63.75	64.12	64.48	64.85
0.4	65.21	65.58	65.94	66.30	66.66	67.02	67.37	67.73	68.08	68.44
0.5	68.79	69.14	69.49	69.83	70.18	70.52	70.87	71.21	71.55	71.88
0.6	72.22	72.55	72.89	73.22	73.55	73.87	74.20	74.52	74.84	75.16
0.7	75.48	75.80	76.11	76.42	76.73	77.04	77.35	77.65	77.96	78.26
0.8	78.55	78.85	79.14	79.44	79.73	80.01	80.30	80.58	80.87	81.15
0.9	81.42	81.70	81.97	82.24	82.51	82.78	83.04	83.30	83.56	83.82
1.0	84.07	84.33	84.58	84.82	85.07	85.31	85.56	85.79	86.03	86.27
1.1	86.50	86.73	86.95	87.18	87.40	87.62	87.84	88.06	88.27	88.48
1.2	88.69	88.90	89.10	89.30	89.50	89.70	89.90	90.09	90.28	90.47
1.3	90.65	90.83	91.02	91.19	91.37	91.55	91.72	91.89	92.05	92.22
1.4	92.38	92.54	92.70	92.86	93.01	93.16	93.31	93.46	93.61	93.75
1.5	93.89	94.03	94.17	94.30	94.43	94.56	94.69	94.82	94.94	95.06
1.6	95.18	95.30	95.42	95.53	95.64	95.75	95.86	96.97	96.07	96.18
1.7	96.28	96.38	96.47	96.57	96.66	96.75	96.84	96.93	97.02	97.10
1.8	97.18	97.26	97.34	97.42	97.50	97.57	97.65	97.72	97.79	97.85
1.9	97.92	97.99	98.05	98.11	98.17	98.23	98.29	98.35	98.40	98.46
2.0	98.51	98.56	98.61	98.66	98.70	98.75	98.79	98.84	98.88	98.92
2.1	98.96	99.00	99.04	99.08	99.11	99.15	99.18	99.21	99.24	99.28
2.2	99.31	99.33	99.36	99.39	99.42	99.44	99.47	99.49	99.51	99.53
2.3	99.55	99.58	99.60	99.61	99.63	99.65	99.67	99.68	99.70	99.71
2.4	99.73	99.74	99.76	99.77	99.78	99.79	99.81	99.82	99.83	99.84
2.5	99.85	99.86	99.86	99.87	99.88	99.89	99.89	99.90	99.91	99.91
2.6	99.92	99.92	99.93	99.93	99.94	99.94	99.95	99.95	99.96	99.95
2.7	99.96	99.96	99.97	99.97	99.97	99.98	99.98	99.98	99.98	99.98
2.8	99.98	99.99	99.99	99.99	99.99	99.99	99.99	99.99	99.99	99.99
2.9	99.99	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 14

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.39	50.78	51.17	51.56	51.95	52.34	52.73	53.11	53.50
0.1	53.89	54.28	54.67	55.05	55.44	55.83	56.21	56.60	56.98	57.37
0.2	57.75	58.13	58.51	58.89	59.28	59.66	60.03	60.41	60.79	61.17
0.3	61.54	61.92	62.29	62.66	63.04	63.41	63.78	64.15	64.51	64.88
0.4	65.24	65.61	65.97	66.33	66.69	67.05	67.41	67.76	68.12	68.47
0.5	68.82	69.17	69.52	69.87	70.21	70.56	70.90	71.24	71.58	71.92
0.6	72.25	72.59	72.92	73.25	73.58	73.91	74.23	74.55	74.88	75.19
0.7	75.51	75.83	76.14	76.45	76.76	77.07	77.38	77.68	77.98	78.28
0.8	78.58	78.88	79.17	79.46	79.75	80.04	80.32	80.61	80.89	81.16
0.9	81.44	81.72	81.99	82.26	82.52	82.79	83.05	83.31	83.57	83.83
1.0	84.08	84.33	84.58	84.83	85.08	85.32	85.56	85.80	86.03	86.26
1.1	86.50	86.72	86.95	87.17	87.40	87.61	87.83	88.05	88.26	88.47
1.2	88.68	88.88	89.08	89.28	89.48	89.68	89.87	90.06	90.25	90.44
1.3	90.62	90.81	90.99	91.16	91.34	91.51	91.68	91.85	92.02	92.18
1.4	92.34	92.50	92.66	92.82	92.97	93.12	93.27	93.41	93.56	93.70
1.5	93.84	93.98	94.11	94.25	94.38	94.51	94.64	94.76	94.88	95.01
1.6	95.12	95.24	95.36	95.47	95.58	95.69	95.80	96.91	96.01	96.11
1.7	96.21	96.31	96.41	96.50	96.59	96.68	96.77	96.86	96.95	97.03
1.8	97.11	97.19	97.27	97.35	97.43	97.50	97.57	97.65	97.72	97.78
1.9	97.85	97.92	97.98	98.04	98.10	98.16	98.22	98.28	98.33	98.39
2.0	98.44	98.49	98.54	98.59	98.64	98.68	98.73	98.77	98.82	98.86
2.1	98.90	98.94	98.98	99.01	99.05	99.08	99.12	99.15	99.18	99.22
2.2	99.25	99.28	99.31	99.33	99.36	99.39	99.41	99.44	99.46	99.48
2.3	99.50	99.53	99.55	99.57	99.59	99.60	99.62	99.64	99.66	99.67
2.4	99.69	99.70	99.72	99.73	99.74	99.76	99.77	99.78	99.79	99.80
2.5	99.81	99.82	99.83	99.84	99.85	99.86	99.87	99.88	99.88	99.89
2.6	99.90	99.90	99.91	99.91	99.92	99.92	99.93	99.93	99.94	99.94
2.7	99.95	99.95	99.95	99.96	99.96	99.96	99.97	99.97	99.97	99.97
2.8	99.97	99.98	99.98	99.98	99.98	99.98	99.99	99.99	99.99	99.99
2.9	99.99	99.99	99.99	99.99	99.99	99.99	99.99	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 15

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.39	50.78	51.17	51.56	51.95	52.34	52.73	53.12	53.51
0.1	53.90	54.29	54.67	55.06	55.45	55.84	56.22	56.61	56.99	57.38
0.2	57.76	58.15	58.53	58.91	59.29	59.67	60.05	60.43	60.81	61.19
0.3	61.56	61.94	62.31	62.69	63.06	63.43	63.80	64.17	64.54	64.90
0.4	65.27	65.63	66.00	66.36	66.72	67.08	67.43	67.79	68.15	68.50
0.5	68.85	69.20	69.55	69.90	70.24	70.59	70.93	71.27	71.61	71.95
0.6	72.28	72.61	72.95	73.28	73.61	73.93	74.26	74.58	74.90	75.22
0.7	75.54	75.85	76.17	76.48	76.79	77.10	77.40	77.70	78.01	78.30
0.8	78.60	78.90	79.19	79.48	79.77	80.06	80.34	80.62	80.90	81.18
0.9	81.46	81.73	82.00	82.27	82.54	82.80	83.06	83.32	83.58	83.84
1.0	84.09	84.34	84.59	84.83	85.08	85.32	85.56	85.80	86.03	86.26
1.1	86.50	86.72	86.95	87.17	87.39	87.61	87.82	88.04	88.25	88.46
1.2	88.66	88.87	89.07	89.27	89.47	89.66	89.85	90.04	90.23	90.42
1.3	90.60	90.78	90.96	91.14	91.31	91.48	91.65	91.82	91.99	92.15
1.4	92.31	92.47	92.63	92.78	92.93	93.08	93.23	93.37	93.52	93.66
1.5	93.80	93.94	94.07	94.20	94.33	94.46	94.59	94.71	94.84	94.96
1.6	95.08	95.19	95.31	95.42	95.53	95.64	95.75	95.85	95.95	96.06
1.7	96.16	96.25	96.35	96.44	96.54	96.63	96.72	96.80	96.89	96.97
1.8	97.06	97.14	97.21	97.29	97.37	97.44	97.51	97.59	97.66	97.72
1.9	97.79	97.86	97.92	97.98	98.04	98.10	98.16	98.22	98.27	98.33
2.0	98.38	98.43	98.48	98.53	98.58	98.63	98.67	98.72	98.76	98.80
2.1	98.84	98.88	98.92	98.96	99.00	99.03	99.07	99.10	99.13	99.17
2.2	99.20	99.23	99.26	99.29	99.31	99.34	99.37	99.39	99.42	99.44
2.3	99.46	99.48	99.51	99.53	99.55	99.57	99.58	99.60	99.62	99.64
2.4	99.65	99.67	99.68	99.70	99.71	99.73	99.74	99.75	99.76	99.77
2.5	99.79	99.80	99.81	99.82	99.83	99.83	99.84	99.85	99.86	99.87
2.6	99.87	99.88	99.89	99.89	99.90	99.91	99.91	99.92	99.92	99.93
2.7	99.93	99.94	99.94	99.94	99.95	99.95	99.95	99.96	99.96	99.96
2.8	99.97	99.97	99.97	99.97	99.97	99.98	99.98	99.98	99.98	99.98
2.9	99.98	99.99	99.99	99.99	99.99	99.99	99.99	99.99	99.99	99.99
3.0	99.99	99.99	99.99	100.0	100.0	100.0	100.0	100.0	100.0	100.0

ESTIMATION OF LOT QUALITY LEVEL

SAMPLE SIZE = 30

Q	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	50.00	50.40	50.79	51.19	51.58	51.98	52.37	52.76	53.16	53.55
0.1	53.95	54.34	54.73	55.12	55.52	55.91	56.30	56.69	57.08	57.47
0.2	57.85	58.24	58.63	59.01	59.40	59.78	60.17	60.55	60.93	61.31
0.3	61.69	62.07	62.45	62.82	63.20	63.57	63.95	64.32	64.69	65.06
0.4	65.42	65.79	66.15	66.52	66.88	67.24	67.60	67.96	68.31	68.67
0.5	69.02	69.37	69.72	70.07	70.41	70.76	71.10	71.44	71.78	72.11
0.6	72.45	72.78	73.11	73.44	73.77	74.10	74.42	74.74	745.06	75.38
0.7	75.69	76.01	76.32	76.63	76.93	77.24	77.54	7784	78.14	78.43
0.8	78.73	79.02	79.31	79.60	79.88	80.16	80.44	80.72	81.00	81.27
0.9	81.54	81.81	82.08	82.34	82.60	82.86	83.12	83.37	83.63	83.88
1.0	84.12	84.37	84.61	84.85	85.09	85.33	85.56	85.79	86.02	86.25
1.1	86.47	86.69	86.91	87.13	87.34	87.55	87.76	88.97	88.18	88.38
1.2	88.58	88.78	88.97	89.16	89.36	89.54	89.73	89.91	90.10	90.28
1.3	90.45	90.63	90.80	90.97	91.14	91.31	91.47	91.63	91.79	91.95
1.4	92.10	92.26	92.41	92.56	92.70	92.85	92.99	93.13	93.27	93.40
1.5	93.54	93.67	93.80	93.93	94.05	94.18	94.30	94.42	94.54	94.66
1.6	94.77	94.88	94.99	95.10	95.21	95.32	95.42	95.52	95.62	95.72
1.7	95.82	95.91	96.01	96.10	96.19	96.28	96.37	96.45	96.53	96.62
1.8	96.70	96.78	96.85	96.93	97.01	97.08	97.15	97.22	97.29	97.36
1.9	97.43	97.49	97.55	97.62	97.68	97.74	97.80	97.86	97.91	97.97
2.0	98.02	98.07	98.13	98.18	98.23	98.27	98.32	98.37	98.41	98.46
2.1	98.50	98.54	98.58	98.62	98.66	98.70	98.74	98.78	98.81	98.85
2.2	98.88	98.91	98.95	98.98	99.01	99.04	99.07	99.10	99.12	99.15
2.3	99.18	99.20	99.23	99.25	99.28	99.30	99.32	99.34	99.37	99.39
2.4	99.41	99.43	99.44	99.46	99.48	99.50	99.52	99.53	99.55	99.56
2.5	99.58	99.59	99.61	99.62	99.63	99.65	99.66	99.67	99.68	99.70
2.6	99.71	99.72	99.73	99.74	99.75	99.76	99.77	99.78	99.78	99.79
2.7	99.80	99.81	99.82	99.82	99.83	99.84	99.84	99.85	99.86	99.86
2.8	99.87	99.87	99.88	99.88	99.89	99.89	99.90	99.90	99.91	99.91
2.9	99.91	99.92	99.92	99.92	99.93	99.93	99.93	99.94	99.94	99.94
3.0	99.95	99.95	99.95	99.95	99.95	99.96	99.96	99.96	99.96	99.96
3.1	99.97	99.97	99.97	99.97	99.97	99.97	99.98	99.98	99.98	99.98
3.2	99.98	99.98	99.98	99.98	99.98	99.98	99.99	99.99	99.99	99.99

3.3	99.99	99.99	99.99	99.99	99.99	99.99	99.99	99.99	99.99	99.99
3.4	99.99	99.99	99.99	99.99	99.99	100.0	100.0	100.0	100.0	100.0